Solar Thermal Power Plant Technology

Workshop for Investors

New and Renewable Energy Authoriy (NREA)

Cairo, Egypt, 18 - 19 January 2000

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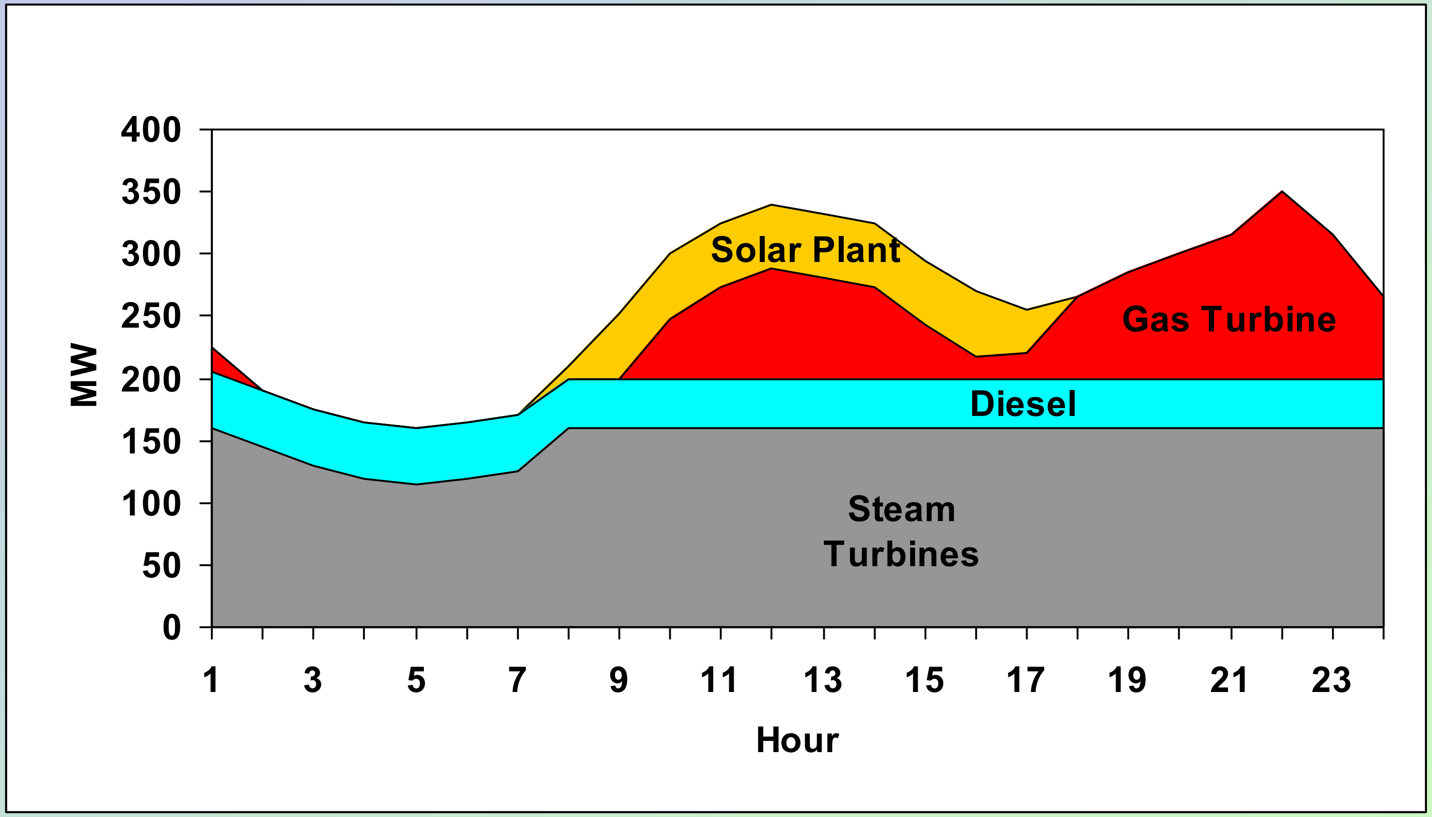
Fichtner Solar GmbH

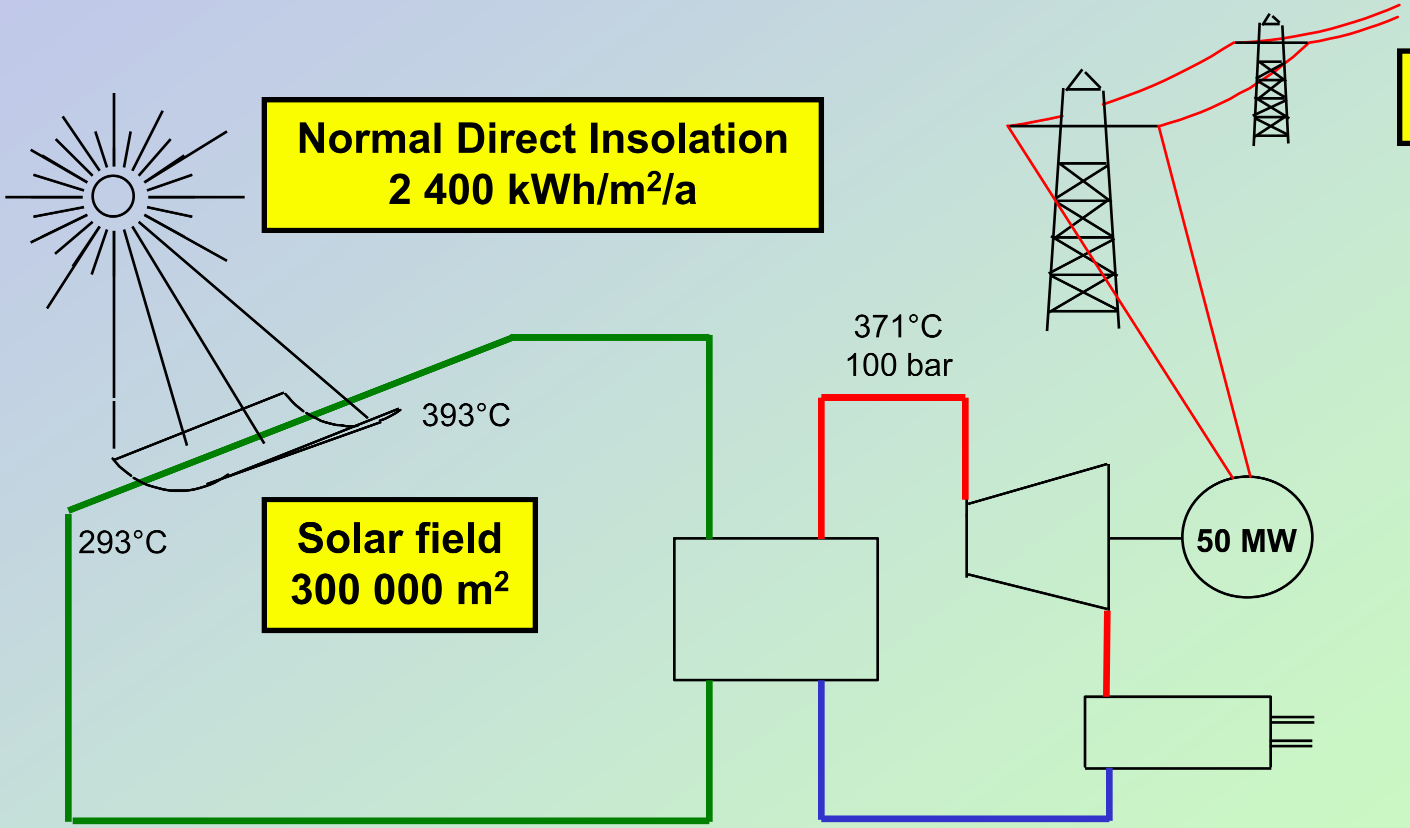
Power Production Profile for Crete

Typical Summer Workday

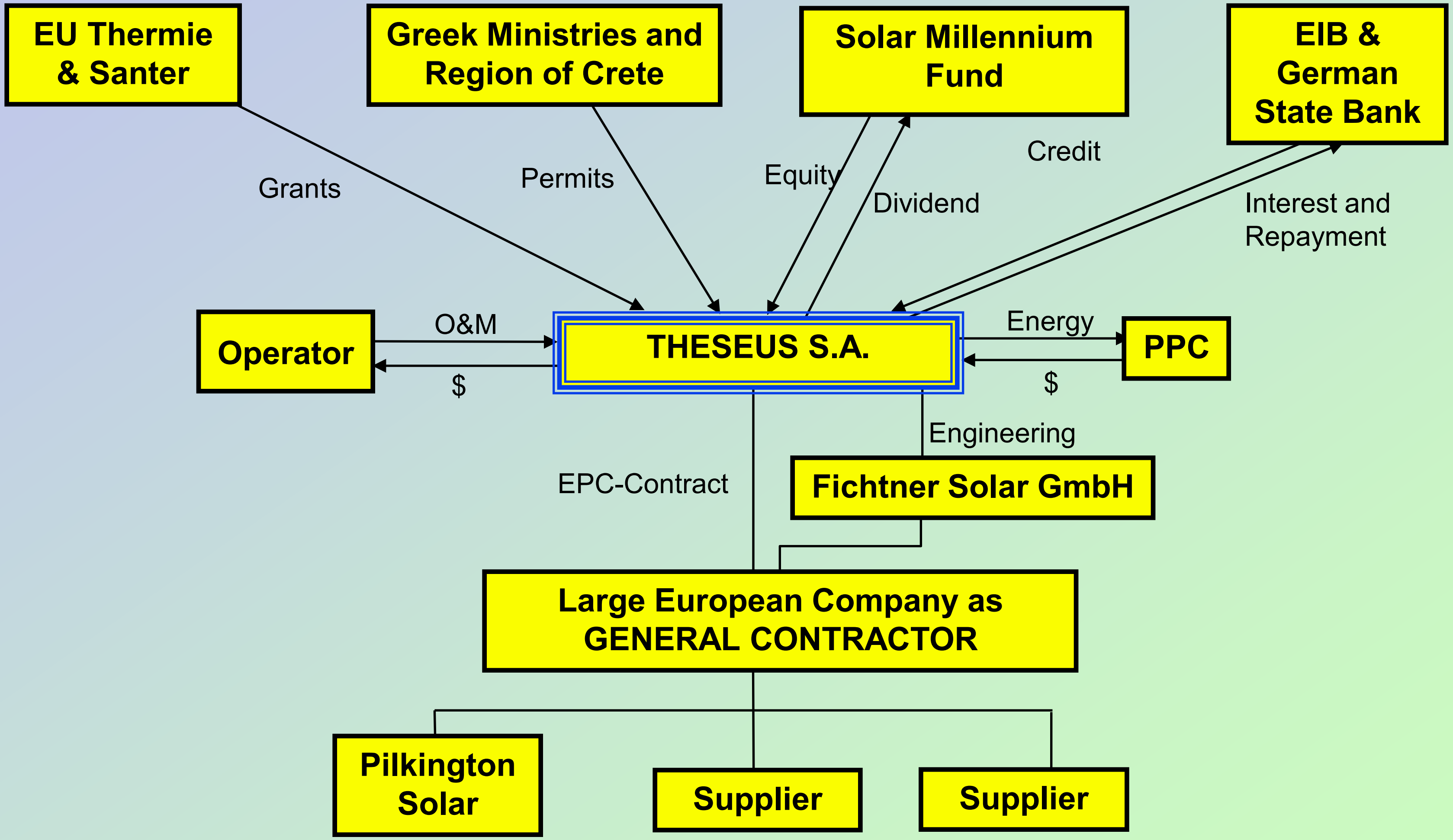


Solar plant avoids costly operation and emissions of gas turbines.

Concept of THESEUS
Solar-only Plant for Crete



THESEUS Organization as IPP



Theseus Solar Power Company S.A.

- **Private Share Holding Company, registered in Chania with business purpose to build, own and operate the Solar Power Plant under the IPP scheme**
- **Founding Shareholders:**
  - **Fichtner (40%)**
  - **Pilkington (40%)**
  - **O.A.DY.K. (20%)**
- **Solar Millennium AG (SM) purchased 70% of the total shares, 35% from Fichtner and 35% from Pilkington, and will provide the majority of the Equity for the Project**

Benefits of the Theseus Solar Project

- **Competitive electricity generation cost on Crete**
  - * with grants less than average of existing fossil power plants in Crete
  - * without grants less than gas turbine generation cost
- **Balance of payment**
  - * 4 million Euro saved every year by displacement of 28,000 tons of oil imports
- **Reduction of CO2 and other emissions**
  - * 80,000 t CO2 annually starting in first year of operation
- **Creation of more than 2 000 qualified jobs (man-years)**
  - * for supply, construction and erection and operation
- **Pure solar renewable electricity generation with 95% security of supply in summer**
  - * In general, excellent match with Cretan power demand profile
- **Higher Tax Revenues to Greece**
  - * Income from manpower and capital is taxed higher than fuel imports

Solar Technology Assessment: Parabolic Trough

- **The technology is commercially proven** since more than 10 years
- **The development is continuing**, improvements are being retrofitted into existing commercial projects.
- **Thermoil as HTF presents fire hazard** but can be handled without requiring extreme qualifications of the operating personnel.
- **Future developments** are towards **direct steam generation** avoiding the need for thermoil. Thereby further cost reductions can be achieved and the fire hazards reduced**.**
- **Maximum HTF temperature of 393°C allows thermodynamic cycle efficiencies of 38.5%** in Rankine cycles and of 41% (as incremental efficiency) if integrated into ISCC.
- **Potentially the cost of the solar field can be cut in half until the year 2010.** Such cost reduction can be made possible by technology improvements and mass production if further projects will be installed.
- **Storage can be accomplished by storage in concrete or phase change material (salt).** Industrial companies have stated their willingness to submit now a commercial offer for a concrete storage device, if asked to do so.

Solar Technology Assessment: Solar Tower

- **R&D projects only,** commercial viability is still to be proven.
- **Salt as HTF is difficult** to handle, in particular in developing countries, due to its potential freezing at some 300°C. This requires **heat tracing** with consequentially **large parasitic consumption**. It requires a **high technical qualification and discipline from the operating crew**.
- Start-ups in the morning are rather difficult, due to the necessity to introduce the hot molten salt very rapidly into the cold receiver. This might **delay start of operation** into the late morning hours with consequential production losses.
- The **HTF temperature of up to 1000°C** allows thermodynamic cycle efficiencies of around 42% in Rankine cycles. **The full potential of the high temperature cannot be exploited**, since molten salt cannot be used in a gas turbine.
- The heliostats require **2-axis tracking at a high accuracy**. The reflected beam has to travel **a long distance** from the reflector to the receiver at a very low elevation with potential **atmospheric contamination and thereby additional losses.**
- The size of the heliostats is limited to some 150 m^2 against 560 m^2 for the parabolic trough collectors. Thereby the **cost for foundations as well as the tracking system (six times as many motors and gears) is increased**.
- The **land requirement is much larger (typically by a factor of three)** than for the parabolic trough collectors, due to the wider spacing of the heliostats to avoid shading. Since the availability of the land is limited in Mathania only a smaller solar tower plant could be incorporated.
- Storage in the molten salt is easier but **cannot accomplish base load operation**, since it cannot store the larger production in months with large insolation for use in the low insolation months.

Parabolic Troughs:
Preferred Technology for Solar Projects

- **354 MWe Solar Generating Capacity** are operating without any major problems since the late 1980s in California**.**
- **7% increase in the output due to technical improvements** since the implementation of the plants.
- The SEGS plants logged **all time performance records in 1998** after being for 10 years in operation
- **European sourcing** of most components is possible. A new and improved entirely **European design** will be ready by 2001.

Like the Ford model T in the 1920s: Today the Parabolic Trough Technology is proven but has still a large potential for cost reduction and advances in technology. Until 2010 the cost is likely to be cut in half.

Arguments for molten salt solar tower plants (1)

- Higher temperatures lead to higher thermodynamic cycle efficiencies.
  - **Yes, but** the difference to parabolic trough plants is not that much. (In Rankine cycles it is 42% for tower plants against 38% for parabolic troughs. As ISCCs the parabolic troughs can reach incremental cycle efficiencies of 42%). The parasitic power required by molten salt tower plants is much larger due to heat tracing. For solar plants the thermodynamic cycle efficiency is not so important; the overall efficiency based on money (LEC) or on land area is more relevant.
  - For parabolic trough plants the LEC is lower and is better known. The efficiency of a parabolic trough plant based on the required land area is about three times better.
- Due to the higher temperature tower plants have a better market potential for industrial process heat than do parabolic troughs.
  - **Wrong:** About 50% of the industrial process heat demand is at temperatures which can best be served by parabolic troughs. This presents a huge market potential. Furthermore, parabolic troughs can better be installed in small standardized units such as are required by the industries.
- Tower plants have a larger cost reduction potential than troughs.
  - **Not proven:** The cost of troughs is based on commercial operating plants. Further cost reductions will occur if more plants will be built, due to mass production, competitive pressure and technical advances. The cost of tower plants are only theoretical estimates based on speculation regarding the cost of heliostats to be a much lower than the cost of parabolic trough collectors.

Arguments for molten salt solar tower plants (2)

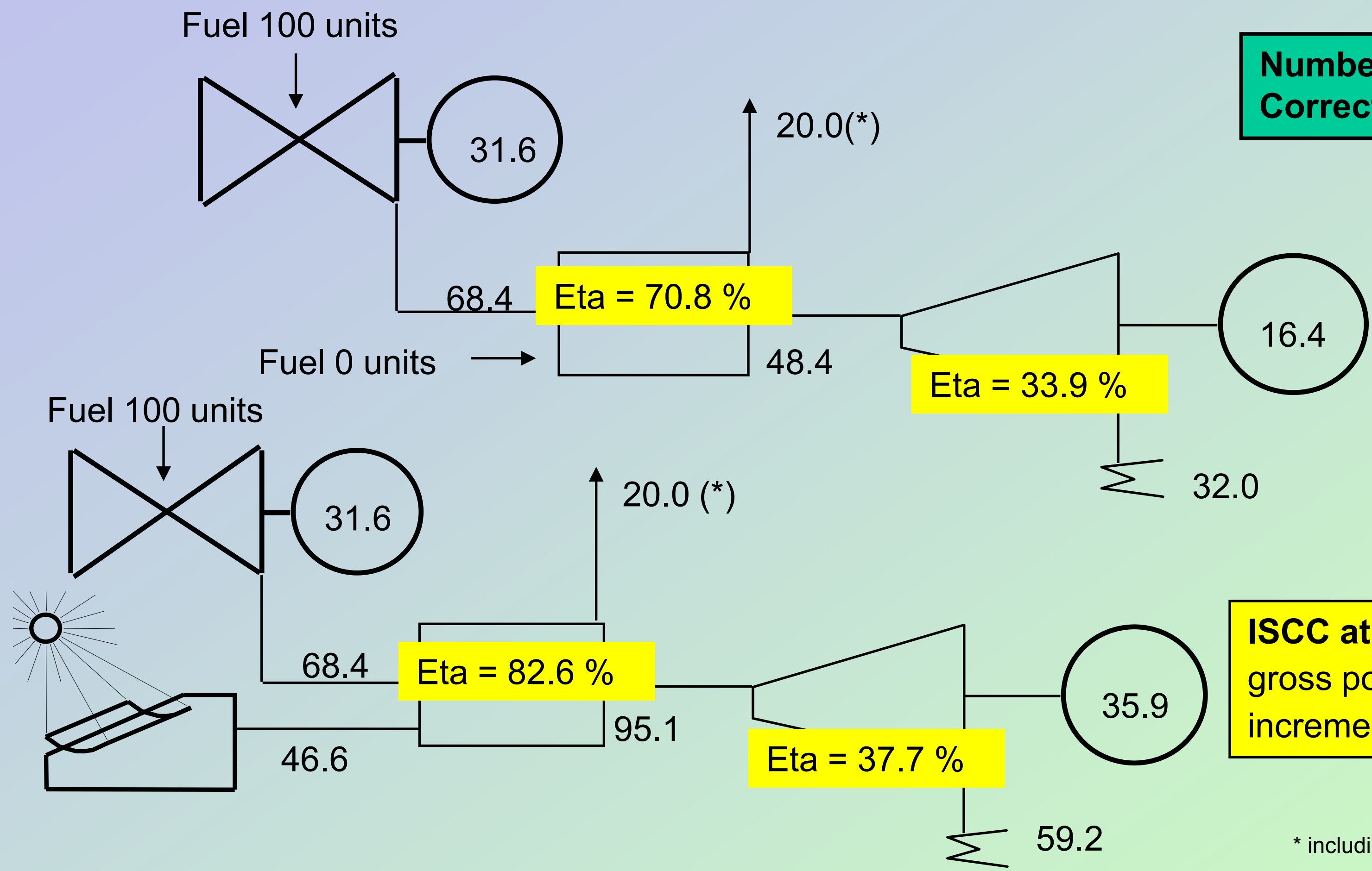
- Molten salt towers can be easily operated and maintained.
  - **Wrong:** The molten salt requires electric heat tracing and a very disciplined O&M staff in order to prevent freezing of the pipes.
  - Furthermore filling and start-up of the cold receiver every morning is a rather difficult task. Delayed start-ups will drastically reduce the overall annual output.
- Base load operation can be accomplished with molten salt tower plants because of the low cost of heat storage.
  - **Wrong:** The thermal energy production in the month with lowest insolation is only about 30% of the one with the highest insolation. To operate at base load would require extremely large seasonal storage which is practically not possible.

Potential for conversion of solar thermal into electric energy by parabolic trough technology

- **In Rankine cycles: 37.5 % gross efficiency** during rated solar operation
- **In solar hybrid plants (ISCC): 42 % gross efficiency for incremental solar generation during sunhours**
- **Net annual solar incremental efficiency** for solar hybrid plants depends on operating mode must be based on annual operation hours. Any **performance losses of the fossil only operation during no-sun hours as well as part load losses are subtracted** from the solar incremental generation :
  - in a typical **Rankine cycle** plant it is **30 %**
  - for a typical **ISCC** it is **31 %**
  - for a typical **ISCC using thermal storage** it is **32 %**

Efficiency change in a combined cycle plant due to addition of solar thermal energy

Numbers are for demonstration only. Correct values are site dependent.



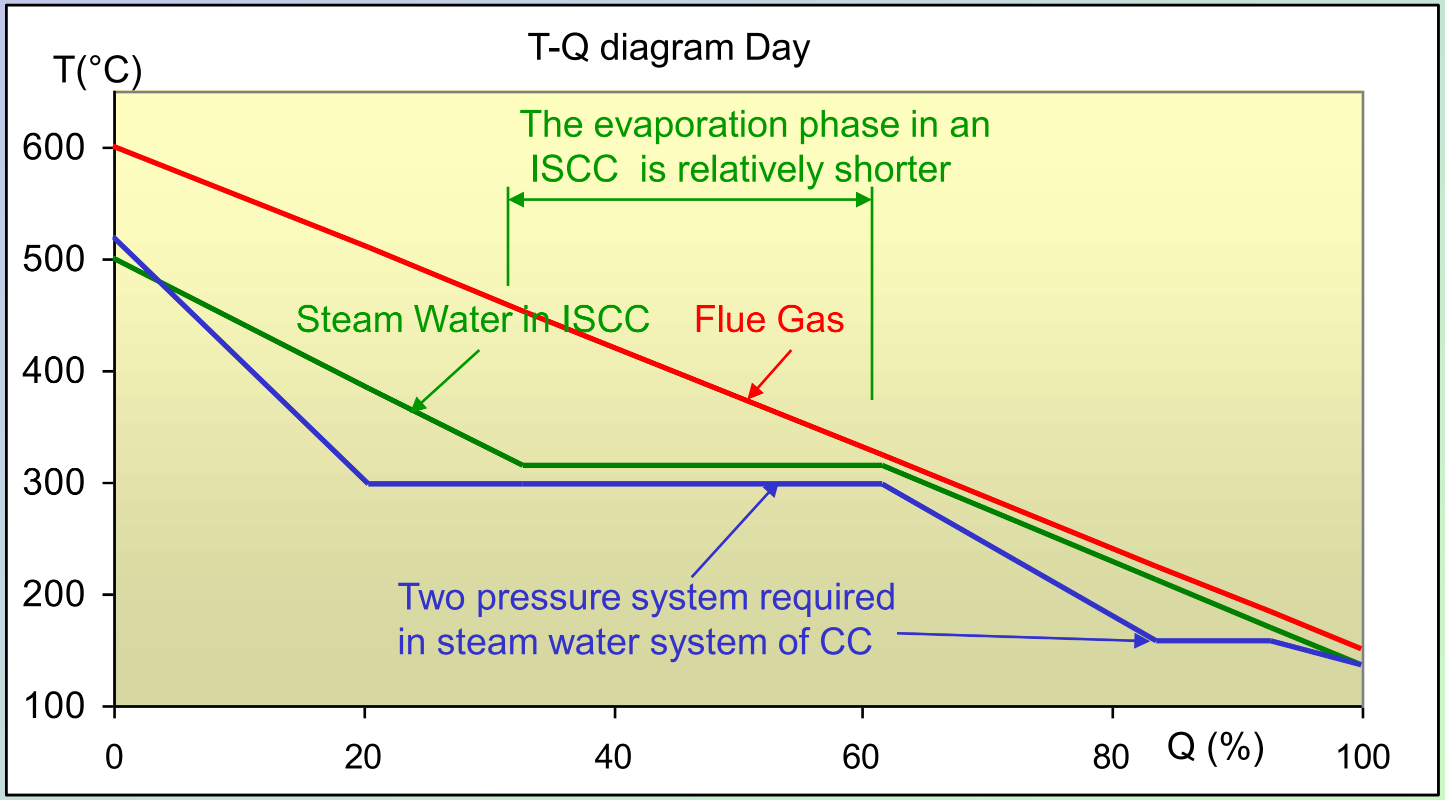
Fossil CC at day
No auxiliary firing
gross eff. = 48.0 %

ISCC at sunhours
gross power/ fossil fuel ratio = **67.4 %**
incremental solar gross efficiency = **41.7 %**

* including latent heat of injected water for NOx control

Due to solar addition the plant efficiency is reduced, but not very much as the efficiency in the steam water cycle is increased due to less entropy in the heat exchanger and the solar thermal energy does not contribute to stack losses

Solar field increases the efficiency in the steam water cycle



The efficiency in the ISCC is improved due to:

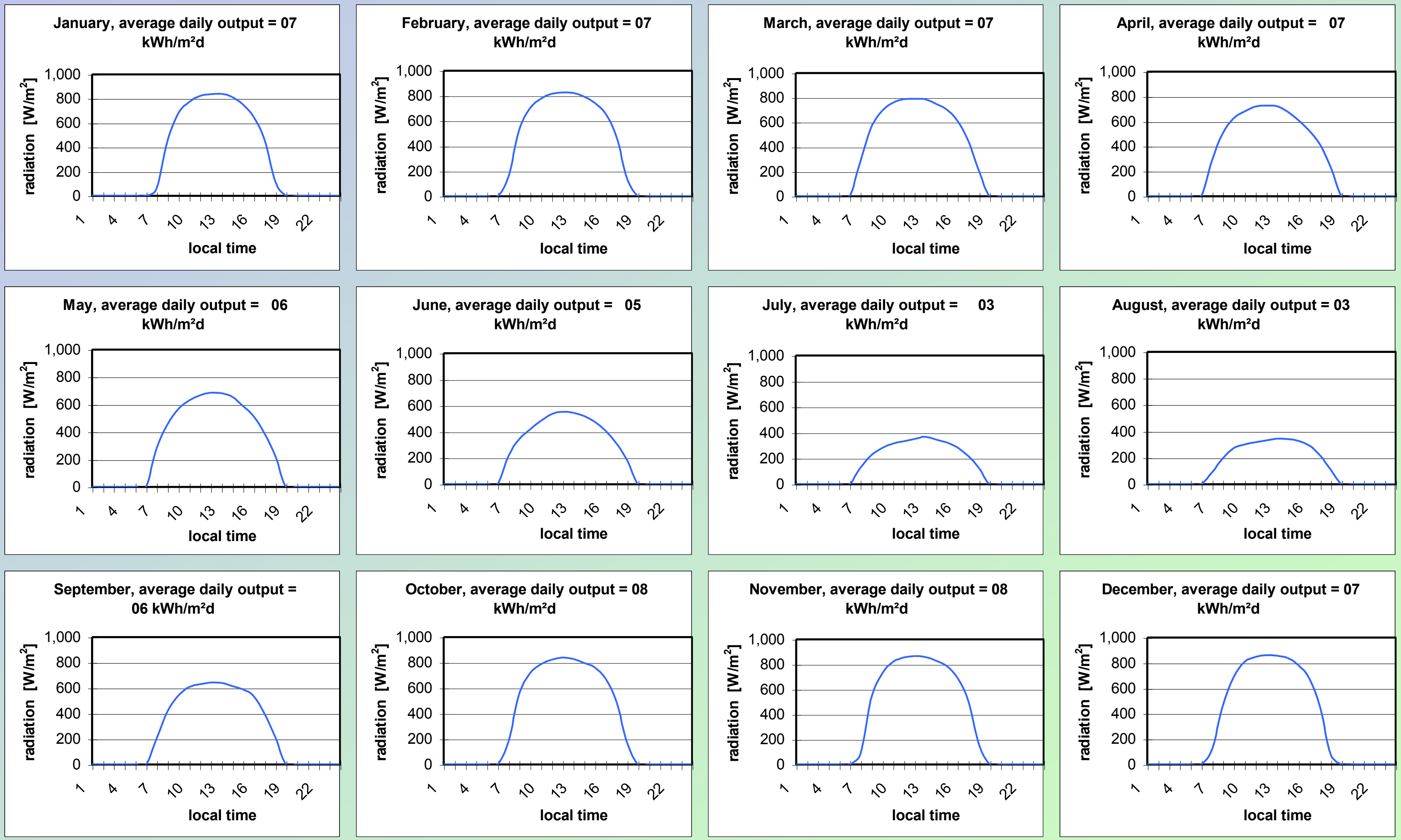
- **Part of the steam generation in the ISCC is by solar, therefore the evaporation portion in the WHRB of the ISCC is shorter and the preheating and superheating curves are flatter. Thereby the steam water curve is closer to the flue gas curve, resulting in less entropy.**
- **The heat transferred from the solar field does not contribute to stack losses**

Thermodynamic cycle design for ISCCs

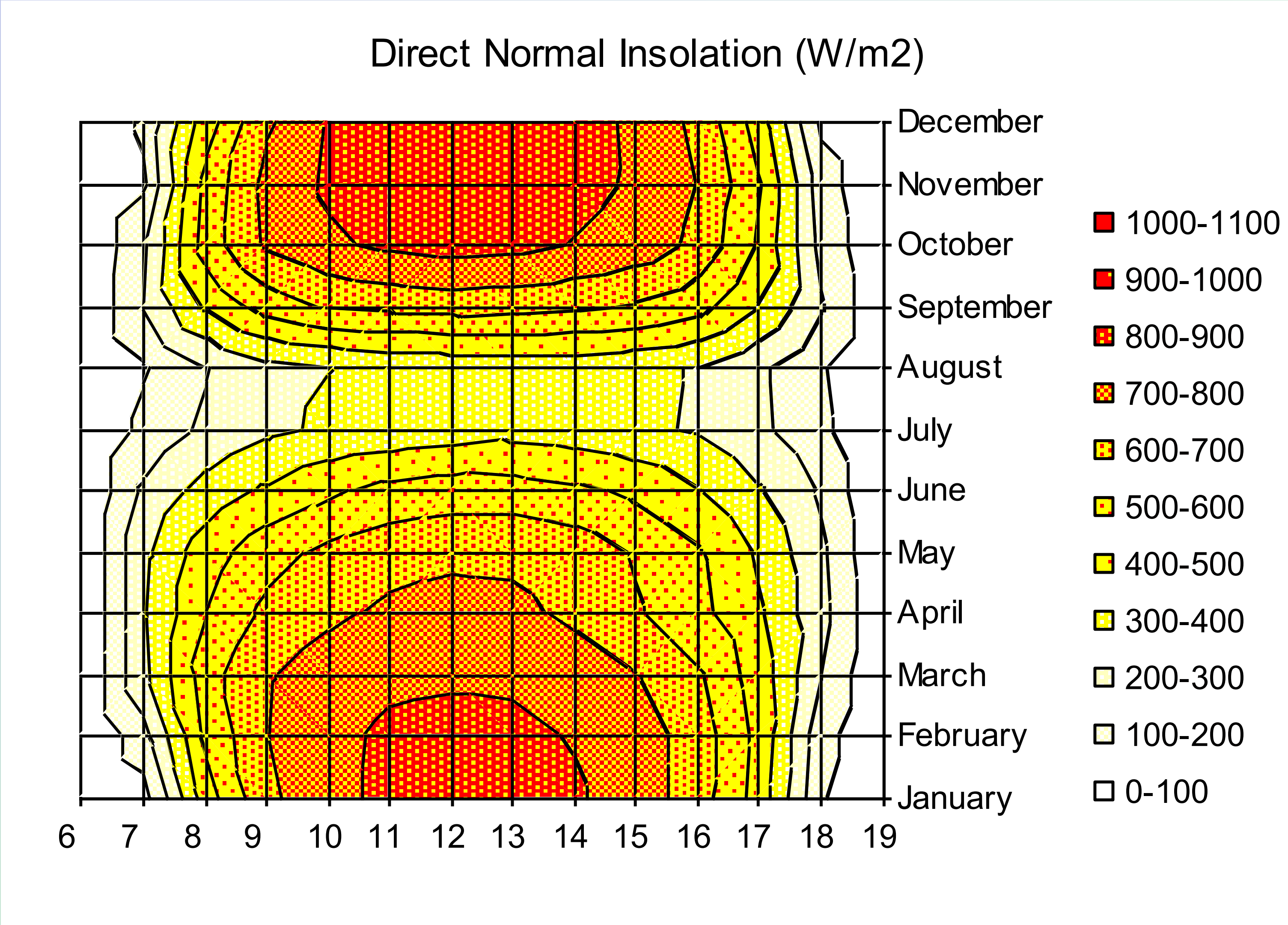
- Integrating a solar portion into a combined cycle plant requires careful tuning of the thermodynamic cycle for all operating conditions. If not done properly, then the solar generated heat will be converted at only a reduced efficiency. Furthermore the losses due to partload operation or auxiliary firing will be larger than necessary.
- Design simplifications can grossly change results and even produce negative solar shares.
- Due to the relatively small solar share in an ISCC (typically less than 10 % on annual basis), **a small percentage error in the efficiency** of both, the base case CC as well as the ISCC, would **drastically change the incremental solar power generation**

Proper tuning of the thermodynamic cycle for all operating conditions is extremely important and requires sophisticated computer software like Fichtner’s own KPRO and SOLPRO programs.

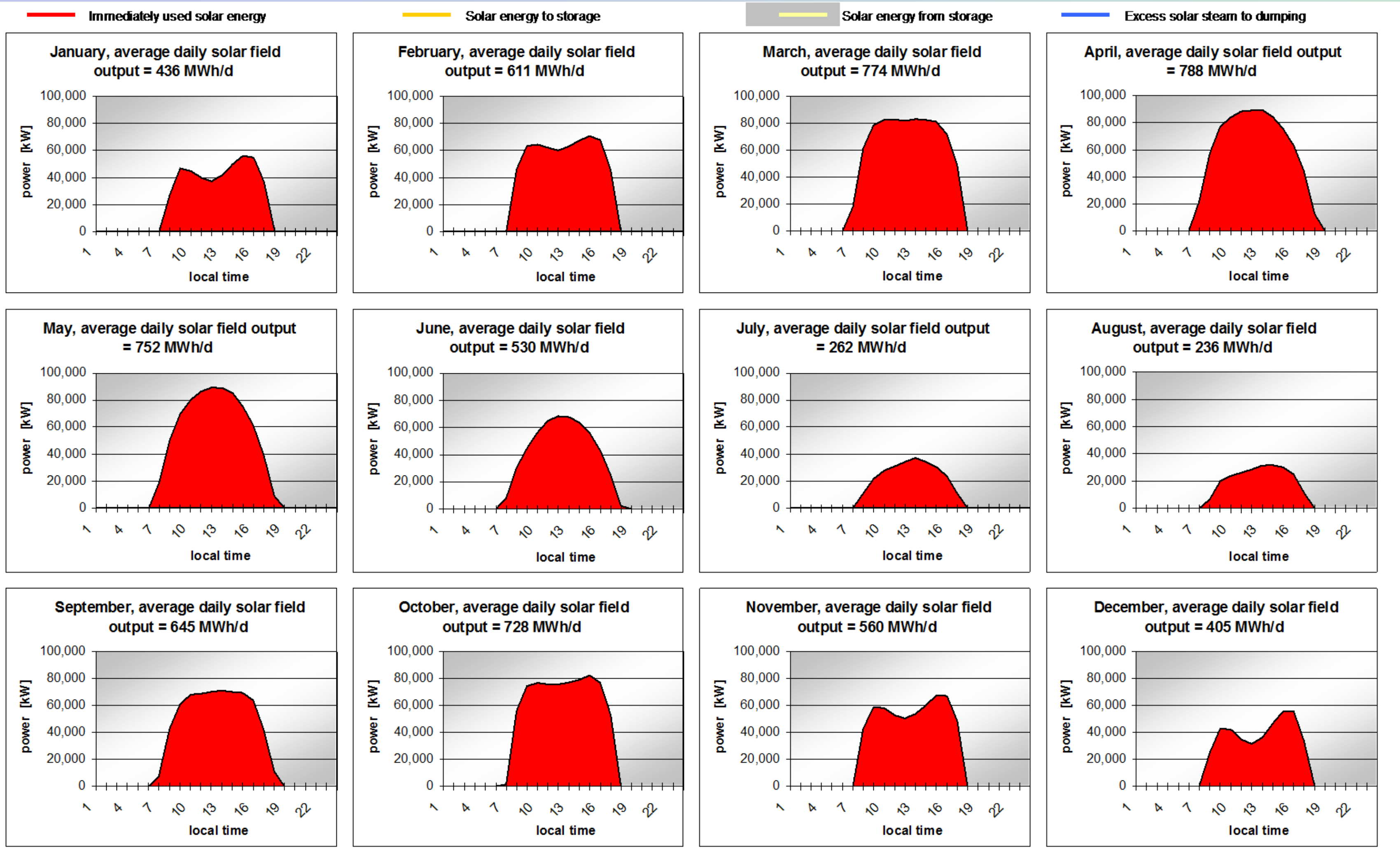
Typical direct normal insolation for a location with summer monsoon (W/m²)



Typical insolation map for a location with summer monsoon

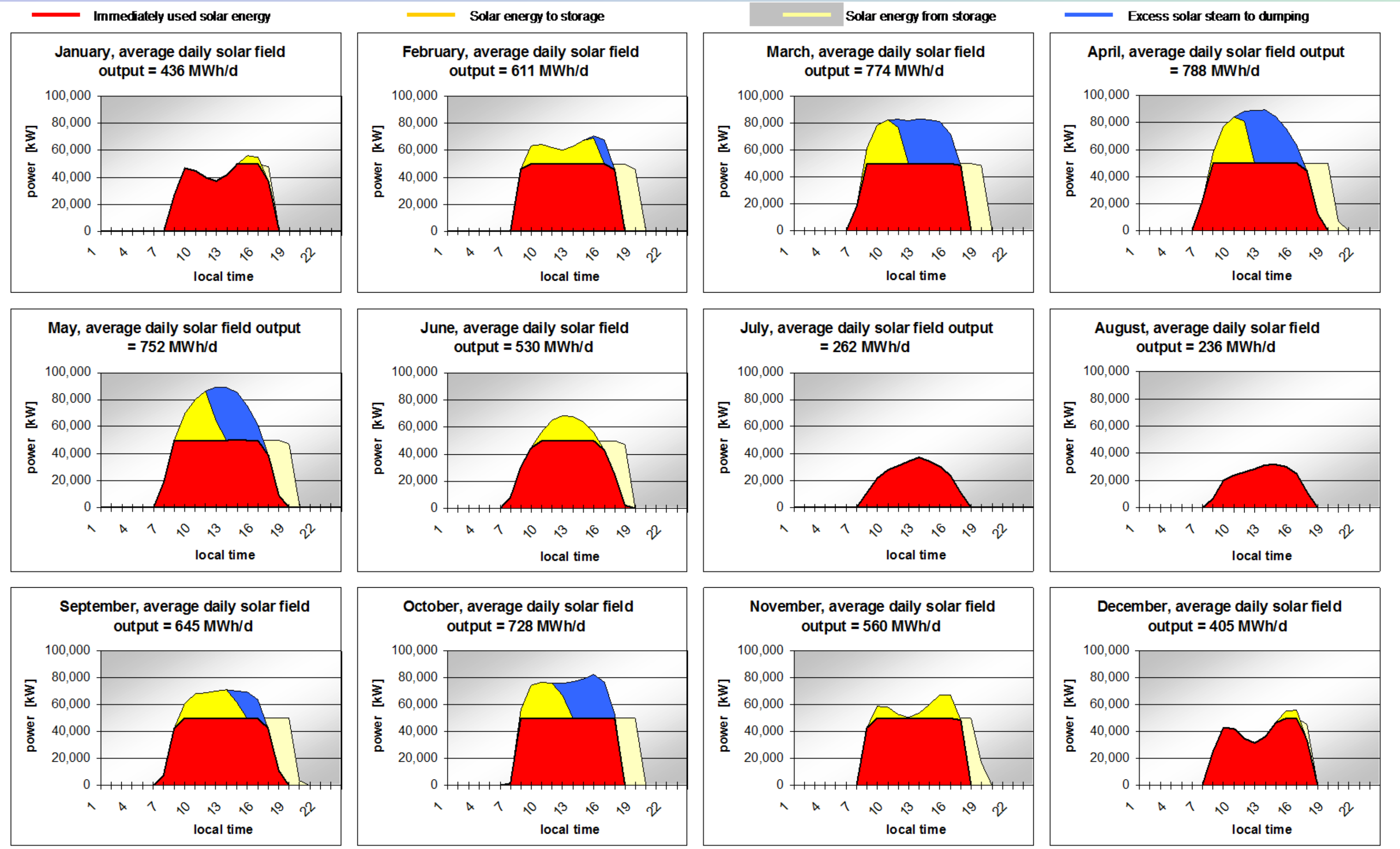


Typical solar field performance without storage



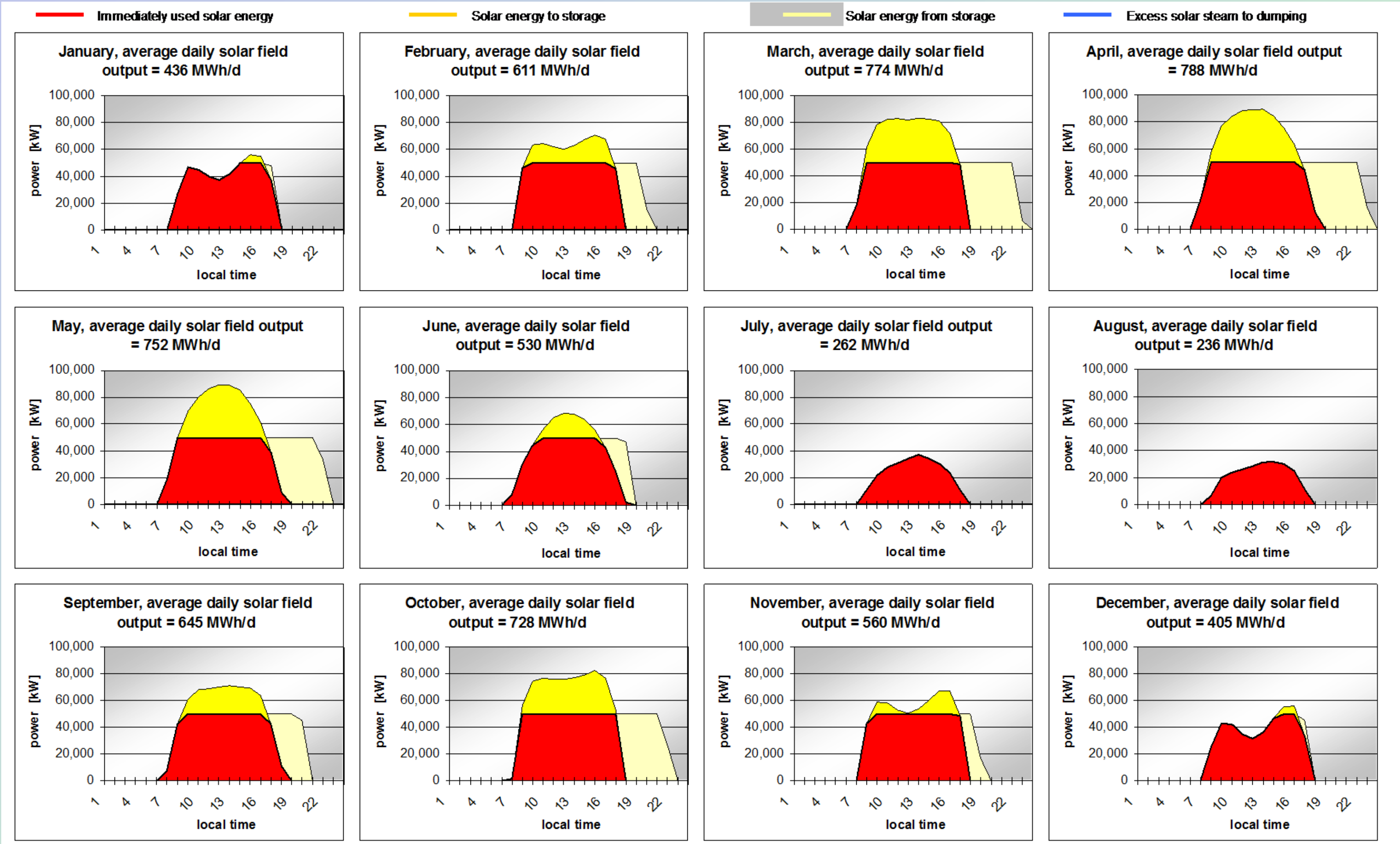
Storage Capacity	0.0 MWh	Capacity to use thermal power	90.0 MW
Total annual production	204.2 GWh/a	Direct used thermal energy	204.2 GWh/a
Total used	204.2 GWh/a	From storage 99%	0.0 GWh/a
Energy dumped and lost	0.0 GWh/a		

Typical solar field performance with 100 MWh storage



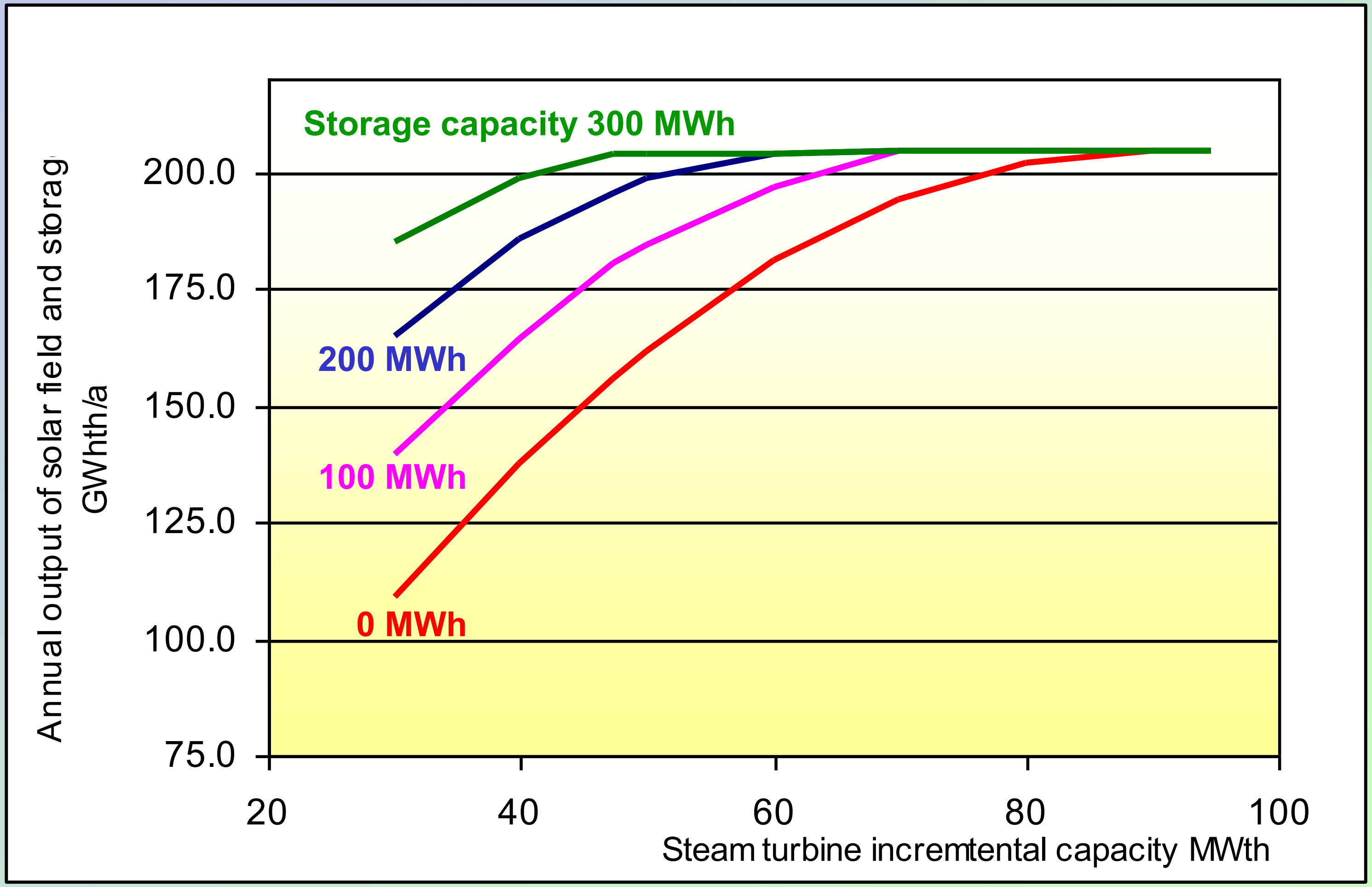
Storage Capacity	100.0 MWh	Capacity to use thermal power	50.0 MW
Total annual production	204.2 GWh/a	Direct used thermal energy	161.5 GWh/a
Total used	184.4 GWh/a	From storage 99%	22.9 GWh/a
Energy dumped and lost	19.8 GWh/a		

Solar field performance with 300 MWh storage



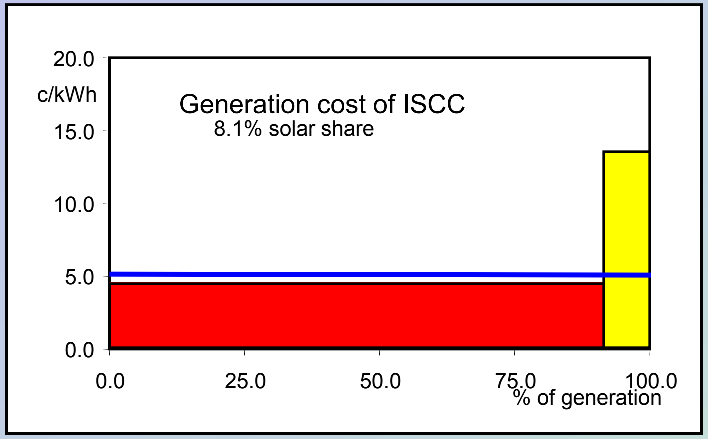
Storage Capacity	300.0 MWh	Capacity to use thermal power	50.0 MW
Total annual production	204.2 GWh/a	Direct used thermal energy	161.5 GWh/a
Total used	203.8 GWh/a	From storage 99%	42.3 GWh/a
Energy dumped and lost	0.4 GWh/a		

Graph of performance calculation for solar field and thermal storage

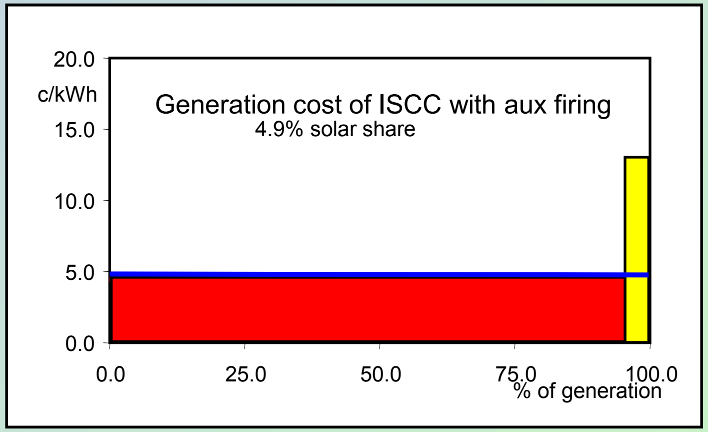


Graph of typical generation cost

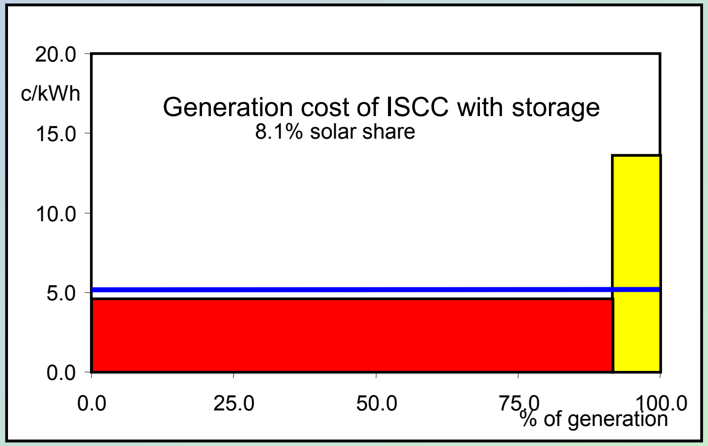
**Numbers are for demonstration only.
Correct values are site dependent.**



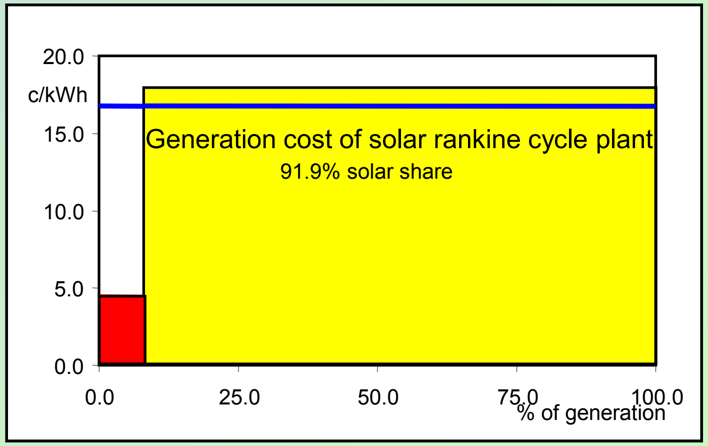
Genrtn cost (c/kWh) 5.7 solar 13.7 Fossil 5.0



Genrtn cost (c/kWh) 5.5 solar 14.4 Fossil 5.0



Genrtn cost (c/kWh) 5.6 solar 12.7 Fossil 5.0



Genrtn cost (c/kWh) 16.4 solar 17.4 Fossil 5.0

Conclusions

- **Solar Parabolic Trough technology is commercially proven** and able to produce solar electricity at **lowest cost**. Due to mass production and technological advances from a large solar implementation program **the cost will further decrease** and could be cut in half by 2010.
- Integrating the solar generated thermal energy into the steam turbine of a combined cycle power plant **(ISCC) results in lower generation costs for the incremental solar generated electricity.**
- **The thermodynamic cycle must be properly tuned for the specific site and for all operating conditions**. Suboptimal thermodynamic integration of a solar field into a combined cycle power plant would result in grossly reduced or even negative solar shares.
- Most of the components for Solar Parabolic Trough Plants have been supplied by European Companies. **European Industrial Consortia are ready to offer Solar Parabolic Trough Power Plants** under the IPP scheme.