RENEWABLE ENERGY SOURCES

GEETHANJALI COLLEGE OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF *Mechanical Engineering*

(Name of the Subject / Lab Course) : Renewable Energy Sources

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Contents

2. Syllabus copy

JAWAHARLAL NEHRU TECHNOLOGIVAL UNIVERSITY HYDERABAD

II Year B.Tech. MECH -II Sem **L T/ P/ D C**

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RENEWABLE ENERGY SOURCES

UNIT – I:

PRINCIPLES OF SOLAR RADIATION: Role and potential of new and renewable source, the solarenergy option, Environmental impact of solar power, physics of the sun, the solar constant, extraterrestrialand terrestrial solar radiation, solar radiation on titled surface, instruments for measuring solar radiation and sun shine, solar radiation data.

UNIT – II

SOLAR ENERGY COLLECTION: Flat plate and concentrating collectors, classification of concentrating collectors, orientation and thermal analysis, advanced collectors.

UNIT – III

SOLAR ENERGY STORAGE AND APPLICATIONS : Different methods, Sensible, latent heat and stratified storage, solar ponds. Solar Applications- solar heating/cooling technique, solar distillation and drying, photovoltaic energy conversion.

WIND ENERGY: Sources and potentials, horizontal and vertical axis windmills, performance characteristics, Betz criteria

UNIT-V

BIO-MASS: Principles of Bio-Conversion, Anaerobic/aerobic digestion, types of Bio-gas digesters, gas yield, combustion characteristics of bio-gas, utilization for cooking, I.C.Engine operation and economic aspects.

UNIT-VI

GEOTHERMAL ENERGY: Resources, types of wells, methods of harnessing the energy, potential in India.

UNIT-VII

OCEAN ENERGY: OTEC, Principles utilization, setting of OTEC plants, thermodynamic cycles. Tidal and wave energy: Potential and conversion techniques, mini-hydel power plants, and their economics.

UNIT-VIII

DIRECT ENERGY CONVERSION: Need for DEC, Carnot cycle, limitations, and principles of DEC. Thermo-electric generators, seebeck, peltier and joul Thomson effects, Figure of merit, materials, applications, MHD generators, principles, dissociation and ionization, hall effect, magnetic flux, MHD accelerator, MHD Engine, power generation systems, electron gas dynamic conversion, economic aspects. Fuel cells, principles, faraday’s law’s, thermodynamic aspects, selection of fuels and operating conditions.

TEXT BOOKS :

1. Reneweble energy resources/ Tiwari and ghosal/Narosa.
2. Non conventional Energy Sources / G.D.Rai CBS.

REFERENCE BOOKS:

i) Renewable Energy Sources / Twidell & Weir

ii) Solar Energy/ Sukhatme

iii) Solar power Engineering/ B.S. Magal Frank Kreith & Frank Kreith

iv) Principles of Solar Energy / Frank Kreith & John F Kreider

v) Non Conventional Energy / Ashok V Desai / Wiley Eastern

vi) Non Conventional Energy Systems / K Mittal / Wheeler

vii) Renewable Energy Technologies / Ramesh & Kumar / Narosa

3. Vision of the Department

To become a Regionally and Nationally recognized Department in providing high Quality Education in Mechanical Engineering, leading to well qualified, innovative and successful engineers.

4. Mission of the Department

1. To prepare professionally competent Mechanical Engineers by developing analytical and research abilities.
2. Prepare its graduates to pursue life-long learning, serve the profession and meet intellectual, ethical and career challenges.
3. To develope linka ges with R&D organizations and Educational Institutions in India and abroad for excellence in teaching, research and consultancy practices.

5. PEOs and POs

Program Educational Objectives (PEOs):

I. To prepare students with excellent comprehension of basic sciences, mathematics and engineering subjects facilitating them to gain employment or pursue postgraduate studies with an appreciation for lifelong learning.

II. To train students with problem solving capabilities such as analysis and design with adequate practical skills wherein they demonstrate creativity and innovation that would enable them to develop state of the art equipment and technologies of multidisciplinary nature for societal development.

III. To inculcate positive attitude, professional ethics, effective communication and interpersonal skills which would facilitate them to succeed in the chosen profession exhibiting creativity and innovation through research and development both as team member and as well as leader.

Program Outcomes (POs):

The Program Outcomes of the Department of Mechanical Engineering are to educate graduates, who by the time of graduation, will be able to demonstrate:

1. An ability to apply knowledge of mathematics, science, and engineering.
2. An ability to design and conduct experiments, as well as to analyze and interpret data.
3. An ability to design a system, component, or process to meet desired needs.
4. An ability to function on multi-disciplinary teams.
5. An ability to identify, formulate, and solve engineering problems.
6. An understanding of professional and ethical responsibility.
7. An ability to communicate effectively.
8. An ability to apply their broad education toward the understanding of the impact of engineering solutions in a global and societal context.
9. A recognition of the need for, and the ability to engage in life-long learning.
10. A knowledge of contemporary issues.
11. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

6. Course Objectives and Outcomes

Course Objectives (as per JNTU-H)

The recent sharp increases in the prices of oil, natural gas, uranium and coal underline the importance for all countries to focus on development of alternative energy resources. For developing countries, these price increases can have ruinous economic consequences; for many countries already plagued by poverty this means a choice between fuel and food, health care, education and other essentials. Renewable energy resources need priority because: 1) the overwhelming scientific evidence that anthropological emissions of greenhouse gases from carbon combustion threaten catastrophic results from rapid climate change; 2) the severe health and environmental consequences from fossil fuel combustion being experienced in every major developing country city; and 3) the high cost, environmental damages and security threats of nuclear power.

The world already is responding to these imperatives. "Annual investment in renewable energy was an estimated $17 billion worldwide in 2002, up from $6 billion in 1995. And cumulative investment of at least $80 billion was made in renewable energy during the period 1995 – 2002."[i]

There are a host of economic, social and legal barriers that account for the failure of renewable resources to reach their potential. Those barriers can be overcome. They have been overcome successfully in many jurisdictions. There are successful examples in many developing countries. Legislation can remove these barriers, get the price signals right, and encourage successful utilization of renewable resources anywhere. This paper explores mechanisms that can be used and that have been used successfully in developing countries in various parts of the world to remove those barriers and to promote greater use of renewable resources, particularly in rural areas of developing countries.

Course Objectives (as per our college plan)

1. It helps in substantiation a reason for failure of mechanical device.
2. Mechanics of machines provide a remedial action for mechanical device failure.

3. Enables problem solving approach including vibration, noise, power, transmission and mechanical mechanism.
4. Enables proper selection of gear and bearing systems.
5. Helps in investigation of problems of cam, flywheels and linkages.
6. Above all it enables precise interpersonal skill development with ethical behavior.

Course Outcomes

There are abundant examples, only a few of which have been identified here, in both developed and developing countries, of successful adoption of cost-effective renewable energy measures to ameliorate pollution while aiding their economies. A wide variety of legislative and voluntary programs have been undertaken and the legal and financial mechanisms for doing so also are many and varied. It is possible to meet the world's energy, development and environmental needs. This achievement can even be done on a basis of long term profitability. But achieving these goals will take determined action and political will among all the governments and international institutions of the world. For the developed countries and international institutions, achieving these goals will require a vast increase in the resources they devote to funding sustainable energy, technology transfer and education and training in the developing countries. For developing countries, achieving these goals will require an increased commitment to eliminating the barriers to adoption of sustainable energy measures and creating a climate and legislation to encourage private investment in them.

7. Brief Importance of the Course and how it fits into the curriculum

Renewable resources covered here include: electricity produced from the light of the sun via photovoltaic cells on individual buildings or for communities of buildings, or for the production of central station power in vast arrays; from the heat of the sun, again for localized tasks like providing homes and businesses with hot water or space heating, or providing central station power using fields of parabolic collectors focused on a fixed hot water source[ii] or solar ponds; from the power of the wind; from the heat below the earth through various geothermal applications; from the power of ocean tides and waves; from the temperature variations between ocean surfaces and depths; from small hydroelectric installations; from agricultural wastes through biomethanation; and from biomass crops grown for energy use or from crop waste cellulose; the biomass can be refined to produce ethanol or gasified for heat, electric and transportation applications.

Traditional biomass in the form of firewood is not covered as a renewable resource, however, because it most often involves the cutting down of ecologically valuable forests that act as protection against floods and erosion and as sinks for carbon dioxide and because the gathering of firewood is so debilitating to women and children who also suffer serious health hazards when the firewood is burned in enclosed spaces for heating and cooking. The same is true of burning animal dung for heating and cooking. However, so-called modern biomass consisting of crops to ethanol and gasified wood and crop wastes is included.

8. Prerequisites if any

1) Eradicate extreme poverty and hunger

2) Achieve universal primary education Promote gender equality and empower women.

3) Reduce child mortality. Improve maternal health. Combat malaria and other diseases ensure environmental sustainability. Reverse the losses of environmental resources. Halve the proportion of people without sustainable access to safe drinking water.

4) Develop a global partnership for development. Includes the commitment to good governance, development and poverty reduction – both nationally and internationally. Address the special needs of the least developed countries. More generous ODA for countries committed to poverty reduction.

5) Improve access to reliable and affordable energy services to achieve sustainable development and to facilitate the achievement of the Millennium Development Goals, including the goal of halving the proportion of people living in poverty by 2015.

6) Promote education to provide information for both men and women on available energy sources and technologies.

7) Facilitate, with the financial and technical assistance of developed countries, the access of the poor to reliable energy services to improve the standards of living of their populations.

8) Develop and disseminate alternative technologies with the aim of giving a greater share of the energy mix to renewable energies.

9) Utilize financial instruments and mechanisms to provide financial resources to developing countries to meet their capacity needs for training and technical know-how, including promoting energy efficiency and conservation, renewable energies and clean technologies.

10) Renewable energies provide a substantial amount of local jobs indirect impacts, such as providing evening courses in small villages due to the availability of local electricity.

11) Health benefits reflected in well being and a cleaner atmosphere, Cleaner, more sustainable and long term energy; well-being provided by access electricity services.

12) Energy self-sufficient countries; meeting the special needs of isolated communities; shared global responsibility

9. Instructional Learning Outcomes

- It helps in substantiation a reason for failure of mechanical device.
- Mechanics of machines provide a remedial action for mechanical device failure.
- Enables problem solving approach including vibration, noise, power, transmission and mechanical mechanism.
- Enables proper selection of gear and bearing systems.
- Helps in investigation of problems of cam, flywheels and linkages.
- Above all it enables precise interpersonal skill development with ethical behavior.

10. Course mapping with PEOs and POs

Mapping of Course with Programme Educational Objectives:

S.No	**Course component**	**code**	**course**	**Semester**	**PEO 1**	**PEO 2**	**PEO 3**
1	Mechanical Engineering		RES	2	√	√	

Mapping of Course outcomes with Programme outcomes:

*When the course outcome weightage is < 40%, it will be given as moderately correlated (1).
*When the course outcome weightage is >40%, it will be given as strongly correlated (2).

POs	1	2	3	4	5	6	7	8	9	10	11	12	13	**Mechanical Engineering**
RES	**2**	**2**	**2**	**1**	**2**				**1**	**1**	**2**	**2**	**2**	
CO 1:	**2**	**2**	**2**	**1**	**2**				**1**	**1**	**2**	**2**	**2**	
CO 2: .	**2**	**2**	**2**	**1**	**2**				**1**	**1**	**2**	**2**	**2**	
CO 3:	**2**	**2**	**2**	**1**	**2**				**1**	**1**	**2**	**2**	**2**	
CO 4:	**2**	**2**	**2**	**1**	**2**				**1**	**1**	**2**	**2**	**2**	
CO 5:	**2**	**2**	**2**	**1**	**2**				**1**	**1**	**2**	**2**	**2**	
CO 6:	**2**	**2**	**2**	**1**	**2**				**1**	**1**	**2**	**2**	**2**	
CO 7:	**2**	**2**	**2**	**1**	**2**				**1**	**1**	**2**	**2**	**2**	
CO 8:	**2**	**2**			**2**		**2**		**1**	**1**	**2**	**2**	**2**	

1. Time table of concerned class

Time	9.30-10.20	10.20-11.10	11.10-12.00	12.00-12.50	12.50-1.30	1.30-2.20	2.20-3.10	3.10-4.00	4.00-4.50
Period	**1**	**2**	**3**	**4**		**5**	**6**	**7**	
Monday			**RES**	**RES**					
Tuesday	**RES**	**RES**							
Wednesday					**LUNCH**				
Thursday									
Friday									
Saturday									

12. Individual time table

Time	9.30-10.20	10.20-11.10	11.10-12.00	12.00-12.50	12.50-1.30	1.30-2.20	2.20-3.10	3.10-4.00	4.00-4.50
Period	**1**	**2**	**3**	**4**		**5**	**6**	**7**	
Monday			**RES**	**RES**					
Tuesday	**RES**	**RES**							
Wednesday					**LUNCH**				
Thursday									
Friday									
Saturday									

13. Lecture schedule with methodology being used / adopted

Sl No	Unit No.	Total No. of Periods	Topics to be covered	Reg./ Additional	Teaching aids used LCD. OHP.BB	Remarks
1	**I**	9	**PRINCIPLES OF SOLAR RADIATION**	Regular	OHP,BB	
2			Role and potential of new and renewable source	Regular	OHP,BB	
3			the solar energy option, Environmental impact of solar power	Regular	OHP,BB	

4			physics of the sun, the solar constant	Regular	OHP,BB	
5			Extraterrestrial and terrestrial solar radiation	Regular	BB	
6			solar radiation on titled surface	Regular	BB	
7			instruments for measuring solar radiation and sun shine	Regular		
			solar radiation data			
8			Tutorial class – 1	Regular	BB	
9			Assignment – 1	Regular		
10	**II**	7	**SOLAR ENERGY COLLECTION**	Regular	OHP,BB	
11			Flat plate and concentrating collectors	Regular	OHP,BB	
12			classification of concentrating collectors	Regular	BB	
13			orientation and thermal analysis	Regular	BB	
14			advanced collectors	Regular	OHP,BB	
15			Tutorial class – 2	Regular	BB	
16			Assigment – 2	Regular		
17	**III**	6	**SOLAR ENERGY STORAGE AND APPLICATIONS**	Regular		
			Different methods	Regular		
			Sensible, latent heat and stratified storage			
			solar ponds. Solar Applications			
18			solar heating/cooling technique	Regular	OHP,BB	
19			solar distillation and drying	Regular	BB	
20			photovoltaic energy conversion	Regular	OHP,BB	
21			Tutorial class- 3	Regular	BB	
22			Assignment – 3	Regular	BB	
23	**IV**	7	**WIND ENERGY**	Regular	OHP,BB	

24			Sources and potentials	Regular	OHP,BB	
25			horizontal and vertical axis windmills	Regular	BB	
26			performance characteristics	Regular	LCD,OHP, BB	
27			Betz criteria	Regular	OHP,BB	
28			Tutorial class – 4	Regular	BB	
29			Assignment – 4	Regular	OHP,BB	
	V	7	**BIO-MASS**	Regular	OHPBB	
			Principles of Bio-Conversion	Regular	OHP,BB	
			Anaerobic/aerobic digestion	Regular	OHPBB	
30			types of Bio-gas digesters	Regular	OHP,BB	
31			Gas yield, combustion characteristics of bio-gas	Regular	OHPBB	
32			utilization for cooking,	Regular	OHP,BB	
33			I.C.Engine operation	Regular	OHPBB	
34			Economic aspects.	Regular	OHPBB	
35			Tutorial class – 5	Regular	OHP,BB	
36			Assignment – 5	Regular		
	VI	5	**GEOTHERMAL ENERGY**	Regular	BB	
37			Resources		BB	
38			types of wells	Regular	OHP,BB	
39			methods of harnessing the energy	Regular	OHP,BB	
40			potential in India.	Regular	OHP,BB	
41			Tutorial class – 6	Regular	OHP,BB	
42			Assigment – 6	Regular		
43	**VII**	5	**OCEAN ENERGY**	Regular	BB	

44			OTEC Principles utilization	Regular	OHP,BB	
45			setting of OTEC plants	Regular	OHPBB	
46			thermodynamic cycles	Regular	OHP,BB	
47			Tidal and wave energy	Regular	BB	
48			Potential and conversion techniques	Regular	BB	
49			mini-hydel power plants	Regular	BB	
50			mini-hydel power plants, and their economics	Regular	OHP,BB	
51			Tutorial class – 7	Regular	BB	
52			Assignment – 7	Regular		
53	**VIII**	8	**DIRECT ENERGY CONVERSION**	Regular	OHP,BB	
54			Need for DEC, Carnot cycle, limitations, principles of DEC.	Regular	BB	
55			Thermo-electric generators, seebeck	Regular	BB	
56			peltier and joul Thomson effects	Regular	OHP,BB	
57			Figure of merit, materials, applications,	Regular	OHP,BB	
58			MHD generators	Regular	BB	
59			principles, dissociation and ionization, hall effect	Regular	LCD,OHP, BB	
60			magnetic flux, MHD accelerator, MHD Engine	Regular	OHP,BB	
61			power generation systems, electron gas dynamic conversion, economic aspects	Regular	OHP,BB	
62			Fuel cells, principles, faraday's law's, thermodynamic aspects	Regular	BB	
63			selection of fuels and operating	Regular	BB	
64			Tutorial class – 8	Regular	OHP,BB	
65			Assignment – 8			

14. Detailed Notes

UNIT-1 & 2

Solar Energy

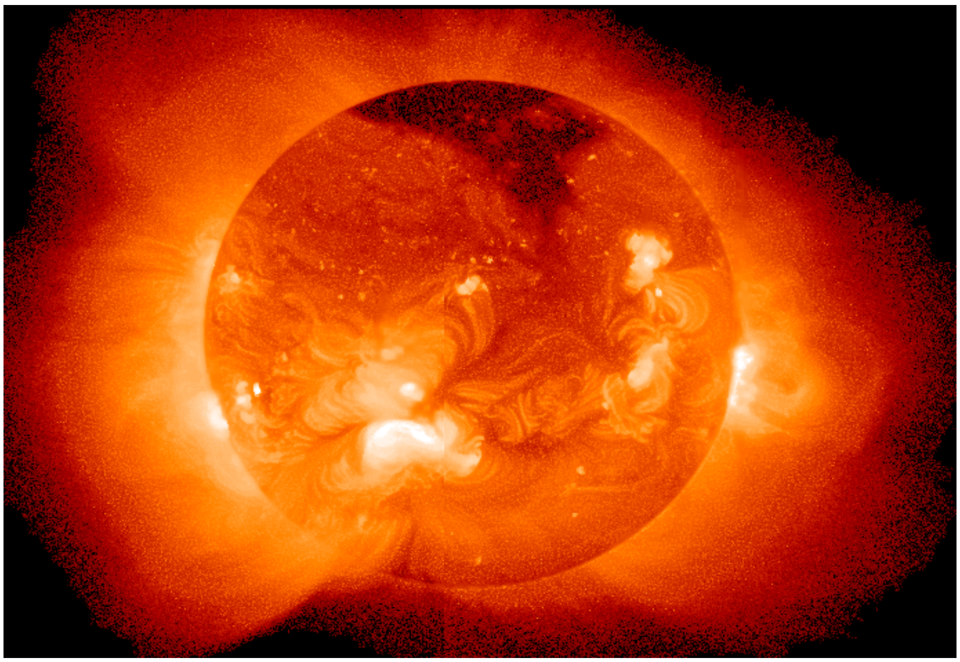


Fig. 1: The sun

IL 1 ** Source of figure 1.

(eclipsenow.blogspot.com/2007/07/solar.html)

Videos:

ILV 1 ** Solar energy in the world today**

http://video.google.ca/videosearch?hl=en&q=Solar%20energy&um=1&ie=UTF-8&sa=N&tab=wv#

See especially:

SOLAR ENERGY TECHNOLOGY BREAKTHROUGH!

How Solar Energy Panels Work

Solar energy

Learn about Solar Energy and Solar Panel Installation from an ...

'Major discovery' from MIT primed to unleash solar revolution ...

How Solar Energy Works

Clean solar energy

Saving Energy with Solar Power: How Solar Energy is Converted

Ecuador Solar Energy Project

Astralux Solar Energy Installations - Part 1

Astralux Solar Energy Installations - Part 1

How To Produce Electricity From Solar Energy

Unlimited Energy Solar Solutions

THE MAIN IDEA:

Energy from the sun travels to the earth in the form of electromagnetic radiation similar to radio waves, but in a different frequency range. Available solar energy is often expressed as energy per time per unit area, Joules per second per square meter, or watts per square metre (W/m^2). The amount of energy available from the sun outside the Earth's atmosphere is approximately 1400 W/m^2; that's nearly the same as a high power hair drier for every square meter of sunlight! Some of the solar energy is absorbed as it passes through the Earth's atmosphere. As a result, on a clear day the amount of solar energy available at the Earth's surface in the direction of the sun depend of the angle of elevation and is typically only about 400 W/m^2 in Canada. At any particular time, the available solar energy is primarily dependent upon how high the sun is in the sky and current cloud conditions. On a monthly or annual basis, the amount of solar energy available also depends upon the location. Furthermore, useable solar energy depends upon available solar energy, other weather conditions, the technology used, and the application involved.

There are many ways that solar energy can be used effectively. Applications of solar energy use can be grouped into there are three primary categories:

1. Heating/cooling,

2. Electricity production, and

3. Chemical processes.

In this LCP we will discuss the first two only.

The most widely used applications are for water and space heating. Ventilation solar air heating is also growing in popularity. Uptake of electricity producing solar technologies is increasing for the applications photovoltaics (primarily) and concentrating solar thermal-electric technologies. Due to recent advances in solar detoxification technologies for cleaning water and air, these applications hold promise to be competitive with conventional technologies. Taken from:

IL 2 * Earth's Energy Budget**

(http://www.canren.gc.ca/tech_appl/index.asp?CaId=5&PgId=121)

Fig. 2: The energy budget of the Earth

IL 3 ** Source of figure 2

(http://www.solar-benefits.com/index.5.gif)

IL 4 ** Properties of the sun

(http://ircamera.as.arizona.edu/astr_250/Lectures/Lecture_12.htm)

A brief history of solar energy

Here are some links to examples of good summaries (histories) of solar energy:

IL 5 *

http://www.californiasolarcenter.org/history_solarthermal.html

IL 6 *

http://www.southface.org/solar/solar-roadmap/solar_how-to/history-of-solar.htm

IL 7 **

http://www.alternate-energy-sources.com/history-of-solar-energy.html

IL 8 **

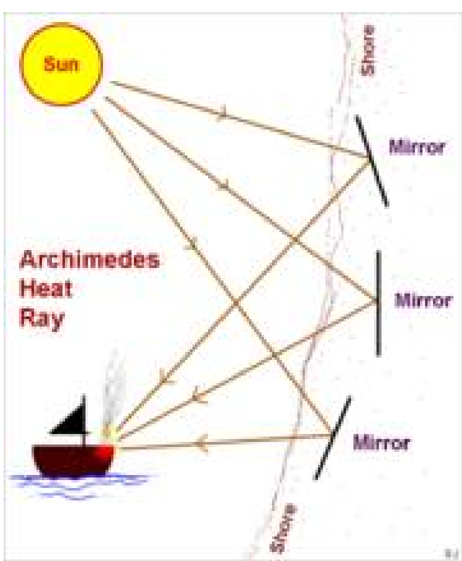
http://www.uccs.edu/~energy/courses/160lectures/solhist.htm

IL 9 *

http://www.abc.net.au/rn/science/earth/stories/s225110.htm

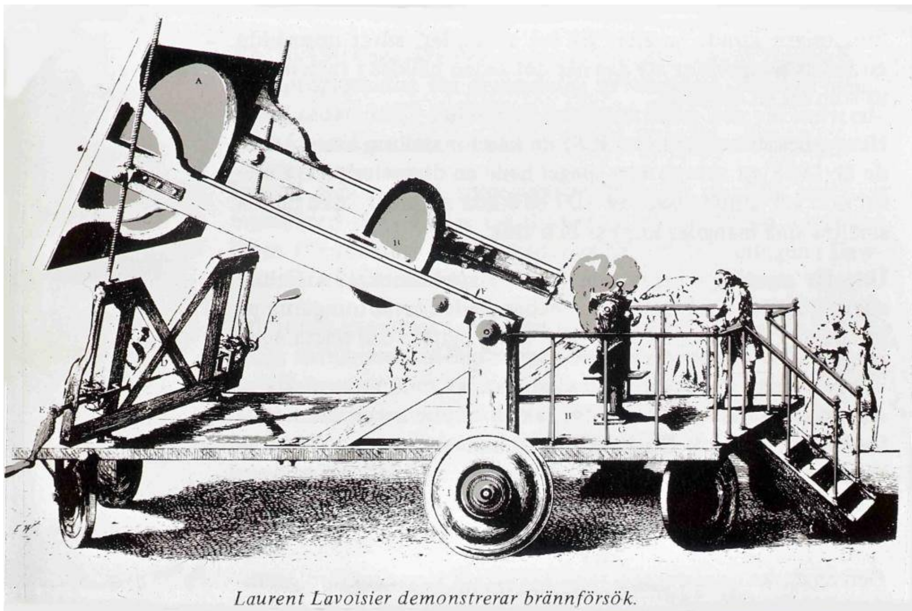
IL 10 *

http://www.annesley.sa.edu.au/amep/energyconservation_solarenergy/history.htm



Fig, 3: Archimedes "heat ray" gun. (a legend only)

Legend claims that Archimedes used polished shields to concentrate sunlight on the invading Roman fleet and repel them from Syracuse.



Laurent Lavoisier demonstrerar brännförsök.

Fig. 4: The French chemist Lavoisier experimented with concentrating solar energy using a large parabolic mirror.

Combustion, generated by focusing sunlight over flammable materials using lenses, experiment conducted by Lavoisier circa 1770s.

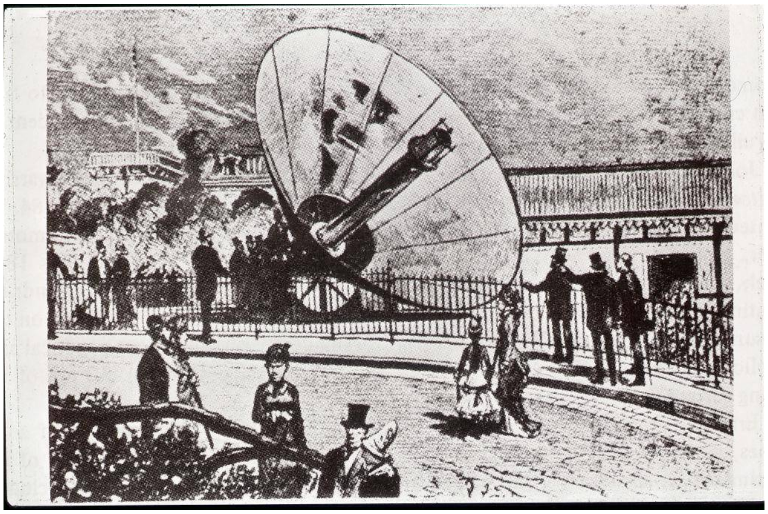


Fig. 5: In 1866, Auguste Mouchout used a parabolic trough to produce steam for the first solar steam engine.

Auguste Mouchout, inventor of the first active solar motor, questioned the widespread belief that the fossil fuels powering the Industrial Revolution in the 19th century would never run out. Prophericaly he said:

> *Eventually industry will no longer find in Europe the resources to satisfy its prodigious expansion. Coal will undoubtedly be used up. What will industry do then?*

In 1861, Mouchout developed a steam engine powered entirely by the sun. But its high costs coupled with the falling price of English coal doomed his invention to become a footnote in energy history. Nevertheless, solar energy continued to intrigue and attract European scientists through the 19th century. Scientists developed large cone-shaped collectors that could boil ammonia to perform work like locomotion and refrigeration. France and England briefly hoped that solar energy could power their growing operations in the sunny colonies of Africa and East Asia.

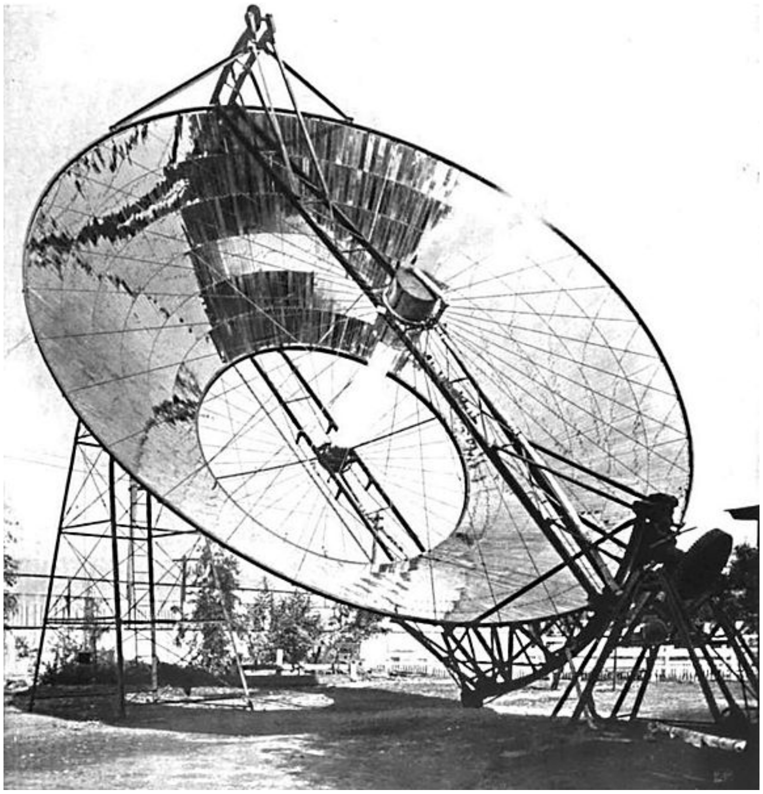


Fig. 6: 1901 "solar motor" in operation in California.

IL 11 * Timeline of solar energy history**
(http://www1.eere.energy.gov/solar/solar_time_1900.html)

IL 12 * Timeline of solar energy history**
(http://www.noutilitybill.com/solar_history.html?solar+history=)

IL 13: ***

http://www.anglophone-direct.com/Mont-Louis-Font-Romeu-Odeillo-Via

The solar furnace in Mont Louis**,** built in 1949 by Professor Félix Trombe, was the first solar furnace in the world. This dual reflection solar furnace has been in steady evolution over the past 50 years and in 1993, was taken over by the limited liability company "Solar Furnace Development" who, along with continued scientific research, is the first company to use a solar furnace for industrial and manufactured products such as the firing of ceramics, and bronze and aluminum products.

Professor Trombelater (1969-1971) directed the design and the construction of the largest solar furnace in the world that we will discuss in detail.

Fig. 7: The solar furnace in Mont Louis.

Sun power in the Pyrenees

In 1972 Time magazine's Science section described the world's largest solar furnace in sufficient technical detail to allow the setting for an investigation that involves a great deal of students' knowledge of physics and, with some guidance, can lead to her asking a series of questions that lead to problems and experimentation that go beyond the textbook. These questions eventually lead to the discussion radiation, optics, wave motion, thermodynamics, solar energy, quantum mechanics and thermonuclear reactions. It should also be mentioned that the Mont-Louis solar furnace in the Pyrenees is still the largest in the world**.**

Fig. 8: The Solar Furnace of Odeillo in the French Pyrenees.

(This is the largest solar furnace in the world)

IL 14 ** Source of figure 8

(http://www.stacey.peak-media.co.uk/Pyrenees/Odeillo/Odeillo.htm)

Perched high in the Pyrenees, France's powerful new solar furnace (1970) harnesses the almost limitless energy of the sun. Eight stories tall, the furnace's gleaming reflector dwarfs the ancient buildings near by and turns the surrounding hillsides topsy-turvy on its curved surface. Lined up in tiers on a pasture in front of the big reflector stand 63 smaller mobile mirrors. These heliostats, as they are called, can be individually adjusted so that each one reflects the sun's rays directly into the big parabola, thereby creating striking flare-ups of light. Focusing these rays at the oven building only a short distance from its base, the giant mirror concentrates the sun's radiation on the small target area. The converged beams, which are no wider than a foot at their target, can create temperatures as high as 6,300° F (3500 °C.)

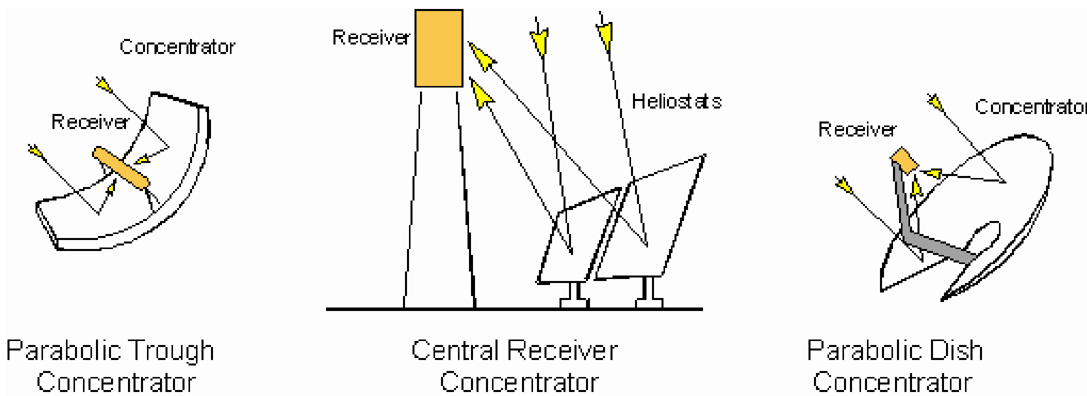


Fig. 9: Three commonly used reflecting schemes for concentrating solar energy to attain high temperatures.

IL 15 ** Source of figure 9

(http://www.powerfromthesun.net/chapter1/Chapter1.htm)

The description of this context is based on an article in Time magazine's Science section that appeared in the May 18. 1970 issue. The Time article describes the world's largest (1970) solar furnace in sufficient detail for an investigation that involves a great deal of the young physics student's knowledge of physics. The situations described below move from the practical aspects of the furnace to a discussion of geometric optics, radiation, quantum theory, and thermonuclear reactions. The following is the content of the article as it was given in Time magazine.

A simple magnifying glass, focusing the sun's rays, can scorch a piece of wood or set a scrap of paper on fire. Solar radiation can also be concentrated on a much more awesome scale. It can burn a hole through thick steel plate, for example, or simulate the thermal shock of a nuclear blast. It can, that is, with the aid of a super reflector of the sort that has been set up by French scientists high in the Pyrenees. Ten years in the building, the world's largest solar furnace is a complex of nearly 20,000 mirrors and can concentrate enough sunlight to create temperatures in excess of 6,000° F, or 3500°C.

Harnessing solar energy is hardly a new accomplishment. Nearly 22 centuries ago, the Greek mathematician Archimedes is said to have temporarily saved Syracuse from Roman conquest by setting the invading fleet aflame with numerous large mirrors. In the 18th century, the pioneer French chemist Lavoisier produced enough heat with 52-inch-wide lenses to power his experiments. Though Lavoisier's work was cut short by the French Revolution (he was guillotined in 1794)), his history has not discouraged contemporary French scientists—notably Physical Chemist Felix Trombe, a research director of France's National Center for Scientific Research and its premier experimenter with the sun's energy.

For more than 20 years, Trombe has championed solar furnaces as an ideal source of intensive heat for both industrial uses and scientific experimentation. In 1946 he fashioned his first sun stove out of a captured German antiaircraft searchlight mirror at an observatory near Paris. Moving to the old Pyrenean citadel town of Mont-Louis where the sun shines as many as 200 days a year, he has since built five larger solar furnaces. Now, in masterly style, he has created his *pièce de résistance* on a hillside in the nearby ski resort of Odeillo. Compared with similar devices in several other countries, such as the U.S. Army's 30-kilowatt stove at Natick, Mass., Odeillo's 1,000-kilowatt structure is easily the Mount Palomar of solar furnaces.

Fig. 10: The Solar Furnace of Odeillo; The parabolic shape of the giant solar collector is evident here.

Fig. 11: The array of mirrors are controlled by a computer and turn with the sun.

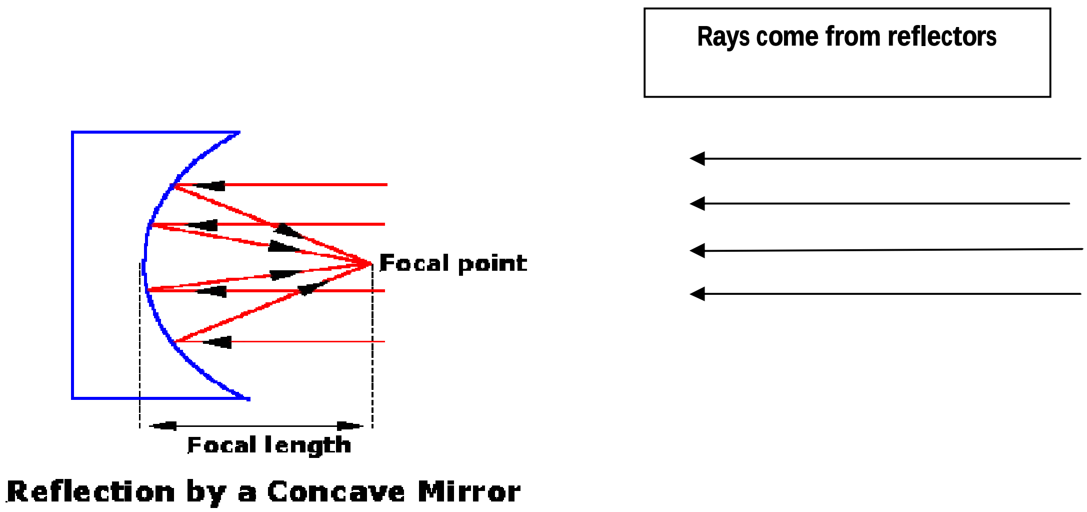


Fig. 12: The geometry of reflection depend on the law of reflectivity

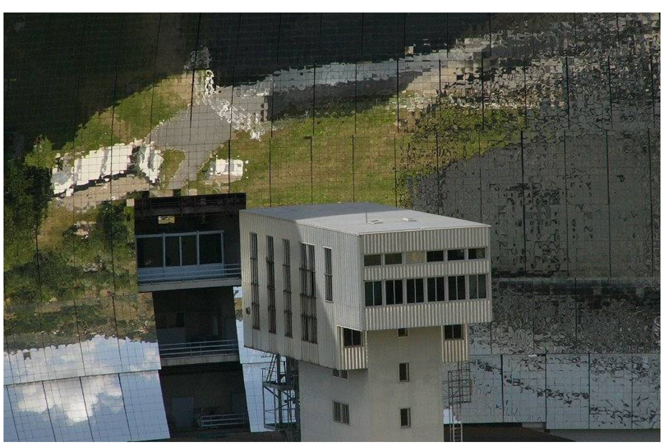


Fig. 13: The furnace is located at the focus of the parabolic mirror

Fig. 14: The array of solar collector and the mirrors in perspective.
See Google Earth for pictures of the solar furnace as well as surrounding area.

IL 16 ******* Pictures of the Odeillo solar furnace and area

(**http://commons.wikimedia.org/wiki/Forn_solar_d'Odell%C3%B3**)

IL 17 ***** Summary report on 10 years of operation**

(**http://www.dlr.de/en/Portaldata/1/Resources/kommunikation/publikationen/109_nachrichten/dlr-nari109_en_76-79.pdf**)

Delicate Adjustment (A report from the early 1970s)

The furnace's appearance is as spectacular as its power. Its glittering eight-story-high parabolic reflector (roughly half the size of a football field) towers over Odeillo's centuries-old houses. Anchored against a reinforced concrete office and laboratory building, the huge concave mirror consists of **8,570 individual reflectors**. For the furnace to operate efficiently, these small (**18 inches** square, or **46 cm** square) mirrors must be precisely adjusted so that their light will converge at the parabola's focal point **59 ft (18.0 m)** in front of the giant reflector. Only half of the mirrors have been aligned thus far, although the structure has been finished for more than year. Reason: the work is so delicate that technicians can usually adjust no more than a few dozen even on the sunniest of days. The “focal point” is actually about 0.10 m^2.

Far too huge to follow the sun itself, the parabolic reflector depends on the help of 63 smaller mirrors set in eight rows on a terraced slope in front of it. Called heliostats (from the Greek *helios,* sun; *statos,* to cause to stand still), they track the solar disk across the sky, capture its light and bounce it in parallel beams into the big mirror. The system involves some ingenious engineering. Each heliostat is controlled by its own photoelectric cells. Whenever one of the heliostats (each of which is made of 180 individual mirrors) loses its lock on the sun, these tiny electric eyes inform a minicomputer, which in turn controls a pair of hydraulic pumps that can rotate and tilt the heliostat into the proper position. Only one manual adjustment is needed to operate the heliostats. It is made at the end of the day, when they must be reset to face the position of the next day’s sunrise.

Rotating Vats.

The crucible of the furnace is located inside a smaller T-shaped building near the base of the big mirror (See Fig. 14). It is set behind large stainless-steel doors at the focal point of the parabola—where the sun’s scorching rays are concentrated into a blazing circle only twelve inches wide. Target material, hoisted into place by a ten-ton lift, is placed into an inclined trough; as the target melts, it runs off into catch pans. Another, more sophisticated technique is to load the material into two aluminum vats whose outer walls are water-cooled to prevent melting. Placed with their open ends at the focal point and rotated like washing machines to distribute the heat evenly, these containers can hold up to 2¾ tons of molten material at one time (See Fig. 20).

Is all this elaborate effort worth the French government’s $2,000,000 (in 1970 currency) investment in the furnace? Professor Trombe says so. For one thing, the power is almost entirely free (only 13 kilowatts of electric power is needed to operate the mirrors). More important, the furnace gives off what he calls “aristocratic” or uncontaminated heat; there is, for example, none of the adulterating carbon that is produced by the hot electrodes in ordinary high-intensity electric arc furnaces. Thus the solar oven is ideal for the production of chemically pure materials

French industry is beginning to agree. In a recent test for an electronics manufacturer, the furnace fused several tons of bauxite and ceramics to produce high-voltage insulators of unmatched purity. The oven could easily fuse other highly heat-resistant materials: quartz crystals for radio transmitters, corundum for industrial grinding stones and zircon parts for nuclear reactors. It could also be used in experiments to develop new space-age alloys, such as special tungsten or cobalt steels, and even materials to withstand the searing heat of a nuclear blast.

Initial Fears.

Aside from the industrial and scientific benefits, the furnace has produced an entirely unexpected dividend. At first, Odeillo's villagers thought they might be blinded by the intense light from what they call *le four solaire* (the solar oven). Now they know that the light is concentrated at only one small area and that there is no such danger. In fact, the villagers have become quite proud of the strange, shimmering edifice in their midst. And why not? The solar furnace is not only handsome in an other-worldly way; it is also a significant tourist attraction, bringing thousands of people to gaze in awe at Odeillo's mighty mirror.

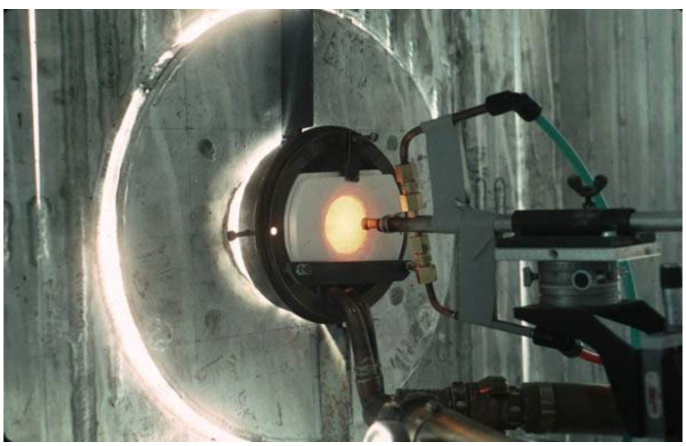


Fig. 15: Beam focus

Fig. 16: Command centre.

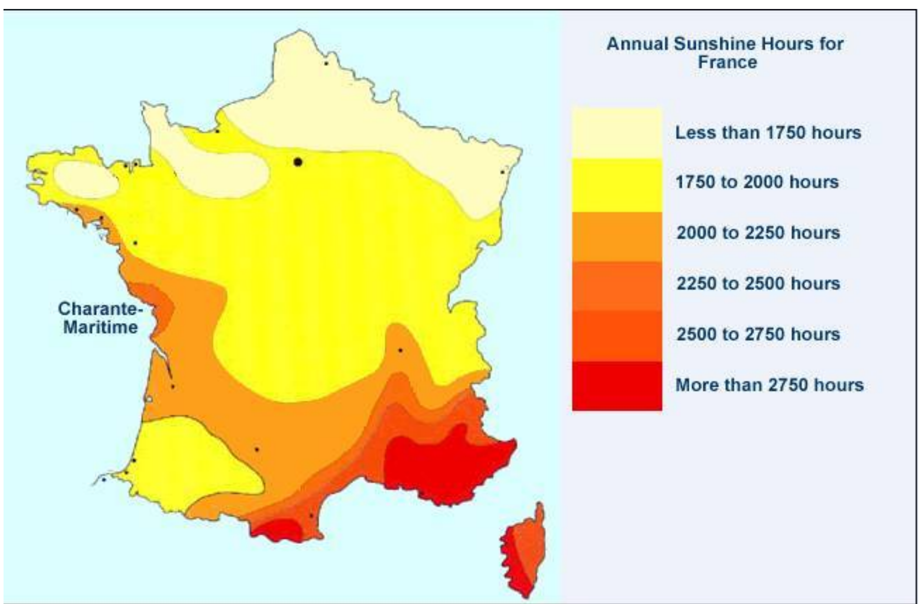


Fig. 17: Sunshine "map" of France

IL 18 ** Source of figure 17

http://www.french-holiday-property.com/regional.htm

(http://www.french-holiday-property.com/regional)

IL 19 ** The most comprehensive description of the GSF and vicinity**

(http://www.stacey.peak-media.co.uk/Pyrenees/Odeillo/Odeillo.htm)

IL 20 * An adjustable view of the GSF on Google Earth**

(http://perljam.net/google-satellite-maps/id/3384/France//Font_Romeu/Solar_Furnace_at_Odeillo_Font_Romeu_in_the_French_Pyrenees)

The solar furnace is located in Odeillo in the Pyrénées Orientales (France) in latitude of 42° 29' 48" North, and in longitude of 2° 1' 49" East and at 1500 meters up. This geographical position guarantees very good weather conditions for this kind of facilities. The total number of sunny hours is 3000h/Year, the humidity is very low and the direct solar flux is between 800 w/m^2 and 1050 w/m^2 for the maximum.

The parabolic reflector gives at the focal point a maximum flux of 1000 W/cm^2. The experimentations takes place at the focal zone (18 m in front of the paraboloid. The range of available temperature is from 800° to 2500 °C (the maximum reachable temperature is 3800 °C) for a maximum thermal power of 1000 kW. 63 heliostats, installed on 8 terraces reflects the sunlight on the parabolic reflector. Every heliostat position is calculated so that the reflected light is parallel to the symmetry axis of the paraboloid. See the figure below.

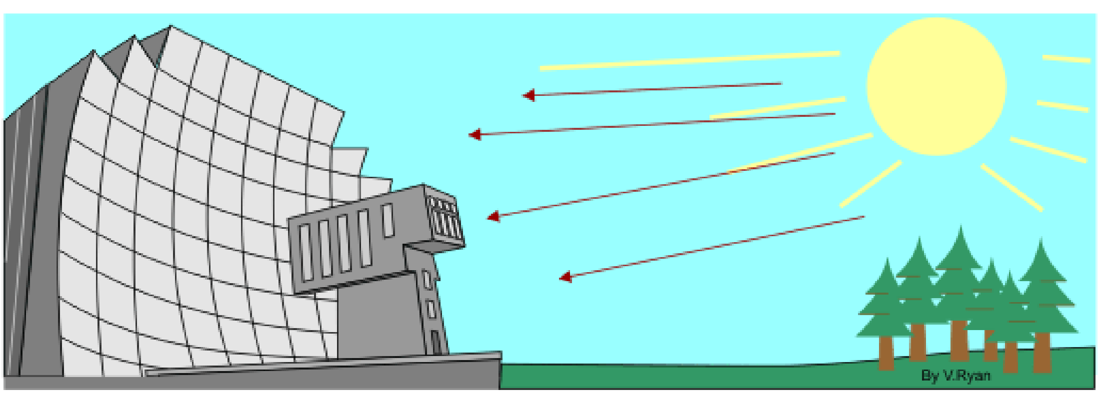


Fig. 18: The picture above shows the parabolic reflector of the Odeillo-Font-Romeau Solar Furnace in France. 63 flat mirrors, shown in figure 19, track the sun and concentrate the light on a reflector. The reflector

then concentrates the rays to produce 1000 kilowatts and a temperature of about 3500 K.

Fig. 19: The 63 mirrors (heliostats), each having an area of 45 m^2, with a combined area of 2835 m^2. The reflectivity is 0.79.

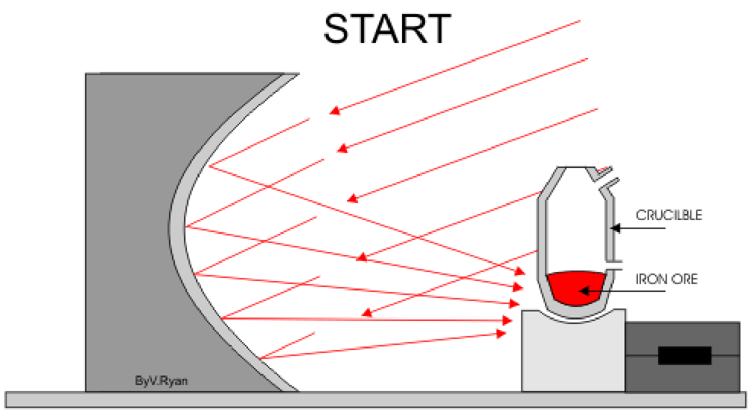


Fig. 20: The picture above shows how the sun's rays are focused on the crucible holding the ore. The ore is heated to a very high temperature (depending on the material or substance) until it becomes molten, and then it is poured. Pollution is kept to a minimum as solar power is a clean source of energy.

Fig. 21: A good view of the giant parabolic solar collector It has a reflective area of 1830 m^2. The reflectivity is 0.79.

IL 21 * Source of figures 18, 20 and 21. Also nice applets. http://www.technologystudent.com/energy1/solar4.htm**

IL 22 * Source of the following treatment**

http://www.trekearth.com/gallery/Europe/France/photo829169.htm

A technical description of the solar furnace

1. Technical details of the heliostats field:

- Weight : 5000 kg with 800 kg of mirrors
- Number of mirror by heliostat : 180 (50 x 50 x 0.75 cm)
- Type of mirror : polished, rear face silver coated
- Dispersion : 1-2 angle minutes
- Reflectivity : 0.79
- Adjustment by autocollimation with a theodolite
- 2 axis movements
- Control command by calculated coordinates
- Precision : 1/60 of degree
- Total reflective area : 2835 m^2
- Horizontal reflected beam, North South, height 40 m, width 54 m

- Number : 63 placed on 8 terraces
- Surface : 45 m^2 for each heliostat.
- Dimensions : 7.5 m (width) x 6.0 m (height)

2. Technical details of the parabolic reflector

- Parabaloid, vertical axis facing north
- Focal length 18 m, height 40 m, width 54 m
- Horizontal focal axis at 13 m from the ground
- Optical aperture f/D = 0.3
- Area 1830 m^2
- 9130 mirrors (average dimension 48,5 x 48,5 x 0,4 cm)
- Tempered glass, silver coated on the rear face
- Reflectivity 0.79
- Mirrors mechanically bended
- Possible individual adjustment of each mirror

3. Technical details of the "focal" tower

- T shape tower, 20 m high
- Shadow: 5% of the paraboloid area
- Control room at the 5th floor north side
- Focal room at the 5th floor south side

IL 23 * Pictures of Odeillo and the countryside**

(http://www.stacey.peak-media.co.uk/Pyrenees/Odeillo/Odeillo.htm)

IL 24 ** A detailed description of solar energy in general

(http://en.wikipedia.org/wiki/Solar_furnace)

Questions and problems 1

(Before answering these questions, read the section on the solar constant and atmospheric absorption.)

1. The solar power that is concentrated on the focal area of the solar furnace is

   1.00 x10^6 W (J/s). The solar radiation is obtained from the 63 heliostats. The reflecting area of the solar furnace is 1830 m^2, and the total reflecting area of the heliostats is 2835 m^2. The reflectivity of the mirror surfaces is 0.79.

Show that:

a. The solar energy arriving from the sun per second that is intercepted by all the heliostats must be about 1.60×10^6 J.

b. The optimal solar constant for Odeillo must be about 560 W/ m^2.

c. The solar constant outside the atmosphere is about 1400 W/ m^2, what percentage of the solar radiation is reflected and /or absorbed by the atmosphere?

IL 25 ** Absorption of radiant energy by the atmosphere

(**http://www.everythingweather.com/atmospheric-radiation/absorption.shtml**)

Absorption is mainly caused by three different atmospheric gases. Contrary to popular belief, water vapor causes the most absorption, followed by carbon dioxide and then ozone. In the picture below, one can see how much of the total incoming radiation the atmosphere typically absorbs.

The second way in which absorption helps the earth is as a heat source for it. If one were to take a vertical cross section of the entire atmosphere, one would note that the temperature generally increases with height. This increase in temperature is caused by an increase in absorption of electromagnetic radiation with height due to higher concentrations of high-energy wavelength (low wavelength a and high frequency) absorbing gases present at higher atmospheric levels.

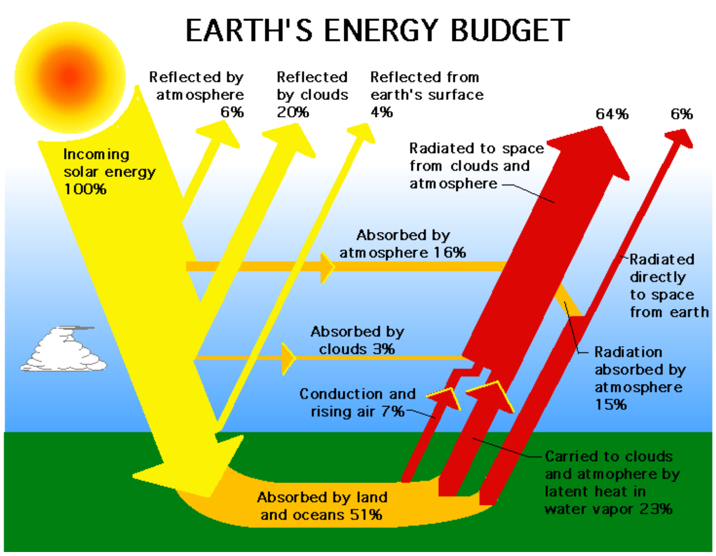


Fig. 22: The Earth Radiation Budget is the balance between incoming energy from the sun and the outgoing *longwave* (thermal)

and reflected *shortwave* energy from the Earth.

Sunlight is *reflected* by surfaces and *absorbed* by gases and surfaces. Greenhouse gases *do not* reflect sunlight. Infrared energy is *emitted* and absorbed by surfaces and greenhouse gases. Radiation refers to radiant energy, not nuclear radiation.

Notice also that the amount of infrared energy emitted at the top of the atmosphere (235 W/m^2) must equal almost exactly the amount of solar energy absorbed by earth (342–107 W/m^2). The small difference, about a watt per square meter, leads to global warming or cooling.

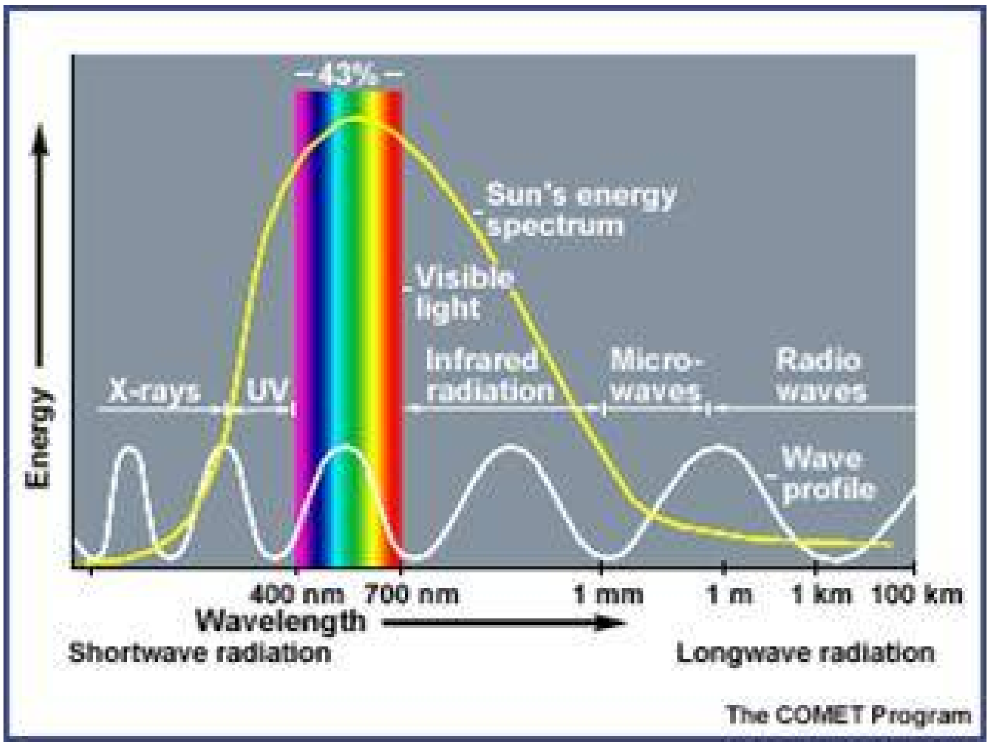


Fig. 23: The solar spectrum.

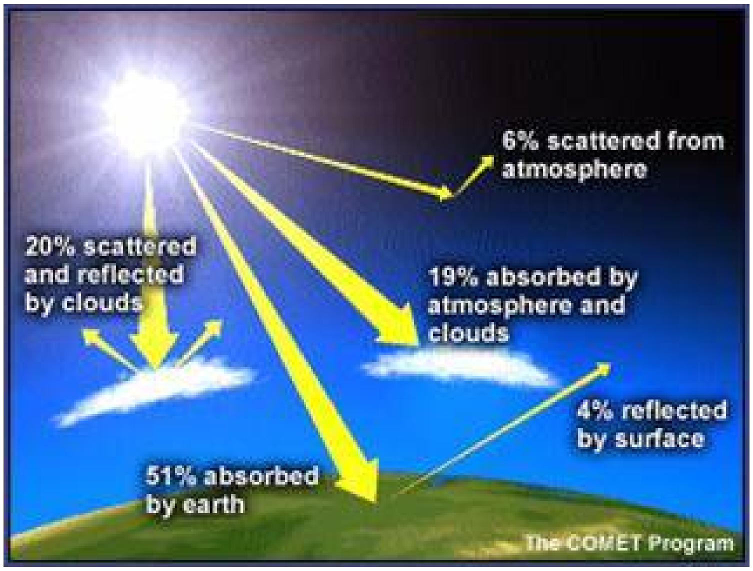


Fig. 24: This figure gives approximate percentages for solar radiation absorbed and reflected by the earth

IL 26: * Source of figures 23 and 24.**

(http://www.energysustained.com/global_warming.htm#ref3#ref3)

Measuring the temperature of a glowing material.

How do you determine the temperature reached by an object, materials, or matter, being heated in the focal are of the solar furnace?

How do you determine the temperature reached in the element of an electric stove? Clearly, you cannot find the temperature by touching it with a thermometer!

Physicists and engineers use a pyrometer (see figure 26). The illustration below shows a very simple type of radiation pyrometer. Part of the thermal radiation emitted by a hot object is intercepted by a lens and focused onto a thermopile. The resultant heating of the thermopile causes it to generate an electrical signal (proportional to the thermal radiation) which can be displayed on a recorder.

The optical pyrometer should more strictly be called the disappearing-filament pyrometer. In operation, an image of the target is focused in the plane of a wire that can be heated electrically. A rheostat is used to adjust the current through the wire until the wire blends into the image of the target (equal brightness condition), and the temperature is then read from a calibrated dial on the rheostat. See problem 1 below. .

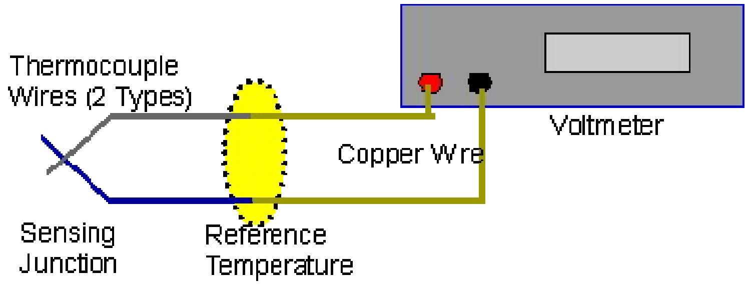


Fig. 25: Thermocouple

IL 27 ** Source of figure 25 and description of the thermocouple

(http://www.facstaff.bucknell.edu/mastascu/elessonshtml/Sensors/TempThermCpl.html)

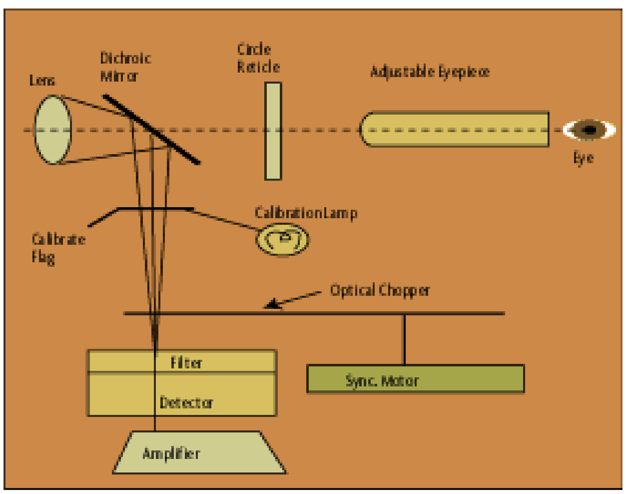


Fig 26: Automatic optical pyrometer

IL 28 ** Source of figure 26

(http://www.omega.com/literature/transactions/volume1/thermometers3.html)

IL 29 ** Description of thermometers and pyrometers (http://www.omega.com/literature/transactions/volume1/thermometers3.html)

IL 30 * General discussion of solar furnaces

(http://www.madsci.org/posts/archives/2004-07/1090857033.Ph.r.html)

The energy output of the sun

We will first discuss how the energy output of the sun can be measured and then show how the surface temperature can be estimated. To estimate the energy output of the sun, we need to know:

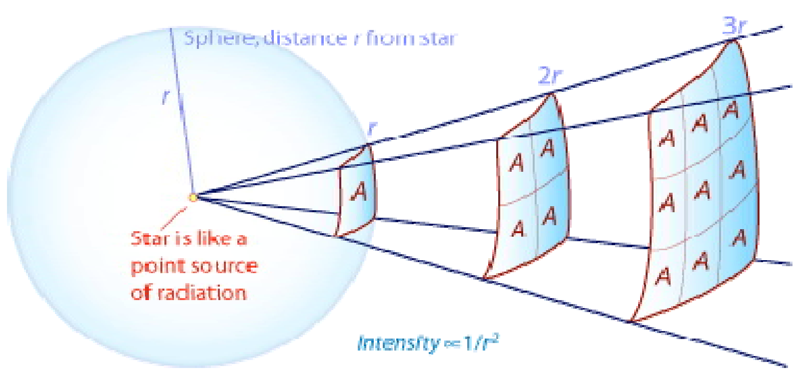
1. The distance between the earth and the sun, and
2. The amount of radiant energy the sun provides at the top of the atmosphere (about 100 km from the surface of the earth).

In addition, we must assume that the radiation is given out evenly (isotropic) in all direction. See Fig. below.

We could, of course measure the amount of radiation energy the sun provides on the surface of the earth by simply measuring the energy required to heat up an object that is exposed to the sun for a certain time. Unfortunately, we can only guess the amount of solar energy that the atmosphere absorbs or reflects (see Fig.).

The distance to the sun was well known already in the 19th century, about 1.5x10^{11} m. We must then know the radiation energy of the sun striking the Earth, or find the value of the *solar constant.*

The Inverse-Square Relationship for Light



At a distance 2*r* from the source the radiation is spread over four times the area so is only 1/4 the intensity that it is a distance r.
Radiation obeys an *inverse-square* relationship with distance.

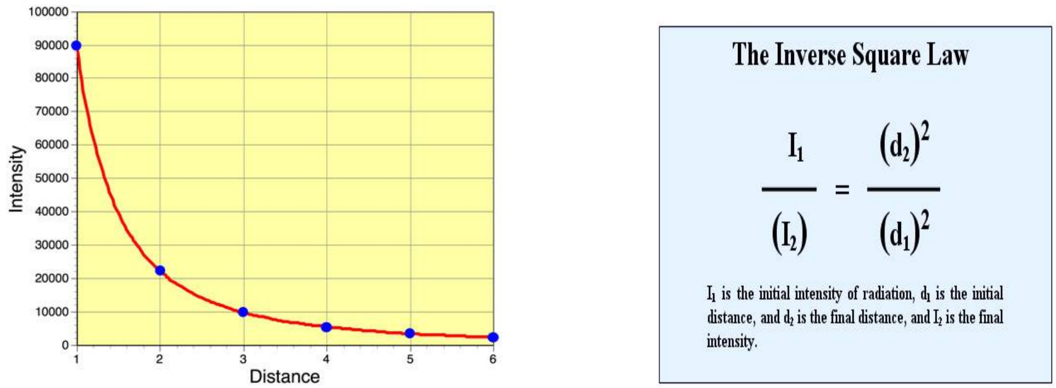


Fig. 27: The inverse square law of radiation, with three representations: visual, graphical and mathematical all showing intensity reduction with distance travelled.

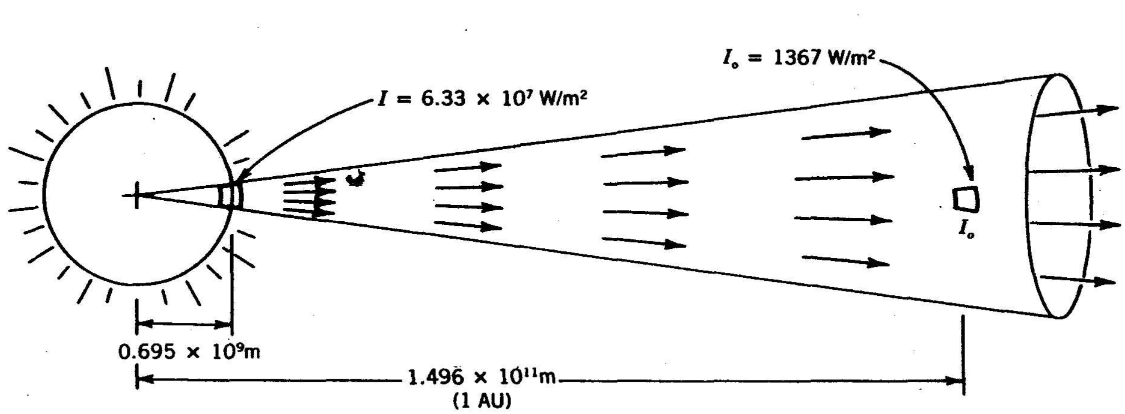


Fig. 28: The inverse square law of radiation from the sun.

The solar constant and its determination.

The *solar constant* is defined as the amount of heat energy received per second per unit area ($J/s/m^2$, or W/m^2) and completely absorbed by a "perfect black body" at the surface of the Earth with the surface being held perpendicular to the direction of the sun's rays.

One instrument used for measuring the solar constant is called Pyroheliometer. In the middle of the 19th century, a very good measurement was made by the French physicist Pouillet. Later, the Swedish physicist Angstrom developed an improved version, called a compensation pyroheliometer, is described below.

Various scientists had tried to calculate the Sun's energy output, but the first attempts at a direct measurement were carried out independently and more or less simultaneously by the French physicist Claude Pouillet (1790-1868) and British astronomer John Herschel (1792-1871). Although they each designed different apparatus, the underlying principles were the same: a known mass of water is exposed to sunlight for a fixed period of time, and the accompanying rise in temperature recorded with a thermometer. The energy input rate from sunlight is then readily calculated, knowing the heat capacity of water. Their inferred value for the solar constant was about half the accepted modern value of 1367 ± 4 Watts per square meter, because they failed to account for of absorption by the Earth's atmosphere.

The following is taken from IL 31

IL 31 * Source of figure 30**

(**http://www.tutorvista.com/content/physics/physics-iii/heat-and-thermodynamics/solar-constant.php**)

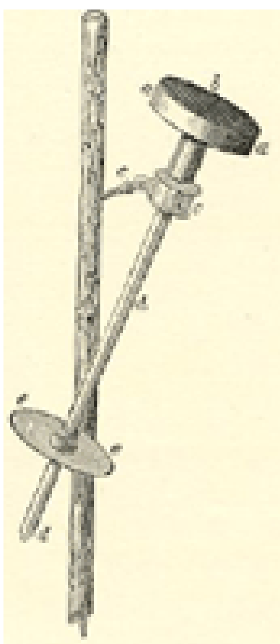


Fig. 29: Pouillet's pyroheliometer.

IL 32 * Source of figure 29.**

(http://www.hao.ucar.edu/Public/education/Timeline.D.html#1838)

Water is contained in the cylindrical container a, with the sun-facing side b painted black. The thermometer d is shielded from the Sun by the contained, and the circular plate e is used to align the instrument by ensuring that the container's shadow is entirely projected upon it. [Reproduced from A.C. Young's The Sun (revised edition, 1897).

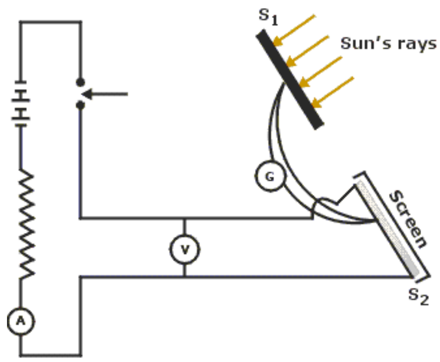


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Fig. 30: Angstrom's compensation pyroheliometer

IL 33 ** Operating principles of a solar furnacewith good figures and applets**

(http://www.promes.cnrs.fr/TOUT-PUBLIC/Les-fours/eng-lesfours1.htm)

The total energy output of the sun.

We are now ready to estimate the total energy output of the sun, assuming that the inverse square law is applicable. We know the following:

1. The value of the solar constant. We will take it as approximately 1400 W/m^2.
2. The distance to the sun: approximately $1.5x10^{11}$ m.
3. The inverse square law: The radiation, measured in W/m^2 from a point source (consider the sun's energy to come from a point source (see Fig. above)) is inversely proportional to the distance from the source squared.
4. The area of the surface of a sphere is $\mathbf{4\pi\ r^2}$**.**

The following then is a guide for solving this problem:

First show that the inverse square law requires that the radiation energy from the sun intercepted by 1 m on the earth's surface is the solar constant, or about 1400 W/m^2. Secondly, calculate the total energy going through the surface of the giant sphere with a radius of the distance to the sun, namely $1.5x10^{11}$ m. Finally, show that this is equal to about $\mathbf{3.9x10^{26}}$ **J/s.**

This is an enormous amount of energy given out each second. See problem xx for more detail.

Determining the temperature of the surface of the sun.

Having estimated the energy output of the sun to be $3.9x10^{26}$ J/s, it is now possible to estimate the temperate of the surface of the sun. We have already suggested that the temperature of the surface of the sun by a measurement using a pyrometer, or more precisely, a pyroheliometer.

The temperature of the sun is found to be about 6000 K. See figure 29.

However, it is also possible to confirm this value with a theoretical approach by using the physics of black body radiation. See discussion of black body radiation and Fig. xx below.

According the theory of black body radiation, the sun is radiating energy, given by the Stephan-Boltzmann law **$R = \delta A T^4$** (see detail below). R is the radius of the sun, A the area of the surface of the sun, **δ** an experimentally determined constant ($5.67x^{-8}$ watts / m^2 x T^4.), and T the temperature of the surface of the radiating black body object.

You can now show that the temperature of the sun, according to this approach, is about 5900 K.

Although the sun is millions of degrees in its core, pyrometric measurment of the surface of the sun produces a black body temperature of about 6000 degrees K and the maximum power wavelength of the black body curve, shown below, is:

Wavelength (max) = (0.0029)/T = .0029/6000 = 483 nanometers (nm).

Thus the sun appears white hot because the peak radiation output is in the blue/green portion of the visible spectrum.

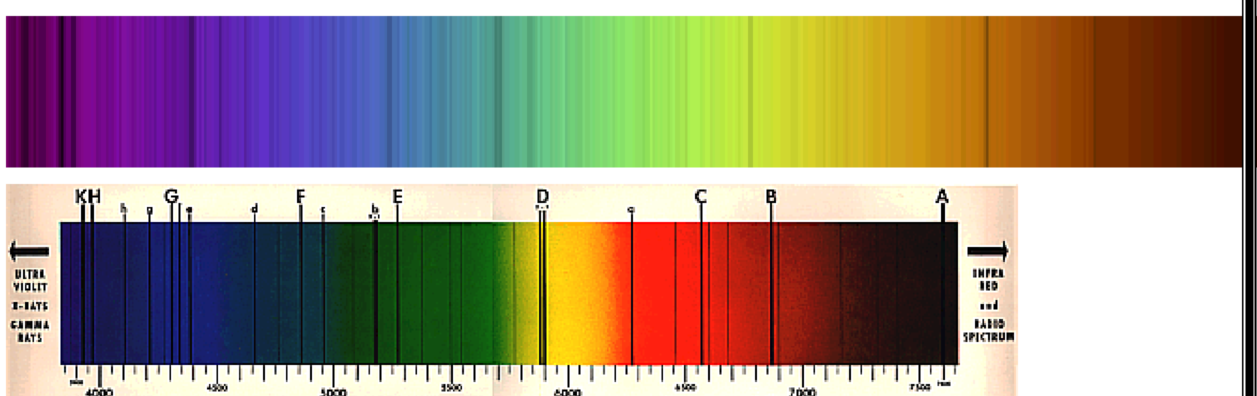


Fig. 31: The Solar Spectrum

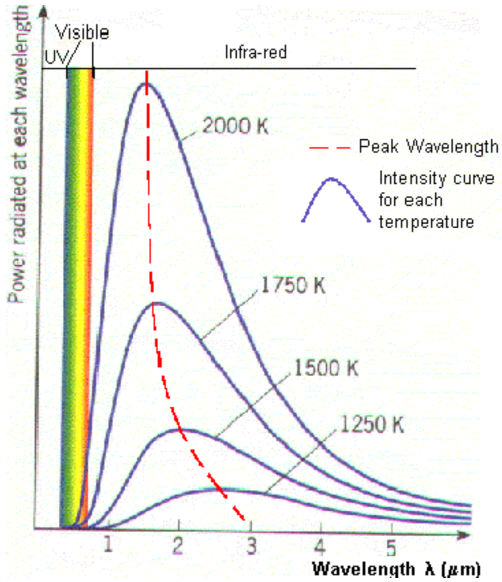


Fig. 32: Black body radiation

IL 34 ** Source of figure 32 and an advanced discussion of BB radiation (http://www.egglescliffe.org.uk/physics/astronomy/blackbody/bbody.html)

The wavelength of the maximum power is in the middle of the ultraviolet range of the electromagnetic spectrum and the material would appear blue hot; however, the greatest amount power is in ultraviolet radiation and would be invisible and very dangerous to human eyes and tissue.

IL 35 * A discussion of black body radiation**

http://physics-history.suite101.com/article.cfm/blackbody_radiation)

IL 34 and IL 35 contain excellent pictures and videos of the furnace and should be looked at prior to solving the problems below.

Fig. 33: The glow of an incandescent lamp. See problem 3 below.

Estimating the temperature at the focal area of the solar furnace.

To estimate the temperature of the focal area we again us two methods, one experimental and the other theoretical:

Assume the outgoing radiation to be that of the incoming $1.00x10^6$ J. of the solar furnace.

1. Actual measurement using a pyrometer.
2. Apply a theoretical approach by using the physics of black body radiation.

   The Odeillo facility has been used to measure hypersonic aircraft and missile parts and other high temperature materials. One advantage of a solar furnace is that it can almost instantly provide maximum heating (KE) were conventional furnaces may take hours to reach similar temperatures. Also the power in the focal plane of the Odeillo facility must be reduced so that the materials being tested are not totally destroyed instantly.

1. Direct measurement: Pyrometric measurements show that the temperatures reached when a metal is melted reaches value of over 3000 K.

2. Estimating the temperature using the Stephan-Boltzmann radiation formula $\mathbf{R = \delta\ A\ T^4}$

   Using the equation above you can proceed as follows: Imagine an object placed in the focal area of 0.1 m^2 to be radiating, rather that being irradiated by the solar furnace. You can show that the black body radiation equation predicts a temperature of about 3600 K.

Questions and problems 2

In this section we will continue our discussion by involving the students to make some sophisticated calculations with some guidance.

1. According to Fig. 34 the flux of the solar radiation of the sun leaving the surface of the sun is about 1.33x10 W/ m^2. Verify this value. The radius of the sun is $7.0x10^7$m.

2. Study Fig. and answer the following question:

   On the average what percentage of the solar radiation can be intercepted by solar device on the surface of the earth in North America?

3. The filament of an incandescent lamp is made of tungsten, that has a very high melting point, at 3422ºC , or 3695 K. We can us the glowing incandescent lamp as an example of black body radiation.

   a. Look at an incandescent lamp through a hand-held spectroscope and he spectrum you see with the solar spectrum shown in Fig.x .

   b. An incandescent lamp has a tungsten filament with a total surface area of 1 cm^2. The power rating of the lamp is 120W. Using the Stephan/Bolztmann law of radiation calculate the temperature of the temperature of the filament. Show that the temperature is about 2150 K, or about 2400 ºC.

(Note that about 95% of the radiation is in the infrared and only 5% in the visible region of the radiation spectrum of the lamp. This is why we are replacing these lamps with more efficient lamps). See figure 34.

IL 36 * A very comprehensive discussion of various electric lamps and the radiation produced**

(http://www.squidoo.com/tungstenlamps)

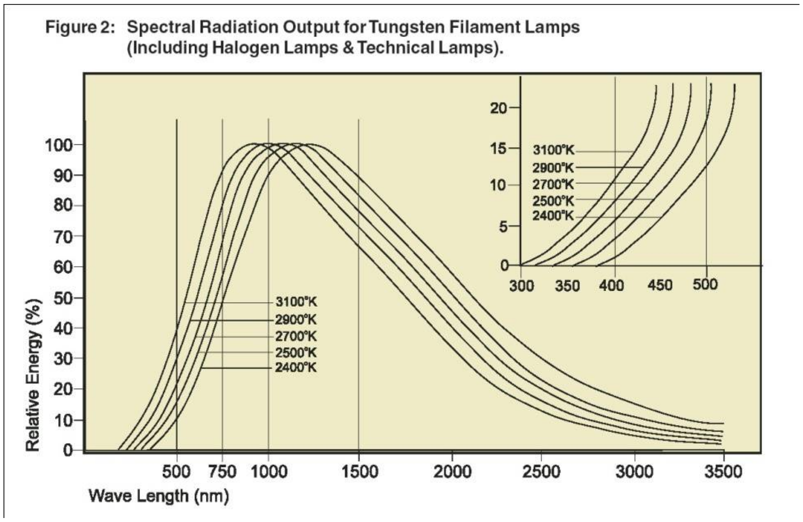


Fig. 34: Spectral radiation output

c. Study figure 34 above. Estimate the percentage of the energy produced that is in the visible light region. Approximately how efficient is this tungsten incandescent lamp?

4. What would be a rough estimate of the black body temperature of a material placed at the maximum power point in the focal plane of the Odeillo solar furnace if we could make one square centimeter of a theoretical material that could survive long enough for us to make a pyrometric measurement? We will assume that the sample is in a vacuum and that thermal conduction and convection are not an issue.

5. Again, use the Stephan/Boltzmann law of radiation to show that the temperature on this small area would be about 20,000K. Note: Assume that all the radiation reflected from the solar furnace (about 1000 kW) is concentrated on an area of 1 cm^2.

IL 37 * Detailed description of the sun.**
(http://www.uwgb.edu/dutchs/planets/sun.htm)

IL 38 ** The greenhouse effect and affected weather patterns
(http://oceanworld.tamu.edu/resources/oceanography-book/radiationbalance.htm)

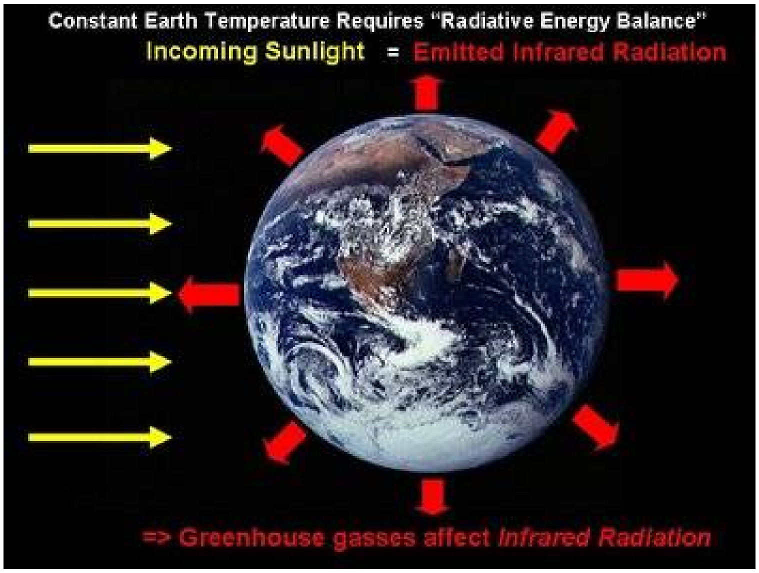


Fig. 35: The radiation balance of the earth

Solar energy for cooking: Small scale solar furnaces

Solar cooking is the simplest, safest, most convenient way to cook food without consuming fuels or heating up the kitchen. Many people choose to solar cook for these reasons. But for hundreds of millions of people around the world who cook over fires fueled by wood or dung, and who walk for miles to collect wood or spend much of their meager incomes on fuel, solar cooking is more than a choice — it is a blessing. For millions of people who lack access to safe drinking water and become sick or die each year from preventable waterborne illnesses, solar water pasteurization is a life-saving skill. There are numerous reasons to cook the natural way — *with the sun*.

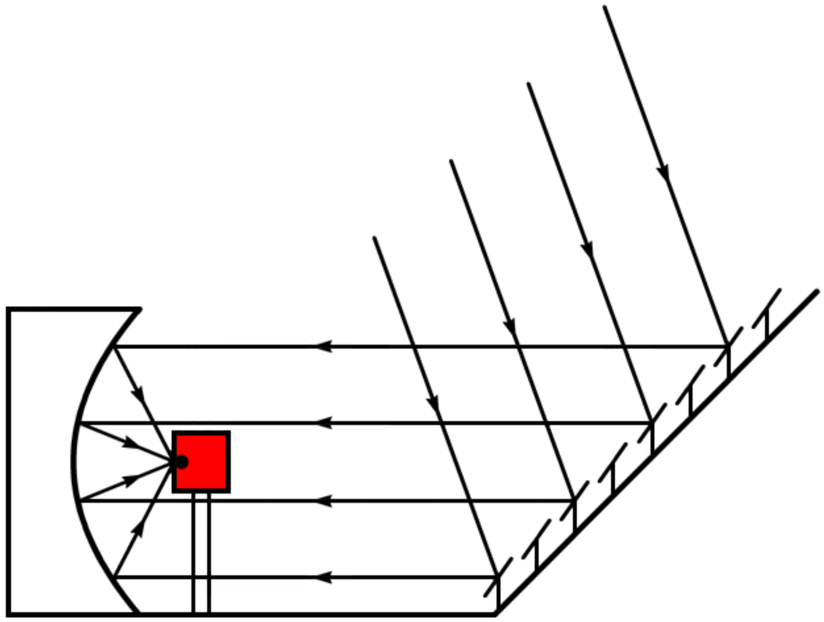


Fig. 36: Concentrating solar radiation by a parabolic reflector

Solar cookers for personal use

IL 39 **** Solar cookers**

(http://www.solarcookers.org/basics/why.html)

IL 40 ******** An excellent discussion of the physics of solar cookers

(http://en.wikipedia.org/wiki/Solar_cooker)

IL 41 ******* Very good sites to see many different solar cookers

(**http://www.builditsolar.com/Projects/Cooking/cooking.htm#Cooking**)

A solar oven or solar cooker is a device which uses solar energy as its energy source. Because they use no fuel and they cost nothing to run, humanitarian organizations are promoting their use worldwide to help slow deforestation and desertification caused by using wood as fuel for cooking. Solar cookers are also sometimes used in outdoor cooking especially in situations where minimal fuel consumption or fire risk are considered highly important.

<u>The basic principles of all solar cookers are:</u>

- Concentrating sunlight: Some device, usually a mirror or some type of reflective metal, is used to concentrate light and heat from the sun into a small cooking area, making the energy more concentrated and therefore more potent.
- Converting light to heat: Any black covering on the inside of a solar cooker, as well as certain materials for pots, will improve the effectiveness of turning light into heat. A black pan will absorb almost all of the sun's light and turn it into heat, substantially improving

the effectiveness of the cooker. The better a pan conducts heat, the faster the oven will work.

- Trapping heat: Isolating the air inside the cooker from the air outside the cooker makes an important difference. Using a clear solid, like a plastic bag or a glass cover, will allow light to enter, but once the light is absorbed and converted to heat, a plastic bag or glass cover will trap the heat inside using the *greenhouse effec*t. This makes it possible to reach similar temperatures on cold and windy days as on hot days.

  However, each of these strategies alone for heating something with the sun is fairly ineffective, but most solar cookers use two or all three of these strategies in combination to get temperatures high enough for cooking most foods.

  The top can usually should be removed to allow dark pots containing food to be placed inside. The box usually has one or more reflectors with aluminum foil or other reflective material to bounce extra light into the interior of the box. Cooking containers and the inside bottom of the cooker should be dark-colored or black. The inside walls should be reflective to reduce radiative heat loss and bounce the light towards the pots and the dark bottom, which is in contact with the pots.

Fig. 37: Solar tea kettle in Tibet.

Fig. 38: Gathering wood for cooking in Africa.

Fig. 39: A small solar cooker in Africa.

Fig. 40: Large parabolic solar cookers.

Fig. 41: Solar cookers in the Andes

Fig. 42: Solar cooker in the Sudan

Fig. 43: Cooking in the backyard

Fig. 44: A common solar cooker, seen in Beijing.

Home solar collectors and solar ovens, alternate energy.

The cooking time in a small solar cooker depends primarily on the equipment used, the amount of sunlight at the time, and the quantity of food that needs to be cooked. Air temperature, wind, and latitude also affect performance. Food cooks faster in the two hours before and after the local solar noon than it does in either the early morning or the late afternoon. Larger quantities of food, and food in larger pieces, take longer to cook. As a result, only general figures can be given for cooking time. For a small solar panel cooker, it might be possible to melt butter in 15 minutes, to bake cookies in 2 hours, and to cook rice for four people in 4 hours. However, depending on the local conditions and the solar cooker type, these projects could take half as long, or twice as long.

It is difficult to burn food in a solar cooker. Food that has been cooked even an hour longer than necessary is usually indistinguishable from minimally cooked food. The exception to this rule is some green vegetables, which quickly change from a perfectly cooked bright green to olive drab, while still retaining the desirable texture.

IL 42 **** An excellent source discussing the science of solar cooking

(**http://solarcooking.org/solarcooking-faq.htm**)

The Science of Solar Cooking:

See Appendix

Questions and problems 3

1. In India "mini solar surfaces" are used for cooking purposes. They are parabolic reflecting dishes with a diameter of about 1 meter. Approximately how long would it take to heat 2 liters of water from 30ºC to the boiling point, 100ºC using one of these "furnaces"? Assume that the solar flux here is about 500 W/m^2 and that the focal area covers the cooking area and that the reflectivity is 80.

2. In Fig there is a large satellite dish that was converted to a solar cooker. How long would it take to heat 2 l of water under the same conditions as in problem 1? Hint: Since the conditions are the same except that the dish has twice the diameter you should be able to find the answer immediately.

Fig. 45: A satellite dish converted to a solar cooker.

3. You focus the sun on your skin with a magnifying glass. The radius of the magnifying glass is 6 cm and the radius of the focal area is 0.5 cm. Assuming that the solar flux is about 400 W/m^2 and that your skin is a perfect black body and also assuming that you could stand the pain, estimate the temperature of your skin that is covered by the focal area after 10 seconds.

Fig. 46: Focusing the sun with a magnifying glass.

4. Discuss the following: Taken from IL 42.

Safety for food cooked by any method requires meeting specific rigid conditions. Cooked food at temperatures between 125° F and 50° F (52° C - 10° C) can grow harmful bacteria. This temperature range is known as the danger zone. To protect against food poisoning, microbiologists and home economists strongly recommend that food be kept either above or below these temperatures.

These precautions are the same whether food is cooked with gas, electricity, microwaves, wood fire, or solar heat as well as foods cooked by retained heat, crock pot, barbecue pit or any other method.

In cooked food held at room temperature, there is a chance of Bacillus cereus food poisoning, a major intestinal illness. Worse, if the food is not thoroughly reheated before consumption, there is a chance of deadly botulism poisoning or salmonella. Even if it is reheated, when cooked food has been in the danger zone for three to four hours, there remains a risk of food poisoning in solar cooked food as in food cooked by any other method.

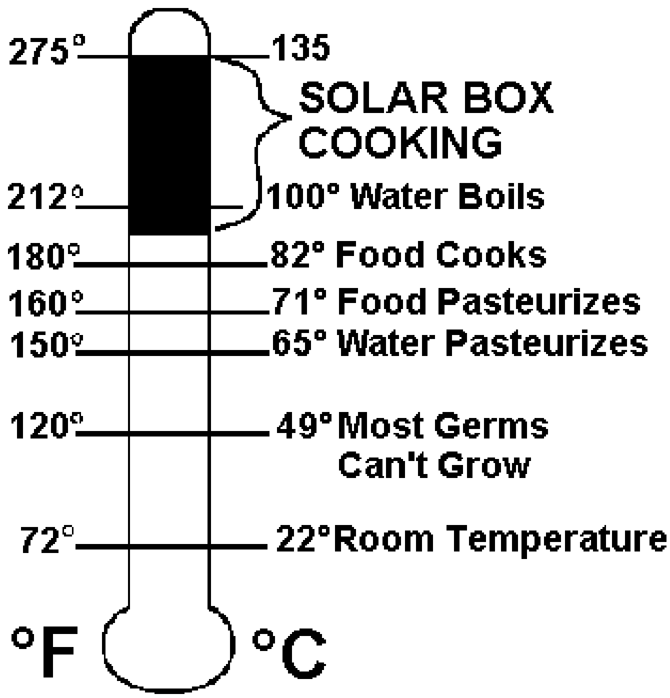


Fig. 47: Use this for discussing question 5.

Large Scale Solar Collection A: Using troughs

A parabolic trough power plant's solar field consists of a large, modular array of single-axis-tracking parabolic trough solar collectors. Many parallel rows of these solar collectors span across the solar field, usually aligned on a north-south horizontal axis.

The basic component of a parabolic trough solar field is the solar collector assembly or SCA. A solar field consists of hundreds or potentially thousands of solar collector assemblies. Each solar collector assembly is an independently tracking, parabolic trough solar collector composed of the following key subsystems:

- Concentrator structure
- Mirrors or reflectors
- Linear receiver or heat collection element
- Collector balance of system

Taken from IL 43 below.

IL 43 * Parabolic trough solar fields**

(http://www.nrel.gov/csp/troughnet/solar_field.html#balance#balance)

Each parabolic trough solar collector assembly consists of multiple, torque-tube or truss assemblies (often referred to as solar collector elements or modules.

Taken from: IL 44.

IL 44 *** All about parabolic trough solar collectors (**http://thefraserdomain.typepad.com/energy/2005/09/about_parabolic.html**)

About Parabolic Trough Solar Collectors

Trough solar systems use parabolic curved, trough shaped reflectors focus the sun's energy onto a receiver pipe running at the focus of the reflector. Because of their parabolic shape, troughs can focus the sun at 30-60 times its normal intensity on the heats a heat transfer fluid (HTF), usually oil, flowing through the pipe. This fluid is then used to generate steam which powers a turbine that drives an electric generator.

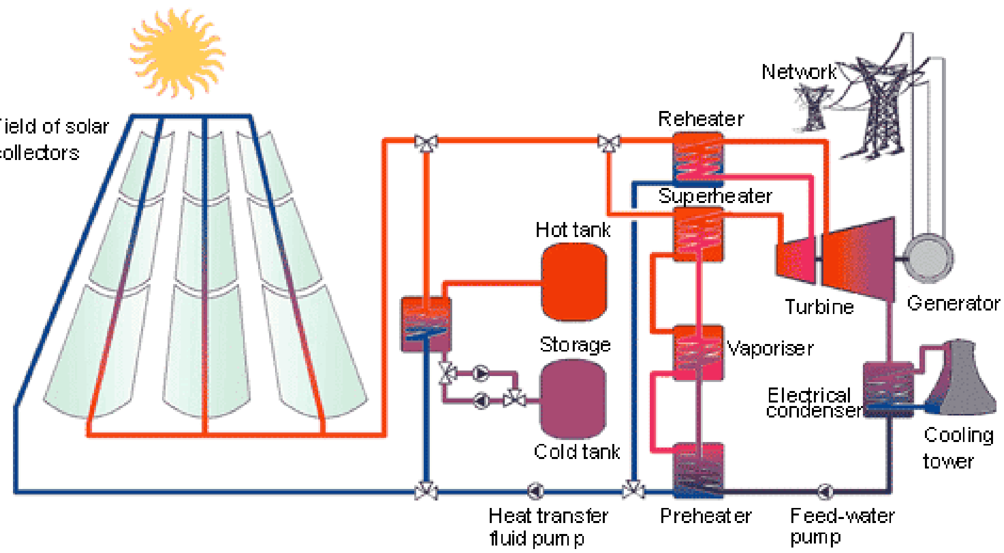
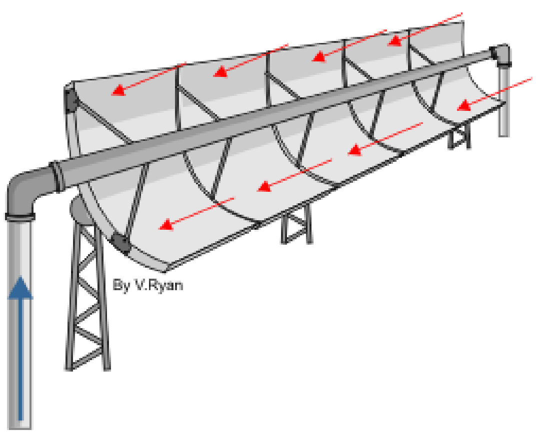


Fig. 48: Function scheme of a solar thermal parabolic trough power plant. Source: DLR. [Wording: Field of solar collectors, Hot tank, Storage, Cold tank, Heat transfer fluid pump, Reheater, Superheater, Preheater, Network, Turbine, Condenser, Feed-water pump, Generator, Cooling tower

The collectors are aligned on and east-west axis and the trough is rotated to follow the sun to maximize the suns energy input to the receiver tube. Click on flow diagram above to see a full size flow diagram of the new plants being built in Spain. Current cost of electricity from these plants is $0.10 to $0.12 per kWh. The current goal of ongoing development by EERE is to reduce the cost to $0.035 to $0.043 per kWh by 2020.

The concentrated energy heats a heat transfer fluid (HTF), usually oil, flowing through the pipe. This fluid is then used to generate steam which powers a turbine that drives an electric generator. The collectors are aligned on an east-west axis and the trough is rotated to follow the sun to maximize the suns energy input to the receiver tube.

Fig. 49: Trough solar collecting farm in Spain.



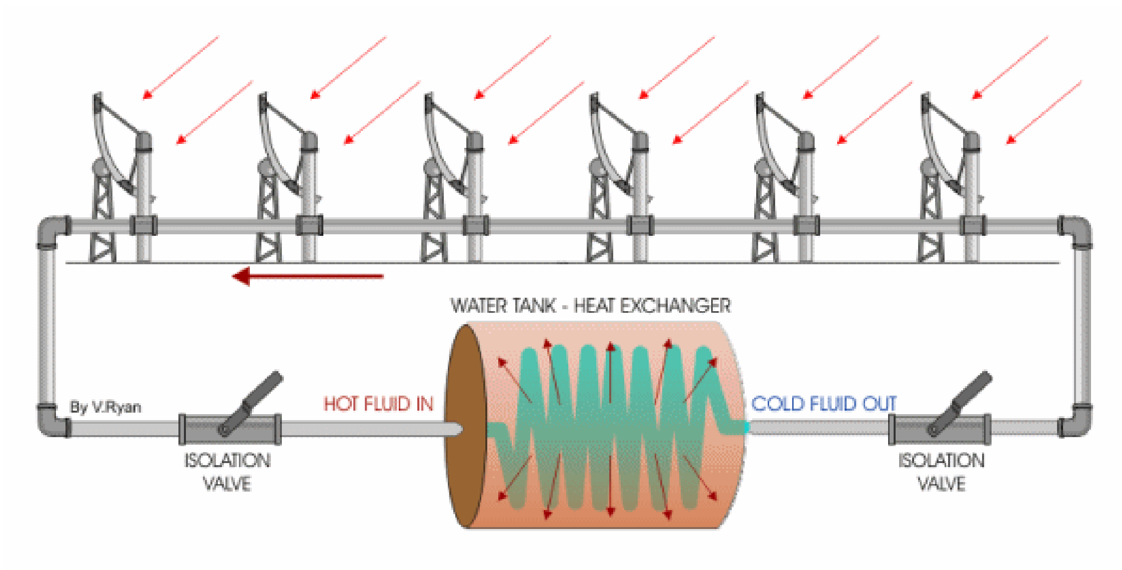


Fig. 50: Detailed images of a solar collecting system using arrays of troughs.

IL 45 * Source of figure 50 and animated motion presentation.**

(**http://www.technologystudent.com/energy1/solar3.htm**)

The fluid going through the receiver pipe is routed through a thermal storage system which permits the plant to keep operating for several hours after sunset while the electrical demand is still relatively high. The thermal storage system (to be used in Spain) is a two tank system in which the HTF flows through the solar field and then through a heat exchanger where it gives up a portion of its heat to heat a nitrate salt solution that is stored in a hot salt tank. The slightly cooled HTF continues on to the power generation system. At night the hot salt solution flows through the same heat exchanger heating up the HTF for generating power. The cooler oil flows from the heat exchanger to the cold storage tank where it stays until daytime when it is reheated and returned to the hot storage tank.

Questions and problems 5:

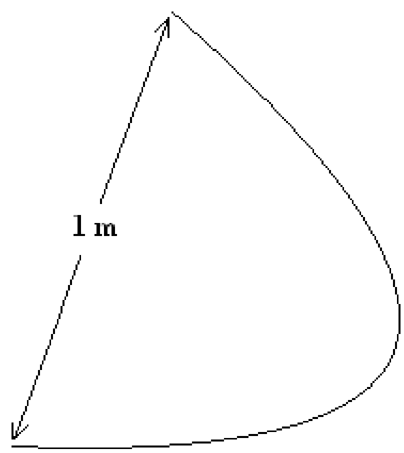


Fig. 51: Cross section of a parabolic solar collector

In the following problems we will assume the following dimensions for the troughs and the "solar field":

1. Width: 1 m,
2. Length: 100m
3. Number of troughs distributed over a large area: 100.
4. The reflectivity of the surface is 80.
5. The average solar flux for a sunny day is 350 watts/ m^2 .
6. The separation distance between the centres of troughs is 3m.
7. The diameter of the flow pipe: 5 cm.

Fig. 52: For problems: The troughs are 100 long, 1m wide, and separated by 3 m. There are 100 troughs in the "solar field".

1. Estimate the approximate size of the field, in:
   a. Square meters
   b. Hectares
   c. Acres
2. The size of the field is 100mx300m, or 30,000 m^2.

   Calculate:
   a. The solar energy arriving on the surface of the field every second.
   b. The solar energy collected along the pipe by each trough every second.
   c. The solar energy collected in the whole solar field.
   d. The average 'solar power' of the field.
   e. The overall efficiency of the field
3. Assume that the average household requires about 10 kilowatts of power. How many households is this solar field able to supply with energy? Remember, the average solar flux of 350 watts/ m^2 is taken over a period of 6 hours.

Solar water heaters.

IL 46 * General description of solar water heaters**

(http://www.canren.gc.ca/prod_serv/index.asp?CaId=141&PgId=750)

General description of solar water heaters (taken from IL 46).

Water heating is one of the most cost-effective uses of solar energy, providing hot water for showers, dishwashers and clothes washers. Every year, several thousands of new solar water heaters are installed worldwide.
Canadian manufacturers have developed some of the most cost-effective systems in the world. Cconsumers can now buy "off-the-shelf" solar water heaters that meet industry-wide standards, providing a clean alternative to gas, electric, oil or propane water heaters. Freeze-protected solar water heaters manufactured in Canada have been specifically designed to operate reliably through the entire year, even when the outside temperature is either well below freezing or extremely hot.

There are many possible designs for a solar water heater. In general, it consists of three main components

1. Solar collector, which converts solar radiation into useable heat.
2. Heat exchanger/pump module, which transfers the heat from the solar collector into the potable water.
3. Storage tank to store the solar heated water.

The most common types of solar collectors used in solar water heaters are flat plate and evacuated tube collectors. In both cases, one or more collectors are mounted on a southerly-facing slope or roof and connected to a storage tank. When there is enough sunlight, a heat transfer fluid, such as water or glycol, is pumped through the collector. As the fluid passes through the collector, it is heated by the sun. The heated fluid is then circulated to a heat exchanger, which transfers the energy into the water tank.

When the homeowner uses hot water, cold water from the main water supply enters the bottom of the solar storage tank. Solar heated water at the top of the storage tank flows into the conventional water heater and then to the taps. If the water at the top of the solar storage tank is hot enough, no further heating is necessary. If the solar heated water is only warm (after an extended cloudy period), the conventional water heater brings the water up to the desired temperature.

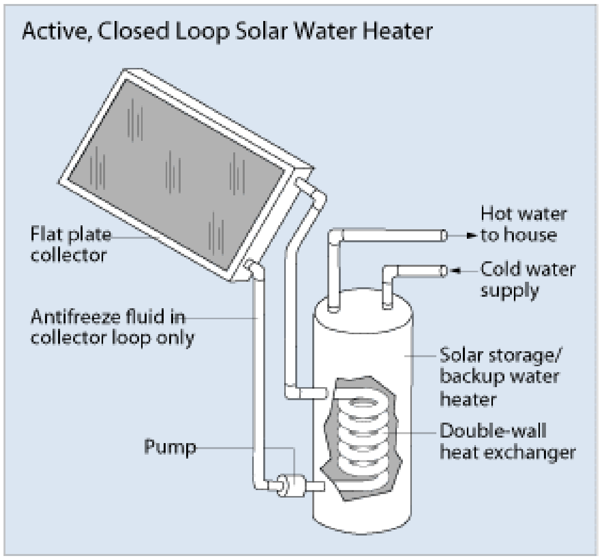
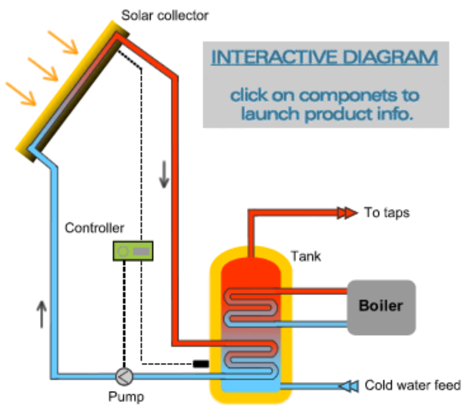


Fig. 53: Active, closed loop solar water heater.

A large, flat panel called a flat plate collector is connected to a tank called a solar storage/backup water heater by two pipes. One of these pipes runs through a cylindrical pump into the bottom of the tank, where it becomes a coil called a double-wall heat exchanger. This coil runs up through the tank and out again to the flat plate collector. Antifreeze fluid runs only through this collector loop. Two pipes run out the top of the water heater tank; one is a cold water supply into the tank, and the other sends hot water to the house.

Fig. 54: A roof- mounted simple solar water heater.

Fig. 55: Balcony solar water heaters



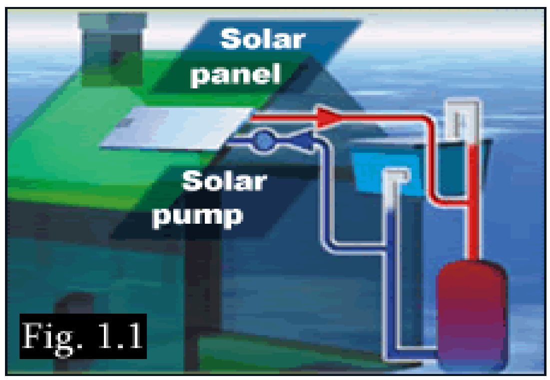


Fig. 56: A Polar Bear water system that can be bought and installed

A Polar Bear solar water system typically consists of glazed collectors mounted on a roof and connected to a storage tank. Fluid is pumped to the collectors where it is warmed by the sun, then returned to a heat exchanger where it heats the water in a storage tank.

Active Polar Bear solar systems use solar collectors and additional electricity to power pumps or fans to distribute the sun's energy. The heart of a solar collector is a black absorber which converts the sun's energy into heat. The heat is then transferred to another location for immediate heating or for storage for use later. The heat is transferred by circulating water, antifreeze or sometimes air. Applications for active Polar Bear solar energy include heating systems, heating swimming pools, domestic hot water use, ventilation and industrial process air and water for commercial facilities such as laundries, car washes and fitness centres.

Questions and problems 6

1. A solar water collector (see Fig.) has an area of 1 square meter. It has dimensions of 1mx1mx0.10 m. The solar flux for that day is about 400 W/ m^2. Assume that the solar energy is absorbed by the black surface with an efficiency of 80%.
   a. What is capacity of the collector in liters?
   b. If the temperature outside as well as the temperature of the water is 20ºC, how long would it take to heat the water to 50º C ? to the boiling point?

2. There are 10 solar water collectors on the roof in problem 1. How long would it take to change the water temperature from 20ºC to the boiling point of the tank that has a capacity 1 m^3 (1000liters)?

Solar batteries (voltaic cells) used commercially

IL 47 * This a very comprehensive history and description of photovoltaic cells**

(http://en.wikipedia.org/wiki/Solar_cell)

IL 48 ** Video showing how photovoltaic cells operate

(http://www.alternative-energy-news.info/technology/solar-power/photo-voltaics/)

Solar panels are devices that convert light into electricity.They are also called photovoltaics which means "light-electricity". Solar cells or PV cells rely on the photovoltaic effect to absorb the energy of the sun and cause current to flow between two oppositely charge layers.

Photovoltaic (or PV) systems convert light energy into electricity. The term "photo" is a stem from the Greek "phos," which means "light." "Volt" is named for Alessandro Volta (1745-1827), a pioneer in the study of electricity. Photovoltaics literally means light-electricity.

Most commonly known as "solar cells," PV systems are already an important part of our lives. The simplest systems power many of the small calculators and wrist watches we use every day. More complicated systems provide electricity for pumping water, powering communications equipment, and even lighting our homes and running our appliances. In a surprising number of cases, PV power is the cheapest form of electricity for performing these tasks.

IL 49 * How a photovoltaic cell works**

(http://inventors.about.com/library/inventors/blsolar3.htm)

Solar cells absorb the visible light of the sun, though half of the sun's output is made up of infrared light that too strikes the earth and it remains completely un-utilized. That is why only about 30% of the total sunlight can be converted to electricity thus lowering photovoltaic cells' efficiency. But Spanish scientists have developed a new material that can absorb this invisible infrared light too. It will possibly give a boost to the solar cells' producing energy and help in combating the current energy crisis. These special solar cells are developed by the scientists from Institute for Solar Energy at the Polytechnic University and the Institute of Catalysis of the Spanish Higher Scientific Research Council in Madrid, Spain

IL 50 * A detailed discussion of the physics of PV cells**

(http://www.lbl.gov/Science-Articles/Archive/sb-MSD-multibandsolar-panels.html)

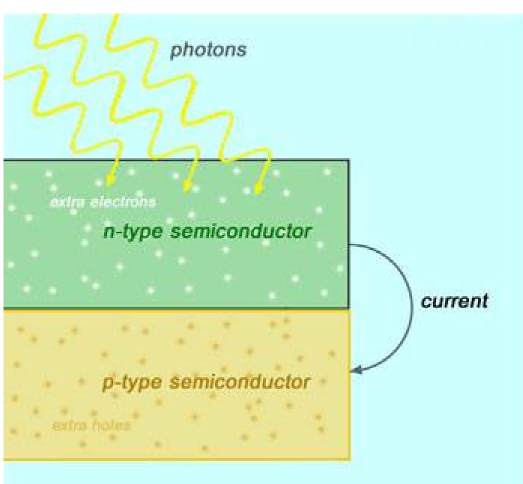


Fig. 57: In the material of a photovoltaic cell, incoming photons free electrons of

corresponding energy, which migrate toward the positive side of the junction, forming an electric current.

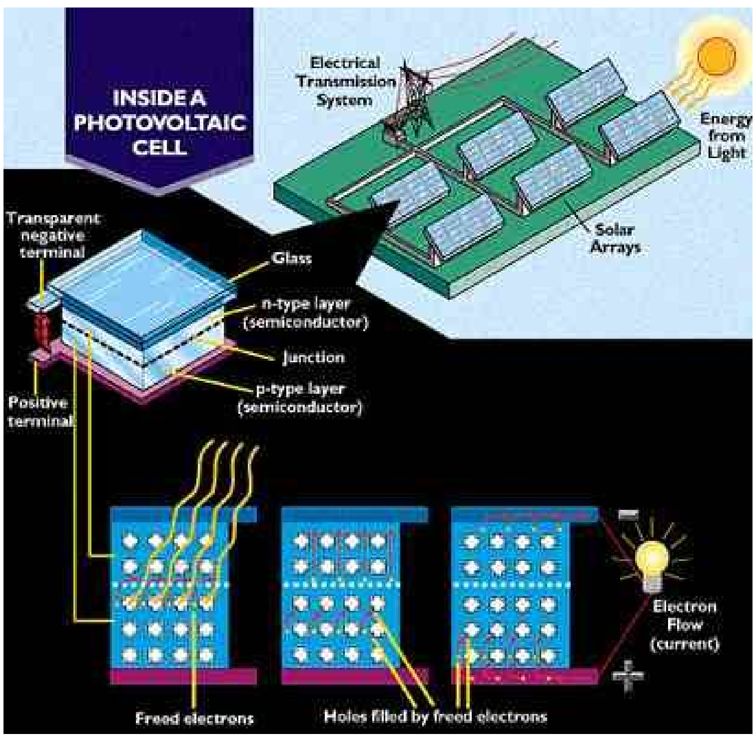


Fig. 58: The photovoltaic cell: p-Types, n-Types, and the Electric Field

The "photovoltaic effect" is the basic physical process through which a PV cell converts sunlight into electricity. Sunlight is composed of photons, or “particles” of solar energy. These photons contain various amounts of energy corresponding to the different wavelengths of the solar spectrum. When photons strike a PV cell, they may be reflected or absorbed, or they may pass right through. Only the absorbed photons generate electricity.

When this happens, the energy of the photon is transferred to an electron in an atom of the cell (which is actually a semiconductor). With its newfound energy, the electron is able to escape from its normal position associated with that atom to become part of the current in an electrical circuit. By leaving this position, the electron causes a "hole" to form. Special electrical properties of the PV cell—a built-in electric field—provide the voltage needed to drive the current through an external load (such as a light bulb).

IL 51 **

(http://inventors.about.com/library/inventors/blsolar3.htm)

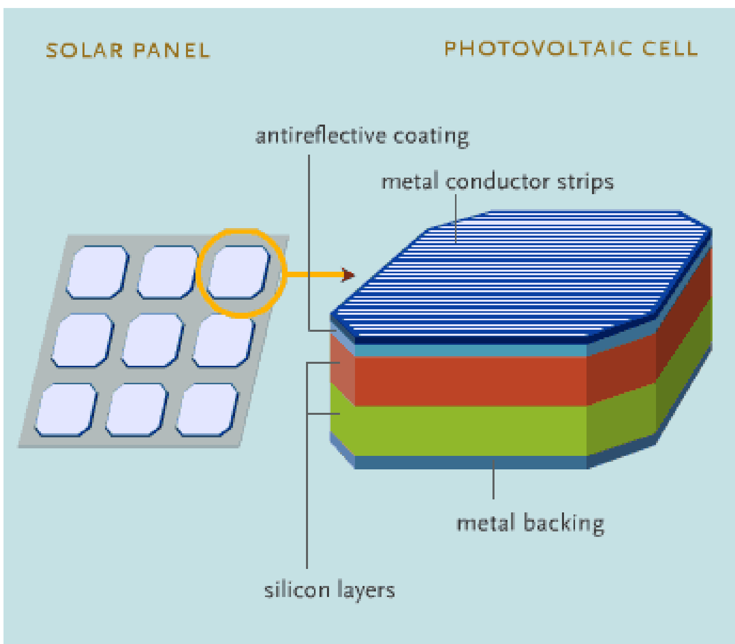


Fig. 59: Anatomy of a solar cell

Efficiency of modern solar cells

IL 52 * Description of the history of the photovoltaic cell**

(http://en.wikipedia.org/wiki/Solar_cell)

See IL 52 for a comprehensive discussion of the history of the efforts mad to improve the efficiency and the economic viability of solar cells. The authors are claiming that "Current research is targeting conversion efficiencies of 30-60% while retaining low cost materials and manufacturing techniques”.

Efficiency:

Energy conversion efficiency is the ratio between the useful output of an energy conversion machine and the input, in energy terms. The useful output may be electric power, mechanical work, or heat. We can say that:

$$\mathbf{e = P_{out} / P_{in}}$$

Where e is efficiency (between 0 and 1), $\mathbf{P_{out}}$ is the energy output and $\mathbf{P_{in}}$ the energy that enters the system.

Solar cell efficiencies vary from 6% for amorphous silicon-based solar cells to 40. % with multiple-junction research lab cells and 43 % with multiple dies assembled into a hybrid package. However, the highest efficiency cells have not always been the most economical — for example a 30% efficient multijunction cell based on exotic materials such as gallium arsenide or indium selenide and produced in low volume might well cost one hundred times as much as an 8% efficient amorphous silicon cell in mass production, while only delivering about four times the electrical power.

A common method used to express economic costs of electricity-generating systems is to calculate a price per delivered kilowatt-hour (kWh). Using the commercially available solar cells (as of 2006) and system technology leads to system efficiencies between 5 and 19%. As of 2005, photovoltaic electricity generation costs ranged from ~0.60 US$/kWh (0.50 €/kWh) (central Europe) down to ~0.30 US$/kWh (0.25 €/kWh) in regions of high solar irradiation.

This electricity is generally fed into the electrical grid on the customer's side of the meter. The cost can be compared to prevailing retail electric pricing (as of 2005), which varied from between 0.04 and 0.50 US$/kWh worldwide. (Note: in addition to solar irradiance profiles, these costs/kwh calculations will vary depending on assumptions.

A typical advertisement found on the internet:

IL 53 ** Solar energy and finance

(**http://www.livescience.com/environment/081006-energy-costs.html**)

The following is a typical advertisement for buying and installing solar energy in a house:

As utility costs mount ever higher, Americans now have real options to take home energy matters into their own hands with "green" systems that can pay for themselves in as little as a few years.

Among the choices: wind, solar, geothermal and a "microhydro" option that is potentially cheaper than a year's tuition at many state colleges.

Choosing the do-it-yourself route can offer the freedom of going partially or totally off the grid. And, if the energy generated exceeds your actual usage, you can even sell the excess juice to your utility company. But none of this is free. Here's how much change you should expect to kick in:

The economics of a small photovoltaic system depend not only on the cost of designing and installing the system, which can vary considerably, but also the expense of maintaining and operating the system over the course of its serviceable lifetime, which usually spans between 25 to 30 years. The cost-effectiveness of such a system also depends on how much sun you get where you live, your electricity usage, and the size of your system.

If you're an average American household that uses 11,000 kilowatt-hours (kWh) per year, and you want to harness the power of the sun for 50 percent of your energy use, you can expect a 7.76 kilowatt (kW) peak power system to set you back about $35,000 to $52,000, according to FindSolar.com, an online calculator sponsored by the U.S. Department of Energy, the American Solar Energy Society, and the Solar Electric Power Association.

You can probably shave off a few thousand dollars once state and federal rebates come into play.

Assuming a property value appreciation of $14,000 to $27,000, as well as average annual utility savings of $1,000 to $2,000, you can potentially recoup your investment in three to 14 years.

Fig. 60: Photovoltaic solar panels on the roof of a house near Boston, Mass.

IL 54 **A list of FAQ and answers from Ameco – a southern Californian solar energy company

(http://www.solarexpert.com/grid-tie/FAQs.html)

IL 55 ** A list of FAQ and answers from General Electric

(http://www.gepower.com/prod_serv/products/solar/en/faqs/resid_sys.htm)

IL 56 ** Good discussions of residential solar electric power

(http://www.canren.gc.ca/prod_serv/index.asp?CaId=143&PgId=765)

IL 57 ** Solar electric systems (http://www.quantumenergy.ca/products_and_services/solar_electric_systems.html)

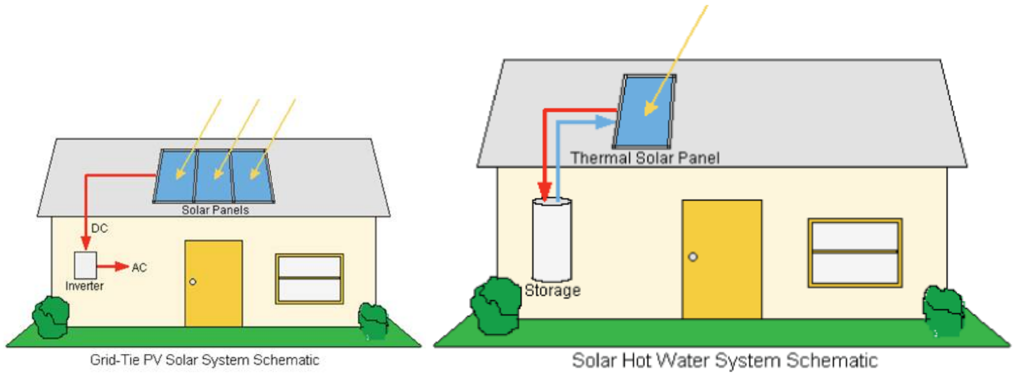


Fig. 61: Two types of solar collectors for domestic use.

Fig. 62: Anatomy of a solar panel

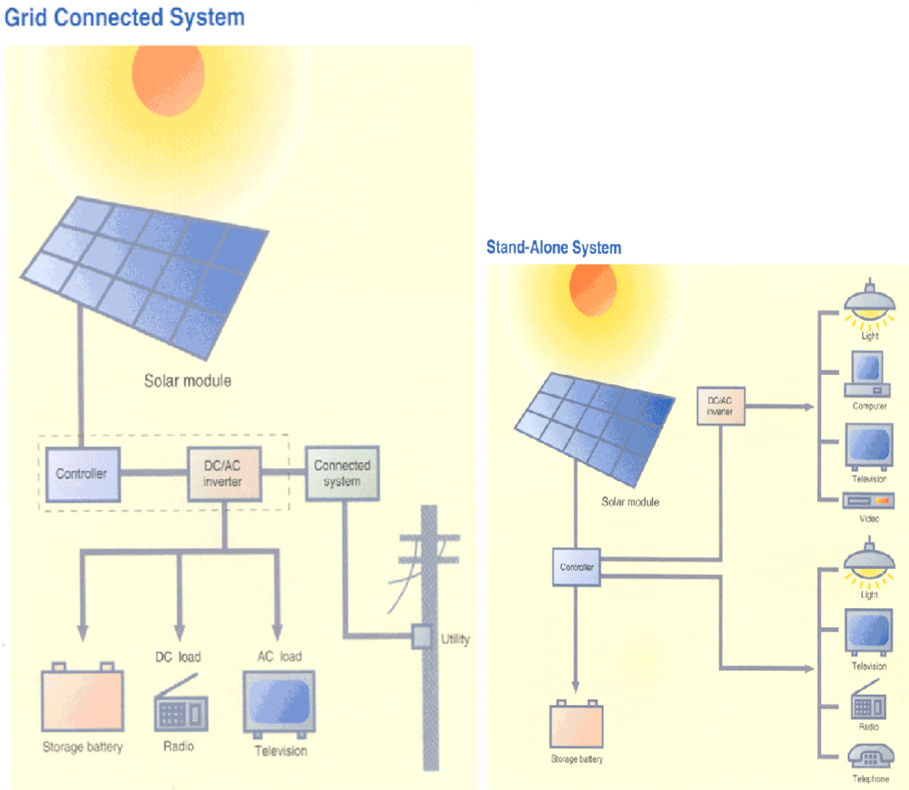
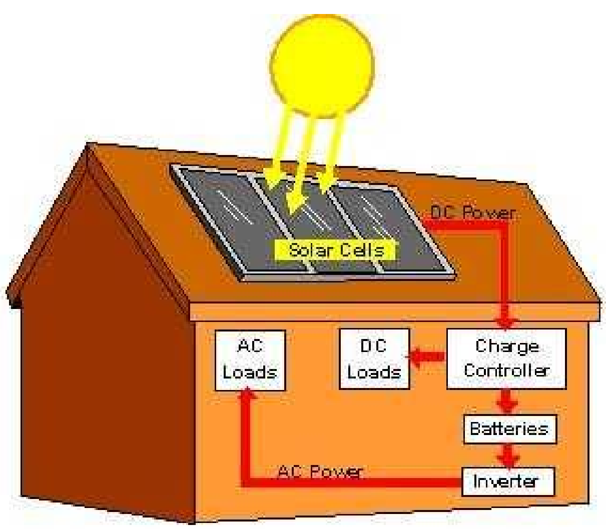


Fig. 63: Schemata for a grid connected system and stand-alone system.



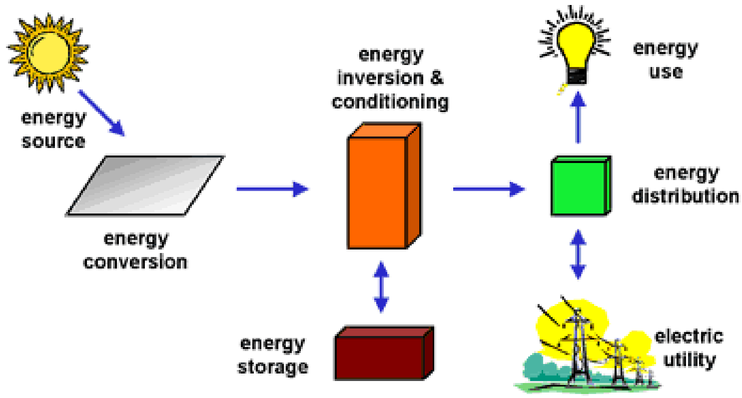


Fig. 64: The energy distribution of a solar driven electric system.

The size and configuration of a system depend on its intended task. Modules and arrays can be used to charge batteries, operate motors, and to power any number of electrical loads. With the appropriate power conversion equipment, solar power systems can produce alternating current (AC) compatible with any conventional appliances, and can operate in parallel with, and interconnected to, the utility grid (see grid coupling).

Among the components of a complete solar power system may be a DC-AC power inverter, a battery bank, a system and battery controller, auxiliary energy sources, and sometimes the specified electrical load (appliances). In addition, an assortment of balance of system (BOS) hardware, including wiring, overcurrent, surge protection and disconnect devices, and other power processing equipment.

A converter is a device that converts direct current electricity (for example, from a solar module or array) to alternating current (single or multiphase), for use in operating AC appliances or supplying power to an electricity grid.

Stand-alone inverters, also known as *off-grid inverters*, convert DC power stored in batteries to AC power that can be used as needed. Synchronous inverters, also called *grid-tie inverters*, can be used to convert the DC output of a photovoltaic module, a wind generator, or a fuel cell to AC power to be connected to the utility grid.

Questions and problems 7

For the following problems we will examine a house like the one shown in figure 64 above.

You can see that there are 16 collectors in one row and altogether 3 rows. Each collector area is 1 m^2. Also assume that the average solar flux in a six hour period on sunny days is about 300 w/ m^2. Also assume that solar cells (voltaic cells) are about 20% efficient in transforming solar radiation to electric power

1. How many watts of electric power could you generate when the sun shines?

2. Over a period of 10 days how much energy in kWhrs would you expect to collect?

3. In an average North American household uses 11,000 kilowatt-hours (kWh) per year, and you want to harness the power of the sun for 50 percent of your energy use, you can expect a 7.76 kilowatt (kW) peak power system to set you back about $35,000 to $52,000.

   You can probably shave off a few thousand dollars once state and federal rebates come into play.

   Assuming a property value appreciation of $14,000 to $27,000, as well as average annual utility savings of $1,000 to $2,000, you can potentially recoup your investment in three to 14 years. Discuss.

The energy output of sun; the modern explanation

IL 58 ** Detailed description of the sun and the solar system

(http://www.nineplanets.org/sol.html)

<u>Data for our sun</u>

Our Sun is a normal main-sequence G2 star, one of more than 100 billion stars in our galaxy.

diameter:	1,390,000 km.
mass:	1.989×10^{30} kg
temperature:	800 K (surface) 1.6×10^{7} K (core)

The Sun is by far the largest object in the solar system. It contains more than 99.8% of the total mass of the Solar System (Jupiter contains most of the rest). The Sun is, at present, about 70% hydrogen and 28% helium by mass everything else ("metals") amounts to less than 2%. This changes slowly over time as the Sun converts hydrogen to helium in its core.

Conditions at the Sun's core (approximately the inner 25% of its radius) are extreme. The temperature is 15.6×10^{6} Kelvin and the pressure is 2.50×10^{11} atmospheres. At the center of the core the Sun's density is more than 150 times that of water.

The Sun's energy output (3.86 x10 ^{26} Watts) is produced by nuclear fusion reactions. Each second about 700,000,000 tons of hydrogen are converted to about 695,000,000 tons of helium and 5,000,000 tons (=3.86e33 ergs) of energy in the form of gamma rays. As it travels out toward the surface, the energy is continuously absorbed and re-emitted at lower and lower temperatures so that by the time it reaches the surface, it is primarily visible light. For the last 20% of the way to the surface the energy is carried more by convection than by radiation.

Try the following guided problems:

1. Physicists use the unit of electron volts (eV) for energy. This is the energy required to accelerate an electron by a potential difference of 1 volt, that is, $1.6x10^{-19}$ J. In the thermonuclear reaction shown by the equation below, the “mass defect” is 0.0287.

   a. Using Einstein’s equation $E = mc^2$, show that this energy can be expressed as about 26 MeV.

   b. Show that the “mass defect’ is 0.0287 u that represents only 0.07 % of the total mass of H entering the thermonuclear reaction.

   c. We will see that the energy output of the sun per second (power) is about $3.9x10^{26}$ J/s. Calculate the total mass of hydrogen that reacts every second to produce this enormous output.

2. If we could tap the Sun's energy directly, our energy problems would be solved. Unfortunately, only a tiny part of this energy reaches the earth. Almost all the energy of the Sun escapes into space, as does the energy of other stars. We see some of this energy as starlight. What solar energy does strike the earth is spread out too broadly to be collectable in large amounts.

   a. Estimate the solar energy intercepted by the earth each second. Show that this energy is equal to $2 \pi R x S$, where R is the radius of the earth and S, the solar constant is about 1400 W/m^2.

   b. The surface of the Sun, called the **photosphere**, is at a temperature of about 5800 K. Sunspots are "cool" regions, only 3800 K (they look dark only by comparison with the surrounding regions). Sunspots can be very large, as much as 50,000 km in diameter. Sunspots are caused by complicated and not very well understood interactions with the Sun's magnetic field.

3. A small region known as the **chromosphere** lies above the photosphere. The highly rarefied region above the chromosphere, called the **corona**, extends millions of kilometers into space but is visible only during a total solar eclipse (left). Temperatures in the corona are over 1,000,000 K.

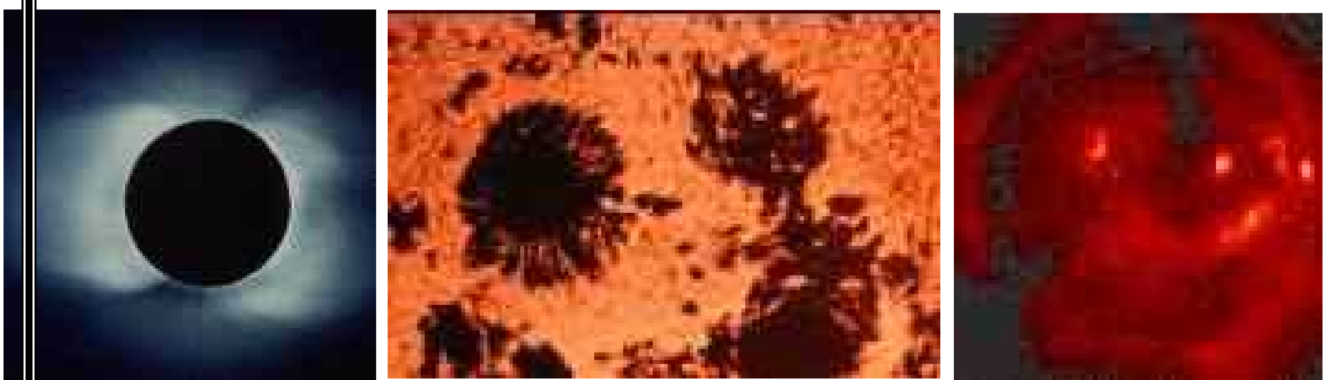


Fig. 65: From left to right: The sun's *corona* during a total eclipse, *sun spots*, and the *chromosphere.*

The following is taken from IL 58

a. *The Sun, average star though it is, puts out energy on a staggering scale. The largest energy unit most people are familiar with is the* megaton, *used in measuring the power of nuclear weapons. A megaton is the energy of a million tons of high explosive. The Sun's energy output is about equal to 90 billion megatons every second. The entire power-generating capacity of the earth equals about 60,000 megatons per year, so in one second the Sun produces over a million ears' worth of energy for the earth. If the Sun derived its energy by burning coal, it would take only 18 hours to burn a mass of coal equal to the earth. And the Sun has been doing this for 4.6 billion years.*

Verify the claims made above:

Claim 1: The entire power-generating capacity of the earth equals about 60,000 megatons per year, so in one second the Sun produces over a million years' worth of energy for the earth.

Claim 2: If the Sun derived its energy by burning coal, it would take only 18 hours to burn a mass of coal equal to the earth.

b. *Where the Sun gets its energy was one of the great scientific problems of the 1800's, because geologists had found evidence the earth was very old, but astronomers and physicists could not find an energy source capable of powering the Sun for such great spans of time. The discovery of nuclear energy in the 20th century solved the problem. The Sun derives its energy by* nuclear fusion*, in which four hydrogen atoms collide, in a complex process, to form a helium nucleus. This process is much the same as takes place in a thermonuclear weapon, but on a vastly greater scale.*

Discuss some of these claims.

IL 59 * Nuclear fusion**

(http://library.thinkquest.org/3471/fusion_body.html)

By the late 1930s the German-American physicist Hans Bethe and the German astrophysicist Weizecker showed that sun the solar energy is produced by a series of thermonuclear reactions involving hydrogen (protons). See IL .

Overall, this amounts to the combination of four protons and two electrons to form an alpha particle (^{4}He), two neutrinos, and six gamma rays. Thus, the overall equation is

$$4\,^1H + 2e^- \rightarrow \,^4He + 2\nu + 6\gamma$$

The energy release in this reaction is

$$\Delta E = [(4)(1.007825u) - 4.002603u][931\,^{MeV}/_{u}]$$
$$= 26.7\ MeV$$

The final energy produced is a combination of radiation energy (γ rays), kinetic energy (neutrinos) and the energy due to the mass loss obtained by subtracting the mass of one α particle, where **1.007825u** is the mass of a hydrogen atom and **4.002603u** is the mass of a helium atom. (Neutrinos and gamma-ray photons have no mass and thus do not enter into the calculation of disintegration energy). Note that particle physicist us the mass of the proton (1.67x10^{-27} kg as an unit of mass called atomic unit or **u.**

a. Physicists use the unit of electron volts (eV) for energy. This is the energy required to accelerate an electron by a potential difference of 1 volt, that is, $1.6x10^{-19}$ J. In the thermonuclear reaction shown by the equation above, the "mass defect" is 0.0287. Using Einstein's equation $E = mc^2$, show that this energy can be expressed as about 26 MeV.

b. Show that the "mass defect' is 0.0287 u that represents only 0.07 % of the total mass of H entering the thermonuclear reaction.

c. We will see that the energy output of the sun per second (power) is about $3.9x10^{26}$ J/s. Calculate the total mass of hydrogen that reacts every second to produce this enormous output.

Fig. 66: Imagine a bridge made of ice connecting the earth and the sun.

How large a solar surface would you have to build on Mars to have the same radiation-power gathering capacity as on Earth, assuming an absorption by the atmosphere of only 15%? The distance of Mars from the earth is about 1.50 times the distance between the earth and the sun.

In IL 59 the following claim is made:

The amount of energy the sun provides for the earth in one minute is large enough to meet the earth's energy needs for one year. The problem is in the development of technology that can harness this 'free' energy source.

The total World Annual Energy Consumption is $4.37x10^{20}$ Jand the total energy from the Sun that strikes the face of the Earth each year is 5.5×10^{24} J.

Check this claim and comment.

IL 60 ** Explanation of grid-tied solar power

(http://www.solsmart.com/gridtiedsolar.php)

IL 61 ** Solar thermal collectors (http://www.folkecenter.net/gb/rd/solar-energy/solar_collectors/)

IL 62 ** A good summary of photovoltaic cells (http://www1.eere.energy.gov/solar/pv_basics.html)

IL 63 ** Good source of solar energy discussion (**http://www.powerfromthesun.net/chapter1/Chapter1.htm**)

Appendix

History of Solar Energy

From ancient Greek homes built to face the warm winter sun to advanced thin-film photovoltaics, which generate electricity from the sun, humans have used the sun's rays to meet their energy needs. This makes sense, given that the sun showers the earth every hour with enough energy to meet world demand for a year. And the best part: this energy is pollution-free, inexhaustible and accessible to many.

Ancient Greeks and Romans saw great benefit in what we now refer to as passive solar design—the use of architecture to make use of the sun's capacity to light and heat indoor spaces. The Greek philosopher Socrates wrote, "In houses that look toward the south, the sun penetrates the portico in winter." Romans advanced the art by covering south facing building openings with glass or mica to hold in the heat of the winter sun. Through calculated use of the sun's energy, Greeks and Romans offset the need to burn wood that was often in short supply.

Auguste Mouchout, inventor of the first active solar motor, questioned the widespread belief that the fossil fuels powering the Industrial Revolution in the 19th century would never run out. "Eventually industry will no longer find in Europe the resources to satisfy its prodigious expansion. Coal will undoubtedly be used up. What will industry do then?" Mouchout asked prophetically.

In 1861, Mouchout developed a steam engine powered entirely by the sun. But its high costs coupled with the falling price of English coal doomed his invention to become a footnote in energy history. Nevertheless, solar energy continued to intrigue and attract European scientists through the 19th century. Scientists developed large cone-shaped collectors that could boil ammonia to perform work like locomotion and refrigeration. France and England briefly hoped that solar energy could power their growing operations in the sunny colonies of Africa and East Asia.

In the United States, Swedish-born John Ericsson led efforts to harness solar power. He designed the "parabolic trough collector," a technology which functions more than a hundred years later on the same basic design. Ericsson is best known for having conceived the USS Monitor, the armored ship integral to the U.S. Civil War.

Solar power could boast few major gains through the first half of the 20th century, though interest in a solar-powered civilization never completely disappeared. In fact, Albert Einstein was awarded the 1921 Nobel Prize in physics for his research on the photoelectric effect—a phenomenon central to the generation of electricity through solar cells.

Some 50 years prior, William Grylls Adams had discovered that when light was shined upon selenium, the material shed electrons, thereby creating electricity.

In 1953, Bell Laboratories (now AT&T labs) scientists Gerald Pearson, Daryl Chapin and Calvin Fuller developed the first silicon solar cell capable of generating a measurable electric current. The New York Times reported the discovery as "the beginning of a new era, leading eventually to the realization of harnessing the almost limitless energy of the sun for the uses of civilization."

In 1956, solar photovoltaic (PV) cells were far from economically practical. Electricity from solar cells ran about $300 per watt. (For comparison, current market rates for a watt of solar PV hover around $5.) The "Space Race" of the 1950s and 60s gave modest opportunity for progress in solar, as satellites and crafts used solar paneling for electricity.

It was not until October 17, 1973 that solar leapt to prominence in energy research. The Arab Oil Embargo demonstrated the degree to which the Western economy depended upon a cheap and reliable flow of oil. As oil prices nearly doubled over night, leaders became desperate to find a means of reducing this dependence. In addition to increasing automobile fuel economy standards and diversifying energy sources, the U.S. government invested heavily in the solar electric cell that Bell Laboratories had produced with such promise in 1953.

The hope in the 1970s was that through massive investment in subsidies and research, solar photovoltaic costs could drop precipitously and eventually become competitive with fossil fuels.

By the 1990s, the reality was that costs of solar energy had dropped as predicted, but costs of fossil fuels had also dropped—solar was competing with a falling baseline.

However, huge PV market growth in Japan and Germany from the 1990s to the present has reenergized the solar industry. In 2002 Japan installed 25,000 solar rooftops. Such large PV orders are creating economies of scale, thus steadily lowering costs. The PV market is currently growing at a blistering 30 percent per year, with the promise of continually decreasing costs. Meanwhile, solar thermal water heating is an increasingly cost-effective means of lowering gas and electricity demand.

As you've seen, technologies have changed and improved for decades. Still, the basics of solar thermal and photovoltaics have remained the same.

What are the basic kinds of solar cookers?

There are three basic kinds:

- Box cookers
  This type of cooker has been the advantage of slow, even cooking of large quantities of food. Variations include slanting the face toward the sun and the number of reflectors. You'll find an article discussing solar box cooker designs here.

- Panel cookers
  This recent development was sparked by Roger Bernard in France. In this design, various flat panels concentrate the sun's rays onto a pot inside a plastic bag or under a glass bowl. The advantage of this design is that they can be built in an hour or so for next to nothing. In Kenya, these are being manufactured for the Kakuma Refugee Camp project for US$2 each.

- Parabolic cookers
  These are usually concave disks that focus the light onto the bottom of a pot. The advantage is that foods cook about as fast as on a conventional stove. The disadvantage is that they are complicated to make, they must be focused often to follow the sun, and they can cause burns and eye injury if not used correctly. Some of these concerns have recently been reduced by Dr. Dieter Seifert's design.

There is a detailed document here showing a large number of variations on these themes. You can also listen to a good introduction to solar cooking here.

Who made the first solar cooker?

The first solar cooker we know of was invented by Horace de Saussure, a Swiss naturalist experimenting as early as 1767. See this article for more info.

Where are solar ovens being used the most?

There are reliable reports that there are over 100,000 cookers in use in both India and China. We are aware of solar cooking projects in most of the countries of the world. Solar Cookers International has recently had a breakthrough in Kenya using the CooKit panel cooker. More than 5000 families are now solar cooking there.

How hot do solar ovens get?

Place an oven thermometer in the sunny part of the oven to get a reading similar to what the cooking pot is "feeling". The temperature reached by box cookers and panel cookers depends primarily on the number and size of the reflectors used. A single-reflector box cooker usually tops out at around 150° C (300° F) as the food approaches being done. High temperatures, however, are not needed for cooking. Your oven will cook just fine as long as it gets up to about 90° C (200° F) or so. Higher temperatures cook larger quantities, cook faster, and allow for cooking on marginal days; However, many people prefer to cook at lower temperatures, since then they can leave the food to cook while they go about their business. With a single-reflector box cooker, once the food is cooked, it just stays warm and doesn't scorch. It's good to keep in mind that no food can go above 100° C (212° F) at sea level anyway, unless a pressurized cooking vessel is used. The high temperatures you see in cookbooks for conventional ovens are just for convenience and for special effects such as quick browning.

How long does it take to cook a meal?

As a rule of thumb, you can figure that food in a single-reflector box cooker will take about twice as long as in a conventional oven . However, since you can't really burn your food, you don't have to watch the cooker or stir any food as it cooks. You can just put in a few pots with different foods and then come back later in the day and each pot will cook to perfection and then stay hot until you take it out.

Panel cookers cook smaller portions, usually only in a single pot, but often they cook slightly faster. Some people have reported the need to stir food every once in a while when using this kind of cooker to assure that the food heats evenly.

Cooking with a parabolic cooker is very similar to cooking on one burner of a conventional stove. Since the concentrated sunlight shines directly on the bottom of a pot, the pot heats up and cooks very quickly. The food will burn though. So you have to stir it and watch it carefully.

Do you have to turn the cooker to follow the sun?

Box cookers with one back reflector don't need to be turned unless you are cooking beans which take up to 5 hours. Panel cookers need to be turned more often than box cookers, since they have side reflectors that can shade the pot. Parabolic cookers are the most difficult to keep in focus. These need to be turned every 10 to 30 minutes, depending on the focal length.

Should I take the time to build a box cooker out of "real" materials like plywood or glass or is cardboard good enough?

Unless you need a cooker that can stay outside even in the rain, you'll do just fine with a cardboard cooker. Cardboard is much easier to work with and holds heat just as well. Some people we know have used the same cardboard box cooker for over 10 years.

Would a mirror make a better reflector?

While mirrors are more reflective than simpler materials such as aluminum foil, but the added gain is probably not worth the increased cost and fragility involved with using a mirror.

Does it help to paint the walls black?

Some people prefer to paint the walls black thinking that the oven will get hotter. It seems, however, that the walls will get hotter, but the food won't necessarily get hotter. We prefer to cover the inner walls with aluminum foil to keep the light bouncing until it hits either the dark pot or the dark bottom tray. Since the bottom tray is in contact with the pot, the heat the tray collects will move into the pot easily.

What type of paint should I use?

In developed countries you can buy flat-black spray paint that says "non-toxic when dry" on the label. Otherwise, black tempera paint works, but you have to be careful not to wash it off when you wash the pot. Solar cookers in Uganda report that they use aluminum pots that have been blackened on the outside by fire.

Is glass better than plastic for the window?

People generally report that glass provides about 10% better performance than plastic. And there is reason to believe that under windy conditions, glass is preferred since it doesn't flap in the wind and dissipate heat from the cooker. Plastic, however, is often recommended since is much less fragile and easier to transport and works plenty well. One excellent, easily-obtained plastic film is oven cooking bags. These are for sale in grocery stores and cost less than US$1 per bag. Other plastics will also work. Plexiglas also works well.

What kind of pots work best?

Ideally, you want to use a dark, light-weight, shallow pot that is slightly larger than the food you will cook in it. Metal pans seem to cook best. Hardware stores in the US usually carry dark, speckled, metal pans called Graniteware. Shiny aluminum pots--so common in developing countries--can be painted black or can be blackened in a fire. Cast iron pots will work, but extra solar energy is used to heat up the pot as well as the food, so they will not work in marginal conditions.

What is the best insulation to use?

If you wish, you can insulate the walls of a box cooker with various substances. Fiberglass or Styrofoam is usually not recommended since they give off ill-smelling gases as they heat up. Natural substances such as cotton, wool, feathers, or even crumpled newspapers work well. Many people, however, leave the walls empty of any stuffing, preferring instead to place a piece of foiled cardboard as a baffle inside the wall airspace. This makes a lighter cooker and seems to be adequate. Most of the heat loss in a box cooker is through the glass or plastic, not through the walls. This is why a few percentage points of efficiency here or there in the walls doesn't effect the overall temperature and cooking power that much.

Could I use high-tech materials to make a more efficient solar cooker?

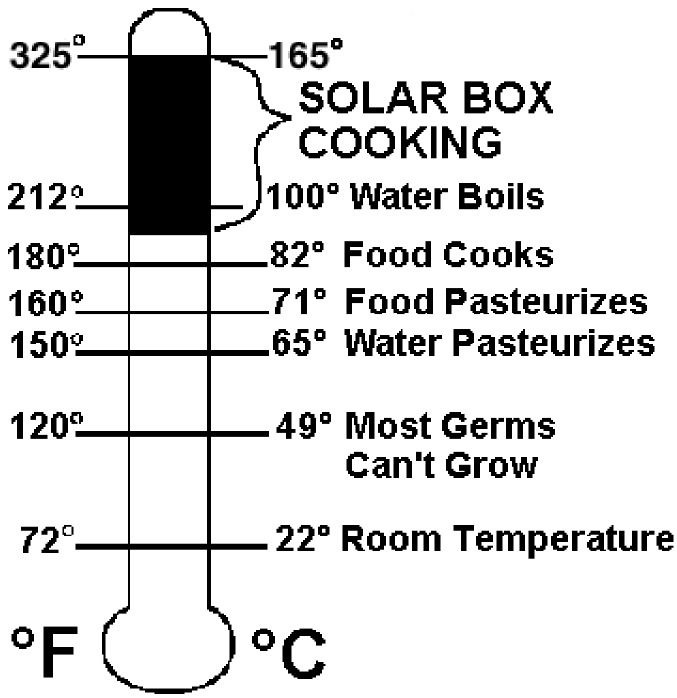
You may find that creating a high-performance cooker using fancy materials will make solar cooking more attractive to people in developed countries. In these countries, cooking only makes up a small percentage of daily energy use, but this is because people in developed countries consume enormous amounts of energy for other purposes (driving, lighting, air conditioning, etc.). Introducing these people to solar cooking is a good way to show them that they can integrate alternative energy into their lives. Solar cooking and drying clothes outside on a line are the simplest, least expensive ways to use solar energy to offset some of this high energy consumption. This will hopefully open them to the possibility of using alternative energy in other ways.

Millions of poor people around the world, however, still cook over a smoky fire everyday. To find wood for the fire, they have to walk many hours everyday. Other poor city dwellers don't have access to wood, so they have to spend up to half of their income on cooking fuel. These people could never afford an oven made of high-tech materials.

So it's up to you to decide which population you want to serve. You could work on creating the most practical solar cooker for people in developed countries to help lead them into a greener future, or you can investigate how to make cookers out of cheap, locally-available materials for people in poor countries who can't afford more.

Can you sterilize water in a solar oven?

Yes. In all three types, water can be brought to a boil. A little-known fact, however, is that to make water safe to drink, it only has to be pasteurized, not sterilized. Pasteurization takes place at 65° C (150° F) in only 20 minutes. This treatment kills all human disease pathogens, but doesn't waste the energy needed to bring the water to a boil. One reason that people are told to boil their water is that thermometers are not readily available in many places and the boiling action serves as the temperature indicator. Dr. Robert Metcalf has written a very informative piece called Recent Advances in Solar Water Pasteurization. You will find other references in the Documents page of the Solar Cooking Archive



Can you use a solar box cooker for canning?

Yes, but for fruits only! Do not can vegetables or meat in a solar box cooker, since these foods need to be canned under pressure! You'll find information on canning here.

Can you cook pasta in a solar box cooker?

To keep the pasta from getting pasty, use two pans. Heat the dry pasta with oil in one pan; heat the liquid with herbs in another. Fifteen to 20 minutes before eating, combine the two. If you are going to use a sauce, heat that in a third container.

If solar ovens are so good, why isn't everyone using one?

There are many factors at work here. First and foremost, the vast majority of the world's population does not even know that it is possible to cook with the sun. When they find out about it there is almost universal enthusiasm, especially in regions where the gathering of cooking fuel and the process of cooking over a smoky fire is a great burden. There are many factors that need to be in place to make it possible for poor people to solar cook on an ongoing basis. The most successful projects have been ones where the need was the greatest, the weather the most favorable, and where the solar cooking promoters have taken a long-range approach to the transition. An example of this is the work by Solar Cookers International in the Kakuma refugee camp in Kenya.

If you build a box cooker out of cardboard, won't it catch fire?

No. Paper burns at 451° F (233° C) and your cooker won't get that hot.

How much of the year can you cook?

In tropical regions and in the southern US you can cook all year depending on the weather. In areas as far north as Canada you can cook whenever it is clear except during the three coldest months of the year. Click the picture to see a map showing the amount of sunlight each part of the world receives.

What foods should I try first in my new Cooker?

A good first food to try is a small quantity of rice, since it is fairly easy to cook and looks very different cooked than it does raw. Chicken or fish is also very easy to cook. See cooking hints or cooking times.

My cooker only gets up to 250° F (121° C). Is this hot enough to cook when recipes call for 350°F (177° C) or even450°F(232°C)?

A temperature of 250° F (121° C) is hot enough for all kinds of cooking. Remember that water cannot get hotter than 212° F (100° C). Thus if you are cooking food that contains water, it cannot get hotter than this either. Conventional cookbooks call for high temperatures to shorten the cooking time and for browning. Food just takes longer in most solar cookers, but since the sun is shining directly on the lid of the pot, the food browns just about as wellasinaconventionaloven.

What happens if the sun goes in front of the clouds while I'm cooking?

Your food will continue to cook as long as you have 20 minutes of sun an hour (using a box cooker). It is not recommended that you cook meats unattended when there is a possibility of substantial cloudiness. More information on food safety, go here. If you can be sure that the sky will stay clear though, you can put in any type of food in the morning, face the oven to the south, and the food will be cooked when you get home at the end of the day.

I'm planning to do a science project on solar cooking. What should I study?

If you're planning a science project, Solar Cooker International wants you to know that your research can help extend the world's knowledge of solar cooking and be of great help to people around the world. You should be aware that it's easy to build a high-performance solar cooker if you have access to modern materials. However, the more than a billion poor people in the world, who could really benefit from having a solar cooker, don't have access to such materials. This means that your research will be most useful if it concentrates on the simplification of cooker design or on the use of low-tech, local materials. For more information, see Topics Needing Research.

What resources are available online?

Solar Cookers International sponsors the Solar Cooking Archive on the World Wide Web at http://solarcooking.org where you will find illustrated construction plans, photographs, documents, and an international directory of solar cooking promoters. Their thrice-yearly newsletter, the Solar Cooker Review, is also available there. An excellent document for further reading is The Expanding World of Solar Box Cooking, by Barbara Kerr. You'll find a number of audio programs that you can listen to online here. Don't forget to read about eye safety here.

Measurement of Sunshine Duration

Definition

Sunshine duration is the length of time that the ground surface is irradiated by direct solar radiation (i.e., sunlight reaching the earth's surface directly from the sun). In 2003, WMO defined sunshine duration as the period during which direct solar irradiance exceeds a threshold value of 120 watts per square meter (W/m^2). This value is equivalent to the level of solar irradiance shortly after sunrise or shortly before sunset in cloud-free conditions. It was determined by comparing the sunshine duration recorded using a Campbell-Stokes sunshine recorder with the actual direct solar irradiance.

Sunshine Duration Measuring Instruments

Campbell-Stokes sunshine recorders and Jordan sunshine recorders have long been used as instruments to measure sunshine duration, and are advantageous in that they have no moving parts and require no electric power. Their disadvantages are that the characteristics of the recording paper or photosensitized paper used in them affect measurement accuracy, differences between observers may arise in determining the occurrence of sunshine, and the recording paper must be replaced after sunset.

As sunshine is defined quantitatively at present, a variety of photoelectric sunshine recorders have been developed and are used in place of these instruments. As the threshold value for the occurrence of sunshine is defined in terms of direct solar irradiance, it is also possible to observe sunshine duration with a pyrheliometer.

Campbell-Stokes Sunshine Recorders

(1) Principles and Structure

A Campbell-Stokes sunshine recorder concentrates sunlight through a glass sphere onto a recording card placed at its focal point. The length of the burn trace left on the card represents the sunshine duration.

The device's structure is shown in Figure .1 (a). A homogeneous transparent glass sphere L is supported on an arc XY, and is focused so that an image of the sun is formed on recording paper placed in a metal bowl FF' attached to the arc. The glass sphere is concentric to this bowl, which has three partially overlapping grooves into which recording cards for use in the summer, winter or spring and autumn are set (Figure .1 (b)). Three different recording cards (Figure .1 (c)) are used depending on the season. The focus shifts as the sun moves, and a burn trace is left on the recording card at the focal point. A burn trace at a particular point indicates the presence of sunshine at that time, and the recording card is scaled with hour marks so that the exact time of sunshine occurrence can be ascertained. Measuring the overall length of burn traces reveals the sunshine duration for that day. For exact measurement, the sunshine recorder must be accurately adjusted for planar leveling, meridional direction and latitude. Campbell-Stokes and Jordan sunshine recorders mark the occurrence of sunshine on recording paper at a position corresponding to the azimuth of the sun at the site, and the time of sunshine occurrence is expressed in local apparent time.

UNIT-IV

Types of Wind Turbines

Modern wind turbines fall into two basic groups: the horizontal-axis variety, as shown in the photo, and the vertical-axis design, like the eggbeater-style Darrieus model, named after its French inventor.Horizontal-axis wind turbines typically either have two or three blades. These three-bladed wind turbines are operated "upwind," with the blades facing into the wind.

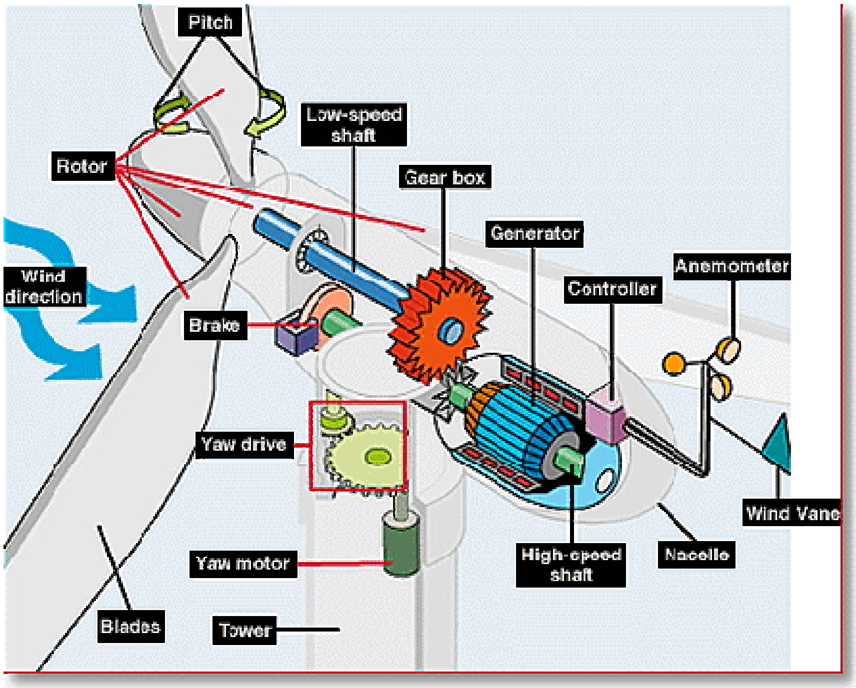
GE Wind Energy's 3.6 megawatt wind turbine is one of the largest prototypes ever erected. Larger wind turbines are more efficient and cost effective.

Sizes of Wind Turbines

Utility-scale turbines range in size from 100 kilowatts to as large as several megawatts. Larger turbines are grouped together into wind farms, which provide bulk power to the electrical grid.

Single small turbines, below 100 kilowatts, are used for homes, telecommunications dishes, or water pumping. Small turbines are sometimes used in connection with diesel generators, batteries, and photovoltaic systems. These systems are called hybrid wind systems and are typically used in remote, off-grid locations, where a connection to the utility grid is not available.

Inside the Wind Turbine



Anemometer:

Measures the wind speed and transmits wind speed data to the controller.

Blades:

Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate.

Brake:

A disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.

Controller:

The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above about 55 mph because they might be damaged by the high winds.

Gear box:

Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

Generator:

Usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

High-speed shaft:

Drives the generator.

Low-speed shaft:

The rotor turns the low-speed shaft at about 30 to 60 rotations per minute.

Nacelle:

The nacelle sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake. Some nacelles are large enough for a helicopter to land on.

Pitch:

Blades are turned, or pitched, out of the wind to control the rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor:

The blades and the hub together are called the rotor.

Tower:

Towers are made from tubular steel (shown here), concrete, or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

Wind direction:

This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind," facing away from the wind.

Wind vane:

Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

Yaw drive:

Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive, the wind blows the rotor downwind.

Yaw motor:

Powers the yaw drive.

UNIT-VI OTHER POWER PLANTS AND ECONOMICS OF POWER PLANTS

GEOTHERMAL POWER PLANT:

Geothermal electricity is electricity generated from geothermal energy. Technologies in use include dry steam power plants, flash steam power plants and binary cycle power plants. Geothermal electricity generation is currently used in 24 countries while geothermal heating is in use in 70 countries.

Estimates of the electricity generating potential of geothermal energy vary from 35 to 2000 GW. Current worldwide installed capacity is 10,715 megawatts (MW), with the largest capacity in the United States (3,086 MW), Philippines, and Indonesia.

Geothermal power is considered to be sustainable because the heat extraction is small compared with the Earth's heat content. The emission intensity of existing geothermal electric plants is on average 122 kg of CO_2 per megawatt-hour (MW·h) of electricity, about one-eighth of a conventional coal-fired plant.

OTEC:

Ocean thermal energy conversion (*OTEC*)uses the difference between cooler deep and warmer shallow or surface ocean waters to run a heat engine and produce useful work, usually in the form of electricity.

A heat engine gives greater efficiency and power when run with a large temperature difference. In the oceans the temperature difference between surface and deep water is greatest in the tropics, although still a modest 20^oC to 25^oC. It is therefore in the tropics that OTEC offers the greatest possibilities. OTEC has the potential to offer global amounts of energy that are 10 to 100 times greater than other ocean energy options such as wave power. OTEC plants can operate continuously providing a base load supply for an electrical power generation system.

The main technical challenge of OTEC is to generate significant amounts of power efficiently from small temperature differences. It is still considered an emerging technology. Early OTEC systems were of 1 to 3% thermal efficiency, well below the theoretical maximum for this temperature difference of between 6 and 7%.[2] Current designs are expected to be closer to the maximum. The first operational system was built in Cuba in 1930 and generated 22 kW. Modern designs allow performance approaching the theoretical maximum Carnot efficiency and the largest built in 1999 by the USA generated 250 kW .

The most commonly used heat cycle for OTEC is the Rankine cycle using a low-pressure turbine. Systems may be either closed-cycle or open-cycle. Closed-cycle engines use working fluids that are typically thought of as refrigerants such as ammonia or R-134a. Open-cycle engines use vapour from the seawater itself as the working fluid.

OTEC can also supply quantities of cold water as a by-product . This can be used for air conditioning and refrigeration and the fertile deep ocean water can feed biological technologies. Another by-product is fresh water distilled from the sea.

Cycle types

Cold seawater is an integral part of each of the three types of OTEC systems: closed-cycle, open-cycle, and hybrid. To operate, the cold seawater must be brought to the surface. The primary approaches are active pumping and desalination. Desalinating seawater near the sea floor lowers its density, which causes it to rise to the surface.

The alternative to costly pipes to bring condensing cold water to the surface is to pump vaporized low boiling point fluid into the depths to be condensed, thus reducing pumping volumes and reducing technical and environmental problems and lowering costs.

Closed

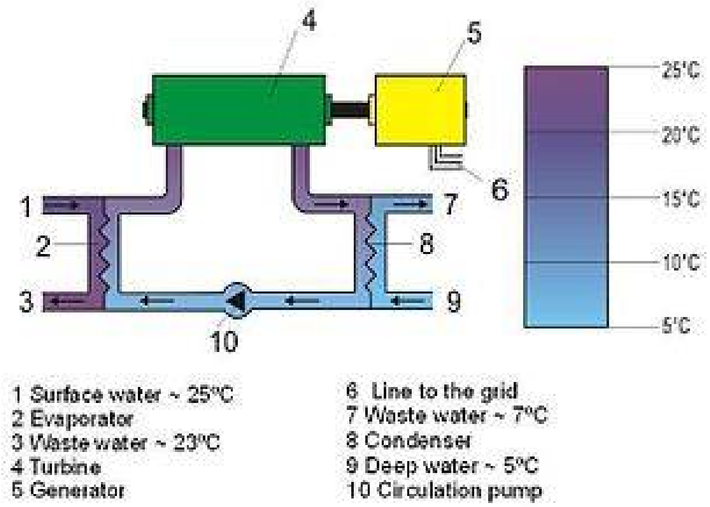


Diagram of a closed cycle OTEC plant

Closed-cycle systems use fluid with a low boiling point, such as ammonia, to power a turbine to generate electricity. Warm surface seawater is pumped through a heat exchanger to vaporize the fluid. The expanding vapor turns the turbo-generator. Cold water, pumped through a second heat exchanger, condenses the vapor into a liquid, which is then recycled through the system.

In 1979, the Natural Energy Laboratory and several private-sector partners developed the "mini OTEC" experiment, which achieved the first successful at-sea production of net electrical power from closed-cycle OTEC.[12] The mini OTEC vessel was moored 1.5 miles (2 km) off the Hawaiian coast and produced enough net electricity to illuminate the ship's light bulbs and run its computers and television.

Open

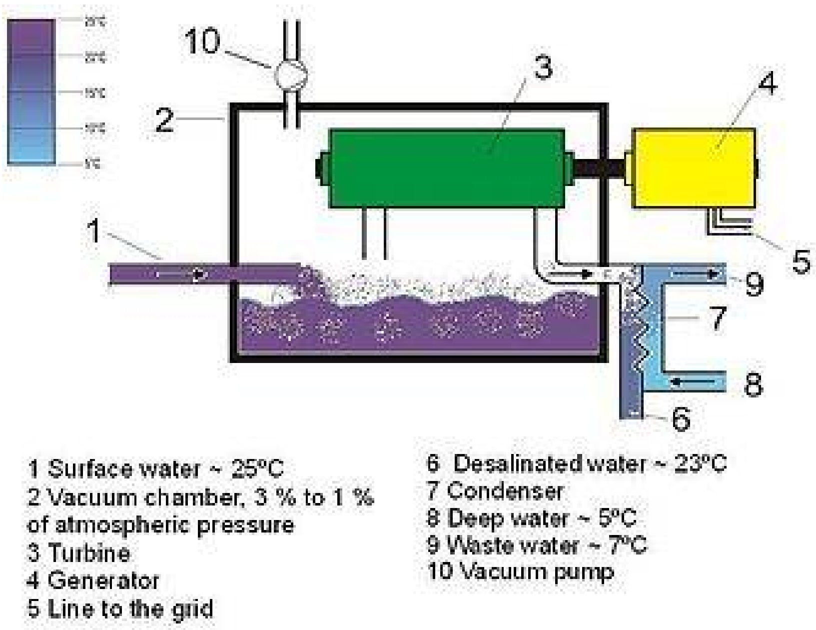


Diagram of an open cycle OTEC plant

Open-cycle OTEC uses warm surface water directly to make electricity. Placing warm seawater in a low-pressure container causes it to boil. The expanding steam drives a low-pressure turbine attached to an electrical generator. The steam, which has left its salt and other contaminants in the low-pressure container, is pure fresh water. It is condensed into a liquid by exposure to cold temperatures from deep-ocean water. This method produces desalinized fresh water, suitable for drinking water or irrigation.

In 1984, the *Solar Energy Research Institute* (now the National Renewable Energy Laboratory) developed a vertical-spout evaporator to convert warm seawater into low-pressure steam for open-cycle plants. Conversion efficiencies were as high as 97% for seawater-to-steam conversion (overall efficiency using a vertical-spout evaporator would still only be a few per cent). In May 1993, an open-cycle OTEC plant at Keahole Point, Hawaii, produced 50,000 watts of electricity during a net power-producing experiment. This broke the record of 40 kW set by a Japanese system in 1982.

Hybrid

A hybrid cycle combines the features of the closed- and open-cycle systems. In a hybrid, warm seawater enters a vacuum chamber and is flash-evaporated, similar to the open-cycle evaporation process. The steam vaporizes the ammonia working fluid of a closed-cycle loop on the other side of an ammonia vaporizer. The vaporized fluid then drives a turbine to produce electricity. The steam condenses within the heat exchanger and provides desalinated water.

Working fluids

A popular choice of working fluid is ammonia, which has superior transport properties, easy availability, and low cost. Ammonia, however, is toxic and flammable. Fluorinated carbons such asCFCs and HCFCs are not toxic or flammable, but they contribute to ozone layer depletion. Hydrocarbons too are good candidates, but they are highly flammable; in addition, this would create competition for use of them directly as fuels. The power plant size is dependent upon the vapor pressure of the working fluid. With increasing vapor pressure, the size of the turbine and heat exchangers decreases while the wall thickness of the pipe and heat exchangers increase to endure high pressure especially on the evaporator side.

UNIT VII

TIDEL POWER PLANT:

Tidal power, also called **tidal energy**, is a form of hydropower that converts the energy of tides into electricity or other useful forms of power. The first large-scale tidal power plant (the Rance Tidal Power Station) started operation in 1966.

Although not yet widely used, tidal power has potential for future electricity generation. Tides are more predictable than wind energy and solar power. Among sources of renewable energy, tidal power has traditionally suffered from relatively high cost and limited availability of sites with sufficiently high tidal ranges or flow velocities, thus constricting its total availability. However, many recent technological developments and improvements, both in design (e.g. dynamic tidal power, tidal lagoons) and turbine technology (e.g. new axial turbines, crossflow turbines), indicate that the total availability of tidal power may be much higher than previously assumed, and that economic and environmental costs may be brought down to competitive levels.

Historically, tide mills have been used, both in Europe and on the Atlantic coast of North America. The earliest occurrences date from the Middle Ages, or even from Roman times.

Tidal power is extracted from the Earth's oceanic tides; tidal forces are periodic variations in gravitational attraction exerted by celestial bodies. These forces create corresponding motions or currents in the world's oceans. The magnitude and character of this motion reflects the changing positions of the Moon and Sun relative to the Earth, the effects of Earth's rotation, and local geography of the sea floor and coastlines.

Tidal power is the only technology that draws on energy inherent in the orbital characteristics of the Earth–Moon system, and to a lesser extent in the Earth–Sun system. Other natural energies exploited by human technology originate directly or indirectly with the Sun, including fossil fuel, conventional hydroelectric, wind, biofuel, wave and solar energy. Nuclear energy makes use of Earth's mineral deposits of fissionable elements, while geothermal power taps the Earth's internal heat, which comes from a combination of residual heat from planetary accretion (about 20%) and heat produced through radioactive decay (80%).

A tidal generator converts the energy of tidal flows into electricity. Greater tidal variation and higher tidal current velocities can dramatically increase the potential of a site for tidal electricity generation.

Because the Earth's tides are ultimately due to gravitational interaction with the Moon and Sun and the Earth's rotation, tidal power is practically inexhaustible and classified as a renewable energy resource. Movement of tides causes a loss of mechanical energy in the Earth–Moon system: this is a result of pumping of water through natural restrictions around coastlines and consequent viscous dissipation at the seabed and in turbulence. This loss of energy has caused the rotation of the Earth to slow in the 4.5 billion years since its formation. During the last 620 million years the period of rotation of the earth (length of a day) has increased from 21.9 hours to 24 hours;[4] in this period the Earth has lost 17% of its rotational energy. While tidal power may take additional energy from the system, the effect is negligible and would only be noticed over millions of years.

Generating methods

The world's first commercial-scale and grid-connected tidal stream generator – SeaGen – in Strangford Lough. The strong wake shows the power in the tidal current.

Top-down view of a DTP dam. Blue and dark red colors indicate low and high tides, respectively.

Tidal power can be classified into three generating methods:

Tidal stream generator

Tidal stream generators (or TSGs) make use of the kinetic energy of moving water to power turbines, in a similar way to wind turbines that use moving air.

Tidal barrage

Tidal barrages make use of the potential energy in the difference in height (or *head*) between high and low tides. Barrages are essentially dams across the full width of a tidal estuary.

Dynamic tidal power

Dynamic tidal power (or DTP) is a theoretical generation technology that would exploit an interaction between potential and kinetic energies in tidal flows. It proposes that very long dams (for example: 30–50 km length) be built from coasts straight out into the sea or ocean, without enclosing an area. Tidal phase differences are introduced across the dam, leading to a significant water-level differential in shallow coastal seas – featuring strong coast-parallel oscillating tidal currents such as found in the UK, China and Korea.

PUMPED STORAGE:

Pumped-storage hydroelectricity is a type of hydroelectric power generation used by some power plants for *load balancing*. The method stores energy in the form of water, pumped from a lower elevation reservoir to a higher elevation. Low-cost off-peak electric power is used to run the pumps. During periods of high electrical demand, the stored water is released through turbines. Although the losses of the pumping process makes the plant a net consumer of energy overall, the system increases revenue by selling more electricity during periods of *peak demand*, when electricity prices are highest. Pumped storage is the largest-capacity form of grid energy storage now available.

SOLAR CENTRAL RECIVER SYSTEM:

The **solar power tower** (also known as 'central tower' power plants or 'heliostat' power plants or power towers) is a type of solar furnace using a tower to receive the focused sunlight. It uses an array of flat, movable mirrors (called heliostats) to focus the sun's rays upon a collector tower (the target). Concentrated solar thermal is seen as one viable solution for renewable, pollution free energy production with currently available technology.

Early designs used these focused rays to heat water, and used the resulting steam to power a turbine. Newer designs using liquid sodium has been demonstrated, and systems using molten salts (40% potassium nitrate, 60% sodium nitrate) as the working fluids are now in operation. These working fluids have high heat capacity, which can be used to store the energy before using it to boil water to drive turbines. These designs allow power to be generated when the sun is not shining.

COST OF ELECTRICAL ENERGY:

Electric power transmission or "high voltage electric transmission" is the bulk transfer of electrical energy, from generating power plants to substations located near to population centers. This is distinct from the local wiring between high voltage substations and customers, which is typically referred to as electricity distribution. Transmission lines, when interconnected with each other, become high voltage transmission networks. In the US, these are typically referred to as "power grids" or just "the grid", while in the UK the network is known as the "national grid." North America has three major grids: The Western Interconnection; The Eastern Interconnection and the Electric Reliability Council of Texas (or ERCOT) grid.

Historically, transmission and distribution lines were owned by the same company, but over the last decade or so many countries have liberalized the electricity market in ways that have led to the separation of the electricity transmission business from the distribution business.

Transmission lines mostly use three-phase alternating current (AC), although single phase AC is sometimes used in railway electrification systems. High-voltage direct-current (HVDC) technology is used only for very long distances (typically greater than 400 miles, or 600 km); submarine power cables (typically longer than 30 miles, or 50 km); or for connecting two AC networks that are not synchronized.

Electricity is transmitted at high voltages (110 kV or above) to reduce the energy lost in long distance transmission. Power is usually transmitted through overhead power lines. Underground power transmission has a significantly higher cost and greater operational limitations but is sometimes used in urban areas or sensitive locations.

A key limitation in the distribution of electricity is that, with minor exceptions, electrical energy cannot be stored, and therefore must be generated as needed. A sophisticated system of control is therefore required to ensure electric generation very closely matches the demand. If supply and demand are not in balance, generation plants and transmission equipment can shut down which, in the worst cases, can lead to a major regional blackout, such as occurred in California and the US Northwest in 1996 and in the US Northeast in 1965, 1977 and 2003. To reduce the risk of such failures, electric transmission networks are interconnected into regional, national or continental wide networks thereby providing multiple redundant alternate routes for power to flow should (weather or equipment) failures occur. Much analysis is done by transmission companies to determine the maximum reliable capacity of each line which is mostly less than its physical or thermal limit, to ensure spare capacity is available should there be any such failure in another part of the network.

ENERGY RATES:

Electricity pricing (sometimes referred to as **electricity tariff** or the **price of electricity**) varies widely from country to country, and may vary signicantly from locality to locality within a particular country. There are many reasons that account for these differences in price. The price of power generation depends largely on the type and market price of the fuel used, government subsidies, government and industry regulation, and even local weather patterns.

Basis of electricity rates

Electricity prices vary all over the world, even within a single region or power-district of a single country. In standard regulated monopoly markets, they typically vary for residential, business, and industrial customers, and for any single customer class, might vary by time-of-day or by the capacity or nature of the supply circuit (e.g., 5 kW, 12 kW, 18 kW, 24 kW are typical in some of the large developed countries); for industrial customers, single-phase vs. 3-phase, etc. If a specific market allows real-time dynamic pricing, a more recent option in only a few markets to date, prices can vary by a factor of ten or so between times of low and high system-wide demand.

TYPES OF TARIFFS:

In economic terms, electricity (both power and energy) is a commodity capable of being bought, sold and traded. An **electricity market** is a system for effecting purchases, through bids to buy; sales, through offers to sell; and short-term trades, generally in the form of financial or obligation swaps. Bids and offers use supply and demand principles to set the price. Long-term trades are contracts similar to power purchase agreements and generally considered private bi-lateral transactions between counterparties.

Wholesale transactions (bids and offers) in electricity are typically cleared and settled by the market operator or a special-purpose independent entity charged exclusively with that function. Market operators do not clear trades but often require knowledge of the trade in order to maintain generation and load balance. The commodities within an electric market generally consist of two types: Power and Energy. Power is the metered net electrical transfer rate at any given moment and is measured in Megawatts (MW). Energy is electricity that flows through a metered point for a given period and is measured in Megawatt Hours (MWh).

Markets for power related commodities are net generation output for a number of intervals usually in increments of 5, 15 and 60 minutes. Markets for energy related commodities required by, managed by (and paid for by) market operators to ensure reliability, are considered Ancillary Services and include such names as spinning reserve, non-spinning reserve, operating reserves, responsive reserve, regulation up, regulation down, and installed capacity.

In addition, for most major operators, there are markets for transmission congestion and electricity derivatives, such as electricity futures and options, which are actively traded. These markets developed as a result of the restructuring

UNIT VII

Oceanic Energy

Offshore Wave Energy. An inventor approaches you with the design for a wave energy device that he claims will generate 50 GWh of energy annually. The device has a wave inlet 25 meters wide and converts wave energy to electricity by some secret process he won't reveal.

a. Might you be interested in investing in the development of this project? Discuss.
b. How high would waves need to be to generate this amount of power? Assume the average time between waves is T = 10s and that the wave energy generator works with 100% efficiency (all available wave energy is converted to electricity)

Hint:

a. Calculate the average power of the device per meter of wave inlet assuming continuous operation (24x365). Compare this value with the Global Wave Energy

Averages shown in the lecture slides and available online at http://www.wavedragon.net/pics/world-map.jpg.

b. Use the wave energy formula $P= (H^2)(T)/2$ shown in class to calculate wave height H

Shoreline Wave Energy. The LIMPET OWC (oscillating water column) shoreline wave generator described in class has a nameplate rating of 500 kW with wave intensities of about 20 kW/m (http://www.wavegen.co.uk/what_we_offer_limpet_islay.htm)

a. How many household could one LIMPET OWC support assuming that an average household requires an average of 1 kW power? Assume a capacity factor of 40%.

b. How many LIMPET units would be required to support a community of 25,000 households (about the size of Boulder)?

c. Discuss the pros and cons of incorporating a series of LIMPET units in a new breakwater that is to be built to protect a large marina in a resort community.

Barrage Tidal System. You have a summer cabin on a remote island in the San Juan Islands of Peugeot Sound near Seattle. Currently, the only power you have at the cabin is a noisy and smelly gasoline generator that you would like to replace. On the shore of your island near your cabin is a natural cleft in the steep shoreline. If build a low dam across the cleft at the proper height, the dam would be flooded at high tide, but would create a pool or lagoon behind it at low tide. If you install a pipe through the bottom of the dam with a simple turbine and generator, you could generate electricity on the ebb flow of the tide. You do some quick measurements and find that the area of the lagoon behind the dam would be about 5m wide by 20m long, and the lagoon would be about 3m deep at high tide, and 1m deep at low tide.

a. As you think about going forward with this project, what environmental factors should you consider?

b. Assuming a capacity factor of 25%, how much energy could you generate from this setup with each tidal cycle? Recall that $E=1397\eta R^2A$ for each tidal cycle, where η is the capacity factor, R is the range of the tide in meters, and A is the area of the tidal pool in <u>square kilometers</u>.

c. How long could you light a 100W bulb with this energy if it all could be captured and used without loss?

d. Should you proceed with the project?

Wave Power. A container ship having a displacement of 70,000 metric tons (70 million kg) is raised 1 meter in 5 seconds by an ocean wave. Compare the lift power of the wave to the ship's shaft horsepower of 50,000 hp (37,280 kW). Discuss.

Hints:

- Calculate the increase in potential energy when the ship is raised by 1 meter using the formula $E=mgh$, where E is energy expressed in Joules (J), m is mass (kg), $g=9.8m/s^2$ is the gravitational constant, and h (meters) is the height to which the mass is raised.
- Convert Joules (J) to kWh using 1kWh = 3.6 MJ (million Joules)
- Calculate the <u>power</u> (energy per unit time) of the wave – note that the ship is raised in 5 seconds, not 1 hour.

2 Renewable Energy Technologies and Applications

The study focuses on concentrating solar thermal power generation because this is by far the greatest renewable energy resource in the EU-MENA region, but other renewable energy sources are represented as well, in order to obtain a well balanced mix of energies that can not only cope with the growing energy demand, but also with the needs of power security and grid stability. The renewable energy technology portfolio that was considered within the study is described in the following. An overview and comparison of all technologies is given in **Error! Reference source not found.** and in the literature /BMU 2004-2/, /ECOSTAR 2004/, /NREL 2003/.

2.1 Concentrating Solar Thermal Power Technologies

Concentrating solar thermal power technologies (CSP) are based on the concept of concentrating solar radiation to be used for electricity generation within conventional power cycles using steam turbines, gas turbines or Stirling engines. For concentration, most systems use glass mirrors that continuously track the position of the sun. The concentrated sunlight is absorbed on a receiver that is specially designed to reduce heat losses. A fluid flowing through the receiver takes the heat away towards the power cycle, where e.g. high pressure, high temperature steam is generated to drive a turbine. Air, water, oil and molten salt are used as heat transfer fluids.

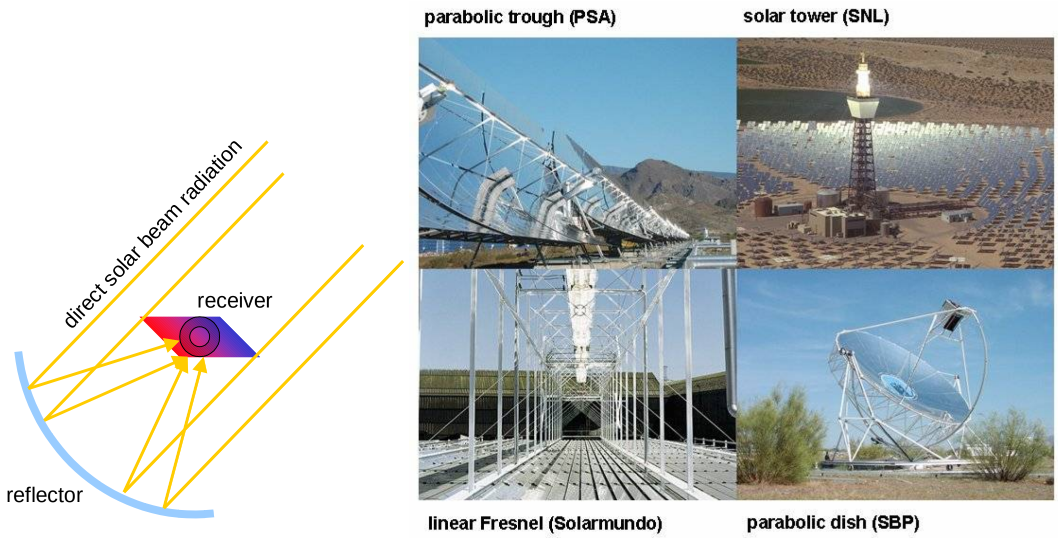


Figure 2-1: Principle of concentrating solar beam radiation and the four CSP collector technology main streams realised up to date (Sources: DLR, SNL, Solarmundo, SBP)

Parabolic troughs, linear Fresnel systems and power towers can be coupled to steam cycles of 5 to 200 MW of electric capacity, with thermal cycle efficiencies of 30 – 40 %. Dish-Stirling engines are used for decentralised generation in the 10 kW range. The values for parabolic troughs have been demonstrated in the field. Today, these systems achieve annual solar-to-electricity-efficiencies of about 10 – 15 %, with the perspective to reach about 18 % in the medium term (Table 2-1). The values for the other systems are based on component and prototype system test data and the assumption of mature development of current technology. The overall solar-electric efficiencies include the conversion of solar energy to heat within the collector and the conversion of the heat to electricity in the power block. The conversion efficiency of the power block remains basically the same as in fuel fired power plants.

Power towers can achieve very high operating temperatures of over 1000 °C, enabling them to produce hot air for gas turbine operation. Gas turbines can be used in combined cycles, yielding very high conversion efficiencies of the thermal cycle of more than 50 %.

Each of these technologies can be operated with fossil fuel as well as solar energy. This hybrid operation has the potential to increase the value of CSP technology by increasing its power availability and decreasing its cost by making more effective use of the power block. Solar heat collected during the daytime can be stored in concrete, molten salt, ceramics or phase-change media. At night, it can be extracted from the storage to run the power block. Fossil and renewable fuels like oil, gas, coal and biomass can be used for co-firing the plant, thus providing power capacity whenever required (Figure 2-2).

	Capacity Unit MW	Concen-tration	Peak Solar Efficiency	Annual Solar Efficiency	Thermal Cycle Efficiency	Capacity Factor (solar)	Land Use m²/MWh/y
Trough	10 – 200	70 - 80	21% (d)	10 – 15% (d)	30 – 40 % ST	24% (d)	6 - 8
				17 – 18% (p)		25 – 90% (p)	
Fresnel	10 - 200	25 - 100	20% (p)	9 - 11% (p)	30 - 40 % ST	25 - 90% (p)	4 - 6
Power Tower	10 – 150	300 – 1000	20% (d)	8 – 10 % (d)	30 – 40 % ST	25 – 90% (p)	8 - 12
			35 % (p)	15 – 25% (p)	45 – 55 % CC		
Dish-Stirling	0.01 – 0.4	1000 – 3000	29% (d)	16 – 18 % (d)	30 – 40 % Stirl.	25% (p)	8 - 12
				18 – 23% (p)	20 – 30 % GT		

Table 2-1: Performance data of various concentrating solar power (CSP) technologies

(d) = demonstrated, (p) = projected, ST steam turbine, GT Gas Turbine, CC Combined Cycle. Solar efficiency = net power generation / incident beam radiation

Capacity factor = solar operating hours per year / 8760 hours per year

Moreover, solar energy can be used for co-generation of electricity and process heat. In this case, the primary energy input is used with efficiencies of up to 85 %. Possible applications cover the combined production of industrial heat, district cooling and sea water desalination.

All concepts have the perspective to expand their time of solar operation to base load using thermal energy storage and larger collector fields. To generate one Megawatt-hour of solar electricity per year, a land area of only 4 to 12 m² is required. This means, that one km^2 of arid land can continuously and indefinitely generate as much electricity as any conventional 50 MW coal - or gas fired power station.

Thus, two main characteristics make concentrating solar power a key technology in a future renewable energy supply mix in MENA:

- it can deliver secured power as requested by demand
- its natural resource is very abundant and practically unlimited

Their thermal storage capability and hybrid operation with fuels allows CSP plants to provide power on demand. Their availability and capacity credit is considered to be 90 %. CSP plants can be build from several kW to several 100 MW capacity.

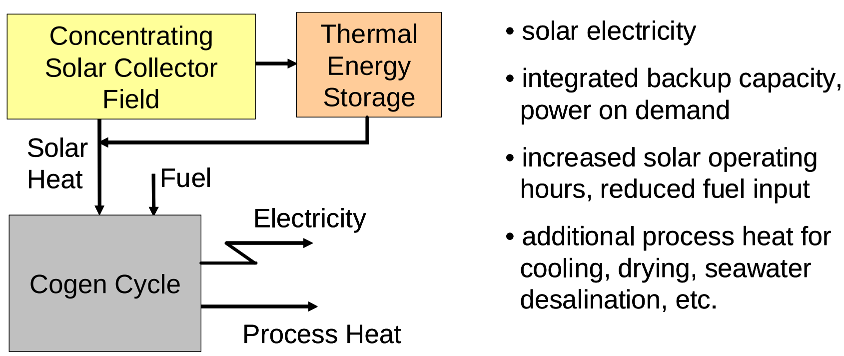


Figure 2-2: Principle of solar thermal co-generation of heat and power

Prospects of CSP Research and Development and Projects Ahead

While present parabolic trough plants use synthetic oil as heat transfer fluid within the collectors, and a heat exchanger for steam generation, efforts to achieve direct steam generation within the absorber tubes are underway in the DISS and INDITEP projects sponsored by the European Commission, with the aim to reduce costs and to enhance efficiency by 15-20% (Table 2-2). Direct solar steam generation has recently been demonstrated by CIEMAT and DLR on the Plataforma Solar in Almeria/ Spain, in a 500 m long test loop, providing superheated steam at 400 °C and 100 bar. All those R&D efforts aim at increasing efficiency and reducing costs.

A European industrial consortium has developed the new parabolic trough collector SKAL-ET, which aims to achieve better performance and cost by improving the mechanical structure and the optical and thermal properties of the parabolic troughs. Another European consortium has developed a simplified trough collector prototype with segmented flat mirrors following the principle of Fresnel.

The high temperatures available in solar towers can not only be used to drive steam cycles, but also for gas turbines and combined cycle systems. Such system promises up to 35 % peak and 25 % annual solar-electric efficiency when coupled to a combined cycle power plant. A solar receiver was developed within the European SOLGATE project for heating pressurised air by placing the volumetric absorber into a pressure vessel with a parabolic quartz window for solar radiation incidence. Multi-tower solar arrays may be arranged in the future so that the heliostat reflectors can alternatively point to various tower receivers. Like in other Fresnel systems, the horizontally arranged heliostats almost completely cover the land area and create a bright, semi-shaded space below for agricultural or other purposes.

A review of presently existing or developed CSP projects is given in Annex 9.

Table 2-2: **Selected CSP Technology Overview ***

Technology	**Experience**	**Next Step**	**Current Providers/Developers of the Solar Components**
Parabolic trough reflector with oil-cooled vacuum-isolated absorber tube in hybrid steam cycle power plant	SEGS I – IX , 354 MW installed between 1985 and 1991 in California, since then operating, steam generated in oil/steam heat exchangers at 370°C, 100 bar	50^{+} MW projects under development in Israel and USA	Solel, Israel (design, absorber), Flagsol (Germany (reflectors)
Re-designed and up-scaled structure of oil-cooled parabolic trough for steam cycle operation	100 & 150 m units of SKAL-ET (up-scaled EuroTrough) collector integrated to SEGS VI in California since April 2003	2 x 50 MW project under development in Southern Spain	EuroTrough Consortium, Solarmillennium AG, Flagsol, Schlaich, Bergermann & Partner, Schott, Germany (reflectors, structure, absorber tube)
Direct steam generating parabolic trough	700 m DISS test-loop in Plataforma Solar de Almeria, Spain, direct steam generation demonstrated at 400 °C, 100 bar	Concept for a 5 MW demo plant under development (INDITEP project)	Iberinco, Initec, Ciemat, (Spain) Flagsol, DLR, ZSW (Germany)
Solar tower system with pressurised hot-air central receiver for solar gas turbine and combined cycle operation	240 kW gas turbine operated first time December 2002 at Plataforma Solar de Almeria, gas turbine operated at 800 °C, 8 bar, (SOLGATE project)	2 x 80 kW gas turbine co-generation system for electricity and cooling under construction in Italy	DLR (Germany), Esco Solar (Italy)
Solar tower system with un-pressurised volumetric hot-air receiver	3 $MW_{thermal}$ TSA project in 1996-1998, steam generated at 550 °C, 100 bar; new modular ceramic hot-air-receiver presently tested in the European. Solair Project	Receiver endurance test and concept development for a 2 MW prototype plant within the German Cosmosol project	Solucar, Ciemat (Spain), Heliotech (Denmark), DLR, Kraftanlagen München, (Germany)
Linear Fresnel collector with secondary concentrator and direct	100 m prototype tested in Liege, Belgium, direct saturated steam	200 m test loop for superheated steam generation at	FhG-ISE, PSE, DLR (Germany)

steam generating absorber tube	generated at 275 °C	Plataforma Solar, Spain	
	Compact Linear Fresnel Reflector 1 MWth prototype installed in a steam cycle plant in Liddell in New South Wales, Australia	Design and construction of a first 1 MWe pilot plant	Solar Heat & Power (Germany)

* only the existing plants in California and selected European main-stream activities are listed, RD&D of CSP technology is also taking place in other parts of the world, mainly USA and Australia (the famous solar tower test facility Solar 2 has been deactivated in the meantime). There is also parabolic trough development going on in Italy, however, the author had no reliable information on that.

2.2 Renewable Energy Technology Options for Europe and MENA

The market potential of CSP plants must be seen in the context of other renewable energy technologies for power generation. In the following we show those options and how they are modelled within the study (Figure 2-3). A description of each technology can be found in /BMU 2004-3/.

Figure 2-3: Renewable energy technologies considered in the MED-CSP study in addition to concentrating solar thermal power plants

Wind Power

Wind power can be generated in distributed wind power plants of up to 5 MW capacity each, or in large wind parks interconnecting tens or even hundreds of such plants. There are onshore and offshore wind parks, build into the sea where it is not deeper than 40 m. Wind power is typically fluctuating and cannot be delivered on demand. Wind power is stored for some seconds in the rotating mass of the wind turbines or as chemical or mechanical energy in batteries or large pump storage systems. There are also investigations on storing wind power in form of pressurized air. Fluctuations of the wind velocity are only correlated within a few kilometres of distance. Therefore, the fluctuations of a number of wind mills spread over a large area will usually compensate each other to some extend, leading to power supply transients that are quite manageable by the rest of the power park. However, their share on secured power capacity (capacity credit) is only between 0 and maximum 30 % of their installed capacity in very good areas with continuous trade winds /EWEA 2002/.

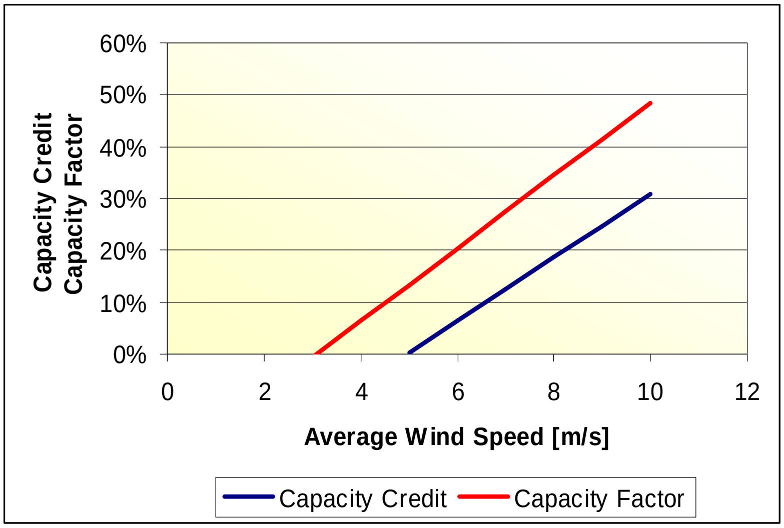


Figure 2-4: Capacity factor and capacity credit of wind power as function of the average wind speed derived from /EWEA 2002/ pp. 47 and from own calculations based on time series analysis

The technical performance of large wind power parks is modelled by the functions shown in Figure 2-4 that define their overall annual full load hours and their annual electricity yield. Even under optimum conditions with an average wind speed of 10 m/s, a large wind park will deliver only 50 % of its capacity over the year, and only 30 % as secured continuous contribution.

The electricity yield E_{wind} from wind power plants is calculated with the following equation, taking into consideration the capacity factor of the wind power park that is approximately a function of the average annual wind speed as shown in Figure 2-4:

$$E_{wind} = P_{wind} \cdot CF_{wind} \cdot 8760 \text{ h/y}$$

E_{wind} Annual electricity yield from wind power [MWh/y]

CF_{wind} Capacity factor as function of the average annual wind speed

P_{wind} Installed wind power capacity [MW]

8760 represents the total hours per year

Photovoltaic Power

PV systems are typically used for distributed or remote power systems with or without connection to the utility grid. Their capacity ranges from a few Watt to several MW. Batteries are usually applied in smaller decentralized supply systems to store the solar energy over the night. There are also scenarios for very large PV systems up to 1.5 GW each to be built in desert areas until 2050 /IEA 2003-1/. Both small and large scale options have been included in the MED-CSP scenario, but only grid connected PV has been quantified in the renewable electricity mix. The electricity yield of PV systems is modelled as function of the global irradiance on a surface tilted at the respective latitude angle. PV cannot offer any secured capacity. Backup capacity must be provided by other technologies within the grid. Energy from very large PV could be stored in pump storage systems. The annual capacity factor and the annual full load hours are defined by the annual solar irradiance and the relation of the annual mean system efficiency to the layout efficiency (q-factor). The q-factor is today typically 0.67 and expected to become 0.85 in the year 2050. This results in the performance functions shown for different annual irradiances in Figure 2-5.

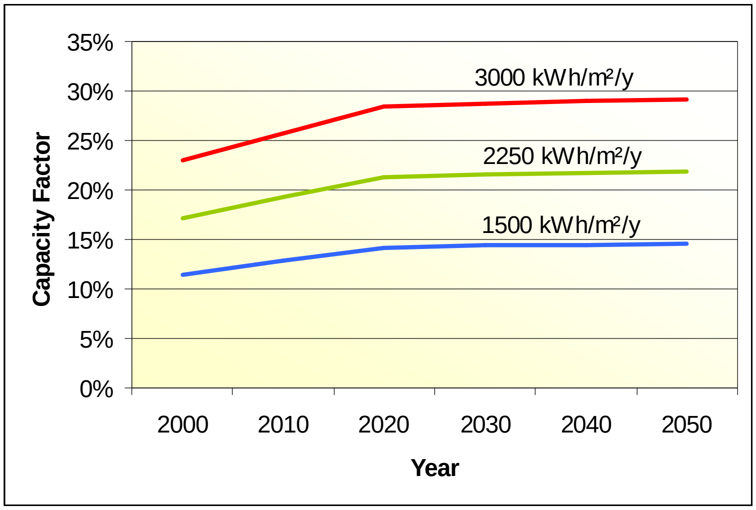


Figure 2-5: Capacity factor of grid-connected PV systems as function of global irradiance on a surface tilted at latitude angle and year of commissioning. There is no capacity credit for PV-power.

The electricity yield E_{PV} from photovoltaic systems is calculated with the following equation, taking into consideration the capacity factor of the PV power plants that is a function of the average annual irradiance on a tilted surface as shown in Figure 2-5:

$$E_{PV} = P_{PV} \cdot CF_{PV} \cdot 8760 \text{ h/y}$$

$$CF_{PV} = q_{PV} \cdot GTI \cdot \eta_{PV} \cdot A_{PV} / 8760 \text{ h/y}$$

E_{PV} Annual electricity yield from photovoltaics [kWh/y]

CF_{PV} Capacity factor as function of the annual global irradiance

P_{PV} Installed photovoltaic power capacity [kW]

q_{PV} annual system efficiency / standard design efficiency

GTI Global irradiance on a tilted surface [kWh/m²/y]

η_{PV} Annual PV system efficiency in first year (assumed as $\eta_{PV} = 0.1$)

A_{PV} Design collector area for standard efficiency [m²/kW] ($A_{PV} = 10$ m²/kW)

8760 represents the total hours per year

Geothermal Power (Hot Dry Rocks)

Geothermal heat of over 200 °C can be delivered from up to 5000 m deep holes to operate organic Rankine cycles or Kalina cycle power machines. Unit sizes are about 1 MW today and limited to about 100 MW maximum in the future. Geothermal energy is often used for the co-generation of heat and power. Geothermal power plants are used all over the world where surface near geothermal hot water or steam sources are available, like in USA, Italy and the Philippines. In the MED-CSP study region those conventional geothermal potentials are significant in Island, Italy, Turkey, Yemen and Iran. Those potentials are small in comparison to the HDR potentials and are not quantified separately in the study. The Hot Dry Rock technology aims to make geothermal potentials available everywhere, drilling deep holes into the ground to inject cold water and receive hot water from cooling down the hot rocks in the depth /IGA 2004/. However, this is a very new though promising approach and technical feasibility must still be proven. Geothermal power plants provide power on demand using the ideal storage of the earth's hot interior as reservoir. They can provide peak load, intermediate load or base load electricity. Therefore, the capacity factor of geothermal plants is defined by the load and their operation mode. Assuming a plant availability of 90 %, their capacity credit would have that same value.

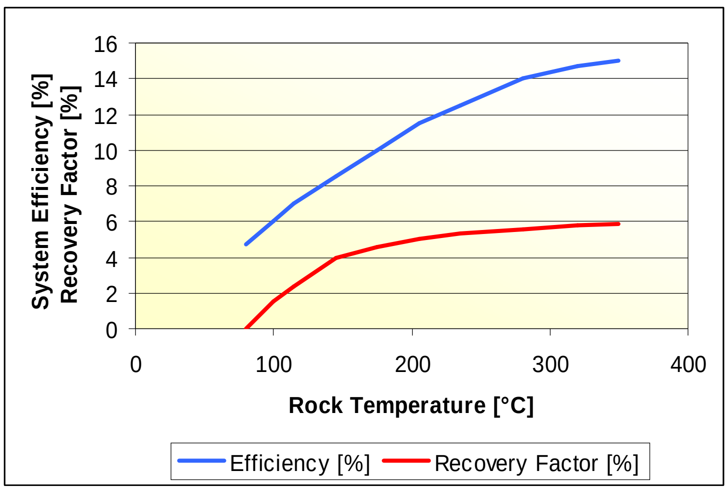


Figure 2-6: Efficiency (η) and recovery factor (R) of geothermal power schemes as function of temperature adapted from /TAB 2003/.

The available heat in place E_{th} is calculated as a function of the volume of rocks that will be affected by the cooling process /TAB 2003/. From that, the extracTable 2-geothermal electricity per year E_{geo} can be calculated as a function of the power cycle efficiency, the recovery factor and the total time of extraction. The recovery factor takes into account that only a small part of the affected rock volume is cooled down, and that the lower cycle temperature is higher than the surface temperature.

$$E_{th} = c_G \cdot \rho_G \cdot V \cdot (T_{5000} - T_{surface})$$

$$E_{geo} = E_{th} \cdot R \cdot \eta / t_{extract}$$

E_{th}	Heat in place [J]
E_{el}	ExtracTable 2-electricity [J/y]
c_G	Spezific heat of the rocks [J/kg K]
ρ_G	Density of the rocks [kg/m^3]
V	Volume of rock affected [m^3]
T_{5000}	Temperature of the rocks at 5000 m depth [°C]
$T_{surface}$	Surface Temperature [°C]
R	Recovery Factor
η	System Efficiency
$t_{extract}$	Extraction time [y]

For the study we have made the following assumptions:
c_G = 840 [J/kg·K], ρ_G = 2600 kg/m^3, T_S = 10°C, V = 1 km^3, $t_{extract}$ = 1000 years

Biomass Power (Waste and Wood)

There are a number of potential sources to generate energy from biomass: biogas can be produced by the decomposition of organic materials like municipal liquid waste, manure or agricultural residues. Biogas reactors usually require large quantities of water. The calorific value of biogas is about 6 kWh/m^3. Biogas can be used in combustion engines or turbines for electricity generation and for co-generation of heat and power. Landfill gas can be used in a similar way.

Solid biomass from agricultural or municipal residues like straw or bagasse and from wood can be used to generate heat and power. From every ton of solid biomass about 1.5 MWh of heat or 0.5 MWh of electricity can be generated in steam cycle power plants.

There is also the possibility to raise energy crops. However, this option has been neglected in the MENA region due to their competition with food crops and the severe water supply situation.

The size of biomass plants ranges from some kW (combustion engines) to about 25 MW. Biomass can be stored and consumed on demand for power generation. However, there are often seasonal restrictions to the availability of biomass. Typical plants have capacity factors between 0.4 and 0.6 that are equivalent to 3500 – 5500 full load hours per year. They are usually operated to provide intermediate or peaking power but seldom for base load. The availability of biomass plants is high at 90 % and so is their capacity credit. This credit can be lower if the plants are used for co-generation of heat and power and if heat is the primary product. Electricity generation from biomass is calculated with the following equations:

$$E_{bio} = E_{mun} + E_{agr} + E_{wood}$$

$E_{mun} = N \cdot w_{mun} \cdot e_{bio}$

$E_{agr} = w_{agr} \cdot e_{bio}$

$E_{wood} = p_{wood} \cdot A_{forest} \cdot e_{bio}$

E_{bio} Electricity from biomass [MWh/y]

E_{mun} Electricity from municipal waste [MWh/y]

E_{agr} Electricity from agricultural residues [MWh/y]

E_{wood} Electricity from wood [MWh/y]

e_{bio} Specific electricity yield from biomass [MWh/ton]

w_{mun} Specific municipal waste production per capita [tons/capita/year]

w_{agr} Agricultural waste production [tons/year]

p_{wood} Biomass productivity [tons/ha/year]

A_{forest} Forest area of a country [ha]

N Urban population [persons]

For the study we have made the following assumptions: e_{bio} = 0.5 MWh/ton, w_{mun} = 0.35 ton/capita/year.

Hydropower

Hydropower is already used in many MENA countries. Plants range from large multi-Megawatt dams like Aswan to micro-hydropower schemes of several kW capacity. Hydropower is often submitted to seasonal fluctuations and especially in MENA, dry years often lead to hydropower shortages. There a run-of-river plants that provide power according to the available water flow. Dam storage power plants can provide power on demand and can be used to compensate the fluctuations of other renewable energies. In MENA hydropower is used mainly for peaking and intermediate load with 1000 to 4000 full load hours per year. Capacity factors are defined by the individual regional power demand and water resources. The Nile river is the most plentiful hydropower resource of the region. However, there are some indications that the hydropower potentials in the Southern Mediterranean region may be submitted to a reduction of up to 25 % in the course of this century due to climate change /Lehner et al. 2005/. Capacity credit and availability of hydropower plants are considered to be 90 %. Electricity generation from hydropower is well documented and thus taken from literature /WEC 2004/, /Horlacher 2003/.

$E_{hydro} = P_{hydro} \cdot CF_{hydro} \cdot 8760$ h/y

E_{hydro} Annual electricity yield from hydropower plants [MWh/y]

CF_{hydro} Capacity factor (from existing hydropower plants of a country)

P_{hydro} Installed hydropower capacity [MW]

8760 represents the total hours per year

Concentrating Solar Thermal Power and Solar Chimneys

Concentrating solar thermal power plants with thermal energy storage and fuel co-firing can provide power on demand, with a capacity credit and availability of 90 % like conventional power plants. Electricity generation is a function of their capacity factor which is defined by the demand. The plants are operated in accordance with the rest of the renewable energy mix in order to minimize the gap between the load and the renewable electricity supply.

The electricity yield E_{CSP} from solar thermal power plants is calculated with the following equation, taking into consideration the capacity factor that is defined by the load. The solar share is steadily increased and the fossil share reduced, by increasing the solar collector field and storage capacities.

$$E_{CSP} = P_{CSP} \cdot CF_{CSP} \cdot 8760 = E_{solar} + E_{fossil}$$

E_{CSP} Annual electricity yield [MWh/y]

E_{solar} Annual solar electricity yield [MWh/y]

E_{fossil} Annual fossil electricity yield [MWh/y]

CF_{CSP} Capacity factor as function of load

P_{CSP} Installed capacity [MW]

8760 represents the total hours per year

Solar chimneys are also considered as solar thermal power plants, though not concentrating. They consist of a very large glass or plastic roof with a chimney in its centre. The air underneath the glass roof is heat and by its lower weight forced into the chimney, where it activates a wind turbine for power generation. They can be built in the range of 100 - 200 MW capacity. Heat can be stored in the soil and in water storage below the collector for night-time operation. They cannot be used for co-generation of electricity and heat. Hybrid operation with fuels is not possible. There availability and capacity credit is considered 90 %. They are suited for base load and intermediate power. Solar chimney potentials are considered part of the solar thermal power potential and are not quantified separately.

Conventional Power

The MED-CSP study also looks at conventional power technologies as possible alternative or complement to a sustainable energy supply. The availability and capacity credit of all conventional systems is assumed to be 90 %. They provide power on demand with different capacity factors. All thermal plants can be used for co-generation of electricity and heat.

- **Oil and Gas fired Power Plants**

Oil and gas can be used in steam cycle, gas turbine or combined cycle power plants. They are built in all capacity classes from several kW to several 100 MW. The can provide peak, intermediate and base load.

- **Coal Steam Plants**

Only a few countries in MENA use coal fired steam cycles. Coal must be imported. Capacities range from some 10 to several 100 MW. Due to the long start-up time and the relatively high investment cost, they are only applied in the intermediate and base load segment.

- **Nuclear Fission and Fusion**

Nuclear plants use nuclear fission processes to generate steam for steam turbines. There is intensive research on nuclear fusion aiming at providing first results in terms of a first power plant in the year 2050 or beyond. Projected units sizes are in the GW capacity range. Due to their high investment cost, they are only applied in the base load segment.

2.3 Renewable Energy Applications

Electricity Generation

All the technologies investigated within this study can be used for electricity generation. Only biomass, hydropower, geothermal power, solar thermal and conventional power plants can deliver electricity on demand. Photovoltaic systems, micro-hydropower, wind power, biogas motor generators and dish-Stirling engines are specially suited for decentralized and remote electricity generation. In the quantification of market potentials in our scenario we do not distinguish between centralised, grid-connected power and remote systems. Both centralized and decentralized systems have considerable market potentials and will complement each other rather than compete.

Combined Generation of Electricity and Heat

All thermo-electric systems like biomass, geothermal, solar thermal and conventional plants can be used for co-generation of electricity and heat (see Annex 10 for examples).

- **Seawater Desalination**

Electricity can be used for seawater desalination by reverse osmosis, while co-generated heat can be applied to multi-effect, vapour compression and multi-stage flash thermal desalination plants. Also combinations are possible. Thermal seawater desalination uses input steam with a temperature range between 70 – 110 °C.

- **Cooling**

Electricity can be used directly in conventional mechanical compression chillers for air conditioning, cooling and refrigeration. Co-generated heat can be applied to drive vapour absorption chillers. Vapour absorption chillers use input steam with a temperature between 120 – 180 °C. Concentrating solar power has also been directly applied to provide cooling and air conditioning for a Hotel in Turkey.

- **Industrial Process Heat**

Industrial process heat in form of steam or hot air in the temperature range of 50 - 300 °C can be delivered by all thermal systems that are capable of co-generation. It is particularly efficient to cascade the use of heat at different temperature levels.

- **Integrated Systems and Multipurpose Plants**

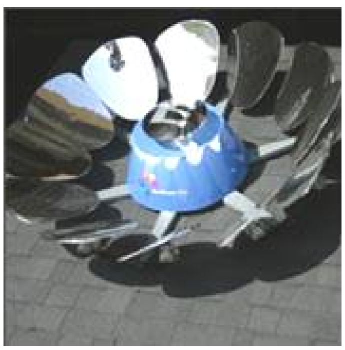
The collectors of some CSP systems provide shaded areas that could be used for purposes like greenhouse, chicken farm, parking etc. Integrated systems that use power, desalted water and shade for generating a new environment for farming in desert regions could become feasible in the future as countermeasure to desertification and loss of arable land. This requires more investigation on the possibilities and restrictions of such systems (Annex 10).

UNIT-VIII

Example of solar dish collector/focus

MHD – or MagnetoHydroDynamics – is a little known and under-exploited branch of physics discovered by Faraday over 100 years ago. The related phenomena of generative and motive forces are well known and aren't exotic in the least; they are in fact very simple to reproduce and utilize. Known applications of MHD include the Tokamak and other experimental hot fusion devices, a solid-state submarine propulsion system, the Ionic Breeze air filter and other obscure inventions. Our particular system relies on focused solar energy to heat and pressurize a unique medium.

It is claimed that the design described herein is the perfect blend of solar and MHD technologies and will maximize both of these ideal conversion methods. In Solar Energy less attention has been given to collector technologies; instead, Photovoltaic cells with efficiency no greater than most fossil fuels have been adopted. This is reasonable since there have only been a few methods of using the solar focus. In Plasma physics, MHD generators have taken a back seat to Hot Fusion that requires even more insane temperatures. Through refinement of all components and aspects, our conceptual fusion will prove to be superior.



UNFAIR ADVANTAGES

In comparison to Photovoltaic Solar Cells, our system is far more efficient, not only in terms of manufacturing but also because it maximizes the potential of focused sunlight (from an equivalent area) to the highest degree possible – it simultaneously converts light into heat *and* electricity.

The Sunflower 250

In contrast to the nearest competitor IP, Innovative Energy’s SUNFLOWER 250, our system is far more efficient because our system utilizes three different means of tapping the sunlight as opposed to one Stirling engine. Another thing to consider as well is that our hydraulic/rotary system is always going to be more efficient than a pneumatic/piston system.

SUPERIOR PERFORMANCE ASPECTS

- Uses new proprietary medium better than Plasma or Liquid Metal

- Harnesses solar focus three ways (MHD Induction, Turbine, Heat)
- Uses variable combinations of forces to generate electricity
  - expansion of working fluid
  - convection
  - magneto-caloric pumping
  - induction

UNIQUE MHD WORKING FLUID

The Solar MHD Generator **uses a saturated ionic ferrofluid in critical (single-phase) state as working medium** – that is, an aqueous magnetite (or other diamagnetic material with proper Curie temp) based suspension with some sea salt added. Ionic fluids are known MHD mediums but have not been used commercially; ferrofluids are unique and are just beginning to see serious research among German MHD scientists. The combination of these fluids creates a truly unique medium. Compared to the two common MHD working mediums, plasma and liquid metal, several issues have been avoided and new properties are available:

1 - Ferrofluid has two properties that can be exploited in this system: the ability for magneto-caloric pumping and reverse viscosity.

Magneto-Caloric Pumping - When the Curie temperature of the ferrofluid is lower than that of the permanent magnet (in this case the same magnet used in the MHD channel) and sufficient heat is applied to one side of the MHD channel (the ferrofluid is drawn towards the field but would other wise stop upon equilibrium of the fluid mass) the ferrofluid will flow continuously because it has lost its magnetic attraction to the magnet. This is not the primary method of moving the medium; rather, it is a positive side effect of the design.

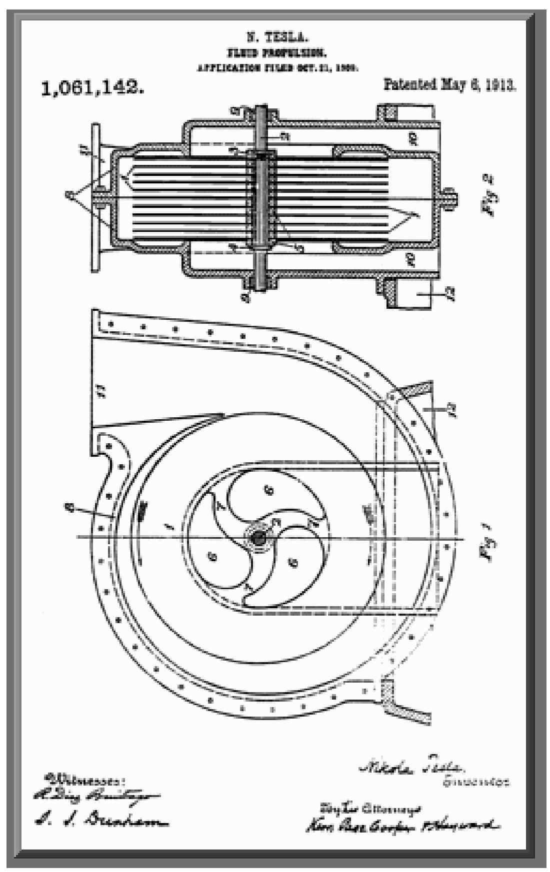
Reverse Viscosity - When ferrofluid is allowed to flow through a channel subjected to an alternating magnetic field, the boundary layer friction to that inner wall of the channel is significantly reduced. Utilizing this property is simple and not only adds to the efficiency, it (the frequency) can be harmonically coupled to the pulse of the pressure valve and discharge of the capacitor bank.

2 - An aqueous medium used in its critical state doesn't require super-heating, which in turn doesn't burn out electrodes as plasma based systems do. The medium maintained in this state – or as near to it as possible – will allow an expansion of the fluid to occur without precipitation of the mineral suspension (a problem with the two-phase option which may or may not be negligible depending on several factors). Liquid metal based MHD generators also suffer from viscosity and the necessity to infuse gas for expansion, this makes it even more inefficient.

MID-STAGE TESLA TURBINE

In the 50’s and 60’s the USSR and US both conducted research on large centralized MHD generators. These were mostly intended for emergency use of 10 to 15 seconds. Even though both countries approached the MHD question (Is this a viable conversion technology?) in different ways the consensus was that even though the conversion is direct and inherently efficient, the designs and methods of the day didn’t warrant further development. One attempt to increase efficiency was introducing second-stage turbines to utilize the thrust exiting the MHD channels (generally in open-cycle systems). This is a logical component, as MHD generators are essentially solid-state and adding one rotary element can only add to the output.

One type of turbine – also like the aforementioned to see practically no commercial use but amazingly efficient – is the Tesla Turbine. Simply stated the Tesla Turbine is a turbine in which the blades run parallel to the flow of the medium as opposed to conventional turbines where the blades meet the medium perpendicularly or at an angle. The force of the flowing medium is transferred in a Tesla Turbine therefore, not through direct impact and transfer of inertia but via the boundary layer. The primary advantage is that the freely spiraling flow can impart rotary force without incurring cavitation or any turbulence – it is laminar.



The use of the Tesla Turbine is more than an add-on source of generation; it functions as a heat sink. It is known that an inward spiraling flow of a fluid will cool, ordering and condensing that fluid. This is exactly what the Tesla Turbine does as configured with the hot input along the periphery, and cool output in the perpendicular center.

The Tesla Turbine in this design is mid-stage because there are two MHD channels, one before and one after the Turbine.

Interesting note:

In an initial consultation with NYSERDA, and then again with a physicist at Cornell, curiously, I was told not to use a Tesla Turbine. The NYSERDA rep admitted he knew of the claims that the Tesla Turbine was the most efficient rotary engine ever conceived but stated that normal turbines have likely improved beyond the performance of a Tesla Turbine since. The physicist had never heard of a Tesla Turbine and admitted it would be efficient, but said that I shouldn't try to be too innovative and that off-the-shelf turbines would be better.

TWIN INTERNAL INDUCTION MHD CHANNELS

Unlike conventional MHD Channels with external horseshoe magnets this design has ring or disk magnets arranged inside the center of the channel. Another major difference is that electricity is not generated via potential across electrodes, it is generated via induction. Ion transfer and direct current is not the goal but simply a varying magnetic field and perpendicular flow of a conductor across that field. This will be an AC MHD Generator not DC.

Induction and local oscillation on the permanent magnet stack occur via a bifilar coil where one coil is insulated and one is bare. The insulated wire will pulse the designated frequency at a minimal voltage (enough to produce reverse viscosity) and the bare wire will induct a current.

It is the intent, through the use of harmonic capacitor banks and diodes, to recreate the flow and pulsing of the fluid in the electric circuit – that is, to create a self-similarity of the electricity and working fluid within the wires and channels/piping respectively.

The primary purpose of two MHD channels is to provide as much effective surface for induction as possible. Secondarily, since one is before the heat source and one is after, they can help regulate temperature of the working fluid. Specifically, Channel 1, (before the heat source) is the Channel that uses the magneto-caloric pumping. As the cool fluid passes over the magnets it generates a current and in turn heats up the induction coil, which in turn adds to the effect and simultaneously preheats the fluid for the critical phase.

Channel 2 (after the heat source) will help pre-cool the fluid when it gives up energy; this makes the Turbine more effective because the fluid is that much denser.

Thermoelectric experiments to create the Seebeck and Peltier effects in the channels will be tested too.

SOLAR FOCUS CHAMBER

AND

CRITICAL PHASE REGULATION

The Solar Focus Chamber is where the sun's rays impart their energy into the generator by thermally exciting the working fluid. It is simply a coil of tubing with the upper length returning back down through the center. It joins below to the MHD channels, and between these two junctions are valves. On the Channel 1 junction, a one-way valve is used. Heat from the coil is allowed to dissipate in heat sink fins for which the valve is also designed – a means of inducing the magneto-caloric pumping effect at the proper point in the channel. On the channel 2 side is a pressure valve. The timing and coordination of this valve with another component is necessary to isolate and harness the critical state. The other governing component is a Fresnel lens and transparent piston mechanism. This will be designed to add pressure to the fluid in the chamber while simultaneously adjusting the focal point of the Fresnel lens so that the critical pressure and temperature are self-regulating relative to the expansion of the fluid.

This is perhaps the most challenging aspect of the overall design and will require independent testing before integration. Initially, independent electronic control and feedback elements will be used in the pressure valve assembly to determine perfect timing for the pulsing of the system. Once this is determined, a mechanical feedback loop can be designed for self-regulation of pulse (according to sunlight intensity).

Another issue is whether this coil/chamber should be made of glass or copper. If glass the BLACK fluid is directly heated and this is efficient, but since this is where the system may precipitate minerals and salt a pulsed copper pipe may prevent coagulation of the minerals, it may be necessary to go with the copper pipe.

PROTOTYPING METHODOLOGY

As mentioned, the USSR and US took different approaches to their MHD designs. Each method yielded valuable information but lacked what the other had. The Russians built MHD facilities all at once as a whole. The Americans tested components individually before putting them all together.

Today we have the option of CAD/CAM but chemical and magneto-rheological aspects must be investigated before mechanical and electrical components can be tested as a whole. Due to the number of novel conversion processes happening simultaneously, it may or may not be cost effective to simulate some before field tests. Simple thermodynamic analysis of collector dimensions is easy enough but the whole system would be difficult to replicate digitally. I've done all the Tesla-esque, eidetic neuroCAD I can for now. It will take help from specialists and perhaps an Edisonian approach to make it happen. The KISS principle must temper the novelty.

Tests to determine the following must be done:

1 - Will the critical fluid expand with sufficient force to pulse jet the fluid through the system?

2 - If sufficient force isn't provided or the critical state timing mechanisms prove to be overcomplicated, can a two phase approach work better?

3 - If going to steam proves a better means of transferring thermal energy, will this destroy the dispersive coating on the ferrofluid particles and precipitate the salt?

3.5 - How would steam affect the MHD dynamics?

4 - If degradation of dispersive coating occurs will the vortices and overall flow keep the particles sufficiently suspended?

4.5 - MHD is actually used for descaling of minerals and salts inside pipes in industrial applications. Will the charged fluid assist in destroying the dispersive coating? Will then the free ions clump the exposed magnetic material? Or will this be another beneficial side effect, the automatic prevention of precipitated and accumulated minerals and salt crystals?

5 - Despite its appeal, would ferrofluid ultimately be better left out of the ionic solution should these problems occur?

5.5 - How will making the ferrofluid conductive affect the reverse viscosity property we wish to exploit?

6 - Is gas infusion an option? It would come out of this liquid more easily than liquid metal, allowing for more efficient recycling.

6.5 - Could we experiment with different gases to enhance expansion or conductivity?

7 - If a single phase system is used, will the critical fluid cavitate after the pressure valve closes?

7.5 - If cavitation occurs, would this necessarily cause a significant net loss of inertia? A pulse jet engine doesn’t. Could the implosion be used in some way?

15. ADDITIONAL TOPICS

1. Solar energy application.
2. Tidal & Ocean Applications
3.MHD Applications.

16. University previous Question papers

17. Question Bank

UNIT- I

1. a) Write a short note on role and potential of new and renewable sources?

   b) Explain environmental impact of solar power?

2. Define solar energy. Explain extra-terrestrial and terrestrial solar radiation?

3. What are the instruments for measuring solar radiation sunshine and solar radiation data?

4. How the solar radiation effect on titled surface?

UNIT - II

1. Write the advantages and disadvantages of concentrating collectors and flat plate collectors?

2. Describe the flat plate collectors with the help of neat sketch?

3. What is a green house? Explain the types of concentrating collectors?
4. Explain performance analysis of cylindrical parabolic collector (CPC)?

UNIT- III

1. With the help of schematic diagram explain technique of solar heating & cooling?

2. With the help of schematic diagram explain solar drier & solar distillation?

3. Explain solar pond? Write down the solar applications?

4.Describe the principle of solar photo voltaic energy conversion?

UNIT- IV

1. Using Betz model of a wing turbine, derive the expression for power extracted from wind? What is the maximum theoretical power that can be extracted and under what condition?

2. What are the most favourable sites for installing of wind turbines? Explain the major application of wind power?
3. Sketch the diagram of a HAWT and explain the functions of its main components?

4.Sketch the diagram of a VAWT and explain the functions of its main components?

UNIT- V

1. What are the Principles of bioconversion? Write a short note on arobic digestion?
2. What are the types of digestors? Explain gas yielding
3. What are the characteristics of bio-gas?

4. Discuss the method of power generation from liquid waste? Explain the Production process of ethanol from bio-mass?

UNIT-VI

1. What is geothermal energy. What is plate technic theory on geothermal energy?
2. Discuss the various ways of geothermal power generation
3. Define geothermal gradients & advantages of geothermal power plants?
4. Explain various types of geothermal resources? How are geothermal sides earthquakes & volcanoes related?

UNIT-7

1. What do you mean by OTC? Explain briefly
2. What do you mean by tidal & wave energy. Explain in detail
3. Explain about mini hydel power plants & their economics
4. How OTC plants are related to Thermodynamic cycles?

18. Assignment topics

ASSIGMENT-I

1. a) Write a short note on role and potential of new and renewable sources?

b) Explain environmental impact of solar power?

2. Define solar energy. Explain extra-terrestrial and terrestrial solar radiation?

3. What are the instruments for measuring solar radiation sunshine and solar radiation data?

4. How the solar radiation effect on titled surface?

ASSIGMENT-II

1. Write the advantages and disadvantages of concentrating collectors and flat plate collectors?

2. Describe the flat plate collectors with the help of neat sketch?

3. What is a green house? Explain the types of concentrating collectors?
4. Explain performance analysis of cylindrical parabolic collector (CPC)?

ASSIGMENT-III

1. With the help of schematic diagram explain technique of solar heating & cooling?

2. With the help of schematic diagram explain solar drier & solar distillation?

3. Explain solar pond? Write down the solar applications?

4.Describe the principle of solar photo voltaic energy conversion?

ASSIGMENT-IV

1. Using Betz model of a wing turbine, derive the expression for power extracted from wind? What is the maximum theoretical power that can be extracted and under what condition?

2. What are the most favourable sites for installing of wind turbines? Explain the major application of wind power?
3. Sketch the diagram of a HAWT and explain the functions of its main components?

4.Sketch the diagram of a VAWT and explain the functions of its main components?

ASSIGNMENT-V

5. What are the Principles of bioconversion? Write a short note on arobic digestion?
6. What are the types of digestors? Explain gas yielding
7. What are the characteristics of bio-gas?
8. Discuss the method of power generation from liquid waste? Explain the Production process of ethanol from bio-mass?

ASSIGNMENT-VI

5. What is geothermal energy. What is plate technic theory on geothermal energy?
6. Discuss the various ways of geothermal power generation
7. Define geothermal gradients & advantages of geothermal power plants?
8. Explain various types of geothermal resources? How are geothermal sides earthquakes & volcanoes related?

ASSSIGNMENT-VII

5. What do you mean by OTC? Explain briefly
6. What do you mean by tidal & wave energy. Explain in detail
7. Explain about mini hydel power plants & their economics
8. How OTC plants are related to Thermodynamic cycles?

19. Unit-wise quiz questions

UNIT-1

UNIT-II

UNIT – III

UNIT-IV

UNIT-V

UNIT-VI

UNIT-VII

UNIT-VIII

20. Tutorial Problems:

TUTORIAL-1

1. a) Write a short note on role and potential of new and renewable sources?

b) Explain environmental impact of solar power?

2. Define solar energy. Explain extra-terrestrial and terrestrial solar radiation?

3. What are the instruments for measuring solar radiation sunshine and solar radiation data?

4. How the solar radiation effect on titled surface?

TUTORIAL-2

1. Write the advantages and disadvantages of concentrating collectors and flat plate collectors?

2. Describe the flat plate collectors with the help of neat sketch?

3. What is a green house? Explain the types of concentrating collectors?
4. Explain performance analysis of cylindrical parabolic collector (CPC)?

TUTORIAL-3

1. With the help of schematic diagram explain technique of solar heating & cooling?

2. With the help of schematic diagram explain solar drier & solar distillation?

3. Explain solar pond? Write down the solar applications?

4.Describe the principle of solar photo voltaic energy conversion?

TUTOTIAL-4

1. Using Betz model of a wing turbine, derive the expression for power extracted from wind? What is the maximum theoretical power that can be extracted and under what condition?

2. What are the most favourable sites for installing of wind turbines? Explain the major application of wind power?
3. Sketch the diagram of a HAWT and explain the functions of its main components?

4.Sketch the diagram of a VAWT and explain the functions of its main components?

TUTORIAL-V

9. What are the Principles of bioconversion? Write a short note on arobic digestion?
10. What are the types of digestors? Explain gas yielding
11. What are the characteristics of bio-gas?

12. Discuss the method of power generation from liquid waste? Explain the Production process of ethanol from bio-mass?

TUTORIAL-VI

9. What is geothermal energy. What is plate technic theory on geothermal energy?
10. Discuss the various ways of geothermal power generation
11. Define geothermal gradients & advantages of geothermal power plants?
12. Explain various types of geothermal resources? How are geothermal sides earthquakes & volcanoes related?

TUTORIAL-VII

9. What do you mean by OTC? Explain briefly
10. What do you mean by tidal & wave energy. Explain in detail
11. Explain about mini hydel power plants & their economics
12. How OTC plants are related to Thermodynamic cycles?

21. Known Curriculum Gaps and inclusion of the same in the lecture schedule:

1. POWER PLANT ENGIEERING
2. SOLAR ENERGY

22. Group discussion topics

1. Shall be provided later.

23. References, Journals, websites and E-links

REFERENCES:

i) Renewable Energy Sources / Twidell & Weir

ii) Solar Energy/ Sukhatme

iii) Solar power Engineering/ B.S. Magal Frank Kreith & Frank Kreith

iv) Principles of Solar Energy / Frank Kreith & John F Kreider

v) Non Conventional Energy / Ashok V Desai / Wiley Eastern

vi) Non Conventional Energy Systems / K Mittal / Wheeler

vii) Renewable Energy Technologies / Ramesh & Kumar / Narosa

WEBSITES

1. en.wikipedia.org/wiki/solar
2. www.**energy**shouldbe.org
3. http://www.gmrit.org/resources/syllabus me.pdf
4. NPTEL Resources

JOURNALS

1. International journal of Solar energy.
2. International of Non conventional energy systems
3. International journal of Renewable energy sources

24. Quality Control Sheets

A. Course End Survey:

Course end survey will be collected at the end of the semester.

B. Teaching Evaluation

Quality control department conducts online feedback, two times in the semester.

25. Students list

S.No	Roll No	Student Name
1	11R11A0303	ANNE HAREEN
2	12R11A0301	A R SAI PRAVESH
3	12R11A0302	ALLURI KAVYA SREE
4	12R11A0303	ANNAVARAPU VISHAL
5	12R11A0304	ASWANI KUMAR RAI
6	12R11A0305	BAIRI SRIDHER
7	12R11A0306	BALLARI RAHUL
8	12R11A0307	BANOTHU AJAY
9	12R11A0308	BARLAPATHI MAHESH KUMAR
10	12R11A0309	BODDUPALLI PRADEEP KUMAR
11	12R11A0310	BUKIYA JAYA VENKATA VARDHAN
12	12R11A0311	BURRA SANJAY KUMAR
13	12R11A0312	CHINDAM RAVI
14	12R11A0313	CH SANDEEP
15	12R11A0314	CHANDANAGIRI JALANDHAR
16	12R11A0315	CHIRUMALLA SHRAVANKUMAR
17	12R11A0316	DEERAVATH RAJESH
18	12R11A0317	DINESH NAIK BHUKYA
19	12R11A0318	GOLLAMUDI SAI VENKATA BALARAM KRIS
20	12R11A0319	GADDALA SURYA KIRAN
21	12R11A0320	HEMANTH PRASAD K
22	12R11A0321	INDIRALA RAJESH
23	12R11A0322	K NAGENDRA BABU
24	12R11A0323	K P ARVIND

25	**12R11A0324**	**K PANDU**
26	**12R11A0325**	**K SEETHA RAMAIAH**
27	**12R11A0327**	**KALVAKUNTLA AKHIL KUMAR**
28	**12R11A0329**	**KASULA RAHUL REDDY**
29	**12R11A0330**	**KATAPALLI DAYAKAR REDDY**
30	**12R11A0332**	**KOLKURI MOUNIKA**
31	**12R11A0333**	**KOMMU PRAKASH**
32	**12R11A0334**	**LELLA AKSHAY KRISHNA**
33	**12R11A0335**	**MADHIREDDY VINAY KUMAR REDDY**
34	**12R11A0336**	**MADHAMSHETTY RAHUL**
35	**12R11A0337**	**MALLOTH NAVEEN KUMAR NAYAK**
36	**12R11A0338**	**MANTHA PAVAN**
37	**12R11A0339**	**MARAKALA SHEETHAL**
38	**12R11A0340**	**MOHD SIRAJUDDIN**
39	**12R11A0341**	**MOODETI SAI PRAVEEN NAIK**
40	**12R11A0342**	**MULUGU DEEPA**
41	**12R11A0343**	**MUTTENI MAHESH**
42	**12R11A0344**	**PAKANATI SHAILENDHAR REDDY**
43	**12R11A0345**	**PANJALA VENU GOPAL**
44	**12R11A0346**	**PERAPALLI SAI KUMAR**
45	**12R11A0347**	**S JOHNSON**
46	**12R11A0348**	**SANGIREDDY LAKSHMI KANTH**
47	**12R11A0349**	**SHAIK AHMED MIYA**
48	**12R11A0351**	**SUNKARI NARAYANA**
49	**12R11A0353**	**T SHIVA DAMODAR PRASAD**

50	**12R11A0354**	**THAKUR SAI DILIP SINGH**
51	**12R11A0355**	**THIRUNAHARI ANUDEEP**
52	**12R11A0356**	**VANGARI VENKATESH**
53	**12R11A0357**	**VUCHULA SANDEEP**
54	**12R11A0358**	**VULLENGALA RAJASHEKAR**
55	**13R15A0301**	**B LAXMAN NAIK**
56	**13R15A0302**	**D SANTOSH KUMAR**
57	**13R15A0303**	**PUPPALA NAGARJUN GOUD**
58	**13R15A0304**	**SHIKARI SAI KIRAN**
59	**13R15A0305**	**MARRIPELLY RAMAKRISHNA**
60	**13R15A0306**	**SHEELA VENKATA JAGADEESH KUMAR**
61	**13R15A0308**	**M VENU**
62	**13R15A0309**	**MAHESHWARAM MADHAVA CHARY**
63	**13R15A0310**	**MUTHYALA SRINIVAS RAJU**
64	**13R15A0311**	**PARTHANAGARI RANJITH**

26. Group-wise students list for discussion topic:

The Groups will be formed after start of the class work.