Module 13

Supply-side management

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

CONTENTS

1. MODULE OBJECTIVES

1.1. Module overview

Supply-side management (SSM) refers to actions taken to ensure the generation, transmission and distribution of energy are conducted efficiently. The term is used mainly with reference to electricity but it can also be applied to actions concerning the supply of other energy resources such as fossil fuels and renewables.

For the purpose of discussion in this module, the “supply-side” has been taken to include the following activities:

- Supply and utilization of energy resources—including clean coal technologies, fuel substitution and renewable energy use.
- Power generation and energy conversion—including operational improvements in existing plants, upgrading units and cogeneration.
- Transmission and distribution of electricity—including lines, substations and on-site generation.
- Transport of fuels—liquid, gaseous and solid fuels.

These topics—addressed primarily to electricity—are discussed in this module and various means of improving energy efficiency are mentioned. As the module is an introduction to the improvement of SSM, detailed technical topics have not been included but a number of references are provided to allow the reader to explore opportunities in greater depth.

As well as mentioning the benefits of SSM, a brief review is made of the constraints and challenges to cost-effective implementation.

1.2. Module aims

The aims of this module are:

- To introduce the concept of supply-side management, especially as it applies to electricity systems.
- To discuss options of supply-side management at each stage of the supply chain, e.g. energy resources used, generating plants, transmission systems, and distribution. This includes topics such as clean coal technologies, fuel substitution, cogeneration and decentralized (local) generation.

- To show how well known demand-side measures such as housekeeping and preventative maintenance can also apply in various parts of the supply side and how they have useful benefits in reducing energy waste.
- To give an overview of the constraints and the benefits of conducting supply-side management measures and programmes.

1.3. Module learning outcomes

This module attempts to achieve the following learning outcomes:

- To be able to define supply-side management and appreciate why it should be pursued.
- To understand the different types of supply-side management measures and programmes.
- To appreciate the constraints, challenges and benefits of supply-side management.

2. INTRODUCTION

2.1. What is supply-side management?

Supply-side management (SSM) refers to actions taken to ensure the generation, transmission and distribution of energy are conducted efficiently. This has become especially important with the deregulation of the electricity industry in many countries, where the efficient use of available energy sources becomes essential to remain competitive.

SSM is used primarily with reference to electricity but it can also be applied to actions concerning the supply of other energy resources such as fossil fuels and renewables. Utility companies may look at means of modifying their load profile to allow their least efficient generating equipment to be used as little as possible (compared with high efficiency equipment that should be used to the maximum). They may improve maintenance and control of existing equipment, or upgrade equipment with state-of-the-art technologies.

Energy users will normally focus their efforts on demand-side management methods (DSM) but some will consider the supply side too. For example, they may look at on-site generation alternatives—including cogeneration—or consider diversifying to alternative fuel sources (such as natural gas, solar, wind, biofuels).

2.2. Why pursue SSM?

For an electricity system, effective SSM will increase the efficiency with which the end-users are supplied, allowing the utility company to defer major capital expenditure, which might otherwise be required for increasing their capacity in growing markets (see box 1 below). SSM makes installed generating capacity able to provide electricity at lower cost (permitting lower prices to be offered to consumers) and reduces environmental emissions per unit of end-use electricity provided. SSM can also contribute to improving the reliability of a supply system. With the current trend of deregulating the supply industry, it is becoming more important to embark on supply-side management where the supplier, user and the environment all win.

In the case of SSM applied to biomass, the advantage of higher efficiency in the supply chain is the reduction in resources needed to meet a specific demand. This helps reduce the risk of deforestation and thus avoids not only a loss of energy supply but potential environmental damage.

In brief, an electrical utility may embark on SSM to:

- Ensure reliable availability of energy at the minimum economic cost ultimately increasing its profits;
- Provide maximum value to its customers by reducing energy prices;
- Meet increasing electricity demand without incurring in unnecessary major capital investments in new generating capacity;
- Minimize environmental impact.

Suppliers of other types of energy will have corresponding motives.

Review question

Give at least three reasons why utilities undertake SSM programmes.

Box 1. **Electricity growth in the developing world**

Electricity consumption is growing rapidly worldwide. The highest rates of growth are in developing and transitional economies.

Examples of electricity consumption growth rates are as follows:

- Chile +53%
- China +19%
- India +20%
- Bangladesh +14%
- Senegal +8%

Source: World Commission on Dams, Project Output and Dissemination, Annex #3—Thematic Reviews (2001).

3. SSM OPTIONS AND OPPORTUNITIES

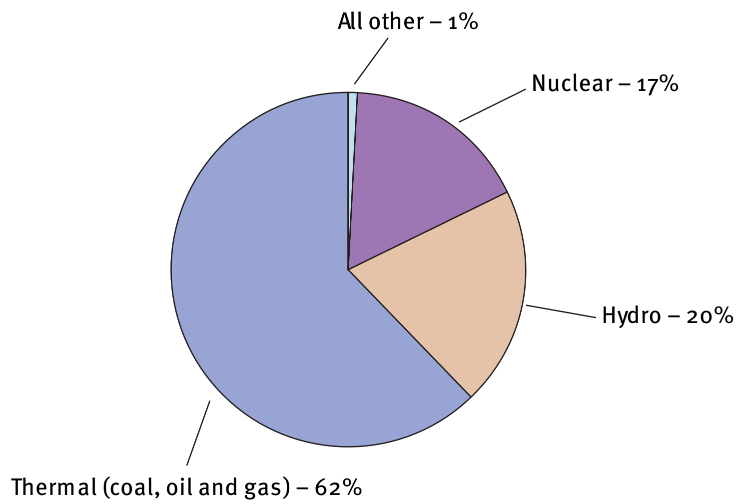
3.1. Introduction

As SSM is most often discussed in connection with electricity supplies, we will focus in this module on measures applying mostly to electric utilities. Electricity is of course a secondary source of energy and is derived from a wide range of primary energy sources, such as:

- Coal
- Natural gas
- Petroleum-based fuels.
- Nuclear energy
- Hydropower
- Geothermal energy
- Renewable energy such as solar, wing, tidal, biomass

To put the remainder of the module in context, figure I shows the breakdown of primary energy resources used worldwide for electricity generation.

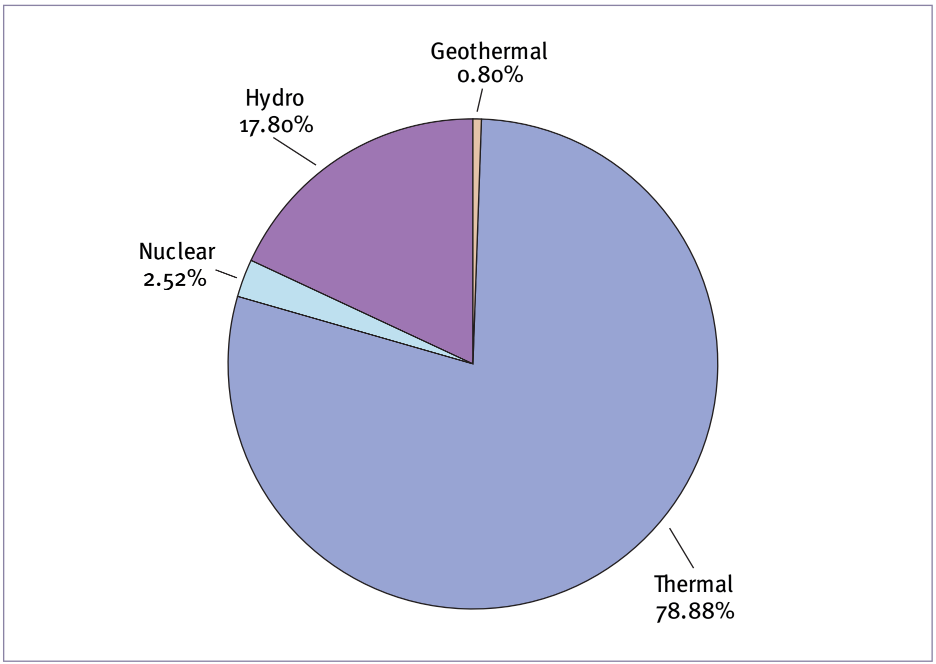
Figure I. Dominant electricity supply resources



Source: World Commission on Dams, 2001.

The contribution of renewables is small but growing. The bulk of the electricity generated in Africa is produced from conventional thermal power plants, with large coal plants in South Africa and oil-fired plants in Nigeria. In spite of very large exploitable hydropower capacity in Africa, its contribution remains relatively low at about 18 per cent, as shown in figure II below (see module 2 to know more about energy resources in Africa).

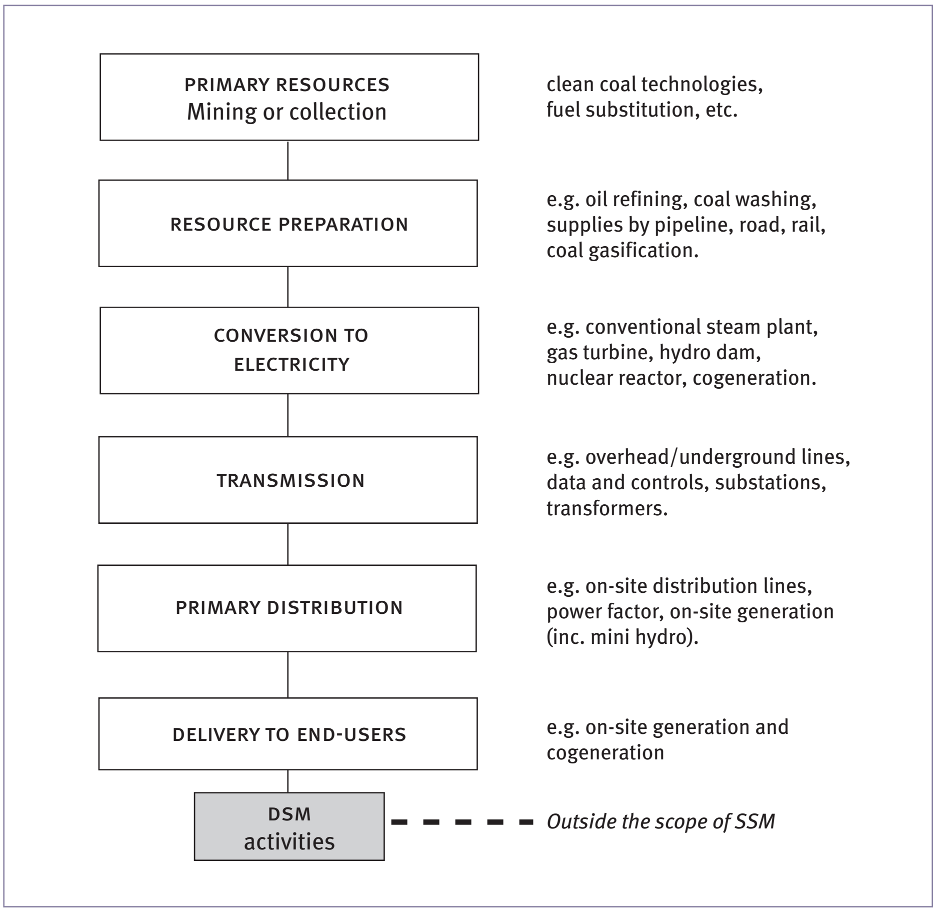
Figure II. Electricity production in Africa (2004)



Source: IEA, 2005.

For the rest of the discussion on SSM—most of which concerns electricity—the overall supply chain for electricity will be viewed according to the simplified structure shown in figure III.

Figure III. Simplified electricity supply chain



The indicated topics are dealt with in the order given above.

3.2. Resources and resource preparation

In this section, the various aspects of resource utilization for the production of electricity are addressed. The items presented all offer the potential for cost-effective efficiency improvements in elements of the supply chain and thus are classed as SSM options.

Clean coal technologies

Clean coal technologies (CCTs) are designed to improve the efficiency of the extraction, preparation and use of coal. Some of the technologies are well established and proven, others are relatively new and less well established, at least in developing countries. New technologies offer huge potential for using discarded coal. Improved efficiency in extracting energy from the coal delivers the same amount of electricity but with reduced gaseous emissions and solid waste. The importance of CCTs in general is that they offer more environmentally friendly means of exploiting a widely available and abundant resource—coal—that has traditionally been a difficult fuel to burn efficiently and is normally associated with environmental degradation.

There are many ways of using coal efficiently and cleanly, depending on different coal types, different environmental issues and different levels of economic development. Some CCTs require highly complex and expensive technology and infrastructure and therefore may not be relevant to all developing countries.

CCTs can include a broad range of items (Upgrading Transmission Capacity for Wholesale Electric Power Trade, John Makens) such as:

- Coal cleaning—processes used to increase the heating value and the quality of the coal, by lowering the level of sulphur and non-combustible mineral constituents. These simple methods—almost always used in developed countries—are suitable for developing countries.
- Emission reduction technologies—“bolt on” or “end of pipe” technologies including:
    - Activated carbon injection, to absorb pollutants.
    - Electrostatic precipitators, in which particulate/dust laden flue gases are passed between collecting plates where an electrical field creates a charge on the particles. The particles are attracted towards the collecting plates, where they accumulate and from which they are subsequently removed.
    - Fabric filters, to collect particulates by passing flue gas through tightly woven fabric.
    - Wet particle scrubbers, in which water is sprayed into the flue gas stream as a fine mist of droplets. The fly ash particles impact with the droplets forming a wet by-product, which is then removed for disposal.
    - Flue gas desulphurization (FGD), the process by which sulphur emissions are removed post-combustion by wet scrubbers, by dry scrubbers, by sorbent injection processes, by regenerable processes, or combined SO_2/NO_x removal processes.
    - Selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR), in which steam is used as the reducing agent and is injected into the flue gas stream (passing over a catalyst in the SCR process).
- Efficient power generation processes, such as reducing emissions and improving efficiencies by the integrated gasification combined cycle (IGCC) process

in which the coal is gasified to produce a gaseous fuel for gas turbines to generate power. Fluidized bed combustion is another example—see the section on power generation and energy conversion.

- "Next generation" technologies, such as underground coal gasification (UCG) where coal is converted in-situ to combustible gas that can be used for power generation thus eliminating a large portion of the supply chain normally associated with coal fired generation. The gasified coal can be treated to remove sulphur derivatives and particulates to ensure combustion is clean.

Overall, CCTs improve the efficiency of coal-based electricity generation, with benefits such as:

- Increased electrical power output per unit of coal fired;
- Reduced environmental impact per unit of coal fired, possibly in conjunction with removal of CO_2 and SO_x emissions.

Fuel substitution

Fuel substitution (or fuel switching) is simply the process of substituting one fuel for another. Examples would be expanding the use of natural gas for industry, transport, domestic cooking and heating, and for electricity generation, rather than using liquid petroleum based fuel. Although such actions refer to energy supplies, most will in practice involve the energy user for implementation and thus could also be considered "demand-side management" measures in many cases.

As a general rule, the combustion of natural gas can be carried out much more efficiently than oil or coal, on a heating value basis. In industrial equipment, control of gas-fired equipment is usually much more precise and maintenance easier to carry out (partly because there will normally be much lower levels of corrosive components in the exhaust gases). A similar situation applies for commercial and domestic furnaces and boilers. The increased efficiencies that are achievable will often result in useful cost reductions even where the "new" fuel is somewhat more expensive than the "old" fuel. Thus fuel substitution can be regarded as a cost effective SSM measure.

An example of fuel substitution in energy supply in the transport sector is in Delhi, where 84,000 public vehicles converted from using gasoline and diesel as the fuel source to compressed natural gas (CNG) in a period of one year. In other sectors, the increased use of natural gas for electricity generation and public investment to develop the natural gas infrastructure for long distance and local distribution is also promoting fuel switching in Delhi. The share of gas in power generating capacity has risen from 2 per cent to 8 per cent over the past 10 years and LPG has largely replaced coal and kerosene in urban households (UNFCCC/SBI/2003/INF.14, 20 November 2003).

Renewable energy

Although the total contribution of renewable energy resources to energy demand in Africa is still very modest, the number of projects being implemented is growing. In 2003 developing countries that have no greenhouse gas emission reduction obligations under the Kyoto Protocol reported 141 supply-side improvement projects (UNFCCC/SBI/2003/INF.14, 20 November 2003). Of these, 82 projects involve renewable energy development:

- 31 with solar energy
- 23 with hydropower
- 14 with wind power
- 14 with various other renewable energies.

Renewable energy (RE) as a means of energy supply is covered in detail in the RE modules. However, due to its potential as part of supply-side management and on-site generation, it is briefly covered in this module too. Applications of on-site generation using RE are well suited for locations with no grid connection, where RE can offer a cost effective alternative to capital intensive extension of transmission and distribution lines and other highly priced fuels.

There are many examples of RE systems such as photovoltaic (PV) systems in remote rural areas of Africa powering schools, clinics or homes. Solar water heaters (SWH) are increasingly being recognized as a simple way to supply heat to homes or provide hot water in the industrial sector.

Utilization of biomass may offer important opportunities for providing energy supplies at moderate cost. Organic matter may be converted into energy in various ways. This organic matter is generally a renewable resource, which is either grown to replenish stocks (such as agricultural crops, trees or grasses) or collected as waste (e.g. animal or municipal waste).

The organic matter may be directly or indirectly:

- Used as a fuel—such as burning wood for cooking or burning bagasse to produce steam for electricity generation in a conventional steam turbine;
- Processed to liquid fuel (such as biodiesel from oil seed crops, or ethanol by fermentation of other crops) or a gas (such as methane from anaerobic digestion).

Box 2. **On-site wind generation**

"Wind Direct was formed in early 2004 to offer a service to intensive energy users by providing them with a cheap, direct energy supply from wind turbines. This demand has evolved from the present and future rise in electricity prices that industry has had to come to terms with. By utilizing on-site wind energy, the long term prospects of cheaper electricity allows for a more optimistic outlook and significant cost savings."

Source: www.wind-direct.co.uk

Sugar cane bagasse is an important example of biomass with significant potential for use as a fuel in the generation of electricity. Sugar cane has a high photosynthesis conversion efficiency, with yields of up to 130 tons per hectare. Generally only the stalk is used for sugar production leaving the fibrous bagasse consisting typically of around half fibre, half moisture and maybe around 2 per cent sugars. The bagasse can be burnt to produce steam and electricity (although it can also be processed into paper if economic conditions are favourable). Typically the full energy requirements of a sugar mill can be met by burning bagasse in special boilers and may often produce surplus power, which can be sold to the grid. The amount of electricity generated is around 55 to 85 kWh per ton of sugar cane processed, depending on the specific design of the system.

Sugar is produced in a number of Eastern and Southern African countries. It is a major agricultural export for Ethiopia, Madagascar, Malawi, Mozambique, Swaziland, Zambia and Zimbabwe. The potential for electricity generation from bagasse is high, since cogeneration equipment is almost always an integral component of sugar factory design. However, despite this potential, at present only Mauritius and Réunion have succeeded in exploiting bagasse to a significant degree (Kassiap Deepchand, 2004) (see the case study in module 2 for more on the Mauritius experience).

Another application of fuel derived from biomass is methane produced by anaerobic digestion. Sewage, manure and organic waste can be used as the feedstock. The information provided in box 3 illustrates the potential of methane generation in Lusaka, Zambia, by anaerobic digestion of municipal sewage.

Box 3. **Methane generation in Lusaka**

Background

Lusaka Water and Sewerage company (LWSC) is involved in waste treatment and supply. It services Lusaka and surrounding areas. For pumping purposes LWSC has a total of 172 AC induction motors with a total demand of 10.4 MW.

Project objective

Investigation of the possibility of introducing an alternative energy supply through generation of electricity from methane from sewerage plant

Description

Conduct a feasibility study on the generation of electricity using methane derived from sewerage ponds at Manchinchi Sewer.

Electricity generation from methane

A detailed study was undertaken and, based on the results, it was found—and thus recommended—that electricity can be generated from waste material at Manchinchi sewerage plant through combustion of methane in a gas engine with a capacity of 1 MW. This will contribute to reducing the current LWSC power requirement of 10.4 MW, and save the corresponding amount from the electricity bill. A closed tank anaerobic digester is shown above.

Description of follow-up action

LWSC is in the process of sourcing funds for the methane production and combustion project through a CDM arrangement. Implementation of the project will result in a saving of 26,000 tonnes of CO_2 equivalent.

Finally, there are some locations where geothermal power could be exploited. The energy within hot rocks deep in the earth is "recovered" by pumping water into the rocks and collecting the resulting steam for the generation of electricity. Until now its potential—much of it in the Eastern African Rift Valley region—has remained largely untapped.

At a conference in Nairobi in April 2003—the Eastern African Geothermal Energy Week (UNEP)—a "challenging yet achievable target" for geothermal exploitation was set by the attending government energy experts, scientists, engineers and members of the private sector. This target was to develop 1,000 MW of geothermal energy recovery across Eastern Africa by 2020. This is equivalent to the electricity needs of several million people in the region. In total, Africa was said to have a potential of up to 7,000 MW of untapped geothermal energy resources.

At the time, Kenya, which has pioneered geothermal energy in the region, generated 45 MW of electricity from "hot rocks". The technology has proven very reliable, as Kenya has used geothermal energy for power generation for at least 22 years at greater than 97 per cent availability. Geothermal energy is clean energy and, unlike hydro-electricity, is not vulnerable to droughts. It also is not prone to unpredictable price fluctuations as can be the case with oil-fired power generation (UNEP).

Although not necessarily associated with geothermal resources, ground source heat pumps are another means of exploiting the heat that occurs naturally underground. Heat pumps can be used to convert the low temperature energy into high-grade heat, using electric or gas powered drivers. The higher temperature energy is then suitable for heating (or cooling) buildings.

3.3. Power generation and energy conversion

Power generation and energy conversion is almost certainly the activity where most energy losses occur and therefore where efforts to improve energy efficiency are most likely to prove most beneficial. Several topics relating to improving power plants are introduced and discussed below. Some apply mainly to existing facilities while others will represent opportunities for higher energy efficiency to be achieved through replacing old technologies and equipment with new and best modern practice designs.

Operation improvement in existing plants

The typical energy efficiency of a modern, well-maintained power plant is around 33 to 38 per cent (Frans van Aart, 2004). This is the amount of energy that is used in the plant as fuel and is converted into electricity for sale to customers. The main losses—the 62 to 67 per cent of energy that is not usefully converted—are in the hot exhaust gases from the boiler stack and in warm cooling water used in heat exchangers to condense low pressure exhaust steam. There are some technological limitations, deriving mainly from the laws of thermodynamics, that make it impossible to eliminate some of the lost energy but there are also many situations where equipment is not run at top efficiency and thus improvements could be made.

Housekeeping

Measures to reduce energy consumption and improve energy efficiency in enterprises and other organizations may be divided into three basic categories:

- No-cost and low-cost measures;
- Measures requiring moderate levels of investment;
- Measures requiring significant investment.

Each organization will have to make its own decision regarding what “moderate” and “significant” mean, as this depends on many factors, such as the size of facilities, levels and cost of energy consumption, and the financial situation of the organization.

The first category—the no and low-cost measures—covers items usually known as "good housekeeping" and these should be implemented by the organization to "tidy up" its operations. This applies to all the organizations involved with supply side activities but particularly to power plants (which are quite similar to industrial plants in terms of energy efficiency improvement activities). Organizations should always consider implementing housekeeping measures promptly because they can reduce energy demand in the short-term, usually for very small capital investments and low installation costs.

Some examples of good housekeeping are:

- Maintaining appropriate boiler and turbine control settings—optimizing the efficiency of the steam raising and electricity generating processes, thus reducing internal energy requirements.
- Checking boiler feed-water quality regularly to ensure water treatment is working properly and the appropriate blowdown of water is being carried out at all times.
- Repairing steam, water and compressed air leaks—improves system efficiency and reduces the energy needed to generate the equivalent of the leaked steam, to treat additional water to boiler feedwater purities, and to compress additional air using electricity for compressors.
- Removing redundant lighting fixtures—many sites undergo modifications and reorganization but lighting systems are often not correspondingly moved, with the result that lights may become redundant.
- Removing redundant pipework—often steam and water piping (and sometimes related equipment such as pumps) become redundant as a power plant is developed or changed over time. Unless properly insulated or removed, the redundant items may contribute to unnecessary heat losses and leaks of steam or other process fluids.
- Operating cooling towers efficiently—maintaining design parameters for water flows and temperatures in and out, and ensuring that scale is not allowed to accumulate on heat exchange surfaces.

Maintenance

Good maintenance has an essential part to play in achieving good levels of energy efficiency. For example, here are some typical deficiencies in industrial facilities and power plants:

- Meters are uncalibrated or out of service;
- Steam traps are defective—not working as traps, leaking etc;
- Valves are leaking at the spindle, losing steam, water, compressed air and process fluids;

- Insulation of steam distribution piping is inadequate.

Many power plants will be able to benefit from improved maintenance, increasing their energy efficiency performance and reducing emissions correspondingly. All too often maintenance is only performed when a breakdown occurs, whereas prevention of breakdowns can contribute greatly to long-term energy efficiency. Preventive maintenance can take various forms, some examples of which are:

- Developing and applying routine lubrication schedules;
- Replacing critical items on a regular schedule (e.g. steam traps);
- Monitoring lubricant composition to determine when excessive wear of metal parts is occurring (e.g. steam turbines, rotating generation equipment);
- Monitoring noise and vibration of bearings before failure actually occurs;
- Regular filter cleaning on air compressors, pumps, upstream of steam traps, in ventilation ducts, etc.;
- Continuous scale removal from heat exchangers;
- Monitoring hot spots on boilers to check for refractory failure.

Introducing a preventive maintenance system should include keeping good records of actual failure rates and an analysis of the reasons for breakdown of different types of equipment. Preventive maintenance thus contributes to machines running at optimum efficiency, as well as minimizing unscheduled downtime.

Data and performance monitoring

This section introduces the need for data to conduct regular performance monitoring of existing power plants, an essential management activity to keep conversion efficiency at its highest. Unfortunately many plants do not carry out rigorous analysis of performance on a regular basis. As this is an introduction, much detail has been omitted and only the main ideas and concepts are discussed here.

To ensure that existing plants and processes perform at their best—and this includes both industrial plants and electricity generating facilities—a routine monitoring system should be set up with three main activities:

- Checking selected material balances, to verify the efficient use of materials throughout the plant;
- Undertaking routine data analysis, to monitor energy performance and key consumptions (e.g. electricity, fuels, water) and the corresponding costs;
- Inspecting the physical condition of the plant to observe the general condition of process equipment and systems.

These activities are complementary and give senior management a regular review of energy (and other) performance. The well known phrase—"if you cannot measure it, you cannot manage it"—applies to most aspects of enterprise activities and therefore routine energy performance monitoring should be recognized as an important management tool in any type of plant.

The types of data needed for routine monitoring may be divided into three main categories:

- Consumption and production
- Cost
- Drivers

Consumption and production data—including fuels and materials consumed, and production (e.g. electricity output)—are the most basic data required for energy performance management, and are essential for environmental management too. The main data are meter readings although some items may be delivered in bulk and not measured on site (e.g. coal). In these cases, an alternative form of measurement is needed such as the weight of trucks or rail wagons. **Cost data** is important for any organization running an energy management programme to put costs into perspective and ensure savings are made. Cost also provides a common language across departments and disciplines. The principal sources of energy cost data are the energy or fuel suppliers, either from tariffs or actual invoices. A **driver** is any factor that influences energy consumption. For most industrial processes, the main driver is the production. For a power plant, it is the electricity output.

There are many sources of data in a typical power plant. Some examples are:

- Production statistics, e.g. steam produced by boilers, electricity produced;
- Material consumption reports, e.g. purchased fuels and other consumables;
- Purchasing reports for miscellaneous items such as refractory lining and chemicals;
- By-product and waste disposal reports, e.g. for wastes in liquid or solid form;
- Log sheets from individual departments and workshops, e.g. boiler operating data. These can include data on water treatment and water quality, and combustion gas analyses (to check combustion efficiency).

While measurement of oil or gas burned in a boiler is made in most plants, the measurement of coal burned in individual boilers is relatively rare. Again, plants tend to allocate coal consumption simply for accounting purposes and the figures appearing in reports are not the real data. Coal consumption is difficult to measure with any accuracy. Account should be taken of changes in inventory, for example, and it is difficult to estimate how much coal there is in a large pile on the ground. Also, coal quality is notoriously variable from one shipment to another, in terms of ash content and moisture for example. For proper energy analysis, an effort should be made to adjust the reported raw coal tonnages by the calorific value, deriving figures for the tons of “standard coal” consumed (usually defined as coal with a calorific value of 7000 kcal per kg). With coal quality taken into account, the quantity of coal burned in any individual boiler can then be compared to the steam production to give a figure that represents the combustion efficiency of that boiler.

Most industrial and electricity generating plants collect the main data on a monthly basis so this is a suitable time period on which to base analyses. The availability of reliable data varies from place to place but most power plants actually collect a great deal of information every month (although not all will analyse the data properly or treat data as a valuable management tool). Seasonal effects need to be checked and their impact removed from the consumption data: heating and cooling of buildings and offices should be analysed separately from the main boiler data.

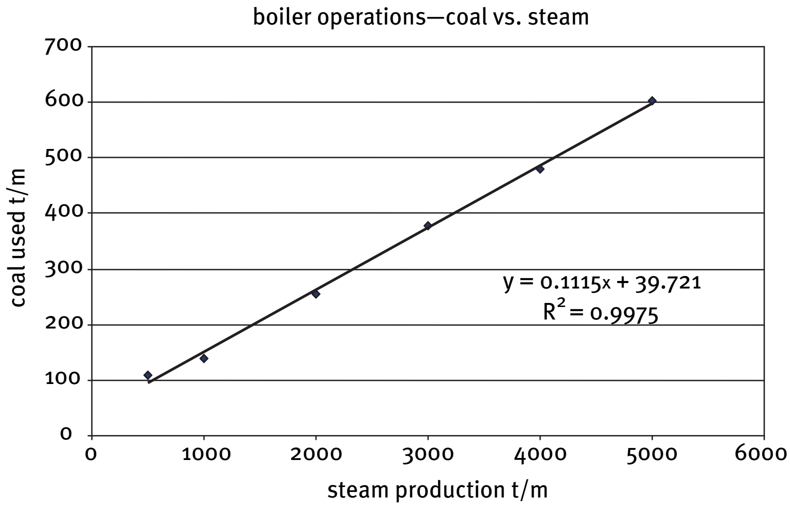
Above all, it is important that energy performance evaluations using monthly data be carried out promptly and preferably close to the end of each month. A monthly performance review should lead to a monthly report that is suitable for wide distribution within the power plant (both successes and failures can provide motivation for management and the workforce). If the analysis is left for later, it becomes much more difficult to account for any discrepancies that are observed, and of course it is always desirable that corrective measures be taken as soon as possible.

Regular monitoring of energy data forms the basis for continuous performance evaluation and control. The performance assessment will indicate if and where deficiencies in performance have occurred—such as a drop in boiler combustion efficiency—and indicate the necessary remedial action. It will also provide quantified evidence of exactly how successful any energy efficiency improvement (or supply-side management) measures have been.

The analysis of routine data is best presented graphically. A better appreciation of variations is almost always obtained from a visual presentation rather than from a table of numbers. For most power plants, a graph of “energy (fuel) used per month” against “monthly electricity production” can reveal a great deal about the energy efficiency of the process. Note that fuel use must be analyzed separately from internal electricity use (such as that used for auxiliary activities like cooling water pumping). Separate graphs should always be drawn. The efficiency improvement measures applicable to the different energy types are usually quite different and the efficiency of use of each energy type will also be different, and hence adding together the different energy forms using an assumed conversion factor to give a total energy consumption figure merely obscures what is actually happening.

From the separate graphs, we can develop equations that express in numerical terms, the “fuel consumption-electricity production” relationship (a proxy for boiler efficiency). For most typical power plants, the energy consumption plotted against electricity output, the energy-production graph will approach a straight line. The slope of the line is representative of the efficiency of the operation. We may also draw graphs against electricity production of compressed air consumption and of cooling water use.

Box 4. **Graph of coal consumption versus steam production for a boiler**



The equation for the best-fit line indicates efficiency of the boiler:

Efficiency based on best-fit line

Equation from graph: *Coal (t) = 0.1115 Steam (t) + 39.7*

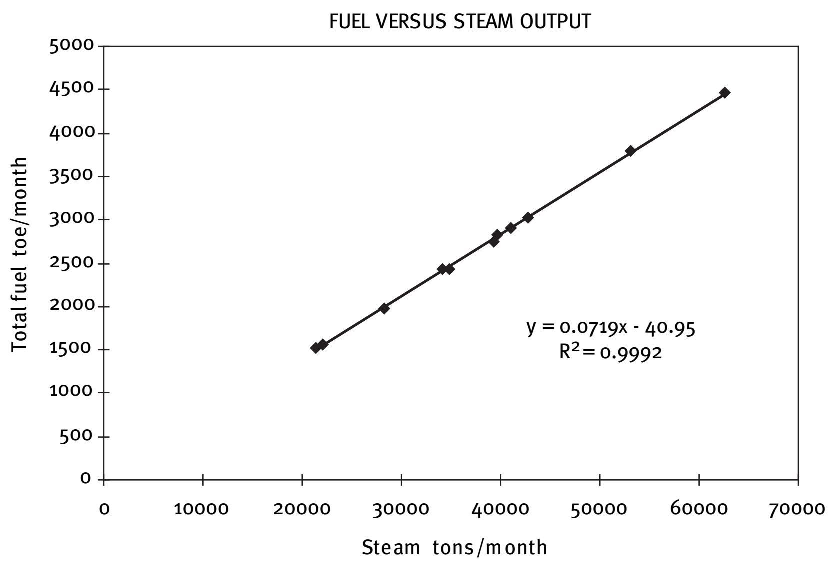
Steam Tons	Coal Tons	OUT heat Million KJ	IN fuel Million KJ	Efficiency %
500	95	1324	2673	49.5
1000	151	2648	4234	62.5
2000	263	5296	7356	72.0
3000	374	7944	10478	75.8
4000	486	10592	13600	77.9
5000	597	13240	16722	79.2

Based on 8 bar steam and coal calorific value of 28 MJ/kg

We may draw some conclusions by looking at various aspects of the graphs. For example, the degree of scatter of points in any graph is a general indication of the standard of energy management in the plant. If no significant changes in fuel type have occurred, widely scattered points usually mean that energy consumption is not properly controlled and operating practices are poorly defined and inadequately monitored by supervisors and managers. Points that follow a straight line quite closely suggest good process control.

Of course, it is quite common to find plants that falsify the steam-fuel data, or perhaps use design factors that remain constant for many years. In many cases therefore, the data points lie on a perfect straight line, a line that is too perfect to be a realistic picture of the actual situation. As an example, figure IV below shows data given by a large oil refinery in China: clearly the data are not real figures because the fit is perfect (R^2 = 0.999) and the line passes almost exactly through the origin. This implies a boiler efficiency that is identical every month and at every level of output, a situation that never occurs in the real world. Almost certainly, the steam production figures are correct and the fuel figures are calculated based on a fixed boiler efficiency of 90 per cent.

Figure IV. Example of unrealistic fuel-steam output data



Combustion control

For practical purposes, combustion refers to the burning of a fuel in air to release the energy in the fuel. In industrial plants, this energy might be used in many different ways. For example, to heat solids in a furnace (e.g. to heat steel ingots prior to rolling into steel sheets), to heat process fluids for a chemical reaction, or—most commonly—to heat water in a boiler in order to produce steam for heating or mechanical use (e.g. to power turbines).

With respect to power plants, minimum operating costs are achieved by running boilers at high thermal efficiency. Heat losses will include losses as hot flue gases (typically 15-30 per cent of fuel input energy), losses through the wall or structure of the boiler (typically 2-6 per cent of fuel input), and losses in blowdown (necessary to control boiler water quality, typically 2-5 per cent). In round figures, the losses thus add up typically to around 20 to 40 per cent of the fuel energy input, equivalent to a boiler efficiency of (100-20) or 80 per cent at best to (100-40) or 60 per cent at worst. It is possible to add various types of heat recovery devices to a boiler to improve on these figures. The figures quoted are of course only approximate, the actual figures for a boiler can vary greatly and depend on a large number of factors, including the skills of the operators, the maintenance levels, and the basic design of equipment (all of which are site-specific).

Most fuels contain differing amounts of carbon and hydrogen, both of which can be burned to release heat. The amount of oxygen needed to achieve complete combustion can be calculated accurately if the exact composition of the fuel is known—as it is in most cases. The amount of combustion air required can also be calculated since the composition of air is well known. However, while a certain amount of oxygen is needed from the air, any excess oxygen above the theoretical needs (also known as the stoichiometric amount of oxygen) is not needed, and all of the nitrogen introduced as part of the air is also unnecessary. Unfortunately the air will have been introduced at ambient temperature, say 15-20 °C, and will leave at the flue gas temperature, say 200-300 °C or maybe higher. Thus a lot of fuel will be used to heat up the unnecessary air, which becomes significant heat loss when it is discharged.

The key to keeping boiler efficiency high is to introduce just the right amount of air for combustion and as little as possible in excess of this amount. For this reason, the extra and unnecessary air is known as “excess air” and this should be kept—depending on the fuel used and the burner design—to say 5 to 10 per cent of the stoichiometric amount. This small amount of extra air is needed to ensure the combustion of the fuel is complete in the boiler. Too little air can lead to incomplete combustion and the formation of smoke in the stack (as well as significant amounts of carbon monoxide that should have been burned to carbon dioxide).

To maintain excess air at the lowest level possible, it is necessary to check the flue gas composition and keep the oxygen in flue gas to around 3-5 per cent in most cases. It is not enough to add air to the boiler until there is no smoke visible and then add a little more—the practice of some boiler operators. Accurate analyses of flue gas are essential. Analytical instruments are readily available to do this measurement, either as a fixed analyser mounted on the stack or as a portable analyser used regularly by plant operators. The cost of instruments can be quite modest: a simple hand held unit would cost say $US 1,000 while more comprehensive instruments will range up to perhaps $US 10,000. The more expensive instruments will include measurement of oxygen, carbon monoxide, nitrogen oxides and temperature: many such instruments compute and display excess air and combustion efficiency as percentages.

Where fixed gas analysers are installed, it is common to find that the instrument is used to adjust the air rate automatically, in line with the oxygen level actually found. Usually a signal is sent to an actuator that opens or closes a valve in the air supply line. Boiler controls can therefore be useful to maintain combustion efficiency at the highest level, even where loads fluctuate, fuel quality changes and ambient air temperature varies.

The fuel saved by ensuring the excess air is correctly set will of course depend on the situation at the boiler before corrective action is taken. Where no gas analysis has been done before, it is not uncommon to find excess air at 40-50 per cent on oil and gas fired boilers, and perhaps 100 per cent or more on coal fired units. Reducing these figures to levels around 5 to 10 per cent—closer to the minimum levels recommended—represents typically a saving in fuel costs of at least 5 per cent, or possibly 10 per cent in extreme cases. For a very modest investment in a gas analyser, the savings are often substantial and paybacks of 1-2 weeks are not unknown.

Fluid bed combustion

Fluidized beds are used to suspend solid fuels on upward-blowing jets of air during combustion. The result is a turbulent mixing of fuel and combustion air, like a bubbling fluid, and this ensures good contact between the fuel and the oxygen in the air. Combustion is improved and heat transfer between the hot bed and pipes within the bed is encouraged.

Fluidized bed combustion (FBC) evolved from efforts to develop a combustion process able to control pollutant emissions without external devices such as scrubbers. The technology burns fuels at temperatures of around 750 to 950 °C, well below the threshold at which nitrogen oxides form (typically about 1370 °C). The mixing action of the fluid bed also brings the flue gases into contact with a sulphur-absorbing chemical that can be introduced into the bed. Examples are limestone or dolomite particles. More than 95 per cent of sulphur pollutants in coal fuels can be removed in this way.

Pressurized fluid bed combustion (PFBC) was developed from the original FBC. The first generation systems use a bubbling bed technology in which a relatively stationary fluid bed is established in the boiler with low air velocities and a heat exchanger immersed in the bed. Cyclone separators remove particulate matter from the exhaust gases prior to their entry into a gas turbine, which operates as part of a combined cycle (see "Cogeneration" below). Second generation systems use a circulating fluid bed and other efficiency enhancement methods. These include integrating a coal gasifier to produce a fuel gas for burning in the PFBC.

Because of the vigorous mixing of fuel and air, FBC is suitable for many types of fuel that might otherwise be difficult to burn completely, such as coal, wood wastes, municipal solid waste, plastic and used tyres.

Upgrading generation units

Upgrading generating units can improve reliability, increase output and reduce environmental impacts from electricity generation. Typical improvements are the installation of new and improved burners, extra flue gas heat recovery, additional heat recovery from hot blowdown water, as well as modernization of instruments and combustion control systems. For very old power plants, it may be justified to replace the old equipment completely with a new generation plant designed and built to the best modern efficiency standards.

There are a large number of possible measures to adopt to raise the operating efficiency of an existing power plant. Implementation depends on the type of plant, the technology currently used, the level of maintenance, and many such factors that are site-specific. It is therefore impossible to estimate the potential improvements without a careful analysis of the actual plant and the costs involved. However, it is possible to make very rough estimates of the typical range of figures that might be encountered in practice.

In table 1, figures are quoted for the efficiency of various types of plant. They are based on the net calorific value of the fuel and are very approximate (Frans van Aart, 2004). Each plant is different and will achieve an efficiency dictated by site-specific conditions—the exact design adopted, the exact composition and quality of the fuel, the operating load, and maintenance. The figures suggest the approximate gains in efficiency that can be obtained by changing the technology used in a power plant. The economics of such a change are of course open to question and need to be assessed on a case-by-case basis.

Table 1. Best possible efficiencies for different types of generating plant

Fuel	Technology	Existing plants *(percentage)*	New plants (BAT) *(percentage)*
ELECTRICITY ONLY – figures for net electrical efficiency			
Bituminous coal	Pulverized coal, with conventional boiler and steam turbine	Typically 30 to 40	43-47
	Fluid bed combustion	30-40	>41
Lignite	Pulverized coal	30-40	39-45
	Fluid bed combustion	30-40	>40
Biomass	Grate firing Spreader stoker Fluid bed combustion	— — —	Approx. 20 >23 28-30 or more
Peat	Fluid bed combustion	—	28-30 or more
Gas firing	Gas turbine to power the generator	25-40	36-40
Gas firing	Conventional boiler and steam turbine	35-40	40-42
Gas firing	Combined cycle, with or without supplementary firing for electricity generation only	40-54	54-58
COGENERATION – fuel utilization			
All fuels	Boiler plus steam turbine with various configurations for heat production and heat recovery	75-80	75-80

BAT = best available technology

Cogeneration

Cogeneration is the production of heat as well as electricity from a single fuel source. This is also known as combined heat and power (CHP). Both power plants and industrial plants may use cogeneration to meet their needs for electricity and heat (in the form of steam or hot water, as required).

A typical large-scale cogeneration plant consists of a boiler to raise steam at high pressure and a steam turbine to drive an electricity generator. The steam turbine will often be a “back pressure” turbine in which the exhaust steam is discharged at a moderate pressure and distributed to various users such as industrial processes. Sometimes the steam is condensed at moderate pressure by heat exchange against cooling water. In such cases, the temperature of the resulting condensate is moderate to high, and can serve as a source of energy for space heating. Such an arrangement results in an energy output that is a combination of electricity and heat (hence “cogeneration”) and is often seen in a utility plant that exports electricity and is connected also to a municipal heating system.

The cogeneration system is in contrast to a conventional electricity generating plant in which the exhaust steam is discharged at the lowest possible pressure and condensed at low temperature by the cooling water. Such an arrangement results in the maximum amount of electricity being generated and no heat being produced for downstream energy users. We can compare typical systems as follows:

For cogeneration to be economically attractive to an industrial plant, the demands for electricity and steam need to be relatively stable all year round. Where this is so, the cogeneration option represents an important increase in energy efficiency compared with individual units to generate electricity and heat separately.

The benefits of cogeneration include (Cogeneration Technologies, 2006):

- Economic—improved operational efficiency to produce heat and electricity reduces overall energy costs;
- Environmental—improved efficiency reduces emissions per unit of output (heat plus electricity);
- Enhanced reliability of electricity supply—when industrial plants generate their own power demand, they either reduce or eliminate their need for electricity purchases from a utility company.

The choice to install a conventional power plant or to install a cogeneration plant will depend on the demands for electricity and heat. For a public utility company, the heat will probably be distributed as circulating hot water for space heating. Local heat exchangers can be used to generate domestic hot water too. The problem is of course the ratio of energy produced as electricity to that produced as heat. With a steam boiler/turbine arrangement, the ratio is not necessarily fixed but the flexibility to change the ratio to meet customer demands all year round may be limited.

There are basically two types of cogeneration system (Cogeneration Technologies, 2006), which differ depending on whether electricity or thermal energy is produced first:

Topping cycles, where electricity is produced first and the low grade thermal energy exhausted is captured for further use in a process. Supplementary fuel may be required to meet all the process heat demand. Topping cycle cogeneration systems are widely used in food, pulp and paper, petroleum refining and textile industries.

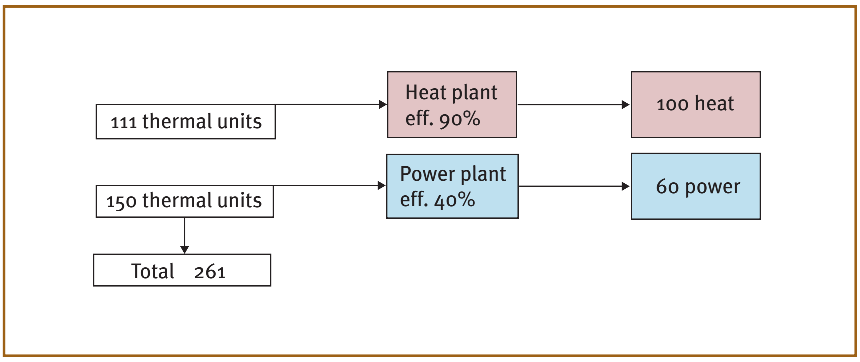
Bottoming cycles, where thermal energy is first used at high temperature in a process and excess thermal energy is then used to produce power, typically through a turbine driving a generator. Power is normally generated without the need for further fuel, and the turbine exhaust can be further used to provide lower grade heat to a process. Bottoming cycle cogeneration systems are used in processes that have large waste heat streams at relatively high temperatures, such as the steel industry, glass and chemical industries.

Box 5. **Comparison of conventional and cogeneration systems**

Assumptions

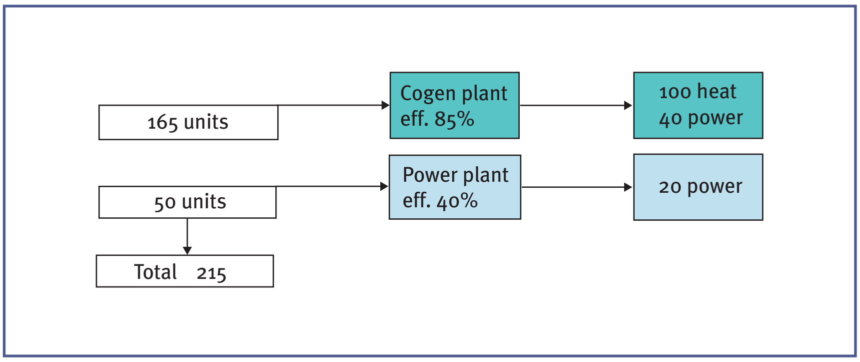
Heat demand = 100 thermal units
Electricity demand = 60 thermal units equivalent
Power only plant = 40 per cent efficiency
Heat only plant = 90 per cent efficiency
Cogen plant = 85 per cent efficiency

Without cogeneration



Total fuel consumption 261 units
Total output 160 units
Overall efficiency 160/261 = 61 per cent

With cogeneration



Total fuel consumption 215 units
Total output 160 units
Overall efficiency 160/215 = 74 per cent

Thus the cogeneration scheme is much more efficient (provided of course the simultaneous demands for heat and power are present consistently throughout the year).

Where a single cycle—as described above—provides a high grade heat output, this heat may be used in a waste heat boiler to generate more steam which in turn is fed in total or in part to a steam turbine to generate additional electricity. This system is known as a “combined cycle”. It is most often applied to a basic gas turbine unit which produces a high grade heat output as an exhaust, which can be used to generate high pressure steam for powering a steam turbine (to make electricity) with the exhaust from that turbine still able to provide a site with low pressure steam or hot water for process use. Combined cycle systems such as this can achieve efficiencies approaching 60 per cent in converting the original fuel energy into electricity and—with supplementary firing available—will typically provide the most flexible cogeneration system for industrial plant use. Figure V shows the various possible cogeneration cycles.

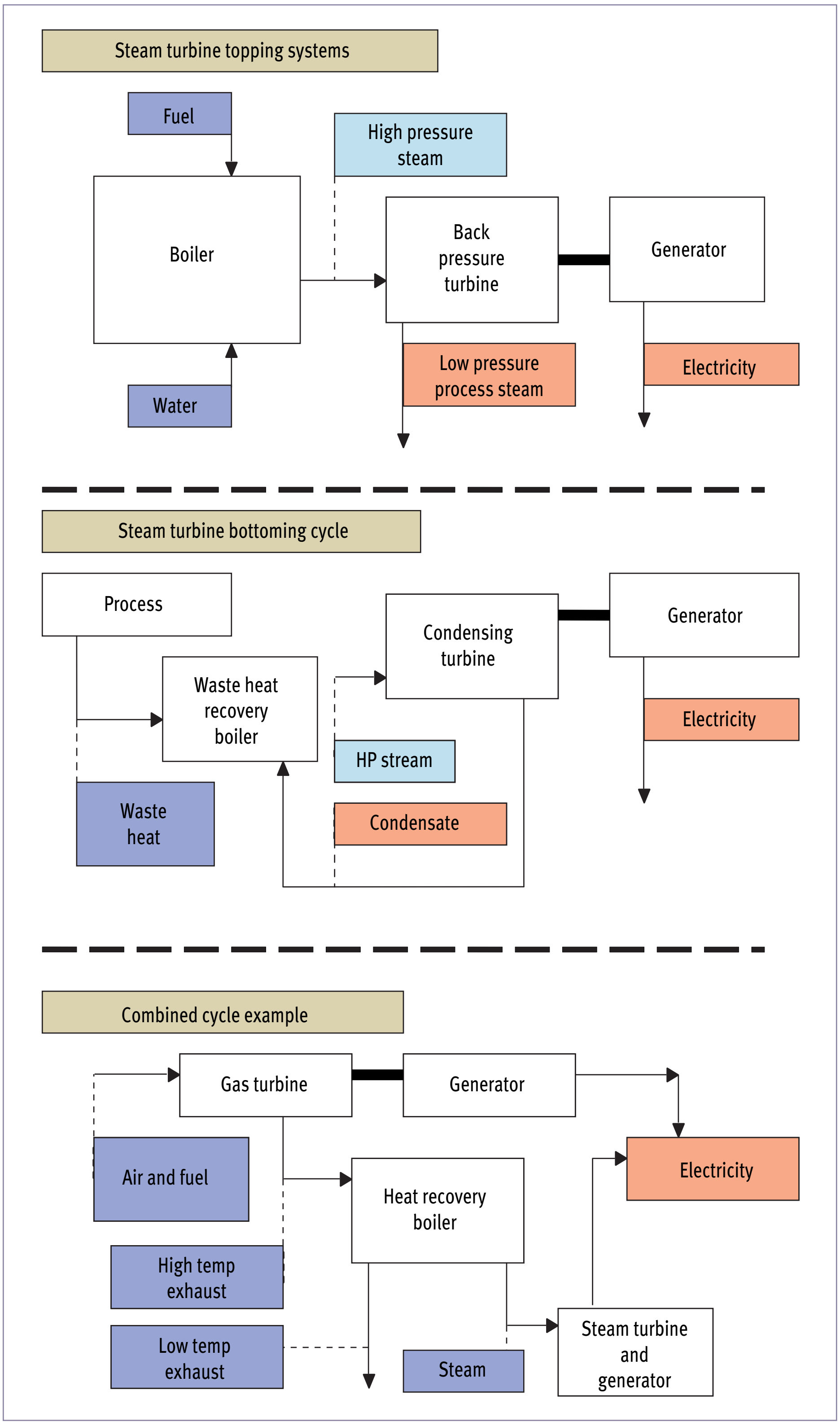
There are many variations on the basic cogeneration system based on different “prime movers”—the equipment that drives the electricity generator (Good Practice Guide 43, 1994). Table 2 shows some typical examples.

Table 2. Basic cogeneration systems base on prime movers

Type of equipment	Typical output	Typical fuels	Typical heat to electricity ratio	Grade of heat output required
Gas turbine	1 MWe upwards	Natural gas; gasoil; biogas; methane	1.5:1 to 3:1 Up to 5:1 with supplementary firing	High
Compression engine (diesel)	Up to 15 MWe	Natural gas with up to 5 per cent gasoil; heavy fuel oil	1:1 to 1.5:1 Up to 5:1 with supplementary firing	Low and high
Spark ignition engine	Up to 2 MWe	Natural gas; biogas; mine gas	1:1 to 2:1	Low and high
Steam turbine	0.5 MWe upwards	Any, converted to steam	3:1 to 10:1	Medium
Combined cycle	3.5 MWe upwards	Natural gas; gasoil; biogas; methane	Down to 1:1	Medium

It is important to note that different types of equipment permit the ratio of thermal to electrical energy to be designed into a system to match the anticipated demands. With supplementary firing as an option for some types of plant, flexibility can be built into the cogeneration plant to allow for seasonal changes in demands to be met. However, the flexibility may be limited and therefore it is particularly important to assess the likely heat and electricity demands carefully at the design stage, and to select the right type of system before the investment is finalized.

Figure V. Cogeneration cycles



The fuel used for cogeneration can be conventional fossil fuels or waste materials, such as crop residues. Box 6 illustrates the use of bagasse from sugar mills.

Finally, we may note that the heat produced by a cogeneration system may be utilized as heat for a process, and some may be used to power a refrigeration cycle. In this way, a cogeneration system can be designed to produce electricity, heat and "cold"—a trigeneration system. This type of configuration addresses the supply side for several items but remains relatively uncommon, mainly because of its complexity.

Box 6. **Benefits of bagasse cogeneration**

Economic benefits

Benefits and advantages of bagasse cogeneration include:

- Increasing the viability of sugar mills;
- Near-zero fuel costs, paid in local currency and valuation of bagasse as a waste product;
- Increasing diversity and security of electricity supply;
- Location at the point of energy demand, leading to minimal transmission and distribution (T&D) losses and costs.

Social benefits

The social benefits of on-site bagasse-fired cogeneration are:

- Greater employment for local populations;
- More widespread availability of electricity;
- More secure and reliable supply of electricity for existing consumers.

Environmental benefits

As a biomass fuel, bagasse supplies a raw material for the production of natural, clean and renewable energy, enabling its use to further government targets for renewable energy use. In brief, the environmental advantages of bagasse cogeneration are:

- Low emission of particulates, SO_2, NOx and CO_2 compared to coal and other fossil fuels;
- In GHG terms, bagasse combustion emits less than composting;
- Fuel efficiency.

Source: Bagasse Cogeneration – Global Review and Potential, June 2004, Aurelie Morand, Research Executive, World Alliance for Decentralised Energy:
www.localpower.org/documents_pub/report_bagasse_cogeneration.pdf#search=%22cogeneration%20constraints%22
Accessed on 2 September 2006.

Review question

What is the difference between bottoming cycles and topping cycles, and what type of SSM do they fall under?

3.4. Transmission

One area of supply-side management concerns transmission and distribution of electricity to customers. A reliable system depends on the reliability of the lines taking power from the generator to the end-users, and this includes other parts of the system such as transformers. Losses can occur throughout the system too, and these should be kept to an economic minimum to ensure no undue waste of primary resources to generate the electricity in the first place.

Transmission lines

Transmission lines carry electricity from one location to another, often over long distances. They can carry alternate current (AC) or direct current (DC) current, and may run over-ground or underground (U.S. Dept. of Energy, 2006). The majority of transmission systems operate with AC and are built over-ground. The main difference from distribution lines is that most transmission lines operate at relatively high voltage (typically from about 110 to 765 kilovolts). Overhead lines with polymer insulators are expected to last over 50 years.

Underground transmission lines are much less common than over-ground. Although expected to have a safe life of say 25 to 35 years, some underground lines may become unreliable after 15-20 years especially if water gets into the ducting or there is movement of the ground around the lines. The cost of typical underground lines is about 10 times more than overhead transmission lines.

Greater demands on most transmission systems require greater power transfer capacities. Even with adequate electricity generation, bottlenecks in transmission interfere with the reliable, efficient and affordable delivery of electric power. The amount of power on a transmission line is the product of the current, the voltage and the “power factor” (see Glossary). There are three types of constraints that limit the capability of a transmission line, cable or transformer to carry power—thermal/current constraints, voltage constraints and system operating constraints (John Makens, 2006).

Thermal limitations are relatively common. The flow of electricity through a line causes heat to be produced due to the resistance of the line. The actual temperatures occurring in the transmission system depend on any factors, such as the current and on ambient conditions (e.g. temperature, wind speed, wind direction) because the weather affects dissipation of heat to the air. Thermal ratings for transmission lines are thus expressed in terms of current rather than temperature, for ease of measurement. Thermal limits are imposed because overheating leads to two potential problems:

- The transmission line loses strength because of overheating which can reduce the expected life of the line;
- The transmission line expands and sags in the centre of each span between supporting towers. If the temperature is repeatedly too high, an overhead line may stretch permanently and its clearance from the ground may become less than required for safety reasons.

Because damage from overheating is a gradual process, higher current flows can be allowed for limited time periods, and the “normal” thermal rating for a line is the current flow it can support indefinitely. Underground lines and transformers also have thermal constraints. Overheating in both cases causes shortened lives primarily due to damage to insulation.

Voltage fluctuations can occur due to variations in electricity demand and to failures of transmission and distribution lines. Constraints on the maximum voltage levels are set by the design of the transmission system. If the maximum is exceeded, short circuits can occur and transformers and other equipment at substations and in customer facilities can be damaged or destroyed. Minimum voltages are also to be avoided as these cause improper operation of equipment at the customer end and motors can be damaged.

System operating constraints result from considerations of safety and reliability. For example, power flows in connected networks are affected by characteristics of the lines in the different networks, and by interconnecting systems at more than one point, electricity flows can become rather complex and limitations on the power transmission capacity of each network can be affected. Power system stability problems may also occur when networks are connected, causing fluctuations in AC frequency and possibly voltage instability.

Various options are available for reducing limitations on power transfers due to the thermal rating of overhead transmission lines (John Makens, 2006), although measures for underground cables and for transformers are more limited:

- With modern methods of calculating ratings, it may be possible to define higher ratings without any physical changes to the lines. For example, power flow limits based on reaching a maximum temperature can be calculated instantly using data on actual weather conditions and on the actual power flow. Some utilities measure the line temperatures with detectors in the lines. This data—calculated or actual—are transferred to the utility control centre for appropriate action.

- Since the thermal limit of a transmission line is based on the component that would be first to overheat, a substantial increase in overall rating can sometimes result from replacing an inexpensive element. For example, a switch or circuit breaker is much less expensive to replace than to replace a line (or indeed to build a new line).
- It may also be acceptable to increase allowable temperatures (and hence achieve higher power loads) and plan for a decrease in the life of the lines. However this approach can lead to sagging in the lines so that ground clearance is inadequate for safety reasons. In some cases, rebuilding selected towers can solve the problem.
- Finally, the most obvious (but most expensive) option is to replace lines with larger ones by re-stringing existing lines or adding cables. This action may require towers to be rebuilt in order to support the extra weight. Any such measure must be examined to take account of other changes in the system that might become necessary, such as upgrading substations for higher loads.

To address voltage constraints, various technical actions are possible. These include increasing the voltage at the generator during periods of light load, together with adjusting transformer settings (or replacing transformers) to achieve the correct operating voltage. Coordination with any interconnected network is of course essential. For this reason, this option may be difficult to apply in practice. Changing voltage levels permanently usually requires substantial reconstruction of power lines and is thus not considered further here.

Data monitoring

To ensure that generation, transmission and electricity use are all properly balanced and operated at highest efficiency, it is necessary to have comprehensive information on all elements of the system. There are many computerized systems available to do this. These are collectively known as "supervisory control and data acquisition" systems (SCADA). Such SCADA systems are able to switch selected equipment on or off, based on the current situation of the utility company supply system. SCADA systems can also be used to monitor and control buildings operations, operating heating, lights and cooling equipment as required. SCADA systems also are used to switch large loads on or off to ensure a customer does not exceed an agreed maximum demand and thus pay extra for the electricity consumed.

While this control of large loads normally remains with the owner and operator of the equipment, it is possible to set up systems in which control of major loads rests with the utility company, allowing it to delay loads from the highest peak time to another—a more convenient—time. In many such cases, the reduction in peak load represents a shift to more efficient generation by the utility, and is thus a useful supply-side management measure.

Load aggregation

Electric load aggregation is the process by which individual energy users band together in an alliance to secure more competitive prices that they might otherwise receive working independently (Pace Global Energy Services, 2006). Aggregation can be accomplished through a simple pooling arrangement or through individual contracts between suppliers and each member of an aggregate group. While natural gas purchasing alliances have been around for many years, the aggregation of electricity loads across multiple facilities is less well known.

Big industrial companies with large electricity loads have greater purchasing power and more leverage in negotiations with suppliers than smaller companies. For example, depending on the market conditions, a purchaser may be required to buy a 20-25 megawatt block of power in order to approximate wholesale pricing. Companies can look into forming purchasing alliances with other local businesses to purchase larger blocks of power.

Load factor is the ratio of the average load for electricity consumption to peak demand (expressed as a percentage) for each billing period. Energy suppliers usually impose a “demand charge” on each customer to reflect the power generation capacity needed to meet the peak demand for that customer. This demand charge is a fixed item that does not depend on the kilowatt hours consumed in a billing period. If the load factor of a customer is high, meaning their load runs consistently at or near the peak demand, the demand charge will represent a smaller percentage of the overall cost of electricity.

Through load aggregation, companies can enhance their purchasing power by taking advantage of load diversity among multiple facilities as a means of improving the overall load factor of the group. When the loads of several customers are aggregated, non-coincidental peaks and valleys in the load profiles of individual customers generally tend to offset each other. Of course, this needs careful data collection and analysis to monitor the loads at any time. The desired effect will result in a flatter overall load profile, a higher load factor, and ultimately, lower per unit energy costs for all members of an aggregate group. The challenge for consumers is to find suitable aggregation partners.

A smoother load profile can also have a beneficial impact on the supplier who can generate a certain load using the most efficient equipment and does not have to change the load up and down too frequently.

Substation improvements

A substation is used to switch generators, equipment, circuits or lines in and out of a system. It is also used to change AC voltages from one level to another, or to change AC to DC current (or vice versa). Some substations are small with only one transformer, others can be quite large with several transformers and switchgear.

Transformers are electrical equipment designed to convert one AC voltage to another. They are essential in electricity transmission and distribution systems (John L. Fetters, 2002) and are widely used to raise voltages for long distance transmission (say 4 to 35 kilovolts) and then reduce the voltage down to a level suitable for plant equipment (say 120 to 480 volts).

Dry-type distribution transformers are usually found in large commercial and industrial facilities. Liquid filled units are usually used in smaller facilities. Distribution transformers are generally very efficient with losses of less than 0.25 per cent in the largest units. However, when the overall losses of many transformer steps in a distribution system are taken into account, the losses can add up. In addition, the load on transformers decreases when facilities close for the day or at the weekend: the no-load losses in lightly loaded units increase as a percentage. Transformer losses in power distribution networks can exceed 3 per cent of the total electricity generated.

Reducing losses in transformers will increase their efficiency. There are two main types of loss. The first is “core” loss (also called no-load loss), which is the result of magnetizing and demagnetizing the core during normal operation. Core loss occurs whenever the transformer is energized and does not vary with load. Changing the material of construction of the core can reduce losses (e.g. amorphous iron instead of conventional carbon steel cores). The more efficient materials cost more than the standard core materials but losses could be reduced by up to 30 per cent.

The second loss is coil or load loss, so termed because the efficiency losses occur in the primary and secondary coils of the transformer. Coil loss is a function of the resistance of the winding materials and varies with load. The choice of winding material affects the coil loss. Copper is a better electrical conductor than any other material except silver. Electricity thus flows in copper more easily than in aluminium or steel wires of the same diameter. Copper wires result in lower losses, which appear as unwanted heat. Another way to reduce losses is to use larger diameter wires that allow current to flow more easily. Sizing distribution transformers to meet their expected load also affects efficiency. Oversized transformers can contribute to inefficiency.

The cost of installing higher efficiency transformers needs to be evaluated against the anticipated savings. Payback periods of two to five years are typical.

Other key equipment includes switchgear, alarms and controls. Old equipment may become unreliable and require replacement on these grounds. For reliability and safety, such equipment may need replacing, at which time best modern practices should be adopted in specifying the new equipment.

3.5. Distribution

Distribution networks consist mainly of overhead lines, underground cables, transformers, and switchgear. Most consumers are supplied at low voltage, defined typically as less than 1 kV, with domestic customer supplies usually at 230 volts or less. Some of the larger commercial and industrial consumers are typically supplied at high voltage, over 1 kV and some at extra high voltage (over 22 kV).

Electrical losses are an inevitable consequence of the transfer of energy across electricity distribution networks. In the UK, the losses amounted to around 7 per cent in 2000/2001. The level of losses varies from year to year, influenced by a number of factors, both technical and operational.

The International Energy Agency (IEA) publish figures regularly for losses in transmission and distribution. While the numbers vary from year to year, typical figures for 1998-2001 are around 7 to 8 per cent, with European Union figures averaging about 7 to 7.5 per cent (although the range is from under 4 per cent to over 10 per cent). According to various World Bank/ESMAP reports, some countries report distribution losses as high as 30 per cent of the energy supply. Much of these very high losses can often be attributed to theft with say half coming from technical losses. There are likely to be important opportunities for reducing losses by investigating the level of losses and where these occur in any distribution system.

Upgrading distribution systems

While there are many similarities in distribution networks, there can be important differences, such as:

- Geographical size;
- Number of customers connected;
- Quantity of electricity distributed;
- Degree of dispersion of customers across the network;
- Proportion of different types of customers;
- Amount of underground versus overhead lines.

There may also be wide differences in design, operating and investment principles, any of which can influence in detail the network configuration.

The level of losses in a network is driven by a number of factors. There are three main categories of losses; variable losses, fixed losses and non-technical losses:

- Variable losses, often referred to as copper losses, occur mainly in lines and cables, and also in the copper parts of transformers. They vary according to the amount of electricity transmitted through the equipment and are proportional to the square of the current. Losses are also proportional to the length of line, the resistivity of the material, and inversely proportional to cross-sectional area of conductors. Typically variable losses are about two-thirds to three-quarters of the total losses (UK Office of Gas and Electricity Markets, 2003);
- Fixed losses, or iron losses, occur mainly in transformer cores and do not vary according to current. These are typically a quarter to a third of total losses;
- Non-technical losses, unlike the two items above, refer to electricity delivered and consumed but not registered as sales. This includes theft as well as simply errors in recording and billing (e.g. meter errors, lack of calibration, no meters installed).

Measures to reduce variable losses include increasing the cross sectional area of lines. There is thus a trade off between the value of lower losses and the cost of replacing existing lines with larger ones. Use of higher voltage leads to lower currents to transmit the same amount of electricity and this will lead to lower losses. The configuration of a network will clearly affect the losses if distribution distances can be reduced (again, this necessitates investment in new lines and this may be expensive).

Demand management is another means of reducing variable losses because loads transmitted at peak time result in greater increases in losses than the same amount at off peak times. If distribution companies can encourage users to smooth out their demand, losses can be reduced.

Finally, variable losses can be reduced by balancing three-phase loads throughout the network on a regular basis.

Fixed losses do not vary according to current. They take the form of heat and noise and occur so long as a transformer is energized. The level of fixed losses can be reduced by upgrading the core material of transformers (e.g. special steels and amorphous iron). They can also be reduced by eliminating transformer levels (reducing the number of transformers involved), and by switching off transformers in periods of low demand.

Low power factors will also contribute to losses. Raising power factors by installing capacitors will lead to lower distribution losses, as can distributed on-site generation.

On-site generation

Strictly speaking, some might not consider on-site generation to be a true supply-side management measure. On-site generation at an electricity user might be a way of cutting the electricity supplied by the grid to zero of course, and this would no doubt have an effect on the electricity supplier (but this would be specific to the situation so general comments cannot be made).

However, we should consider on-site generation briefly in this module, as this might be encouraged by a utility company that is nearing the maximum level of demand that it can supply. The utility—in the absence of investment funds for increasing generating capacity—might wish to reduce the electricity it supplies to one customer to be able to supply others, provided the original customer is able to self-generate all or part of its power needs.

The benefits of on-site generation can therefore be:

- On-site "self-generation" reduces demand on the grid and may allow deferment of investment in additional capacity;
- The principal electricity supply can be at the end-user itself, reducing transmission losses incurred in getting supply from a distant power source.

The generating equipment can use a variety of energy sources—from conventional fossil fuels to renewables such as solar, wind, bio-energy. Systems may adopt conventional boiler-steam turbine technologies or can be installed as cogeneration plants (often worthwhile if an industrial plant has steady electricity and heat loads year-round, or has a low-cost source of energy available, such as waste heat from an industrial process). In some cases, the on-site generator can be connected to the grid, to import electricity if on site electricity production is inadequate ("stand-by electricity") or to export to the grid if excess electricity is available. The cost of standby power from the grid to satisfy imports, and the value given to surplus electricity exported to the grid, are subjects of negotiation between the parties. Technical standards will also have to be met, such as voltage levels and AC frequency.

Power factor improvement

Power factor is the ratio between the useful load (in KW) and the apparent load (in KVA) for a system (L M Photonics Ltd., 2002). It is a measure of how effectively the current is being converted into useful work output, and is an indicator of the impact of the load on the efficiency of the supply system. A load with a power factor of one results in the most efficient loading of the supply, while a load with power factor say 0.5 will result in much higher losses.

Whenever loads are connected to an AC supply, there is a possibility that current and voltage will be out of phase. Loads such as induction motors draw current that lags the voltage, while capacitive loads (e.g. synchronous motors, battery chargers) draw current that leads the voltage. Loads that are predominantly resistive such as heaters and cookers draw current in phase with voltage. The angle between the current and voltage is known as the "phase angle φ"—this can be leading or lagging (or zero) depending on the load. The power factor is defined as cosine φ and is always less than one. It represents the ratio of active power (or useful power) to the total power supplied by the generating station.

Power factor correction is normally considered a key demand-side management option because it is usually implemented by the electricity customer and leads to a reduction in their electricity bills. However, it is a measure that reduces the power supplied by the utility and therefore it may also be considered a supply-side management option.

Indeed, utility companies often put in place incentives (or penalties) to encourage their customers to improve their power factor, in order to relieve load on their generators. When power factor is less than unity, the amount of useful power supplied by the generating plant at maximum output will be less than its full capacity (in other words, not all the power supplied is turned into useful work). This represents an inefficiency and therefore utility companies usually require customers to achieve a power factor of at least 0.9 (sometimes 0.95). Those who fail to meet the minimum will be charged a penalty on their bills to compensate for the various losses incurred by the generator (e.g. losses in distribution cables and transformers).

Operating at a high power factor allows energy to be used more efficiently (hence the setting of a limit such as 0.9 or 0.95). Since most loads are in practice inductive, and a low power factor can be increased ("corrected") by installing capacitors in the system. In most plants a practical solution is to install capacitor banks at the main point of power supply. Depending on the power factor, more or less capacitance can be connected at any time. Slightly more efficient but costlier is installing individual capacitors around a facility to correct the power factor in different parts of the network. In all cases, the utility company benefits because less power needs to be generated to meet the end use needs of customers with high power factors.

3.6. Transport of fossil fuels

Most of this module is concerned with the supply of electricity and supply-side management measures that might improve the efficiency of electricity delivery to a customer. There are also measures that can be taken to improve the supply of fossil fuels to customers, and these can be deemed supply-side management actions also. Since these actions are typically carried out by users of energy, we usually consider these “demand-side” management, and therefore only a few comments are added here.

With respect to pipelines for delivery of liquid and gas fuels, these will use pumps or compressors to transfer the fuels. Energy efficiency factors applicable to these types of equipment include:

- Oversized, inappropriate motors;
- Opportunity for using high efficiency motors;
- Excessive compressor or fan speed;
- Excessive system resistance (clogged filters, stuck dampers);
- Variable loads, and the inappropriate use of valves and dampers (inlet or outlet side) to control flow rates;
- Long periods of motor idling (running but not pumping or compressing fluids);
- Variable speed drives—energy efficient if adopted in the correct location although variable speed motors might be more cost effective sometimes;
- Leaks of process liquids and gases, including leaks from seals on equipment shafts;
- Steam leaks from steam turbine drivers;
- Gearboxes running hot, noisy;
- Worn or slack belts around pulleys, belts missing, use of ribbed belts
- Pulleys and couplings misaligned;
- Worn motor bearings;
- Low power factor, opportunity for installing capacitors.

With respect to road transport, a common means of supplying liquid fuels to consumers, there are a number of measures that can improve efficiency:

- Performance analysed by driver if vehicles are pooled or shared;
- Tyre pressures checked regularly;
- Planning of routes and loads;
- Vehicles left with engines idling;
- Vehicle aerodynamics;
- Driver motivation and education;
- Improved lubricating oils;
- Thermostatically controlled fans and radiator shutters on vehicle engines;
- Regular maintenance.

4. CONSTRAINTS AND CHALLENGES OF SSM

Supply-side management refers to actions taken to ensure the generation, transmission and distribution of energy—primarily but not exclusively electricity—are conducted efficiently.

Utility companies may change the load profile to allow their least efficient generating equipment to be used as little as possible. They may improve maintenance and control of existing equipment, or upgrade equipment with new items utilizing improved technologies. In brief, an electrical utility may embark on SSM to:

- Ensure reliable availability of energy at reduced generating cost;
- Reduce energy prices to some or all of their customers;
- Meet increasing electricity demand without necessarily incurring major capital investments until later;
- Minimize environmental damage.

Suppliers of other types of energy will have corresponding motives.

Energy users will normally focus their efforts on demand-side management methods (DSM) but some will consider the supply side too. For example, they may look at on-site generation alternatives—including cogeneration—or consider diversifying to alternative fuel sources (such as natural gas, solar, wind, biofuels).

One of the challenges in adopting SSM is the need for comprehensive information to be widely available to utility staff—including operating, technical and commercial departments—about measures that could be appropriate to their specific situation. In some cases (e.g. power factor correction) it will be the primary responsibility of customers to take the relevant measures and make the necessary investments, so that the efficiency of overall supply can benefit. Balancing the interests of the supplier and consumer may sometimes prove difficult, especially when capital investment gets involved. Investors will need incentives of some sort to be persuaded to take action, and these incentives will normally be in terms of improved profits and rarely in terms of environmental improvements.

Even where SSM can typically produce economic benefits to the utility or indeed the customer, there will often remain a problem of convincing company management to authorize expenditures. Sometimes a short-term approach is used and the evaluation of a project requiring a significant investment may fail to take into account long-term benefits and life cycle costing. All too often a "first cost" basis drives decisions: this frequently results from a lack of capital funds (Cogeneration Technologies, 2006).

With respect to clean coal technologies, many are well proven in developed countries but experience is lacking in developing nations. There will often be a lack of technical skills to participate in equipment design and to operate complex process plant, while management of such facilities may lack the necessary experience. Certainly a lack of management and technical training could prove difficult to overcome in the short term for organizations seeking to apply many of the aspects of SSM.

Exploitation of renewable energies is not believed to pose such a problem although large scale units may not have been proven in all countries in Africa. However, it is believed that sharing experiences and knowledge will have a role to play in helping those countries that might lack first-hand knowledge of the latest technologies. Other barriers to developing bagasse as a fuel for electricity generation exist, as described in box 9. These include the cost of power, problems with prompt payment to sugar mills for electricity sold, and sometimes the poor level of efficiency of many sugar mills themselves.

With respect to the efficient operation of existing facilities, it is often the lack of management that leads to poor energy performance, and not the lack of tried and tested equipment and processes. Senior managers all too often fail to appreciate the benefits achievable using simple low cost measures, and focus on expanding production rather than improving efficiency. Some will believe that no progress can be made without massive investments in new technology, and that—since the company lacks funds—nothing can be done.

Energy efficiency is usually highly cost effective and, at least at the beginning, is easy to apply with little or no funding needed. Better maintenance will almost certainly pay dividends immediately. As results are achieved and savings are made, most companies can accumulate funds to devote later to projects that need funding. A serious challenge is thus to educate managers that small and simple actions can make their contribution in the short term, and can pave the way for larger and costlier actions later.

Part of this education is of course to make clear that reliable operating data are important tools to raise plant and system efficiencies, and that collecting and reporting data are not simply tedious chores that are imposed on the operators. Indeed, good data and proper analysis contribute greatly to justifying new equipment in terms of economic benefit to the company. Good data can thus persuade banks or other financing institutions that SSM measures are worthwhile and deserving of loans at acceptable—low risk—interest rates.

Even where a plant has adequate funds for investment, managers should insist on adequate evaluation of all potential projects, especially those requiring large investments and those that have a long life expectancy. Here we may mention cogeneration plants. It is essential that reliable information is collected to define the load curves for heat and electricity supplies, including seasonal variations, so that the original design is correct and able to operate with the necessary flexibility. A large cogeneration plant might expect to operate for 30 to 40 years, or longer.

With respect to transmission and distribution of electricity, the challenge for many utility companies will probably be the funding of large investments to replace old equipment or to add significantly to capacity, as electricity demand grows quickly in developing countries. Technical solutions to problems are generally well known and expertise available from consulting engineers, if not from the utility companies themselves. Here again, good management of existing facilities has its role to play.

Load aggregation is interesting because the problems of several customers can often be solved at the same time. However, it is essential that comprehensive historical data on load profiles are available, and such data are readily available at any time in the future. Analysis of this data may have to be done by outside specialists if the expertise is not available in-house. Reliable and timely data are needed to ensure that the proper combined load profile is being maintained and that all parties—including the utility—are benefiting.

Finally we may mention power factor improvement again and stress that both parties—the electricity consumer (who will probably have to invest in the necessary equipment), and the supplier must see the benefits for themselves.

Box 7. **Barriers and constraints to development of bagasse cogeneration**

India:

- State Electricity Boards are still reluctant to buy power from biomass projects, despite the good example set by Maharashtra Electricity Regulatory Commission with its regulatory process and the provision of the Electricity Act. Many States and State Electricity Boards remain unaware of the opportunity for decentralized energy.
- In many States, there is neither the assurance that electricity can be sold to the grid nor, in fact, any guarantee of timely payment for electricity generated by non-utilities.
- Compensation for failure to supply or fluctuation in grid supply by State Electricity Boards is, more often than not, unavailable. This provides little incentive for forward planning of demand and production among non-utility electricity generators.

Eastern and Southern Africa:

- Bagasse cogeneration can be expensive compared to hydro electric power schemes already in place (6USc/kWh compared to 3USc/kWh) and compared to cheap electricity from the Southern African Power Pool. Therefore, electricity boards may be unwilling to set feed-in tariffs to the higher level required by sugar mills.
- Poor management of some sugar mills has caused the sugar industry to run into difficulties; some sugar mills—especially in Kenya and the United Republic of Tanzania—have been closed down as a result of this, limiting the scope for bagasse cogeneration in these countries.
- As in many other countries, sugar mills often require refurbishment and upgrading to ensure that they are energy efficient so that they can profit from electricity generation. Low sugar prices in world markets mean that sugar mills often have little money to invest in such schemes.

Source: Bagasse Cogeneration – Global Review and Potential, June 2004, Aurelie Morand, Research Executive, World Alliance for Decentralised Energy:

www.localpower.org/documents_pub/report_bagasse_cogeneration.pdf#search=%22cogeneration%20constraints%22

Accessed on 2 September 2006.

Discussion question

What types of SSM options do you think have the most environmental benefits while still offering an affordable electricity supply to the consumers of your country? Consider the current infrastructure and capability of the supply industry and the possible cost savings, or increases, due to the SSM programme.

5. CONCLUSION

With increasing demand for energy worldwide and the resources being limited or becoming ever more expensive, it is important (and usually cost effective) to improve the efficiency of energy supply. In turn, this usually means a benefit to the energy consumer in terms of lower energy prices. Improved efficiency on the supply side will also make a valuable contribution to reducing the impact of energy use on the environment. While demand-side improvements are certainly important, supply-side options also need to be identified, evaluated and implemented where the economics justify.

LEARNING RESOURCES

Key points covered

These are the key points covered in this module:

- What SSM is and why it should be pursued.
- A review of the main options and opportunities for SSM, including better operation of existing power plants, transmission and distribution systems.
- Overview of the some constraints and challenges of implementing SSM measures or programmes.

Answers to review questions

Question: Give four reasons why a utility would embark on an SSM programme.

Answer:

An electrical utility may embark on SSM to:

- Ensure sustained availability of energy;
- Meet increasing electricity demand and expanding supply infrastructure due to economic and population growth;
- Cover electrification programmes or industrial investment;
- And mitigate environmental the impact of energy use.

Question: What is the difference between bottoming cycles and topping cycles, and what type of SSM do they fall under?

Answer:

A bottoming cycle uses the waste heat from a manufacturing process to produce steam and drive a turbine to produce electricity.

A topping cycle produces electricity or mechanical energy by burning or processing a fuel and the waste heat is used to drive a secondary electrical turbine (combine cycle) or provide process heat.

These are two main types of cogeneration technologies used by SSM programmes.

Exercises

1. Which type of SSM interventions could be implemented with the most ease/most rapidly in your country? Which interventions would be the most effective in your opinion and why?

   Write a one page answer.

2. Your government is faced with rising demand and approaching the limit of the reserve generating capacity. The cost of constructing new generating capacity is proving to be too high for the short term. While plans are being made for reducing the demand and raising funds for building additional capacity you have been asked to implement some key supply-side management strategies to increase the output of the existing capacity. You, in your country, have a few thermal generating stations with old transmission lines as well as an active sugar industry and an iron smelting plant. Some funds are available for SSM measures.

   Write a 2-3 page essay discussing the possible SSM options.

Presentation/suggested discussion topics

Presentation:

ENERGY EFFICIENCY – Module 13: Supply-side management

Suggested discussion topics:

1. Do you think clean coal technologies are merely a “gimmick” to promote coal use or do they offer sustainable solutions to energy supply? Discuss.
2. Renewables have an important role to play in future energy supply. Discuss.
3. Which type of SSM interventions could be implemented with the most ease/most rapidly in your country? Which interventions would be the most effective in your opinion and why?

Relevant case studies

1. EU-China partnership on climate change—clean coal technology.

REFERENCES

World Commission on Dams, Project Output and Dissemination, Annex #3—Thematic Reviews.

United Nations Framework Convention on Climate Change, An initial assessment of steps taken by non-Annex I Parties to reduce emissions and enhance removals of greenhouse gases, UNFCCC/SBI/2003/INF.14, 20 November 2003

Upgrading Transmission Capacity for Wholesale Electric Power Trade, John Makens, Energy Information Administration
www.eia.doe.gov/cneaf/pubs_html/feat_trans_capacity/ w_sale.html
Accessed on 13 July 2006.

World Coal Institute, Clean Coal Technologies,
www.worldcoal.org/pages/content/index.asp?PageID=19
Accessed on 30 August 2006.

Cogeneration Technologies, www.cogeneration.net/CogenerationExplained.htm
Accessed on 13 July 2006.

Sugar Cane Bagasse for Electricity Generation in Africa, Kassiap Deepchand, Technical Manager, Mauritius Sugar Authority, published in ESI Africa, Issue 2, 2004.

UNIDO, Report on Capacity in Energy Efficiency and Renewable Energy Regulation and Policy, YA/FRA/05/016, Case Studies on Energy Efficiency, Case Study 2: Investigation of operational, financial and environmental benefits emerging from use of an automatic load control and alternative energy supply at Lusaka Water and Sewerage Company, March 2006.

Use of Solar Water Heaters in Industrial Processes to Reduce Furnace Oil Consumption, I.P. Da Silva, P. Mugisha, P. Onek, H. Molten, P. Simonis, Makerere University, Solar Construct, MEMD/GTZ, Kampala, Uganda. Paper delivered at ICUE, Cape Town, May 2004.

ESI Africa, Issue 1, 2001.

Cogeneration Technologies, www.cogeneration.net/Demand_Side_Management.htm
Accessed on 1 September 2006.

Load Aggregation of Multiple Facilities, Application Note #7, www.obvius.com/
Accessed on 13 July 2006.

UNIDO, Capacity Building in Energy Efficiency and Renewable Energy Regulation and Policy-Making in Africa, Ghana—Energy Efficiency Country Profile, Alfred K. Ofosu Ahenkorah, Accra, January 2006.

Benefits of Electrical Load Aggregation, PACE, Global Energy Services.

AFREPREN (2004), AFREPREN Occasional Paper 23: African Energy Data and Terminology Handbook, Nairobi, AFREPREN.

Geothermal power boost for Kenya and Eastern Africa, UN Environment Programme, www.unep.org/Documents.multilingual/Default.asp?DocumentID=309&ArticleID=3963

Frans van Aart, Energy efficiency in IPPC installations, Vienna, 21 October 2004.

Good Practice Guide 43, Introduction to large scale heat and power, 1994, published by ETSU Harwell, UK.

U.S. Department of Energy, Clean Gas and Natural Gas Power Systems, Overview of Fluidized Bed Technology, updated October 6, 2006 and available at www.fossil.energy.gov/programs/powersystems/combustion

John L. Fetters, Transformer Efficiency, 23 April 2002, see www.energyandpowermanagement.com

U.S. Dept. of Energy, The Electricity Delivery System, February 2006.

Benefits of electric load aggregation, Pace Global Energy Services, PMA Online Magazine, 2006.

L M Photonics Ltd., Power factor correction, 2002, www.lmphotonics.com

Electricity distribution losses – a consultation document, January 2003, U.K. Office of Gas and Electricity Markets.

INTERNET RESOURCES

IEA Clean Coal Centre: www.iea-coal.org.uk

World Coal Institute: www.worldcoal.org

U.K. Carbon Trust: www.carbontrust.co.uk/energy

Cogeneration Technologies: www.cogeneration.net

World Alliance for Decentralised Energy: www.localpower.org

U.S. Energy Information Agency, Dept. of Energy: www.eia.doe.gov

GLOSSARY/DEFINITION OF KEY CONCEPTS

Bagasse	Generally in sugar production only the stalk is used and the waste that is left is known as bagasse, which consists of 50 per cent fibre, 48 per cent moisture and 2 per cent sugars and can be burnt to produce steam and electricity.
BAT	Best available technology, used to refer to technology normally adopted in modern, newly built facilities. Not necessarily the lowest energy consuming technology but representative of proven commercial practice.
Boiler blowdown	Intermittent or continuous discharge of water from a boiler to maintain dissolved solids content below a specified level. The level is set by manufacturers to ensure boiler operation is efficient and there is minimum foaming and carry over of solids into the stem.
Biomass	Can be an important renewable energy resource when managed in a sustainable way, for example, wood from sustainably grown forests.
Bottoming cycle	The waste heat from the manufacturing process is used to produce steam and drive a turbine to produce electricity.
CCT	Clean coal technologies.
Conversion efficiency	As applied to a power plant, this is the ratio of electricity output to fuel (energy) input, calculated in consistent units and expressed as a percentage.
Demand charge	Fee charged to a customer on the electricity bill, corresponding to the agreed maximum load (in kW) that may be drawn in a specified period of time.
Excess air	Refers to boiler and furnace operation. Amount of combustion air above the theoretical amount needed for complete combustion, expressed as a percentage (see “stoichiometric”).
FBC	Fluidized bed combustion.
GTCC	Gas turbine combined cycle.

IGCC	Integrated coal gasification combined cycle.
Net efficiency, gross efficiency	Efficiency of a boiler or furnace, expressed as a percentage and referred to the net calorific value of the fuel (or gross, as relevant).
Power factor	The ratio of the real power (kilowatts) to apparent power (kilovoltampere).
Preventive maintenance	Procedures to monitor equipment performance and carry out maintenance on a regular basis and thus avoid—as far as possible—the equipment breaking down.
SCADA	Supervisory control and data acquisition.
Stoichiometric	The theoretical amount of air needed to achieve complete combustion in a boiler or furnace.
SWH	Solar water heater.
Topping cycle	Electricity or mechanical energy is produced by burning or processing a fuel and the waste heat is used to drive a secondary electrical turbine (combine cycle) or provide process heat.
UCG	Underground coal gasification.

Case study 1.

EU-CHINA PARTNERSHIP ON CLIMATE CHANGE—CLEAN COAL TECHNOLOGY

CONTENTS

1. BACKGROUND

Coal is simultaneously the fossil fuel with the highest carbon content per unit of energy and the fossil fuel with the most abundant resources in the world. Clean or more efficient use of coal is the subject of numerous international collaborative studies aimed at reducing local emissions and/or global CO_2 emissions from its use.

On 5 September 2005, the eighth China-EU Summit was held in Beijing, China. The Summit acknowledged 30 years of peaceful cooperation between the regions and believed that strengthening this relationship would add value to the long-term interests of both China and the EU. Looking to the future, the leaders proposed concrete actions in various strategic areas.

The Partnership on Climate Change (Partnership) was one of the major outcomes of the Summit. The Partnership will strengthen cooperation and dialogue on climate change and energy between the EU and China.

One major objective of this Partnership is the development and demonstration of advanced near "zero emissions" coal technology based on carbon dioxide capture and geological storage to address increasing greenhouse gas (GHG) emissions from the use of coal in China.

The Partnership on Climate Change (Partnership) was one of the major outcomes of the Summit. The Partnership will strengthen cooperation and dialogue on climate change and energy between the EU and China. A Joint Declaration on Climate change set out specific areas of cooperation including the following key areas for technical cooperation:

- Energy efficiency, energy conservation, and new and renewable energy;
- Clean coal;
- Methane recovery and use;
- Carbon capture and storage;
- Hydrogen and fuel cells;
- Power generation and transmission.

2. INTRODUCTION

China's primary commercial energy consumption increased at 5.4 per cent per annum from 1980 to 1996 to reach 1,388 million metric tons of coal equivalent (tce). Coal as the dominant source of energy, accounted for 74.8 per cent of total primary commercial energy production in 1996, followed by oil (17.1 per cent), hydropower (6.2 per cent), natural gas (1.7 per cent) and nuclear (0.2 per cent).

The industrial sector is the largest energy consumer, accounting for 64 per cent of final commercial energy consumption. Residential and commercial sectors have a share of 21 per cent. Transport and agriculture account for 10 per cent and 5 per cent, respectively.

From 1990 to 1996, the average annual growth rate of real gross domestic product (GDP) was 11.6 per cent, while primary energy consumption grew at 5.9 per cent. As a result, the overall energy intensity of the economy declined by almost 30 per cent from 1990 to 1996. This decline reflects changes in economic structure and sources of industrial value added (75-85 per cent), as well as energy efficiency improvements (15-25 per cent). However, the energy intensity figure is still high, more than double the average for industrialized countries.

China is the second largest electricity producer in the world. Between 1980 and 1997, both installed capacity and annual electricity generation grew at an average annual rate of about 8.9 per cent, reaching 250 GW and 1132 TWh. Every year since 1988, 11 to 15 GW of generating capacity has been added.

As of the end of 1997, the total installed capacity was 250 GW from which 75.8 per cent uses fossil fuels, 23.4 per cent hydropower and 0.8 per cent nuclear. Coal-fired power plants provided 81.9 per cent of the total electricity generation of 1132 TWh in 1997.

The annual electricity consumption per capita in 1997 was 897 kilowatt hours (kWh), placing China at the mid-level among the developing countries. Most of the electricity has been consumed by industries. Heavy industry had a share of 58.2 per cent in 1997, followed by light industry (14.6 per cent), residential consumers (11.4 per cent), public and commercial consumers (7.7 per cent), agriculture (6.2 per cent), and transportation and telecommunications (1.9 per cent). (World Bank, undated).

3. MAIN DESCRIPTION

3.1. Aims and objectives

One major objective of this Partnership is the development and demonstration of advanced near "zero emissions" coal technology based on carbon dioxide capture and geological storage to address the challenge of tackling increasing greenhouse gas (GHG) emissions from the use of coal in China. This is in recognition that carbon dioxide emissions from China's increasing coal use are set to double to more than 5000 Mt CO_2/year by 2030.

The Partnership contains two concrete cooperation goals, to be achieved by 2020. The first is to develop and demonstrate, in China and the EU, advanced near "zero-emissions" coal technology. This technology will allow for the capture of CO_2 emissions from coal-fired power plants and its subsequent storage underground, for example in exploited oil or gas fields or in sealed geological strata, thereby avoiding CO_2 emissions into the atmosphere.

The second cooperation goal is to significantly reduce the cost of key energy technologies and to promote their distribution and operation.

3.2. Planning and strategy

The first phase will be a three-year feasibility study, examining the viability of different technology options for the capture of carbon dioxide emissions from power generation and the potential for geological storage in China, and leading towards a possible demonstration project starting up between 2010 and 2015.

The Partnership supports the EU and Chinese efforts to reduce the energy intensity of their economies. China has set the goal of halving the energy intensity of its economy by 2020. In the recently adopted Green Paper on energy efficiency, the Commission has proposed to reduce the EU's energy consumption by 20 per cent over the same period by increasing energy efficiency.

3.3. Institutional issues

The Partnership will also reinforce EU-China cooperation on the Kyoto Protocol's Clean Development Mechanism (CDM). It foresees a dialogue on the further development of this mechanism "post 2012" in combination with an exchange of information and experience on the use of market-based mechanisms such as the EU emissions trading scheme. It furthermore foresees a number of joint research activities on the impacts of climate change.

These efforts will be strengthened through the involvement of the private sector, bilateral and multilateral financing instruments and export credit agencies, and the promotion of joint ventures and public-private partnerships.

4. IMPACT

Most Chinese cities exceed national air quality standards. Air pollution levels in many large cities are among the worst in the world. The central government has set its sight on controlling the total emissions of major pollutants, including total suspended particulates (TSP) and SO_2. The current goal for SO_2 emission control is to cap total emissions in 2010 at 2000 level. Emission standards for coal-fired plants to regulate particulates and SO_2 were first introduced in 1991. They were revised in December 1996 (World Bank, undated).

It is envisaged that carbon capture and storage offers the opportunity to reduce CO_2 emissions per unit of electricity by 85-90 per cent.

5. KEY SUCCESSES

The EU-China Partnership complements the Dialogue on Climate Change, Clean Energy and Sustainable Development, as well as other outcomes of the G8 Summit at Gleneagles in July 2005.

Although not directly linked to the EU-China Partnership, China has had an SO_2 emissions fee system in place since 1992. Beginning January 1998, a 200 yuan/ton SO_2 emission fee for all SO_2 emitting sources has been in effect in the designated acid rain-control and SO_2 pollution-control regions (World Bank, undated).

6. LESSONS LEARNED

While the EU-China Partnership has not been fully implemented and thus does not realize lessons learnt from the process, the following lessons can be drawn from successes and failures of various international collaborative efforts on clean coal technology transfer in China:

- Technology transfer is about more than equipment transfer. The various successes of bilateral efforts and the Global Environment Facility (GEF) to bring clean technologies to China suggest that technology transfer is more widespread when manufacturing technology is also transferred to the host country. Beyond the transfer of clean coal equipment, this implies transferring the technical ability to replicate and manufacture such equipment locally. Enhancing the knowledge of and providing training to manufacturers and users is also critical. More generally, it appears that technology transfer would benefit from policy reform. With a few notable exceptions, transfer of clean coal technology has been witnessed in the context of "one-off" demonstration projects with limited dissemination. Domestic policy that fosters technology diffusion is likely to be a key factor for successful technology transfer.
- Intellectual Property Rights (IPR) protection matters for transferers and transferees. The conventional understanding of the wisdom is that the weak IPR protection in developing countries deters foreign companies from transferring their technology as they see a risk that it may be stolen, once transferred. While this is true, companies in countries that are willing to acquire the technology (via licences) may also be deterred by inadequate IPR protection: host companies may be reluctant to acquire technology that competitors in their own markets could copy while not having to pay. IPR protection addresses both concerns.

An interesting, paradoxical finding from this case study is that strong growth in power demand is not necessarily conducive to the introduction of advanced technologies. While economic growth provides opportunities to introduce new, more efficient technologies, in the particular case of power generation in China, it creates concerns about power shortages. Generators are therefore discouraged from discarding outdated, inefficient and dirty infrastructure. This suggests that technology transfer on the generation side may benefit from efforts to limit too rapid a growth in electricity demand, and may be crucial for the success of an international effort to encourage the transfer of clean coal technologies (Philibert and Podkanski, 2004).

Although not part of the Partnership, joint studies carried out by the World Bank and China in the late 1990s suggest that the total amount of SO_2 reduction potential from non-power sector options is limited. Additional reduction would require measures taken by the power sector. In most cases, coal cleaning and flue gas desulphurization (FGD) were deemed to be the most cost-effective options (World Bank).

7. THE WAY FORWARD

In addition to electrostatic precipitators (ESP) upgrading, coal washing and FGD, China has developed a strategy to acquire clean coal technologies including supercritical pulverized coal, circulating fluidized bed combustion (CBC), pressurized fluidized bed combustion (PFBC) and integrated gasification combined cycle (IGCC) (World Bank, undated).

The Partnership provides for a robust follow-up process, which will include a regular review of progress in the context of the annual EU-China Summits.

8. REFERENCES

World Bank. Clean Coal Technologies in China—A World Bank Project. www.worldbank.org/html/fpd/em/ccts_for_china/ccts_for_china.htm. No date cited on the document. Document accessed via the Internet 6 September 2006.

Cédric Philibert and Jacek Podkanski. International Energy Agency. In collaboration with the OECD Environment Directorate. International Energy Technology Collaboration and Climate Change Mitigation. Case Study 4: Clean Coal Technologies. COM/ENV/EPOC/IEA/SLT(2005)4.2005, www.oecd.org/dataoecd/22/38/34878689.pdf Document accessed via the internet 6 September 2006.

ec.europa.eu/comm/external_relations/china/summit_0905/index.htm

www.defra.gov.uk/environment/climatechange

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Energy Efficiency

Module 13:
SUPPLY-SIDE MANAGEMENT

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Module overview

- What is supply-side management (SSM)?
- Why pursue SSM?
- SSM options and opportunities
- SSM constraints and challenges
- Conclusions

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Module aims

- To introduce the concept of supply-side management
- To discuss options of supply-side management, especially utility upgrades, load aggregation, clean coal technologies, fuel substitution, cogeneration and on-site generation
- To give an overview of the constraints, and benefits of conducting supply-side management measures and programmes

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Module learning outcomes

- To be able to define what supply-side management is and why it should be pursued
- To describe the different types of supply-side management measures and programmes
- To appreciate the constraints, challenges and benefits of supply-side management

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Supply-Side Management

- What is it?

  Measures to:
  - Decrease supply costs
  - Increase supply capacity
  - Improve supply delivery
- Why pursue it?
  - Ensure sustained availability of reliable energy
  - Meet increasing electricity demand
  - Mitigate environmental impact of energy production and supply

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

SSM Options and Opportunities

- Resources and resource preparation
- Power generation and energy conversion
- Transmission
- Distribution
- Transport of fossil fuels

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Resources and Resource Preparation

- Clean Coal Technologies (CCTs)

  Overall CCTs improve the efficiency of coal-based electricity generation, with benefits such as:
  - Increased electrical power output per unit of coal fired;
  - Reduced environmental impact per unit of coal fired, possibly in conjunction with partial or total removal of CO2 and SOx emissions.

  Ex.
  - Fluidized bed combustion
  - Pressurised pulverized coal combustion
  - Next generation: underground coal gasification and carbon capture

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Resources and Resource Preparation (2)

- Fuel substitution

  The process of substituting one fuel for another
  - The combustion of natural gas generally can be carried out much more efficiently than oil or coal

- Renewable energy
  - Wind, solar, geothermal
  - Biomass might provide important energy supplies at competitive/ moderate cost ~ Case study Methane Generation in Lusaka

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Power Generation and Energy Conversion

- <u>Operation improvement in existing plants</u>
  Improvements possible where equipment and systems are not run at top efficiency include:
  - Housekeeping
  - Maintenance
  - Data and performance monitoring
  - Combustion—fluid bed combustion control
  - Upgrading existing power supply

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Power Generation and Energy Conversion (2)

- <u>Upgrading generation units</u>
  It can improve reliability, increase output and reduce environmental impact through:
  - Installation of new and improved burners
  - Extra flue gas heat recovery
  - Additional heat recovery from hot blow-down water

Module 13

Power Generation and Energy Conversion (3)

- Cogeneration
  Production of heat as well as electricity from a single fuel source (combined heat and power - CHP)
  - Benefits:
    - Economic
    - Environmental
    - Enhanced reliability of electricity supply

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Transmission

- Transmission lines
  They operate at high voltage.
  Issues:
  - Thermal limitations
  - Voltage fluctuations
  - System operating constraints
- Data monitoring
  Need for comprehensive information on all system elements:
  - Computerized systems available (SCADA)
  - Normally managed by system owner/operator
  - Could be shifted to utility company

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Transmission (2)

- Load aggregation
  Energy users band together to secure better prices.
  – Desired effect is a flatter overall load profile, a higher load factor and ultimately lower per unit energy costs for members of aggregate group
- Substation improvements
  Higher efficiency equipment
  – Transformers - payback periods of 2 to 5 years are typical
  – Other key equipment: switchgear, alarms and controls.

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Distribution

- Upgrading distribution systems
  – Issues: variable losses, fixed losses and non-technical losses
  – Solutions: increase the cross sectional area of lines / demand-side management…
- On-site generation
  – Interesting when nearing maximum level of demand
  – Benefits:
    - On site “self-generation” reduces demand on the grid.
    - Reduces transmission losses from a distant power source.

Module 13

Distribution (2)

- Power factor improvement

  Power factor = the ratio between the useful load and the apparent load for a system:
  - Incentives (or penalties) to encourage power factor improvement
  - Benefits:
    - Energy to be used more efficiently (at higher power factor)
    - Less power needs to be generated

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Transport of Fossil Fuels

Lots of energy efficiency improvements possible

- Pipelines:
  - Oversized, inappropriate motors
  - Opportunity for using high efficiency motors
- Road transport:
  - Tyre pressures checked regularly
  - Planning of routes and loads

SSM Constraints and Challenges

- Availability of comprehensive information
- "First cost" basis drives decisions
- Experience in new technologies lacking in developing countries
- Case studies on bagasse for India and Eastern and Southern Africa
- When funds for investment available: evaluate all potential projects, especially those requiring large investments and those having a long life expectancy (cogeneration plants)

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

SSM Constraints and Challenges (2)

- Transmission and distribution: challenge will be the funding of large investments to replace old equipment or to add significantly to capacity.
- Power factor improvement might benefit all.

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

CONCLUSIONS

- Both improve the efficiency of current and future supply as the use of renewable resources.
- Supply options need to be identified, evaluated, optimally selected and implemented to sustainably meet the demand while achieving economic and environmental benefits
- The most immediate options for SSM are:
  - Upgrading existing plants and networks
  - Load aggregation
  - Fuel switching
  - Cogeneration and on-site generation

Module 13

SUSTAINABLE ENERGY REGULATION AND POLICYMAKING FOR AFRICA

Questions/Activities

Do you think clean coal technologies are merely a "gimmick" to promote coal use or do they offer sustainable solutions to energy supply?

Discuss

Module 13