From Concept to Product
Solar Thermal Development at the Weizmann Institute

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The Problem

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- The cost of energy (electricity or fuel) produced from solar radiation is presently too high.
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- Solar radiation is an intermittent energy source, mostly available in desert areas. Large-scale use requires storage and transportation solutions.
Solar Technology Options

Concentrated Solar Thermal
- Parabolic Trough
- Linear Fresnel
- Central Receiver (Solar Towers)
- Dish/Engine Systems

Photovoltaic
- Crystalline Silicon
- Thin Film (amorphous Si, CdTe, CIGS)
- Dye-Sensitized solar cells
- Concentrated Photovoltaic

Can be stored as heat or converted to fuel
Can be converted to fuel
Observation

• The Photovoltaic Revolution:
  Years of fundamental research followed by development of production methods have reduced PV panel cost from ~$6/W to <$1/W over the last 5 years.
Observation

• The Photovoltaic Revolution: *Years of fundamental research followed by development of production methods have reduced PV panel cost from \(~$6/W\) to \(<$1/W\) over the last 5 years.*

• No such progress in solar thermal.
Solar Thermal Electrical Power Generation
Solar Thermal Power Generation

• Concentrated solar thermal systems are used as electricity generating heat engines powered by the sun.
Solar Thermal Power Generation

• Concentrated solar thermal systems are used as electricity generating heat engines powered by the sun.

• The main components are
  – Radiation collectors / concentrators
  – Solar Receiver for heating a working fluid with solar radiation
  – Engine for conversion of heat to electrical power
Line Concentration Systems – Parabolic Troughs –

- Most mature concentrated solar thermal technology
- Over 500 MWe installed
- Over 1000 MWe of new contracts issued
- Favorable unit size range 50-100 MWe

Commercial Trough System in California
Line Concentration Systems
– Linear Fresnel Reflectors –

- Nearly mature concentrated solar thermal technology
- 10–50 MWe installed or near completion
- Over 1000 MWe of new contracts issued
- Favorable unit size range 50–100 MWe

Linear Fresnel System in Australia
Solar Tower (Solar Central Receiver)

- 80–100 MWe installed
- About 500 MWe in construction
- Favorable unit size range 0.1–150 MWe
Dish Engine System

- No commercial installation
- About 20 MWe of contracts issued
- Favorable unit size range 0.01–0.1 MWe

Dish-Stirling Systems in Sandia National Lab., Albuquerque, New Mexico
Hybridization and Storage
Solar thermal storage and/or hybridization enables load-following of electricity demand.

*Source: EPRI – Electric Power Research Institute*
Thermal Energy Storage and Hybridization

Thermal Storage Systems

One commercial installation

Excess heat from the solar field heats molten salts going from the cold tank to the hot tank. When needed, the heat from the hot tank is transferred to the steam generator.
Energy Transmission
Vision of possible HVDC lines linking the Southwest to the rest of the United States

Vision of possible HVDC lines linking North Africa to Europe

Source: the DESERTEC Foundation 2009.
Game-Changing Solar Thermal Concepts
Solar Thermal Costs Are Mostly in Glass and Steel

Trough

Dish

Increasing efficiency is the best way to decrease costs
The "Fletcher Principle" of a Solar Heat Engine:

Maximum Thermal to Electric Efficiency = Ideal Heat Engine Efficiency x Ideal Solar Receiver Efficiency

After Fletcher and Moen (1977).

Receiver Max. Efficiency = 1 - \([T(\text{high})^4 - T(\text{low})^4]/IC\)
Heat Engine Max. efficiency = 1 - \(T(\text{low}) / T(\text{high})\)
Ideal Solar Heat Engine Efficiency = \((1 - T(\text{low}) / T(\text{high})) \times \{1 - [T(\text{high})^4 - T(\text{low})^4]/IC\}\)
A Dish can reach the highest system efficiency due to its high optical and solar conversion efficiencies.
Solar System Efficiency – Present & Future

Possible Solution: Solarized Combined Cycle
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Solar Combined Cycle Enabling Requirements

• Solar Receiver:
Efficient energy transfer from highly concentrated solar radiation to working fluid at high temperature and pressure.

• Solar Concentrator:
Main cost and system efficiency parameter.
Concentration Configuration – Central Receiver

System Development & Commercialization by Aora Solar
Concentration Configuration – Dish Concentrator

Low Cost Parabolic Dish

Proprietary Volumetric Receiver

System Development & Commercialization by HelioFocus
Solar-driven fuel production: General Concept

Key to Success: High efficiency and high reaction rate
Recycling CO$_2$ emissions back to fuel using the sun as the energy source.
The larger the CO₂ dissociation plant, the lower the carbon emission
Providing liquid fuel for transportation using CO$_2$ emissions as feedstock

**Power generation plant**

**CO$_2$ dissociation plant**

$CO_2 + H_2O \rightarrow CO + H_2 \rightarrow$ Methanol
Clean Coal Burning & CO₂ Conversion to Transportation Fuel

Electric Grid

Generator

Turbine

Steam

Emission

Coal Boiler I \( P \times (1-X)MW \)

Coal Boiler II \( P \times (X)MW \)

Oxygen storage

CO₂ & Water

CO₂ & Water Dissociation Plant

Syngas (CO + H₂) Storage

Transportation Fuel Production
Reactor Design Concept

System Development & Commercialization by NewCO2Fuels
We can get it done, if…
We can get it done, if we *take the time to do it right*
Supplement
Weizmann’s Solar Laboratories [in operation since 1987]

- A 54m high Solar Tower with 64 Heliostats, each with 56m² of reflective area.
- Tower is set up as a laboratory, with 5 workstation, each capable of housing 2-3 experiments.
- Tests at the tower are conducted at a scale of 1 kW to 1 MW.
- Unique Tower Reflector enables the development of novel high-temperature solar chemistry systems.
Optical Characteristics – Dish and Ideal Central Receiver

Parabolic Dish Concentrator

Fresnel Reflectors

Direct Sunlight

Actual Ray

~45°

~45°
• Focal image increases by 1m per 100m distance due to sun-shape
• Focal image increases further as the rays angle of attack increases with distance from tower
• Heliostat spacings must increase with distance from target to avoid light blocking
The Real World...
Growth of Electricity Consumption

Over *3.5 billion people* live in countries where consumption *more than doubled from 1990 to 2003*

Among them, over *1.5 billion people* live in countries where consumption *more than tripled* at the same time

Per Capita Carbon Emissions Versus Per Capita GDP (Gross Domestic Product)

Carbon Emission is high in the fast-growing countries.
The Fundamental Requirement of Electrical Power Supply:

Get me what I want, when I want it!!!
Intermittent Energy Supply Does Not Match Load Requirements – Case 1

Wind power fed into the power grid and total electricity output in the E.ON TSO area (Germany)
Intermittent Energy Supply Does Not Match Load Requirements – Case 2

The TXU (Arizona) Load Requirement

Average Hourly Profiles - August 2000

Load Required

Capacity Value at Peak = 10.9%

3.7 MW

Wind Output

20,993 MW
Intermittent Energy Supply Does Not Match Load Requirements

The TXU (Arizona) Load Requirement

Average Hourly Profiles - August 2000

- Solar Output
- Wind Output

TXU Load (MW)

Wind Project Output (MW)

Capacity Value at Peak = 10.9%

Load Required

20,993 MW

3.7 MW