Asia-Pacific
Economic Cooperation

DEVELOPMENT OF THE SOLAR THERMAL MARKET IN THE APEC ECONOMIES

Programa de Estudios e Investigaciones en Energía
Instituto de Asuntos Públicos
Universidad de Chile

APEC Energy Working Group (EWG)
Expert Group on Minerals &
Energy Exploration & Development (GEMEED)

March 2009

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Final Report

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Chapter 1

Introduction

This project aims to improve the development of the solar thermal energy market, within the sponsoring APEC economies. In order to accomplish this goal, it is necessary to identify the most efficient technologies for solar thermal energy collection, the barriers to the development of the solar market and the mechanisms to overcome such barriers and promote the efficient use of solar thermal energy.

As a result, the state of the art of the main solar technologies is discussed, differencing the solar technologies that have reached a certain level of maturity from those that haven't. In addition, the most suitable processes for the application of solar energy have been detected for some of the most important mining activities among the APEC economies. This industries are often located in areas with high solar radiation; therefore, becoming an interesting alternative to fossil fuels, as investment in solar heating in this areas can be not only environmentally friendly but also cost-effective.

Then, the barriers to the development of the solar thermal market are analyzed, in order to understand their nature and, therefore, being able to generate proposals to overcome them. To discuss these barriers, they have been classified between those related with the market, the investor or the solar project itself.

Many of these barriers were found to be information-related barriers; therefore, requiring a stronger role from private and state institutions to support solar energy technologies. In order to overcome these barriers, several measures are proposed, involving not only to private and public entities but also public policies and renewable-energy promotion laws.

Finally, a solar project case-study is analyzed. In this case, a 10.000 m^2 parabolic trough solar field —used to replace 18% of the total fuel consumption of a large copper electrowinning plant— is modelled using the simulation software TRNSYS. As a result, an estimation of the net amount of heat delivered to the electrowinning process by the solar field can be obtained. Based on these results, an economic assessment will be performed, in addition with the calculus of the Greenhouse Gas emissions avoided.

Chapter 2

Background

2.1 Solar radiation

The solar radiation is radiant energy emitted by the sun from a nuclear fusion that creates electromagnetic energy. The incident solar radiation could be used to provide heat, light, hot water, electricity and even cooling, for homes, businesses, and industry. Its main advantage is related to their clean and renewable characteristics when it is used as an energy source.

The radiation intensity varies depending on the location, the atmospheric conditions and the time of the day.

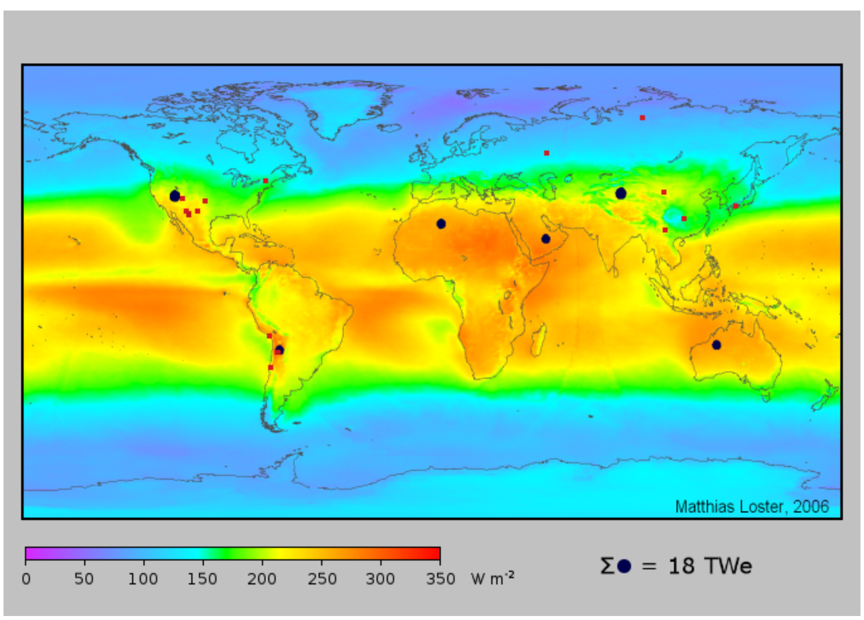

Figure 2.1: Annual average incoming solar radiation. The red squares show the locations of the largest Copper Refineries in the world (considering just APEC members).[1]

As it is shown in the Figure 2.1, there are certain regions in the world with better insolation conditions than others. Solar power systems installed in the areas defined by the dark disks could provide somewhat more energy than the world's current total primary energy demand (assuming a conversion efficiency of 8%) [1].

As an example, in Figure 2.1 appears in red squares, the locations of the largest Copper Refineries in the world (considering just APEC members) [2]. Many of them are in regions with suitable conditions for using solar energy. Specifically, there are two Refineries using the Electrowinning technology (SX/EW), in places with radiation conditions above the average. These installations are *Codelco Norte* in Chuquicamata, Chile and *Morenci* in Arizona, USA.

2.2 Solar Technologies: State of the art

Currently, there are several technologies in use or available for capturing solar radiation and trasfering it as heat to a Heat Transfer Fluid (HTF). Depending on whether the collectors follows the sun through its trayectory or not —and if they do, the way they do it— it is possible to clasify them in three different groups: stationary collectors, 1-axis tracking collectors and 2-axis tracking collectors.

The following table presents the main existing technologies arranged according to the above-mentioned classification:

Clasification	Collector type	Concentration factor
Stationary		
	Flat plate collector (FPC)	1
	Evacuated tube collector(ETC)	1
	Compound parabolic collector (CPC)	1 - 5
1-axis tracking		
	Fresnel lens collector(FLC)	10 - 40
	Parabolic trough collector (PTC)	15 - 45
2-axis tracking		
	Parabolic dish reflector (PDR)	100 - 1000
	Heliostat field collector (HFC)	100 - 1500

Table 2.1: Existing solar energy collectors and its typical geometrical concentration factors. Source: Kalogirou [3].

In report 4, a full simulation of a real solar heating system for a particular mining application is to be performed. The mining industry has large heating requirements, and therefore, not all of the previous technologies are able to deliver considerable amounts of process-heat or have enough maturity to be considered for a deep technical and economical analisys. Thus, the technologies mentioned in the previous table will be described one by one explaining the reasons why they will or will not be taken into account their technical caracteristics, state of the art and market price.

2.2.1 Flat Plate Collector (FPC)

The FPC technology is the oldest and the mot mature one among solar thermal collectors. The FPC collectors are by far the most used solar technology in the world, which accounted for $115GWth$ in 2005 [4]. This technology is used in a masive scale in many economies and its final use is mainly domestic water heating.

The functioning is simple: the solar radiation passes through the glass and it's absorved by the metal plate and inner tubes. The insulation diminishes the heat loss through the back and the sides of the collector, and the transparent glass reduces the air-convection and radiative losses. The components of this collector can be seen clearly in the following figure:

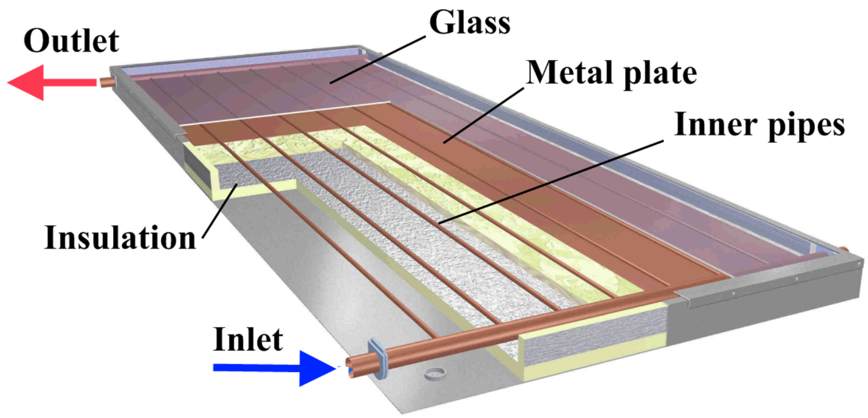

Figure 2.2: Flat Plate collector components.

The FTC technology has been proven in many different weathers and locations with very good results for small domestic applications. However, when a project involves high heating requirements and/or HTF temperatures over 40C, the performance of this technology is very poor and therefore not appropriate. This is explained by several reasons. On the one hand, when temperature over the HTF rises above 40C the radiation losses become considerably high, and the efficiency of the collector falls dramatically. On the other hand, when the solar field becomes larger than a few tens of meters, the piping-heat losses become really high and the high pressure drop leads to major parasitic power requirements.

Considering both, the size of the heat requirements of the mining industry as well as the temperatures required, the use of this technology would be quite inefficient for large solar heating applications and totally discarted for HTF heat requirements over 60C. Thus, this technology won't be considered for the case study simulations on report 4, as its technical features are not suited for considering it in a real alternative for replacing large amounts of fossil fuels for industrial mining applications.

2.2.2 Evacuated tube collector(ETC)

The ETC technology is a type of solar collector that has been specially designed to strongly reduce the convection and radiation losses of conventional stationary technologies like flat plate collectors (FPC). Each ETC collector posses several glass tubes, inside which, there is a radiation capture element and a relative air-vaccum to diminish air-convection and radiation losses.

An evacuated tube is normally composed of a closed glass envelope which contains a metallic plate linked to one or two metallic heat pipes. This pipes transfer the heat to a low-boiling-point fluid (such as methanol) that is contained inside of them. This components can be seen in the following figure:

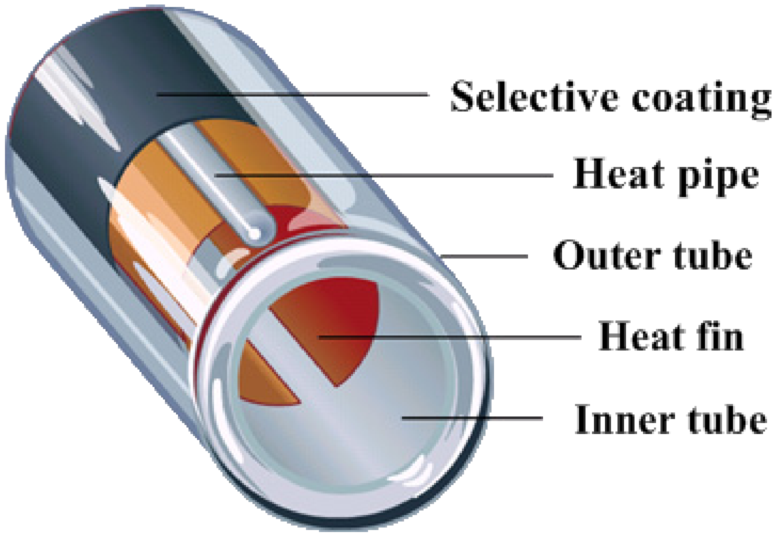

Figure 2.3: Evacuated tube components. Source: Systemlink [5].

Solar radiation heats up the low-boiling-point fluid (usually methane) inside the heat pipe and vaporize it. This hot gas moves along the pipe in an ascending flow motion due to natural convection until it reaches the condenser. Once there, it exchanges heat with the Heat Transfer Fluid (HFT), condensing and then it moves back downwards to where it started its journey from. Thus, the heating of the HTF (generally water) is indirect, for the HTF only passes through a main copper tube where all the condensators of the pipe are placed, but it doesn't really go in through the heat collection pipes. Thus, relatively small overall heat losses are obtained with low pressure drops compared to FT collectors.

The operation of a ETC collector can be seen clearly in the next figure:

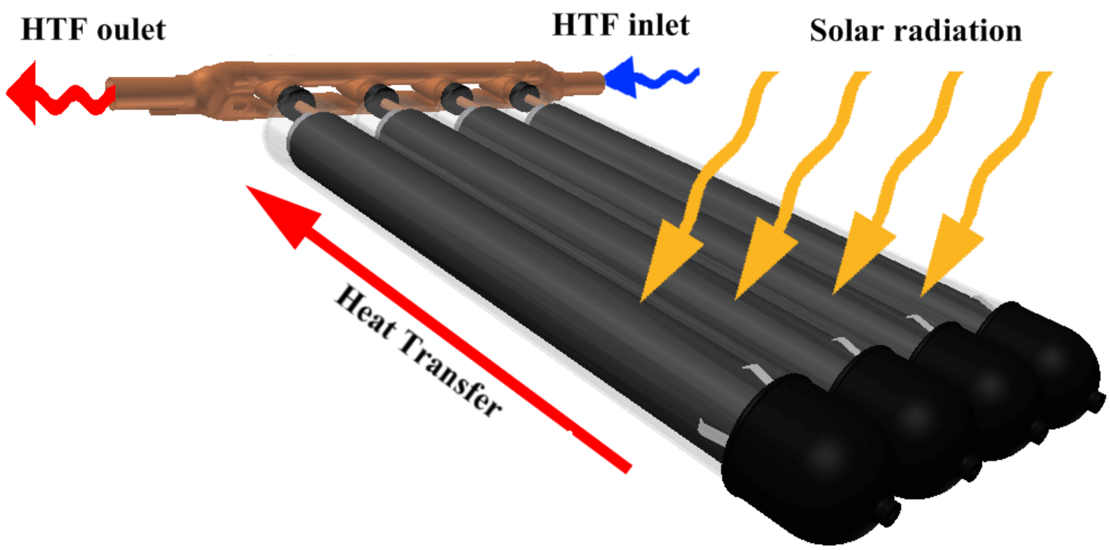

Figure 2.4: ETC collector operating mode. Source: Solarcrest [6].

In this way, this technology offers significant improvements to conventional flat plate collectors, giving superior efficiencies and higher operating temperatures. This collectors are proven to offer a very good performances in cold weathers and in commonly cloudy sky locations, where they have no competition in terms of performance and efficiency. However, in locations with very high radiation and clear sky its characteristics are not impressive anymore, when comparing it to several solar concentrating technologies with a better eficiency and lower costs.

Technical Features

The ETC technology hasn't been used for large industrial heat requirements due to the fact that its costs are to high to became economically interesting. Lately, chinese-manufactured ETC collectors have showed up in the market offering lower efficiency but at considerably lower prices. This low price has made them an alternative for medium size solar fields, as several importers in many economies are trying to sell them as the best and easiest alternative for solar heating in industrial installations. For this reason, this technology will be taken into account, as many manufacturers may consider that it represents a real market alternative for the mining industry.

For further solar field simulations, the technical characteristics of the chinese manufacturer *Sunrain* will be used, and they are presented in the next table:

Parameter	**Value**
Total surface	$5,5m^2$
Real collecting surface	$4,7m^2$
Number of tubes per collector	30
α_0 - optical efficiency	0.708
α_1 - first order efficiency coeficient (W/m^2C)	$1,554$
α_2 - second order efficiency coeficient (W/m^2C)	$0,01$

Table 2.2: Technical specifications for the selected ETC collector [7].

2.2.3 Compound parabolic collector (CPC)

The CPC technology was created in order to take advantage of the higher temperatures that concentration technologies can reach, as well as the easy mantainance and low costs of stationary technologies. CPC collectors can reach values of concentration ratios as high as 5, but normally they get truncated to obtain a more economic optimal collector. Thus, when oriented with a tilt equivalent to the latitud, this collector receive solar radiation as long as the sun is within the collector's aceptance angle.

The main components of this technology can be seen in the following figure:

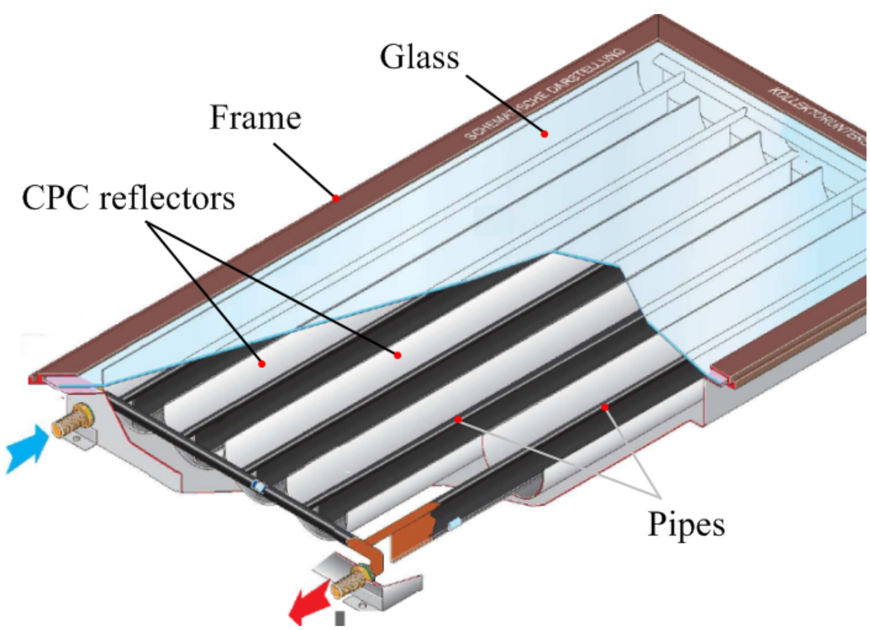

Figure 2.5: CPC collector components. Source: Solarfocus [8].

Technical features

CPC collectors are a technology that has grow considerably in the last few years. Several medium-size fields have been developed lately with this technology, and therefore, this technology should be taken into account. As an example, the AQUASOL project involved several companies and research institutions in the mediterranian area and it used $500m^2$ of CPC collectors from the portuguese manufacturer *Ao Sol*. The final purpose of this plant was to provide heat for the seawater desalination process, in a research/comercial size.

Therefore, for further simulation analysis, the *CPC 3E* collector of *Ao Sol* will be used. The technical specifications of this collector can be seen in the following table:

Parameters	**Value**
Aperture area [m^2]	2.4
Half-acceptance angle [°]	37
Truncation angle [°]	56
Overall loss coeficient [W/m^2 °C]	4,6
Absortance of absorption plate	0,94
Optical efficiency	0,76
Fin efficiency factor	0,9

Table 2.3: Technical specifications for the selected CPC collector [9].

2.2.4 Fresnel lens collector(FLC)

The Fresnel lens solar technology has had a really fast developed in the last few years, with several pilot installations in Europe and Australia. This technology has a high potencial for solar heating in the mid-term future for the high radiation concentration factors it's able to reach and the simplicity of its components, which would allow high cost reductions in its manufacturing.

The classical FLC collectors are basically composed of rectangular flat mirrors that rotates during the day in a way that they reflect the solar radiation over one or several receivers. Inside this receivers, a Heat Transfer Fluid (HTF) circulates and increase its temperature as it moves along the receiver. The main components of this technology can be seen in the following simple diagram:

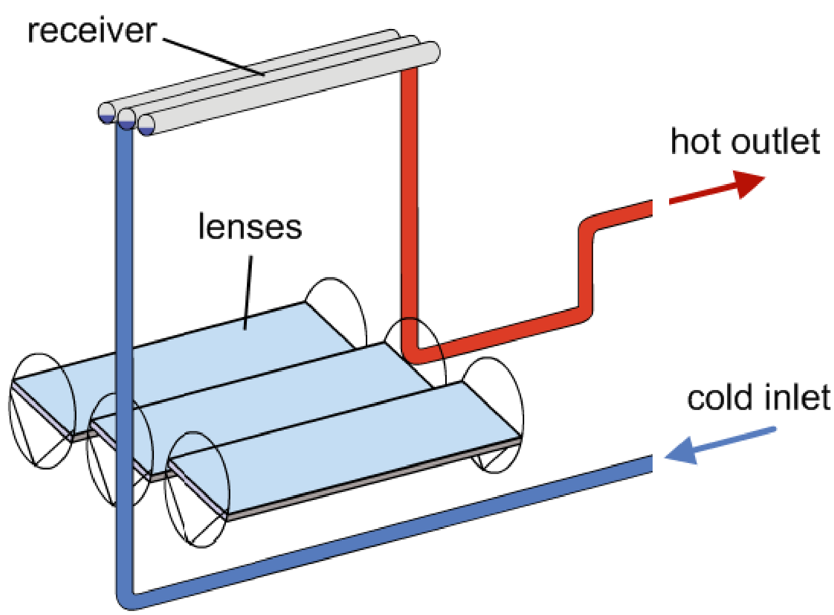

Figure 2.6: Main components of a FLC collector. Source: Ausra Inc. [10].

As it was said before, this technology has major cost reduction potencials as many of its components are simple, and therefore, likely to be mass manufactured and/or to use cheaper materials. However, this technology is fairly new and there are few plants in the world making use of this technology at the moment. Thus, this technology is still fairly expensive and needs to be further developed in the next few years in order to became one of the leading solar technologies for process heating. For this reason, this technology will not be taken into account in the simulation and economical analisys to be performed in report 4, however, this team recognizes the potential of this technology to become as a good alternative in the mid-term.

2.2.5 Parabolic trough collector (PTC)

The PTC technology is basically composed of a parabolic-shaped reflector which concentrates solar radiation over a focal line. Thus, when orienting the collector in the normal direct irradiation direction, the reflected radiation on the parabolic mirror is absorbed in a metal tubular receptor situated along the focal line, transfering the heat to a Heat Transfer Fluid (HTF) that flows inside it. Because of the high radiation concentration factors obtained on the receiver, HTF temperatures of over 450C have been reached in solar power-generation plants [11]. The following figure shows the main components of a PTC collector:

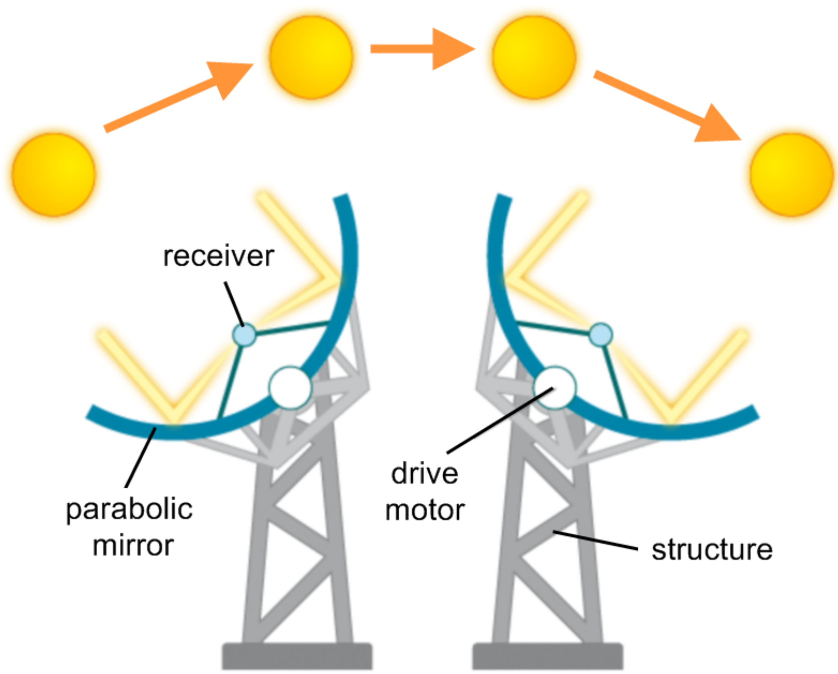

Figure 2.7: Components of a PTC collector and its 1-axis tracking motion.

In the previous figure, the daily East-to-West (E-W) tracking motion of the CCP collectors can be seen. The purpose of this motion is to reflect the solar radiation exactly over the receiver throughout the day. This is accomplished through a controlling system that drives the motorized mechanism which turns the structure in the sun direction. The collectors are aligned usually with its axis in the North-South (N-S), and therefore the tracking movement is performed in the E-W direction. Alternatively, the alignment could be also in the East to West direction, and therefore performing N-S tracking of the solar altitud.

This configuration reduces the fraction of the total parasitic power used to move the collector structures because of the less movement requirements throughout the day compared to the conventional E-W tracking option. The N-S tracking configuration has proved to be less convenient than the conventional E-W one because of the large losses in the morning and evening. These two (2) alternatives will be taken into account when analyzing the case study in report 4.

Technical Features

Several different designs can be found regarding to Parabolic Trough Collectors (PTC). Conventional electricity-production collectors use glass mirrors as the parabolic-reflective surface which have a high weight, and therefore, they require considerable large and heavy sopporting structures. The use of this high-quality mirrors is essencial to achieve the high temperatures required for the electricity production (as high as 400C). Also, the receiver is usually a metalic tube surrounded by a glass envelope with a relative vacuum in between, in order to diminish the convective and radiative losses.

For the purposes of this research, medium and low process temperatures are to be analyzed and therefore temperatures below 200C are the matter of interest. In this sense, PTC collectors that have been designed to fullfil low and medium industrial-heat requirements are to be considered in this study. This collectors make use of lighter and cheaper materials sacrificing the little efficiency - at low temperatures - for large price reductions. The reflectors are usually made of polished aluminium or a mixture between an acrilic base with a silver film, which makes them much lighter than the conventional mirror PTC collectors. As the collectors are lighter, the structure requirements are also lower and therefore the structure weight is lower as well. As a result, the entire collector is considerably lighter than the conventional one which with the tracking-power savings related to it.

For the case study to be performed in report 4, the *PT1* parabolic trough collectors of Abengoa IST (a U.S. subsidiary of the spanish company Abengoa Solar) will be used. The technical specifications for this collector, according to the manufacturer and a study performed by Sandia Labs [12], are given in the following table:

	Parameter	Value
Collector		
	Reflecting surface	Acrilic with silver film
	Aperture width	2.3 m
	Lenght	6.1 m
Receiver		
	receiver material	steel
	Coating	Selective blackened nickel
	Absorption	0,97
	Emittance (80 C)	0,18
	Outer diameter	50,8 mm
Efficiency		
	α_0 - optical efficiency	0,762
	α_1 - first order efficiency coeficient (W/m2 C)	0,2125
	α_2 - second order efficiency coeficient (W/m2 C)	0,001672
	β_0 - incidence angle modifier parameter	0,958
	β_1 - incidence angle modifier parameter	-0,298

Table 2.4: Technical specifications for the IST *PT1* parabolic trough collector [3] and [13].

2.2.6 Parabolic dish reflector (PDR)

The PDR technology concentrates solar radiation in a focus point, which makes it able to heat up to extremely high temperatures in this point. The technical characteristics of this technology are not suited to deliver large ammounts of heat to a circulating fluid at low or medium temperature. Therefore, this technology is discarted from further analysis for its possible aplications escapes the concerns of this study.

2.2.7 Heliostat field (HF)

The HF technology has been under research since the 1970's, which converts it in one the most more mature solar technologies existing in the market. The operation of this system is fairly simple to explain: there is a large field with a fixed central receiving tower in the middle, and a number of mirrors around it. These mirrors follow the sun throughout day in order to reflect its radiation in the collection area of the central receiver. The functioning of the collector can be seen in the following figure:

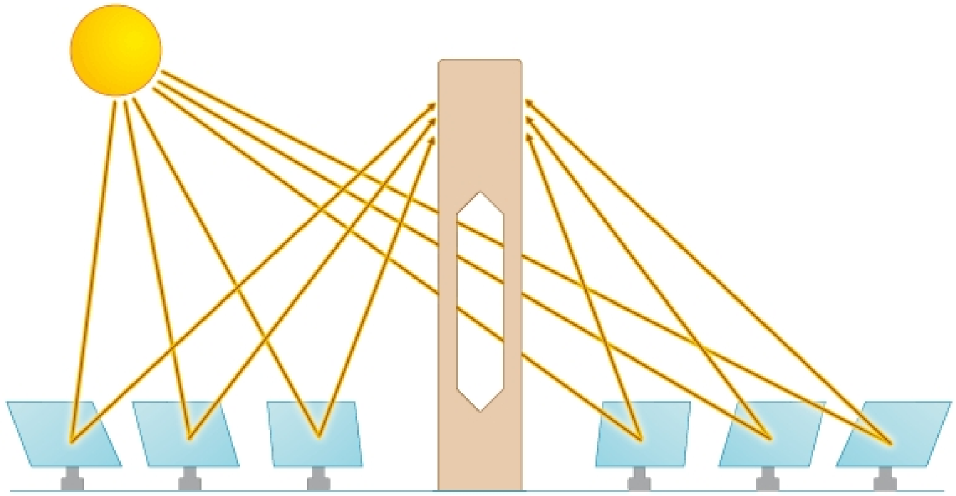

Figure 2.8: Heliostat field operation. (Source: Abengoa Solar [14].)

This technology has been considered as a very good alternative for electricity generation, due to the fact that the total cost asociated with the central receiver diminishes with the size of the project. In this sense, the heating requierements are usually too small for this technology to be competitive, even for the mining applications. Also, this technology can reach very high temperatures which is something particularly interesting for electricity generation, but not so much for low and medium temperature requirements.

This technology will be discarded for further analisys in mining solar heating applications, due to the fact that its costs and technical characteristics are not well suited for this purposes.

2.3 Installation Costs

The installations costs for medium-large size requirements are varied and, in many cases, confidential. However, it is possible to see in Table 2.5 the historical installations costs of parabolic trough solar systems. It is good to make a distinction among SEGS –which were installed to produce electricity– and the others plants, made for solar process heating.

Plant	Location	Year	Size [Sq. Mts.]	Cost [USD]	Cost per meter [USD/Sq. Mts.]
Inland Empire Foods*	Los Angeles, CA	1995	624	308,968	495
Adams County Detention Facility	Brighton, CO	1987	669	407,874	610
Barbers Point Naval Air*	Honolulu, HI	1995	1,338	791,174	591
Koch Materials Company*	Fontana, CA	1995	1,394	522,888	375
Federal Correctional Institution	Phoneix	1997	1,672	850,000	508
El Nasr	Egypt	2001	1,900	1,312,000	691
SEGS I	Mojave Desert, CA	1985	82,960	122,161,000	1,473
SEGS VI	Mojave Desert, CA	1989	188,000	201,046,000	1,069
SEGS II	Mojave Desert, CA	1986	190,338	182,692,000	960
SEGS VII	Mojave Desert, CA	1989	194,280	201,046,000	1,035
SEGS III	Mojave Desert, CA	1987	230,300	201,696,000	876
SEGS IV	Mojave Desert, CA	1987	230,300	208,979,000	907
SEGS V	Mojave Desert, CA	1988	250,500	223,349,000	892
SEGS VIII	Mojave Desert, CA	1990	464,340	382,023,000	823
SEGS IX	Mojave Desert, CA	1991	483,960	431,430,000	891

Table 2.5: Costs of parabolic trough solar plants.[15]

Doing that, it is easier to classify the costs per square meter for both small installations –process heat installations– and big installations –electricity installations. For the first ones, which are the types of installations more related to this study, the cost per square meter is within 375-691 USD, with an average of 545 USD per square meter. In the Figure 2.9 it is possible to see the trend of the small-size plants up to 3,000 square meters.

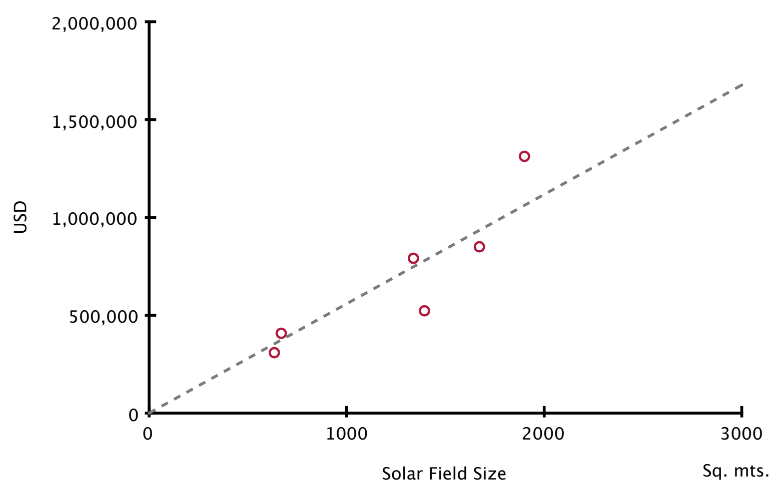

Figure 2.9: Historical installation costs for six projects using parabolic trough collectors. All the costs are in 2007 USD exchange rate.

For the Evacuated Tube Collectors (ETC), prices are known for small-scale installations. Two good examples of such installations are known:

- Galvanic Industry, Germany 851 USD/m2 (100 $m2$).

- Social Security Administration's Mid-Atlantic Center in Philadelphia, USA 1611 USD/m^2 (36 m^2).

For the second project, the installed cost of the system was approximately 58,000 USD. Of this total, 50% was related to engineering and installation labor; 43% was related to solar arrays and their mounting racks; and the remaining 7% represented plumbing supplies, pumps, data logger, and controller costs. [16]

2.4 Operation and Maintenance

The operation and maintenance of a parabolic trough power plant is very similar to the steam power plant, the main difference is the cleaning of the solar field.

An installation of parabolic trough collectors, whose objective is not the generation of electricity, but the production of industrial heat, just has operation and maintenance costs associated with the solar field. Initially, these plants required an important number of mechanics, welders and electricians in order to keep this technology, still immature. In these days, this type of concentrators requires a small preventive maintenance, with the exception of the process of cleaning the mirrors.

The experience has shown that mirrors of the solar field should be washed frequently during the summer. That is justified by the rise of efficiency during the months having the best radiation levels. Solar installations with this type of collectors perform a weekly mirrors cleaning during the sunniest months, but during winter the frequency is lowered to once-a-month cleaning of mirrors.

Figure 2.10: A mirror washing system example (known as Mr. Twister).[17]

The mirror washing is performed with a system that sprays demineralized water at high pressure over the mirror surface. This system, known as Mr. Twister (Figure 2.10), has sprayers that spin as they move down while washing the mirrors. The tractor is a Ford Model 4430 specialty vehicle, characterized by its small frame and high horsepower to pull the 25,000-pound water/pump unit. The tank holds 1,500 gallons of demineralized water, which is delivered by a positive displacement General pump John Deere 150-hp diesel engine. The pump can supply up to 45 gallons per minute at a pressure of 3,500 psi.[17]

The other method, known as deluge washing, uses a large capacity water truck driven by a single driver and employs fixed nozzles on each side of the truck to spray the rows of mirrors simultaneously with a deluge-type stream of water.

Water

The sources of water are demineralizing systems at each plant. To speed up the mirror-washing process, a nursing tank truck containing 4,000 gallons of demineralized water is filled and driven to the location of the Mr. Twister.

LS-2 SCA high-pressure spray method uses approximately 0.19 gallons per square meter of aperture area (0.72 liters per square meter).

Note that the high-pressure spray cleaning is done on a three-week cycle with two weekly deluge washes in between. This aggressive washing processes takes place only during the summer on-peak period.[18]

Personnel

The solar field is characterized by thousands of individual parts in modular solar collector assemblies. The management of O&M requires good tracking tools and a dedicated staff.

In the nominal staffing scenario, management and supervision is focused on the solar field maintenance organization, and skilled personnel are assigned to conduct expedient maintenance and mirror washing. The primary responsibility of field operators is to monitor, in a considerably detailed way, the condition and repair needs in the solar field.

It is very difficult to generalize the requirements in developing economies, where typically, productivity and salaries are lower and the staff assigned to tasks can be considerably larger. According to what we've learned, the required staffing level for a 500,000 m^2 solar field is the following.

	Nominal #	**Reduced #**	**Level**
Solar Field Manager	1	0	Senior
Maintenance Supervisor	1	1	Skilled
Welder	1	1	Skilled
Mech. Tech.	2	1	Exper'd
I&E Tech.	1	1	Skilled
Lead Mirror Wash Supervisor	1	1	Skilled
Equip. Opers.	4	2	Exper'd
Field Operator	5	3	Exper'd

Table 2.6: Staffing in Developed Economies.[18]

	Nominal #	**Reduced #**	**Level**
Solar Field Manager	1	0	Senior
Maintenance Supervisor	1	1	Skilled
Welder	2	1	Skilled
Mech. Tech.	4	2	Exper'd
I&E Tech.	2	1	Skilled
Lead Mirror Wash Supervisor	1	1	Skilled
Equip. Opers.	6	3	Exper'd
Field Operator	10	5	Exper'd

Table 2.7: Staffing in Developing Economies.[18]

Since the projects assessed on this report are considerably smaller (basically below 15,000 m^2), the staffing level above mentioned is going to be taken only as a reference. However, the best information is that with one person driving and controlling the rig, it takes only three nights to fully wash the solar field of a 30-MW plant. Taking into account that information it is possible to considerate that an installation of less than 10-MW –the range of the possible installations assessed on this research– should be washed in one night or less than that.[18] Thus, a considerably smaller plant, such as a heating installation plant, could be washed in a matter of hours.

Costs

For solar heating plants, O&M costs are related to the use of water and personnel. Since water is not plentiful in desert environments, it can be seen as an expensive commodity. However, the costs of cleaning with water are cheaper than the costs of buying fossil fuels to heat water.

The best source of information available about Operation and Maintenance in solar plants is the one related to the Kramer Junction power park located in Boron, California. The available report describes the results of a six-year, 6.3 million USD project to reduce O&M costs.

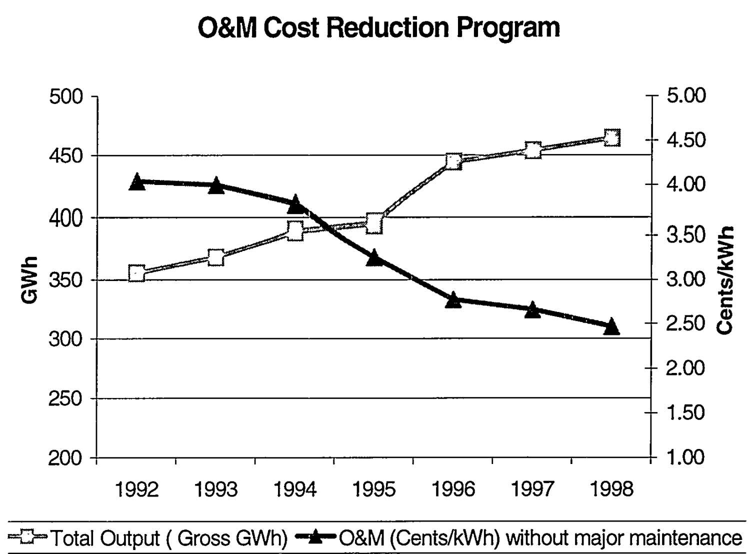

Table 2.8: O&M costs and electrical output at Kramer Junction from 1992 to 1998.[18]

Over the course of the O&MIP, the total O&M costs at Kramer Junction were reduced significantly, and the overall plant output increased dramatically. Figure 2.8 illustrates a 37% reduction in annual O&M costs and a 31% increase in annual gross electrical output. Costs include on-site and contractor labor, spare parts, and consumables for the entire site, but exclude natural gas purchases. Thus, it its possible to take into account this example for plants that do not generate electricity, but industrial process-heat.

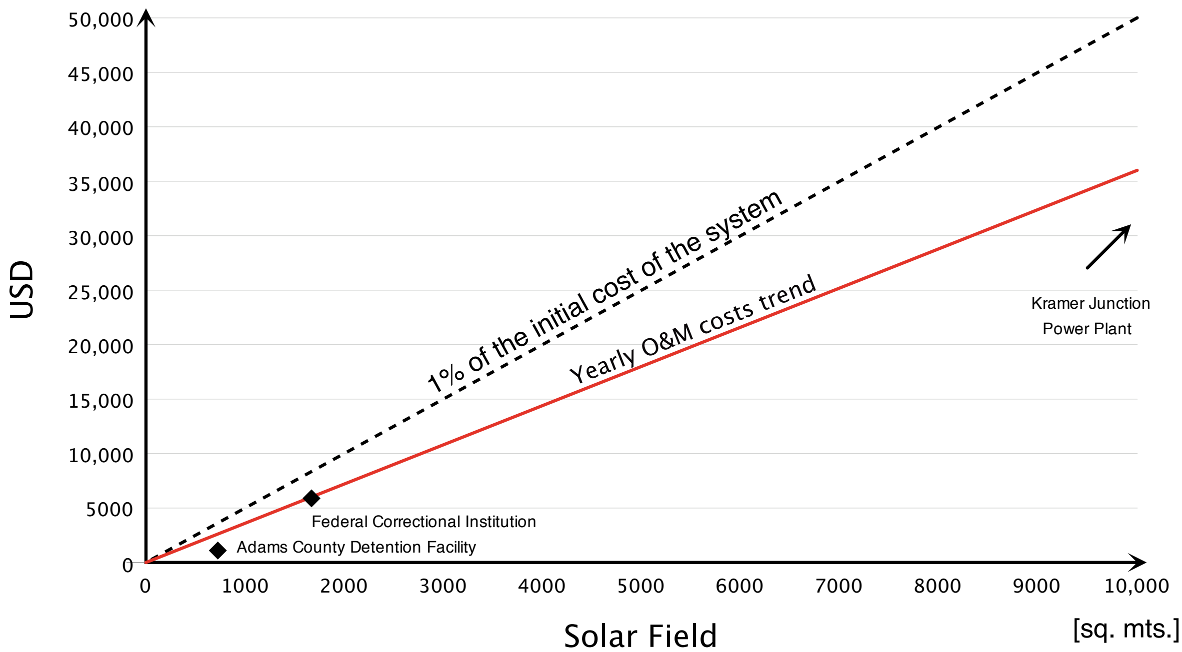

Figure 2.11: Estimated costs of O&M for different plant sizes.[18]

Normally, a 2% of the initial costs of the system is taken as a reference for the yearly O&M costs. However, taking into account the O&M costs for installations like the Adams County Detention Facility, the Federal Correctional Institution and the value showed in the study for the Kramer Junction Power Plant, is possible to establish a trend line. As shown in the above figure, the yearly O&M costs that the trend line indicates are even lower than the 1% of the initial cost of the solar installation.[18]

Chapter 3

Mining Industry

3.1 Copper Industry

3.1.1 Mine Production

The copper ore extraction has become a very important activity relating to the APEC economies, due to the large participation some APEC members have in the total mine production. The following table shows the World copper mine production and the main copper producers by economy.

Economy	**Mine Production [x 103 metric tonnes]**
Chile	5,361
United States	1,220
Peru	1,049
Australia	859
China	844
Indonesia	816
Russian Fed.	675
Canada	607
Zambia	509
Polonia	497
Kazakhstan	434
Mexico	338
Total	**15,008**

Table 3.1: World Copper Mine Production, Year 2006.[19]

An important data can be obtained from the previous table: The first 8 largest mine producers of copper in the world belongs to the APEC economies. This is just a proof of how important are the

APEC economies in the international copper production scenery. The real importance of the APEC copper production in an international analysis can be seen in the next figure:

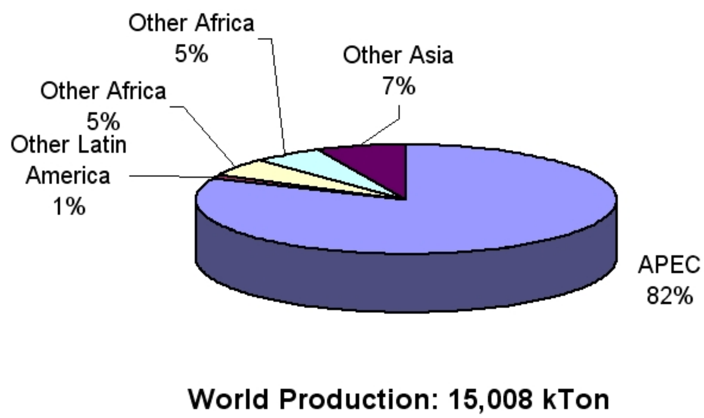

Figure 3.1: Geographical Copper Mine Production, Year 2006.

3.1.2 Refined Copper

The world production of refined copper reached 20.6 million tones by 2006, with China as the leader in production with over 3 million tones and Chile as the main exporter with 2.6 million tones.

Before the first half of the 90's, most of the refined copper was obtained by electrolytic refining. However, the last decade has seen the commercial explosion of SX-EW obtained refined copper, produced by leaching ores. This production accounted for over 16% of the total refined copper production for 2006, where the electrolytic refining represented an 80.5% of the total. The next figure shows the evolution in the copper refining industry from 1980 to 2006.

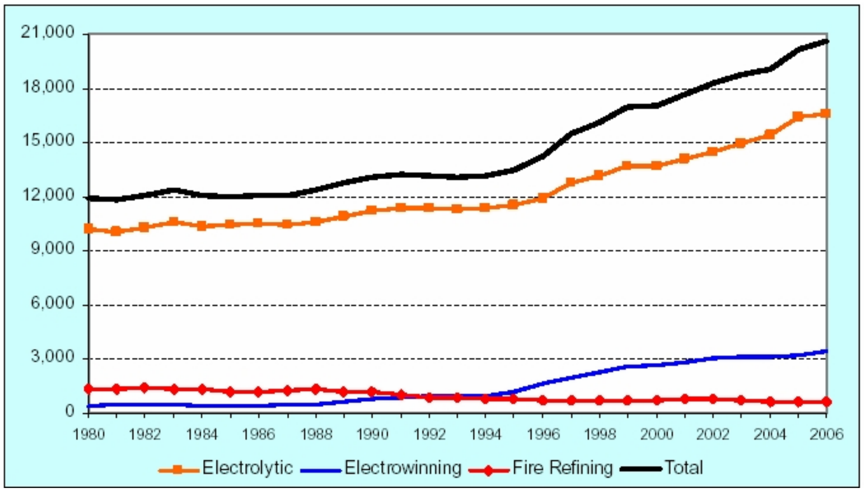

Figure 3.2: World Refined Copper Production [Thousand metric tonnes], Year 2006.[19]

3.1.3 SX-EW Refined copper production

As commented before, in 2006 the SX-EW cathodes production reached a 16% of the total refined copper production, with over 2.7 million metric tones. The SX-EW cathodes production by economy can be seen in the following table:

Economy	**Production**
Chile	1,636.3
United States	584
Peru	167
Zambia	82.6
Mexico	76
Australia	60
Congo	42
Myanmar	31.8
Iran	12
China	5
Mongolia	2.3
Cyprus	1.2
Total	**2,700.2**

Table 3.2: World Copper SX-EW Producction Year 2004 [Thousand metric tonnes].[20]

As the previous table shows that Chile's production accounts for over the 60% of the world SX-EW cathodes production and the APEC economies combined for over a 93%. Chile has been the leader in the development of the ore-leaching market, where this technology represents the 60% of its total refined copper production.

According to Chilean Copper Commission (Cochilco), the total SX-EW copper production for 2005 in Chile was 1,585 thousand metric tones. This production was carried out by both state and private investors, which are listed below with its SX-EW copper productions.

Company	**Production (Tons per year)**
Angloamerican	156.0
Antofagasta Minerals	145.0
Aur Resources	104.0
Barrick	121.0
BHP Billiton	235.0
Codelco Chile	448.0
Doa Ins de Collahuasi	61.0
Phelps Dodge	211.0
Xstrata	63.0
Others	92.3
Total	**1,585**

Table 3.3: Main investors in SX-EW copper production in Chile.[21]

3.1.4 Copper Production Capacity Evolution

Based on the last edition of 'Directory of Copper Mines and Plants', by the ICSG, the production capacities for 2006 are:

Metric Tones	**2006**	**2011**	**% change**
SX_EW	3,330	5,387	61.80%
Concentrates	13,641	16,607	21.70%
Mines Total	16,971	21,994	29.60%
Smelters	16,294	18,785	15.30%
Electrolytic Refineries	16,506	19,026	15.30%
Refineries Total	20,630	25,164	22%

Table 3.4: Evolution in Copper Production Capacity, Period 2006-2011.[22]

Based on this estimation, the copper mine production capacity will grow at an average rate of 5.3%. It is interesting to point out that the annual average growing rate of the SX-EW production is estimated to be around 10%, much higher than the mining activity growing rate.

3.2 Potentials for Solar Thermal Applications in the Copper Industry

The mining industry is well known for being an energy-intensive industry, where a large part of its fuel consumption is related to the generation of heat for different production processes. Due to the state of art of the commercial solar heat technologies and the scope of this work, only low temperature applications will be considered in this study.

The most suitable applications for solar heat in the copper mining industry are explained below.

3.2.1 Hydrometallurgy

As commented above, the production of refined cathodes from hydrometallurgical processing of ores, ie recovered by leaching (LX) and followed by Solvent Extraction (SX) and Electrowinning (EW), accounts for over 16% of the total refined copper production. Also, studies previously presented predicts a high growing rate in the production capacity for this technology, reaching 21.4% of the total refined production capacity by 2011.

Several potentials for low temperature heat requirements can be found along the hydrometallurgical production chain, which will be explained below.

3.2.2 Leaching

Several ways exists for leaching copper ores, most of them are exploited by heap leaching, but there are several cases where older (as dump leaching) and newer techniques (like agitation leaching) are been used. In short, the process consists in dissolving Cu from minerals into an aqueous solution (water and sulfuric acid solution). In heap leaching, the solution (called raffinate) trickles over a 'heap' of mineral for an extended period of time, dissolving Cu in the solution. This copper-loaded solution is known as pregnant solution (PLS) and it is sent to SX for the next step of the process. A simple drawing of the process can be seen in the following figure.

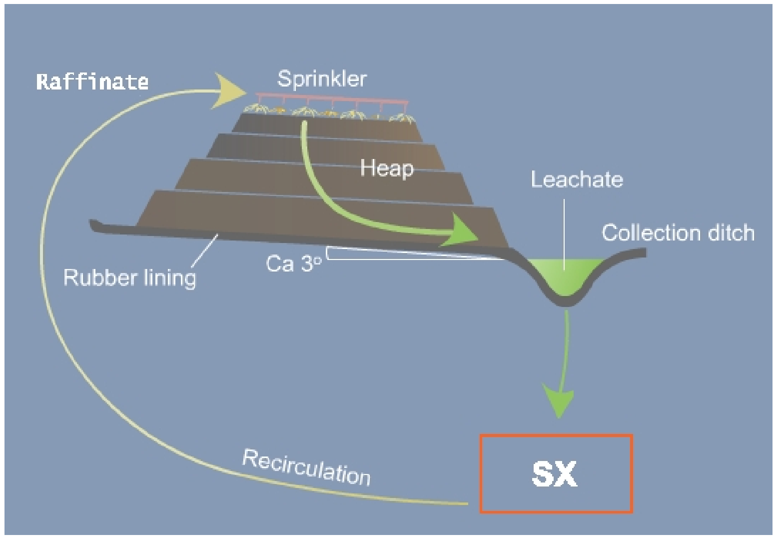

Figure 3.3: Heap Leaching Process.[23]

In copper ores several kind of minerals containing copper can be found. In general, these minerals are classified in 2 groups: copper oxides and copper sulfides. Both of them are commonly found in the same copper ores, where the oxides correspond to the layer closer to the surface and primary while secondary sulfurs are found in deeper soil layers.

In copper oxide ores, it has been proved that no external heat requirements are needed. This way, there are not special heat requirements that need to be satisfied by an external source. How ever, sulfide copper leaching requires bacteria that act as a catalyst speeding up the chemical reaction. These bacteria are present in the leach heaps naturally and appropriate conditions for its optimum action needs to be satisfied (mainly PH, oxygen and temperature conditions).

Most of the minerals are leached with the action of mesophylic microorganisms that operate between 5 to 40°C, with an optimum of 30°C [24]. These conditions are usually obtained with no external heating, mainly by the action of exothermic Fe++ oxidation reactions. However, climatic conditions may reduce the overall temperature and therefore external heating may be needed for reaching the optimum temperature. This heating requirement represents a real possibility for solar process heat generation.

Domic [25], reports two practical examples of this heating requirements. In the *Quebrada Blanca* mine (4,000 m.a.s.l.), due to low environmental temperatures, special concern has been taken to keep the leach operation as warm as possible (18-25°C). However, operational experience has shown that an increment in the temperature in 6-7°C would decrease the leaching required time from 500 to 300-360. A similar case is reported in the *Collahuasi* SX-EW operation (4,300 m.a.s.l.), where no heat is added to the raffinate solutions used in leaching, and therefore bacterial activity is very slow.

Besides heap leaching and similar atmospheric conditions leaching processes (as dump leaching), there are another leaching processes with solar heating potentials. One of them is the BioCOP(TM) Process, implemented by BHP-Billiton and Codelco at *Mansa* Mina, in the north of Chile. This process requires temperatures higher than the ones required by conventional leaching, and takes place in a stirred reactor. Moderately thermophilic and thermophilic microorganisms operates between 60 - 90°C.

3.2.3 Electrowinning

The required duty in the heat exchanger was calculated considering the approximation made in the publicacion of D.J. Durkhardt [26]. The plant configuration used was the one showed in the Figure 3.4.

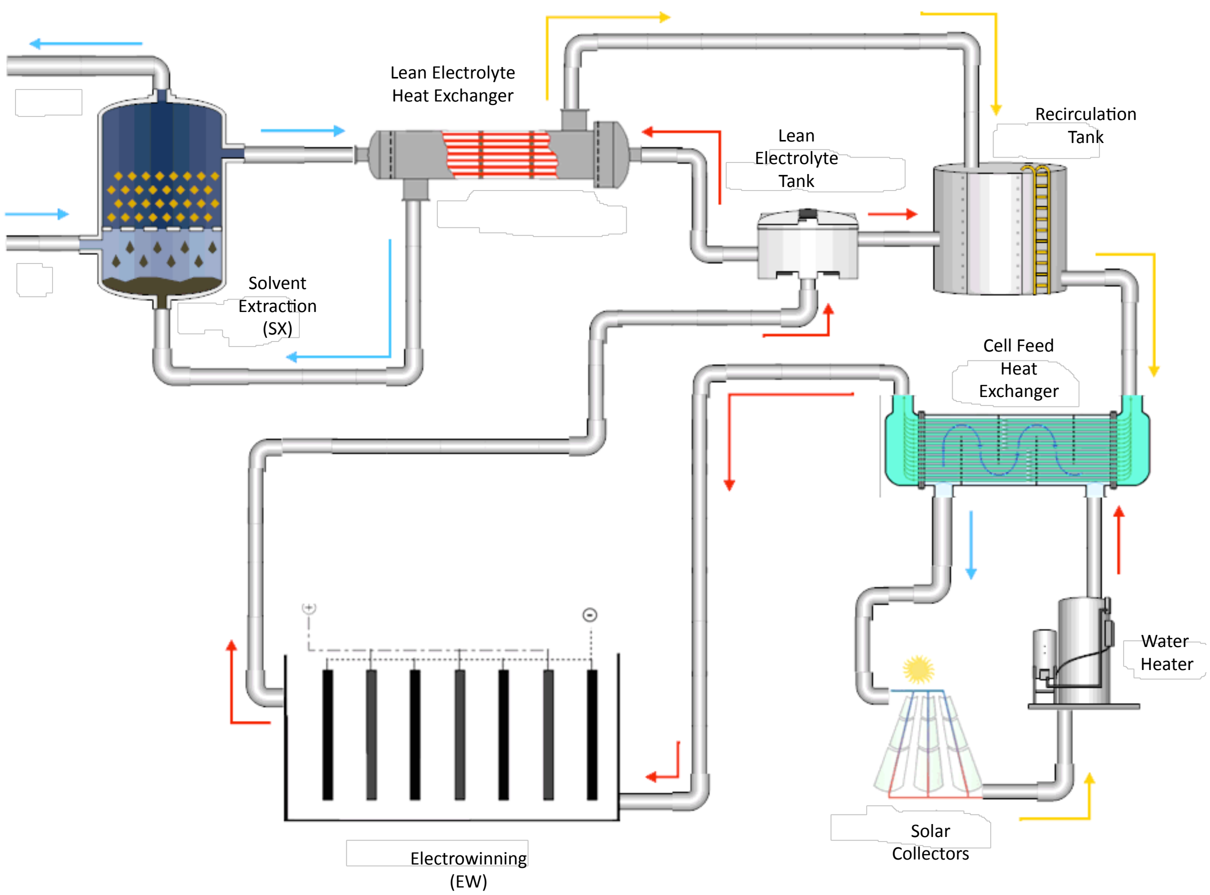

Figure 3.4: Electrowinning Plant Diagram.

Due to the fact that duty is proportional to the number of cells in the plant, it is possible to estimate the required duty for one cell, taking into account the configuration of the SX/EW plant. Large differences in the values appear when adding strip settlers at the end of the SX process. The difference of adding wash settlers is insignificant.

The heat duty considered per cell was:

- 2 Extractors and 1 Strip Settler (2E x 1S) : 20.37 kW
- 2 Extractors and 2 Strip Settlers (2E x 2S) : 61.94 kW

Knowing this values, it is possible to estimate the heating requirement for a SX/EW plant with a specified configuration. The Table 3.5 shows the heat duty requirement for each of the most important Chilean hydrometallurgical SX/EW plants.

Nº	Mine	Production	Configuration	Number of Cells	Heat Duty
		ton/year			MW
1	Codelco Norte Hidro Norte (Ex RT)	305,000	A-B-C: 2E x 1S x 1W. Train D: 2E x 2S x 1W	1,000	30.8
2	El Abra	225,000	2E x 1W x 1S	680	13.9
3	Escondida	150,000	2E x 1W x 1S	480	9.8
4	Codelco Norte Hidro Sur Óxidos	126,000	Train A: 2E x 2S Train B: 2E x 1S	786	32.3
5	Zaldivar	125,000	2E x 1W x 1S	368	7.5
6	Cerro Colorado	100,000	2E x 1S	420	8.6
7	Quebrada Blanca	79,000	2E x 1S	264	5.4
8	El Tesoro	75,000	2E x 1W x 2S	284	17.6
9	Michilla	64,200	2E x 1W x 2S	208	12.9
10	Mantoverde	62,000	2E x 1W x 2S	168	10.4
11	Lomas Bayas	60,000	2E x 1W x 2S	180	11.1
12	Mantos Blancos	60,000	2E x 1W x 2S	164	10.2
13	Collahuasi	50,000	2E x 2S x 1W	188	3.8
14	Codelco Norte Hidro Sur Sulfuros (Ex Mina Sur)	22,516	2E x 1S	94	1.9

Table 3.5: SX/EW plants in Chile.

As showed in the Table 3.5, just considering chilean hydrometallurgical SX/EW plants, the heat requirement is of about 176.1 MW. Normally, these plants operate almost all the year long, 24/7. Considering a 95% of operation per year (347 days), the estimated energy consumption for the Chilean EW plants should be about 1,466,560 MW-h per year. Now, taking into account the Low Heat Value (LHV) of diesel oil equal to 10,523.98 kwh/m^3 and an efficiency of 64% for heater-pipes-exchanger, the yearly consumption of diesel oil is about 217,740 m^3.

3.2.4 Electrorefining

The estimation method for this process was simpler than considering a complex heat balance from a scientific paper due to the fact that the temperature in both sides of the heat exchanger is known (inlet and outlet), it is possible to use the equation:

$$\dot{Q} = \dot{m} \cdot c_p \cdot (T_{out} - T_{in}) \tag{3.1}$$

For an electrolytic solution $c_p = 0.83\ J/kgF$ and $\rho = 225\ kg/m^3$. The average flow rate per cell is $q = 0.02 = 0.00033\ m^3/s$. The referenced temperatures are $T_{out} = 140$ F and $T_{in} = 104$ F. Replacing these values into the equation, the heat requirement per cell is:

$$\dot{Q} = 27.5kW \tag{3.2}$$

It is important to notice that this value is the heat requirement of the electrolyte and it must be given by the heat exchanger. Nevertheless, heating equipment has associated a global efficiency converting the energy from oil to heat, this value should be considered as the minimal duty, supposing 100% of efficiency.

There is detailed information available for some of the most important ER plants in the world (Table 3.6).

Electrorefining Plant	Economy	Production	Number of cells
		kTon/year	
Caraiba Metais	Brazil	220	1,150
Union Miniere	Bulgaria	35	492
Norddeutsche Affineries	Germany	360	1,080
Gresik	Indonesia	220	654
Sumitomo	Japan	123	488
Palabora Mining	South Africa	90	960
Kennecott Utah Cu	Utah	280	1,400

Table 3.6: Main ER plants in the world.

There isn't detailed pieces of information about all the plants in the APEC economies, but from the Table (3.6) is possible to obtain the average number of cells for kTon/year. With this value and having the average yearly production (kTon/year), we estimated an approximation for the number of cells and then the Heat Requirement. As a result, for the 16 largest plants in the APEC economies is possible to project a possible scenario in which the power consumptions are at least in the range of 13.4-39.3 MW (Table 3.7).

Electrorefining Plant	Economy	Production	Number of cells	Heat Requirement
		kTon/year		MW
Amarillo	United States	450	1,430	39.3
Chuquicamata Refinery	Chile	443	1,415	38.9
El Paso	United States	415	1,357	37.3
Guixi	China	400	1,326	36.5
CCR Refinery (Montreal)	Canada	380	1,284	35.3
Pyshma Refinery	Russia	380	1,284	35.3
Las Ventanas	Chile	376	1,276	35.1
Toyo/Niihama (Besshi)	Japan	365	1,253	34.5
Ilo Copper Refinery	Peru	350	1,222	33.6
Jinchuan	China	350	1,222	33.6
Yunnan	China	350	1,222	33.6
Norilsk Refinery	Russia	330	1,180	32.5
Garfield	United States	300	1,118	30.8
La Caridad	Mexico	300	1,118	30.8
Kennecott Utah Cu Magna Utah	United States	280	1,400	38.5
Sumitomo Tokyo	Japan	123	488	13.4

Table 3.7: Main ER plants within the APEC economies.

As showed above, there is a high potential for solar thermal heating in the world copper electrorefining industry. For the plants considered in the Table 3.7, the total heating requirement is about of 539.3 MW. Considering the same operation parameters as for the EW plants, the total energy requirement is 4,491,290 MW-h per year. Transforming this into diesel, the yearly requirement is of about of 666,850 m^3.

3.3 Potentials for Solar Thermal Applications in Other Mining Industries

As explained in detail for the copper industry, many mining industries have a large fuel consumption for providing low-temperature process heat. Some mining industries with important process-heat requirements and real posibilities for the use of solar heat are explained below in detail.

3.3.1 Aluminum Refining: Solar Heating in the Bayer Process

The metallic element aluminum is the third most plentiful element in the earth's crust, comprising 8% of the planet's soil and rocks (oxygen and silicon make up 47% and 28%, respectively). In nature, aluminum is found only in chemical compounds with other elements such as sulphur, silicon, and oxygen. Pure, metallic aluminum can be economically produced only from aluminum oxide ore.

The world production of aluminum is showed in the following table:

Economy	1999	2000	2001	2002
Australia	1,718	1,769	1,797	1,836
Canada	2,390	2,373	2,583	2,709
Chinae	2,530	2,800	3,250	4,300
Japan	11	7	7	6
Mexico	63	61	52	39
New Zealand	327	328	322	335
Russia	3,146	3,245	3,300	3,347
United States	3,779	571	571	605

Table 3.8: Aluminum World Production by APEC members (kTons/year).[27]

Aluminum manufacturing is accomplished in two phases: the Bayer process of refining the bauxite ore to obtain aluminum oxide, and the Hall-Heroult process of smelting the aluminum oxide to release pure aluminum.

The Bayer process consists basically of four stages known as: digestion, clarification, precipitation and finally calcination.

First, the bauxite ore is mechanically crushed. Then, the crushed ore is mixed with caustic soda and processed in a grinding mill to produce a slurry (a watery suspension) containing very fine particles of ore.

The slurry is pumped into a digester and then heated to 230-520 F (110-270°C) under a pressure of 50 lb/in^2 (340 kPa). These conditions are maintained for a time ranging from thirty minutes to several hours [28]. This heat requirement is a potential for solar process heat. However, the required temperatures are in the upper limit of the suitable applications for solar heating.

3.3.2 Zinc: Solar Heating in the Electrowining Process

Zinc is a moderately reactive, blue gray metal that tarnishes in moist air and burns in air with a bright bluish-green flame, giving off fumes of zinc oxide. From 100°C to 210°C zinc metal is malleable and can be easily beaten into various shapes. This metal is the fourth most common in use.

Metallic zinc is used in the production of alloys and in galvanizing to protect steel structures. It is still present as a chemical additive in rubber and paints. Brass is one of the most important zinc alloys, and consists of a mixture of this element with copper. It is generally stronger and more ductile than copper. It has superior corrosion resistance and is widely used in water valves, hardware, instruments and communication equipment.

There are zinc mines throughout the world, with the largest producers being China, Australia and

Peru. In 2005, China produced almost twenty five percent (25%) of the global zinc output.

Economy	**2000**	**2001**	**2002**	**2003**
Australia	1,420,000	1,519,000	1,154,000	1,480,000
Canada	1,002,242	1,012,048	923,931	788,063
Chile	31,403	32,762	36,161	33,051
China	1,780,000	1,700,000	1,550,000	2,030,000
Japan	63,601	44,519	42,851	44,574
Mexico	392,791	428,828	446,104	472,000
Peru	910,303	1,056,629	1,221,830	1,372,790
Russia	136,000	124,000	130,000	159,000
United States	852,000	842,000	780,000	768,000

Table 3.9: Zinc World Production by APEC members (Tons/year).[30]

The main processes by which zinc is extracted from its ores can be categorized under pyro-metallurgical processes and hydro-metallurgical processes.

Presently about 15 - 20% of the world's zinc production comes from pyrometallurgical route. The horizontal and vertical retort processes and electrothermal processes were used in the past for zinc production but they have become obsolete due to high power consumption and low recovery. The only pyrometallurgical process of importance presently is Imperial Smelting Process (ISP).

About 80% of world's total zinc output is produced through conventional hydrometallurgical route i.e. Roast-Leach-Electrowin (RLE) route. This method is mainly used for rocks with high iron percentages. The process involves 3 steps: roast, leach and electrowinning.

The roasting process objective is to convert the zinc sulphide into oxide. The sulphur dioxide obtained from this process is converted into sulphuric acid. The zinc mineral, after roasting, is called calcine. Then, in the leaching process, the calcine is treated with a solution of sulphuric acid (180-190 g/l). In this operation temperatures of about 60°C are used during 1 to 3 hours. After the lixiviation there are still some external elements present in the solution, so it must be purified.

Once purified, the electrowinning process begins. This operation needs between 30-40°C and allows the deposition of zinc in the aluminum cathodes. The production of one cell with 86 cathodes of 1.6 m^2 could reach 3 Ton/day. The zinc obtained trough this method has a purity of 99.995%. It contains less than 50 ppm of impurities, being lead the most abundant.[31]

3.3.3 Gold: Solar Heating in the Electrorefining Process

Gold can be obtained either directly from ore in the mine or as a product from the electrolytic refining of other metals (as anodic mud, like in copper electro-refining).

One way of obtaining high purity gold is by hydrometallurgy, where gold is leached from the ore and eventually electrowon. In the leaching process, higher temperature in the leach solution allows a higher amount of oxygen diluted in it. This way, the leaching time can be shortened as it can be seen in the next picture.

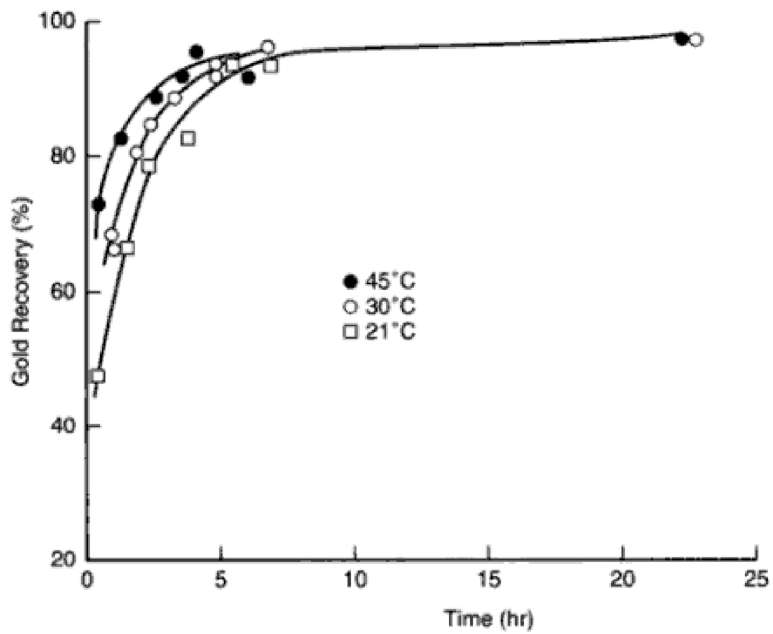

Figure 3.5: Gold recovery vs Leaching time.[32]

This fact should represent a great potential for solar process heat, however, the high cost associated with such a temperature increase can rarely be justified for the treatment of low grade materials, and therefore ambient temperatures are usually applied.

On the other hand, in the pyrometallurgical processing of gold, it is separated from most of its non-metallic impurities by smelting and from metallic impurities by chlorination. The last one consists in injecting chorine gas into the molten gold where most of the Silver and base metals presents in the solution will form chlorides which can be easily removed from the surface of the molten gold as slag.

This process represents a good opportunity for solar process heat because, as discussed before for other metals, impure anodes are electro-refined using an electrolyte where gold is soluble (as aqua regia). This electrolyte contains 80 to 100 g/L and it is heated up to approximately 60°C, for optimum gold recovery. Once again, electrolytic refining of gold represents a good potential for applying solar heat to satisfy the heat requirements of the process.

Gold production in the APEC economies represents a large part of the total world production. Apart from South Africa, all the main gold producers belong to the APEC economies. This can easily seen in the following chart for 2006:

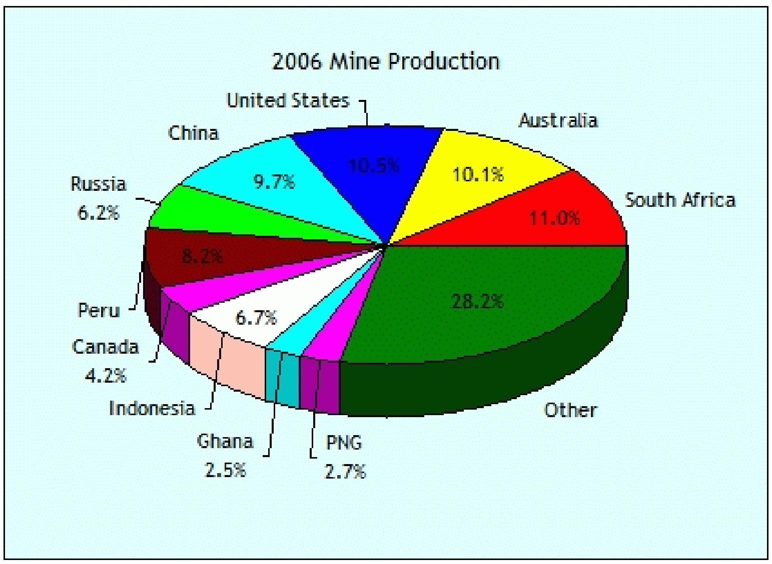

Figure 3.6: Gold mine production for 2006.[33]

It is important to remark that in 2007 China replaced South Africa as the world largest gold producer. South Africa had been the main gold producers for over than 100 years, and lost its position due to new Canadian and Australian-led projects in China.

3.3.4 Silver: Solar Heating in the Electrorefining Process

Silver ores are mined by open-pit and underground methods just like any of the metals explained before. However, silver extraction is always linked to the production of other metal present in larger proportion in the ore. These metals usually are the following: lead, copper and zinc. According to this, the silver recovery process depends basically on the processes applied to recover the major metal.

This way, depending on which of those three is the major metal, silver, gold and platinum-group metals are concentrate by flotation and smelting processes, or as slime from electrolitical refining of the major metal. These slimes or concentrates are treated under special conditions in order to eliminate most of the impurities, so anodes with over 95% silver are obtained.

Thus, these impure silver anodes are electrorefined using a silver nitrate electrolyte solution. As for most electro-refined metals, the electrolyte has to be heated up for optimal silver recovery performance. In this case, the electrolyte is heated up to around 35°C. This heat requirement represents a good potential for solar process heat, specially because silver productions are usually much smaller than those for metals like copper. In this sense, the flux of electrolyte to heat-up will be much smaller and therefore the total heat required could be small enough to be totally satisfied with a solar-heat system during the day in summer days. In the case of copper production, large electrorefining facilities might require over 7MW of heat, several times larger than the largest solar process-heat projects in the world.

As with other metals reviewed in this report, silver production is concentrated mostly in the APEC economies. The 5 top producers (APEC economies) and 8 from the top 10 were members of the APEC in 2006. These economies can be seen in the next table:

Ranking	Economy	Production [millions of ounces]
1	Peru	111,6
2	Mexico	96,4
3	China	75,4
4	Australia	55,6
5	Chile	51,5
6	Poland	40,4
7	Russia	39,6
8	United States	36,7
9	Canada	31,2
10	Kazakhstan	26,1

Table 3.10: Top 10 largest silver producers coutries in the world.[34]

Putting together the silver mine production from APEC members, its contribution to the world silver production was over 80% for 2006.

Saltpeter: Solar Application in the Heap Leaching Process

Known as 'Chile Saltpeter', a mixture between sodium nitrate and potassium nitrate, Saltpeter is a mineral which production has traditionally used solar energy as part of its production processes. This mineral is found in a larger mixture of minerals known as 'caliche' and its larger world deposit is located in the northern part of Chile. This mineral is used mostly for the production of fertilizer and industrial sodium and potassium nitrates.

One potential use for solar heat is related to the leaching process of caliche mineral. After crushing and grinding the ores, Potassium, sodium and lithium are extracted from caliche normally by heap leaching (similar to copper heap leaching) utilizing water as a lixiviant. As in the sulfur copper leaching process caliche leaching is strongly influenced by the temperature, and therefore lixiviant heating is required. The temperature of the process depends on the concentrations of each mineral contained in the caliche, however, temperatures from 48 to 60°C have been reported in the literature.

However, the real importance of the Chilean nitrate industry in this research is the utilization of solar energy in the production processes. Some of the mineral-rich obtaining solution from leaching is then sent to solar ponds where a large amount of water is evaporated and salts are crystallized. These salts are then subsequently taken to specialized plants where final products are produced. In the Salar de Atacama natural mineral rich brines can be found below the crystal salt surface. From this brines 141 million tons of nitrates, 77 thousand tons of iodine, 180 thousand tons of lithium, and 26 million tons of potassium are extracted by the Chilean private firm Soquimich (SQM), the world leader in the potassium nitrate with a 44% market share. These brines are pumped out and sent to the evaporation ponds directly, and therefore no previous leaching process is required.

Chapter 4

Barriers to Solar Energy

With the purpose of facilitating the identification of the barriers to the implementation of the solar thermal technology, it is convenient, first, to analyze how the interaction between the project and the investor works. In this scenario, it is possible to distinguish different factors that can be clasified in three different groups: those related to the project; the ones related to market factors and finally, the ones related to the investor.

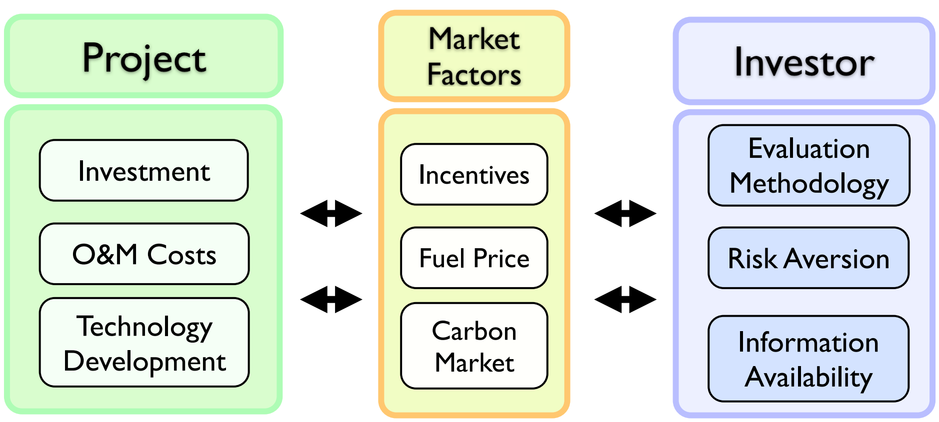

Figure 4.1: Project-Investor interaction scheme.

Each of items contained in these 3 categories is a factor that is may become either a barrier or an incentive to solar energy projects. Thit is the reason why it is relevant to analyze the state of the art of each one of these factors, and then focus on those which represent the most significant barriers. As it is showed in the figure 4.1, each group has some key factors that influence whether a project could be considered as technically and economically feasible or not. As an example, among the market factors —that neither depend on the project nor on the investor— there is one which is extremely important to consider when assessing a fossil fuel replacement project: the fuel price.

Operational costs related to fossil fuels have highly increased during the last 6 years because of the rise in crude oil prices, therefore when evaluating a solar energy project that replaces fuel, this high price can be seen as an incentive for migrating from traditional heating systems (fuel-based systems) to solar heating (alternative system).

The following chapter will analize in detail the factors related to the investor and the market, and their influence on investors when making final investment decisions.

4.1 Market Factors

4.1.1 Incentives

The cost structure of a conventional power generation system differs a lot from the structure that renewable systems possess. Most of the fossil combustion systems have —as a general rule— moderate or even low starting capital costs, but high O&M costs because of the fuel consumption. On the other hand, renewable energy technologies —like a solar thermal heating— do not normally have high O&M costs, but they need a larger initial amounts of investment than fossil technologies do. In Table 4.1 it is possible to see the costs of the SEGS plants at Kramer Junction in Nevada. The last —together with the evaluation method— many times difficult investors to consider alternatives technologies as feasible projects.

Unit	I	II	III	IV	V	VI	VII	VIII	IX
Capacity [MW]	13.8	30	30	30	30	30	30	80	80
Land Area [hectares]	29	67	80	80	87	66	68	162	169
Unit Cost [$/kW]	4,490	3,200	3,600	3,730	4,130	3,870	3,870	2,890	3,440
Total Cost [USDx1,000]	61,962	96,000	108,000	111,900	123,900	116,100	116,100	231,200	275,200

Table 4.1: Costs of SEGS plants at Kramer Junction.[35]

Many governments have justified the use of incentives for promoting their utilization as a consequence of the benefits that alternative technologies offer compared to traditional technologies. The main purpose of this section is to identify the existing incentive measures to the utilization of renewable resources, focusing on the solar thermal heating.

Tax Incentives

Tax incentives programs have been implemented to facilitate the purchase, installation or manufacture of equipments that generate energy from a renewable resource. The main goal of these programs is to lower the investment costs for acquiring and installing equipments. The incentive tools include: income, corporate, property and sales tax incentives. In some cases the incentives have expiration dates.

Corporate Tax Incentives

Corporate tax incentives allow corporations to receive credits or deductions ranging from 10% to 35% on the cost of equipment or installation to promote renewable energy equipment use. In some cases, the incentive decreases over time. For example, some States in the US allow the tax credit only if a corporation has invested a certain dollar amount in a given renewable energy project. In most cases, there is no maximum limit imposed on the amount of the deductible or credit.

Property Tax Incentives

State Property Tax Incentives are more frequently available than any other type of tax incentives for renewable energy. Property tax incentives typically follow one of three basic structures: exemptions, exclusions, and credits. Tax incentives range from straightforward local property exemptions for renewable energy systems, to special assessment of property with value-added by a renewable energy source. That is to say, if a renewable energy heating system costs USD 1,500 to install versus USD 1,000 for a conventional heating system, then the renewable energy system is assessed at USD 1,000.

The only clear example we have found –to depict the idea Property Tax Incentive– was in California State and says:

- California *Property Tax Exemption for Solar Systems.* [36]

  Eligible technologies are Solar Water Heating, Solar Space Heating, Solar Thermal Electric, Solar Thermal Process Heating, Photovoltaics and Solar Mechanical Energy. The amount of exemption is 100% of the system value.

Sales Tax Incentives

Sales tax incentives typically provide an exemption from the state sales tax for the cost of renewable energy equipment.

Grants

A renewable energy feasibility study is broadly defined as an analytical tool that assists in determining the technical and economic viability of a project that uses renewable energy resources to generate electricity, heat and/or to manufacture a fuel. Grants are intended to offset costs of performing a technical/economic analysis of a potential project, product and/or technology. Grants are not intended to offset costs of purchasing energy-generating equipment. Feasibility grants are normally provided by government agencies and the amounts of funding are generally limited. In some cases, not all the renewable energy projects are eligible for grants, it will depend on the type of organization applying for the grant.

Some examples of grants in the APEC economies are listed below.

- Chile *Preinvestment-Program in Non-conventional Renewable Technologies.[37]*
  It finances until 50% of the pre-feasibility study with a limit of USD 66,000. The organization shall not have incomes over USD 40 millions. The project should be implemented in the Regin Metropolitana.

- Oregon *Renewable Energy Feasibility Fund.[36]*
  For this grant, private companies are not eligible. The maximum grant amount awarded is USD 50,000.

Accelerated Depreciation

This process is a method by which a company depreciates a fixed asset in such a way that the amount of depreciation taken each year is higher during the first* years of an asset's life (*the number of years should be less than the numbers of years fixed by the project hosting APEC member). For tax purposes, this provides a way of deferring corporate income taxes by reducing taxable income in the current years, in exchange for increased taxable income in future ones.

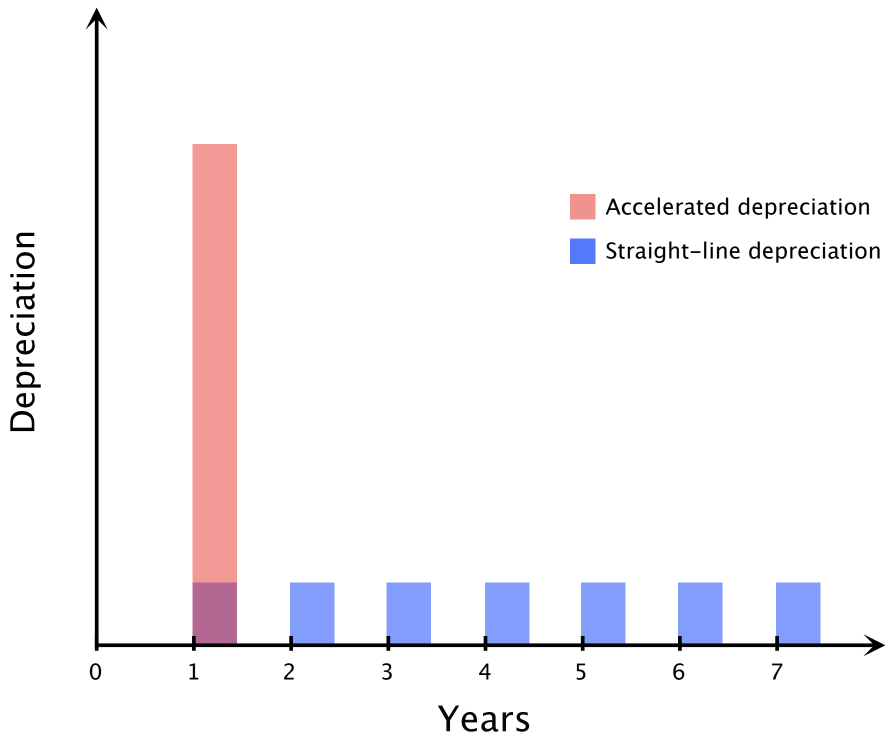

Figure 4.2: This diagram shows an example which considers 100% depreciation during the first year.

The accelerated depreciation can be seen as the government granting the company a loan for a limited period of time. For the company, the use of this method may reduce the need for external financing from other sources. This government loan may be less expensive than money from other lender and, which is the best, it would not require the approval of lenders, particularly when the company's business is risky.

Some APEC economies applying this incentive with eligibility for solar thermal applications are:

- Mexico: *Accelerated Depreciation for Environmental Investment*

Investors are allowed to deduct 100% of the investment after one year of operation. The equipment shall operate for at least five years, following the tax deduction declaration; otherwise, complementary declarations are obligatory. [36]

- USA: *Modified Accelerated Cost-Recovery System (MACRS) + Bonus Depreciation*

  The MACRS establishes a set of class lives for various types of property, ranging from 3 to 50 years, over which the property may be depreciated. For solar, wind and geothermal property placed in service after 1986, the current MACRS property class is five years. The federal Economic Stimulus Act of 2008, enacted in February 2008, included a 50% bonus depreciation provision for eligible renewable-energy systems acquired and placed in service in 2008.[38]

- Canada: *Income Tax Act - Accelerated Capital Cost Allowance* [36]

Effects: case study

The government of India has taken several initiatives for the promotion of solar energy technologies in during the last two decades. A variety of policy measures have been adopted which include provision of financial and fiscal incentives to the potential users of solar energy technologies. B. Chandrasekar et. al. [48] have analyzed the effect of financial and fiscal incentives on the effective capital cost of solar energy technologies to the user.

The incentives considered were:

- Capital subsidy (CS)
- Low interest loan (LIL)
- 100% depreciation income tax benefits (AD)
- Capital gain investment related to income tax benefits (CGI)

A variety of combinations of the above mentioned existing and/or proposed incentives are practically feasible. The amount of investment required by the users availing such benefits is expected to affect the dissemination of solar energy systems to a large extent. Thus, the efficacy of financial and fiscal incentives can also be valued in terms to their role in reducing the effective capital cost to the user.

As an example, they considered the effects of incentives over the cost of an Industrial solar water heating system.

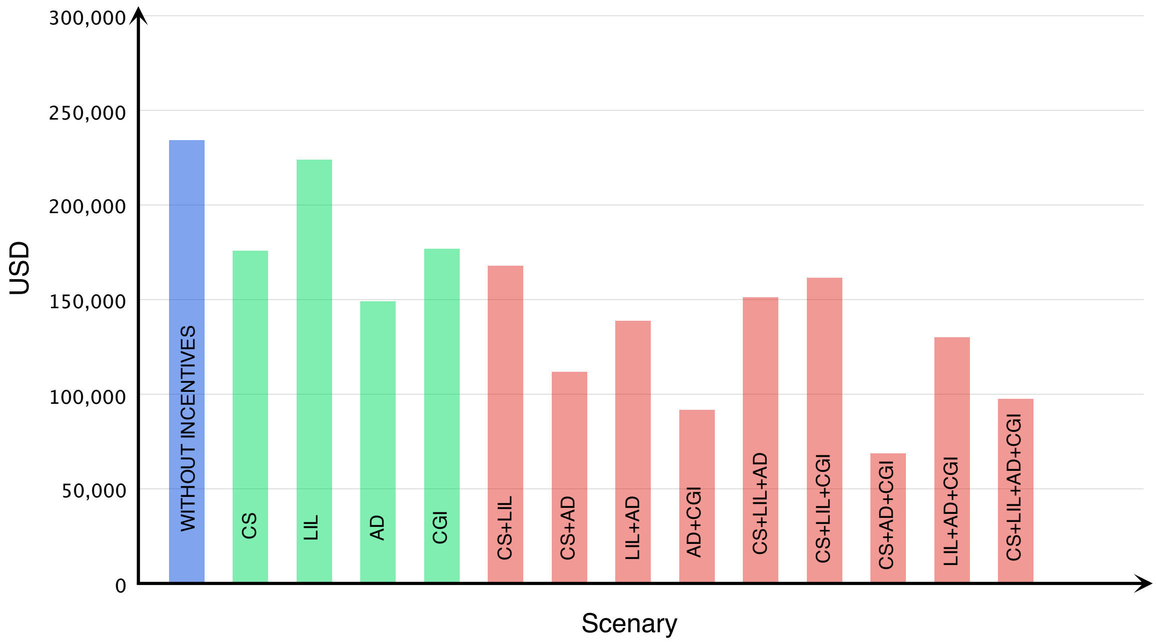

Figure 4.3: Effective capital cost of an Industrial solar water heating system availing financial and/or fiscal incentives.

In Figure 4.3, we show the effects of different combinations of incentives over the cost of the solar water-heating system. The green columns represent the cost of the system after applying a single incentive. The red columns represent the cost of the system after applying a combination of to or more incentives.

As a single incentive, the Accelerated Depreciation could be considered as the most effective one in reducing the cost of the equipment. In the same group, the Low Interest Loan is the least effective. In terms of combining incentives, the Accelerated Depreciation + CGI seems to be the most effective one when using a combination of two. In the third group, when using a combination of three, CS+AD+CGI provides the lowest cost to the investor.

The provision of income tax benefit on the amount of investment made by the user on the purchase and installation of renewable energy system is probably more attractive than the provision of low interest loan. Potential users belonging to the high income and upper-middle income categories could also be motivated by or through the provision of accelerated depreciation.

4.1.2 Fuel Price

Oil Price

There are several different types of crude-oil used as price reference for this commodity and with West Texas Intermediate (WTI), Brent and Dubai crude-oil as the most important ones. Within the APEC economies, WTI is used as benchmark in oil-price in the United States of America and as a reference for fuel-pricing in several APEC economies. In Asia, the most widely used ones are Dubai and Tapis crude-oil. WTI will be used as a reference in this study wherever crude-oil prices are mentioned.

WTI is traded in the New York Mercantile Exchange (NYMEX), with a high API gravity (light) and low sulfur content (sweet). The quality of this fuel is superior to Brent and therefore, its cost is usually USD 1 to USD 2 higher per barrel. The following graph shows the official WTI price evolution from 1990 until today [44]:

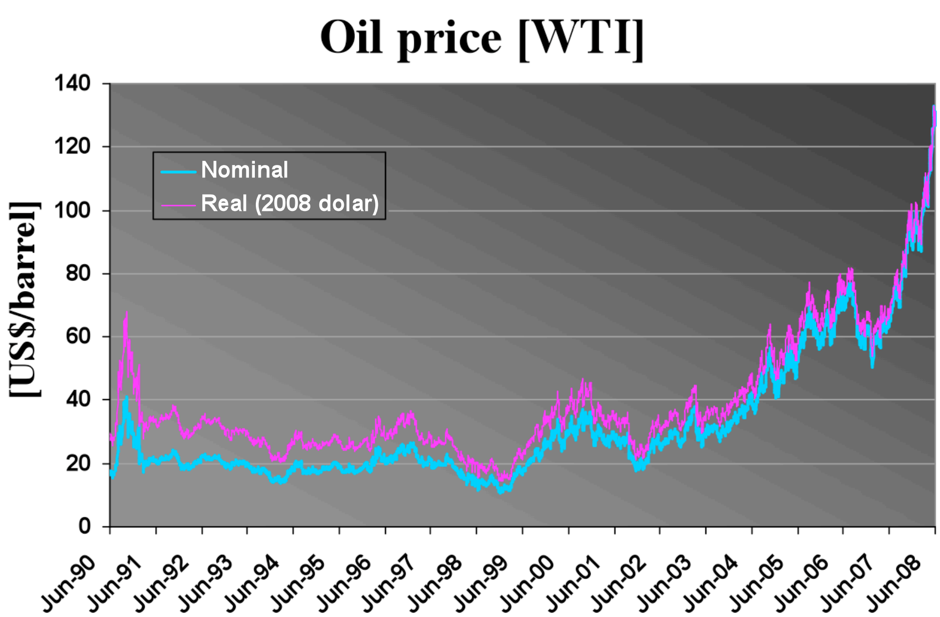

Figure 4.4: WTI price evolution over the last 2 decades.

The blue line represents the official WTI spot price [44] during the last 2 decades, and the purple line the WTI price calculated as 2008-dollar-price using the United States Consumer Price Index for All Urban Consumers (CPI-U) [45].

Now, it is out of question that the current oil prices are the highest in the last 2 decades, reaching a peak spot price of USD 147/barrel in June 2008. At present, there are different opinions about the real reasons why the oil price has increased 100% its price from June 2007 to June 2008. Poor intentions to increase oil-production on the side OPEC despite the fact that China and India have increased their demand, is the main reason why the large-quantity buyers like the US argue. OPEC cartel members claim that this is because of higher production costs due to oil reserve depletion, higher future prices due to oil speculators and the dollar devaluation, as the main causes.

The real reason might be a combination of all the above-mentioned factors, the truth is that the oil-prices have been rising constantly since 2003. Most of the analysts agree on the fact that even if fuel prices could fall from the current price, cheap-oil is part of the past and the market price of this commodity should continue increasing in the mid term.

Fuel-oil price in APEC economies

The mining industry requires large amounts of fuel to fulfill their process-heat requirements. In order to reduce their fuel costs, mining companies buy heating equipment that can work on cheapest types of fuel, as fuel oil n 6. This fuel is basically what is left of the crude after all the distillation phases have been completed, and it is also known as 'Heavy fuel oil' for its high viscosity and long carbon chain.

As a petroleum by-product, the Fuel-oil price has increased significantly in the last years. This is a major concern in the mining industry, especially in places where natural gas can not be obtained. The following graph shows the residual fuel-oil-180 spot price for 3 different locations.

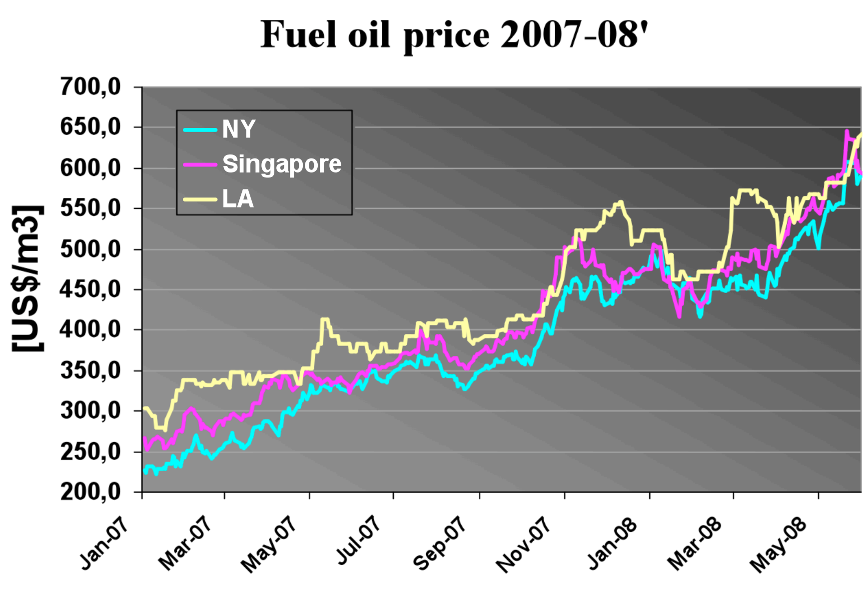

Figure 4.5: WTI price evolution over the last 2 decades.

The price of the replaced fossil fuel is critical for the economical evaluation of any solar-heat production alternatives. The prices shown in the figure 4.5 will be used as a reference for fuel-oil prices in the economical evaluation for the sake of this project, adding the taxes, shipping and other costs related to with the locations selected for the solar field simulations.

As an example of the influence of fuel prices in solar economics, a real solar installation that uses parabolic trough collectors was analyzed. This plant was installed in the Adam county detention facility, Colorado, in 1987 to provide heat to the existent hot water system. This plant was one of the first parabolic trough fields installed for heating purposes and therefore its costs where significatly higher than it is now. Now, the detailed cash flow for the operation of this plant is public [50], and therefore different natural gas price scenarios can be analyzed.

The average natural gas price paid by the industry [51] in May 2008 was be taken to 1987 dollars using the Consumer Price Index for All Urban Consumers (CPI-U)[45]. Then, the cash flow was re-calculated with this new NG price assuming the same inflation assumptions that were made at the moment of the project implementation. The following table shows these assumptions and the influence of the fuel price in the payback of the project:

Item	**Value**
Cost of NG 2008 [US$/MM BTU]	12,10
Adjusted cost of NG 1987 [1] [US$/MM BTU]	6,35
Original cost of NG 1987 [US$/MM BTU]	3,76
Energy requirement to be met by solar [MMBTU]	2000
Annual inflation	2,5%
Starting O&M cost [US$/year]	600
Starting insurance cost [US$/year]	600
Original payback [year]	**17**
Adjusted payback [year]	**10**

Table 4.2: [1] Cost of NG in 2008 brought to 1987 dollars using the CPI-U.

Even if the installation costs for parabolic trough heating where really high in 1987, if we apply the Natural Gas prices the industry is paying today the payback period would have decreased from 17 to only 10 years. This influence will be considered for the economical analysis of the simulated plant in report 4.

4.2 Investor-Related Factors

4.2.1 Project Assessment

There are many ways to assess a project, and which of these methods is chosen, will depend on the evaluator's criteria. Each one represents a different point of view when assessing the economic feasibility of a project. It could even happen that the interpretation of different indicators could be contradictory from the point of view of the investor.

The most widely used methods of assessing a project are the following:

- **Simple Rate of Return (SRR)**

  The SRR is a commonly used criterion of project evaluation. It basically expresses the average net profits (Net Cash Flows) generated each year by an investment as a percentage of investment over the investment's expected life. The calculated SRR should be compared to the investor's Required Rate of Return (RRR) to judge the profitability of the investment.[47]

- **Payback Period (PBP)**

  Payback Period refers to the period required for the return on an investment to repay the original investment amount. The acceptability of the investment is determined by comparing it to the investor's required payback period (RPP). The payback period is considered a method of analysis with serious limitations and qualifications for its use because it does not properly account for the time value of money, risk, financing or other important considerations such as the opportunity cost. It is not an acceptable criterion taken alone. In general, tht PBP and the NPV criteria will never agree with each other. However, it may serve a its purpose usefully as a supplementary consideration. [47]

- **Benefit Cost Ratio (BCR)**

  A BCR is the ratio of the benefits of a project or proposal, expressed in monetary terms, related to its costs, also expressed in monetary terms. All benefits and costs should be expressed in discounted present values. This method is often used, but is not necessarily a good factor for decision-making. This method will probably reject projects with a long gestation period. A project may be selected because it has the shortest pay-off period, but it may provide a smaller return on investment than another project with a longer pay-off period. [47]

- **Net Present Value (NPV)**

  Net Present Value is computed by finding the difference between the present worth of benefit stream less the present worth of cost stream. Or it is simply the present worth of the cash flow stream since it is a discounted cash flow measure of project worth along with internal rate of return.

The biggest disadvantage to the calculation of NPV is its sensitivity to discount rates. After all, NPV computations are really just a summation of multiple discounted cash flows converted into present value terms for the same pint in time (usually when the cash flows begin). A small increase or decrease in the discount rate will have a considerable effect on the final output. www.investopedia.com

- **Internal Rate of Return (IRR)**

  Internal Rate of Return (IRR) is that discount rate which just makes the net present value (NVP) of the cash flow equal to zero. It is considered to be the most useful measure of project worth and it is used by almost all the institutions including World Bank in the economic and financial analysis of the project. It represents the average earning power of the money used in the project over the project life. It is also sometimes called yield of the investment.[47]

Solar Projects

Non-conventional renewable energy projects are characterized by having a high initial investment cost, so the chosen investor's criteria to make his decision could make the difference between being an attractive project or not being an attractive project.

A study carried out by the National Renewable Energy Laboratory [46] investigated 15 "highly promising" projects involving process-heat solar systems, projects for which the technical and economic feasibility was assessed but it resulted in the project not being implemented. All 15 proposed projects were to be installed in existing facilities, with existing fossil energy system to be reconfigured to serve as the backup sub-system for the solar one. The projects were technically feasible and compatible with the operations at the facilities.

Potential User	Solar System Installed-Cost	Required Payback	Project Payback Results
Saginaw Steering Gear	130,000	3	4.4
Eastman Kodak Company	62,000	3	5.2
Koch Materials Company	378,000	7	12
Maui Economic Development Board	822,000	10	20
Barbers Point Naval Air Station	572,000	10	20

Table 4.3: Examples of projects that did not meet the required economic performance criteria.[46]

The primary reason for the proposed solar projects not to be implemented was that they didn't meet their principal capital equipment investment criterion —simple payback period (Table 4.3). The projects did not meet their investment criteria for three major reasons:

- High capital costs of solar systems
- Availability of cheap fuel or natural gas
- Demands for a very short payback period (3 years or less)

Of these three reasons, only one has the potential to be influenced by the industry or government incentives —the high capital cost of solar equipment.

4.2.2 Risk Aversion

Risk aversion is a concept in economics, finance, and psychology related to the behaviour of consumers and investors under uncertainty. Risk aversion is the reluctance of a person to accept a bargain with an uncertain payoff rather than another bargain with a more certain, but possibly lower, expected payoff.

The risk aversion is a very important issue when an investor has the plan of remodeling a process, and it is directly related to the development of the new technology. As an example, a mining investor is an expert on all the equipment/technology typically used in mining or refining for many years, but he is not necessarily used to the implementation of alternative technologies. His aversion to **take the 'risk'** of installing a solar heating system could be also related to more real-world problems, such as the failure of the system. If that happens and no backup system is available, the electrolyte will be below the required temperature to perform the process, therefore, the copper production will decrease and all the piping system could be affected with the appearance of copper incrustations.

In order to lower the aversion of the investor –that seems to be justified– it is necessary to show or give him/her proofs that: 1) the technology is developed and already in the market, and 2) the possibilities of failure are really low . For the first one, the information availability plays a key role, since that is the way the investor is going to 'learn' about the new technology, so that the investor analyzes the possibilities of implementing it afterwards. The second issue is more specific, but it also has an explanation: heating systems in mining plants are already installed and, as a consequence, a solar heating system could be seen as an extra piece of the plant whose main objective is to reduce the fossil fuel consumption. From that point of view, the installation of the new equipment doesn't imply the 'destruction' of the old one, therefore, the fossil fuel system –which has a 100% of reliability for the investor– appears as a backup of the solar system.

4.2.3 Information Availability

One of the biggest barriers that industrial solar energy has to deal with is the lack of information on technologies and theirs costs. Several APEC members have governmental or private associations that promote solar energy for heating up water for domestic purposes with great results. However, in the industrial context, these efforts have been less strong and less effective with little or inexistent governmental information campaigns for solar energy use in most of the APEC economies. In this context, it seems to be important to show a couple of important efforts that are being implemented among the APEC economies.

United States

Solar development in the US has been crucial in the last 30 years. The Californian State grants –for solar-generated electricity in the 1980's– allowed the construction of 9 large solar electricity-generation plants where the technology could be tested in a commercial scale. This was a huge step for solar energy development, for which the technology was for the first time physically available for a commercial purpose. After more than 30 years since the construction of the first plant, the plants are still there delivering power to the Californian electric grid and showing their reliability to any new investor interested in solar technology. Things have changed from those times until today: several states offer grants, tax incentives and research support for solar heating and electricity projects. There are several private and state organizations which make big efforts in promoting solar energy showing that both, environmental and economical savings could be achieved. One very remarkable case is the Energy Savings Performance Contracting (ESPC), a method for financing Federal facilities renewable energy projects, and that has allowed the installation of several solar fields for large hot-water requirements. In this sense, this kind of contract allows the quick technical and economical evaluation of parabolic trough installations for Federal facilities, and it offers a payment mechanism in which the federal institution pays less money for energy than it did before and also makes it cost-effective for the field contractor. The federal government has been performing this kind of contract with parabolic trough technology for over 10 years, which has also represented a very good platform for showing this technology for large heat requirements. The result is highly positive: the industry is much more informed about commercial solar systems and manufacturers have installed several solar fields not only for state facilities, but also for large industrial-process heat requirements. The market is growing faster and faster because of the larger amount of information the industry has about the costs, manufacturers, reliability of the systems and the time required for installing plants. At the moment, large facilities are been built like the 5,065 m2 solar field for Frito-lays (a division of Pepsi Co.) in California, the largest solar field for process-heat production purposes in the world.

SolarPaces

SolarPaces is an international cooperative organization created by the International Energy Agency (IEA) to coordinate experts on the developing and marketing of solar power and heating systems. In the context of this program, a particular task called Solar Heat for Industrial Processes (SHIP) was created concerning the promotion and research on the use of solar heat by the industry. SolarPaces coordinates public and private organizations, and it has currently 13 members, from which 4 are APEC member economies: Australia, Mexico, Republic of Korea and the United States. This organization has mainly 4 subtasks:

- Solar Process Heat Survey and Dissemination of Task Results
- Investigation of Industrial Energy Systems
- Development of Collectors and Components
- System Integration and Demonstration

In this sense, important international efforts are being coordinated among the SolarPaces members to promote the use and to improve the performance of solar heating in industrial activities.

4.3 Investment-Related Factors

4.3.1 Main Actors in Solar Energy Projects and Their Interaction

These three major actors involved in the financial stage of a solar energy project are: private investors and financial market, goverments and last but not least international organizations. Each one of them has its own role and interests in the developement of a solar energy project.

Private investors and financial market provide resources (financial and non-finacial) to carry out the project and they are interested in making their investment profitable.

Besides, governments provides game rules defining tax and laws concerning the energy markets and designing incentives and obligations to promote renewable technologies. However, government decisions concerning renewable energy policies is going to depend on social and economics issues strictly related to each economy, mainly, its level of development, position in the energy global market and knowledge and information about state of art of renewable technologies and possible applications in its region.

At last, international agencies are interested in promoting energy solutions which provide a long-term sustainable development. Nowadays, there is a major concern about lowering GHG emissions and they are making great efforts in R&D and promoting renewable technologies around the world. Organizations like APEC, World Bank, Global Environment Facility, etc. are taking these issues to a global context offering grants, financing studies, sponsoring projects, etc.

The materialization of solar energy projects and, in general, of any non-development renewal energy, will depend on how the three actors are coordinated to allow one another reach their own goals. International agencies should be responsible for promoting the long-term development of renewable technologies, including solar energy, creating, for each specific stage of the evolution of technology, incentives and promotion policies suitable for both governments and private investors. Likewise, Governments must create incentives that make it attractive for investors to risk their capital in developing such projects creating tax and financial mechanisms contributing to minimize the risk of the operation and/or supporting or sponsoring specific projects as well as promoting them. Lastly, the private sector is the actor that should execute the projects, ensuring their construction and operation during the life cycle expected, trying to make their investment a profitable one.

It is essential to generate trustful relationships to ensure to all players that the conditions agreed will be maintained over the time, in fact, this point is central in achieving success in the development of renewable technologies. The creation of mechanisms to achieve such trust is one of the biggest issues that should be developed at the political level.

For the particular case of solar energy, a study sponsored by the World Bank was proposed as the most promising non-developed renewable technology in the field of electricity generation [52]. It is expected that by 2025 there is a competitive market for the generation of it through solar energy, just like the wind technology in the past. It is the duty of international organizations to help both governments and private sectors see this fact. In this sense, agencies like the World Bank and GEF are sponsoring the first solar power plants, then California's plants, and are committed to disseminating this kind of technology in the world.

The main resources of solar energy in the world are in the solar belt, a region between the tropics and which many APEC economies belong to, that is i.e. Chile, Peru, Australia, Mexico, China, etc. In many of these economies, they are increasingly becoming more aware of the great hazard posed by global warming and efforts are being made to decrease it, particularly through the promotion of non conventional renewable energy technologies.

However, many of these are developing economies and there exist barriers created by their budgetary constraints, lack of financial resources and credit which make the subsidiary role of these states –in large solar energy projects– be something unlikely. In addition, these economies have cultural reluctance to not adopt technologies which have not been proved in the developed world, where these technologies R&D have been made. This issue must be addressed in a coordinated way in instances where multilateral and international agencies must play a major role.

Moreover, the APEC economies located in the solar belt have significant natural resources which are operated by large transnational corporations, which would be very interested in to developing energy projects that could add value to their operations. Thus, leading global objectives must be set to create channels for effective coordination between the public and private sectors, which will allow the execution and the profitability of such projects.

4.3.2 Investment and Financing of Solar Energy Projects

For all kind of projects the bottleneck for carrying them out them is to get investors who could evaluate them as financially attractive. This evaluation does not only depend on technical aspects, but also, on the project financial structure mainly it depends mainly: it is important consider whether the project is capital intensive or not, or if a grant or low-interest rate financing is available for the specific technology and application, or if preferential taxes are applied on the investment and/or production in the host economy, the owner's financial position, etc. These factors will have a significant effect on the evaluation's conclusions because they cause considerable changes in the cash flow during the life-cycle of the project.

Unlike a conventional power plant or energy supplier (like conventional fuel-gas steam generators) which depends on fuel that is purchased continuously during the life cycle of the plant, a solar power plant or a solar energy supplier needs to finance generation costs through capital investment at the beginning of the project. Usually, loans will have to be contracted to build the plant and interests will have to be paid during its operation. Financial costs for a solar project could be strongly increased because of the high interest rate of the loans contracted; in fact, this continuous payment item is expected to be the highest one, and along with the taxes payment, it represents the main part or component of the continuous clash-flow.

Interest rates depend strongly on the lender's perception of risk about the project and its variation may involve dramatic changes in financial decisions concerning large solar thermal projects. The main indicator considered by the lender to grant a loan is the income-producing property's ability to generate enough revenue to cover its continuous mortgage payments. So, the lender's risk perception could be severely affected by project's characteristics like ownership, financing structure, tax policies, government incentives, etc. , then, in order to make the project as financially robust as possible, these characteristics should be carefully studied in the early stages of the project.

Source of Capital

As it has been said before, a great capital investment should be made at the beginning of a solar energy project, which will depends on project's size. A key question to answer in this point is how to get the funds required to carry out the project.

Commonly, three have been the ways to finance a renewable energy project: equity, debt and grant financing. Equity must be provided by an independet(s) investor(s) who acquires the ownership of a project. A debt investment is a loan from a financial institution, which must be paid during the project's life-cycle. Additionally, some national and international organizations have offered grants in order to help the development of renewable energy projects and, specifically, solar-based energy projects, like the one discussed in our latest report (number 2). Grants help to pay-down the non-economic portion of the project, and they help to pay attention to for global positive externalities, which otherwise would not be condidered.

Financing and Ownership Structures

Acoording to Kistner and Price, [53] there are two main financing and ownership structures for power facilities:

- Corporate finance.
- Project Finance.

Corporate finance is developed with investor-owned utility ownership. This structure allows companies to have financial advantages that can help companies to make the project more profitable. On the one hand, it is possible to leave aside a partial offset of the specific project risk to the utility/corporate portfolio, using the overall credit rating of the company. Furthermore, thanks to the assets of the corporation as collateral (including the utility), it is possible to obtain a better financial position in the market. The result is lower interest rates, increased debt amortization periods, and less restrictive loan covenants, called debt service coverage ratios (DSCR), debt leverage and, therefore, it is expected a greater profitability of the project.

In the case of thermal applications of solar energy, it is possible to operate in this scheme, in the sense that large corporations can internally develop such projects for their own heat consumption. Specifically, mining industries along the deserts of APEC economies may be attracted to make use of the structure of corporate financing.

However, every investor wants that each of his projects be profitable, especially if the project is capital-intensive. Under this logic, appears project financing structure. In this scheme, investment is financed through a mix of debt, equity, credit enhancement. Lenders assess the cash flow expected for the project and approve the credit depending on it, taken as collateral own facilities financed. This ensures that the project is financially attractive and self-sustained.

This structure might be useful in the context of outsourcing steam service (heat contracts), in which a contractor must provide the service at a reasonable price, in this case, it is crucial that the project is considered as self-financed. The contractor can get extra benefits if they have enough know-how in managing technology and providing service to a wide customer base in the same area, thus generating economies of scale and achieving improved financial ratings of its portfolio [54].

Additional Topics in Project Financing

In the long term, solar energy projects must aim to be self-financed and profitable for investors. Currently, there is great difficulty to use project financing for solar energy applications: the high risk that operations involve, which, of course, discourages investors. That is why it takes great deal of efforts to reverse this situation. One of them is to make possible the use of all the financial techniques that allow the investor to lower the risk of the operation. The following paragraphs discuss two of the most relevant methodologies developed in the financial world to achieve this goal.

The first technique under discussion will be the 'non recourse financing'. In this scheme, the lender has rights only over the assets and profits generated by the project but not on other borrower's assets , even if they do not cover the total loan total debt. This is a way of sharing the risk between the lender and the borrower. However, because of the high risk of the operation, the lender must have a high degree of technical knowledge and a great know-how in financial modeling to estimate more precisely the project's cash-flow. These restrictions limit the use of this technique in low-skilled financial markets, like those of developing economies.

The second technique for improving the project financing scheme is to invest through an off-balance sheet methodology. Basically, a company that wants to use off-balance sheet creates an independent entity with which, thanks to generally accepted accounting principles (GAAP) and tax laws, can finance the new venture, transferring the risk to the new company. In this scheme, the parent company protects its credit ratings and at the same time is non recourse to its other assets.

This methodology can be helpful for those investors who wish to enter into a new and risky business and do not wish to have their balance sheet affected. Besides, to avoid all risk deal, the parent company may be associated with a partner in creating the new venture, so, the parent company owns only a portion of the subsidiary company, while another investor(s) has the remaining portion. Generally, this mechanism is used when the partner wishes to take the risk of developing the new project and he has enough kow-how to do so.

This structure creates a coordination channel with a win-win situation for both sides, the parent company benefits from carrying out the project without risking the value nor increasing its debt burden, while his business partner will probably receive a larger slice of the incomes than he would have expected as a contractor.

This mechanism is usually used when a company wants to make a high-risk operation in the same area or if they want to enter into another business area.

This scheme can be potentially beneficial in the case of mining, manufacturing and processes industries; because these companies have no special expertise in energy and it would be beneficial to make a joint-venture with companies that have such expertise.

Influence of Tax Structure

As mentioned above, in the energy industry there is a wide range of very dissimilar technologies, regarding the use of capital and expenses. This situation creates distortions in the market competitiveness of technologies that offer similar services, because they finally receive a different tax treatment during their life-cycle, because of differences in the structures of their cash flows and property.

Most of the renewable generation technologies, such as solar, wind, geothermal, have to make an intensive use of capital at the beginning of the project. This investment is avoided by the competing fossil plants, but at the expense of future fuel cost. The implications of this difference for taxation are at the root of the unequal tax burdens among projects. Packey (1993) has shown that a major source of the excess tax load carried by capital-intensive technologies arises from property and sales taxes.

From an economic standpoint, an efficient market for competing commodities is one that is perfectly competitive and has no production or consumption externalities (inputs and outputs which lie outside the market pricing). A problem arises when a set of revenue generating taxes is introduced into this ideal world. Taxes can cause distortions in the efficient allocation of resources.

In order to achieve greater efficiency and competitiveness in the competing market of commodities, it is desirable that the distribution of production is not conducted on the basis of tax loads but on other components that affect the service price. That is why it is reasonable to search principles to guide the creation of tax policies that do not affect competitiveness in the competing market commodities, particularly in the energy market.

In the case of power generation; Jenkins, Chapman and Reilly [55] proposed three types of tax neutrality issues that must be addressed before we can achieve a greater market competitiveness. The first two types relate to the possibility of deferring which will affect the relative total tax loads, while the third type concerns the distribution of tax revenue that will have different goverment's levels.

The first two types of tax neutrality issues proposed by Jenkins, Chapman and Reilly [55] are:

- **Type I:** The relative tax loads carried by two plants having/using different technologies which compete to provide the same electric services.
- **Type II:** The relative tax loads carried by the current and advanced versions of two plants having/using the same technology which compete to provide the same electric services.

The third issue gained relevance when tax policies that distorted the coustomary revenues distribution across goverment was applied in California, which, of course, was against injured's interests and set grounds for conflict. The third issue is:

- **Type III:** The relative distribution and amounts of tax revenues received by local, state and federal governments (where applicable) produced by taxation of two plants having/using different technologies which compete to provide the same electric services.

These three issues addressed are applicable not only to the power industry, but they can be extended to other energy applications. The resolution of these issues would help the investor to achieve greater competitiveness among the different technologies and would contribute to their sustained development over time. These issues, with greater or lesser degree depending on each particular the case, should delineate the debate on tax policies that the APEC economies must consider to have competitive energy markets from the standpoint of tax neutrality.

Jenkins, Chapman and Reilly [55] conducted a study comparing tax burdens on four renewable power generation plants in California, USA. They found that the tax burden to plants based on renewable energies at least doubled the tax burden applied to a similar gas-fired plant, even more, the taxes applied to a solar receiver central reach six times more than the taxes applied to a gas-fired plant, when preferential tax to renewable technologies was not condidered.

Besides, they found that the applied tax law gap in 1994 was shortened and did not exceed 2.2 times the applied one to gas-fired plant for all cases. This shows that the implementation of regulatory laws creates conditions that enhance the competitiveness of the market.

However, in many economies with great potential for the development of solar energy, there are no differential taxation policies, as it's the case in Chile. Probably, this will be a great disincentive to investment for this type of technology, if governments don't develop policies that enhance competitiveness in their energy markets.

Chapter 5

Proposals for the Development of the Solar Heating Market

There is a false confidence that renewable energies will be available when they are required to play larger role in our energy matrix. Unfortunately, this view underestimates the fact that every new technology requires space and adequate ground if is to survive and grow strong.

Solar heating technologies do not escape this statement, as they require a tax structure that is both stable in time, and equitable with all energy technologies, especially compared to fossil fuels technologies. Furthermore, the transition to new renewable energy sources can only be made on the base of a stable regulatory environment that encourages investment while eliminating political uncertainties.

Several proposals to both provide more equitable market conditions for solar technologies and to speed-up the development of the solar thermal market are explained further on in this report.

5.1 Publicly Available Radiation Data

Information is always a key requirement when defining policies to develop new markets or technologies. Regarding the use of Solar Energy as a source to supply heat or electricity, good solar radiation data is a key piece of information that should not be underestimated.

Good-quality solar radiation data is absolutely necessary to know the real solar potential of any particular location, and therefore it is essential to select the right technology for that kind of solar resource. Furthermore, the access to solar radiation data is required in order to estimate the performance of the selected solar-energy technology, in both small-scale and industrial-scale.

As an example of the importance of the radiation resource for technology selection, two of the largest solar heating applications in the world will be analyzed. Firstly, what is, currently the largest existing solar-heating plant in the world,located in Marstal, Denmark. The weather in this particular location is characterized by cloudy days and the constant presence of rain throughout the year. As a result, solar technologies that can maintain reasonable performance when working with high diffuse solar radiation rates are required. In this case, the existent 18,300 m^2 of solar collectors were built using flat-plate technology which were proved to offer sufficient performance -for the required range of Temperature- at a low price.

Secondly, the largest industrial solar-heating facility within the USA, located at the SunChips factory in Modesto, California. The climate at this location is characterized by clear skies, high solar radiation and the absence of rain during most of the year. In this context, low-cost concentrating technologies usually are the most cost-effective solution for solar heating. As a result, most of the heat requirements of the factory are fulfilled by 5,300 m2 of parabolic trough collectors (PT). If the weather was as it is in Denmark, a concentration technology such as PT collectors would not be able to operate most of the year, as these kinds of technologies are highly sensitive to the presence of clouds.

This is a clear example of how solar radiation can be a major deciding factor when selecting solar technologies and the lack of good information in this case can lead to non-optimal solutions. For all those reasons, solar radiation data is extremely important for the development of national solar markets, as it provides an important tool for both solar project evaluation and research on local applications for solar energy.

In this sense, national policies should be developed in order to create a public and reliable solar radiation data base. A good example about this can be found at the National Renewable Energy Labs (NREL), USA, with public and high-quality measurements all over the different states. A very good source of solar radiation information can be found at the World Radiation Data Centre (WRDC), in St. Petersburg, Russia. This centre is sponsored by the World Meteorological Organization (WMO) and it contains a large amount of radiation data for many locations worldwide.

On the other hand, there is a need for more ground-based radiation data in several APEC economies, particularly in some Asian economies and Latin America. In some APEC economies, such as Chile, there are only global solar radiation measurements and to access to them is quite complicated even if most of these measurements are performed by public entities.

It is highly recommended that the APEC economies develop policies in order to create these public radiation data bases, by coordinating the already existing information and promoting the creation of new measurement facilities. In regions with high solar radiation, and therefore regions where concentration technologies could be highly competitive, direct normal irradiation (DNI) should be measured in order to provide good information for the technical and economical assessment of these technologies, especially in regions where most of the days are clear-sky days. Therefore, among the APEC economies, good DNI measurements are particularly important for APEC economies as Australia, Chile, Peru and the USA.

5.2 Appropriate Tax Structure

The tax load has been identified as a factor that strongly determines the competitiveness of a capital-intensive technology when it directly competes with an expense-intensive technology. In this sense, several authors have stated that solar technologies are developing within a tax system designed for fossil-fuel technologies (expense-intensive). In this context, the nature of solar energy technologies leads to a higher tax-load for solar projects compared to its fossil fuel equivalents, when calculating the expected life-cycle tax-load taken to present value.

Jenkins & Reilly have stated that there is nothing in the theory of equal tax that would allow unequal tax loads between competing solar and fossil fuels technologies, and therefore an equitable tax system should be a neutral to all technologies. In this sense, if we ignore the fact that there are significant environmental benefits from solar energy technologies that should be incorporated into the market, the different APEC economies should at least level the playing field so that solar energy technologies can compete in equal conditions. There are two factors that should be considered when designing policies to overcome this tax inequality.

Present Value of the Life-cycle Tax Load

Due to the fact that solar energy technologies are capital-intensive, a large part of its tax load is paid at the moment of investment and construction of the solar field and a smaller fraction is paid throughout its life cycle. In contrast, fossil fuels are expense-intensive, and therefore only a small fraction of its tax load is paid on investment and the rest is distributed through its life cycle. As a result, when taking the life-cycle tax-load to present value, solar technologies normally face much higher tax loads than fossil fuel technologies.

It is therefore necessary to build differentiated tax loads for solar technologies, designed in a way that does not represent a disadvantage for solar technologies in comparison to conventional fossil-fuels technologies.

Types of Taxes applying to solar technologies

In addition to the high tax load paid at the beginning of every solar project, these technologies usually incur taxes that fossil fuel technologies do not. A clear example of this is the fact that fuels do not pay property taxes. On the other hand, solar fields actually represent a physical infrastructure property, which is likely to be taxed. This tax can represent a heavy load for solar technologies, as competing fossil fuel technologies would have a much lighter load regarding property tax.

In a similar way, solar technologies have to pay very high sales taxes as would be expected for a capital-intensive technology. However, there is another source of taxes that should not be forgotten: labor-related taxes. Solar technologies are not only capital-intensive but also labor-intensive during the construction phase. These taxes barely exist for fossil-fuels and they can represent a large fraction of the total tax-load for solar technologies they include income taxes of all contractors and subcontractors during the construction process.

In conclusion, in order to create appropriate national tax systems for solar energy, authorities should eliminate tax-barriers or create incentives that help overcome tax-load inequalities for solar energy technologies. Furthermore, the tax-structure for renewable energies in general should be revised, as almost-all of them are capital-intensive technologies where most of the previous tax-inequality arguments can be applied.

Since the tax structure varies significantly among the different APEC economies, this analysis must be performed for each nation. However, the APEC forum could be a good platform to promote and reach agreements on changing the tax structure for solar energy technologies, encouraging the cooperation between the APEC member economies regarding solar energy.

5.3 Capacity Building

In many cases, the main factor that leads to the unsuccessful development of a renewable energy project is its higher costs versus conventional fossil fuel technologies. However, in many instances projects are canceled due to the excessively-high risk associated with renewable energy technologies. This over-estimation of the technologies' risk is based on a generalized lack of information about this technology at all levels, from governmental institutions to private and financial entities.

In this sense, a literature review performed by the NREL [60] summarized most of the non-technical barriers to the development of the solar energy industry. Some of the information-related barriers found are shown below.

- Lack of information on the state of the art and reliability of solar technologies at industrial level.
- Little information about market prices for the different technologies.
- Uncertainty on the performance of the different solar technologies.
- Lack of qualified staff for the construction and operation of large solar plants.
- Very little or no solar fields with industrial purposes at a local level, and therefore, lack of trust when considering medium and large-size solar fields.

5.3.1 Governments

In the first place, it is important for the governments of the APEC member economies to understand that investing in solar energy can provide greater benefits to the economy, even if their costs may appear higher than those of fossil-fuel technologies. Stoddard et al., have calculated the economic impact of concentrating solar power for electric generation (CSP) on the state's economy. The result is that for each dollar spent on CSP there is a total contribution of about $1.4 in California's Gross State Product. In contrast, each dollar spent on natural gas plants contributes only about $0.9 to $1 to the Gross State Product. It is important for governments to acknowledge that solar energy, as a renewable energy source, creates a fourfold dividend by:

In first place, it is important for the governments of the APEC member economies to understand that investing in solar energy can provide greater benefits to the economy, even if their costs might look higher than those of fossil-fuel technologies. Stoddard et al.[59], have calculated the economic impact of concentrating solar power for electric generation (CSP) on the state's economy. The result is that each dollar spent on CSP there is a total contribution of about $1.4 in California's Gross State Product. In contrast, each dollar spent on natural gas plants contributes only about $0.9 to $1 to the Gross State Product.

It is important for governments to acknowledge that solar energy, as a renewable energy source, creates a fourfold dividend [65]:

- Contributing to the protection of the environment in terms of pollution and for the control of climate change.
- Reducing dependence on energy-related imports from non-APEC economies
- It can contribute more to each economy' Gross Domestic Product than conventional fossil-fuel technologies.
- Possibly contributing more to each economy's Gross Domestic Product than conventional fossil-fuel technologies.
- Creating both a significant amount of installation-related jobs and a higher amount of permanent jobs than conventional fossil-fuel technologies.

Also, it is important to understand that solar energy is the most abundant renewable energy resource in the world, and therefore any long-term scenario for the control of global warming will have solar energy as a very important player in the energy matrix. In addition, it is important for governments to acknowledge several important facts about solar energy:

- Currently, several solar technologies are not only mature enough, but they can also be cost-efficient when compared with fossil-fuel technologies.
- Solar energy can be easily integrated with existent thermal processes.
- Its modular structure makes it easy to design fields for different heat requirements, and also makes it easy to enlarge the field to meet a larger heat fraction.
- In many cases, solar energy does not have real competition with other renewable energy technologies.

The economical benefits of solar energy technology are even higher when a part, or all, of the technology is developed in each economy. Those economies which are developing competitive solar technologies can pursue an important fraction of the market, with all the economic benefits related to it.

On the other hand, economies that are not in such condition can establish policies that lead to the development of simpler components for solar technologies and services, such as the solar field installation contractor and maintenance of the solar field components, in order to keep part of the economical benefits in their own economy, and not just to pay for the technology development of another economy. This group of economies should pay attention to this issue, as inaction would lead to a similar situation as that which exists with fossil-fuels, where the oil production mainly benefits a small group of economies with little benefits for the rest.

In its condition as both a major player in the global economy and a developing APEC economy, it is important to acknowledge the important initiative China has carried out lately. In the last few years the central Chinese government has established several groundbreaking laws to promote both clean fossil-fuel technologies and renewable energies. In 2005, China approved the *renewable energy promotion* law in order to meet short-term energy needs while strengthening long-term sustainable development objectives [62]. This law establishes feed-in tariffs for several renewable energy technologies for electric generation, new financing mechanisms and rural uses of renewable energy. The law also promotes renewable energies R&D, geographic resource surveys, technology standards, and new subsidies for certain type of technologies and building codes for integrating solar hot water into new construction [63].

It is remarkable that despite not having the best solar resources, China has taken concrete measurements to develop its own solar technology in addition to a new renewable-energy institutional framework. As a result, China represents by far the largest solar market with a world market share of 51.4%. This can be seen more clearly in the following figure, where the top 10 economies in solar water collectors' capacity are shown:

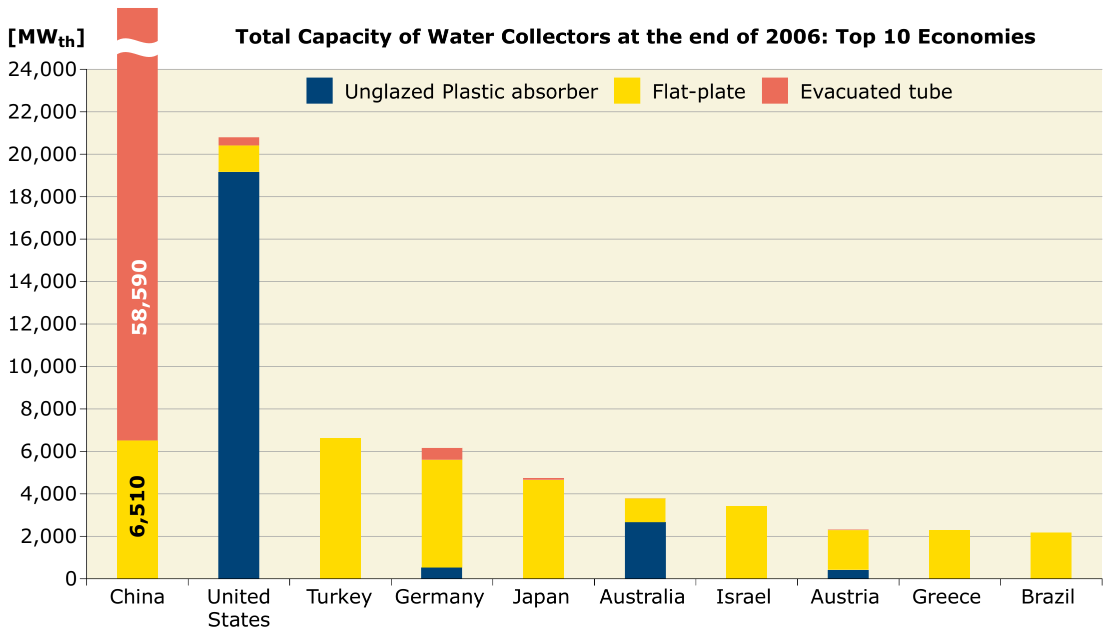

Figure 5.1: Top 10 economies by total solar water collectors installed capacity by 2006 (Source: IEA [64]).

This graph does not only shows the huge Chinese solar market, but also that the larger fraction of these collectors are in fact Evacuated Tube collectors with a smaller fraction -but still one of the largest in the world- of glazed flat plate collectors. It is important to understand that China's central government decisions around solar energy have had strong consequences in the development of a huge internal market and in the creation of a competitive solar industry that is creating cheaper solar technologies and improving efficiency over time. China's market —including the Chinese Taipei— growing over the last decade can be seen in the following figure:

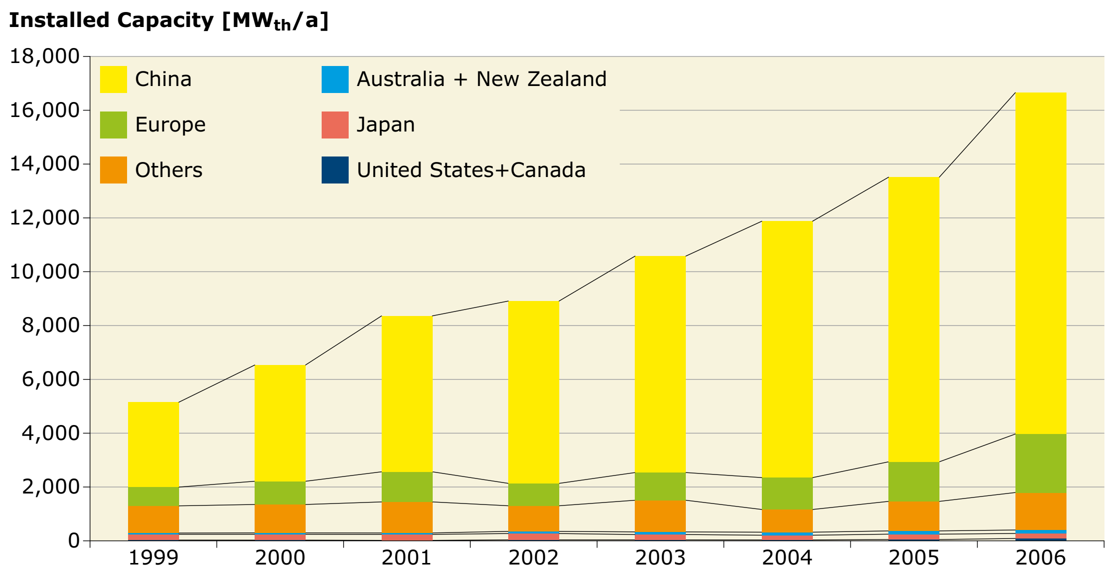

Figure 5.2: Solar collectors installed capacity by economic region in 2006 (Source: IEA [64]).

China is the best example in the APEC region on how a governmental decision can lead to a quick and sustained growth of the solar energy market, generating not only environmental benefits but also thousands of jobs and economic benefits due to internal and export markets.

5.3.2 Financial Institutions

A similar situation can be found in the financial systems among the APEC economies. In general, the credits given for financing solar energy installations are subject to high interest rates, due to the high risk associated with the technology. In most cases, this risk is highly over-estimated, as financial institutions do not have trained stuff for evaluating renewable energy investments, and so the assessment is performed based on their knowledge on conventional natural gas, Diesel or coal plants.

This is highly disadvantageous for solar investments, as they require a higher initial cost for a smaller installed capacity, which is seen as a risk. In the case of non-electrical applications this is particularly important, as conventional fossil fuel technologies require only a boiler and a small pumping and piping system, and therefore, a small investments and construction time is required. On the contrary, solar-heating plants require a large collector field with a relatively large and more complex pumping and piping system. In addition, the initial investment is not only much higher than conventional heating alternatives, but a large-size operative collector field could take over 6 months in construction work.

Now, the main problem is that both the high investment and the long installation-time are factors that are visible to, and understandable by, any investment analyst, and therefore it is easy to see them as negative investment-aspects compared to fossil fuel alternatives. However, the benefits of solar technologies are not as clear, as they require understanding of the technology and its benefits, where the benefits will depend on the solar resource of the particular location, and therefore, they should be estimated as a function of it.

This issue could be resolved in two different ways. The first, and most obvious, is to let the solar market to grow by itself and the financial institutions will, eventually, get to know the technology better and be able to assess this investments with better information tools. This approach is slow, considering that solar-energy market development is crucial for addressing global warming. It is therefore necessary to speed-up the process by building renewable-energy investment capacity inside financial institutions.

Naturally the capacity building on renewable energy investments is normally a result of governmental policies of a state that is aware of the benefits of these technologies.

5.3.3 Private Sector

The private sector is the key to a successful solar thermal market, as government and financial initiatives are useless unless they integrate and incentivize private individuals to use these new technologies. There is a major lack of information about solar technologies in the private sector, where conventional fossil-fuel technologies have been used for a long time. In this scenario, Diesel boilers have proven to be trustworthy technology with many trained professionals in local markets.

However, solar energy does not only help companies to gain independence with respect to their oil consumption: it can also be a highly cost-effective investment where the solar resource is high. Even though in many APEC economies the solar radiation data available is not precise or even public, it is not necessary to be an expert to realize that solar-collector fields in desert climates with mining applications - such as Australia, Chile, China, Mexico, Peru and the United States, among others- would have good technical performances. However, the major problem is the total lack of information about solar energy that companies handle, particularly relating to installation costs.

This should not be a surprise, as companies must be a specialist in their own production field, not necessarily in energy management, and often do not have a specialist in energy use. In this sense, the lack of information leads to a 'chicken and egg' scenario, where no company would invest in solar energy until the technology has been widely used in the industry at low costs, and no low-cost industrial installations can be achieve if no one invests in these technologies on a large scale.

Now, if no company will invest in solar technologies until they are proven to be cheaper than conventional fossil-fuels technologies, then more detailed information about current solar energy costs and performance should not change the status quo. However, the reason why information could make a difference is because for many companies the use of solar energy in their production activities can give added value to their products. Highly competitive markets such as the food and beverages industry can, and already do, use solar energy to sell themselves as 'green products' in particular markets like Europe, without increasing their production costs.

Good-quality and easy-toaccess information about solar technologies will give higher certainty to private individuals willing to invest in solar energy. These "first-movers" could provide the required momentum forthe solar industry to grow towards higher competition and capacity, which wouldlower installation costs.

5.4 Policy Mechanisms for Solar and Renewable Energy Heating

Some authors (i.e. Nast et al [65]) have proposed the creation of energy policies that emulate the mandatory renewable energy targets existing in several APEC economies, applied to the heat market. This investigation stated that mechanisms to promote the use of renewable energy (and subsequently also of solar energy) in the industrial and domestic heat market could be created, by applying the successful case of the electric market. These mechanisms should be designed in order to:

- Promote the protection of climate and natural resources
- Reduce the dependence on fossil-fuel imports
- Stimulate the diversification of the energy matrix
- " Incentivize the economically-efficient operation of these renewable-energy technologies, stimulating heat production while keeping operation and maintenance costs low.

It is important to add that for this purpose, any mechanism or policy should be designed in order to exist for an extended period of time, in order for the industry to have sufficient time to incorporate the new technologies and not to jeopardize the credibility of the market on the mechanism.

Two important differences can be found between the electric and the heat markets. On the one hand, there are clearly assigned supply areas in the electricity market, administrated by one grid operator.

Such an operator does not exist in the Heat Market, makingthe control of any public measure more complex.

On the other hand, in the electricity market, power lines supply the electricity from the generators to consumers located in a different geographical location. Additionally, power lines can be used not only to feed, but also to supply electricity back and sell electricity to the system. The heat generated from renewable energy sources does not function in the same way, as heat must be used locally or, in the best case, distributed in a small geographical area (as in district heating).

Now, these differences between the heat and electricity markets prevent the direct use of the renewable-energy targets mechanism in the heat market. However, several different alternative instruments can be used for the heat market with the same purpose. Nast et al, identify two of them with potential for the development of the solar market in particular.

5.4.1 Ordinance Policy

This policy basically consists of imposing a national or regional ordinance where solar energy should be implemented either in the housing or the industrial sector, for all new project constructions. This type of policy must be implemented gradually, in order to give the solar-technology producers enough time to adapt, avoiding an uncontrolled growth in demand which would lead to high solar energy prices.

The implementation of this measure has been performed by Spain, for the construction market. An ordinance has the advantage that it can be easily understood and assimilated by the industry, as in practice it functions as one of the many existing regulations and standards of the industrial and construction sectors. Another advantage for governments is that this system requires no cost to the state, as the costs for equipment is paid directly by the builders and the final consumers.

On the down side, the regulation of this ordinance can be complex, and sometimes exceptions must be allowed for. Also, the protection of the environment is not achieved at minimum cost and the cost is not necessarily paid by the polluters.Therefore, they become disconnected from the 'polluter pays' principle enshrined in many environmental agreements such as the United Nations Framework Convention on Climate Change or the Kyoto Protocol.

Alternatively, APEC economies like Chile are discussing a different approach. The Chilean congress is discussing the last details of a new solar energy law, where an ordinance-like scheme would be used, with the exception that instead of being mandatory for all constructions and industries, an important tax-credit will beoffered to construction companies.

The state budget for this policy has been set to 1 billion dollars, to be spent in the next six years. This different approach has been taken on the basis of cost-efficiency and effective regulation.

Using this scheme, only cost-efficient solar installation would be built, as the policy is voluntary and not mandatory, therefore industries and buildings would use this tax-credit as long it represents an economically interesting alternative.

On the other hand, the tax credit would be given to companies after a certification process performed by previously-accredited certification entities. This scheme will allow the government to control the information and functioning of the credit-system, outsourcing the technical certification procedure to solar-energy qualified entities.

5.4.2 Quantity Regulations

This measure consists in setting a mandatory target for renewable energy heat in a region, which can be accomplished by both the use of renewable energy heat in certain determined entities or the purchase of emissions reduction certificates. Perhaps the easiest way to implement this kind of measurement would be to apply it to fuel suppliers, as compensation for selling a product that directly endangers the environment. Imposing measures on fuel suppliers is an easier control than imposing measures on final users, as the latter is a very diverse group, subject to broad tax legislation.

The higher cost of this measure would be absorbed by the final users, and its use is supported by the 'polluter pays' principle and its direct contribution to the long-term need to replace fossil-fuels. All quantity regulations have the advantage that the environment protection principle is achieved directly from the legal point of view, as the extra burden is distributed among the polluters.

A similar case to this can be found in Denmark, with the mandatory targets for biofuels among fuel providers. This measure has led to an important growth in biofuels consumption, less foreign-oil dependency and lower emissions as a whole. A similar case, where the renewable energy share on the fuel distributors' sales could be accomplished not only by biofuels, but by buying emissions reduction certificates from any heat-production using renewable energy would both promote solar process-heat installations and achieve the target at a lower cost.

Chapter 6

Case Study: Copper Electrowinning Plant (EW)

The copper electrowinning process (EW) requires a significant production of heat at low temperatures. The following case study shows the economical evaluation of a 10.000 m^2 solar field, to produce 18% of the annual heat requirements.

6.1 Plant Characteristics and Heat Requirements

Generally, the copper electrowinning plants are highly similar in relationship with their main operation variables, and, as a result, the equipment and process stages found in modern EW plants are practically the same everywhere. This is due to the fact that both the electrolyte flow and temperature have been found to maximize the quality of the EW copper cathodes within a narrow range. More details about this process can be found in the first report of this investigation, delivered to the APEC secretariat.

The EW plant being studied is located near Calama, a mining city in the middle of the Atacama desert. Out of all of the existing copper mines, this one has been selected mainly due to the existence of reliable solar radiation data. However, as it is explained further on this document, no direct solar radiation measurements exists within Chile; and therefore, solar radiation models combined with the existent global radiation measurements were used to estimate its value.

Each year, the selected EW plant operates 360 days a year, 24 hours a day, to produce 150.000 Ton of copper in the form of high-purity copper cathodes. In order to maximize the quality of the copper cathodes, the electrolyte must be kept at a temperature of approximately 50C. Considering that the electrolyte mass flow is of the order of thousands of cubic meters per hour, not all the electrolyte is heated directly to 50C. In contrary, a fraction of the total electrolyte flow is extracted to be heated to higher temperatures than 50C, and then it is injected back on the electrolyte stream so the whole mix reaches the desired temperature of 50C.

The electrolyte-heating system used in the selected EW plant can be seen in the following figure.

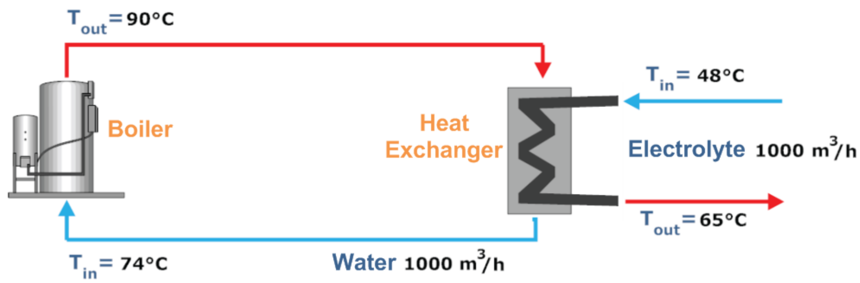

Figure 6.1: Electrolyte-heating system used at the selected EW plant, at Calama, Chile.

As the previous figure shows, the electrolyte is heated from 48C to 65C. This is due to the fact that only around a 25% of the total electrolyte flow is extracted to be heated up. Thus, when injected back to the main electrolyte stream, the final temperature of the electrolyte will be around 52C. Under this regime, the boiler runs at an average power of 18.6 MWth, heating an auxiliary water loop from 74C up to 90C.

Solar energy could be integrated in several different ways to this process; however, some process engineers interviewed for this investigation were skeptical about heating the electrolyte directly with solar heat. Concerns about the reliability of the solar field and the control of the electrolyte temperature lead to a more realistic design. Basically, the solar field is integrated to the heating loop shown in the figure 6.1, preheating the heat transfer fluid (in this case water) before entering the boiler.

The diagram of the selected solar system design can be seen in the following figure:

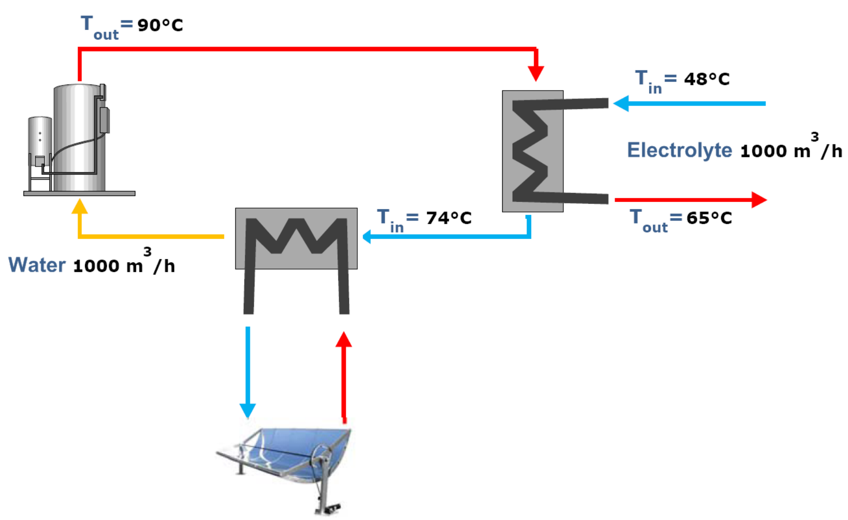

Figure 6.2: Integration of a solar collectors field in the EW process.

This simple diagram shows that the solar field would be integrated to the heating loop in a simple and safe configuration, where the heat generated from the solar field would be transferred to the heating loop by a plate heat exchanger. As a result, any problems with the operation of the solar field would not prevent the system from continuing to work, as the existent boilers can fully deliver the required amount of heat. The solar field will use variable-flow pumps, in order to heat the solar-field water up to 90C.

6.2 Direct Solar Radiation Estimation

For the selected location, global horizontal radiation data is available. This data has been collected by Chile's National Meteorological Agency and published by the World Radiation Data Centre (WRDC), a data base sponsored by the World Meteorological Organization (WMO). This data is considered to be reliable, as it has been generated using relatively new and calibrated instruments. However, in order to model a solar concentration technology direct solar radiation data is required.

To generate the required direct radiation data, the Bird clear-sky direct radiation model was used. This model was used as a base for days when the atmospheric transparency was over 0.7, according to the WRDC measurements. In Calama, these days account for over 90% on a year base, as clouds and rain are rare in the Atacama Desert.

The following figure shows the daily-cumulative direct normal irradiation (DNI) estimation performed for a parabolic trough solar field, for each day of the year:

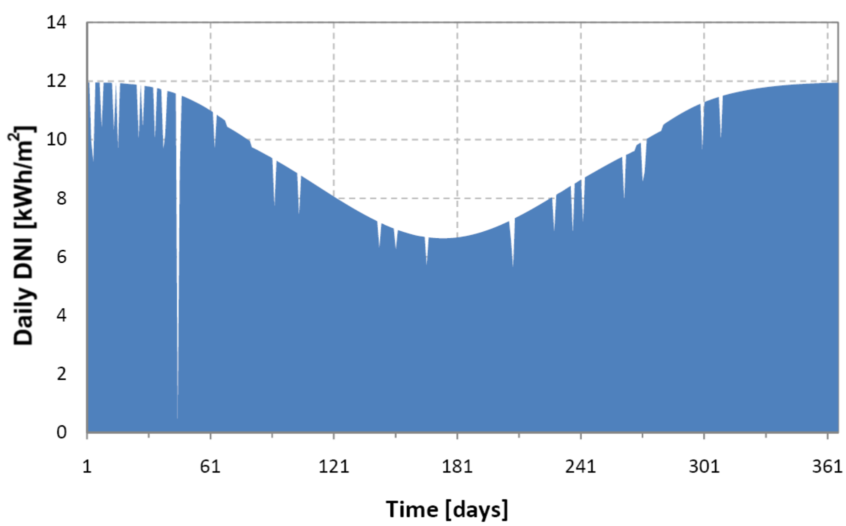

Figure 6.3: Daily estimated DNI.

In the previous figure, the daily direct normal irradiation over the parabolic trough field is shown.

The irregularities that can be seen represent the days of the year that were partially or fully cloudy.

6.3 Simulation Results

The EW plant-solar field system was simulated using the software TRNSYS, an acronym for Transient Energy System Simulation Tool. This tool was selected based on its existent solar energy modules, its simplicity and world-wide use by universities and industry.

The graphic user interface generated in TRNSYS for this solar project is shown in the following figure:

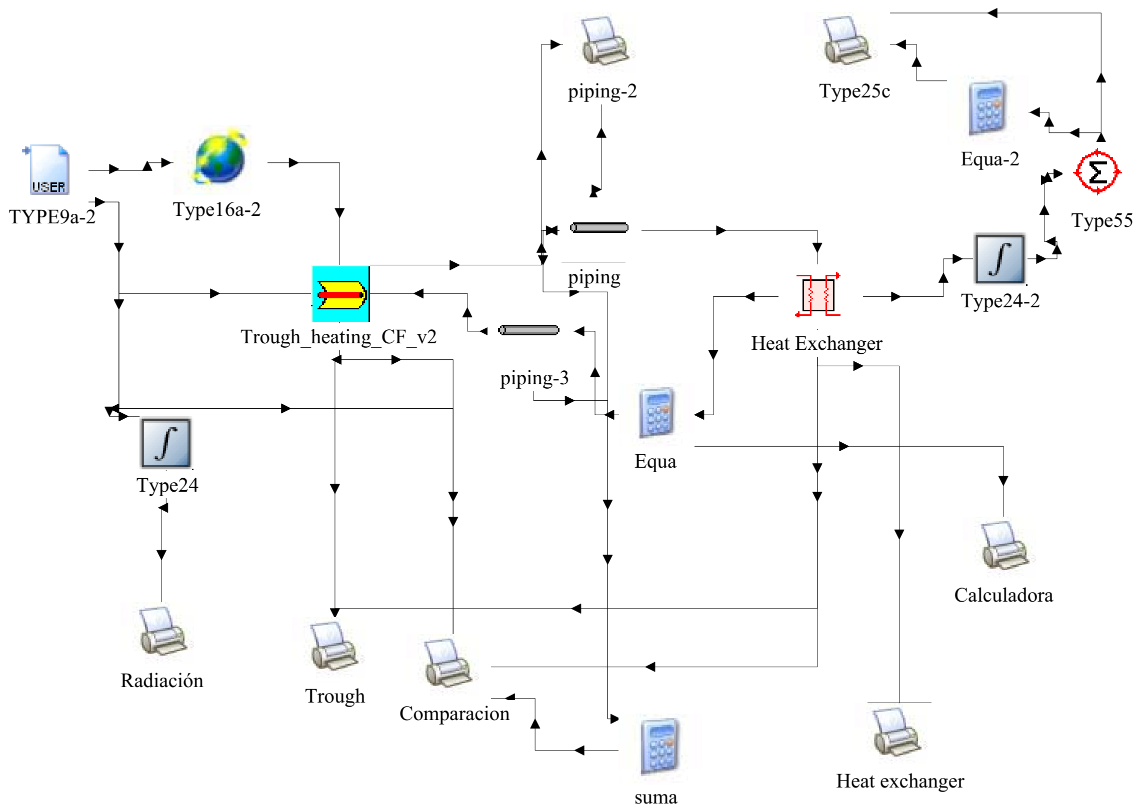

Figure 6.4: Solar heating system implementation in TRNSYS.

As a result, more detailed data can be obtained about the main operation variables of the system, thereby offering greater certainty when performing the economic assessment of the system. As mentioned before, a 10.000 m^2 solar field integrated to the EW heating system will be evaluated, in order to replace 18% of the annual total consumption. This system will not include thermal storage, as the amount of heat produced by the solar field will only reach about 50% of the heating requirements.

A simple pumping configuration with 2 pumps connected in-series was selected, where the pumps would be controlled in order to maintain a temperature of 90C on the circulating water. The monthly circulating water flow and the electricity consumption required to pump it can be seen in the following figure:

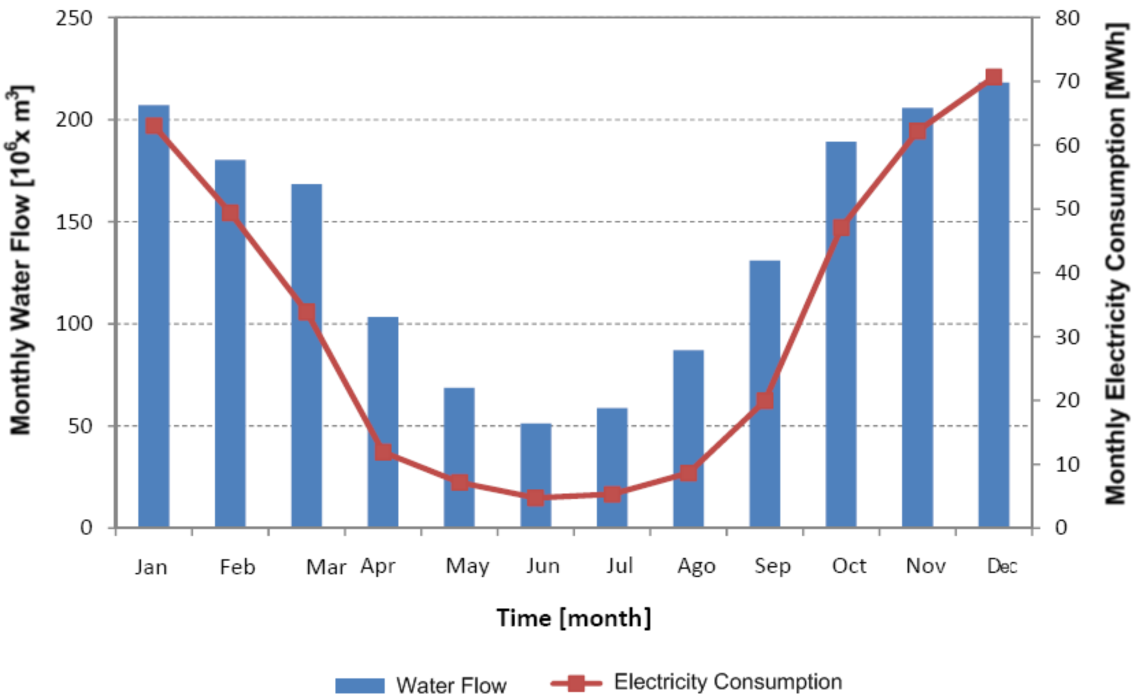

Figure 6.5: Monthly pumped flow and electricity consumption for the selected solar field.

On the one hand, the monthly amount of water flow pumped through the solar field is the highest in December and it decreases until reaching a year-low in June. This is due to the functioning of the pumping control system, as the mass flow is set in order to maintain the water at 90C at the collector's outlet. Therefore, as solar radiation is higher in December, the flow to maintain this temperature must be higher than in the rest of the year, as the collected heat in the collectors is consequently higher.

On the other hand, the electricity consumption falls dramatically from a consumption of 70 MWh in December to only 8 MWh in June. A drop in the electricity consumption in the winter is expected, as the pumping requirements are lower; however, the reason for this dramatic fall in power consumption is the use of Variable Frequency Drives for the pumps.

6.3.1 Economic Assessment

The solar-to-electrolyte heat collected by the solar field -which exact value was provided by the system simulation- will allow the boiler to operate at a lower rate, therefore saving a fraction of the total Diesel consumption. An economic assessment of the system behavior is necessary to analyze how convenient is to include solar heat in the EW process.

The following table shows the main variables used in the economic assessment of this solar heating project:

Table 6.1: Parameters used in the economic assessment of the project.

Parameter	**Value**
Solar Field Cost [US$/$m^2$]	650
Diesel Cost [US/m^3]	850
Electricity Cost [US$/kWh]	0,155
General Inflation Rate	3%
Discount Rate	10%
Boiler Efficiency	80%

The cost per square meter of solar field area has been estimated based on the investment costs of several existing parabolic trough solar plants. A conservative value has been taken in this case, considering that most plants are located in the US, where the proximity to the manufacturer and a lower tax-load for companies could be reflected in lower prices than in Chile.

The rest of the parameters are based on real costs for the copper industry in Chile, and conservative estimates for inflation and boiler efficiency. The total initial investment for the 10.000 m^2 solar field has been estimated at 7.3 million dollars. The annual savings and costs of the operation of this solar plant were calculated over the simulation results and can be seen in the following figure:

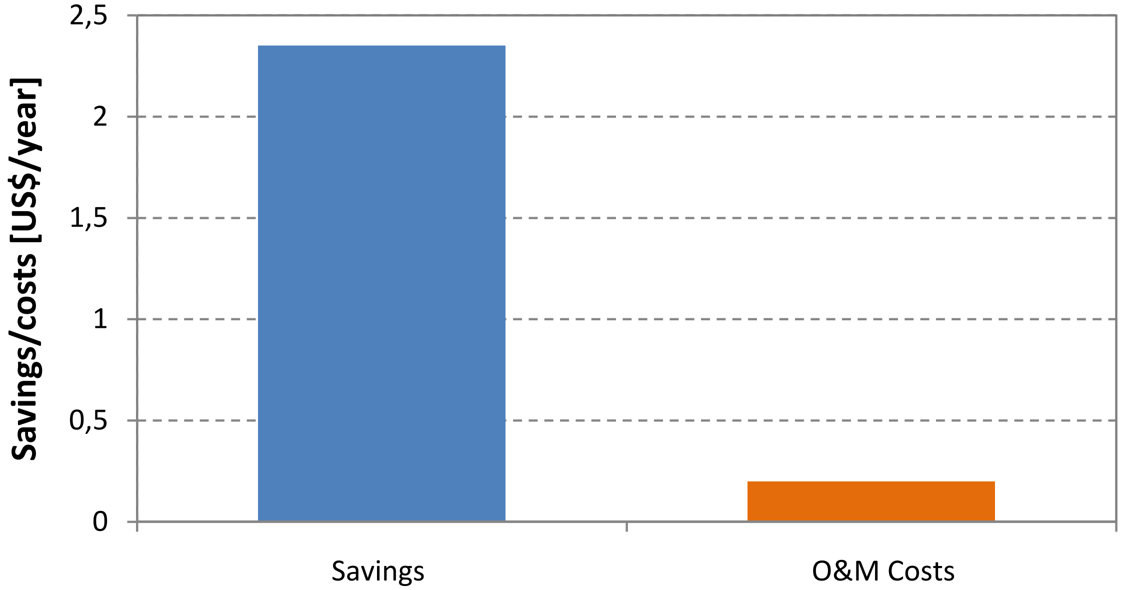

Figure 6.6: Annual savings and costs of the solar heating system.

Based on the results, net annual savings of over 2.2 million dollars can be obtained for a 10.000 m2 solar field. Operation and Maintenance costs (O&M) are relatively low, as they only represent 10% of the annual savings.

Finally, the Present Value of the investment and the payback period has been calculated, and they are shown in the following table:

Table 6.2: Investment indicators for the analyzed solar project.

Indicator	**Value**
Initial Investment [MM US$]	7,3
Present Value (10% discount rate) [MM US$]	13,67
Payback Period [years]	3,2

These indicators clearly show that solar energy can be cost-efficient without any incentive, with proper field designing and a high solar resource. Even if the 3 year payback period seems to be a reasonable time, several local copper companies have seen it as high, claiming that no solar energy projects would be built unless they guaranteed a payback period of two years or less.

As mentioned before, this short-term demand is usually associated with the lack industry trust in these technologies, where the over-estimated risk is reflected by shorter payback expectations.

6.3.2 Greenhouse Emissions Avoided

Using the methodology for calculating the greenhouse emissions of a project, explained in Section 3.1 of Report III, the annual emissions are calculated as following:

$$E = \frac{Q \cdot EF}{\eta_{th}} \tag{6.1}$$

Where, *E* is the annual greenhouse gas emissions displaced by the project in $[Ton_{CO_2eq}]$, *Q* is the annual net quantity of heat supplied by the project in [TJ], *EF* is the greenhouse gas emission factor in $[ton_{CO_2eq}$/TJ] and η_{th} is the net efficiency of the conventional fossil fuel equipment.

In this case, Diesel is used for the electrolyte heating which, according to the IPCC, has the following emission factor:

$$EF_{Diesel} = 74.34 \frac{Ton_{CO_2}}{TJ} \tag{6.2}$$

Then, according to the simulation results, the annual amount of heat supplied by the solar field (Q), is equal to:

$$Q = 583TJ \tag{6.3}$$

Finally, assuming 80% efficiency for the boiler, the annual greenhouse gas emissions displaced by the project are the following:

$$E = 9,759Ton_{CO_2} \tag{6.4}$$

As a result, the 10,000 m^2 solar field would avoid the emission of almost 10,000 Ton_{CO_2} per year. In terms of both the emission reduction and the installed capacity (7MW), this project would qualify as a small-scale CDM project.

If we consider only the emission reductions, a 7 million dollars solar installation reduce only 10,000 Ton_{CO_2} per year. This is a very high cost in comparison with other types of projects to reduce emissions, like HFC-23 or N_2O destruction projects, where a few-million-dollars investment can generate emission reductions of 100,000 Ton_{CO_2} and more.

However, most of these cheaper greenhouse gas emission reductions do not have any other possible application besides the destruction itself, and therefore are not useful for reducing the emissions from heat generation in the industry. As a result, industrial emission mitigation would require the development of more-expensive renewable energy heating technologies, particularly of solar, geothermal and biomass energy.

However, the fact that expensive fuel is being replaced -in addition to the availability of cheaper renewable energies- has lead to a scenario where renewable energy is already cost-effective in many cases. In terms of the emission reductions, these technologies may be seen as an expensive way of reducing emissions, but from an energy point of view they could be a cost-effective alternative to fossil-fuels, and therefore, the industrial greenhouse gas mitigation could be driven by the market itself, looking for the cheapest alternative.

Chapter 7

Summary

Today, the world faces the great challenge of replacing the current development model for a new one that assures sustainability. The concussions of the 2007 IPCC report on the certainty of climate change has put pressure on politicians to adopt stronger emission-reduction commitments on developed economies and to further integrate developing economies in these efforts.

Further more, the possibility of reaching a peak production of oil in the next decade, in addition with a strong and sustained population growth in developing economies requires urgent action to provide alternative energy sources to fossil-fuels. Solar energy has been called to play a large role in scenario, as it can be the most cost-effective alternative to replace fossil-fuels in both power generation and heating requirements.

The mining industry possess large low-temperature heat requirements that can be fulfilled partially or totally by using solar energy. Among the APEC economies, most of the mining activities are located in areas with high solar radiation; therefore, converting solar energy in a strategic resource that can decrease the production costs while increasing the energy security.

The possibility of cheap, clean and secure energy should attract companies to use these technologies; however, there are different barriers that prevents a higher development of the solar thermal market. These barriers are mainly associated with: lack of information, lack of policies for promoting the application of solar technologies and the apparent high costs of the solar technologies. However, as discussed previously in this report, the current state of the art level of several solar technologies allows them to be competitive or even cheaper that fossil-fuel technologies.

In this context, information plays an important role, as potential consumers do not have enough certainty on how reliable existent solar technologies are, and what performance can be expected from them at a particular geographical location. Also, a large-size solar field will have large investment costs, requiring the involvement of financial institutions. In many APEC economies, financial institutions are not prepared to assess renewable energy projects, often associating them with over-estimated technology risks.

Overcoming these information-related barriers will require government planning and political will in order to bring more certainty to investors willing to invest in solar energy.

On the other hand, most renewable energy sources -and solar in particular- must bear a higher tax-load when considering the life-cycle tax load. This is due to the fact that tax loads for heating equipment are not designed for capital-intensive heating options, but more suitable for expense-intensive alternatives such as fossil-fuel technologies. In order to provide a safe ground for solar energy to grow, the APEC states should consider establishing differentiated tax structures for industrial solar technologies, in order to at least leveling the playing ground for all heating technologies, as solar technologies can pay several times the amount of taxes than conventional fossil-fuel technologies do throughout their life time.

Finally, a case study of a parabolic trough solar collector field integrated to the copper electrowinning process was performed. The selected location was in the Atacama Desert, in the city of Calama, the highest solar radiation zone within Chile. The high solar resource of the zone in addition to high-efficiency solar collector technology were found to have very good results, as the economical assessment proved that the system would be a cost-efficient solution with a short payback period of only 3.2 years. This example shows how solar energy can be an economically-convenient alternative to fossil-fuels today, even without state incentives.

Chapter 8

Bibliography

[1] Matthias Loster, 2006. *http://www.ez2c.de/ml/solar_land_area/*

[2] International Copper Study Group *The World Copper Factbook 2007*

[3] Soteris Kalogirou *The Potential of Solar Industrial Process Heat. Applied Energy 76, 2002.*

[4] Weiss W.: *Solar Heat for Industrial Processes*, Task 33/IV Industry Workshop, Rome (March 31, 2006).

[5] Systemlink: *Available at: http://www.systemlink.ie/solar-panels-ireland.asp*.

[6] Solarcrest: *Available at: http://www.solarcrest.ca/public/004_PoolHeating/020_SolarWaterHea.html*.

[7] Sunrain: *Available at: http://en.sunrain.com/PRODUCTS/Collector%20Module.htm*.

[8] Solar Focus: *Available at: http://www.solarfocus.co.uk*

[9] Ao Sol Energias Renovveis S.A.: *Available at: http://www.aosol.pt*

[10] Ausra Inc.: *Available at: http://www.ausra.com*

[11] Zarza E., Rojas M.: *The first pre-commercial DSG solar power plant*, Solar Energy, (2005).

[12] Sandia National Laboratories: *Test results Industrial Solar Technology Parabolic Trough Solar Collector*, Albuquerque, USA (1995).

[13] Industrial Solar Technology: *Available at: http://www.industrialsolartech.com/trghtech.htm*.

[14] Abengoa Solar: *Available at: http://www.abengoasolar.es*.

[15] Federal Technology Alert, Parabolic Trough Solar Water Heating. *U.S. Department of Energy.*

[16] Evacuated-Tube Heat-Pipe Solar Collectors Applied to the Recirculation Loop in a Federal Building, *Solar 2004 Conference, Portland, Oregon.*

[17] http://www.nrel.gov/csp/troughnet/power_plant_systems.html#operation

[18] Final Report on the Operation and Maintenance Improvement Program for Concentrating Solar Power Plants , *June 1999.*

[19] International Copper Study Group, 2007 World Copper Factbook.

[20] International Copper Study Group, Vol. 12, No. 6, June, 2005.

[21] Chilean Copper Commission (Cochilco) Investment in the Chilean Copper, Silver and Gold mining. 2006-2010.

[22] International Copper Study Group, Directory of Copper Mines and Plants.

[23] Wikipedia.org

[24] Extractive Metallurgy of Copper. Davenport, King, Schlesinger and Biswas. (2002)

[25] Biominig, Domic, Esteban. (2007)

[26] D.J. Durkhardt *Heat Balances in Copper SX/EW Operations.*

[27] http://www.indexmundi.com/en/commodities/minerals/aluminum/aluminum_table12.html

[28] http://www.madehow.com/Volume-5/Aluminum.html

[29] *Mineria Chilena. No. 29, Septiembre 2004.*

[30] http://www.indexmundi.com/en/commodities/minerals/zinc/zinc_t17.html

[31] http://www.unctad.org/infocomm/espagnol/zinc/cadena.htm

[32] The Chemistry of Gold Extraction.

[33] GOLDSHEET Mining Directory.

[34] The Silver Institute - Silver Production (2006).

[35] Cost Reduction Study for Solar Thermal Power Plants *Enermodal Engineering Limited, May 5, 1999.*

[36] International Energy Agency website, *www.iea.org*

[37] CORFO website, *Available at: http://www.corfo.cl*

[38] Database of State Incentives for Renewables & Efficiency, *www.dsire.org*

[39] B.Bhardwaj, N. and H.C.d.C. Parthan, Realising the Potential of Small-Scale CDM Projects in India. *IT Power and IT Power India, November 2004.*

[40] Zhang, Z.X., Towards an effective implementation of clean development mechanism projects in China. *Energy Policy, 2007. 35: p. 1088-1099.*

[41] Global Carbon Exchange, *Newsletter May/June 2008.*

[42] UNFCCC. CDM Statistics. *http://cdm.unfccc.int/Statistics*

[43] European Commission, Emissions trading: Commission decides on first set of national allocation plans for the 2008-2012 trading period November 29, 2006.

[44] Energy Information Administration, Historical Spot Prices for Crude Oil and Petroleum Products. *Available at: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_d.htm*

[45] U.S. Department of Labor, Bureau of Labor Statistics: Consumer Price Index All Urban Consumers - (CPI-U). *Available at: http://www.bls.gov/CPI/*

[46] Barriers to Solar Process Heat Projects: Fifteen Highly Promising (But Cancelled) Projects. *Clifton Carwile, Russell Hewet, National Renewable Energy Laboratory, October 1994.*

[47] Methods/Criteria of Project Evaluation or Measures of project Worth of Investment, *DR. A.K. Sarma, Professor, Agril. Economics, FA, AAU, Jorhat.*

[48] Effect of financial and fiscal incentives on the effective capital cost of solar energy technologies to the user. *B. Chandrasekar, Tara. C. Kandpal, Solar Enery 78 (2005), 147-156.*

[49] Leiva R., Bolocco R., Guiez C.: *Estudio de contribucin de ERNC al SIC al 2025 Informe Final*, UTFSM, Chile (2008).

[50] U.S. Department of Energy: *Federal Technology Alert: Parabolic-Trough Solar Water Heating*, (1997).

[51] Energy Information Administration, Natural Gas Prices for 2008. *Available at: http://tonto.eia.doe.gov/dnav/ng/*

[52] The Global Research Alliance *Assessment of the World Bank/GEF strategy for the Market Development of Concentrating Solar Thermal Power*, (2005).

[53] Kitsner, R., Price, H., *Financing Solar Thermal Power Plants*, Proceedings of the ASME Renewable and Advanced Energy Systems for the 21^{st} Century Conference April 11-14, Maui, Hawaii, (1999).

[54] Kelly, B. *Nexant Parabolic Trough Solar Power Plant Systems Analysis. Task 3: Multiple Plants at a Common Location.*, Subcontract Report NREL/SR-550-40164, National Renewable energy Laboratory, (2006).

[55] Jenkins, A., Chapman, R. and Reilly, H., *Tax Barriers To Four Renewable Electric Generation Technologies*, presented at the International Solar Energy Conference, (1996).

[56] Tibet University: *Project: Spatial and regional variation in solar radiation and aerosol concentrations in urban and rural sites in the Himalayan Region*, Project description, China (2007). Available at: http://www2.siu.no.

[57] Lotker M.: *Barriers to Commercialization of Large-Scale Solar Electricity: Lessons Learned from the LUZ experience*, Sandia National Laboratories, USA (1991).

[58] Jenkins A., Reilly H.: *Tax Barriers to Solar Central Rreceiver Generation Technology*, SandiaNational Laboratories, USA (1994).

[59] Stoddard L., Abiecunas J., O'Connell R.: *Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California*, National Renewable Energy Laboratory (NREL), USA (2006).

[60] R. Margolis, J. Zuboy: *Nontechnical Barriers to Solar Energy Use: Review of Recent Literature*, National Renewable Energy Laboratories (NREL), USA (2006).

[61] Nast M.,Langnib O., Leprich U.: *Instruments to promote renewable energy in the German heat marketRenewable Heat Sources Act*, Renewable Energy (2006).

[62] *Renewable Energy Policy in China: Overview*, National Renewable Energy Laboratory (NREL), USA (2004).

[63] Martinot E.: *Available at: http://www.martinot.info/china.htm*, Renewable Energy Information on Markets, Policy, Investment, and Future Pathways, USA (Updated by August 10, 2008).

[64] Weiss W., Bergmann I., Faninger G.: *Solar Heat Worldwide: Markets and Contribution to the Energy Supply 2006*, Solar Heating and Cooling Programme, International Energy Agency (2008).

[65] Nast M., Langni O., Leprich U.: *Instruments to promote renewable energy in the German heat marketRenewable Heat Sources Act*, Renewable Energy, Volume 32, Issue 7 (2007).

[66] Bird R.: *A Simplified Clear Sky Model for Direct and Diffuse Insolation on Horizontal Surfaces*, Solar Energy Research Institute, E.E.U.U. (1991).