Prospects for Combining Desert Food Production with Solar Energy Harvesting

Chris Mackey
Our Energy Situation

Estimated Annual World Energy Use 2008
(16 TW)
Our Energy Situation

Estimated Annual World Energy Use 2008
(16 TW)

Projected Annual World Energy Use 2050
(32 TW)

Our Energy Situation

Estimated Annual World Energy Use 2008
(16 TW)

Projected Annual World Energy Use 2050
(32 TW)

Estimated/Projected World Energy Use 2008-2050
(1032 TW)

Our Energy Situation

Estimated Annual World Energy Use 2008
(16 TW)

Projected Annual World Energy Use 2050
(32 TW)

Estimated/Projected World Energy Use 2008-2050
(1032 TW)

Non-Renewable Total Reserves

Coal
(900 TW)

2. BP Statistical Review of World Energy 2007
Our Energy Situation

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(16 TW)

Projected Annual World Energy Use 2050
(32 TW)

Estimated/Projected World Energy Use 2008-2050
(1032 TW)

Non-Renewable Total Reserves

Coal
(900 TW)

Uranium
(90-300 TW)

---

2 BP Statistical Review of World Energy 2007
3 http://www.wiseuranium.org/stk.html?src=stk03e
Our Energy Situation

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(32 TW)

Estimated/Projected World Energy Use 2008-2050
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Coal
(900 TW)

Uranium
(90-300 TW)

Petroleum
(240 TW)

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2 BP Statistical Review of World Energy 2007
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Our Energy Situation

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Projected Annual World Energy Use 2050 (32 TW)

Estimated/Projected World Energy Use 2008-2050 (1032 TW)

Non-Renewable Total Reserves

Coal (900 TW)

Uranium (90-300 TW)

Petroleum (240 TW)

Natural Gas (215 TW)

2 BP Statistical Review of World Energy 2007
3 http://www.wise-uranium.org/stk.html?src=stkd03e
Our Energy Situation

Renewable Annual Estimates

- **Wind**
  - (70-20 TW)

Estimated Annual World Energy Use 2008
- (16 TW)

Projected Annual World Energy Use 2050
- (32 TW)

Estimated/Projected World Energy Use 2008-2050
- (1032 TW)

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- **Coal**
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- **Uranium**
  - (90-300 TW)

- **Petroleum**
  - (240 TW)

- **Natural Gas**
  - (215 TW)

References:
2. BP Statistical Review of World Energy 2007
4. C. Archer & M. Jacobson, Evaluation of Global Wind Power – Stanford University, Stanford, CA
Our Energy Situation

Renewable Annual Estimates

- Wind (70-20 TW)
- Ocean Thermal Energy Conversion (3-11 TW)

Estimated Annual World Energy Use 2008 (16 TW)

Projected Annual World Energy Use 2050 (32 TW)

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Non-Renewable Total Reserves

- Coal (900 TW)
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Renewable Annual Estimates

Wind
(70-20 TW)

Ocean Thermal Energy Conversion
(3-11 TW)

Biomass
(2-6 TW)

Non-Renewable Total Reserves

Coal
(900 TW)

Uranium
(90-300 TW)

Petroleum
(240 TW)

Natural Gas
(215 TW)

Estimated Annual World Energy Use 2008
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Our Energy Situation

Renewable Annual Estimates

- Wind (70-20 TW)
- Ocean Thermal Energy Conversion (3-11 TW)
- Biomass (2-6 TW)
- Hydro (3-4 TW)

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Non-Renewable Total Reserves

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Our Energy Situation

Renewable Annual Estimates
- Wind (70-20 TW)
- Ocean Thermal Energy Conversion (3-11 TW)
- Biomass (2-6 TW)
- Hydro (3-4 TW)
- Geothermal (0.3-2 TW)

Non-Renewable Total Reserves
- Coal (900 TW)
- Uranium (90-300 TW)
- Petroleum (240 TW)
- Natural Gas (215 TW)

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#### Renewable Annual Estimates
- **Wind**
  - (70-20 TW)
- **Ocean Thermal Energy Conversion**
  - (3-11 TW)
- **Biomass**
  - (2-6 TW)
- **Hydro**
  - (3-4 TW)
- **Geothermal**
  - (0.3-2 TW)
- **Waves**
  - (0.2-2 TW)

#### Non-Renewable Total Reserves
- **Coal**
  - (900 TW)
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- **Petroleum**
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- Ocean Thermal Energy Conversion (3-11 TW)
- Biomass (2-6 TW)
- Hydro (3-4 TW)
- Geothermal (0.3-2 TW)
- Waves (0.2-2 TW)
- Tides (0.3TW)

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Estimated Annual World Energy Use 2008 (16 TW)
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Footnotes:
2. BP Statistical Review of World Energy 2007
4. C. Archer & M. Jacobson, Evaluation of Global Wind Power – Stanford University, Stanford, CA
Our Energy Situation

Renewable Annual Estimates

- **Wind** (70-20 TW)
- **Ocean Thermal Energy Conversion** (3-11 TW)
- **Biomass** (2-6 TW)
- **Hydro** (3-4 TW)
- **Geothermal** (0.3-2 TW)
- **Waves** (0.2-2 TW)
- **Tides** (0.3 TW)

Non-Renewable Total Reserves

- **Coal** (900 TW)
- **Uranium** (90-300 TW)
- **Petroleum** (240 TW)
- **Natural Gas** (215 TW)

Estimated/Projected World Energy Use 2008-2050

1. **Solar** (23,000 TW)
2. **Uranium** (90-300 TW)
3. **Petroleum** (240 TW)
4. **Biomass** (2-6 TW)
5. **Ocean Thermal Energy Conversion** (3-11 TW)
6. **Geothermal** (0.3-2 TW)
7. **Waves** (0.2-2 TW)
8. **Tides** (0.3 TW)
9. **Wind** (70-20 TW)
10. **Estimated Annual World Energy Use 2008** (16 TW)
11. **Projected Annual World Energy Use 2050** (32 TW)

References:

2. BP Statistical Review of World Energy 2007
4. C. Archer & M. Jacobson, Evaluation of Global Wind Power – Stanford University, Stanford, CA
11. Solar energy received by emerged continents only, assuming 65% losses by atmosphere and clouds.
Area of Planet Needed to Power Our Current Civilization

Assumes 8% efficiency to get 18 TW

NOTE: Here our civilization’s energy use is estimated to be 18 TW

Area of Planet Needed to Power Our Current Civilization

Assumes 8% efficiency to get 18 TW

NOTE: Here our civilization’s energy use is estimated to be 18 TW

Source: Desertec Foundation
SOLAR IS...

The Most Abundant Energy Source
The Most Accessible Energy Source
The Least Risky in Terms of Environmental Impact (Only Rivaled by Wind)
Capable of Efficient Storage for Electricity Generation at Peak Demand

And, Consequently,

THE ONLY ENERGY SOURCE CAPABLE OF FULLY SUSTAINING A MODERN CIVILIZATION BEYOND A FEW GENERATIONS
How to Harvest Sunlight

**DIRECT**
- Solar Hot Water
- Passive Solar Heating
- Daylighting

**INDIRECT**
- Photovoltaics
- Concentrated Solar Thermal
How to Harvest Sunlight

DIRECT

$ ECONOMICALLY COMPETITIVE $

Solar Hot Water
Passive Solar Heating
Daylighting

INDIRECT

Photovoltaics
Concentrated Solar Thermal
How to Harvest Sunlight

Photovoltaics

Concentrated Solar Thermal
How to Harvest Sunlight

Photovoltaics

Concentrated Solar Thermal
How to Harvest Sunlight

Concentrated Solar Thermal
How to Harvest Sunlight

**COMPARISON**

**Photovoltaics**
- Performs just as well in cold climates as in warm climates
- Easy to install on buildings and existing infrastructure
- Minimizes the need for transmission if installed close to population centers (although electricity yield might be small for cold climates)
- Encourages development of a localized and more secure grid
  - Difficult to store electrical energy without major losses (at least 30% - 40% energy loss plus storage system costs)
  - Difficult to combine with fossil fuels except gas turbines
- Requires polysilicon, which takes a long (and presently expensive) chemical manufacturing process to extract
- One of the most expensive means of generating electricity
  - (20-25 year unsubsidized return on investment)

**Concentrated Solar Thermal**
- Only viable in desert climates with high and predictable insolation
- Difficult to effectively install on buildings and existing infrastructure
- Will likely require super-grids to transmit electricity from the desert to population centers (3% loss of energy + grid construction)
- Encourages development of a centralized grid that may be less secure
  - Easy to store energy in an insulated hot water tank
  - Easy to combine with fossil fuels for gradual renewable transition (fuels heat water in addition to the collected sunlight)
- All materials necessary for construction can be manufactured quickly in bulk
- The least expensive means of converting solar energy to electricity if done in desert climates
  - (10-15 year unsubsidized return on investment)
Cost Comparison Between Photovoltaics and CSP

Efficiency Comparison Between Photovoltaics and CSP

Optimal Uses of Photovoltaics and Solar Thermal

**Photovoltaics**

- Powering Spacecraft
- Powering Small Portable Electronic Devices (i.e. Calculators)
- Powering Electronic Devices That are Far from the Electricity Grid (i.e. Emergency Phones)

**Concentrated Solar Thermal**

- Generating Electricity to Sustainably Power a Modern Civilization

- Acting as a Backup Source of Electricity in the Event of Grid Failure
- Giving People the Impression that a Building is “Green”
Cost Breakdown of Concentrated Solar Thermal
Cost Breakdown of Concentrated Solar Thermal

$0.19 \text{ kWhr}$

Solar Generating Component: $0.09$

Conventional Fossil Fuel Plant: $0.10$

NOT FEASIBLY SUBSIDIZED ON A LARGE SCALE
Cost Breakdown of Concentrated Solar Thermal Property for Mirror Array $0.01

$0.19 kWhr Extra Transmission

Heat Collection System $0.02

Conventional Fossil Fuel Plant $0.10

Mirrors $0.03

Tracking System $0.025
Cost Breakdown of Concentrated Solar Thermal
Types of Solar Thermal
Cost Breakdown of
Concentrated Solar Thermal
Types of Solar Thermal

Parabolic Trough
Pivot Mirrors and Tower
Parabolic Dish
Linear Fresnel Reflector
Cost Breakdown of
Concentrated Solar Thermal

Minimizes cost of property by putting mirrors close together

Minimizes cost of solar collecting system because collectors are stationary

Minimizes cost of solar collecting system because water can be used as the working fluid

Minimizes cost of tracking system by using low-tech pulley system without pneumatic pumps

Minimizes cost of mirrors by using mirrors with a shape not induced by glass sagging
Cost Breakdown of
Concentrated Solar Thermal

CLFR Potentially Minimizes Thermal Collection Costs Further by Giving Mirrors the Option of Pointing at Two Towers, Allowing Mirrors to be Further Apart.
Cost Breakdown of
Compact Linear Fresnel Reflector (CLFR)

- Property for Mirror Array: $0.01
- Mirrors: $0.03
- Tracking System: $0.025
- Heat Collection System: $0.02
- Extra Transmission: $0.005
- $0.19 kWhr

Conventional Fossil Fuel Plant: $0.10
Cost Breakdown of
Compact Linear Fresnel Reflector (CLFR)

Property for Mirror Array: $0.01

Mirrors: $0.03

Tracking System: $0.025

Heat Collection System: $0.02

$0.19 kWhr

Extra Transmission: $0.005

Conventional Fossil Fuel Plant: $0.10
Cost Breakdown of
Compact Linear Fresnel Reflector (CLFR)

Property for Mirror Array: $0.005

$0.185 kWhr Extra Transmission:

Heat Collection System: $0.005

Mirrors: $0.03

Tracking System: $0.025

Conventional Fossil Fuel Plant: $0.10
Cost Breakdown of Compact Linear Fresnel Reflector (CLFR)

- Property for Mirror Array: $0.005
- Mirrors: $0.03
- Tracking System: $0.025
- Heat Collection System: $0.015
- Extra Transmission: $0.005
- Conventional Fossil Fuel Plant: $0.10
- $0.18 kWhr
Cost Breakdown of Compact Linear Fresnel Reflector (CLFR)

Property for Mirror Array: $0.005

$0.175 kWhr Extra Transmission

Heat Collection System: $0.015

Conventional Fossil Fuel Plant: $0.10

Mirrors: $0.03

Tracking System: $0.02
Cost Breakdown of Compact Linear Fresnel Reflector (CLFR)

- Property for Mirror Array: $0.005
- Mirrors: $0.025
- Tracking System: $0.02
- Heat Collection System: $0.015
- Extra Transmission: $0.005
- $0.17 kWhr

Conventional Fossil Fuel Plant: $0.10
One Industrial Desert-Based Technology With a Lot of Future Promise

Compact Linear Fresnel Reflector
Another Industrial Desert-Based Technology With a Lot of Future Promise

Desert Agriculture
Reasons for Desert Agriculture

Arable Land is Becoming Scarcer

Due to land degradation, 12 million hectares of arable land are lost each year and this is increasing.

20% of all presently-cultivated land is being degraded and will soon not be arable.


Food and Agriculture Organization of the United Nations, 1993.
Reasons for Desert Agriculture

Fresh Water is Becoming Scarcer

Over 70% of all fresh water collected today is used for agriculture.

A number of nations have already drawn almost all of their fresh water resources.

Many agricultural water sources on the planet are drying up due to climate change. Lake Chad, for example (Himilayan watershed is also a big issue supplying 40% of the world’s population).

Demand for Food (and Biofuel) is High and Growing

1 in 7 people on the planet suffer from protein-energy malnutrition.

By 2050, an additional 2 billion people will require food.

As we reach peak oil, certain industries will place a high demand on biofuels. (notably airlines and much of the transportation sector)
Harvesting Food from Ecosystems Other than Deserts will Destroy Major Carbon Sinks

The Amazon contains 40% of all vegetation-based carbon on the planet.

Another Industrial Desert-Based Technology With a Lot of Future Promise

Desert Agriculture
Three Types of Desert Agriculture
Three Types of Desert Agriculture

River Irrigation
Silwa Bahari, Nile River

Fossil Water Irrigation
Farmington, New Mexico

Greenhouse Irrigation
Almeria, Spain
Three Types of Desert Agriculture

River Irrigation
Silwa Bahari, Nile River

Allowed the First Agricultural Civilization to Rise from the Fertile Crescent
Is the Most Commonly Practiced Form of Desert Farming Today
Uses a Water Source that is Renewable and Sustainable (Discounting Climate Change)

HOWEVER
1 in 10 Rivers Today DO NOT Reach the Sea for Several Months of the Year, Indicating that We are Rapidly Maximizing this Method of Desert Farming
Three Types of Desert Agriculture

EAST ASIA
The Yellow River, the Amu Darya, and the Syr Darya

WEST ASIA
The Euphrates, the Tigris, and the River Jordan

NORTH AMERICA
The Colorado River and the Rio Grande

HOWEVER
1 in 10 Rivers Today DO NOT Reach the Sea for Several Months of the Year, Indicating that We are Rapidly Maximizing this Method of Desert Farming

Three Types of Desert Agriculture


>75% of river flow does not reach the sea

>50% of river flow does not reach the sea
Three Types of Desert Agriculture

Fossil Water Irrigation
Farmington, New Mexico

Water Fell on the Desert Millions of Years Ago and Became Trapped Underground
Today, it is Pumped Up and Used to Grow Crops

Fossil Water Contributes Substantially to the Worldwide Production of Grain (Wheat and Rice)

Non-Renewable Water Withdrawal as a Percentage of Renewable Water Resources in Developing Countries

<table>
<thead>
<tr>
<th>Region</th>
<th>Sub-Saharan Africa</th>
<th>Latin America</th>
<th>Near East/North Africa</th>
<th>South Asia</th>
<th>East Asia</th>
<th>All Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>53</td>
<td>36</td>
<td>8</td>
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</tr>
</tbody>
</table>

Three Types of Desert Agriculture

Fossil Water Irrigation
Farmington, New Mexico

HOWEVER
As a Non-Renewable Resource, Desert Fossil Water Aquifers are Often Depleted in 5-15 Years
Three Types of Desert Agriculture

Fossil Water Irrigation
Farmington, New Mexico

HOWEVER
As a Non-Renewable Resource, Desert Fossil Water Aquifers are Often Depleted in 5-15 Years
Three Types of Desert Agriculture


Percentage of Ground Reserves Withdrawn
Three Types of Desert Agriculture

Greenhouses
Almeria, Spain
Three Types of Desert Agriculture

Greenhouses
Almeria, Spain

Are deployed to obtain maximum water efficiency by enclosing the growing environment in an impermeable membrane.

Protects plants from harsh desert wind and sun so that crops such as tomatoes can be grown.

Presently supplies most of Europe’s winter-time vegetables.
Three Types of Desert Agriculture

Greenhouses
Almeria, Spain
Presently supplies all of Europe’s winter-time vegetables
Three Types of Desert Agriculture

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Almeria, Spain
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Almeria, Spain
Presently supplies all of Europe’s winter-time vegetables
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Greenhouses
Almeria, Spain

A breakthrough in the 90’s produced a greenhouse design that can desalinate large quantities of sea water with very minimal energy and at a low cost.
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http://www.seawatergreenhouse.com/
Three Types of Desert Agriculture

A breakthrough in the 90’s produced a greenhouse design that can desalinate large quantities of seawater with very minimal energy and at a low cost.

http://www.seawatergreenhouse.com/
Three Types of Desert Agriculture

A breakthrough in the 90’s produced a greenhouse design that can desalinate large quantities of sea water with very minimal energy and at a low cost.

The greenhouse produces several times more water than it consumes within it.
Two Industrial Desert-Based Technologies With a Lot of Future Promise

Greenhouses
(Seawater Greenhouse)

Concentrated Solar Power
(Compact Linear Fresnel Reflector)
Many have suggested combining the two to achieve a mutually beneficial system.

Extra desalinated water is used to keep mirrors clean and acts as the working fluid for the heat collection system (since superheated seawater can be corrosive).

Cold seawater brought in for agriculture can also drive the cold end of heat engines in power plants.

Waste heat from the concentrated solar power can be used to desalinate more seawater.

Food from greenhouses supports local working populations.
The Dream of the Saharan Forest

http://www.saharaforestproject.com
The Dream of the Saharan Forest

http://www.saharaforestproject.com
While These Two Technologies Can Benefit From Being Next to One Another, They Are Conflict in One Criterion

Greenhouses will thrive best in semi-arid regions where temperatures do not exceed 40°C.

CSP will thrive best in fully arid regions where temperatures can reach as high as 50°C.
These two technologies can be combined in a manner that further cools greenhouse indoor environments, increases yield from greenhouse plants, helps mitigate some of the high cost of solar energy generation with a dual use of “mirrors,” and maximizes overall efficiency of land use, cutting down transportation across the system.
PROPOSAL

Integrate the Systems Using Low-E (Heat Mirror) Glass Instead of Conventional Mirrors and Plastic
PROPOSAL
Integrate the Systems Using Low-E (Heat Mirror) Glass Instead of Conventional Mirrors and Plastic
HEAT MIRROR GLASS SPECTRAL PROPERTIES

HEAT MIRROR GLASS SPECTRAL PROPERTIES

HEAT MIRROR GLASS SPECTRAL PROPERTIES

Properties Vary With Thickness of Silver Layer

Case Study of Almeria

If all greenhouses in Almeria were converted to the design shown previously, how much electricity could be generated and what might be the effect on plant growth?
Part 1: Calculating the Area of Almeria’s Green Houses
Selection of the Test Area

Four Municipalities with many greenhouses were selected as the test area:

- El Ejido
- La Mojonera
- Vicar
- Roquestas de Mar
Selection of the Test Area

Four Municipalities with many greenhouses were selected as the test area

El Ejido
La Mojonera
Vicar
Roquestas de Mar
Selection of the Test Area

A Sample Area With a Diversity of Greenhouse Types was Selected for Close Analysis
Selection of the Test Area

All of the Greenhouses in this Sample Area Were Traced
Selection of the Test Area

All of the Greenhouses in the Sample Area Were Traced
Selection of the Test Area

All of the Greenhouses in the Sample Area Were Traced
Selection of the Test Area

All of the Greenhouses in the Sample Area Were Traced
Classification of Greenhouses

The greenhouses within the sample were used as an region of interest to classify all greenhouses within the scene of Almeria.

This classification was done on 11 images of Almeria. All images had a clear sky and were taken from many different points in the year.

The ultimate goal was to use the area of pixels classified to approximate the area of greenhouse roofs in the municipalities.
### Comparison of Classified Area to Actual Area

The classification consistently underestimated the actual area of greenhouses by 10%.

<table>
<thead>
<tr>
<th>Date of Image</th>
<th>Total Area of Sample (m²)</th>
<th>Greenhouse Area of Sample (m²)</th>
<th>Pixels Classified as Greenhouse in Sample</th>
<th>Area Classified as Greenhouse in Sample (m²)</th>
<th>Ratio of the Actual Greenhouse Area to the Pixel Estimate</th>
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</thead>
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<tr>
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</tbody>
</table>

This is likely the result of mixed pixels.
## Comparison of Classified Area to Actual Area

<table>
<thead>
<tr>
<th>Date of Image</th>
<th>Ratio of the Actual Greenhouse Area to the Pixel Estimate</th>
<th>Pixels Classified as Greenhouse in Whole Scene</th>
<th>Estimated Area of Greenhouses in Whole Scene (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov 12, 2006</td>
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<tr>
<td>Dec 6, 2009</td>
<td>1.1267</td>
<td>146004</td>
<td>148.0</td>
</tr>
<tr>
<td>Feb 24, 2010</td>
<td>1.1176</td>
<td>161521</td>
<td>162.5</td>
</tr>
<tr>
<td>Oct 22, 2010</td>
<td>1.1020</td>
<td>169620</td>
<td>168.2</td>
</tr>
<tr>
<td>Dec 9, 2010</td>
<td>1.1342</td>
<td>144671</td>
<td>147.7</td>
</tr>
</tbody>
</table>

Applying these underestimations to the 11 images, the area of greenhouse roof in Almeria is around 156.9 km².
Part II: Calculating the Portions of Sunlight Going to Electricity Generation and Plant Growth
Spectral Properties of Low-E (Heat Mirror) Glass Were Converted Over Into Excel
Total Incoming Radiation Into Almeria was Obtained.
The Reflected Portion Was Calculated

The Transmitted Portion Was Calculated

Transmitted Solar Radiation

Average On-Ground Radiation in Almeria = 185.7 W/m²
Radiation Transmitted to Plants in Greenhouse = 96.2 W/m²

The Absorbed Portion Was Calculated

Part III: Calculating the Output of Electricity Generation and Plant Growth
Selection of Electricity Generation Scenarios

1) Greenhouse system is used as a pre-heater for a fossil fuel or highly concentrated tower solar collection system. (Operating Temperatures Around 750°C-1000°C)

2) Greenhouse system is used to power an electricity generation cycle on its own. (Operating Temperatures Around 300°C)
1) Greenhouse System is Used as a Pre-heater

**Average Incoming Solar Radiation**

<table>
<thead>
<tr>
<th>Process Occurring for Electricity Generation</th>
<th>Resulting W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portion Going to Pre-Heating Water for Electricity Generation</td>
<td>76.4</td>
</tr>
<tr>
<td>16% will strike elements of the greenhouse that do not reflect energy¹</td>
<td>12.2</td>
</tr>
<tr>
<td>84% of the light will actually strike the glass¹</td>
<td>64.2</td>
</tr>
<tr>
<td>At peak performance, 62% of energy will be lost in the conversion to electricity²</td>
<td>39.8</td>
</tr>
<tr>
<td>At peak performance, 38% of sunlight can be converted into electricity²</td>
<td>24.4</td>
</tr>
<tr>
<td>10% can be lost due to not operating at peak performance</td>
<td>2.4</td>
</tr>
<tr>
<td>Final Conversion of Solar to Electricity</td>
<td>22.0</td>
</tr>
</tbody>
</table>

**On the Scale of Almeria**

<table>
<thead>
<tr>
<th>Watts coming out of Almeria on Average</th>
<th>Gigawatts coming out of Almeria on Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>3446745448</td>
<td>3.45 GW</td>
</tr>
</tbody>
</table>

For comparison, the power consumption of NYC in 2004 was 5 GW⁵

1) Greenhouse System is Used as a Pre-heater (Peak Operation)

<table>
<thead>
<tr>
<th>Process Occurring for Electricity Generation</th>
<th>Resulting W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portion Going to Pre-Heating Water for Electricity Generation</td>
<td>370.5</td>
</tr>
<tr>
<td>16% will strike elements of the greenhouse that do not reflect energy¹</td>
<td>59.3</td>
</tr>
<tr>
<td>84% of the light will actually strike the glass¹</td>
<td>311.2</td>
</tr>
<tr>
<td>At peak performance, 62% of energy will be lost in the conversion to electricity²</td>
<td>192.9</td>
</tr>
<tr>
<td>At peak performance, 38% of sunlight can be converted into electricity²</td>
<td>118.3</td>
</tr>
</tbody>
</table>

On the Scale of Almeria

| Watts coming out of Almeria on Average | 18558827526 |
| Gigawatts coming out of Almeria on Average | 18.6 GW |

This makes an Almeria project it 52.4 times larger than the largest solar power plant constructed to date (SEGS in California)⁶

## 2) Greenhouse System Generates Electricity on its Own

### Average Incoming Solar Radiation

\[
\text{Average Incoming Solar Radiation} = 4.45 \text{ kWh/m}^2/\text{day} = 185.72 \text{ W/m}^2
\]

<table>
<thead>
<tr>
<th>Process Occurring for Electricity Generation</th>
<th>Resulting W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portion Going to Pre-Heating Water for Electricity Generation</td>
<td>76.4</td>
</tr>
<tr>
<td>16% will strike elements of the greenhouse that do not reflect energy(^1)</td>
<td>12.2</td>
</tr>
<tr>
<td>80% of the light will actually strike the glass(^1)</td>
<td>64.2</td>
</tr>
<tr>
<td>At peak performance, 87% of energy will be lost in the conversion to electricity(^2)</td>
<td>55.9</td>
</tr>
<tr>
<td>At peak performance, 13% of sunlight can be converted into electricity(^2)</td>
<td>8.3</td>
</tr>
<tr>
<td>10% can be lost due to not operating at peak performance</td>
<td>0.8</td>
</tr>
<tr>
<td>Final Conversion of Solar to Electricity</td>
<td>7.5</td>
</tr>
</tbody>
</table>

### On the Scale of Almeria

| Watts coming out of Almeria on Average | 1179149759 |
| Gigawatts coming out of Almeria on Average | 1.18 GW |

For comparison, the power consumption of NYC in 2004 was 5 GW\(^5\)

---

I) Greenhouse System is Used as a Pre-heater (Peak Operation)

<table>
<thead>
<tr>
<th>Process Occurring for Electricity Generation</th>
<th>Resulting W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portion Going to Pre-Heating Water for Electricity Generation</td>
<td>355.7</td>
</tr>
<tr>
<td>15.5% will strike elements of the greenhouse that do not reflect energy¹</td>
<td>55.1</td>
</tr>
<tr>
<td>80.5% of the light will actually strike the glass¹</td>
<td>286.3</td>
</tr>
<tr>
<td>At peak performance, 87% of energy will be lost in the conversion to electricity²</td>
<td>249.1</td>
</tr>
<tr>
<td>At peak performance, 13% of sunlight can be converted into electricity²</td>
<td>37.2 GW</td>
</tr>
</tbody>
</table>

On the Scale of Almeria

| Watts coming out of Almeria on Average | 5841146769 |
| Gigawatts coming out of Almeria on Average | 5.84 GW |

This makes and Almeria project it 16.5 times larger than the largest solar power plant constructed to date (SEGS in California)⁶

Selection of Crop Production Scenarios

1) Greenhouses are used to grow tomatoes.

2) Greenhouses are used to generate biofuel in pools of algae capable of turning 60% of their biomass into fuel.
1) Greenhouse System is Used to Grow Tomatoes

<table>
<thead>
<tr>
<th>Process Occurring for Biomass and Food</th>
<th>Resulting W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portion Going to Producing Biomass Transmitted Through Glass and Slipping Through Mirrors</td>
<td>102.3</td>
</tr>
<tr>
<td>32.03% is outside the wavelength usable by photosynthesis (700nm-4000nm)</td>
<td>32.8</td>
</tr>
<tr>
<td>67.97% is inside the wavelengths usable by photosynthesis (300nm-700nm)</td>
<td>69.6</td>
</tr>
<tr>
<td>86% is lost due to light not striking chloroplasts, degrading short-wavelength photons, etc.</td>
<td>59.8</td>
</tr>
<tr>
<td>14% is converted into biomass³</td>
<td>9.7</td>
</tr>
<tr>
<td>40% of biomass is consumed by the plant³</td>
<td>3.9</td>
</tr>
<tr>
<td>60% of biomass is used to build the plant³</td>
<td>5.8</td>
</tr>
<tr>
<td>Conversion factor of photosynthesis wattage to kg/yr is 1.07 W/kg/yr</td>
<td>6.3 kg/m²/yr</td>
</tr>
<tr>
<td>Tomatoes allocate 57–59% of their biomass to their fruit⁴</td>
<td>3.6 kg/m²/yr</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>On the Scale of Almeria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilograms of total biomass being produced</td>
</tr>
<tr>
<td>Kilograms of tomatoes being produced</td>
</tr>
</tbody>
</table>

2) Greenhouse System is Used to Grow Algae Producing Biofuel

<table>
<thead>
<tr>
<th>Average Incoming Solar Radiation</th>
<th>4.45 kWh/m²/day = 185.72 W/m²</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Process Occurring for Biomass and Food</th>
<th>Resulting W/m²²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portion Going to Producing Biomass and Food</td>
<td>102.3</td>
</tr>
<tr>
<td>32.03% is outside the wavelength usable by photosynthesis (700nm-4000nm)</td>
<td>32.8</td>
</tr>
<tr>
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<td>69.6</td>
</tr>
<tr>
<td>86% is lost due to light not striking chloroplasts, degrading short-wavelength photons, etc.</td>
<td>59.8</td>
</tr>
<tr>
<td>14% is converted into biomass³</td>
<td>9.7</td>
</tr>
<tr>
<td>40% of biomass is consumed by the plant³</td>
<td>3.9</td>
</tr>
<tr>
<td>60% of biomass is used to build the plant³</td>
<td>5.8</td>
</tr>
<tr>
<td>40% of remaining biomass is used for plant components other than oil</td>
<td>2.3</td>
</tr>
<tr>
<td>60% of remaining biomass is converted into oil that can be used as biofuel</td>
<td>3.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>On the Scale of Almeria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watts of total biofuel being produced</td>
</tr>
<tr>
<td>Gigawatts of total biofuel being produced</td>
</tr>
</tbody>
</table>

Ranking Scenarios by Best Results

BEST: Preheating and Tomatoes

MEDIUM: Preheating and Biofuel

MEDIUM: Direct CSP and Tomatoes

WORST: Direct CSP and Biofuel
Calculating Average Desalination of Water for a Scenario With Preheating and Tomatoes

<table>
<thead>
<tr>
<th>Average Incoming Solar Radiation</th>
<th>185.72</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Occuring for Absorption by Desalination Equipment</td>
<td>Resulting W/m²</td>
</tr>
<tr>
<td>Total energy being converted to heat within the greenhouse and coming out of the greenhouse’s CSP</td>
<td>132.4</td>
</tr>
<tr>
<td>10% will be lost to the air, soil and equipment as hot water is passed through pipes and transfers mediums</td>
<td>13.24</td>
</tr>
<tr>
<td>90% will be available to desalinate seawater</td>
<td>119.17</td>
</tr>
<tr>
<td>Given heat capacities of seawater, this amount that can be brought over the boiling point from an initial 18°C</td>
<td>4.8E-05 kg/s/m²</td>
</tr>
<tr>
<td>Assuming sea temperature is 18°C and water will be returned at 50°C, some energy will be lost</td>
<td>2.3E-06 kg/s/m²</td>
</tr>
<tr>
<td>Seawater that could be desalinated (kg/s)</td>
<td>4.5E-05 kg/s/m²</td>
</tr>
<tr>
<td>Seawater that could be desalinated (kg/day)</td>
<td>3.91 kg/day/m²</td>
</tr>
</tbody>
</table>

On the Scale of Almeria

| Kilograms of Desalinated Water Produced on Average (kg/day) | 614,230,533 kg/day |
| Kilograms of Desalinated Water Produced on Average (kg/s) | 7109 kg/s |

http://web.mit.edu/seawater/Seawater_Property_Tables.pdf
http://www.kayelaby.npl.co.uk/general_physics/2_7/2_7_9.html
Calculating Average Heat Lost to Ground and Air for a Scenario With Preheating and Tomatoes

Average Incoming Solar Radiation = 4.45 kWh/m²/day = 185.72 W/m²

<table>
<thead>
<tr>
<th>Process Occurring for Absorption by Glass, Ground and Air</th>
<th>Resulting W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0% is absorbed by the glass itself</td>
<td>26.24</td>
</tr>
<tr>
<td>50% of light falls through spaces between the glass and is absorbed</td>
<td>6.12</td>
</tr>
<tr>
<td>Hot water moving through pipes transfers heat to the system</td>
<td>13.24</td>
</tr>
<tr>
<td>Total energy absorbed by ground and air</td>
<td>45.60</td>
</tr>
</tbody>
</table>

On the Scale of Almeria

| Watts Being Lost to Ground and Air on Average | 716142693 |
| Gigawatts Being Lost to Ground and Air on Average | 7.16     |

http://web.mit.edu/seawater/Seawater_Property_Tables.pdf
http://www.kayelaby.npl.co.uk/general_physics/2_7/2_7_9.html
Part IV: Calculating the Overall Efficiency of the System
Total Energy Budget for a Scenario With Preheating and Tomatoes

<table>
<thead>
<tr>
<th>Type of Energy/Product Produced</th>
<th>W/m²</th>
<th>GW Over all Almeria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>22.0</td>
<td>3.45</td>
</tr>
<tr>
<td>Tomatoes (energy)</td>
<td>3.4</td>
<td>0.53</td>
</tr>
<tr>
<td>Desalinated Water</td>
<td>111.7</td>
<td>17.53</td>
</tr>
<tr>
<td>Waste Heat Placed in the Sea</td>
<td>7.0</td>
<td>1.16</td>
</tr>
<tr>
<td>Waste Heat Absorbed by Glass, Air, and Ground</td>
<td>45.6</td>
<td>7.16</td>
</tr>
<tr>
<td>TOTAL</td>
<td>185.7</td>
<td>29.83</td>
</tr>
</tbody>
</table>

Efficiency of Electricity and Tomatoes = 13.7%
Efficiency of Electricity, Tomatoes, and Desalinated Water = 73.8%
Argument Supporting Design: Almeria Albedo Analysis
Some Visible Light That Could Nourish Plants is Reflected

18.9% of visible light (300nm-700nm) is reflected
However, the Present Greenhouses Already Reflect a Lot of Light
However, the Present Greenhouses Already Reflect a Lot of Light.
However, the Present Greenhouses Already Reflect a Lot of Light
LANDSAT Albedo of the Greenhouse Sample Was Analyzed
# Average Albedo of the Eleven LANDSAT Images

<table>
<thead>
<tr>
<th>Date of Image</th>
<th>Broadband Albedo</th>
<th>Visible Albedo</th>
<th>NIR Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov 12, 2006</td>
<td>0.25</td>
<td>0.24</td>
<td>0.26</td>
</tr>
<tr>
<td>Feb 16, 2007</td>
<td>0.24</td>
<td>0.23</td>
<td>0.25</td>
</tr>
<tr>
<td>May 7, 2007</td>
<td>0.31</td>
<td>0.28</td>
<td>0.33</td>
</tr>
<tr>
<td>Jun 24, 2007</td>
<td>0.32</td>
<td>0.31</td>
<td>0.33</td>
</tr>
<tr>
<td>Aug 11, 2007</td>
<td>0.35</td>
<td>0.35</td>
<td>0.37</td>
</tr>
<tr>
<td>Aug 27, 2007</td>
<td>0.34</td>
<td>0.33</td>
<td>0.36</td>
</tr>
<tr>
<td>Jul 15, 2009</td>
<td>0.33</td>
<td>0.33</td>
<td>0.35</td>
</tr>
<tr>
<td>Dec 6, 2009</td>
<td>0.23</td>
<td>0.23</td>
<td>0.24</td>
</tr>
<tr>
<td>Feb 24, 2010</td>
<td>0.23</td>
<td>0.22</td>
<td>0.24</td>
</tr>
<tr>
<td>Oct 22, 2010</td>
<td>0.26</td>
<td>0.25</td>
<td>0.27</td>
</tr>
<tr>
<td>Dec 9, 2010</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>0.28</strong></td>
<td><strong>0.27</strong></td>
<td><strong>0.29</strong></td>
</tr>
</tbody>
</table>
Annual Albedo Cycle Over the Eleven LANDSAT Images
Visible and NIR Albedo Cycle Over the Eleven LANDSAT Images

Visible/NIR Albedo of Greenhouses Throughout the Year

- Visible Albedo
- NIR Albedo

Day of the Year

Albedo

0.15
0.2
0.25
0.3
0.35
0.4
FUTURE RESEARCH

Model in a More Arid Region Where There Are Much Higher Insolation Values

Cost-Benefit Analysis

Better Understanding of How Plants Will Benefit from the Reflection of Infrared Light (What Crops are Best?)