Solar Power for Utility Applications

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Abstract

Solar thermal power stations are mature and commercially proven in more than a decade of utility operation. Not only electricity in the multi-megawatt capacity range, but also heat for industrial or municipal applications like district cooling or sea water desalination can be supplied by those plants. Being conventional steam cycles applied for power generation or for the cogeneration of electricity and heat, they can be driven not only by solar energy during the day, but also by heat from fuel, biomass or waste incineration, thus offering round-the-clock full power availability. The present paper shows, that the intelligent application of energy efficiency measures and the use of renewable energy sources leads to economically and ecologically attractive solutions for municipal and industrial applications in the utility scale.

Introduction

Growing economies in the sun belt countries require economically and ecologically compatible solutions for a series of municipal and industrial services. Among others, the main concern is usually concentrated on a reliable supply of power and water, as well as on the disposal of all kinds of waste. In many solar countries, the electric load for cooling and air conditioning ties up almost 50 % of the installed power capacity. The environmental impact of energy supply and of landfill waste disposal is becoming a major concern of modern industrial and municipal planning authorities.

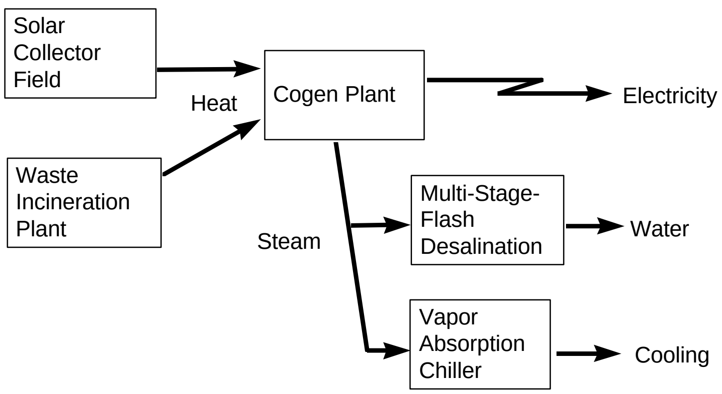


Fig. 1: Sketch of a cogeneration plant driven by solar energy and by energy from waste

Figure 1 shows a system capable of producing useful energy from solar radiation and waste. Maximum efficiency is achieved by the cogeneration of electricity and heat for district cooling and sea water desalination. The system, which is based on state-of-the-art technology, shows not only high environmental benefits, but also yields an economically feasible balance of cost and revenues. In the following, the system components and the technical and economical performance of a projected sample system are presented.

Solar Thermal Power Plants

Solar thermal power plants are technical and economic reality /1/, /2/. More than a decade of operation of 354 MW of solar electric capacity in California reveal a mature technology capable of changing the world's power market, taking pressure from fossil fuels and environment with a preference on renewable energy resources (Fig. 2 and 3).

The technology is simple: concentrating solar collectors, so called parabolic troughs, generate high temperature heat that is used to generate steam for a conventional power cycle or for a cogeneration plant (Fig. 4). The solar heat can be stored for several hours in concrete or other storage media, thus allowing for a shift of solar operational hours into the night time or peaking load periods.

Photo: KJC Operating Company

Fig. 2: 30 MW solar thermal power plant in Kramer Junction, California.

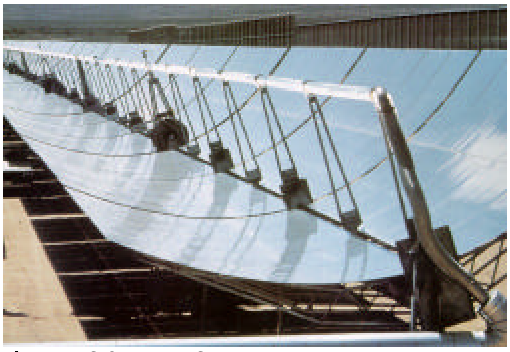


Photo: KJC Operating Company

Fig. 3: Parabolic trough concentrating collector.

Conventional fuels as well as renewable sources like non-recyclable waste or biomass can be used as backup fuel, thus allowing for round-the-clock availability of power and steam for industrial or municipal utility services.

In sunny countries, each square meter of collector can produce enough heat to generate 300 - 400 kWh of electricity per year. Additionally, the thermal energy rejected from the power cycle can be used in a cogeneration system to produce another 300 - 400 kWh of cooling capacity or about 2000 - 3000 m³ of desalted water per square meter of the solar field.

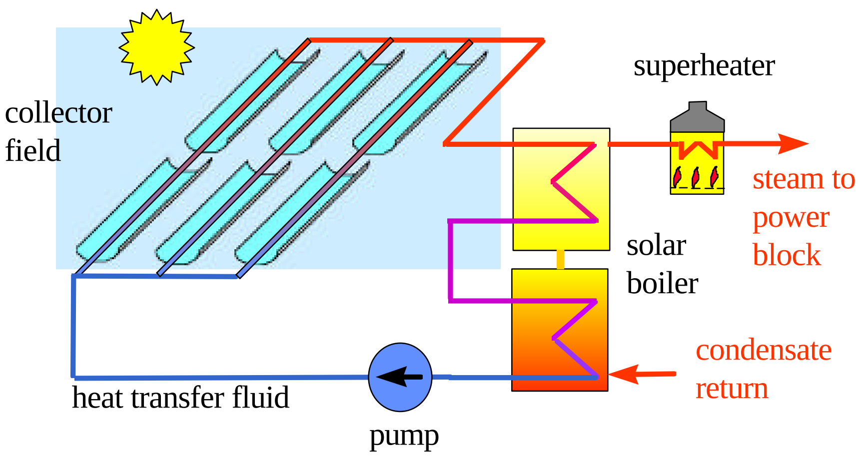


Fig. 4: Simplified sketch of a solar thermal collector field. A special heat transfer fluid is heated in a concentrating solar collector field to 400 °C and is then pumped to a steam generator. Steam conditions can reach up to 100 bar and 370 °C in solar only operation, up to 550 °C with superheating by fuel.

Waste to Energy

Waste disposal by landfill is one of the major environmental hazards of growing economies. Landfills cause pollution to air and groundwater, require large areas of land and constitute a considerable risk for the public health.

Waste incineration plants can not only reduce the volume of non-recyclable waste to about 3 %, but can also destroy the emitted pollutants and by the way, produce thermal energy for power generation, water desalination or other purposes /3/. Municipal waste, after the extraction of the recyclable components like glass and metals, can achieve heating values comparable to lignite or even coal.

Fig. 5: Waste incineration and cogeneration plant of MVV Energie AG, Mannheim

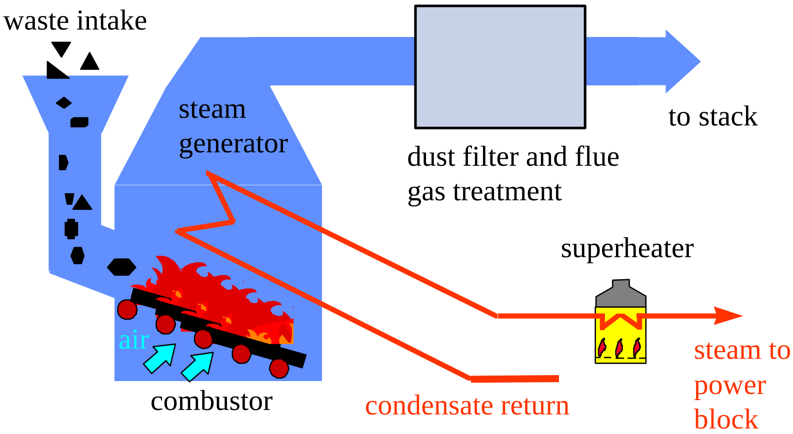


Fig 6: Sketch of a non-recyclable waste incineration plant.

The garbage is fed to a special combustor that provides a good mix of waste and combustion air, which is indispensable for high efficiency and low emission of pollutants. The hot gases pass through a steam generator that provides steam to the power plant. The steam parameters that can be achieved are up to 450 °C and over 120 bar pressure. Steam conditions can be enhanced for power plant operation to over 500 °C and 120 bar by an additional fuel fired superheater (Fig. 6).

The major part of the waste incineration plant consists of a series of filters and other devices for flue gas treatment. Organic pollutants like dioxin, carbon monoxide and others are destroyed in the combustor that operates at temperatures as high as 1200 °C. Fly ash, hydrochloric acid, sulphur dioxide, salts, nitrogen oxides, heavy metals and other pollutants are removed from the flue gases by a dust filter, two stage flue-gas scrubbers, a catalytic reactor and an activated carbon filter. The clean flue gases leave the plant at a temperature of 180 °C through a stack. The emissions of pollutants are within the limits foreseen by the German law for conventional power plant operation.

From one ton of non-recyclable waste, 1500 kWh of thermal energy and 300 kWh of electric power can be generated.

Cogeneration of Electricity and Steam

Cogeneration of electricity and heat is particularly interesting for many industrial and municipal utility applications /3/, /4/. A cogeneration plant can deliver steam for sea water desalination in a multi-stage-flash plant (MSF). Steam can also be used for air conditioning and district cooling by a vapour absorption chiller. Also industrial process heat can be provided, thus making much better use of the input energy than a conventional electric power station and increasing efficiency to 80 %.

Figure 7 shows the simplified sketch of a cogeneration plant. Life steam from the solar field and from the waste incineration plant at 550 °C and 100 bar is fed into a steam turbine for power generation. An additional fuel fired boiler allows for conventional operation of the plant. After passing through the steam turbine, steam is extracted at about 120 °C and 2 bar and is used for running a multi-stage-flash desalination plant and a vapour absorption chiller. If the thermal load of the MSF and of the VAC is not sufficient for condensation, surplus heat of the power cycle can be rejected by a conventional cooling system. The condensate is returned to the steam generator of the waste incineration plant, and to the solar and fuel fired boilers.

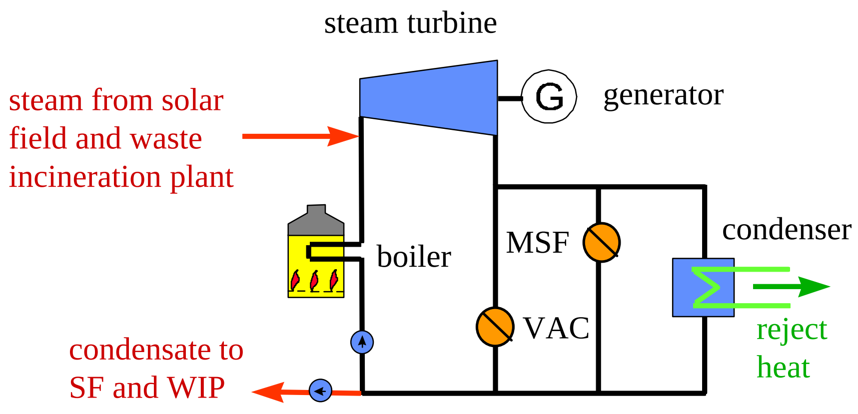


Fig. 7: Sketch of a cogeneration plant with back-pressure steam turbine.

Cogeneration offers two very important attributes for renewable energy utilisation:

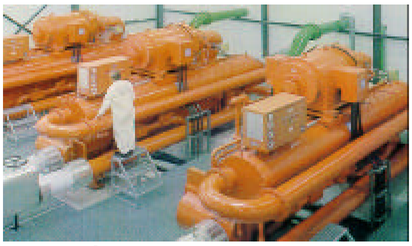
- First, energy from solar and waste is converted to useful energy with the very high efficiency of the cogeneration system, thus making the best possible use of those energy sources.
- Second, backup firing with fossil fuel allows a longer time of utilisation and full availability of the conventional power block, thus enhancing its economic amortisation.

A solar-and-waste-fired cogeneration plant provides solutions for a series of municipal and industrial services: waste disposal, power supply, district cooling and water supply in an environmentally and economically compatible manner. State of the art technologies are combined in a way that yields maximum efficiency, allows the exploitation of local energy resources that have not been used so far, and has a minimum impact on the environment. Not even the additional land requirement for the collector field is critical, as in exchange landfill is reduced by 97 %.

The redundancy of the system is particularly high because of the use of the three independent energy sources solar, waste and fuel. Bypasses for steam supply can allow the operation of the VAC and the MSF independently from the power block. That means, that cooling power and desalination capacity will be still available in case of a turbine overhaul.

District Cooling with Vapour Absorption Chillers

Absorption chillers can use the reject heat from a power cycle to generate cooling capacity, which is distributed to the consumers by a cold water grid /4/. In an absorption chiller, the mechanical vapour compressor is substituted by a so called thermal vapour compressor, that uses only a small pump with 1 % of the electricity requirements of the compression chiller (please compare Figs. 9 and 11). This is possible, because the working medium is absorbed in a liquid in case of the absorption chiller, and the compression of liquids requires much less energy than the compression of vapours. After reaching the high pressure level, the working fluid is desorbed from the liquid, using the reject steam from the power plant. The rest of the cooling cycle is identical to that of a compression chiller.



Source: Sulzer

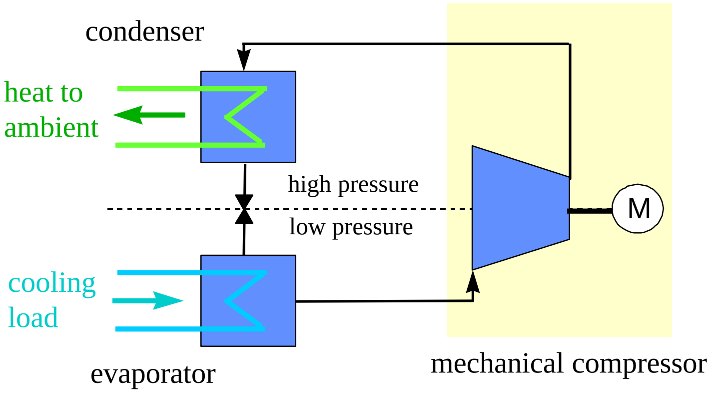


Fig. 8: Vapour compression chiller

Fig 9: Sketch of a vapour compression chiller.

Source: Carrier

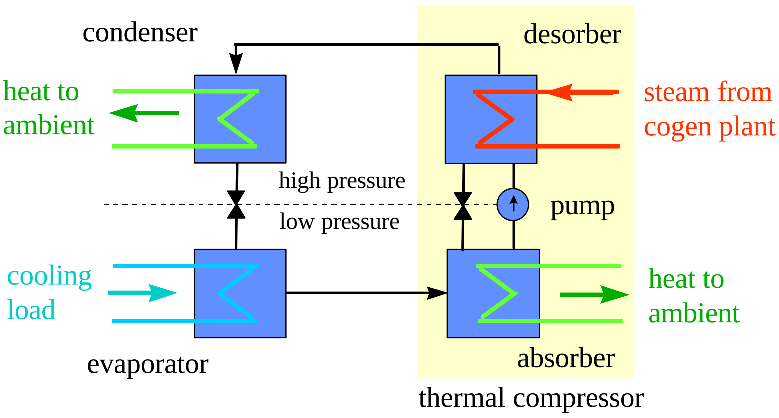


Fig. 10: Vapour absorption chiller

Fig 11: Sketch of a vapour absorption chiller.

In countries with a high electric load due to cooling applications, electric energy consumption as well as the installed power capacity can be reduced by up to 50 %, if the mechanical compression chillers are substituted by district cooling and absorption chillers.

Absorption chillers are basically heat exchangers. There are not many moving parts except of a small pump. Thus, the economic lifetime is higher than that of compression chillers, and there are less expenses for maintenance and repairs. Absorption chillers are particularly important for enhancing the efficiency of municipal and industrial power systems, converting reject heat to useful energy.

Multi-Stage-Flash Desalination

Among the different desalination methods available - evaporation, reverse osmosis, electrodialysis, refrigeration and ion exchange resin systems - the multi-stage-flash method (MSF) is the most applied system world wide /5/.

MSF is an evaporation method. The principle is simple and reliable (Fig. 12): sea water or brackish water is evaporated by an external heat source, e.g. reject steam from a cogen plant at about 120 °C and 2 bar. In the first evaporation chamber, part of the water evaporates. After this, the vapour is condensed in a heat exchanger in the upper part of the chamber, and leaves the stage as fresh water. The condenser is cooled by incoming sea water, that in exchange is pre-heated for evaporation. In the next stage, the pressure is reduced, causing the water to boil at a lower temperature. This principle is repeated in several stages, thus allowing the recuperation of the heat of condensation of the produced fresh water.

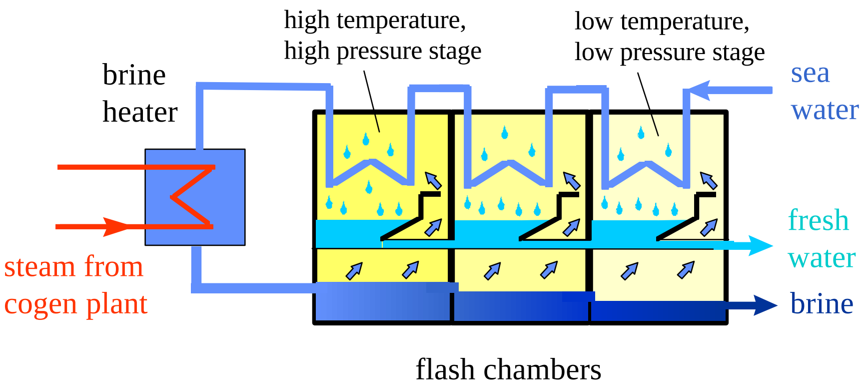


Fig. 12: Principle of a Multi-Stage-Flash Desalination Plant

Fig. 13: Makkah-Taif Multi-Stage-Flash Desalination Plant with 223,000 m³/day Capacity (Source: Mitsubishi Heavy Industries Ltd.)

The brine heater can use fuel or even electricity for heating the incoming sea water. Of course, the use of reject heat from a power plant is much more energy efficient and also less expensive, as there are no additional expenses for fuel. A small amount of electricity is required for the pumps applied in the flash chambers for reducing the pressure and extracting the fluids. MSF plants require between 50 and 60 kWh of thermal energy and 3 kWh of electricity per m³ of distilled water.

Sample Cogeneration System powered by Solar and Waste Energy

Figure 14 shows the simplified sketch of a complete solar and waste driven cogeneration system. The plant produces 35 MW of electricity, 24 MW of cooling power and 8000 m³/day of desalted water. It is fed by heat from a 110,000 m² solar collector field and from a waste incineration plant with an input of about 300 - 400 tons/day. Fuel oil is used for backup firing.

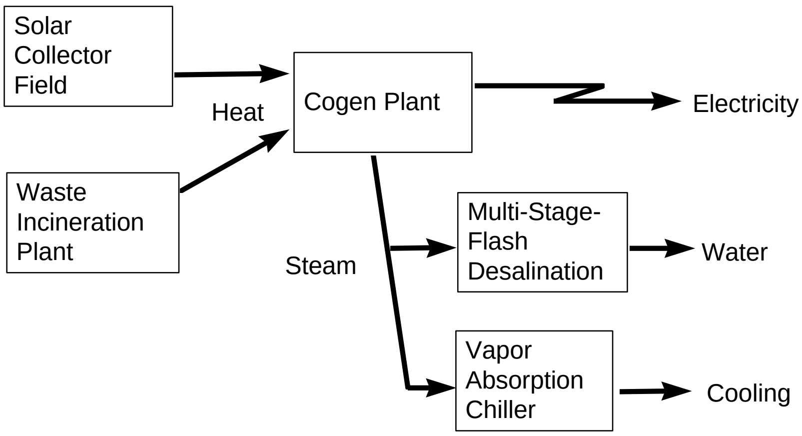


Fig. 14: Sketch of a cogeneration plant driven by solar energy and by energy from waste

A typical daily load curve for such a system is shown in Figure 15. The plant delivers 8 MW of base load electricity, mainly provided by energy from the waste incineration plant, and peak electricity provided by energy from the solar field. The reject heat from the back pressure steam cycle is used around the clock for MSF-desalination and - specially during the day - in a vapour absorption chiller (VAC) for district cooling. Only 16 % of the input energy is lost during the energy conversion process in the cogen plant.

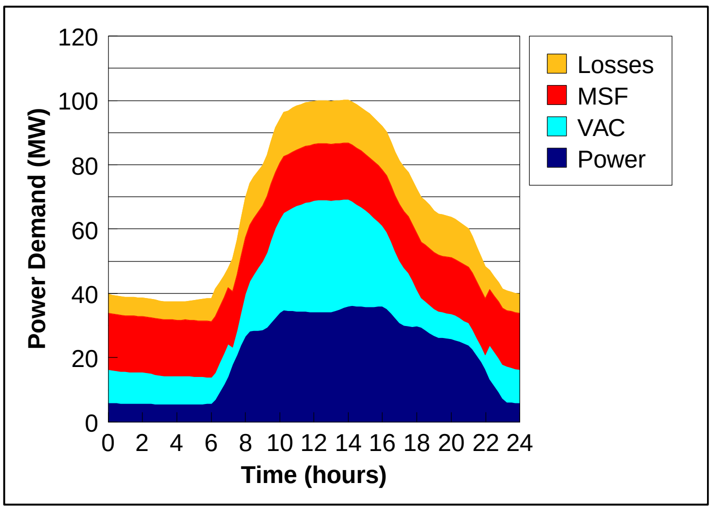


Fig. 15: Typical daily energy output curve of the sample cogen plant. Only 16 % of the input heat is lost during the process. The plant delivers electric power as well as steam for a MSF-desalination plant and for a vapour absorption chiller (VAC) for district cooling.

Only 10 % of the input energy comes from an oil fired backup boiler. The rest is provided by the solar field (30 %) and by the waste incineration plant (60 %). While the solar field covers excellently the peaking load period during the day, the waste incineration plant provides base load energy around the clock (Fig. 16).

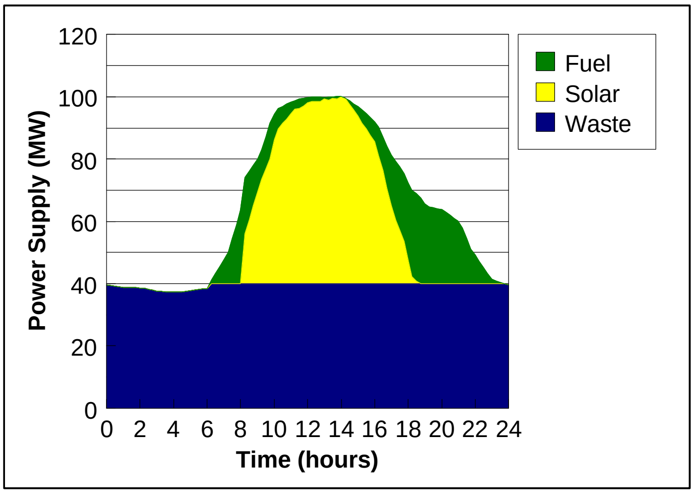


Fig. 16: Typical daily thermal energy input curve of the sample cogen plant. 60 % of the input energy is supplied by the waste incineration plant, 30 % by the solar field and 10 % by the backup fuel oil.

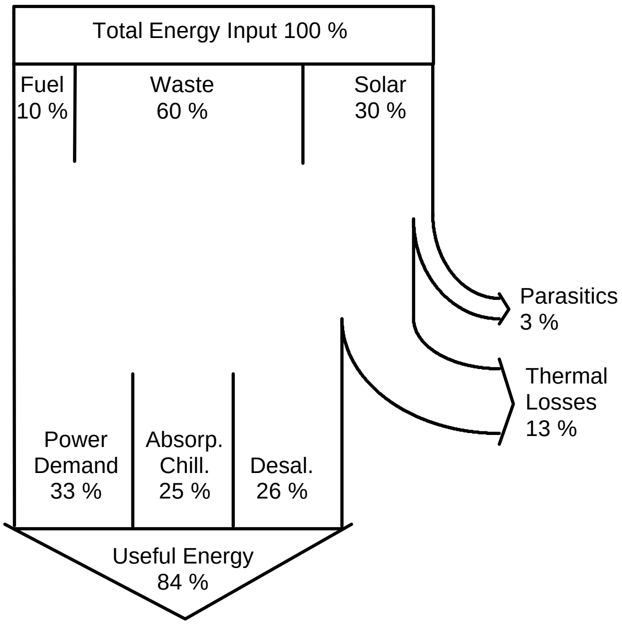


Fig. 17:
Typical daily energy balance of the solar and waste energy driven cogeneration system.

Figure 17 shows the daily energy balance of such a system. 84 % of the energy input, of which only 10 % is derived from fossil fuel resources, is converted to useful energy. In comparison to a conventional supply of electricity, cooling, water and waste disposal by separate oil fired steam cycle power plants, electric compression chillers, oil fired MSF plants and landfill respectively, pollution is reduced by more than 95 %.

Example of Finance

Energy efficiency and use of renewable energy sources always means high investments, because the consumption of fuel resources is substituted by capital goods like the waste incineration plant and the solar collectors. The energy resource itself is free of charge, but the investment usually leads to a considerable capital cost and debt service. In the sample power plant described before, the total investment of 140 MUSD is split into 40 MUSD equity capital and a 100 MUSD loan (see also Fig. 18). The loan is financed with a 3 % interest rate and a repayment period of 10 years.

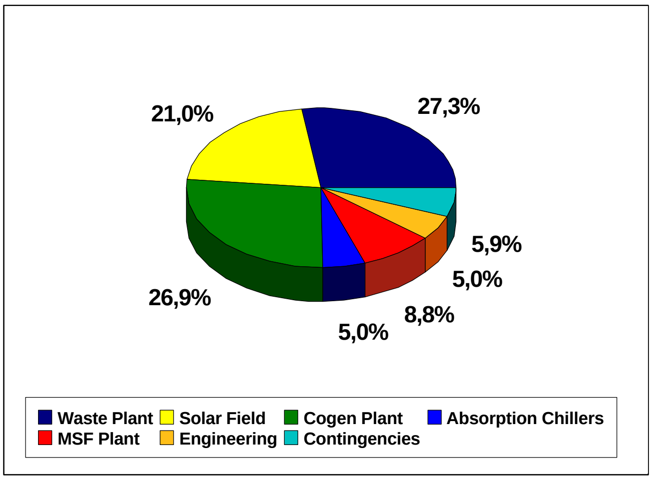
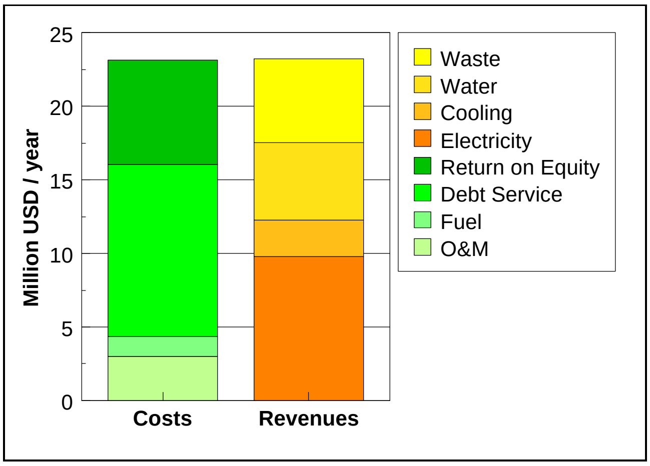


Fig. 18: Break down of investment of the sample solar and waste powered cogeneration plant (total investment 140 MUSD)



Revenues:

Electricity	0.060 USD/kWh
Cooling	0.04 USD/kWh
Water	1.7 USD/m³
Waste	50 USD/ton

Cost Parameters:

Interest Rate	3 %/a
Repayment	10 years
Fuel Cost	10 USD/MWh
Lifetime	25 years

Fig. 19: Expected annual costs and revenues of the sample cogeneration plant

For the annual balance, revenues for the generation of power, cooling capacity and water are assumed to be in the order of 0.06 USD/kWh, 0.04 USD/kWh and 1.7 USD/m³, respectively. For waste disposal, a revenue of 50 USD/ton is assumed (Fig. 19).

Under the assumed financial parameters, equity investment returns within 5 years, the loan is returned within a period of 10 years. Afterwards, the return on investment is particularly high, as the fuel expenditures - that usually are the main running cost in such projects - are very low. The average internal rate of return of the example project is 27 %/year.

SYNTHESIS - The Frame of Finance for Market Extension

The SYNTHESIS Programme was designed by DLR and partners to support and accelerate the market extension of solar thermal power /6/. First class German firms participate in this programme and support market development and concrete projects. SYNTHESIS offers a complete frame for market extension, including project development, general contracting and operation of solar power systems, insurance and re-insurance, loans and equity capital, and - if required - support for obtaining e.g. public funding like the World Bank's Global Environmental Facility or guaranties from the German Federal Government. A scheme of tradable credits from CO2-reduction is presently developed on a private basis as a complement to public funding (Fig. 20).

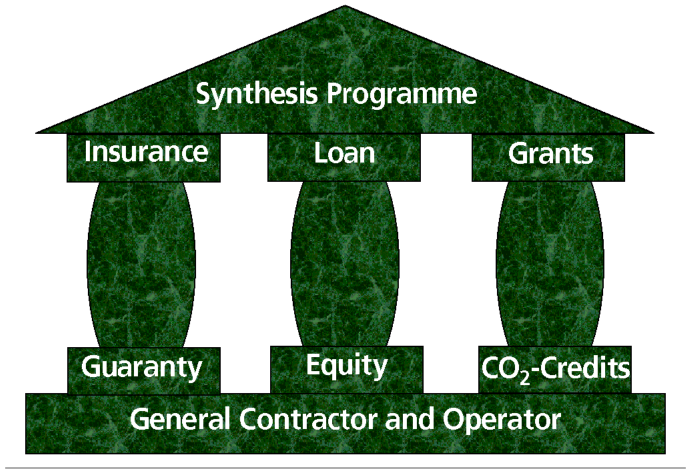


Fig. 20: The SYNTHESIS Frame for Market Extension and Project Development

All projects in the frame of SYNTHESIS are designed such that solar power becomes competitive to conventional power sources. First class partners from industry and finance guarantee professional project development, erection and operation of the power systems on IPP basis.

Requisites for project initiation in a potential host country are the following:

- land and infrastructure should be provided at low cost or preferably free
- low tax and custom duties (because fuel consumption is substituted by capital goods)
- power purchase agreement with a 25 year concession
- corresponding agreements for water, cooling, fuel and waste if applicable
- tariff adaptation to inflation
- grid access at fair tariffs
- bank guaranties on power and services payments

If the necessary infrastructure is available, 20 % to 40 % of the plants should be fabricated in the respective host country. Under those terms, solar power will become a new indigenous energy resource for many solar countries. In the first phase of SYNTHESIS that lasts until 2010, 7000 MW of solar power will be installed world wide in about 50 projects, basically for supplying local power needs. In the second phase, due to the expected cost reductions by mass production, standardisation and continuous research and development, the solar electricity cost will be low enough to start a solar power export scheme with high tension DC-grids.

Conclusions

Solar thermal power stations with parabolic trough concentrating collectors are mature and commercially proven in more than a decade of utility operation. Not only electricity in the multi-megawatt capacity range, but also heat for industrial or municipal applications like district cooling or sea water desalination can be supplied by those plants. Being conventional steam cycles applied for power generation or for the cogeneration of electricity and heat, they can be driven not only by solar energy during the day, but also by heat from fuel, biomass or waste incineration, thus offering round-the-clock full power availability. Intelligent measures to improve energy efficiency and the use of renewable energy sources can lead to economically and ecologically attractive solutions for municipal and industrial applications in the utility scale, as shown by the example of a cogeneration plant for electricity, district cooling and water desalination powered by solar and waste energy.

In the frame of the SYNTHESIS Programme, first class international firms have accepted the challenge to foster the market extension of solar thermal power stations. First steps will rely on highly efficient, hybrid plants with a relatively small solar share of 10 % to 30 %. The target is to achieve economic competitiveness for fully solar powered utility stations within the next decade. Based on this technology, many solar countries will be able to exploit their vast natural resource of solar radiation for industrial and municipal energy needs. The export of solar electricity to other countries is a logic consequence of this development and will be one of the pillars of the next century's world electricity market.

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