# TRANSPORTATION OF ELECTRICITY PRODUCTION

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**ABSTRACT** - The constraints of global warming may require the acceleration of the deployment of renewable energy sources, and the early retirement of useful fossil fuel plants. However, if the presently built systems could be used rather than being discarded, the investment and time needed for the deployment of renewables could be reduced. New high temperature solar receivers make possible the use in future solar systems of investment made today in gas operated power plants and transmission lines. Progressive implementation will reduce the risk of initial systems and improve long term economics by avoiding the disposal of the gas fired power plants when the gas runs out or becomes uneconomically expensive. The initial incremental cost increases of the gas fired combined cycle plants built today will be minimal from the cost point of view, because it will consist only of preparing for the possibility of adding a solar air heating receiver and leaving space for additional collectors. In the short term, modules and receivers will be added, thus increasing the use of solar energy and gaining experience in the solar portion of the system. In the long term, interconnection with hydroelectric power plants through existing transmission lines will allow short term storage and will reduce the dependence on natural gas. In the very long term, interconnecting east-west transmission lines will allow feeding the Global Network from areas facing the sun

## 1. INTRODUCTION

A number of organizations have tried to summarize the critical issues that will control our lives in the next century, and energy supply seems to be one of the crucial components. The intensity of energy-related events in the last century suggests that even stronger processes will occur in the 21st century. Some of these we can try to control, and others that we cannot control will require a modification of our behavior to make it possible to live with the new conditions.

There will be a period of transition from fossil dependent (gas, liquid and coal) power generation systems to a future where the energy supply to mankind is not based on fossil fuels. This process may have to be accelerated because of constraints related to global warming and leading to an era during which power generation has to rely more and more on renewable energy sources. Under certain conditions it may become possible to include nuclear energy in the energy resources basket, but for the present discussion we shall concentrate on the renewable sources that are free from the problems that beset nuclear energy.

The cost of the switch to renewable energies, and the time needed to do this could be reduced if at least a portion of the investment being made in fossil fuel systems could be utilized rather than discarded before the end of their useful life (which may be decades later).

The major source of essentially unconstrained energy is the direct solar radiation that reaches the surface of the earth. The solar energy reaching the sunny deserts of the earth is more than two orders of magnitude greater than the global consumption of thermal energy. The latest WEC or DOE reports show that the use of renewable energy sources, including indirect solar energies (biomass, hydropower, wind and geothermal), is rather limited and even if future price will enhance their usage, they alone will not be sufficient to supply all mankind's' needs.

The reason for the small contribution of solar energy is due both to economics and the fact that the source is discontinuous, although largely predictable. Major improvements were gained in the efficiency of harvesting concentrated solar radiation at high temperatures, as well as developments in high temperature chemical reactions that produce and/or improve fuels. Both provide the basis for a more optimistic view of the future and will be discussed later.

The continuous increase in global energy demand and technological developments, combined with ecological and financial considerations, resulted in the enhanced use of natural gas and the construction of gas pipelines across continents, from Russia to Western Europe, from Canada to the US and from North Africa to Spain and a few more, such as the Latin America Pipeline, Russia to Turkey, yet to come.

Related to this is the rapid increase in use of gas powered combined-cycle generating systems, that began in the mid 1980's. Economic and reliability considerations have also led to the extensive development of power distribution networks. This trend has been further encouraged by the increasing separation between the functions of electricity generation and electricity distribution that opened the window for privatization of power production and stressed the possibilities and advantages of regional and even global electric grids. The latter were made possible by the adoption of HVAC and HVDC transmission lines that can be supplied simultaneously by electricity from various remote fossil and renewable sources such as Hydroelectric, Geothermal Wind or Solar, for example.

## 2. STRATEGY OF MINIMUM REGRETS

The global gas pipeline network that is continuously expanding, crosses deserts and intersects with electric grids, and altogether creates an ideal background for the construction of new combined cycle power plants. These very cost-effective plants can, at no risk and at a minimal additional cost be a part of a "Minimum Regret Strategy". In addition to the conventional combustion system there will be room left to add high temperature solar air heating. The initial renewable contribution may be small, but area has to be secured for future additions. With such a scheme, the development of renewable technology is made possible, with minimum investment, and by the time additional renewable sources are added, as a result of scarcity of fuel and/or increase in price, solar collector and receiver technology will mature and its price be reduced. By then the cost of the power plant itself, and probably the transmission lines would have already been paid for.

The immediate benefit from introducing such integration is the reduction of emissions. For every percentage point increase in the solar fraction of such plants one can claim a comparable one percent reduction of emission from it. Longer-term benefits derive from the extra time gained by extending the lifetime of equipment installed. The electric grids that will initially be fed by combined cycle plants fueled by gas and solar energy will gradually be connected to other renewable sources.

Of the various other renewable energy possibilities, hydroelectric energy is probably the largest and certainly the most familiar. It does, though, involve severe local environmental effects in certain places. Though the major identical sources are already used, there still are very large untapped resources of which some will be connected to long distance transmission lines in the future.

The best known example of such a scheme is, perhaps, the connection of the vast yet untapped hydroelectric resources of Africa into a continental power network with an export potential to Europe. See Fig. 1. Some of the transmission lines planned for this network cross the extensive deserts of North Africa and the Middle East; possibly the richest sources of solar energy on earth. These resources could be tapped by various technologies existing today and fed into the intercontinental network, thus increasing greatly its capacity and its export potential.

The maximum solar fraction that can be accommodated by such projects depends again on the characteristics of the load curve. The maximum daily solar input (the solar fraction) will occur when all of the hydroelectric potential has been used to fill the demand of the network during the periods when the sun is not shining. The results will be similar to those in connection with the fossil integration but the constraint is not the hydro-potential available. It is likely that such integration can lead to a doubling of the network's supply potential over that provided by the hydroelectric potential alone, particularly if the flexibility generated by the export fraction is exploited properly.

Such a project could bring great benefit to the solar source countries and those through which the power lines cross. Not only will the availability of the power itself be beneficial to their development, but so would also be the steady income from it's export, the additional infrastructure, the employment opportunities and the new industries.

One other possible integration of renewable sources is biomass. Biomass, in the form of plant material, either as residue or by-product of agricultural or industrial operations, or especially grown as an energy source, is of course an indirect form of solar energy. Biomass in its various forms can be gasified with the help of solar heat by a technology similar to that described later for the reforming of natural gas. This can be used to fuel combined cycle plants to generate electricity (as in examples I and II below).


Fig. 1. Africa to Europe grid.

## 3. SOLAR ENERGY

One of the main directions of development in recent years in solar energy research has been the use of concentrated sunlight to achieve very high temperatures. These, in turn make it possible to achieve high conversion efficiencies to electricity in thermal processes and to drive chemical processes. Devices (dishes and solar towers) create highly concentrated beams of sunlight (up to several thousand times the intensity of the solar radiation reaching the earth), that in appropriate receivers could generate temperatures of over 2,000°K.

For the applications to be described in this paper the solar tower (central receiver) technology is deemed as most appropriate. A new variant of this device is being developed which provides for an easier direct integration between the solar collector and a gas turbine (in a single or combined cycle), or a chemical reactor. An optical "beam-down" configuration is used to produce high solar radiation concentrations at ground level (see Figure 2). This permits the placement of the receivers, which convert the solar radiation to heat (or chemical energy) on the ground instead of atop the tower. The result is utilization of energy in higher efficiency machines and a reduction in mechanical, structural and logistic costs.

A new type of receiver has been developed, capable of heating the working fluid (air, in an example that follows) to temperatures over 1,000°C at pressures of tens of bars. The exact conditions can be specified to match the requirements of standard gas-turbines and thus simplify the coupling of the solar receiver to a power block.

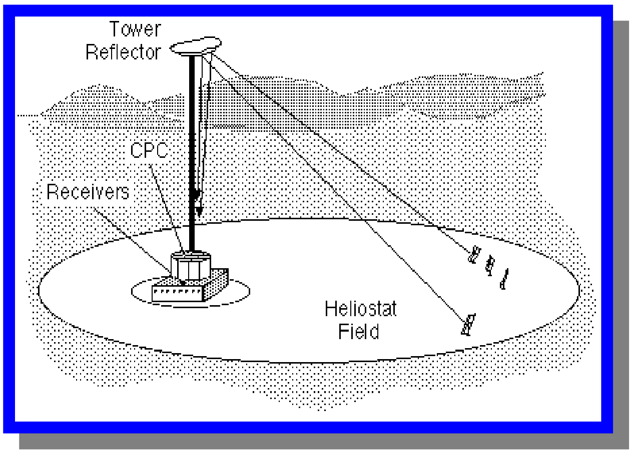


Figure 2 – High Concentration Beam Down Configuration

This combination leads to an overall conversion efficiency of sunlight to electricity of about 0.25, that is higher than on any other large scale solar driven power generation systems. Conversion efficiency reached in Solar 1 was 0.16 and with the trough system of LUZ it was 0.10. The result is that a smaller reflective area is required for a given electric power output and hence the plant cost is reduced.

Our main chemical interest in the present context is a reaction known as the 'reforming reaction'. Essentially, it converts natural gas (or other hydrocarbons, even biomass) to a mixture of hydrogen and carbon monoxide by reacting it, in the presence of a catalyst, with water vapor or carbon dioxide. The resulting gaseous mixture is know as 'synthesis gas'. In our present context we are interested mainly in the fact that its heating value is some 30% higher than that of the starting materials. The extra energy comes, of course, from the sun.

These advances, together with developments in the energy-conversion technologies can be combined to make solar energy a much more effective source and almost immediately applicable. This can be achieved by integrating a solar source with one or more of the other renewable or fossil sources with mutual advantage to both.

One can distinguish several levels of integration. The most basic one is when the two sources (i.e. the sun and another source) are integrated at the power block. A somewhat looser integration results when the two sources are combined in the feed line or share common transmission and distribution systems. We present examples of both.

## 4. SOME POSSIBLE INTEGRATED SYSTEMS

We turn now to examples of possible integration of the technologies discussed above with gas driven combined cycle systems. Because of their higher efficiency, lower costs and lower pollution, these are currently becoming more common and their integration with solar energy much easier.

(I) *Integration at the power block*

In this example we describe the integration of solar energy and fossil energy (again in the form of natural or artificial gas) at the input to a combined cycle power generator. In a combined cycle power plant the first stage is a gas-turbine (the Brayton cycle) that is, a turbine fed by air heated to the design high temperature by the combustion of gaseous or liquid fuel. The second stage of the Combined cycle utilizes the exhaust heat from the gas turbine to feed a Rankine cycle steam turbine. See Figure 3. As mentioned, recent developments make it possible to heat air to the necessary temperatures and pressures directly by solar radiation. This means that the same combined cycle plant can be fed simultaneously by the two sources of heat in any desired proportion.

We have here, therefore, an example of an almost seamless integration of solar and fossil energy sources with minimal risk, since the system can always be switched to fuel operation in full loading when desired. Such system is being developed under the United States and Israel High Tech. Commission (USISTC). A demonstration plant is expected to work in the Weizmann Institute of Science (WIS) solar tower early 1999 and the first commercial plant in mid 2002.

All that is necessary, of course, is that the combined-cycle plant be erected in a sunny region and that the gas turbine be fitted with a hybrid heating system (to accept both the heat output of a regular combustion chamber and heat from a solar receiver). It is also necessary that sufficient area be available and reserved very close to the plant for the collection of the maximum anticipated solar energy. It will then be possible to install the solar plant incrementally and with increasing confidence.

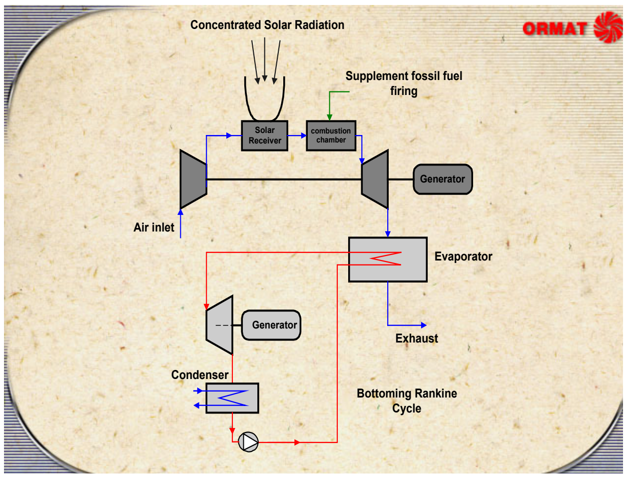


Fig. 3. Combined Cycle Power generation System

(II) *Integration at the feed supply line*

As was mentioned above, one of the advantages of the availability of solar energy captured at high temperatures is the possibility of driving certain endothermic reactions. The one specifically mentioned above is the reforming reaction that converts natural gas to a mixture of hydrogen and carbon monoxide, with a heating value 30% higher.

If the line feeding natural gas to the combined-cycle plant passes through a sunny region, or of course, if the plant itself is in a sunny region, then it is possible to pass all of some of the feed gas through a solar driven reforming unit. The output (synthesis gas) will be used to drive gas turbines in single or combined cycle (Figure 4). It is clear that in this mode the solar fraction of the plant's energy output will be 23%. And this also will be the maximum solar contribution possible for this system, irrespective of the shape of the load and insolation curves. Sufficient storage capacity for the synthesis gas must be provided in the line between the reforming plant and the gas turbine to uncouple the two. The synthesis gas can be stored for any length of time and used as needed for optimum effect. Thus, the system can be designed to run 24 hours a day on synthesis gas that was, of course, produced only during daylight hours. The solar components must then be sized accordingly.

The feasibility of solar reforming has been demonstrated in extensive successful tests at the WIS solar facility, and is ready for scaling up. A gas turbine electricity generator is being designed now to run on both solar-produced synthesis gas and on LPG.

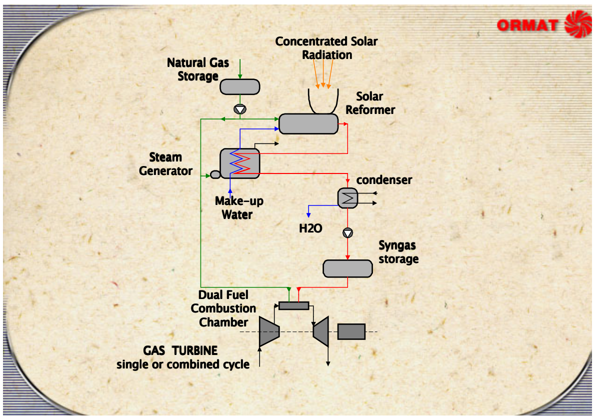


Fig. 4. Gas Reformer, Syngas Storage & Power Generation

There is a general consideration that governs the maximum proportion of solar energy that can be integrated in mode I. While the solar energy is usually not constrained in amount, it is constrained in the time at which it is available. Therefore, the solar fraction of the daily energy delivered by the plant will depend on the degree of overlap between the insolation curve (solar intensity as a function of time) and the load curve (the demand as function of time). We will illustrate this point with simple examples. Let us assume first, for the sake of simplicity, a level load curve (i.e. a steady demand throughout the 24 hours of the day).

If we now size the solar plant so that at solar noon (maximum insolation) the power delivered just supplies all the load at that time, we ensure that all the possible output of the solar plant is integrated. The solar fraction in this case is the ratio of the area under the insolation curve to the total area under the load curve. For a plant located at 30° and at around equinox this amounts to 0.396.

If the solar plant is oversized, some of its possible output will have to be rejected (unless some storage capacity is provided) with only partial compensation by the increase in the solar fraction For the above example, a 10% increase in the size of the solar plant (and its cost) will increase the solar fraction by 5.6%, to 41. If storage is provided for the extra energy generated around noon, then, of course, all the surplus energy can be fed back to the network for use at some later time, and raise the solar fraction to 0.435, in the above example.

It should be emphasized that all these numbers are very sensitive to the shape of the load curve, and the time of the year. For example, using a more realistic load curve applicable to Israel at equinox, the solar fraction can reach 0.47.

An even larger increase in the solar fraction may be achieved by the combination of the two modes described above. This, if the feed to the combined cycle plant described above is synthesis gas, produced as in example II (and not natural gas), the overall solar fraction can be shown to reach 0.59 in the example above and 0.52 in the example with the flat load curve.

The two examples presented above illustrate another important aspect relating to the title of this paper - the acceleration of the introduction of solar energy. There is here a situation particularly convenient for the introduction of the new technologies. One can regard the installation of systems of examples I and II as an add-on or retrofit, in the sense that they can be carried out gradually and with no or little risk, even to an existing plant.

Thus, in example I, if the combined cycle power block is designed so as to be capable of accepting the two heat feeds (fuel and solar heating of the compressed air), one can at any time construct a solar high temperature air heater of the appropriate size and connect it. If satisfied with the result one can add more and more such units.

In example II, similarly, once the combined cycle is installed and operating, one can decide at any time how much solar energy one wants to add, and then construct a solar reforming plant of the appropriate size and just connect it to the feed line.

In both examples these additions can be made up to the maximum values mentioned above. These can then be installed gradually, without large up-front investments and with minimal risk.

## 5. CONCLUSIONS

The integration of solar energy with other energy resources at the plant, as well as at the power grid level, makes it possible to develop renewable energy systems that can be introduced much sooner with lower risks and investments spread over time.

All the technologies needed have been proved feasible. Integration reduces hurdles of the introduction of the solar technologies without having to discard existing investments in power conversion and transmission equipment.