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From Concept to Product

Solar Thermal Development at the Weizmann Institute

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October 30, 2011

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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.
- Solar radiation is an intermittent energy source, mostly available in desert areas. Large-scale use requires storage and transportation solutions.

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Solar Technology Options

Concentrated Solar Thermal

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

Can be stored as heat or converted to fuel

Photovoltaic

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

Can be converted to fuel

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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.*

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  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

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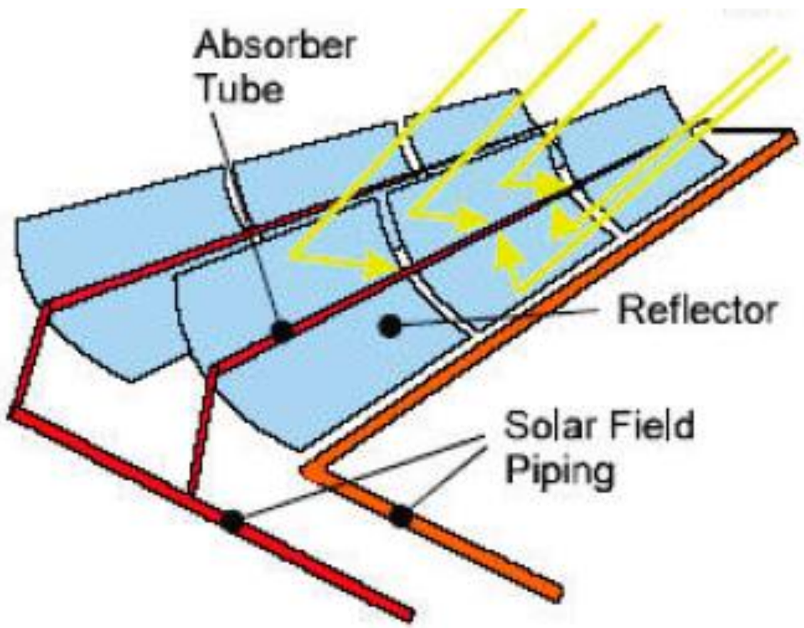
Solar Thermal Power Generation

- 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 –

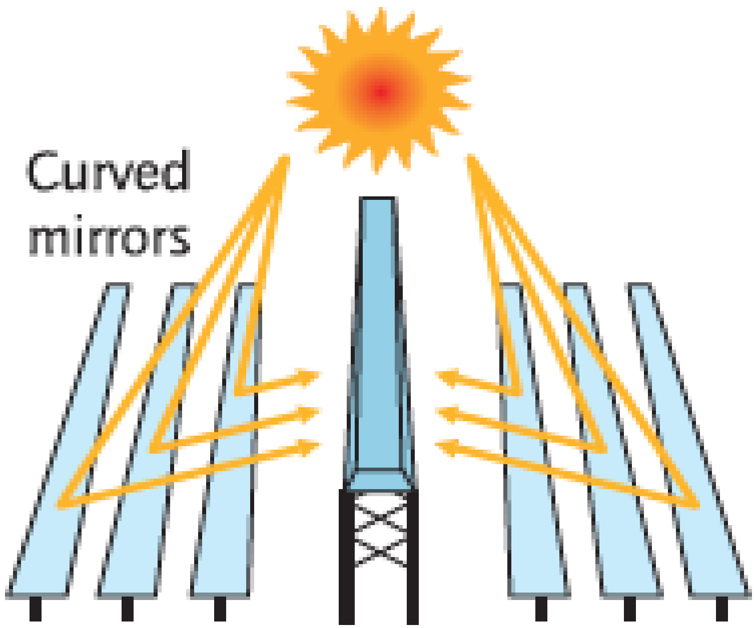
- *Most mature concentrated solar thermal technology*
- *Over 500 MWe installed*
- *Over 1000 MWe of new contracts issued*
- *Favorable unit size range 50-100MWe*



Commercial Trough System in California

Line Concentration Systems
– Linear Fresnel Reflectors –

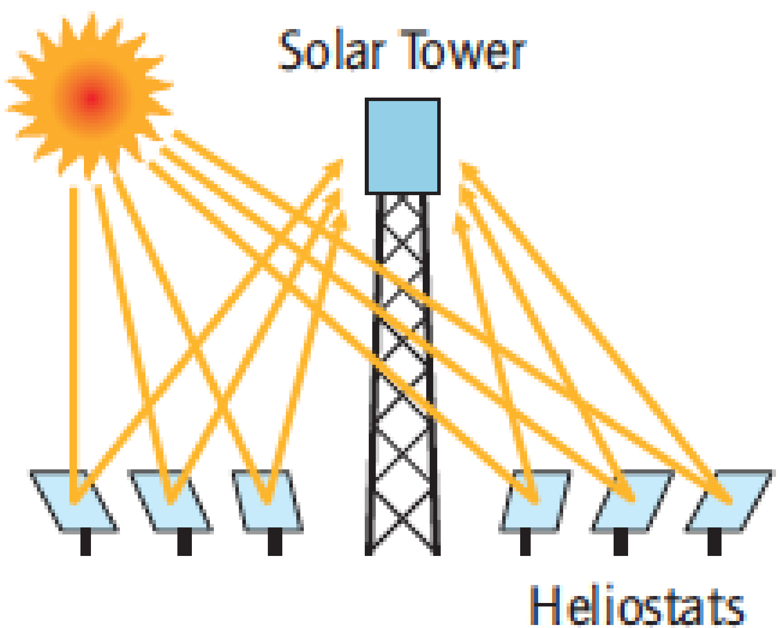
- Nearly mature concentrated solar thermal technology
- 10–50 MWe installed or near completion
- Over 1000 MWe of new contracts issued
- Favorable unit size range 50–100MWe



Linear Fresnel System in Australia

Solar Tower (Solar Central Receiver)

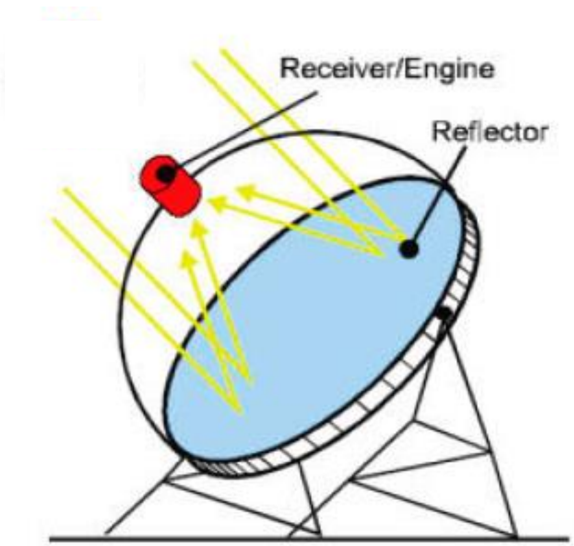
- *80–100 MWe installed*
- *About 500 MWe in construction*
- *Favorable unit size range 0.1–150MWe*



10MWe Demonstration SCR Plant in California

Dish Engine System

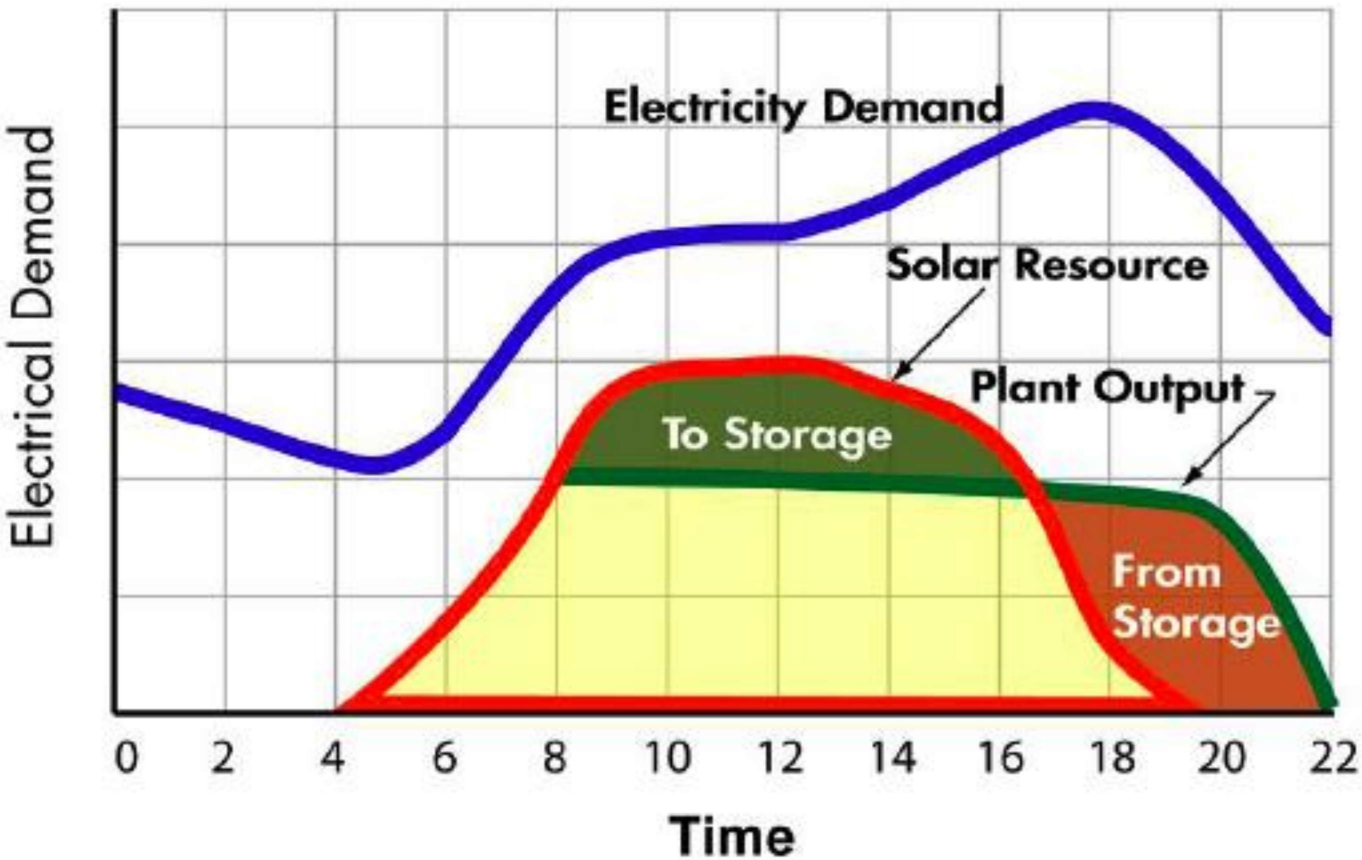
- *No commercial installation*
- *About 20 MWe of contracts issued*
- *Favorable unit size range 0.01-0.1 MWe*



Dish-Stirling Systems in Sandia National Lab., Albuquerque, New Mexico

Hybridization and Storage

Thermal Energy Storage or Hybridization



Solar thermal storage and/or hybridization enables load-following of electricity demand

Source: EPRI – Electric Power Research Institute

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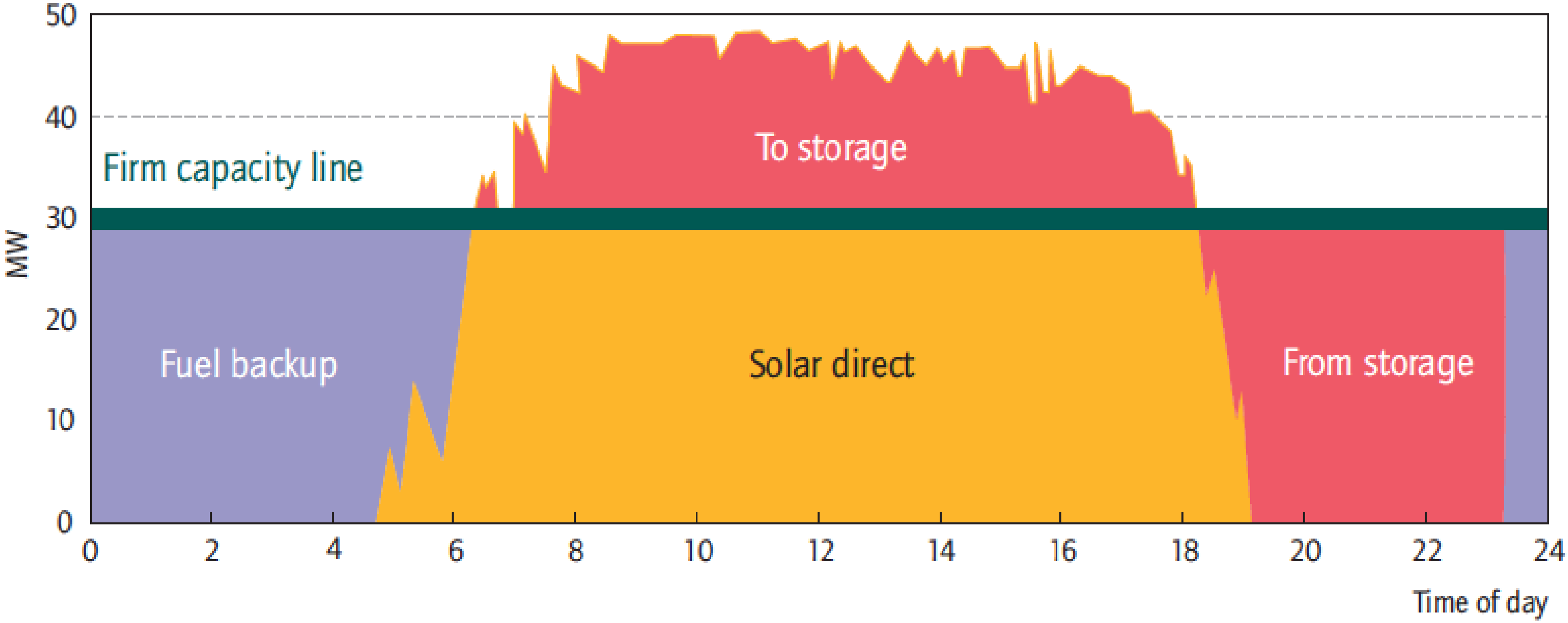
Thermal Energy Storage and Hybridization



Source: Geyer, 2007, *SolarPACES Annual Report.*

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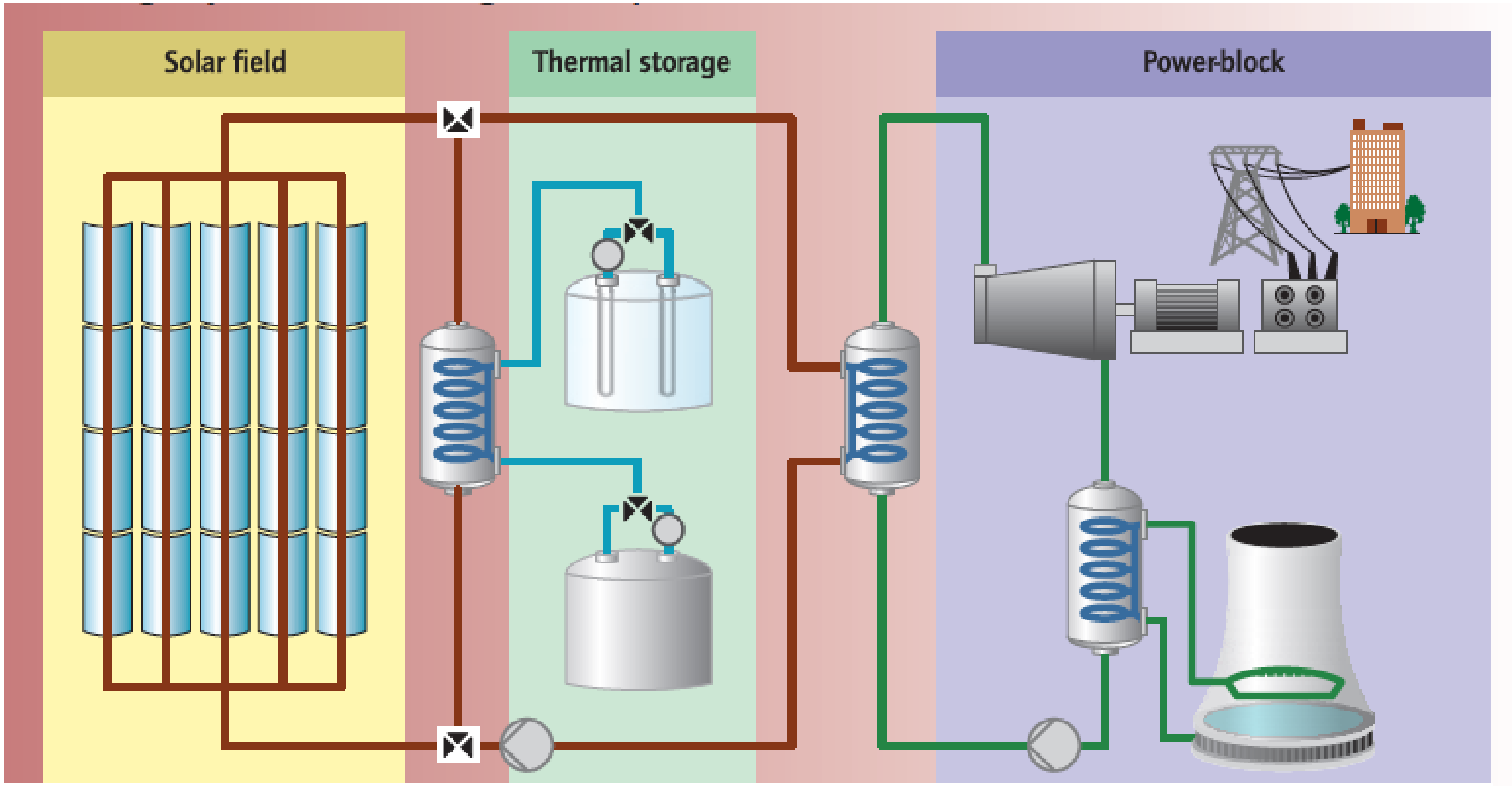
Thermal Storage Systems

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

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Vision of possible HVDC lines linking the Southwest to the rest of the United States

Source: Hank Price, US DOE, 2007.

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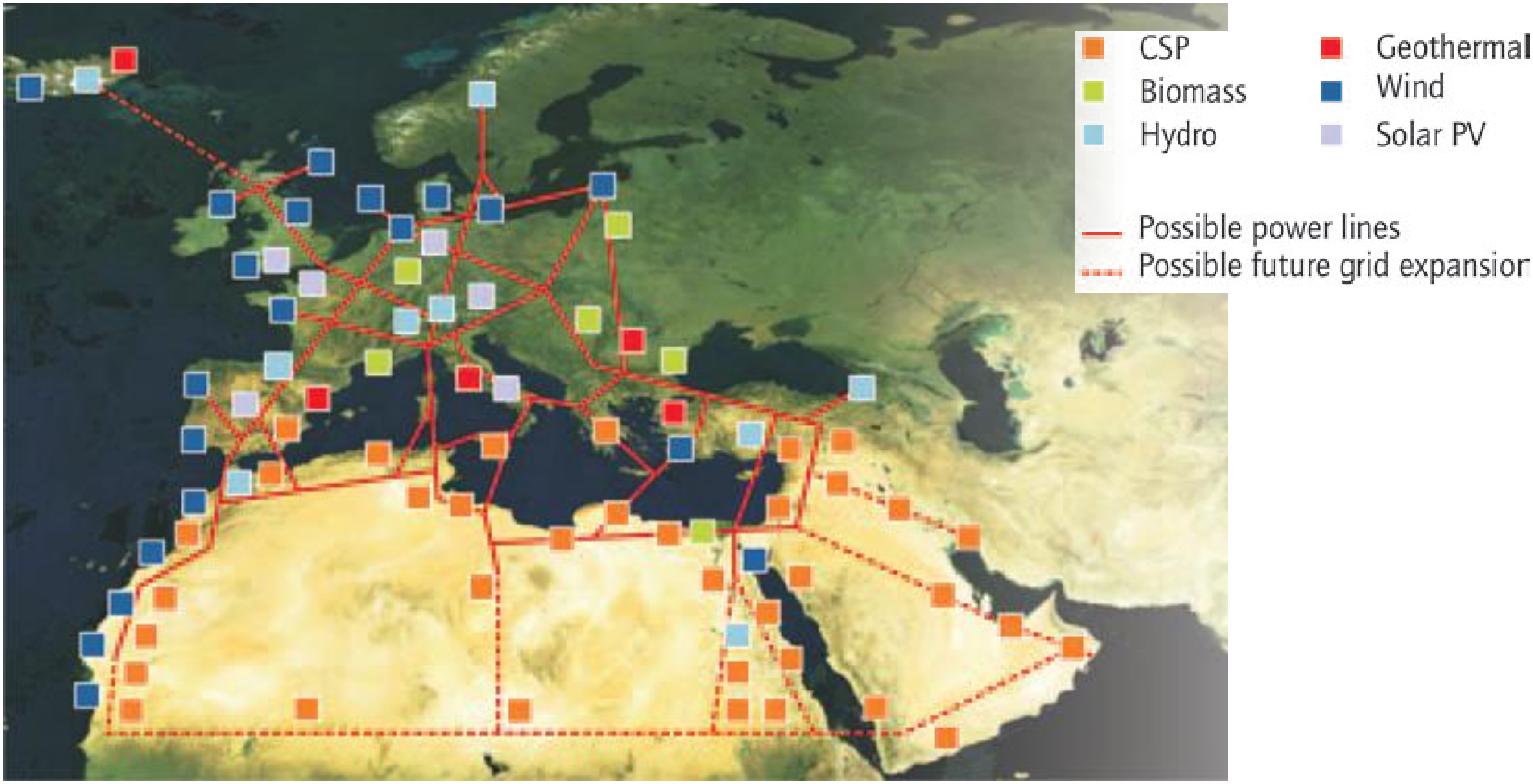
Vision of possible HVDC lines linking North Africa to Europe



Source: the DESERTEC Foundation 2009.

Game-Changing Solar Thermal Concepts

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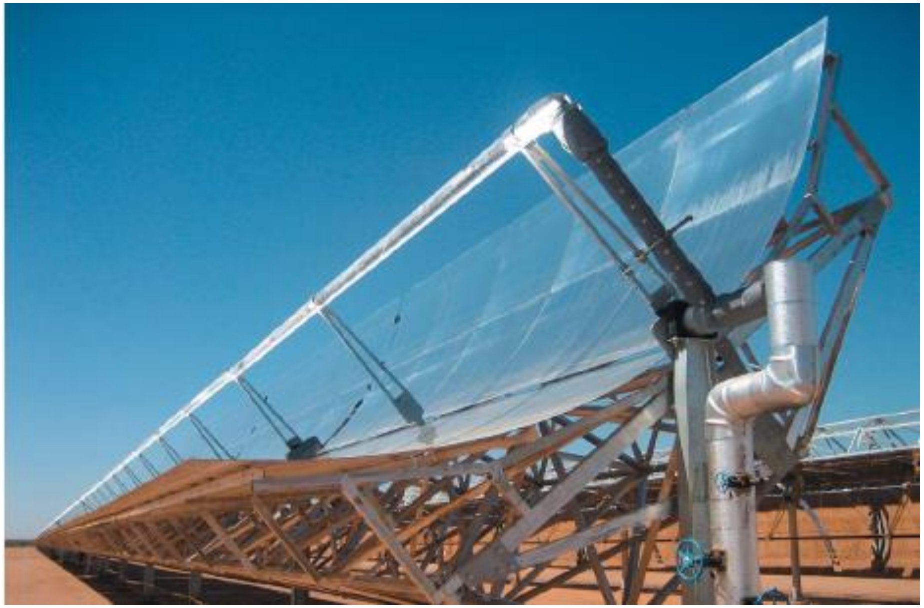
Solar Thermal Costs Are Mostly in Glass and Steel



Trough

Dish

Increasing efficiency is the best way to decrease costs

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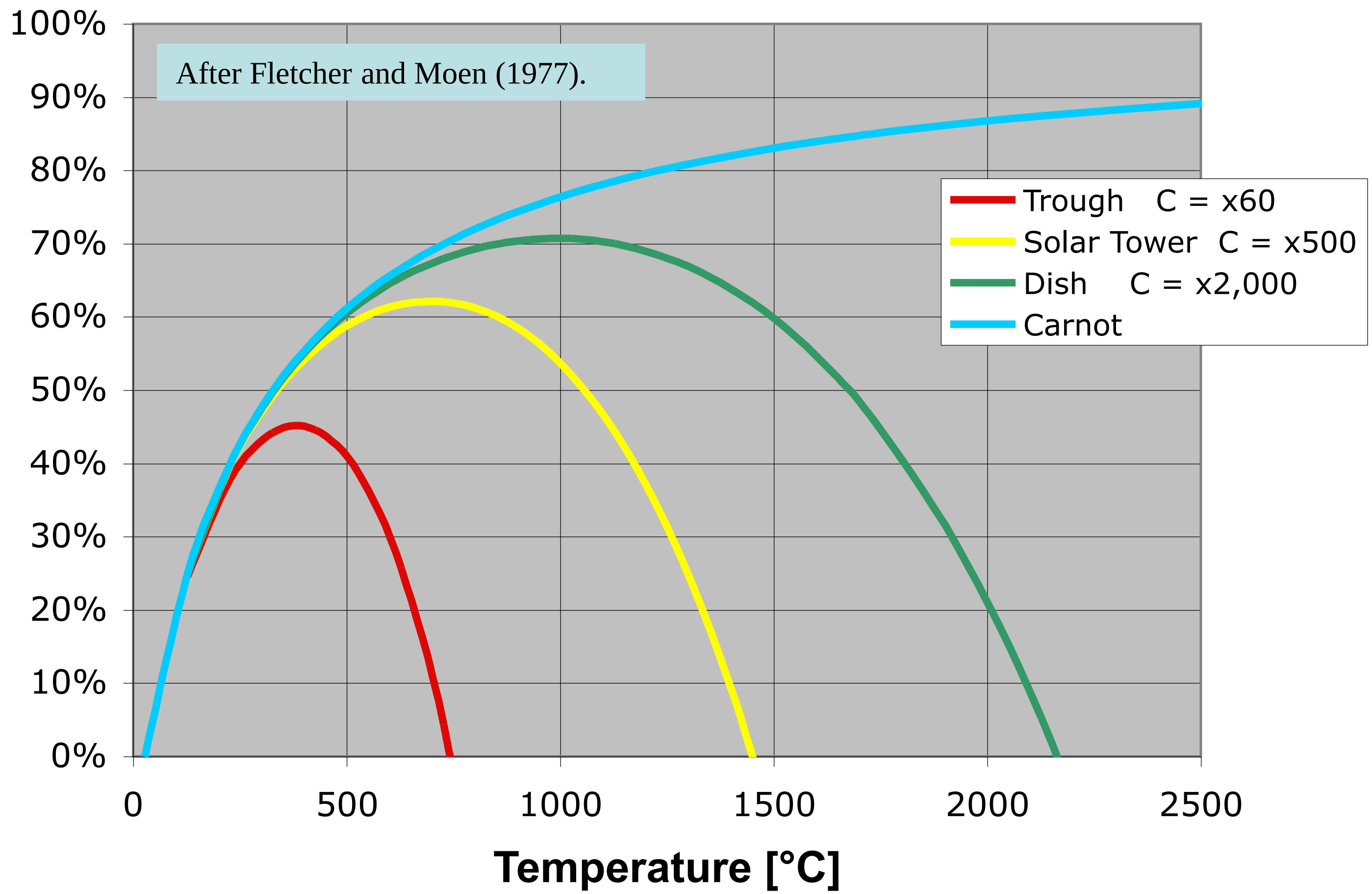
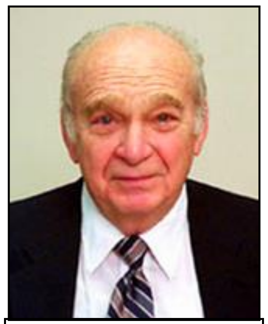
The *"Fletcher Principle"* of a Solar Heat Engine:

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





Edward E. Fletcher

Receiver Max. Efficiency	=	$1 - s[T(high)^4 - T(low)^4]/IC$
Heat Engine Max. efficiency	=	$1 - T(low) / T(high)$
Ideal Solar Heat Engine Efficiency	=	$(1 - T(low) / T(high)) * \{1 - s[T(high)^4 - T(low)^4]/IC\}$

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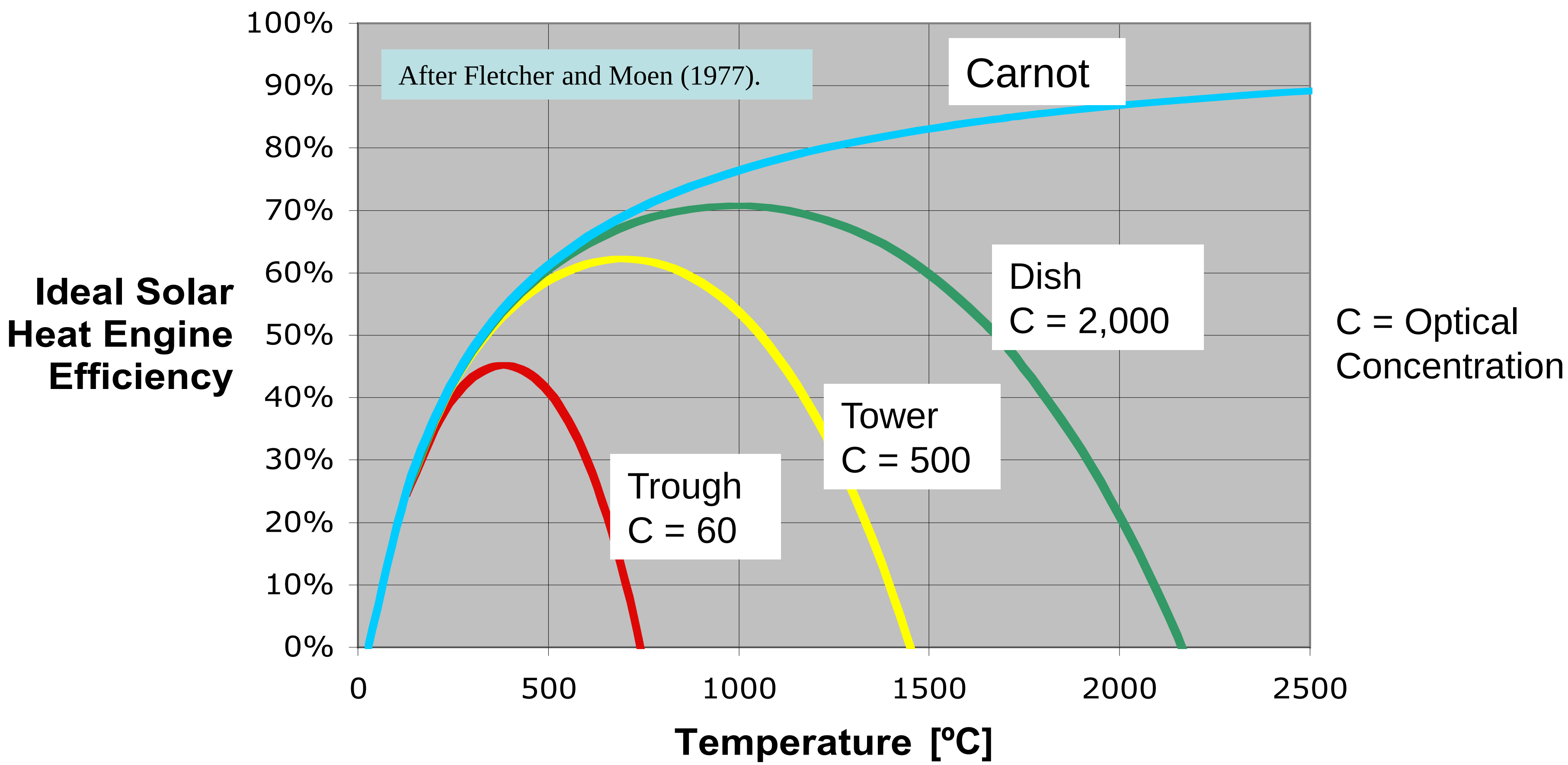
Optimum System Efficiency



A Dish can reach the highest system efficiency
due to its high optical and solar conversion efficiencies

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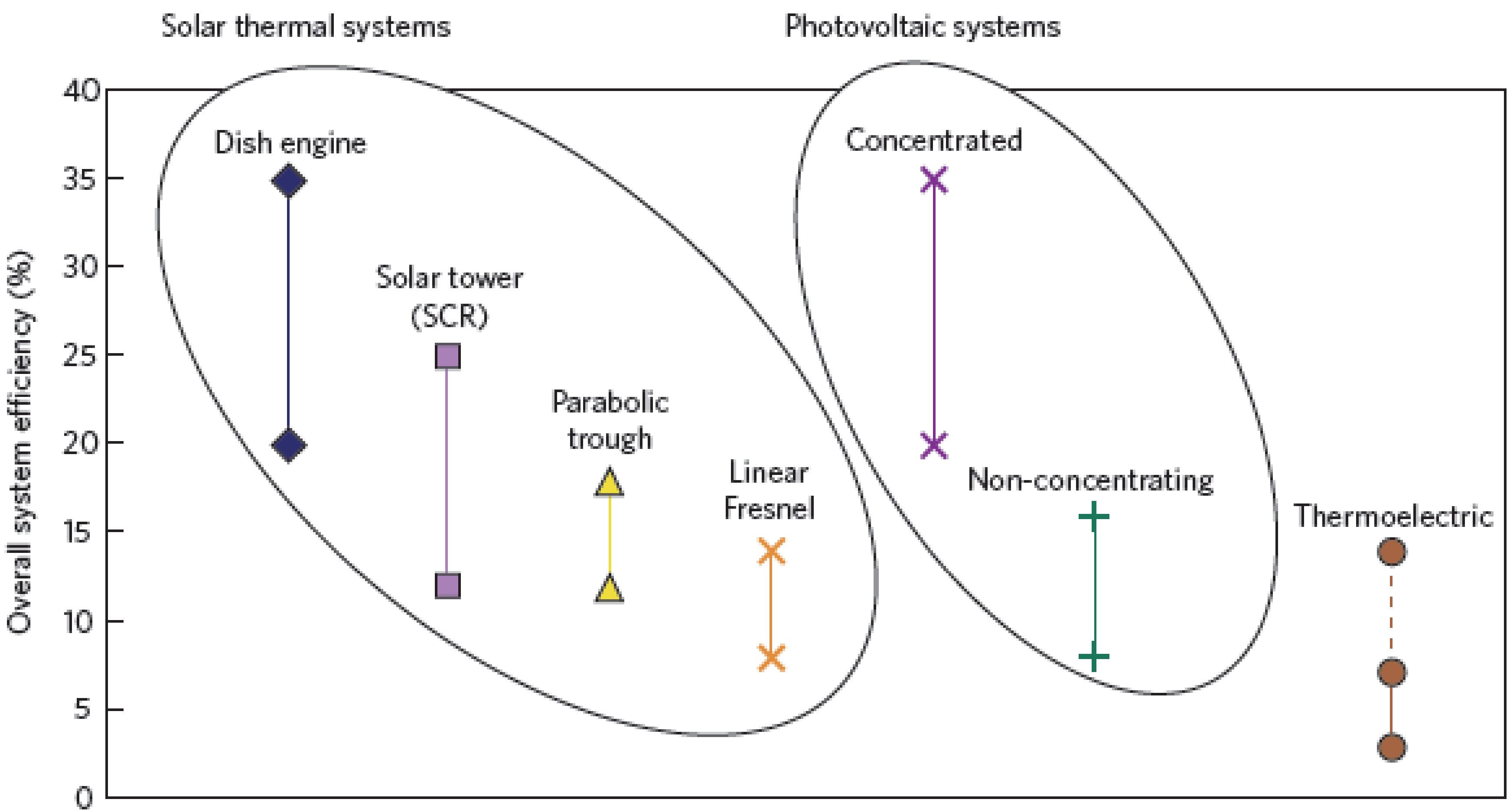
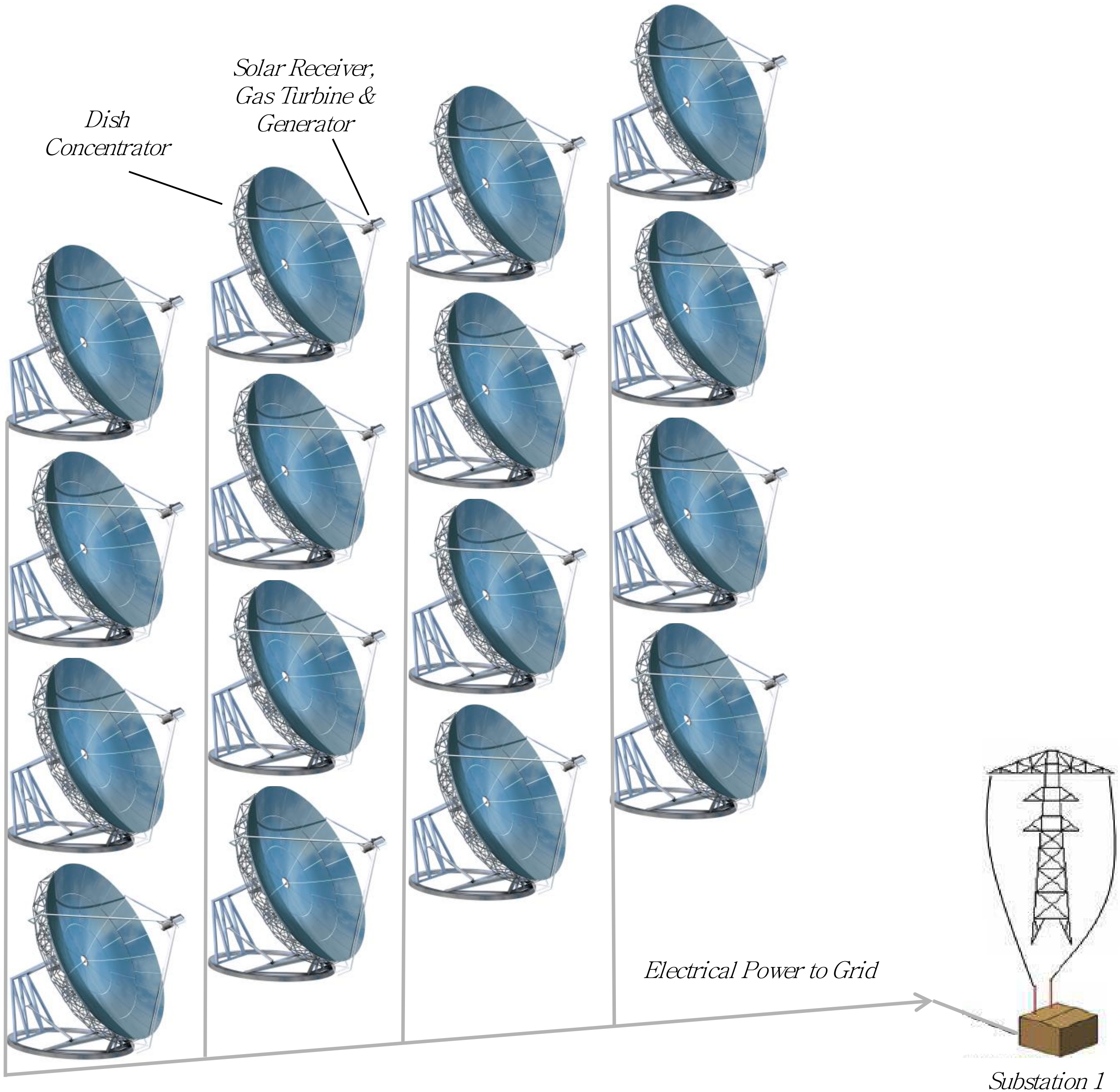
Solar System Efficiency – Present & Future



Source: J. Karni, Nature Materials, V. 10, 2011.

Possible Solution: Solarized Combined Cycle



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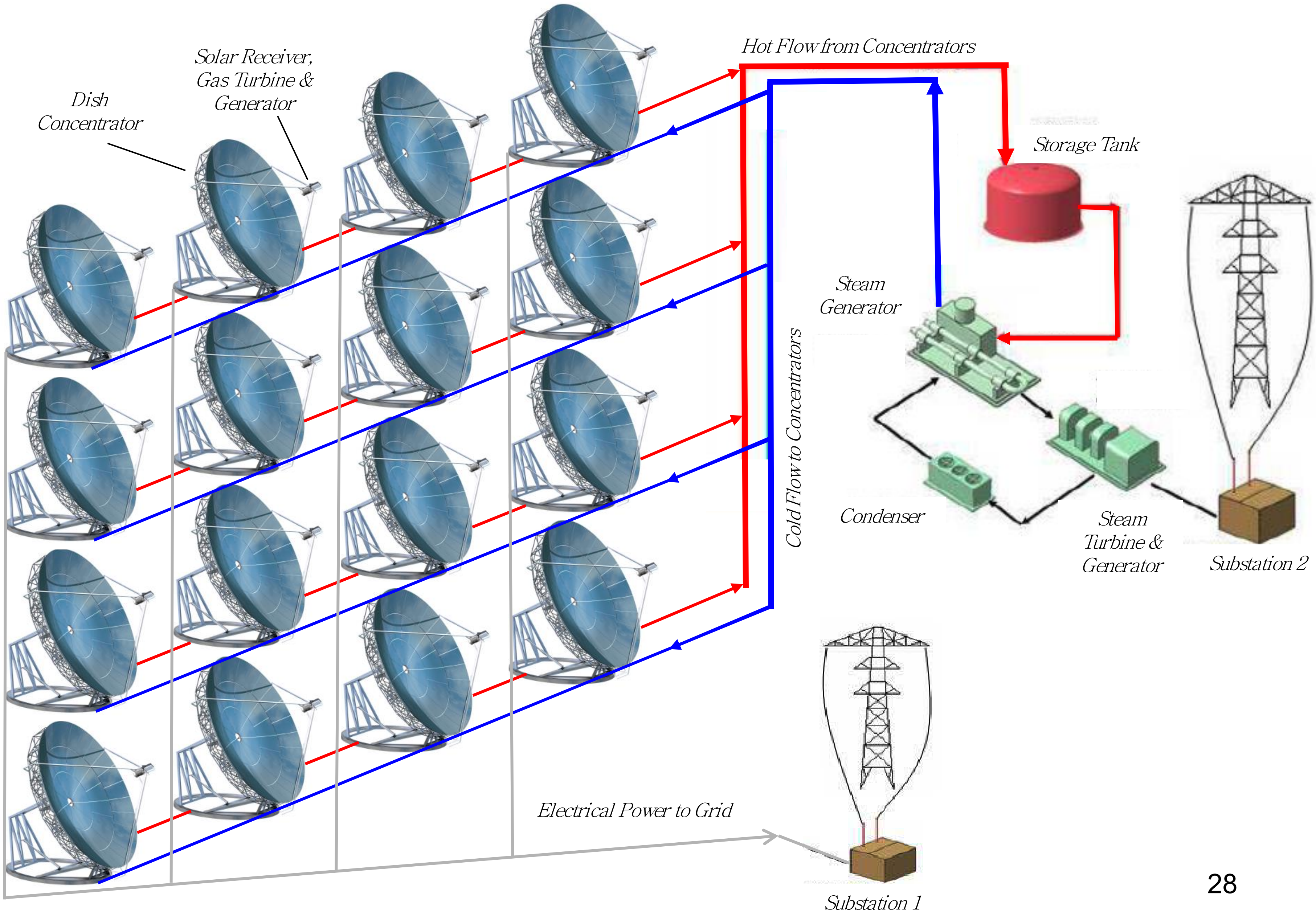
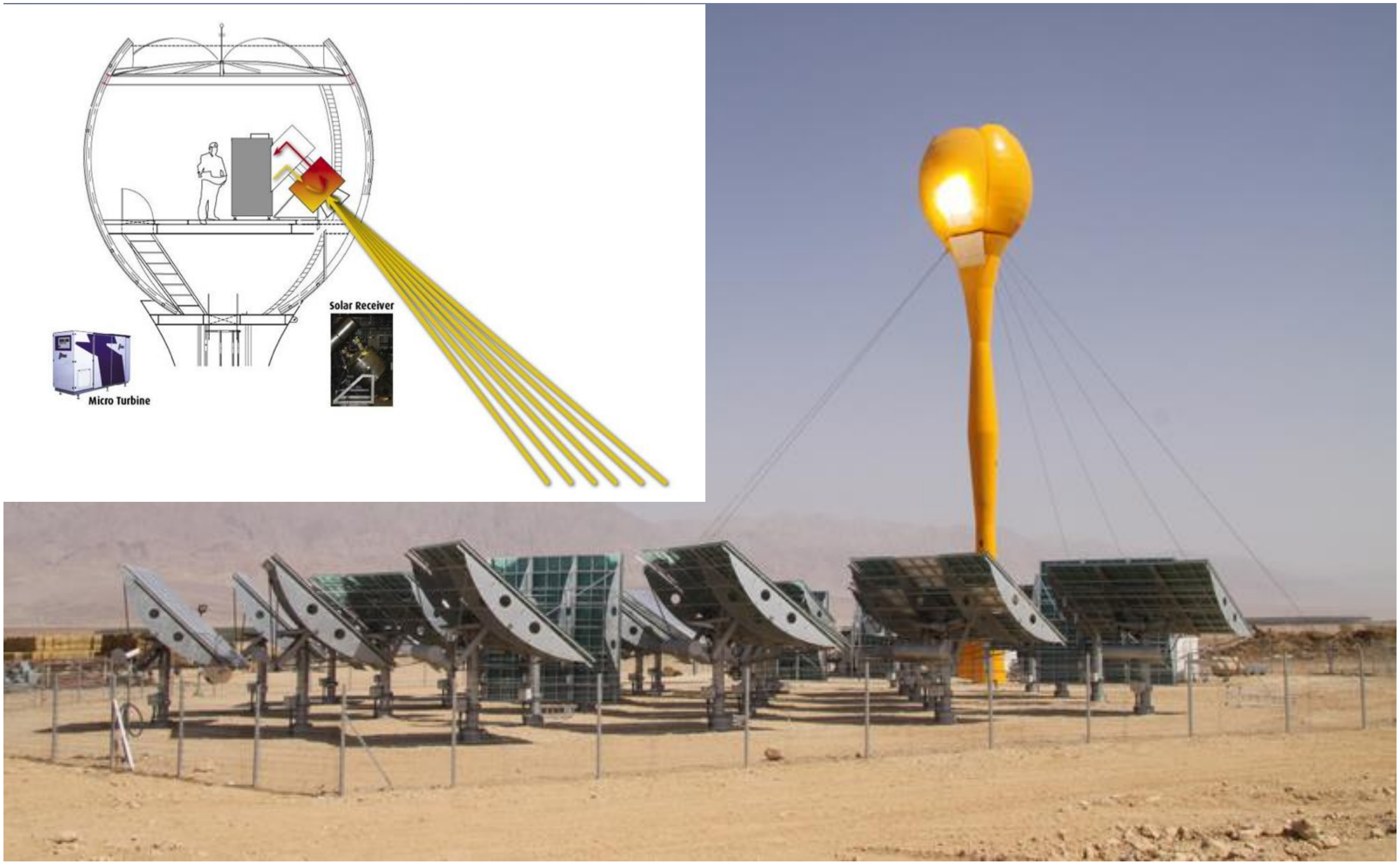
Possible Solution: Solarized Combined Cycle



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

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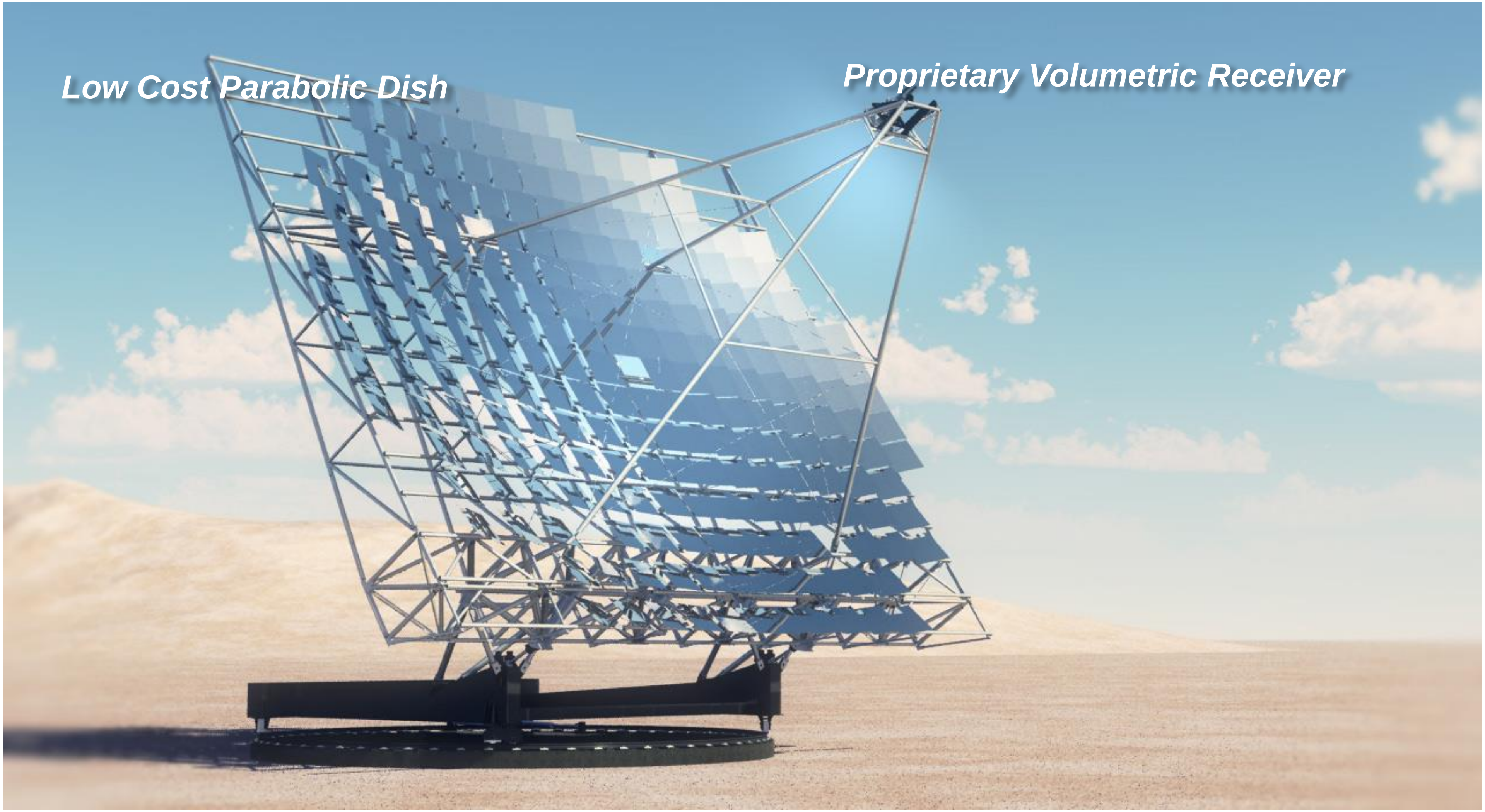
Concentration Configuration – Dish Concentrator



System Development & Commercialization by HelioFocus

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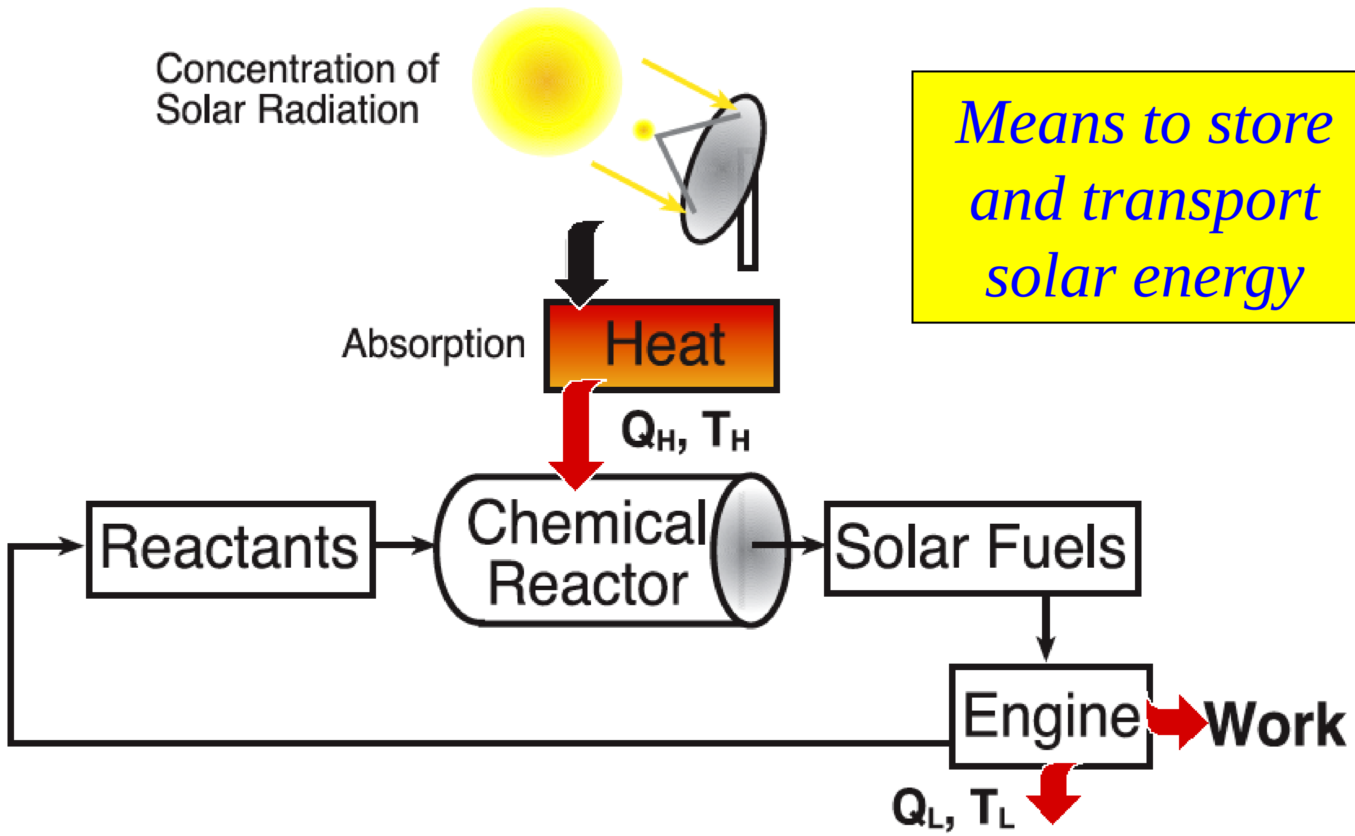
Solar-driven fuel production: General Concept



Means to store and transport solar energy

Key to Success: High efficiency and high reaction rate

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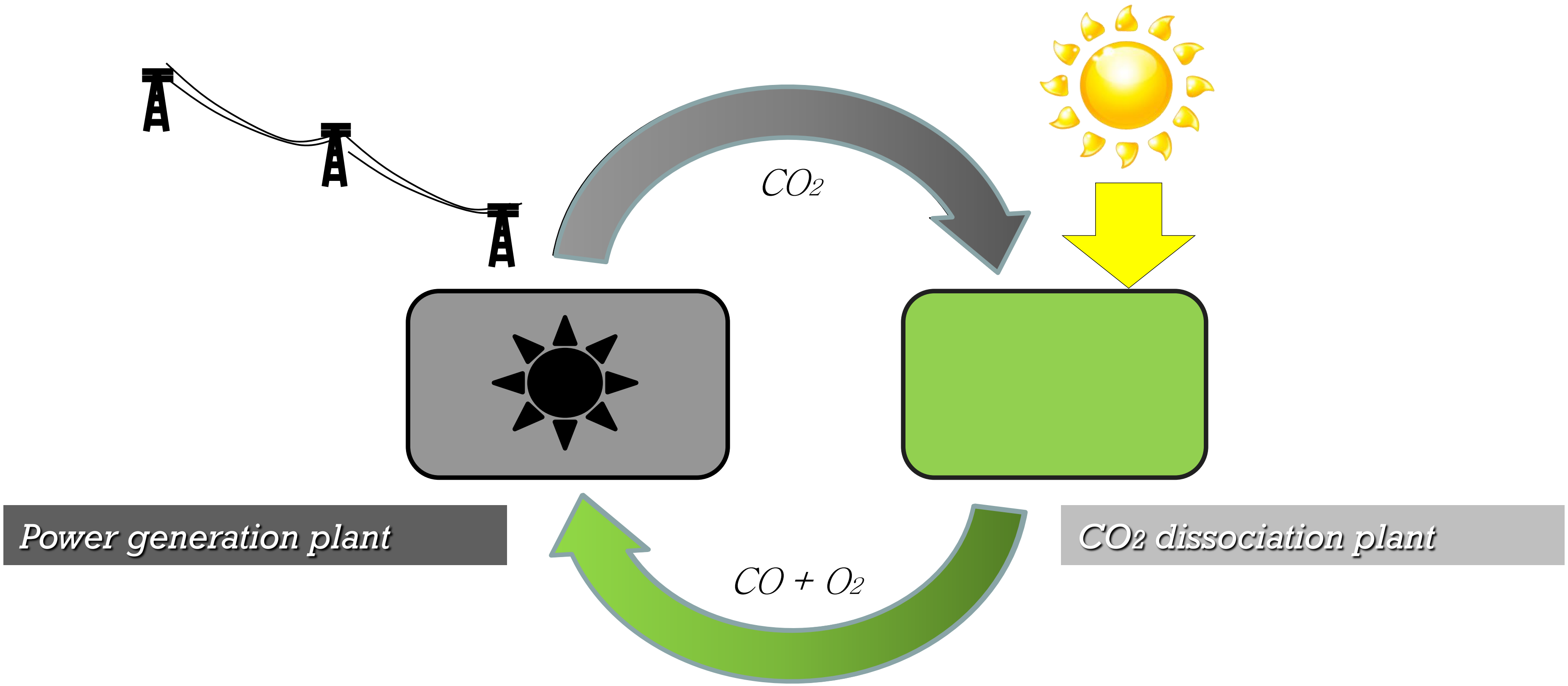
Recycling CO_2 emissions back to fuel using the sun as the energy source



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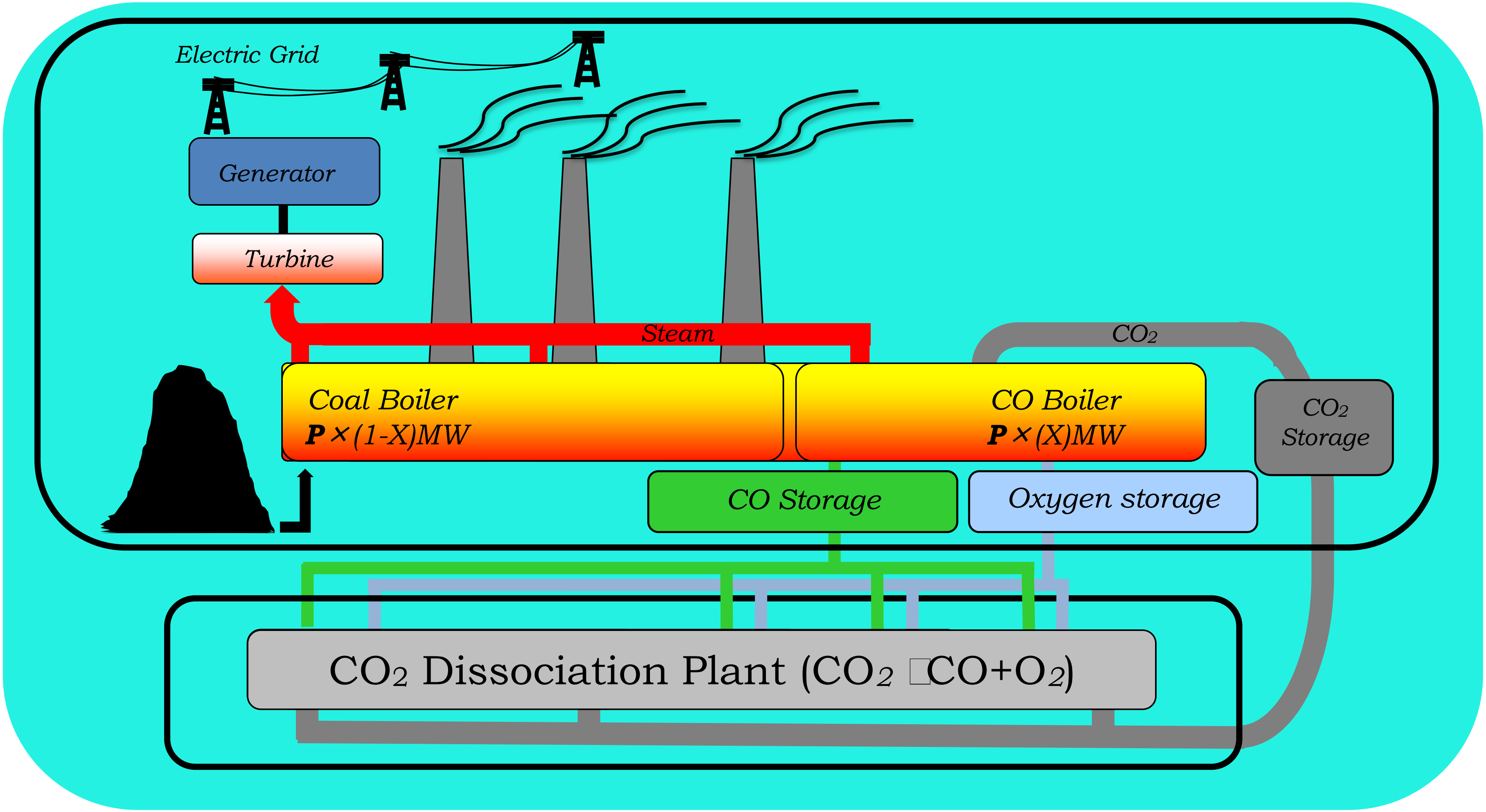
Emission Free Power Generation



The larger the CO_2 dissociation plant, the lower the carbon emission

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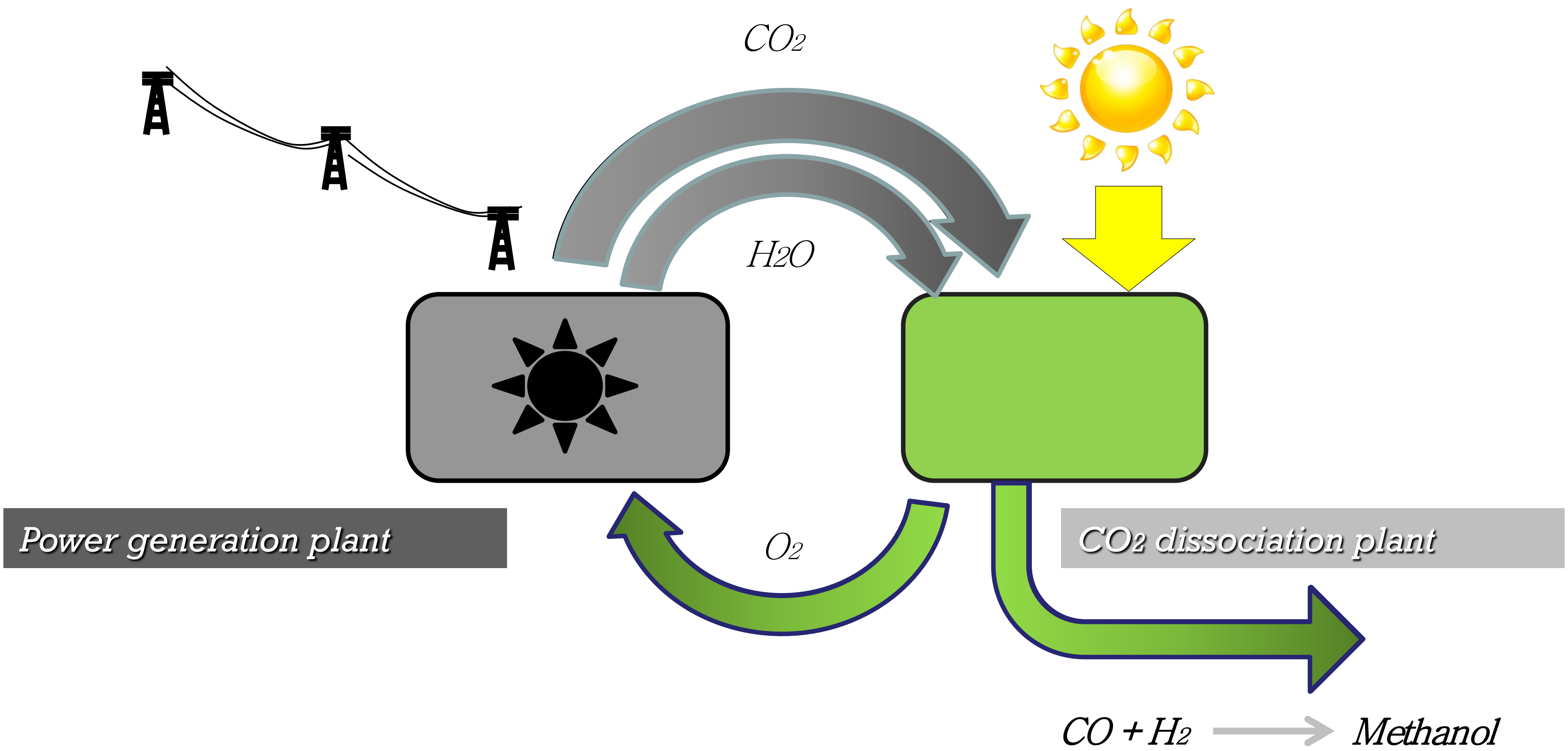
Providing liquid fuel for transportation using CO_2 emissions as feedstock



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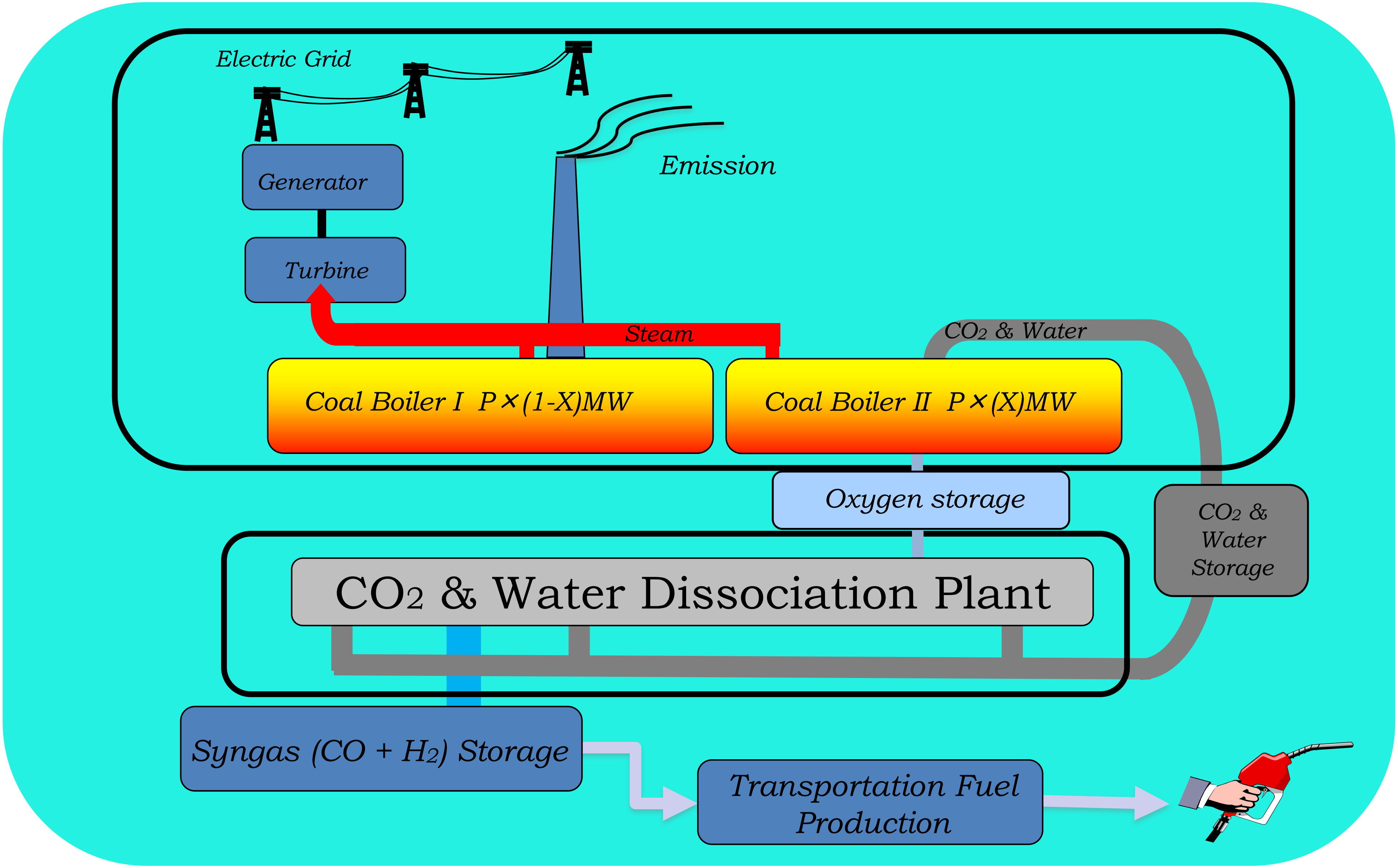
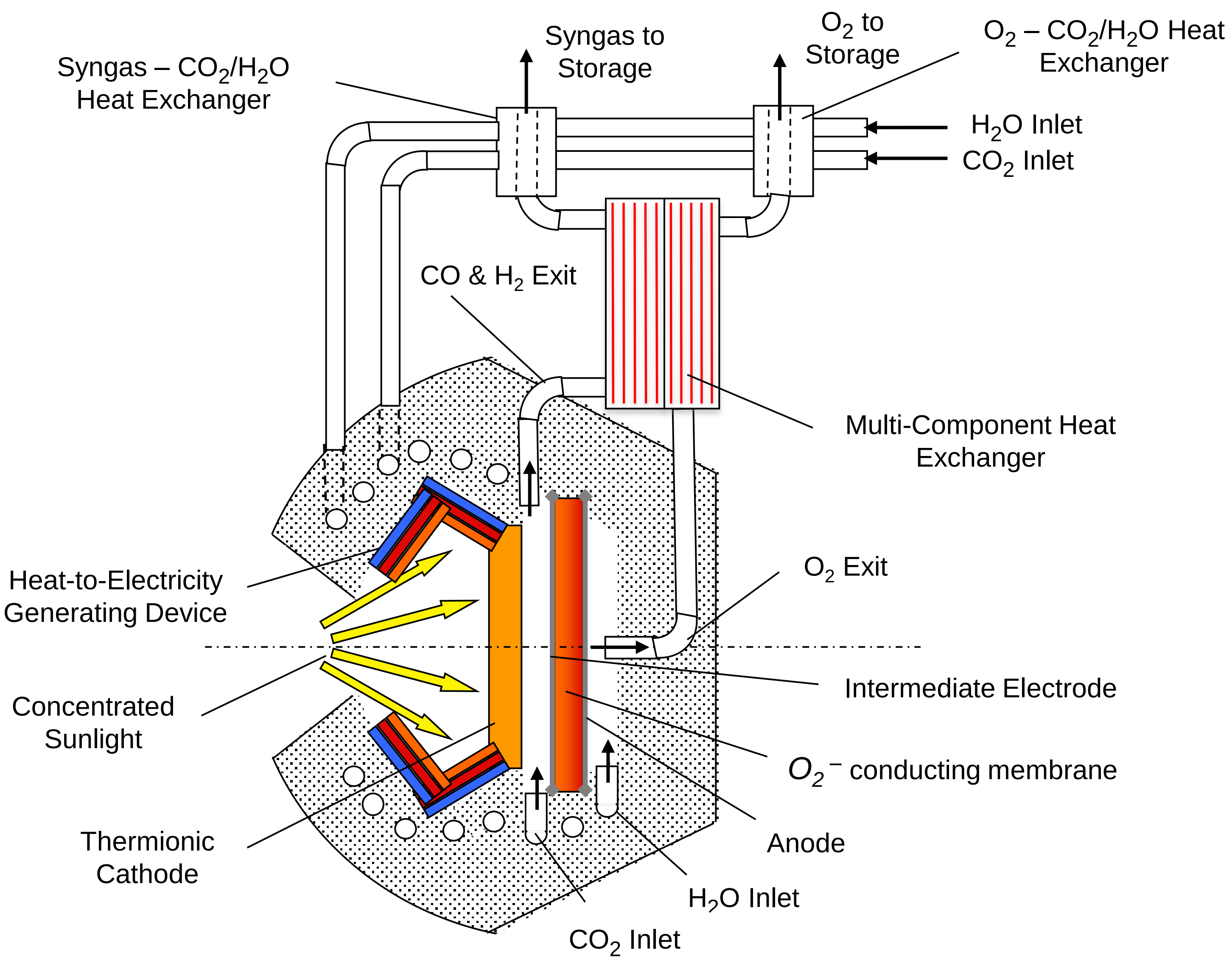
Clean Coal Burning & CO_2 Conversion to Transportation Fuel

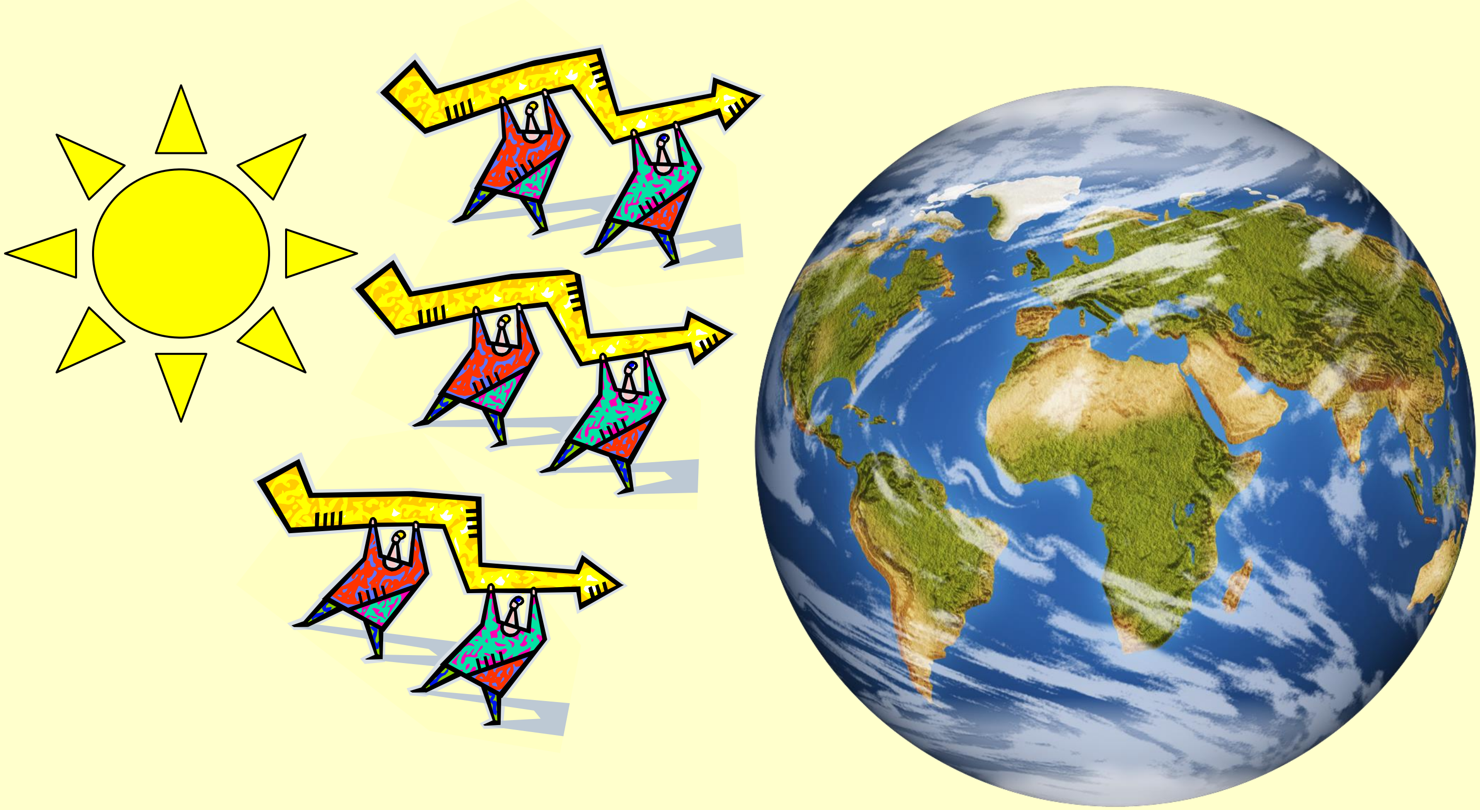


Reactor Design Concept



System Development & Commercialization by NewCO2Fuels

We can get it done, if…



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We can get it done, if ***we take the time to do it right***

Supplement

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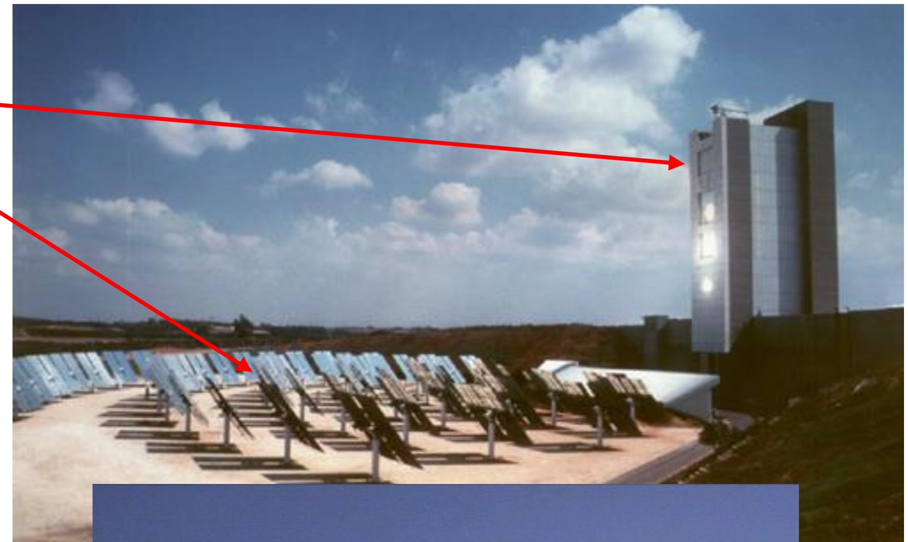
Weizmann's Solar Laboratories [in operation since 1987]

- A 54m high Solar Tower with 64 Heliostats, each with $56m^2$ 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.



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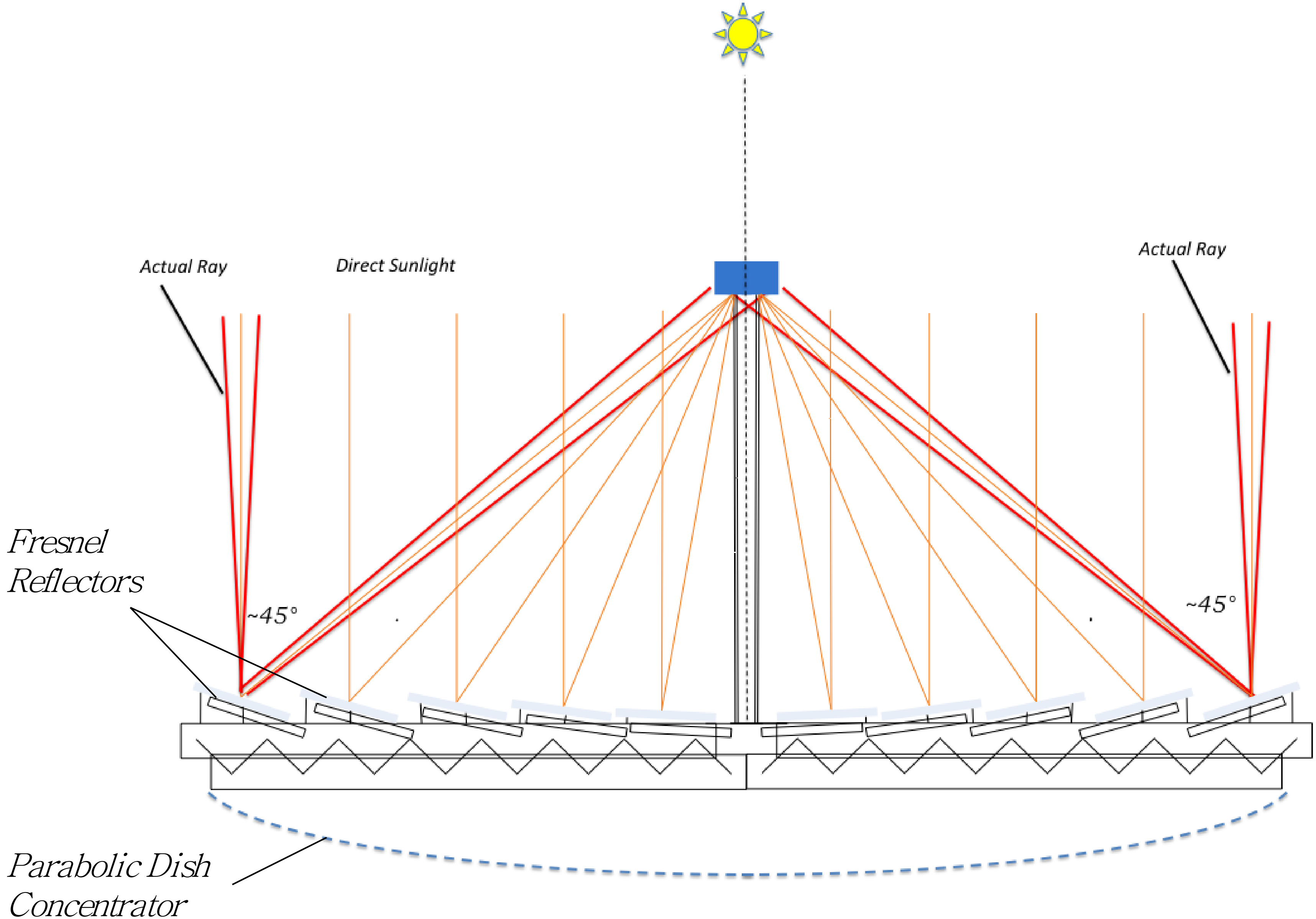
Optical Characteristics – Dish and Ideal Central Receiver



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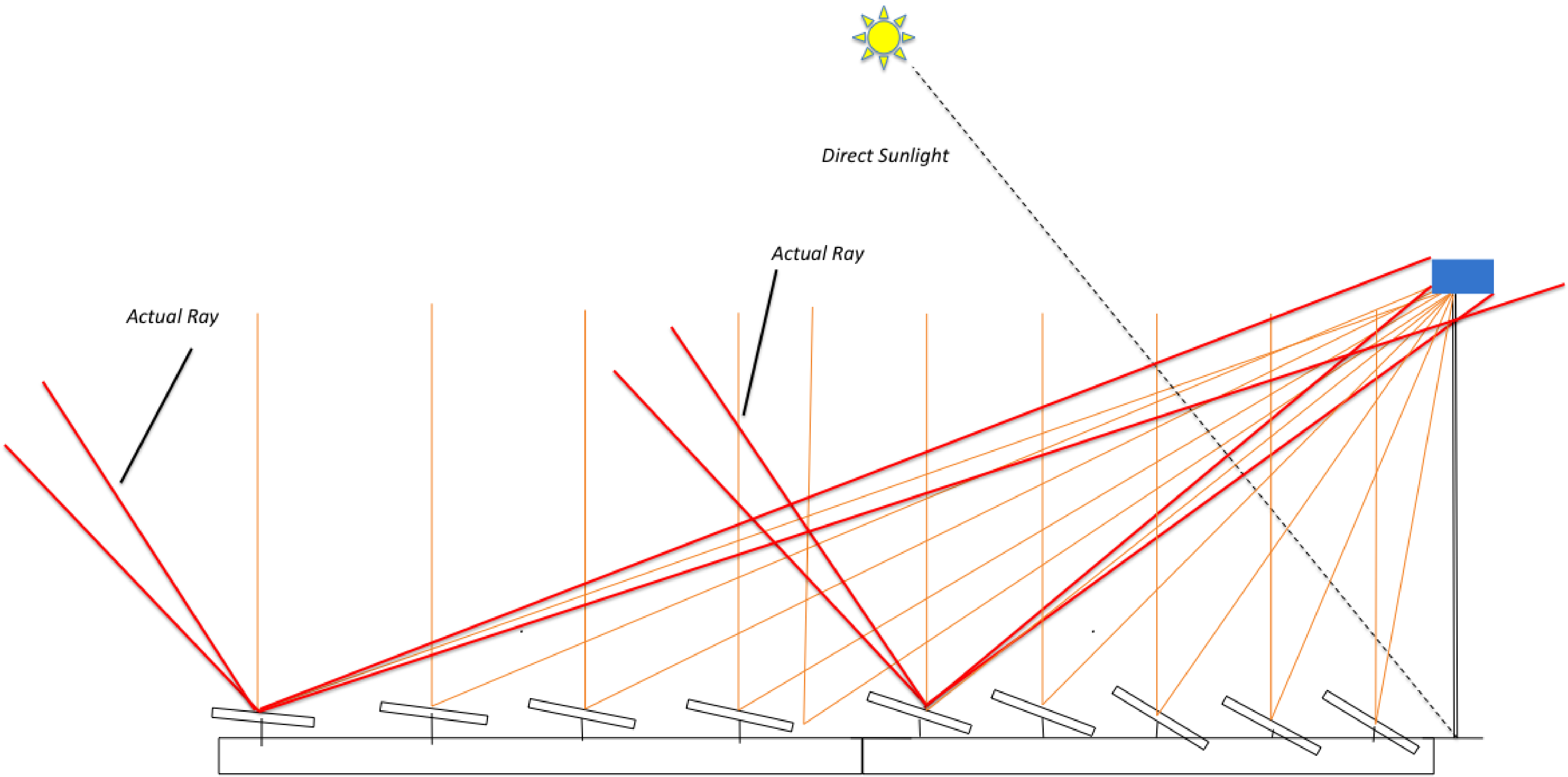
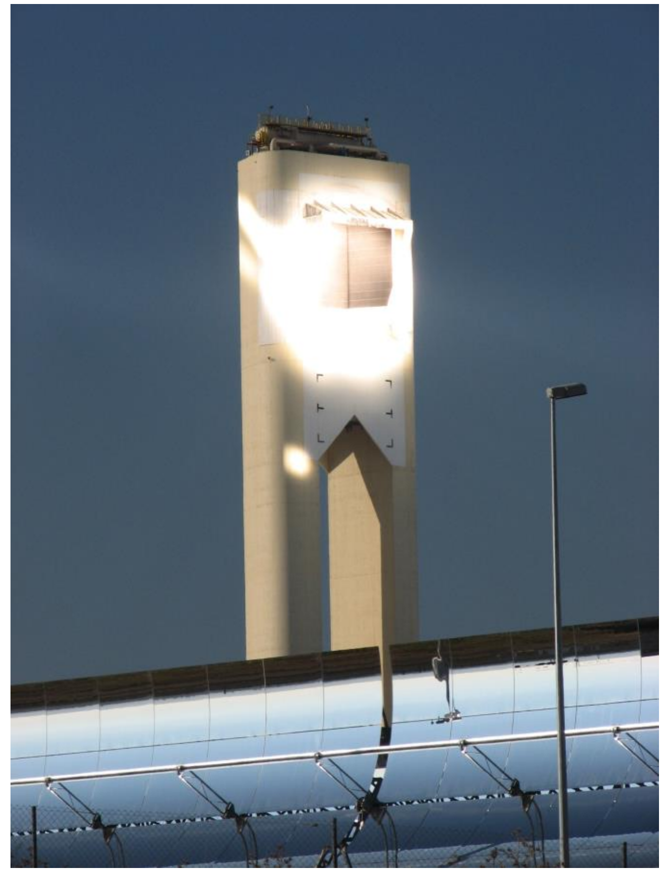
Optical Characteristics – Real Central Receiver



- 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…



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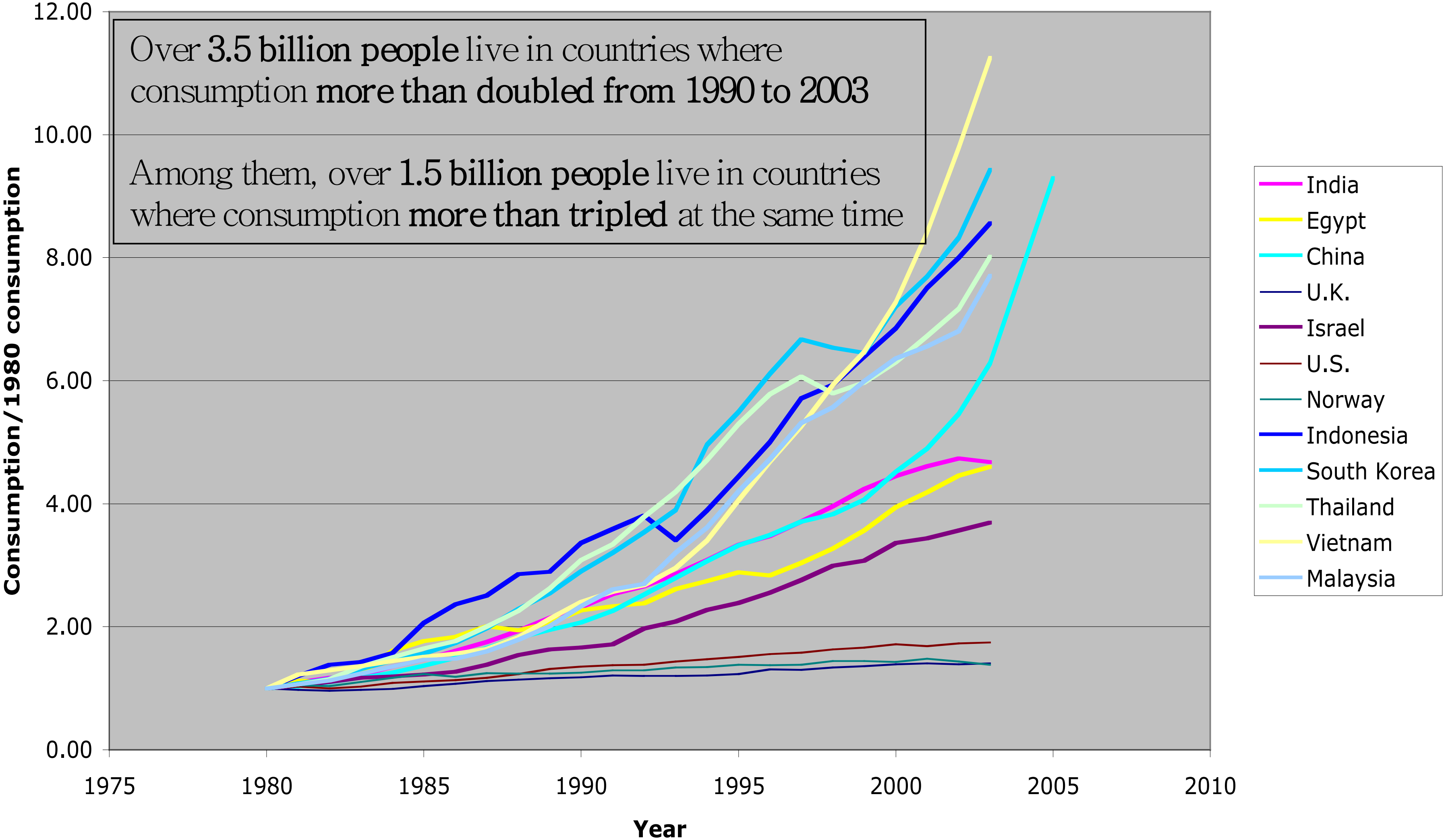
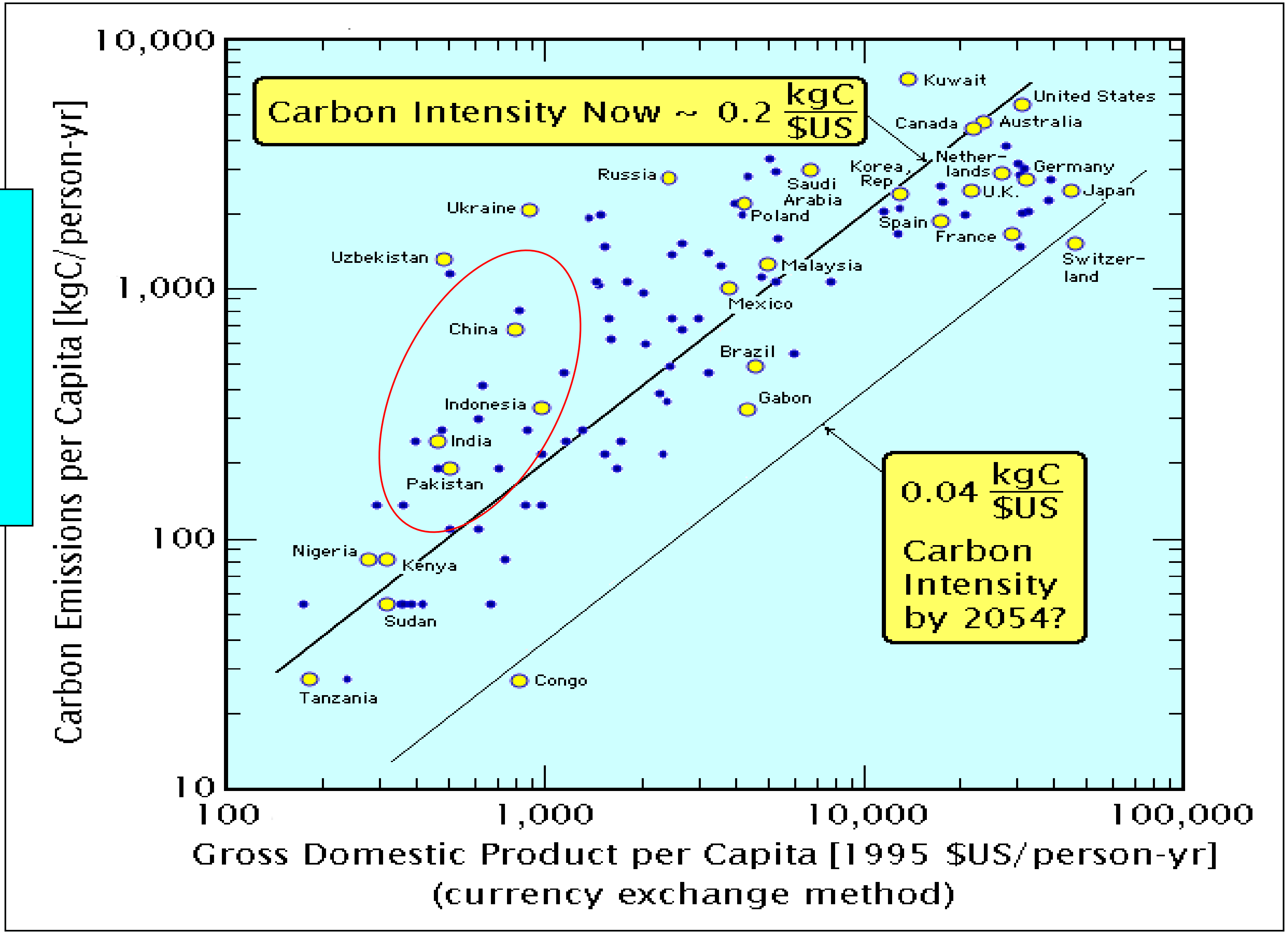
Growth of Electricity Consumption



Source: DOE, Energy Information Administration, *International Energy Annual 2003*

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

Carbon Emission is high in the fast-growing countries



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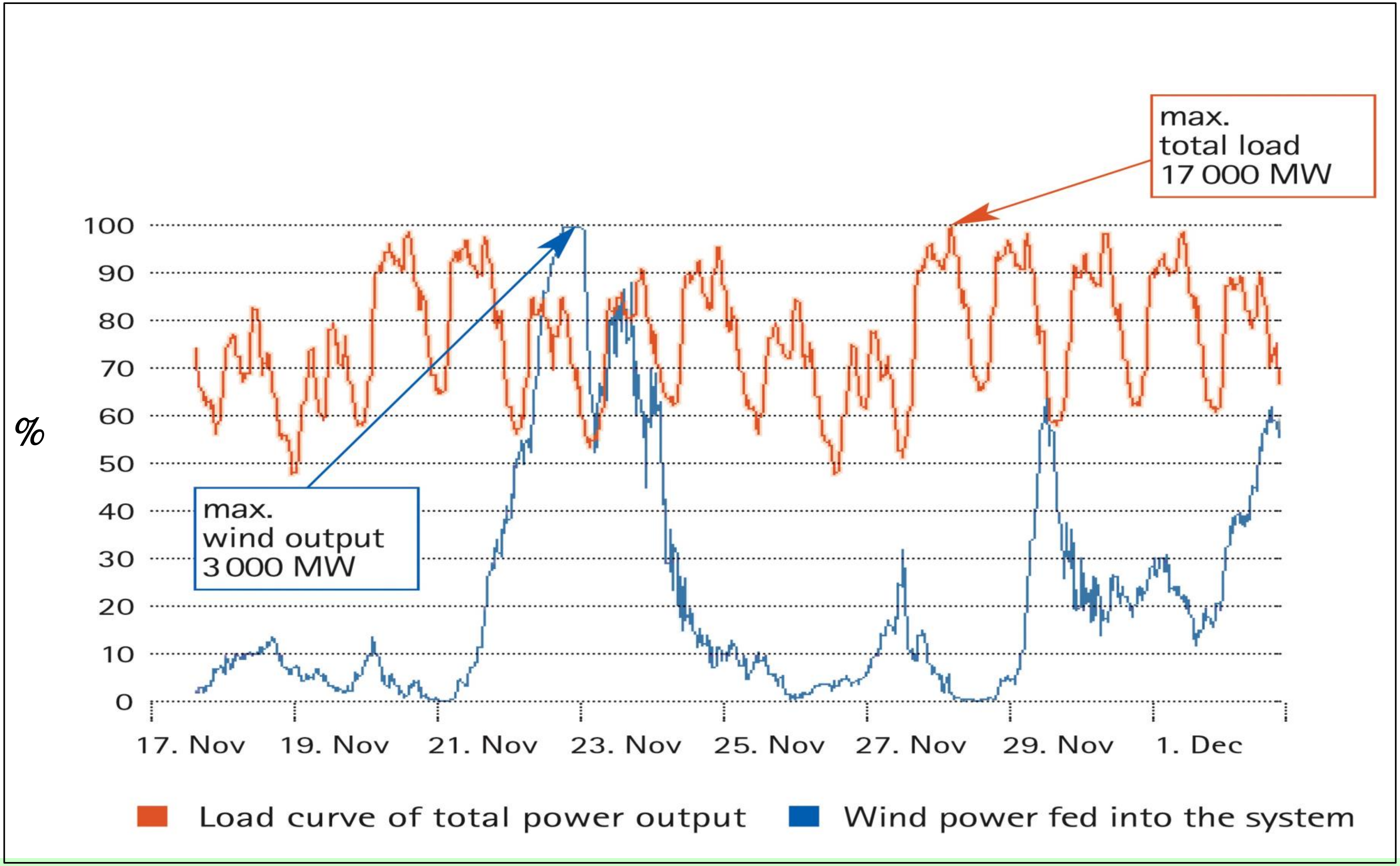
The Fundamental Requirement of Electrical Power Supply:

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)

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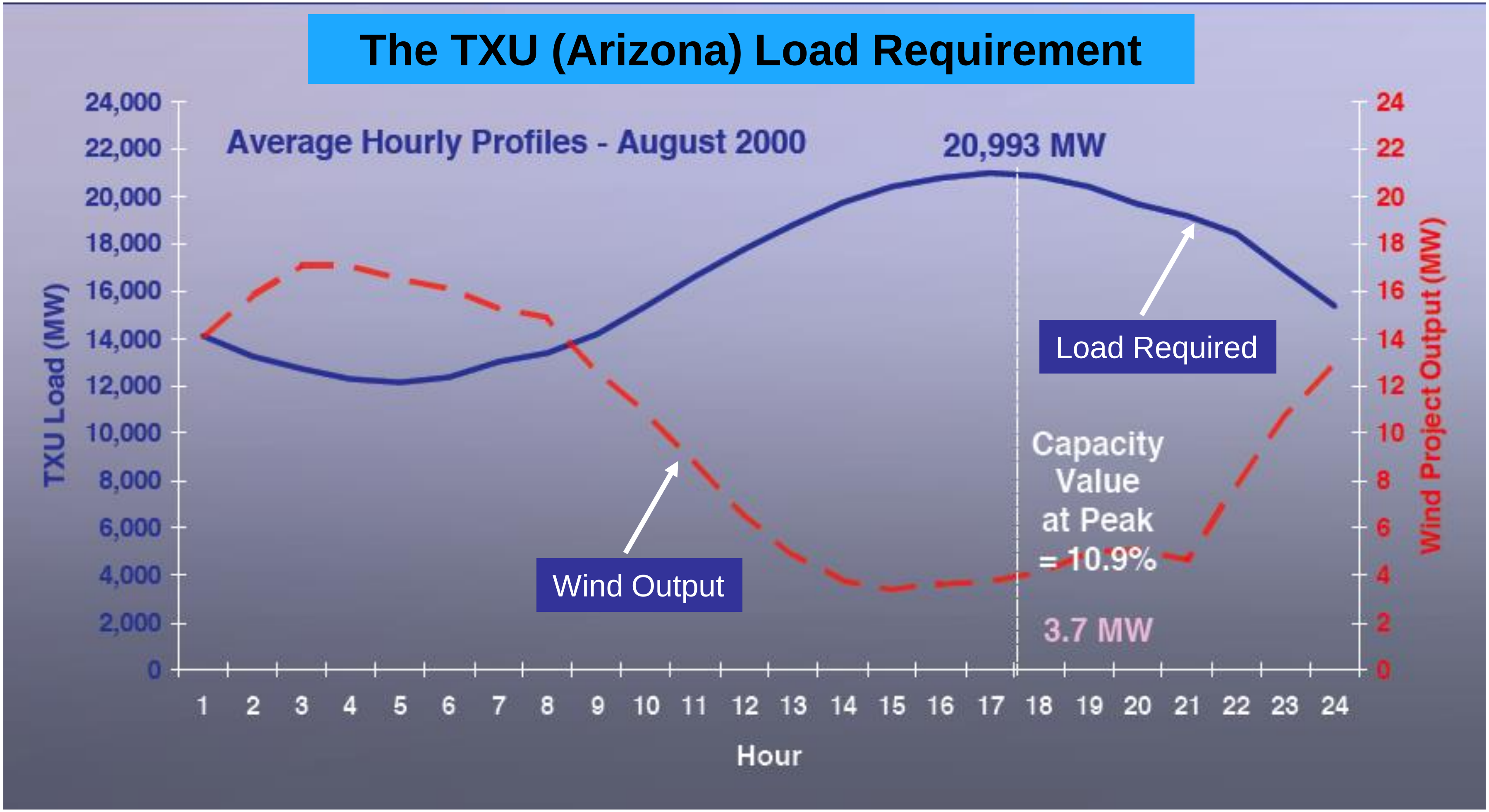
Intermittent Energy Supply Does Not Match Load Requirements – Case 2



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Intermittent Energy Supply Does Not Match Load Requirements