Prospects for Combining Desert Food Production with Solar Energy Harvesting

Chris Mackey

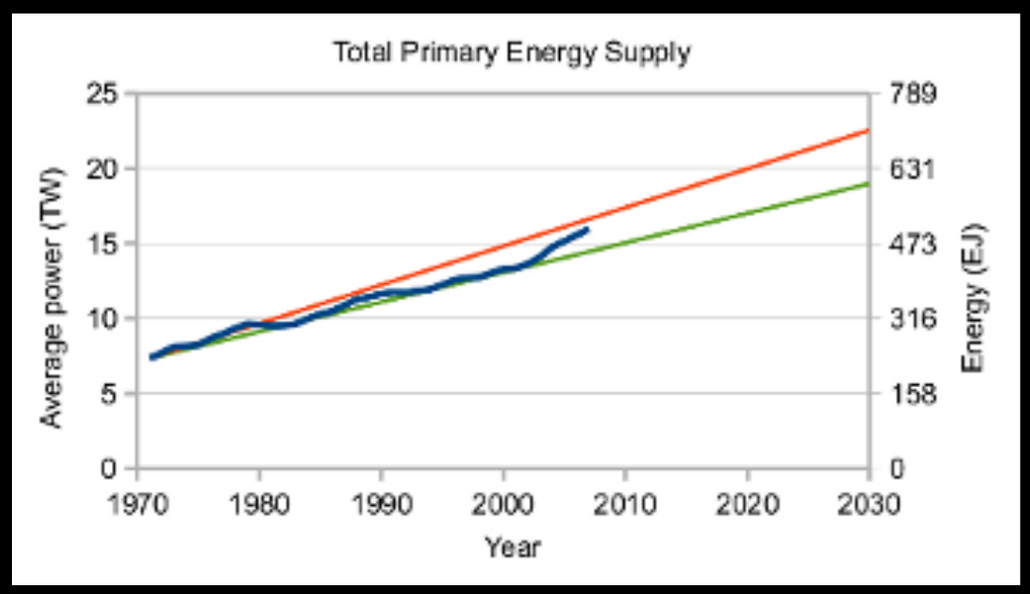
Our Energy Situation

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)[1]



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Our Energy Situation

Non-Renewable Total Reserves

Coal
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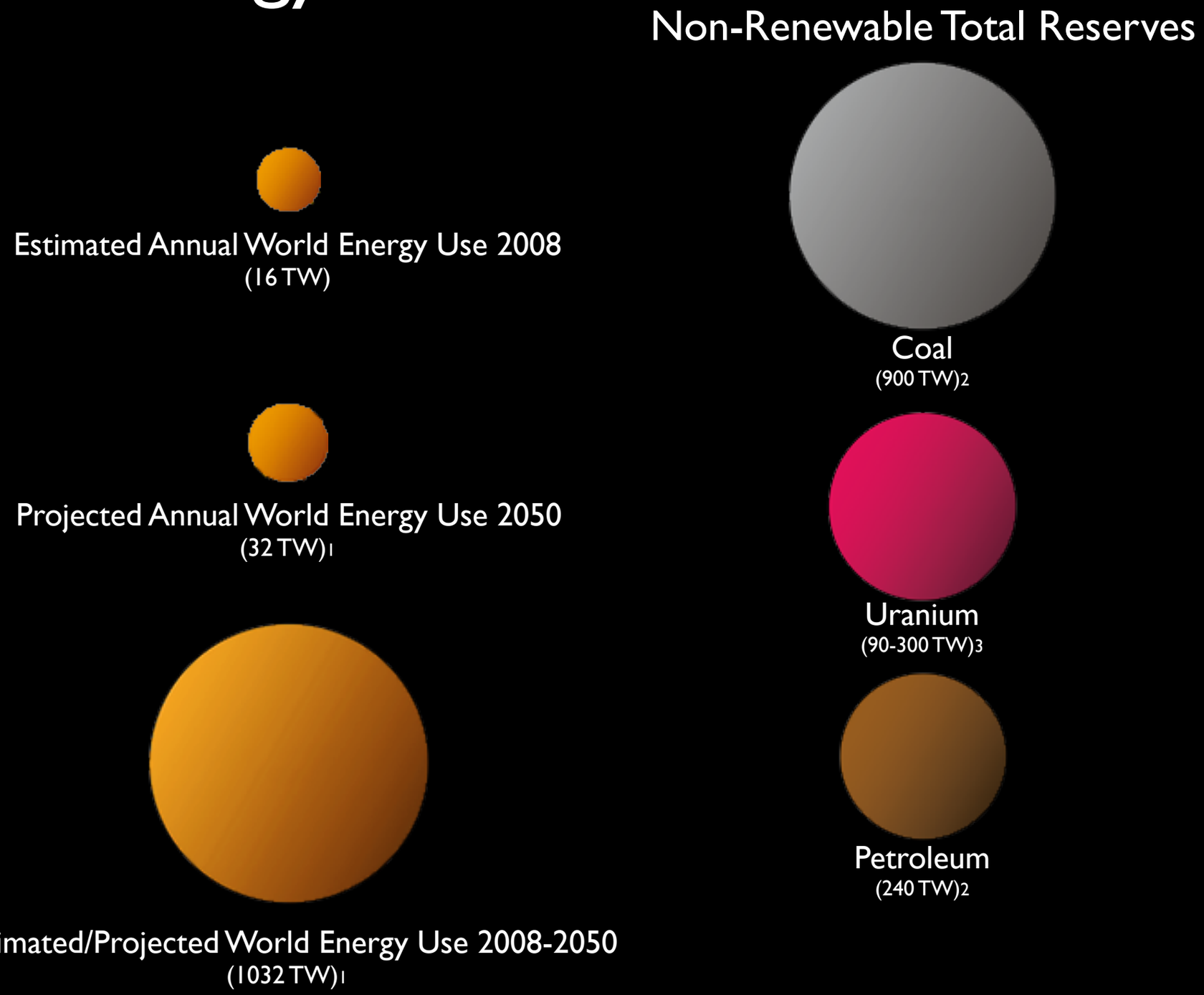

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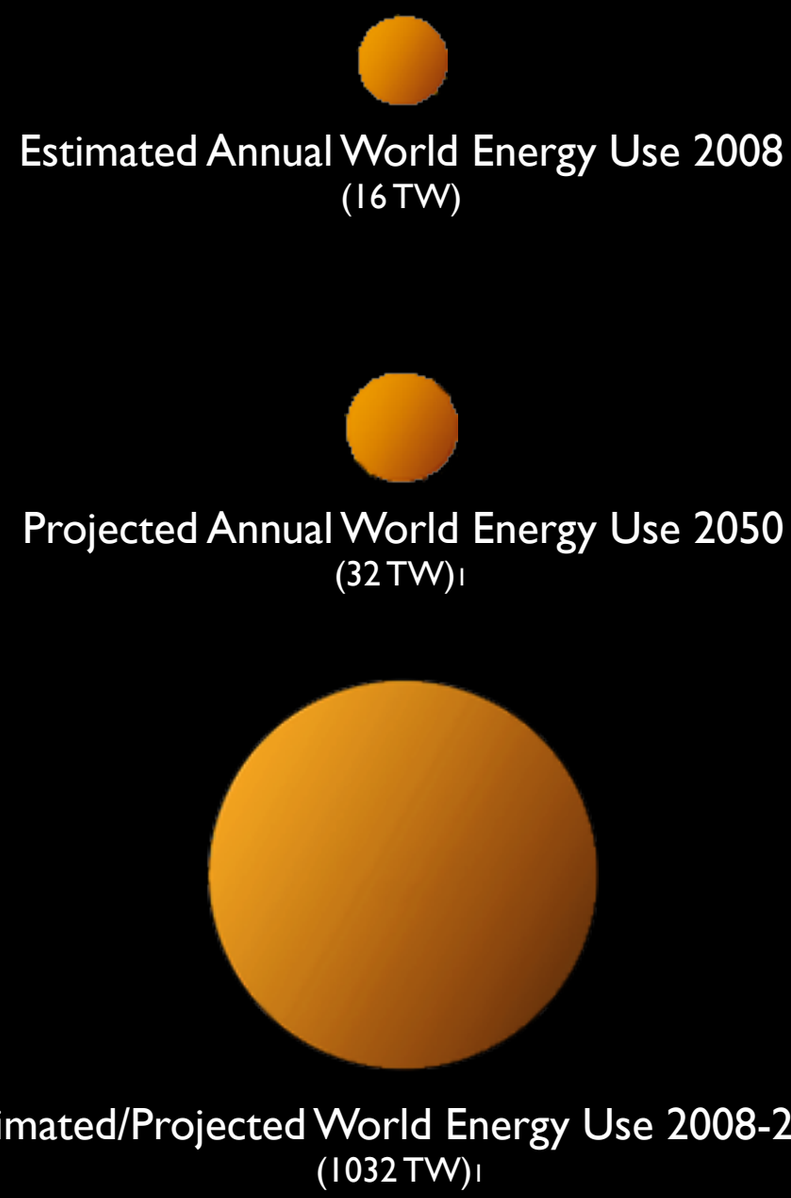

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Our Energy Situation

Renewable Annual Estimates

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(70-20 TW)4

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Our Energy Situation

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Waves
(0.2-2 TW)9

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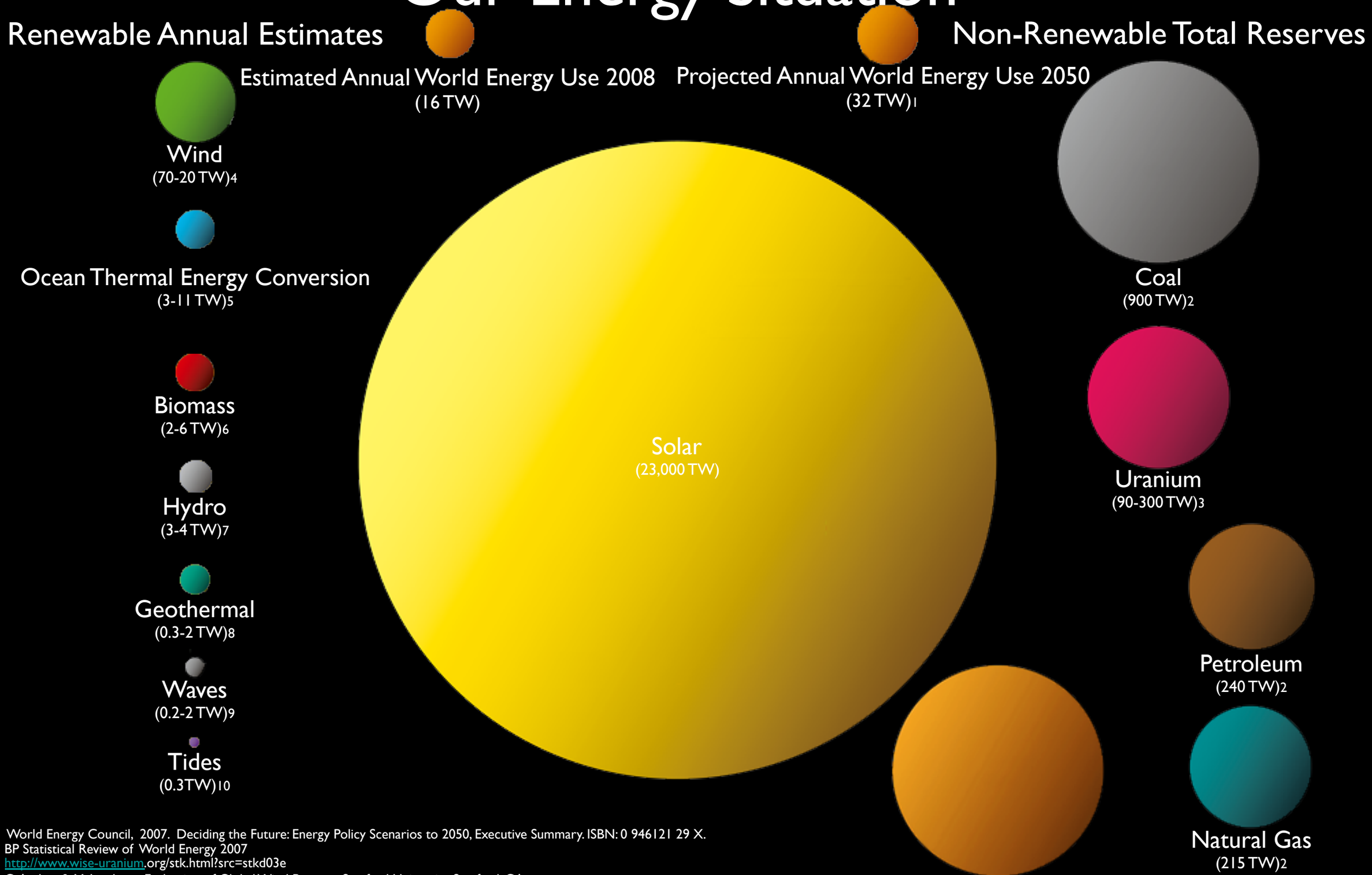
Our Energy Situation



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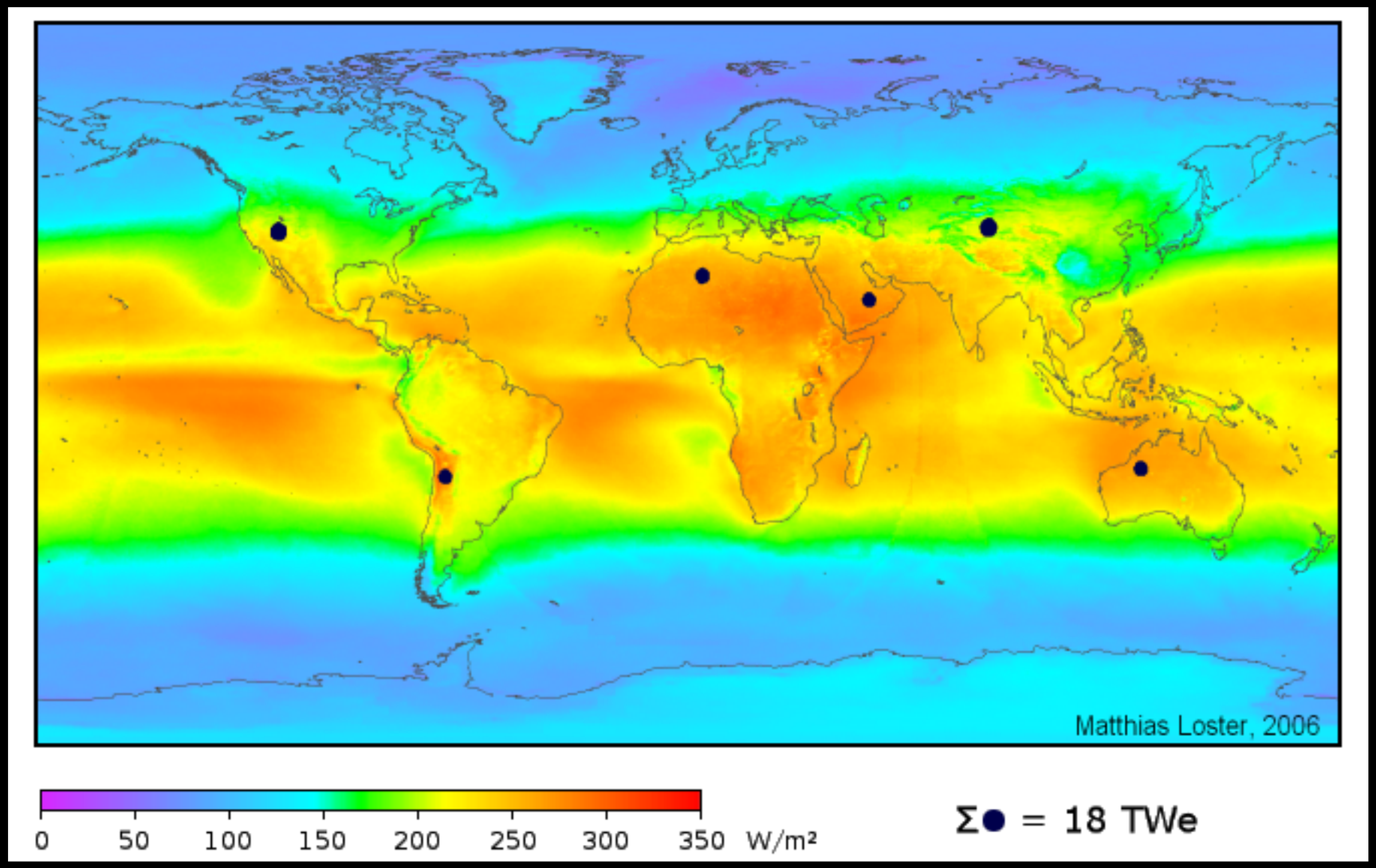
11 Solar energy received by emerged continents only, assuming 65% losses by atmosphere and clouds

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

International Energy Agency (IEA). "Key World Energy Statistics 2009." http://www.iea.org/

Map of World Deserts. http://www.mapsofworld.com/world-desert-map.htm

J. K. B. Bishop and W. B. Rossow. "Spatial and temporal variability of global surface solar irradiance." J. Geophys. Res. 96, 16839 (1991).

International Satellite Cloud Climatology Project (ISCCP). http://isccp.giss.nasa.gov/

National Geophysical Data Center (NGDC), NOAA Satellite and Information Service, Coastline Extractor. http://rimmer.ngdc.noaa.gov/mgg/coast/

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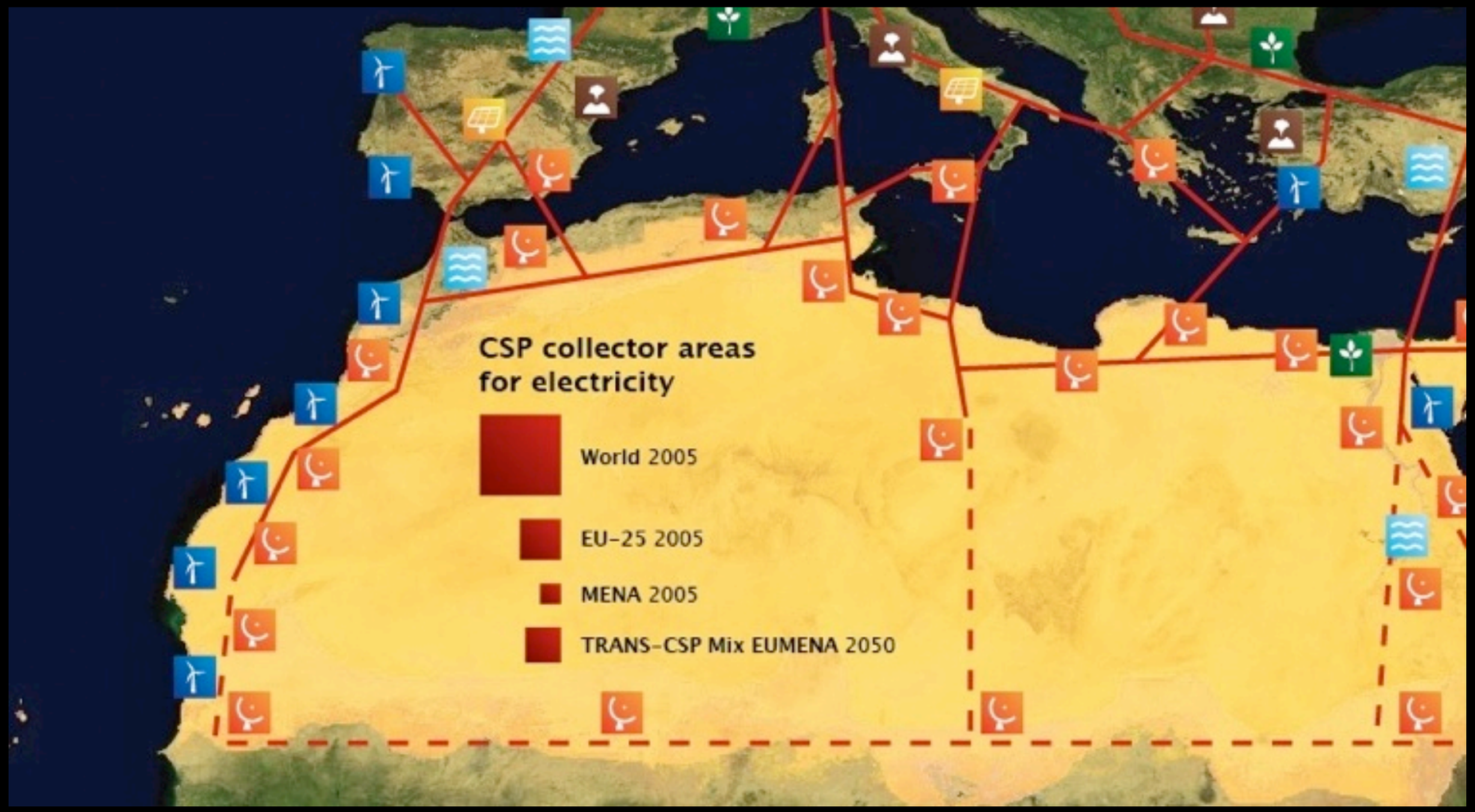

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Source: Desertec Foundation

SOLAR IS...

The Most Abundant Energy Source

The Most Accessible Energy Source

The Least Risky in Terms of Environmental Impact (Only Rivaled by Wind)

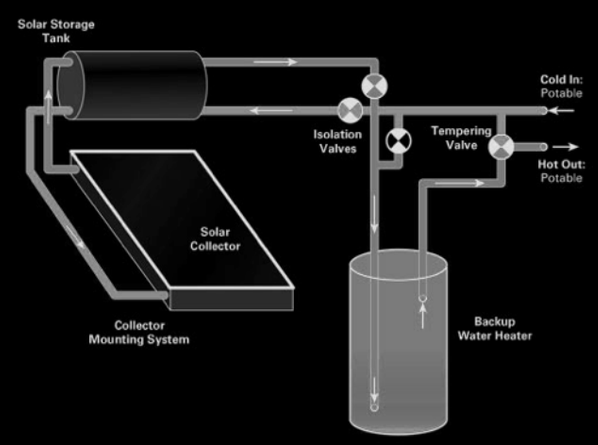
Capable of Efficient Storage for Electricity Generation at Peak Demand

And, Consequently,

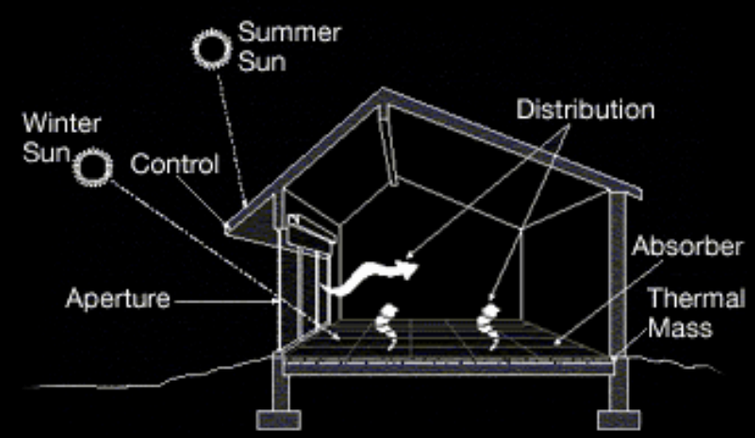
THE ONLY ENERGY SOURCE CAPABLE OF FULLY SUSTAINING A MODERN CIVILIZATION BEYOND A FEW GENERATIONS

How to Harvest Sunlight

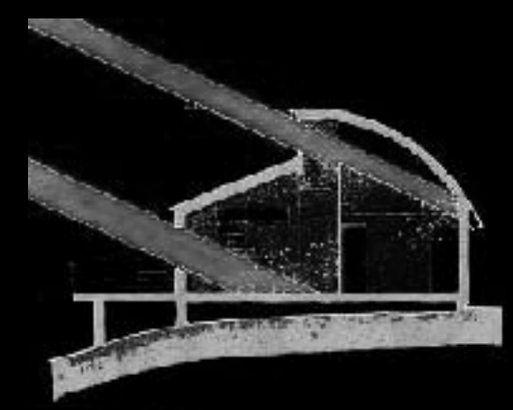
DIRECT



Solar Hot Water



Passive Solar Heating



Daylighting

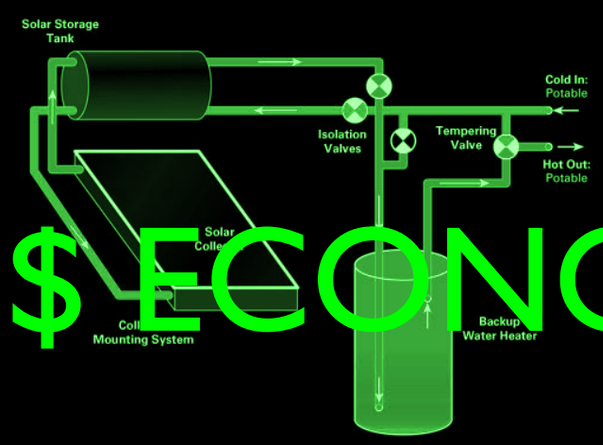
INDIRECT

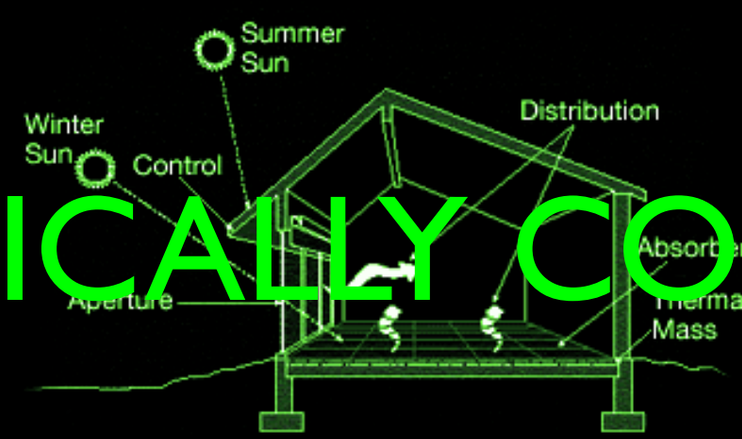
Photovoltaics

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

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Photovoltaics

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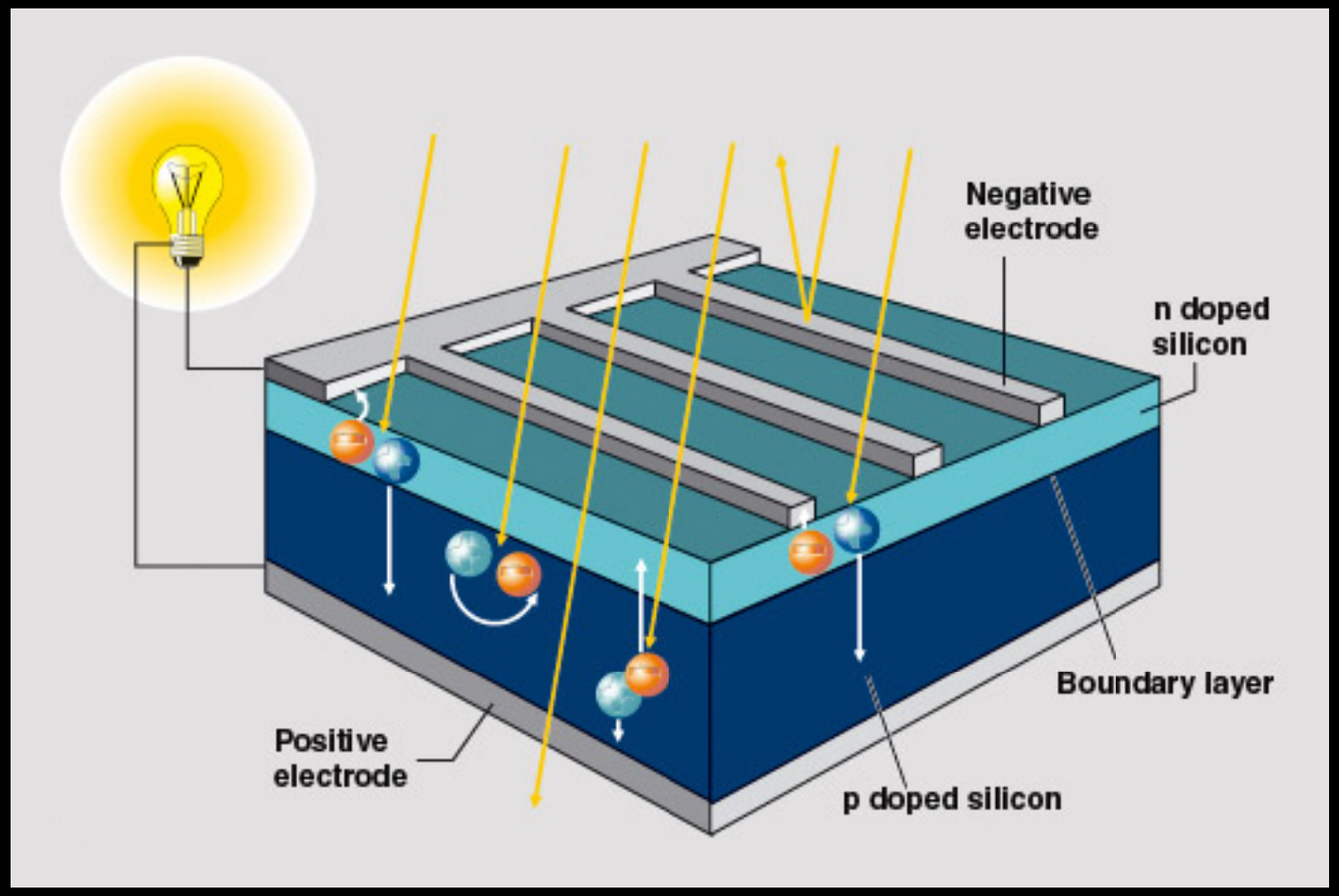
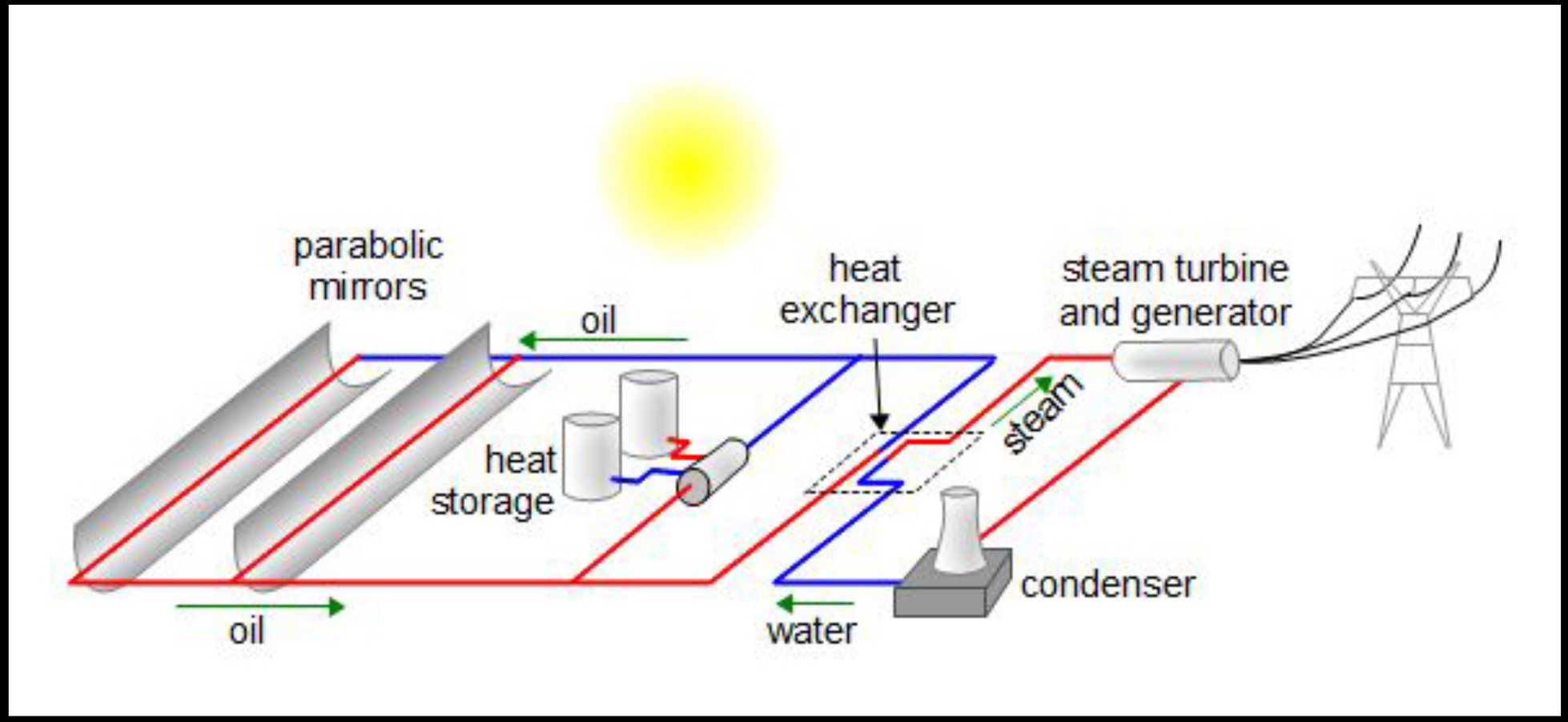


How to Harvest Sunlight

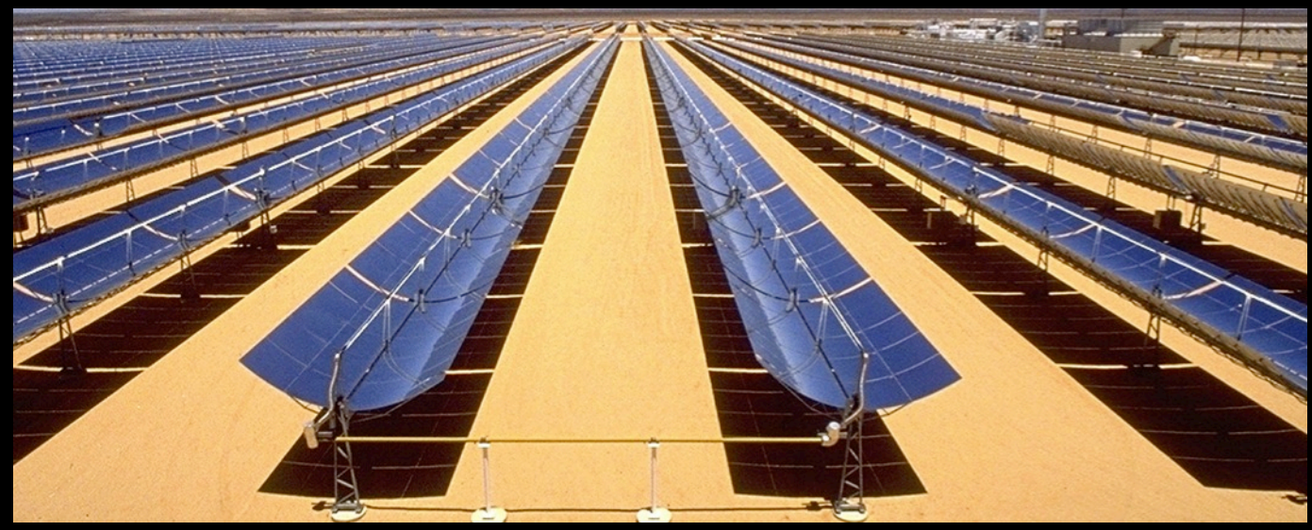
Photovoltaics

Concentrated Solar Thermal



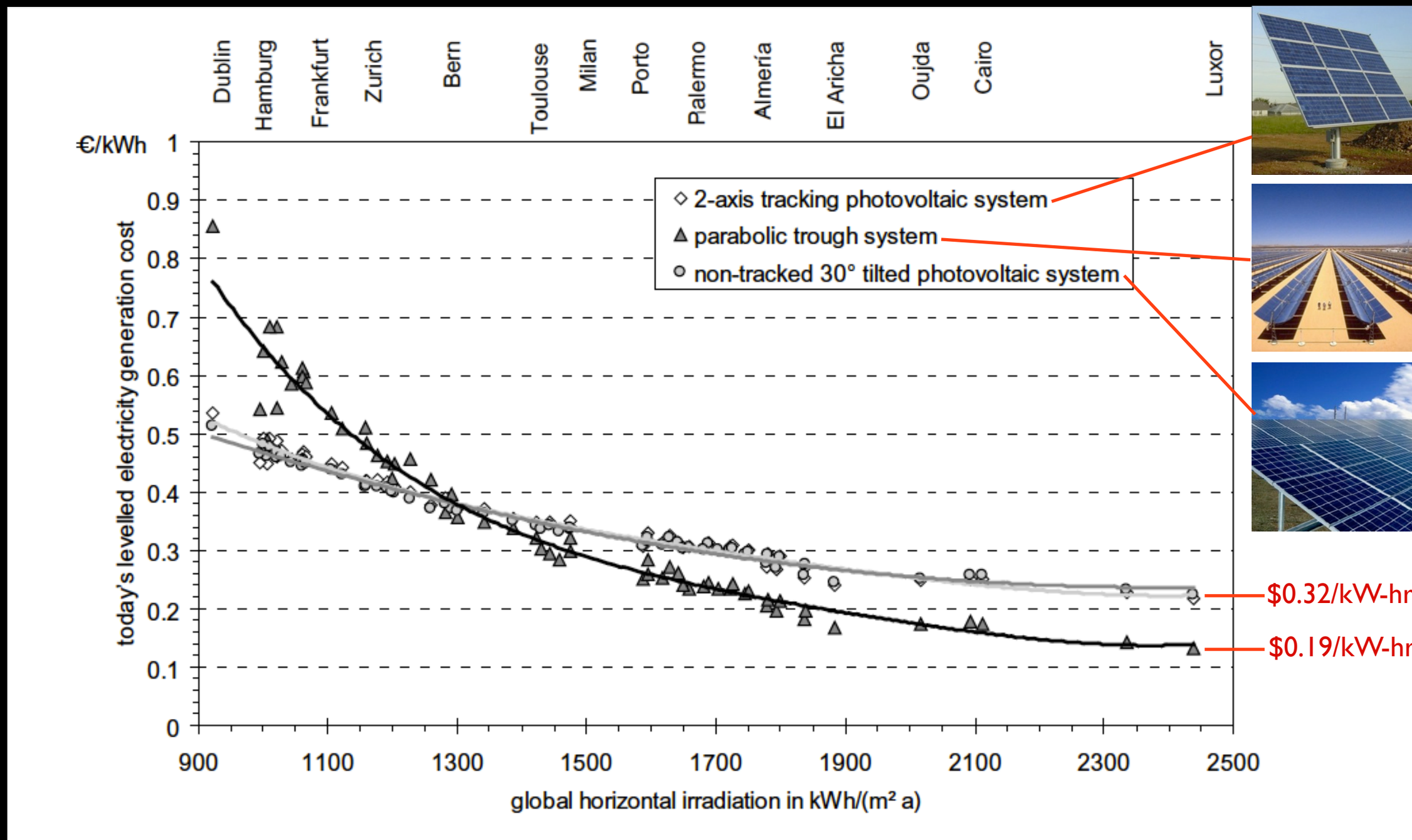
How to Harvest Sunlight

COMPARISON



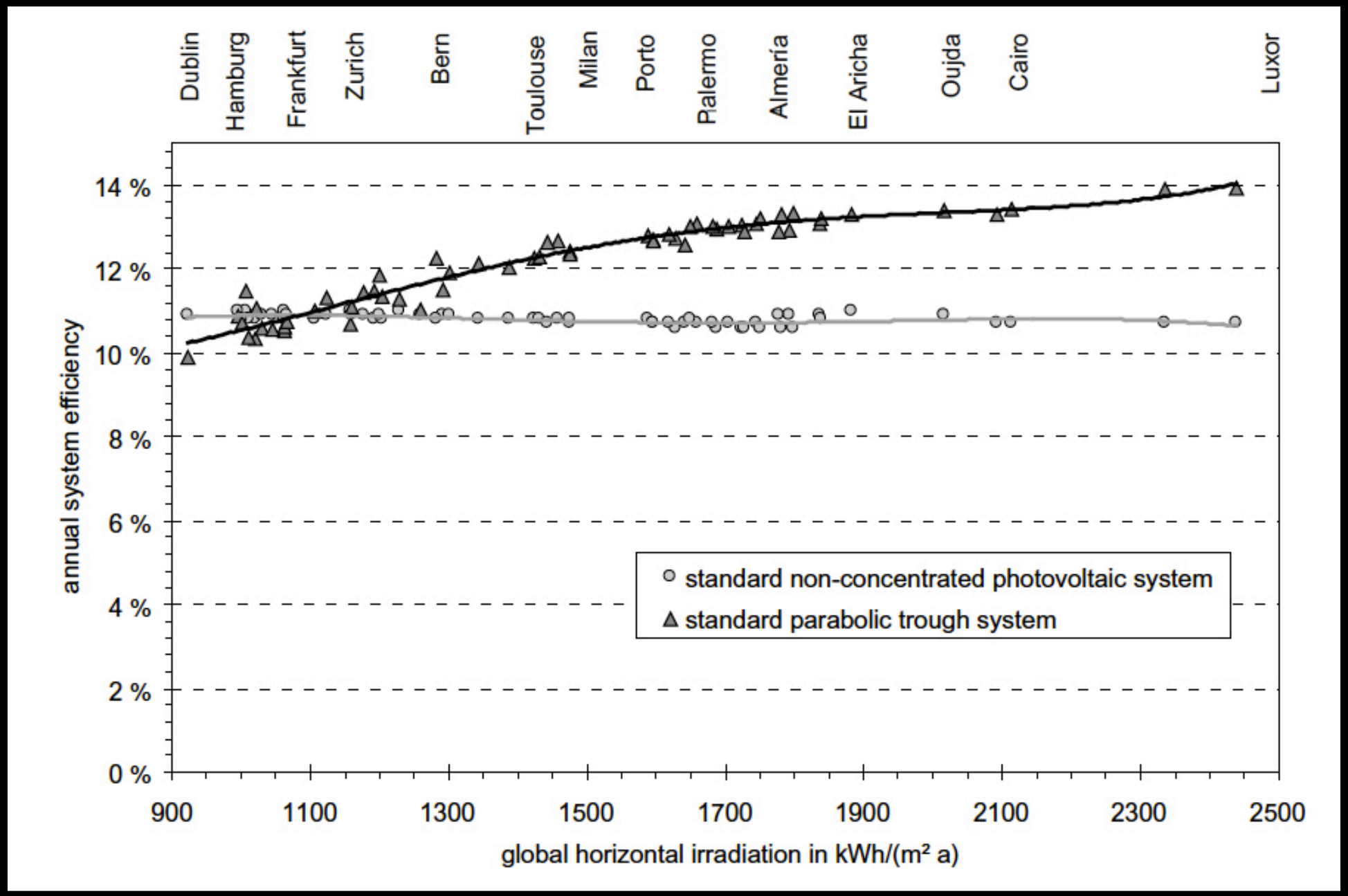
Photovoltaics	Concentrated Solar Thermal
Performs just as well in cold climates as in warm climates	Only viable in desert climates with high and predicable insolation
Easy to install on buildings and existing infrastructure	Difficult to effectively install on buildings and existing infrastructure
Minimizes the need for transmission if installed close to population centers (although electricity yield might be small for cold climates)	Will likely require super-grids to transmit electricity from the desert to population centers (3% loss of energy + grid construction)
Encourages development of a localized and more secure grid	Encourages development of a centralized grid that may be less secure
Difficult to store electrical energy without major losses (at least 30% - 40% energy loss plus storage system costs)	Easy to store energy in an insulated hot water tank
Difficult to combine with fossil fuels except gas turbines	Easy to combine with fossil fuels for gradual renewable transition (fuels heat water in addition to the collected sunlight)
Requires polysilicon, which takes a long (and presently expensive) chemical manufacturing process to extract	All materials necessary for construction can be manufactured quickly in bulk
ONE OF THE MOST EXPENSIVE MEANS OF GENERATING ELECTRICITY (20-25 year unsubsidized return on investment)	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



V. Quaschning, 2004. Technical and economical system comparison of photovoltaic and concentrating solar thermal power systems depending on annual global irradiation. Solar Energy 77, 171–178

Efficiency Comparison Between Photovoltaics and CSP



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Optimal Uses of Photovoltaics and Solar Thermal

Photovoltaics

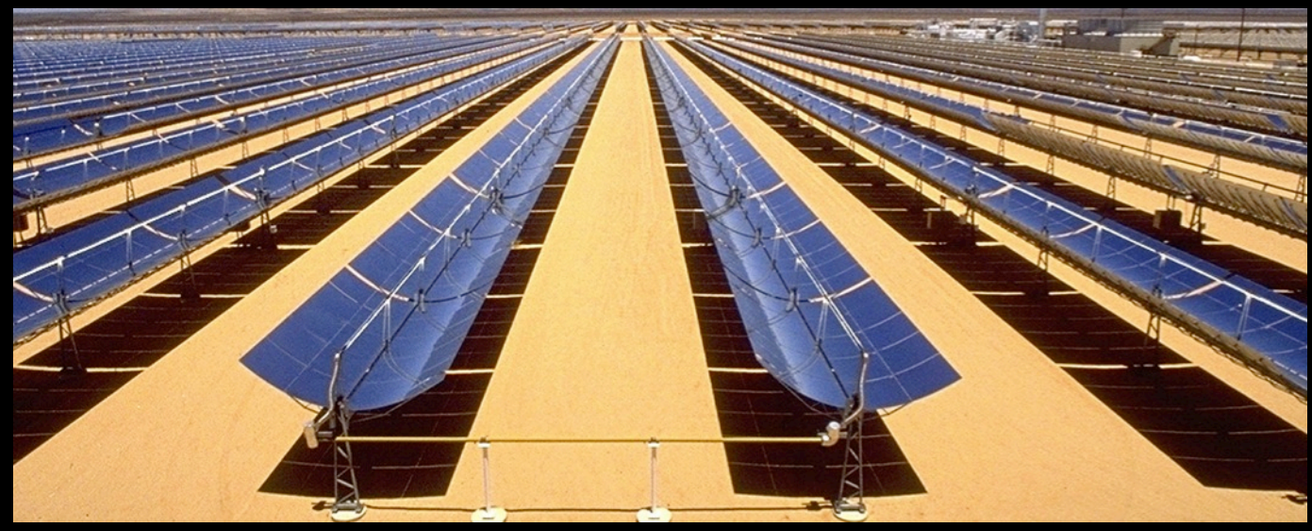
Powering Spacecraft

Powering Small Portable Electronic Devices (i.e. Calculatos)

Powering Electronic Devices That are Far from the Electricity Grid (i.e. Emergency Phones)

Acting as a Backup Source of Electricity in the Event of Grid Failure

Giving People the Impression that a Building is “Green”

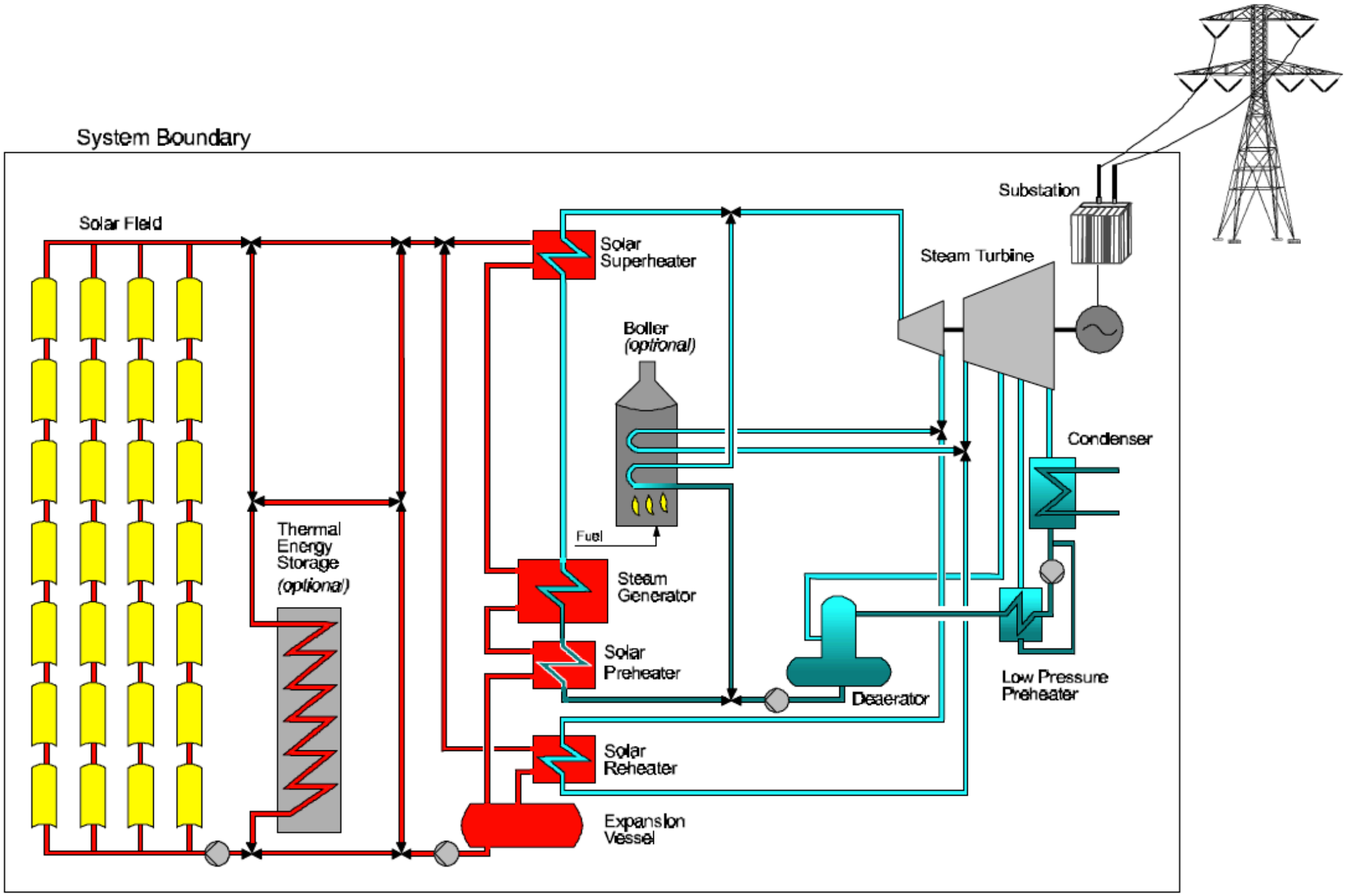


Concentrated Solar Thermal

Generating Electricity to Sustainably Power a Modern Civilization

Cost Breakdown of

Concentrated Solar Thermal



Cost Breakdown of

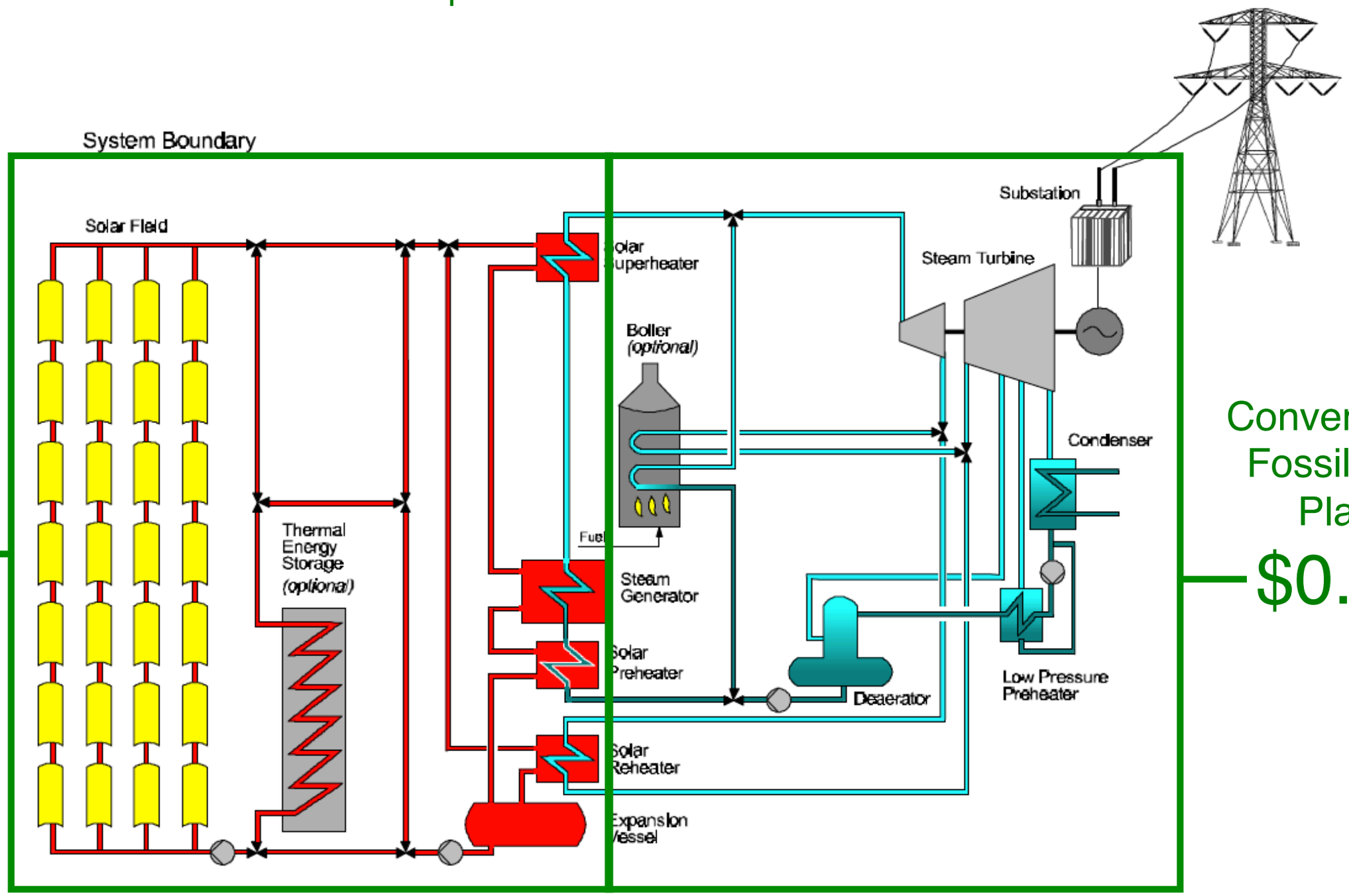
Concentrated Solar Thermal

$0.19 kWhr

Solar Generating Component

$0.09

NOT FEASIBLY SUBSIDIZED ON A LARGE SCALE

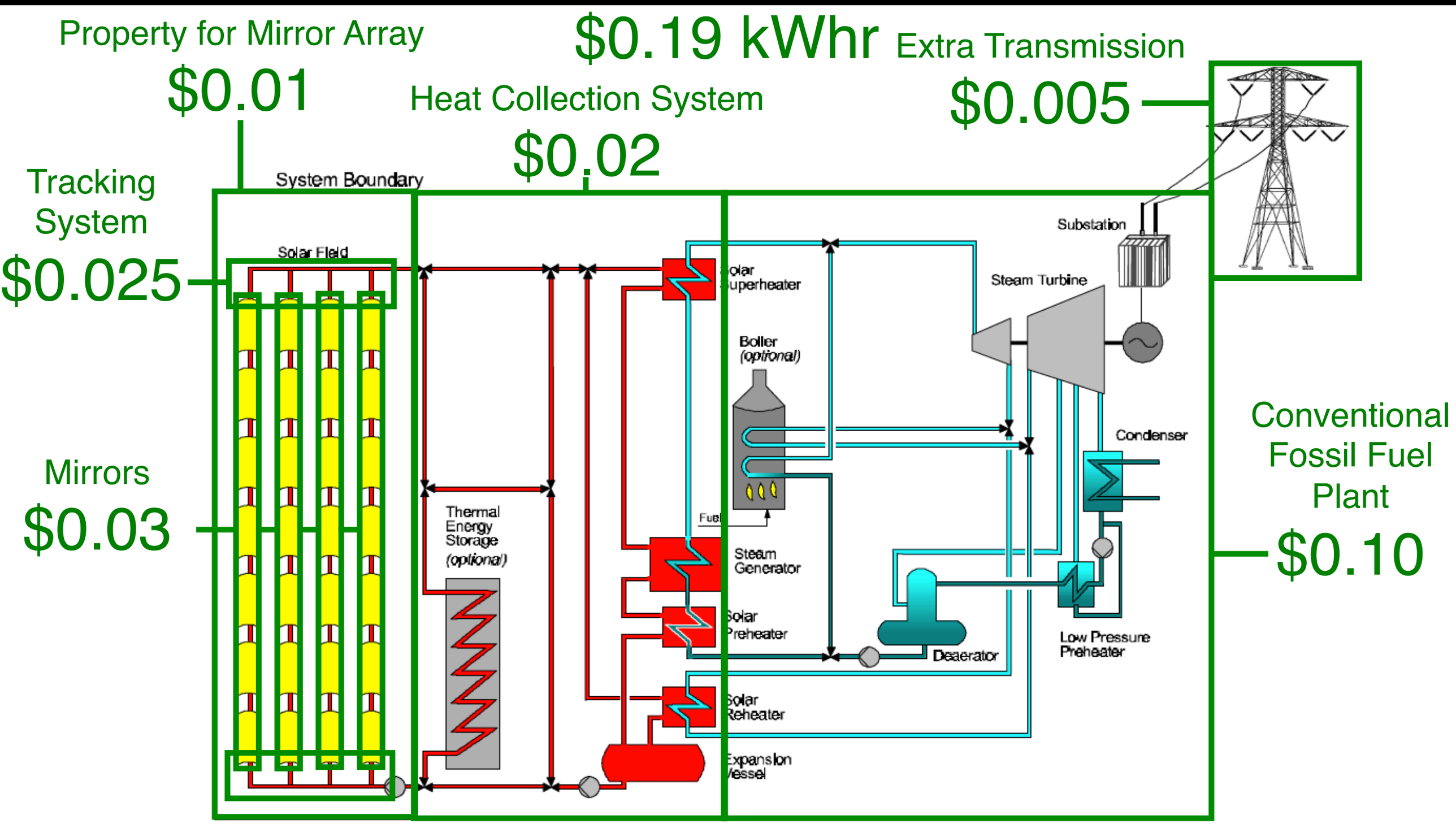


Conventional Fossil Fuel Plant

$0.10

Cost Breakdown of

Concentrated Solar Thermal



Cost Breakdown of

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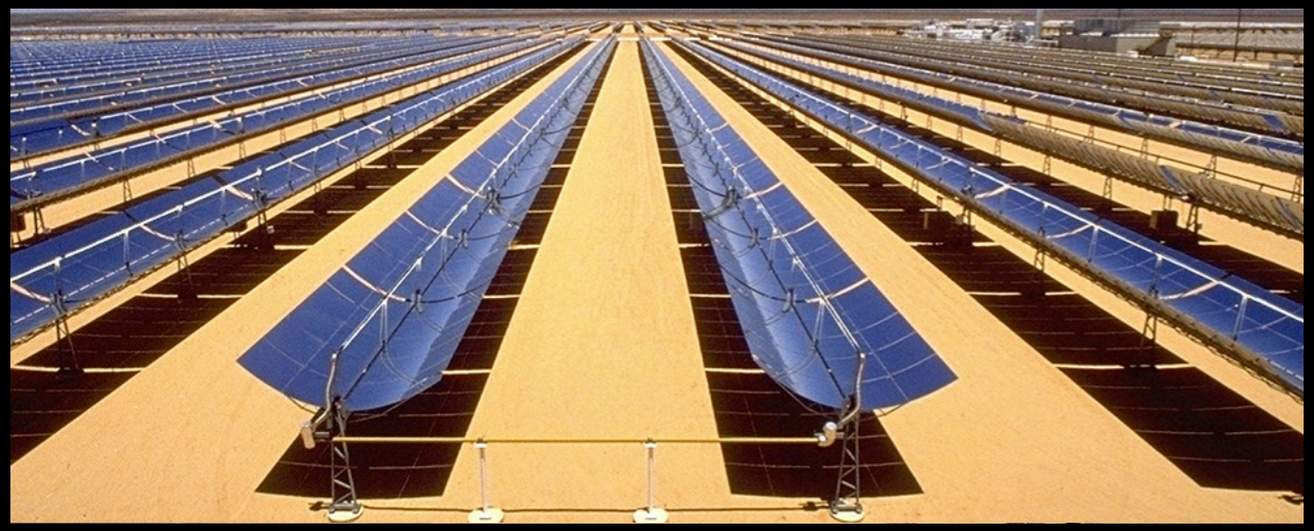
Types of Solar Thermal



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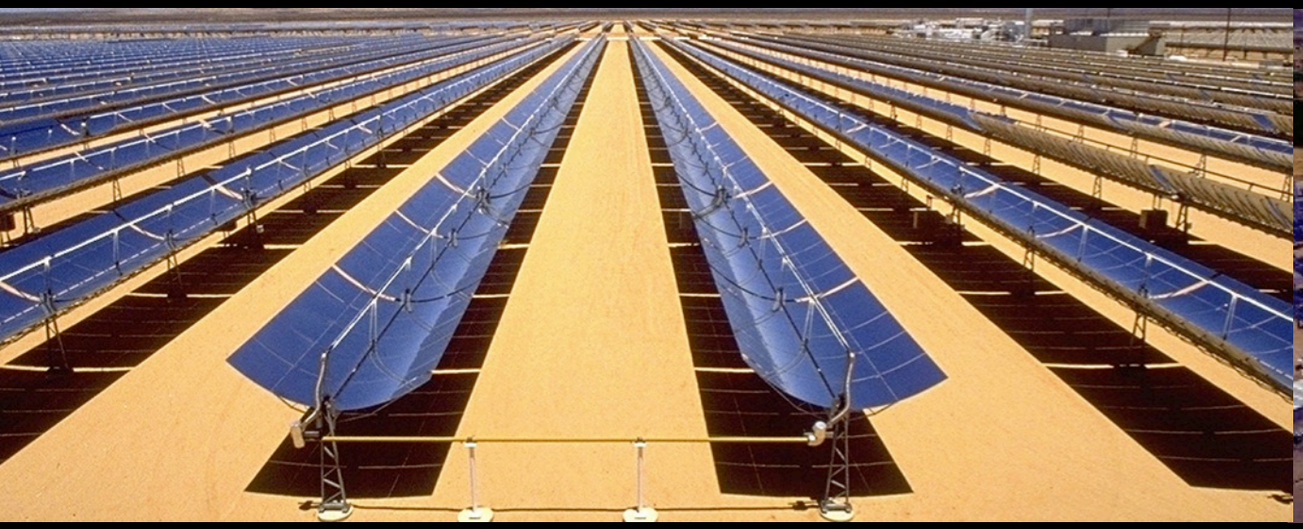


Parabolic Trough

Pivot Mirrors and Tower

Parabolic Dish

Linear Fresnel Reflector

Cost Breakdown of

Concentrated Solar Thermal

Linear Fresnel Reflector

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

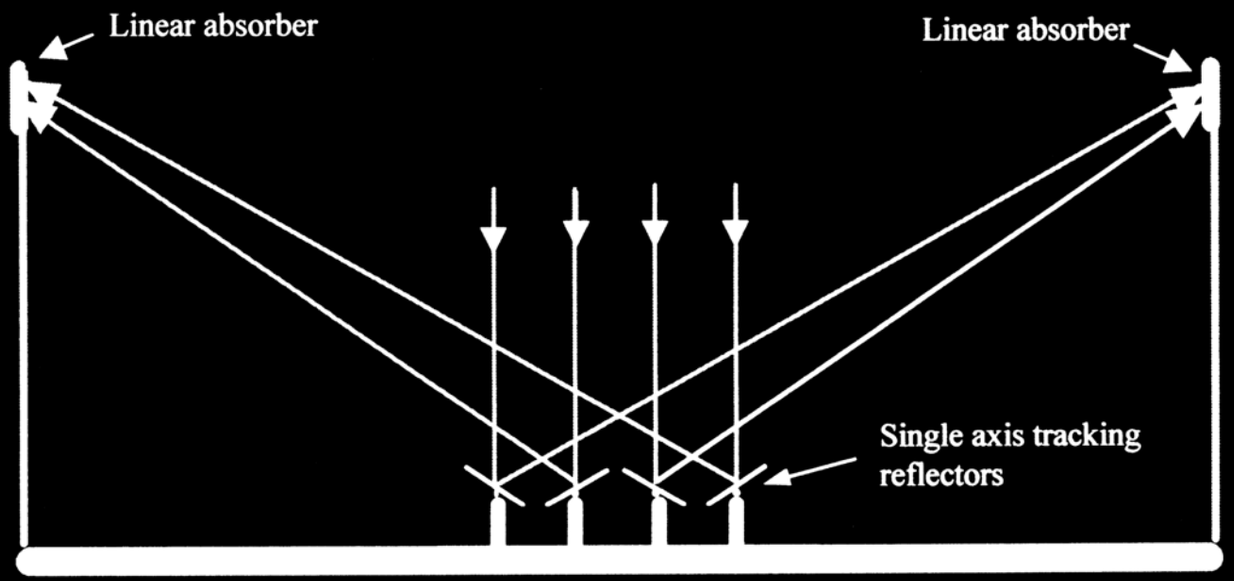
Minimizes cost of tracking system by using low-tech pulley system without pneumatic pumps

Minimizes cost of mirrors by using mirrors with a shape not induced by glass sagging

Cost Breakdown of

Concentrated Solar Thermal

Linear Fresnel Reflector

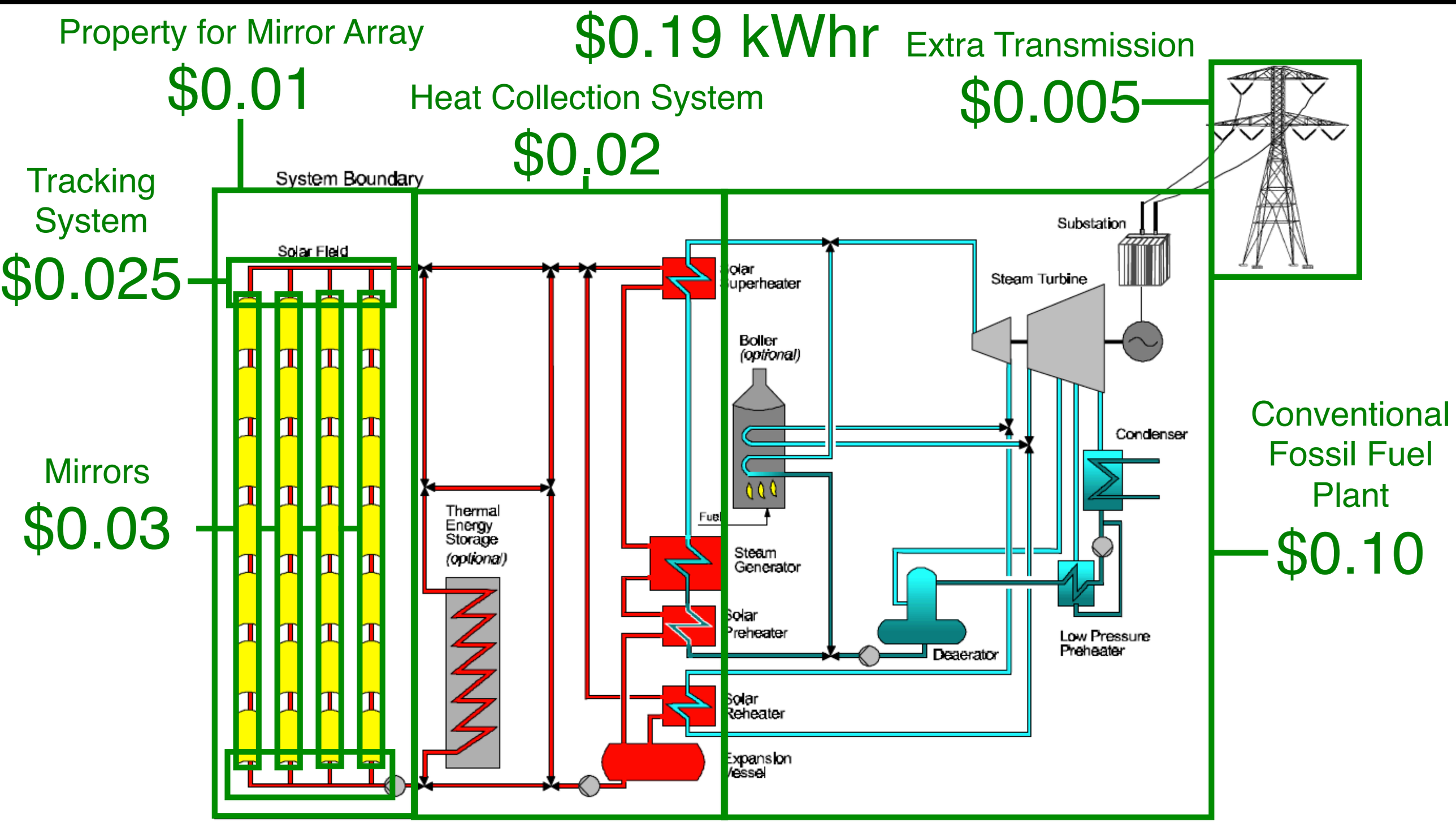


Compact Linear Fresnel Reflector (CLFR)

CLFR Potentially Minimizes Thermal Collection Costs Further by Giving Mirrors the Option of Pointing at Two Towers, Allowing Mirrors to be Further Apart.

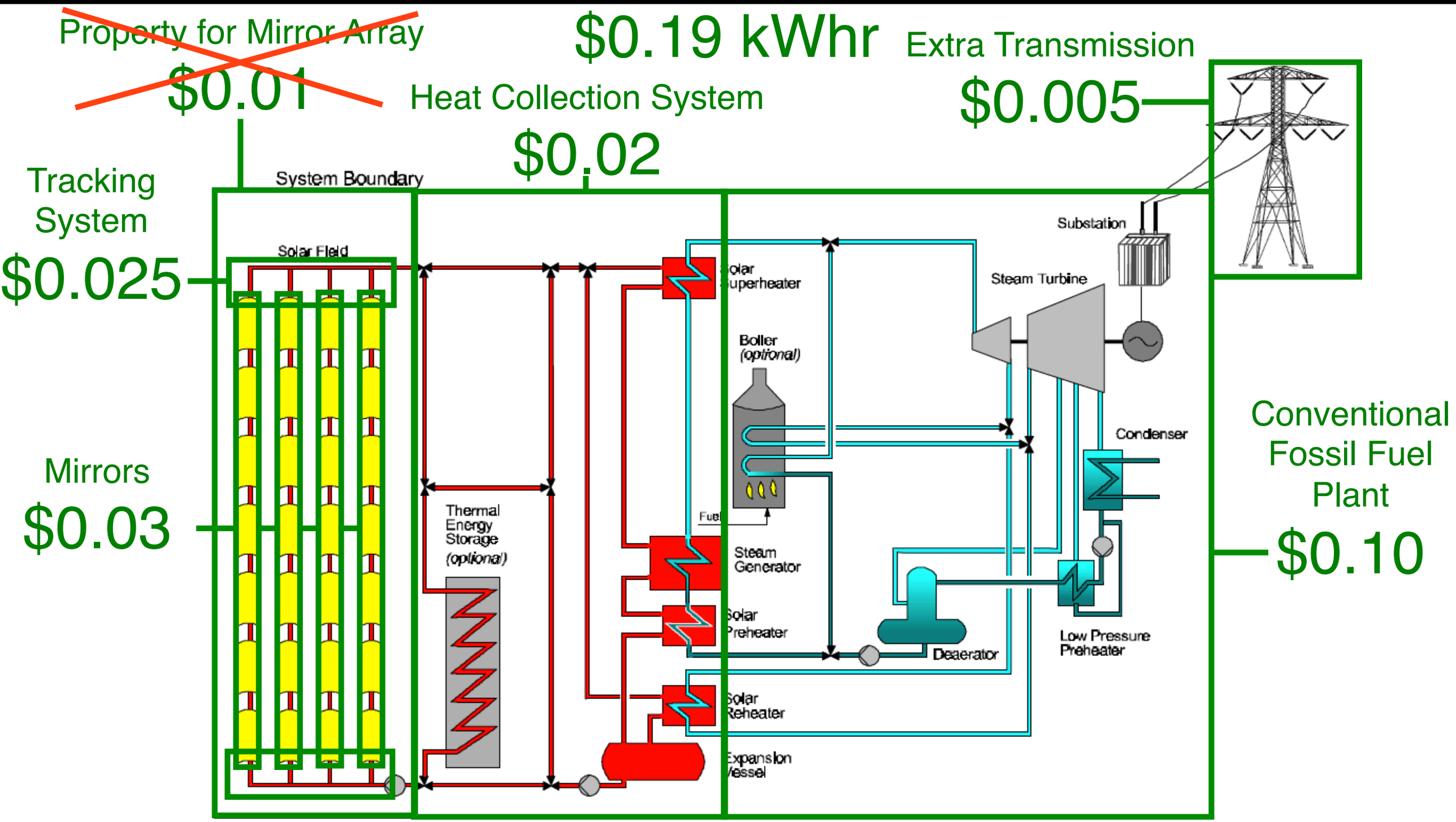
Cost Breakdown of

Compact Linear Fresnel Reflector (CLFR)



Cost Breakdown of

Compact Linear Fresnel Reflector (CLFR)



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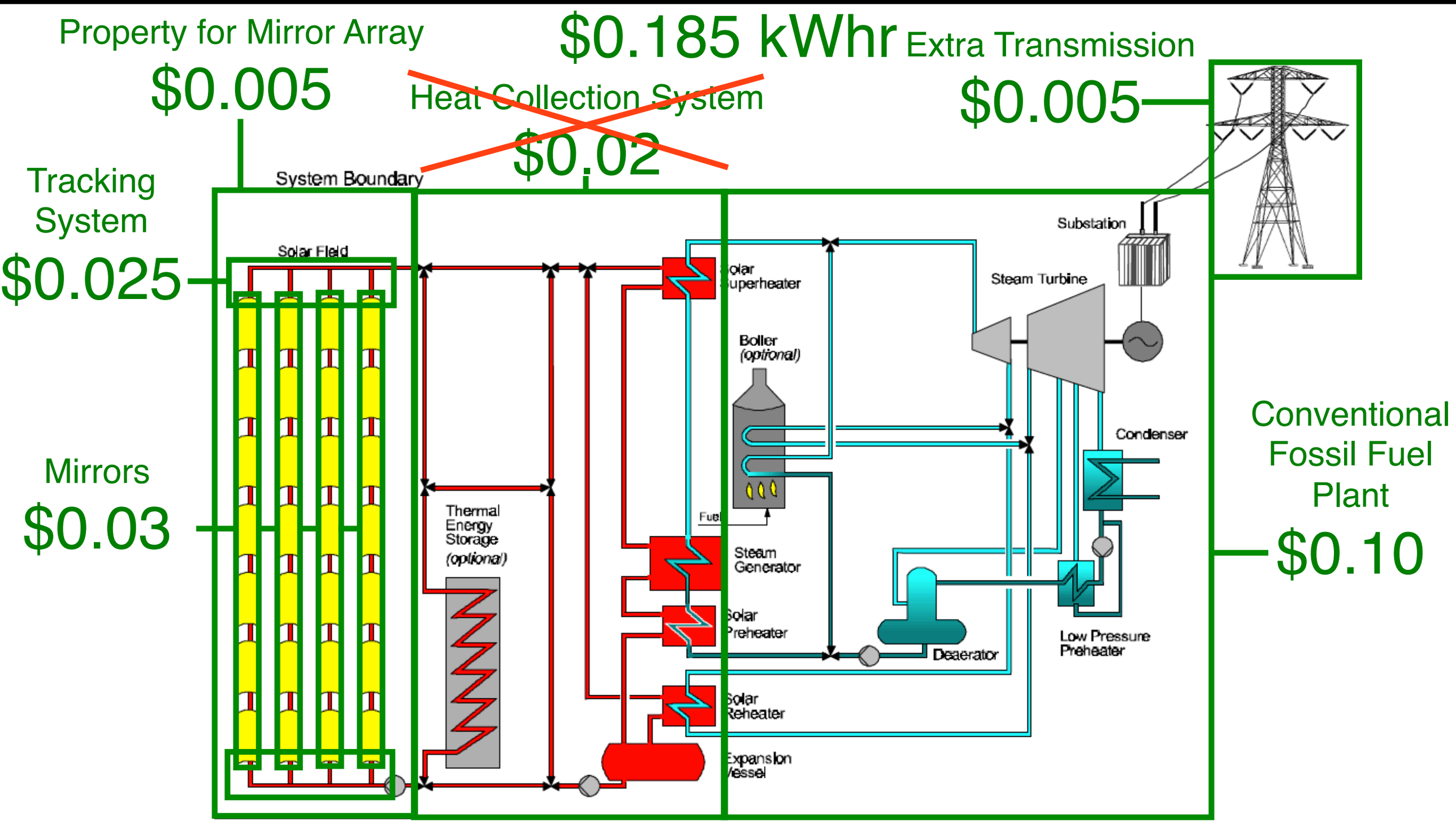

Cost Breakdown of

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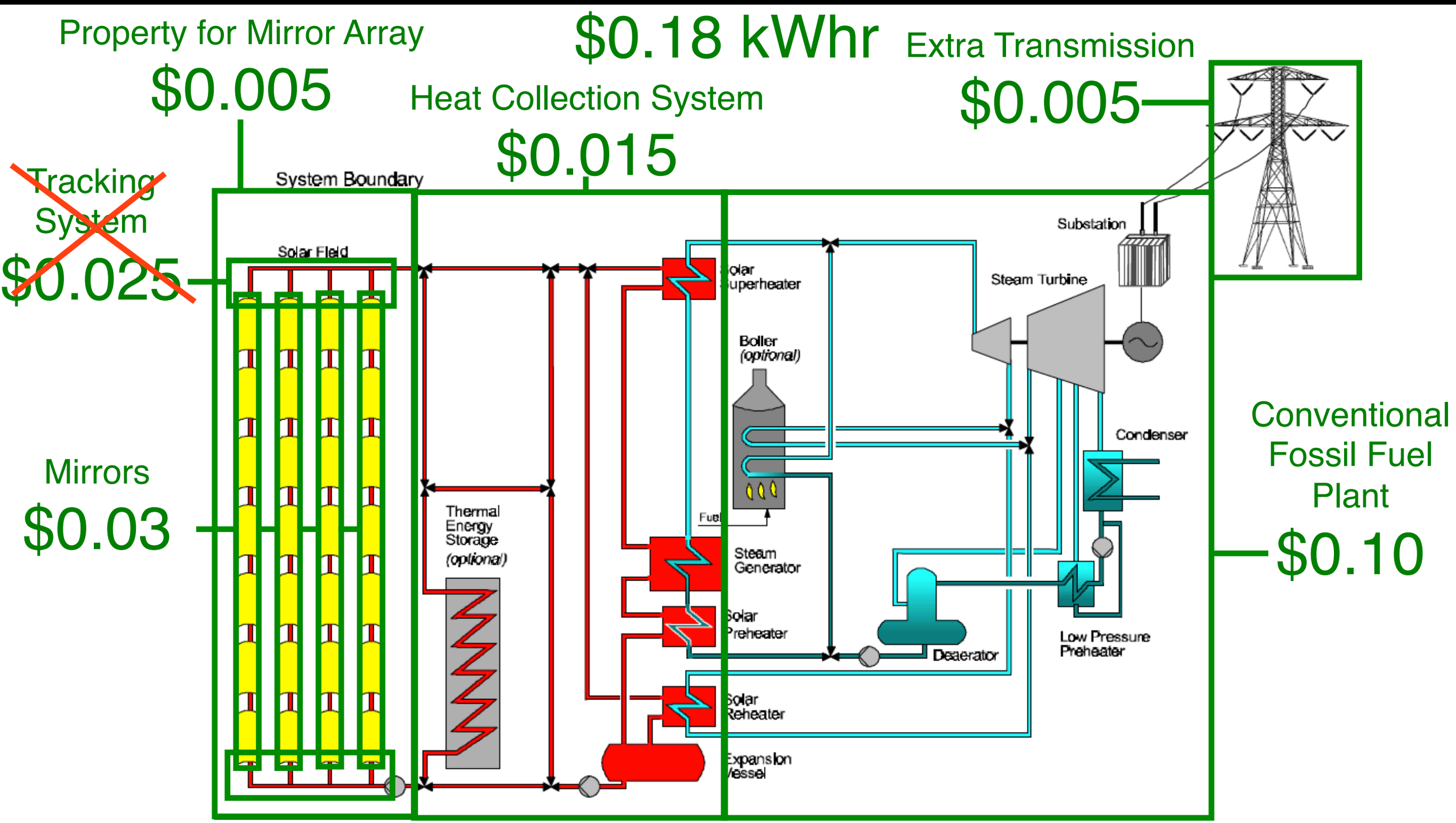

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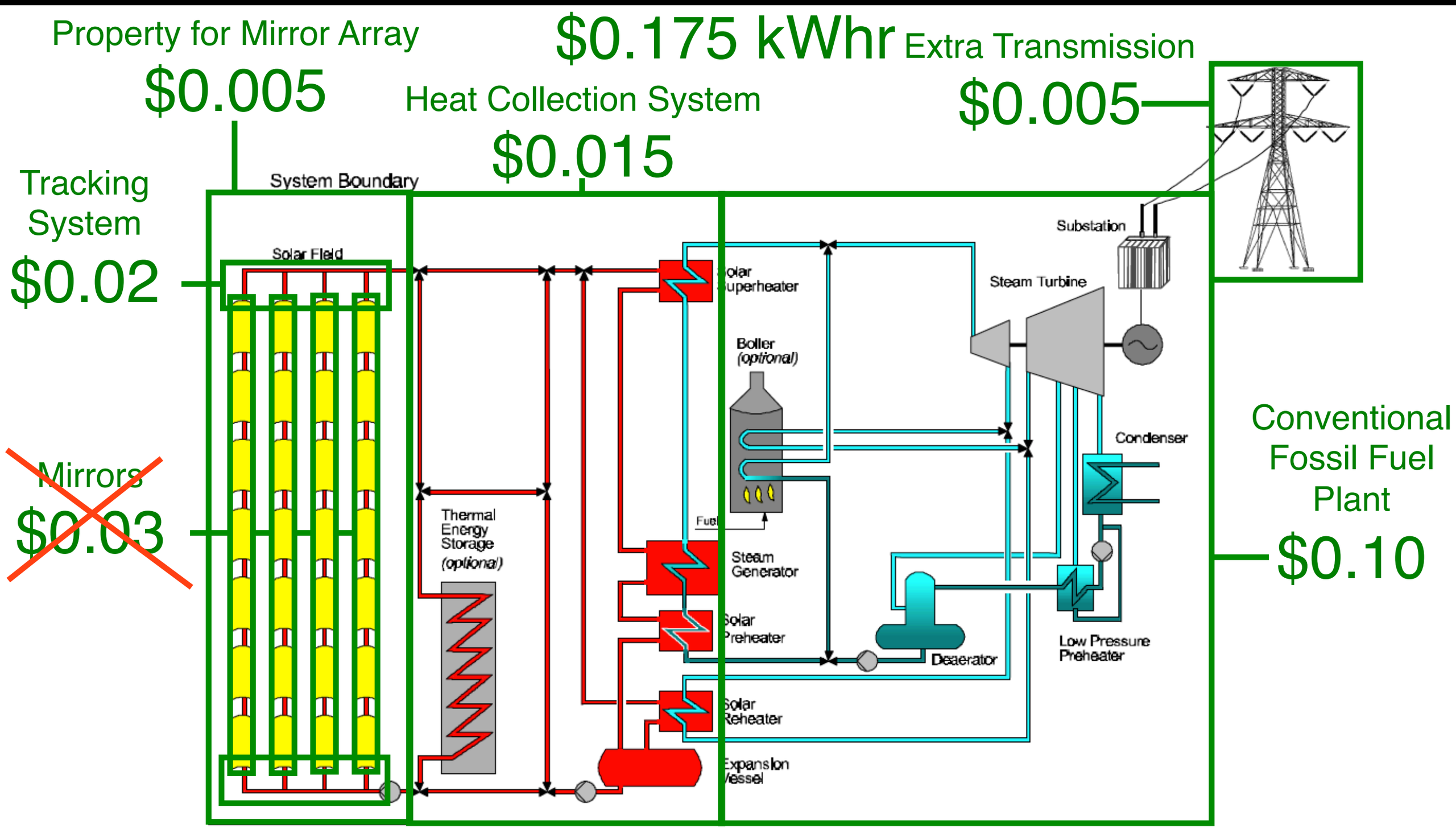

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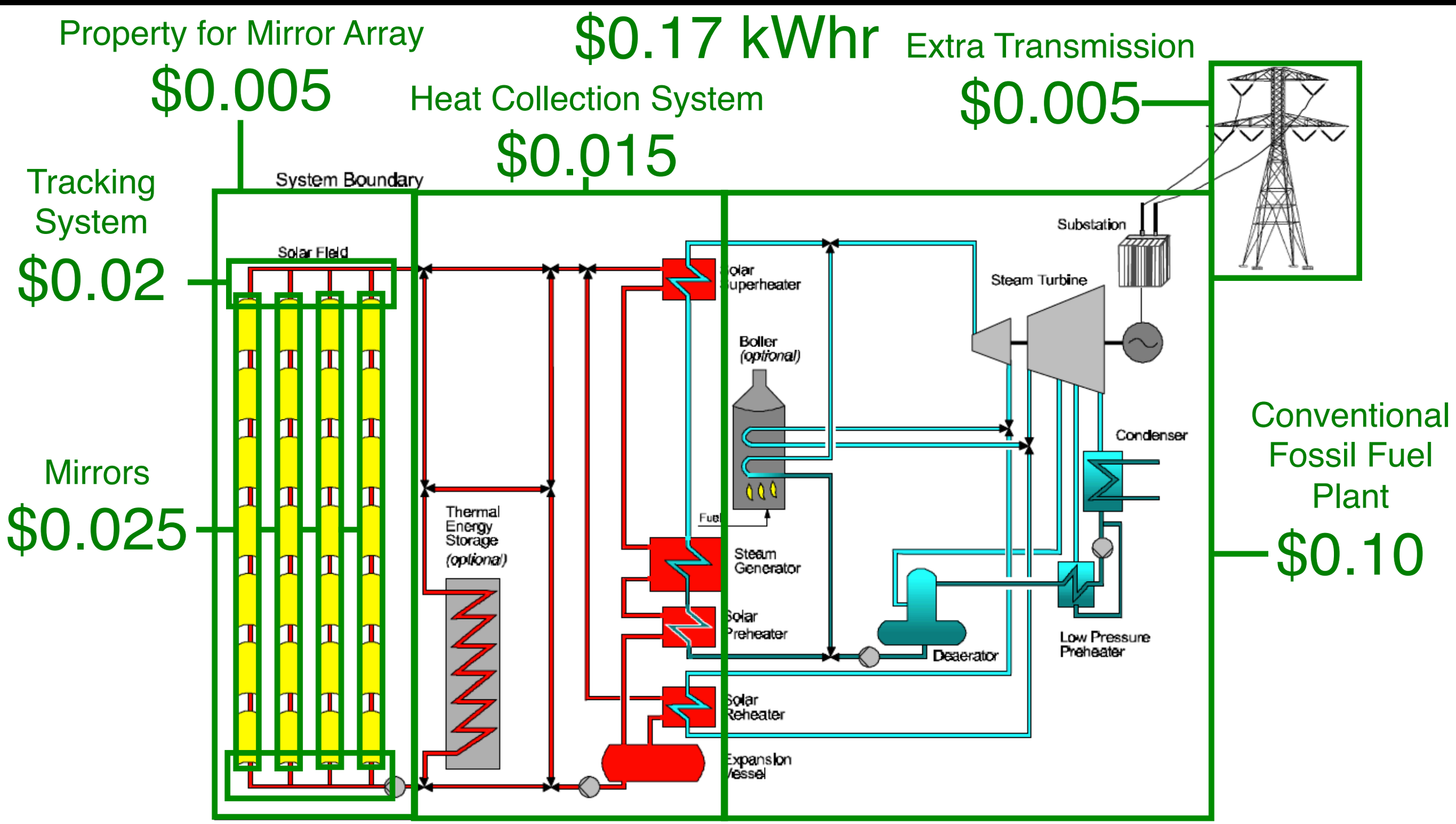


One Industrial Desert-Based Technology With a Lot of Future Promise

Compact Linear Fresnel Reflector

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

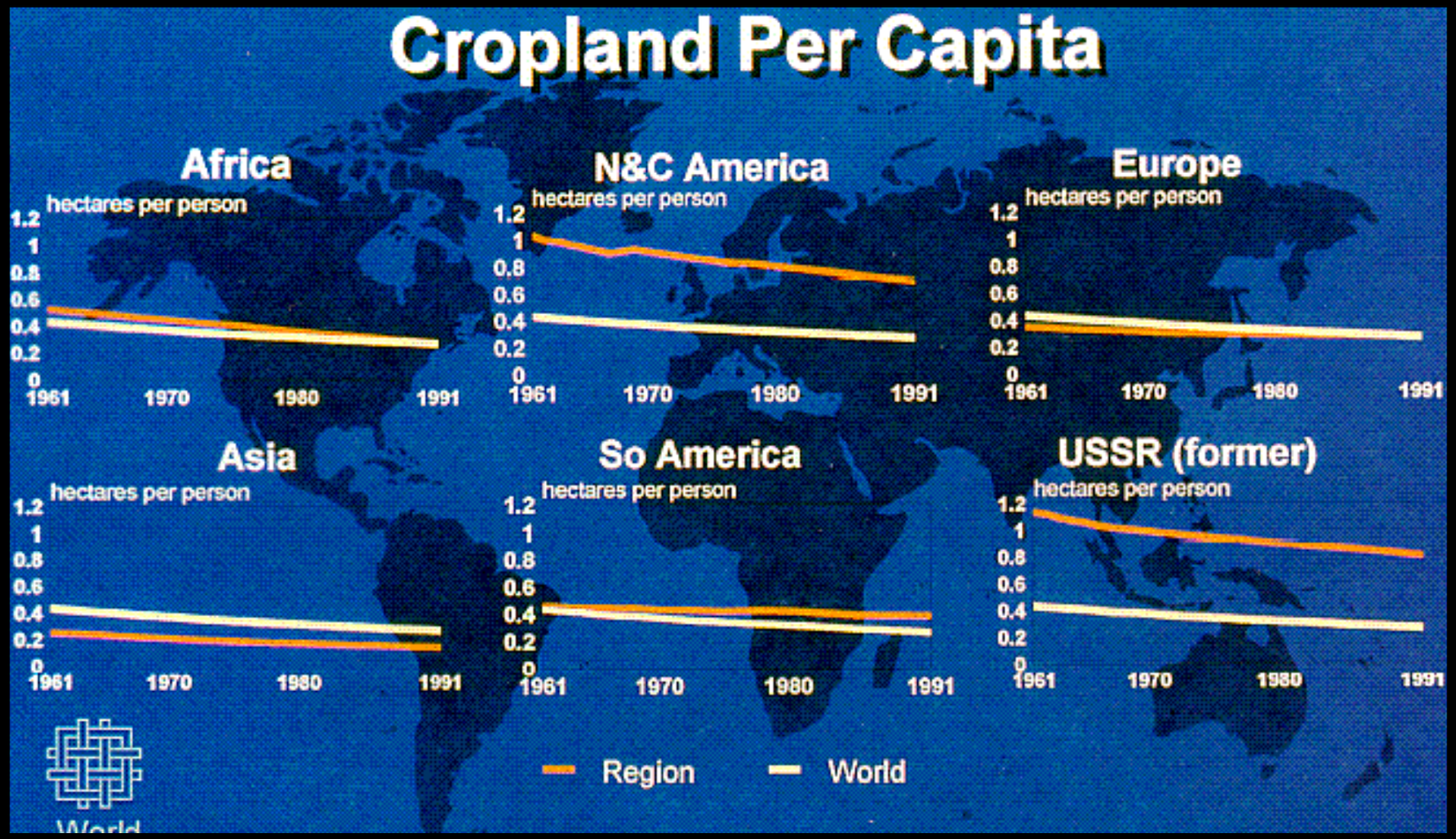
Desert Agriculture

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



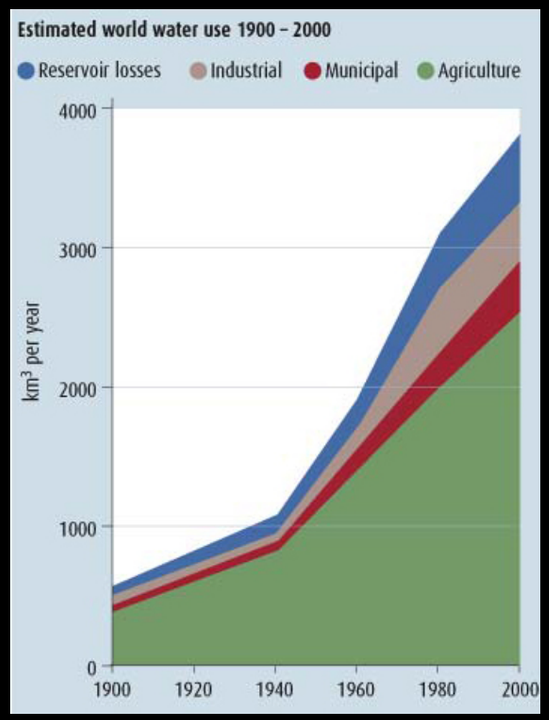
IFAD, 2011. http://www.ifad.org/pub/factsheet/desert/e.pdf

Bai, Z.G., D.L. Dent, L. Olsson, and M.E. Schaepman. 2008. Global assessment of land degradation and improvement 1:identification by remote sensing. Report 2008/01, FAO/ISRIC - Rome/Wageningen.

Food and Agriculture Organization of the United Nations, 1993.

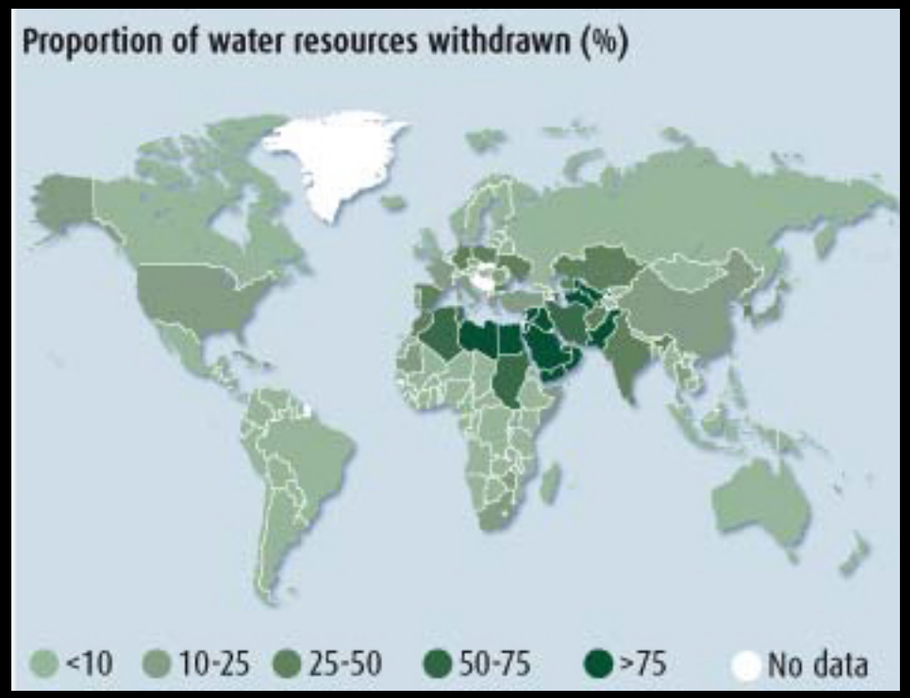
Reasons for Desert Agriculture

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)

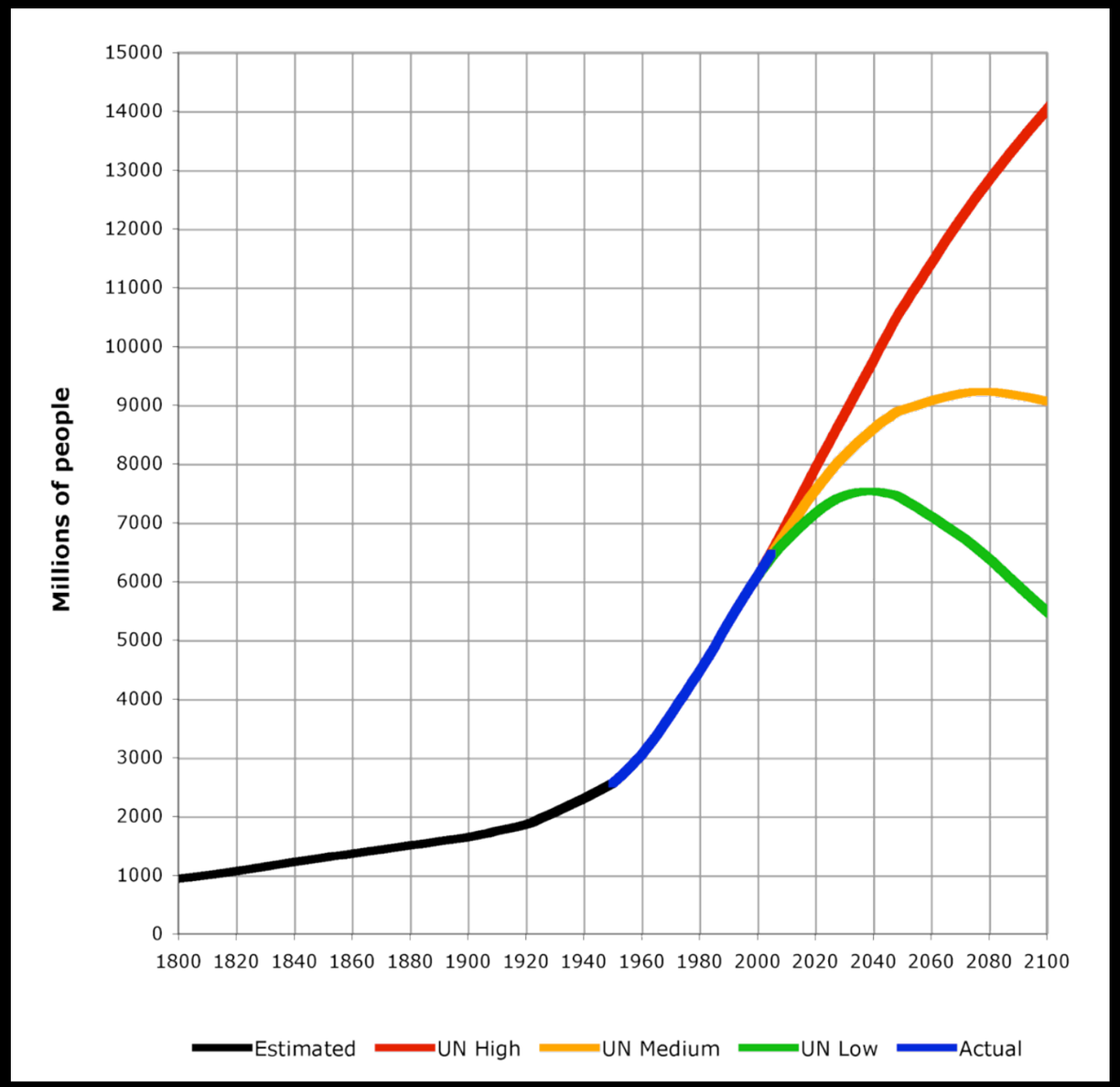
United Nations Food and Agriculture Organization, 2010. http://www.fao.org/publications/sofi/en/

Philippe Rekacewicz, Fevrier, 2008.http://www.solcomhouse.com/africalchad.htm

NASA Goddard Space Flight Center, http://www.gsfc.nasa.gov/gsfc/earth/environ/lakechad/chad.htm

Reasons for Desert Agriculture

Demand for Food (and Biofuel) is High and Growing



United Nations Food and Agriculture Organization, 2010. http://www.fao.org/publications/sofi/en/

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

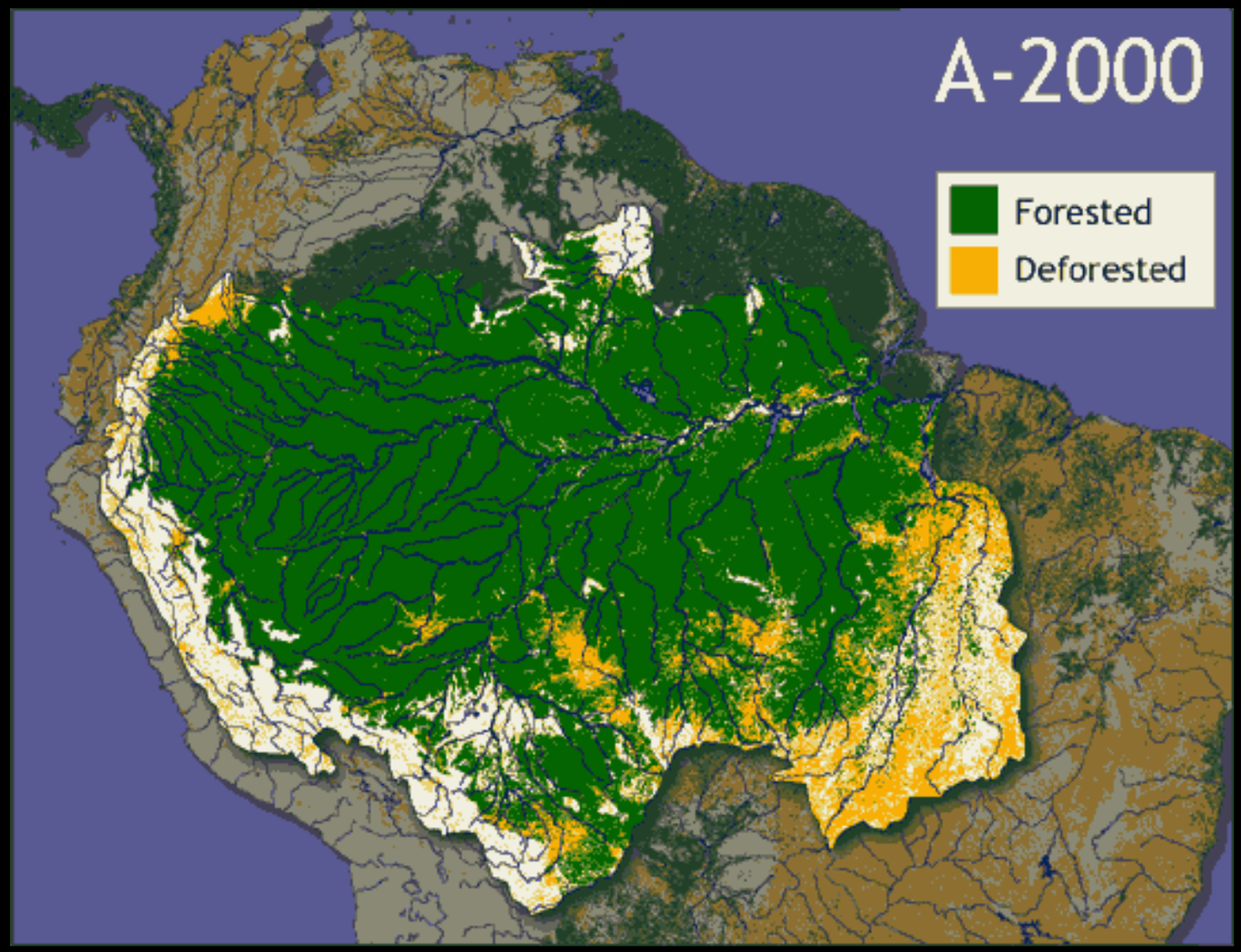
By 2050, an additional 2 billion people will require food.

As we reach peak oil, certain industries will place a high demand on biofuels. (notably airlines and much of the transportation sector)

Reasons for Desert Agriculture

Harvesting Food from Ecosystems Other than Deserts will Destroy Major Carbon Sinks

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



Stuart Grudgings and Cynthia Osterman, 2008. Amazon deforestation seen surging - with high oil prices http://www.kleanindustries.com/s/PressReleases.asp?ReportID=284002

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

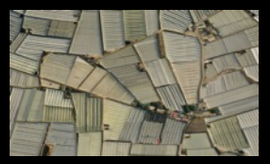
Fossil Water Irrigation

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

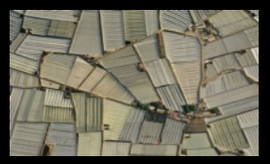
Is the Most Commonly Practiced Form of Desert Farming Today

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



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

EAST ASIA

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

WEST ASIA

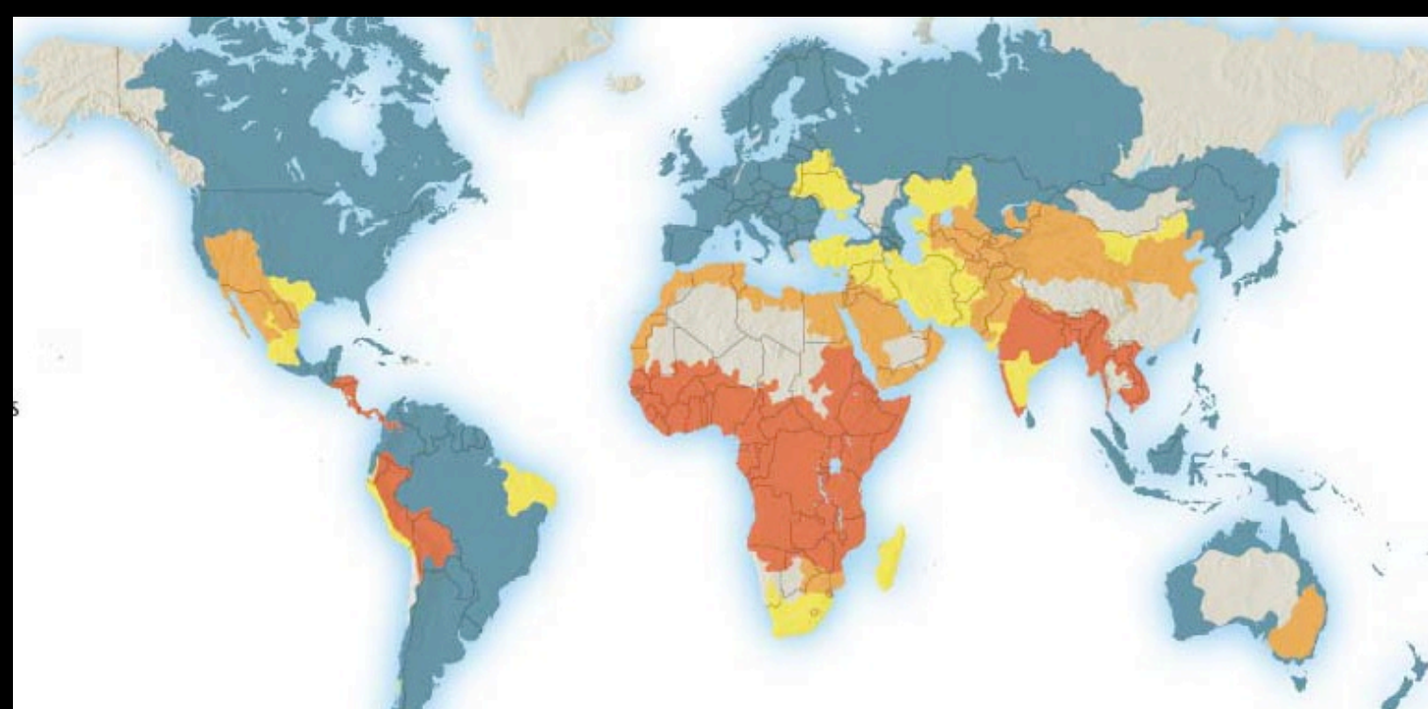
The Euphrates, the Tigris, and the River Jordan

NORTH AMERICA

The Colorado River and the Rio Grande

Jun, Jan, 2006. Overused Rivers Struggle To Reach The Sea. Radio Free Europe. http://www.rferl.org/content/article/1066933.html

Three Types of Desert Agriculture



>75% of river flow does not reach the sea

>50% of river flow does not reach the sea

United Nations Food and Agriculture Organization, 2010.
http://www.fao.org/publications/sofi/en/

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

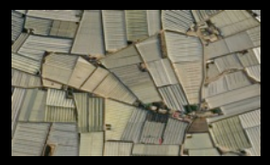
Fossil Water Contributes Substantially to the Worldwide Production of Grain (Wheat and Rice)

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

Sub-Saharan Africa	Latin America	Near East/North Africa	South Asia	East Asia	All Countries
2	1	53	36	8	8

Source: FAO, 2002.

Three Types of Desert Agriculture



Fossil Water Irrigation

Farmington, New Mexico

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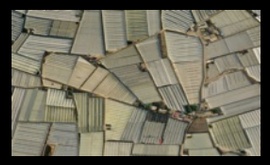
As a Non-Renewable Resource, Desert Fossil Water Aquifers are Often Depleted in 5-15 Years

Three Types of Desert Agriculture



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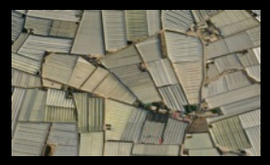
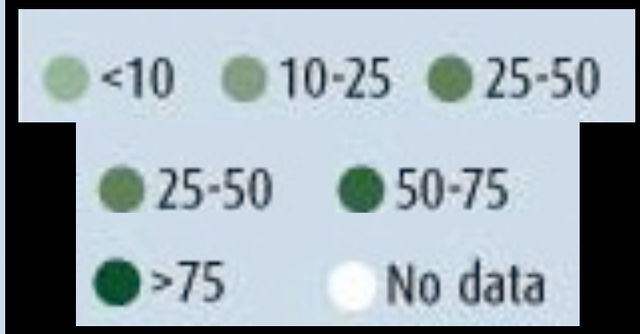


Percentage of Ground Reserves Withdrawn



United Nations Food and Agriculture Organization, 2010.
http://www.fao.org/publications/sofi/en/

Three Types of Desert Agriculture

Greenhouses

Almeria, Spain

Three Types of Desert Agriculture

Greenhouses

Almeria, Spain

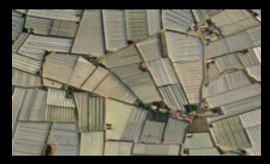
Are deployed to obtain maximum water efficiency by enclosing the growing environment in an impermeable membrane

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





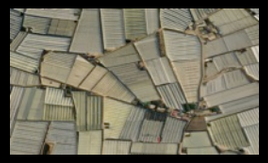
Greenhouses

Almeria, Spain

Presently supplies all of Europe's winter-time vegetables

Three Types of Desert Agriculture



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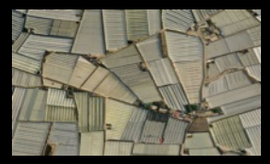
Three Types of Desert Agriculture






Greenhouses

Almeria, Spain

Presently supplies all of Europe's winter-time vegetables

Three Types of Desert Agriculture

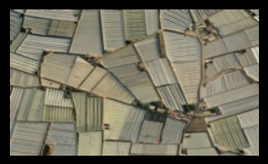
Greenhouses

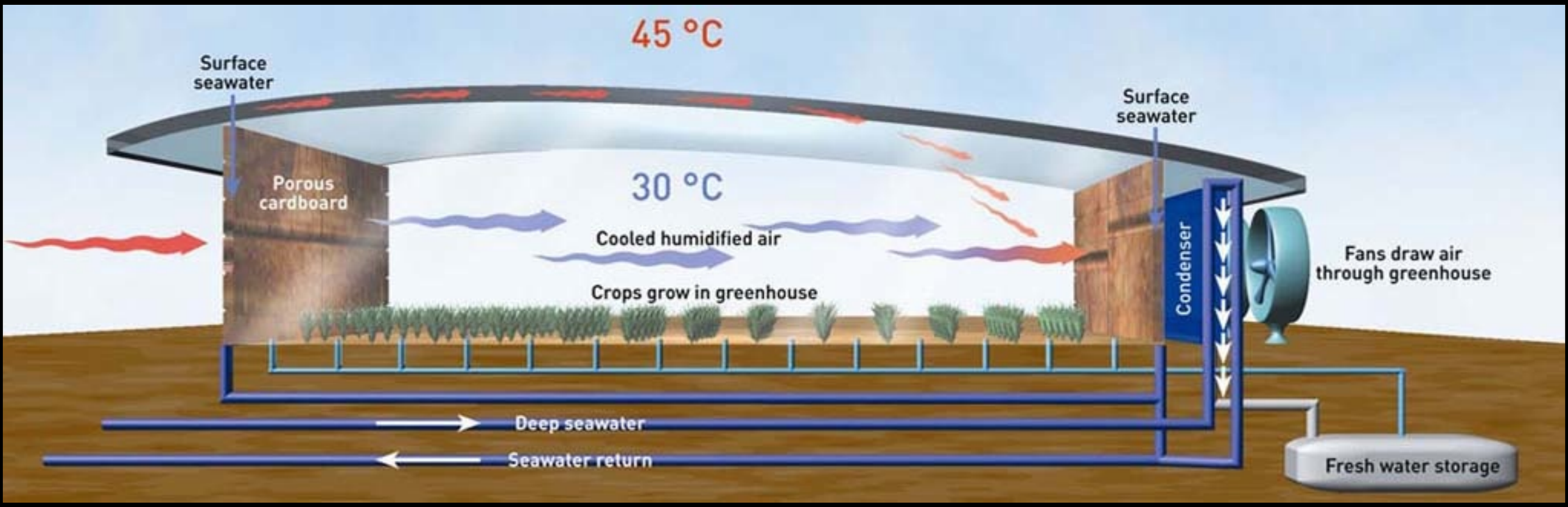
Almeria, Spain

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

Three Types of Desert Agriculture





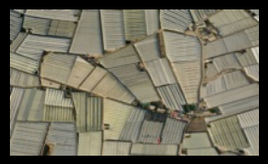


A breakthrough in the 90's produced a greenhouse design that can desalinate large quantities of sea water with very minimal energy and at a low cost

http://www.seawatergreenhouse.com/

Three Types of Desert Agriculture





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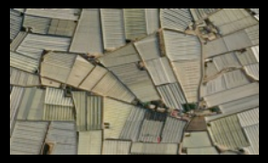
Three Types of Desert Agriculture





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

http://www.flickr.com/photos/theearthawards/4775038752/sizes/l/in/photostream/

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

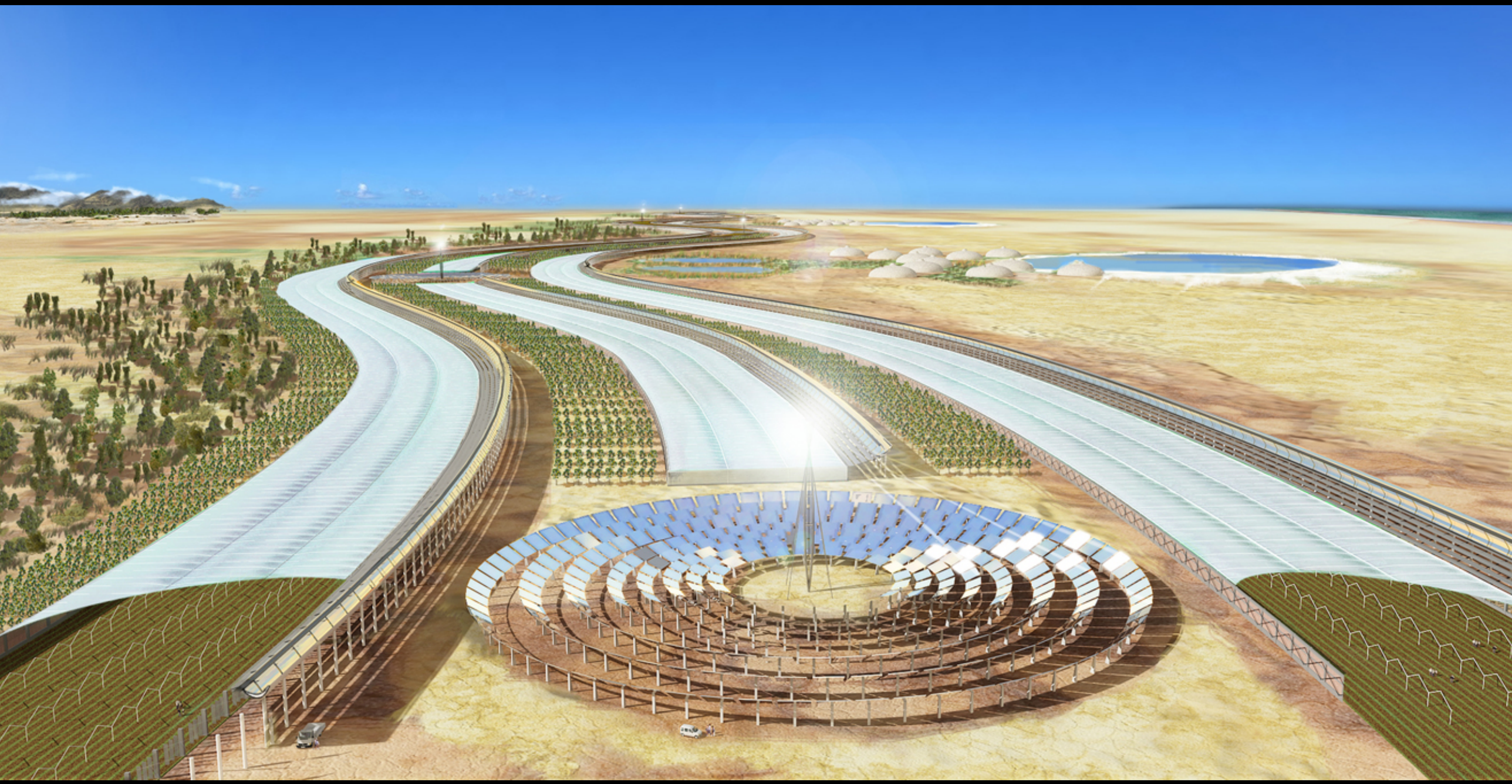
Extra desalinated water is used to keep mirrors clean and acts as the working fluid for the heat collection system (since superheated seawater can be corrosive).

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.

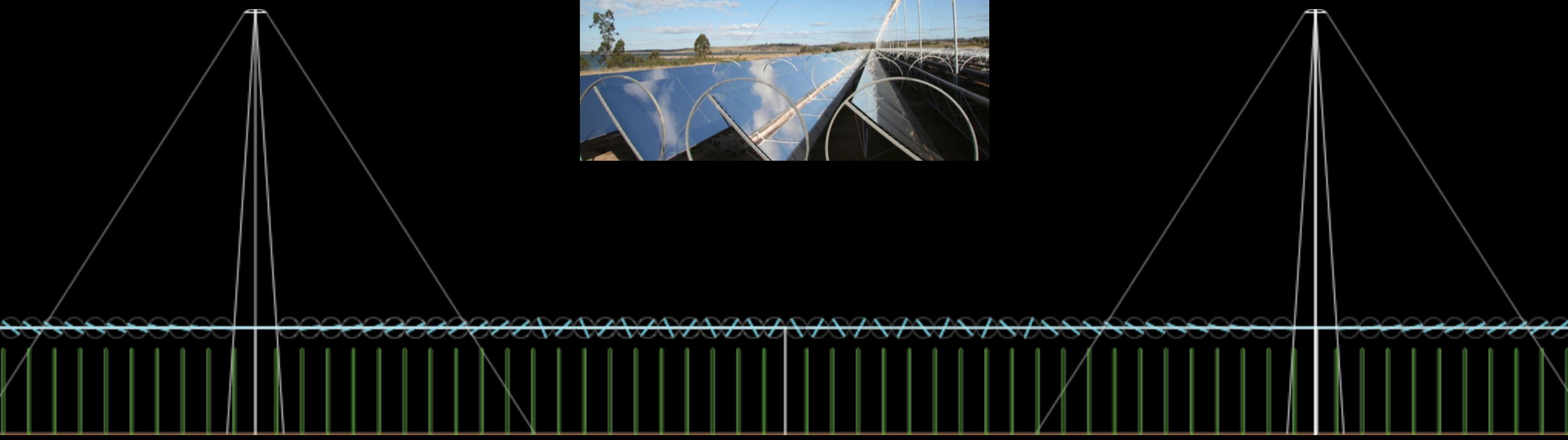
CSP will thrive best in fully arid regions where temperatures can reach as high as 50°C.

HYPOTHESIS

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



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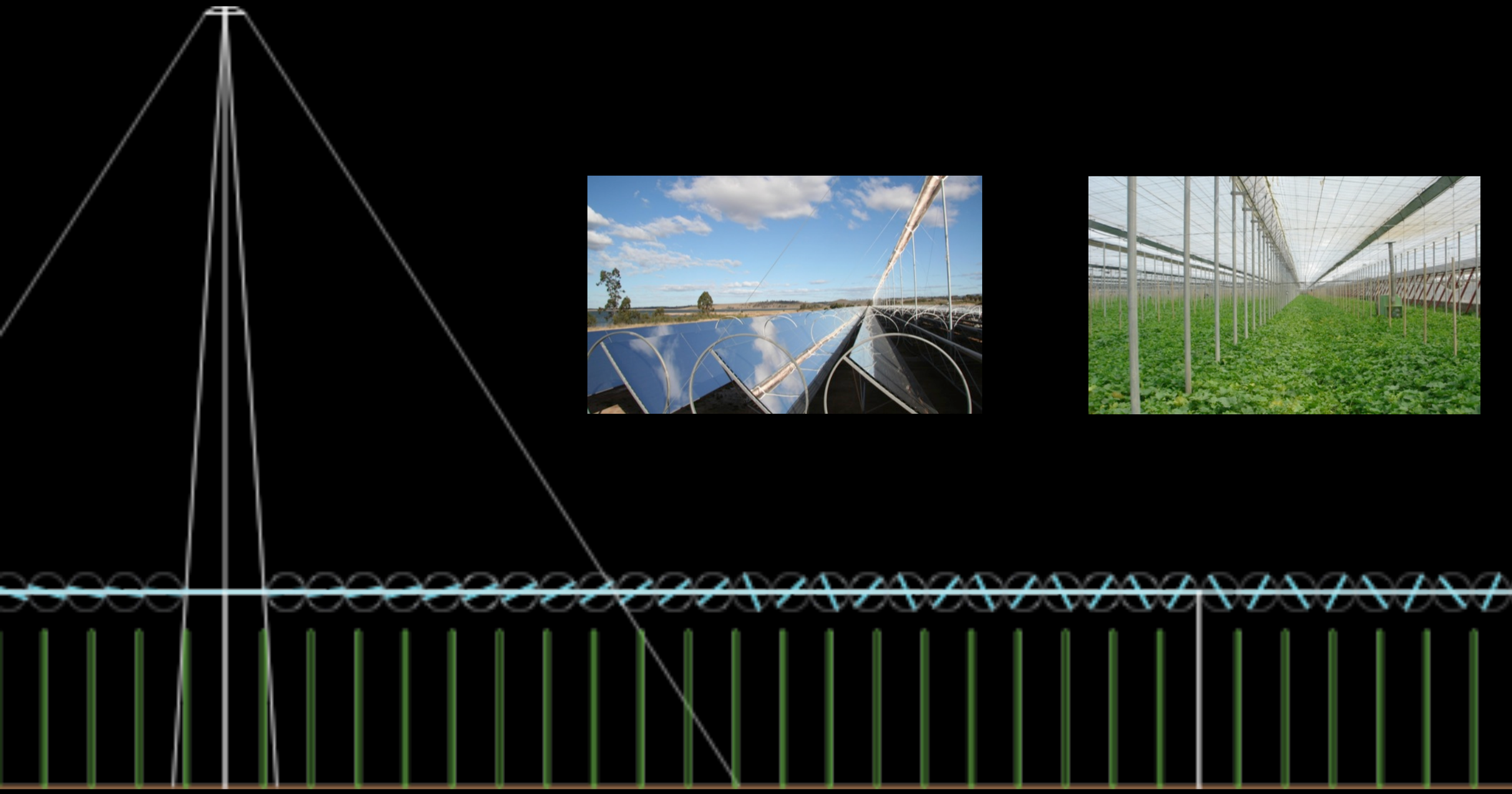
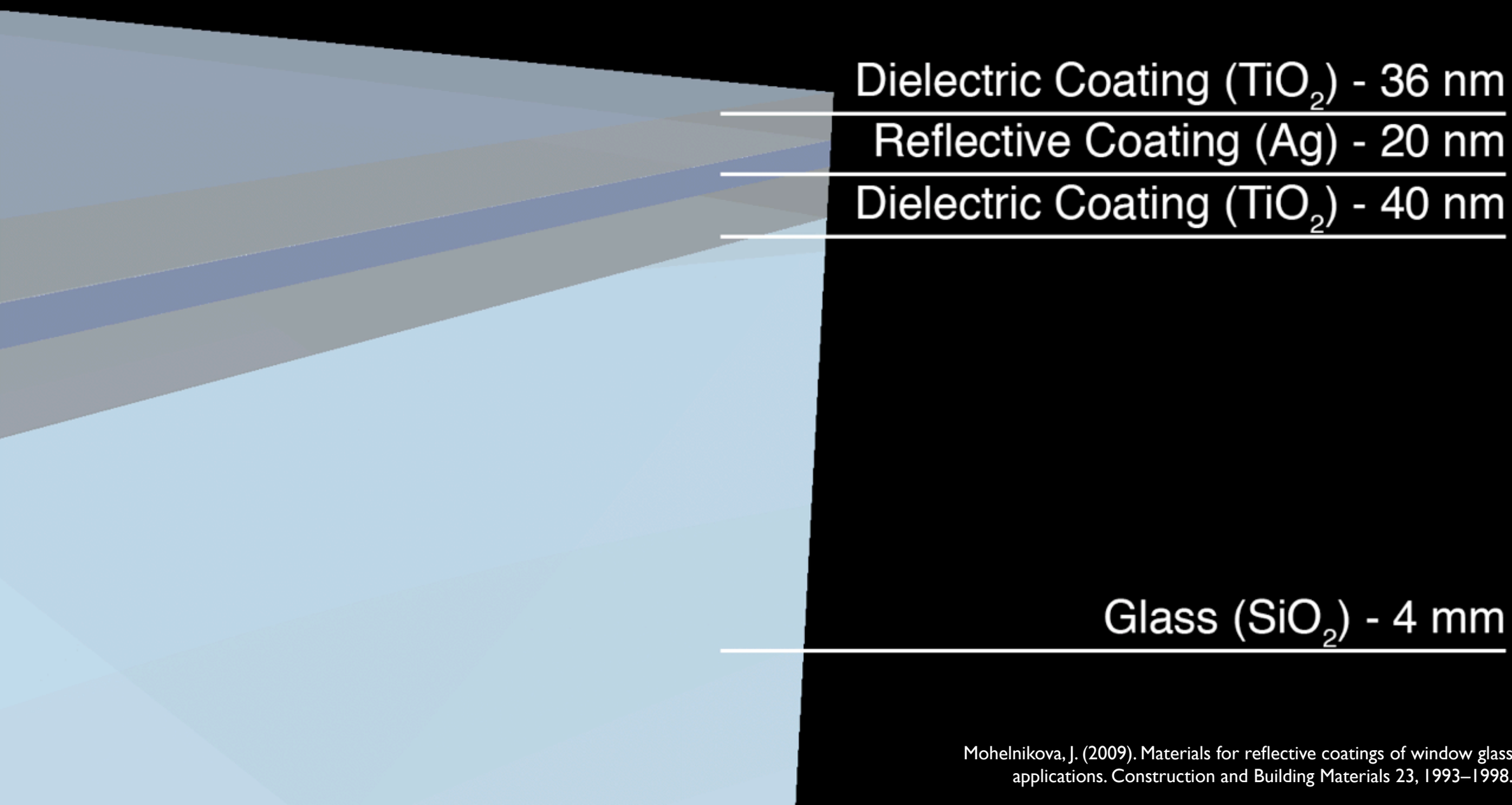
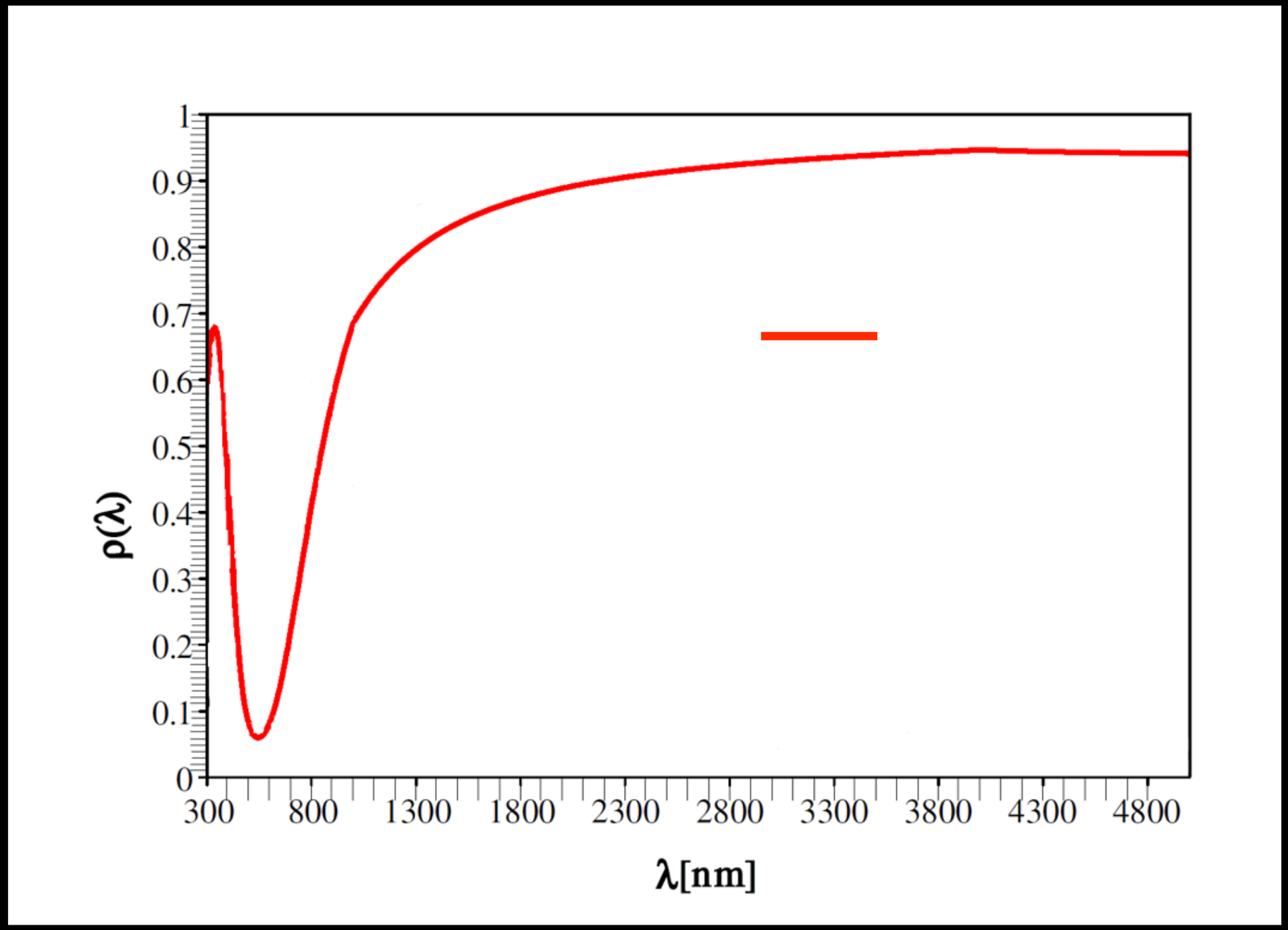


HEAT MIRROR GLASS NANO-STRUCTURE



Mohelnikova, J. (2009). Materials for reflective coatings of window glass applications. Construction and Building Materials 23, 1993–1998.

HEAT MIRROR GLASS SPECTRAL PROPERTIES



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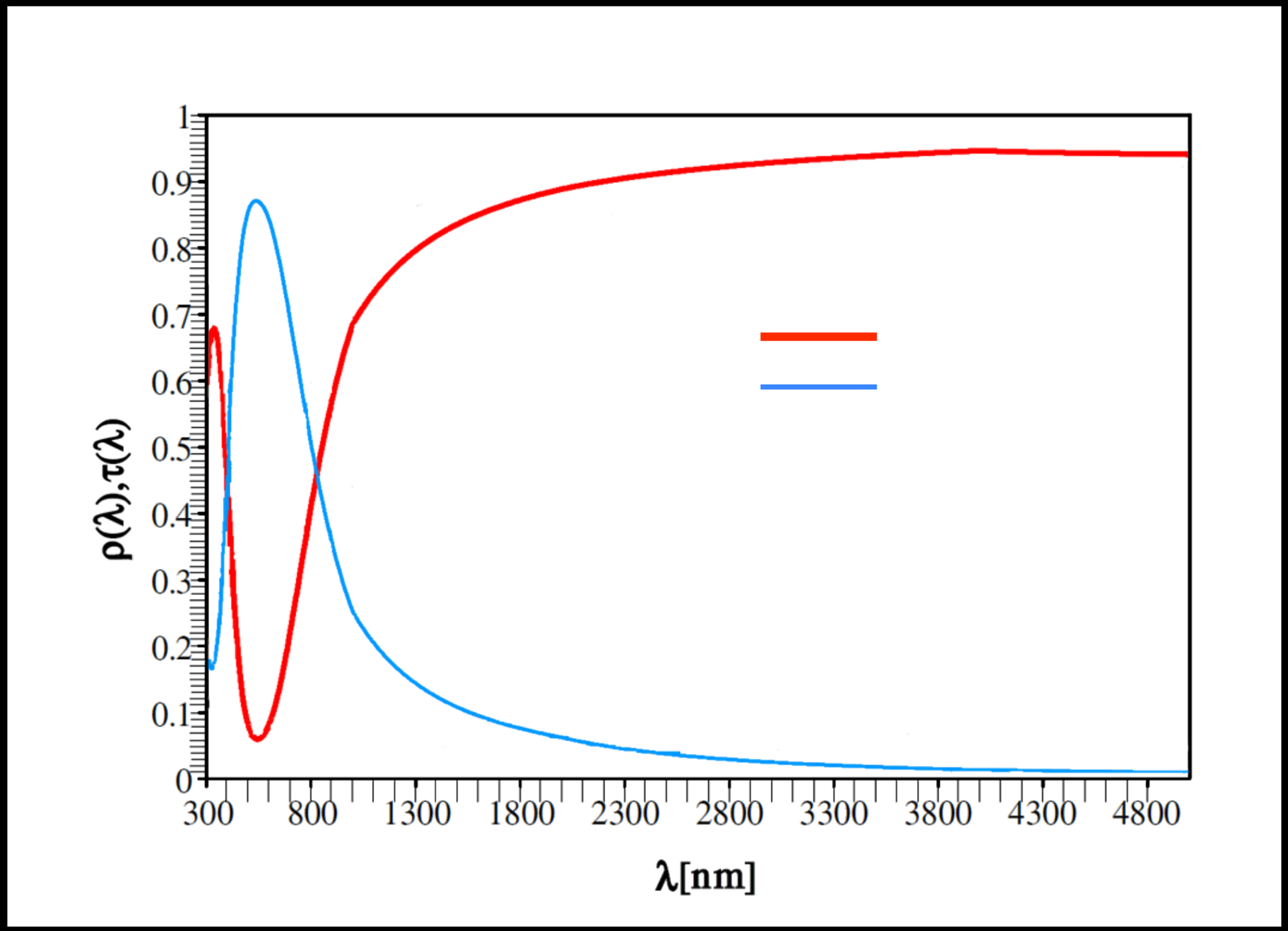

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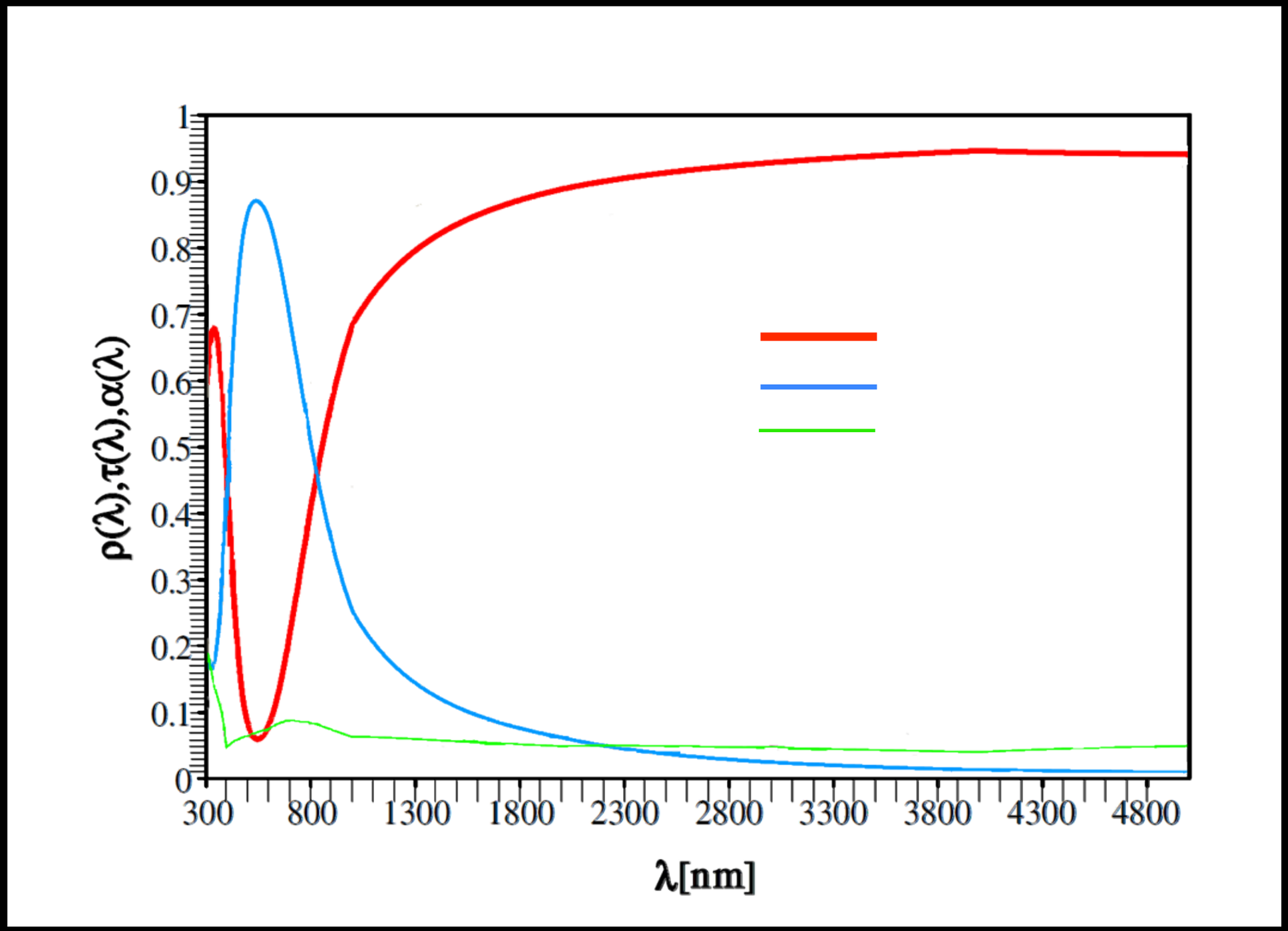

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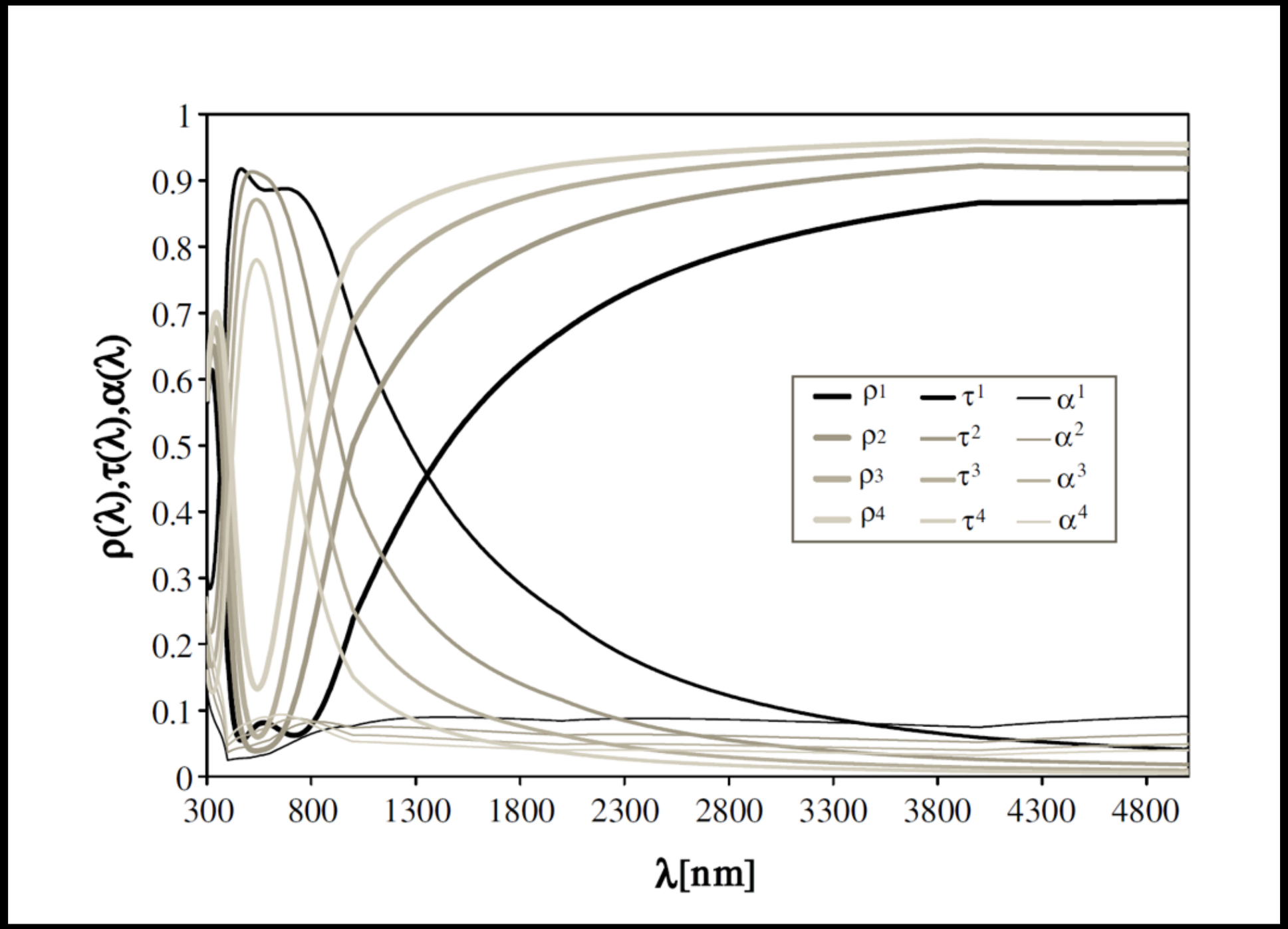


Properties Vary With Thickness of Silver Layer

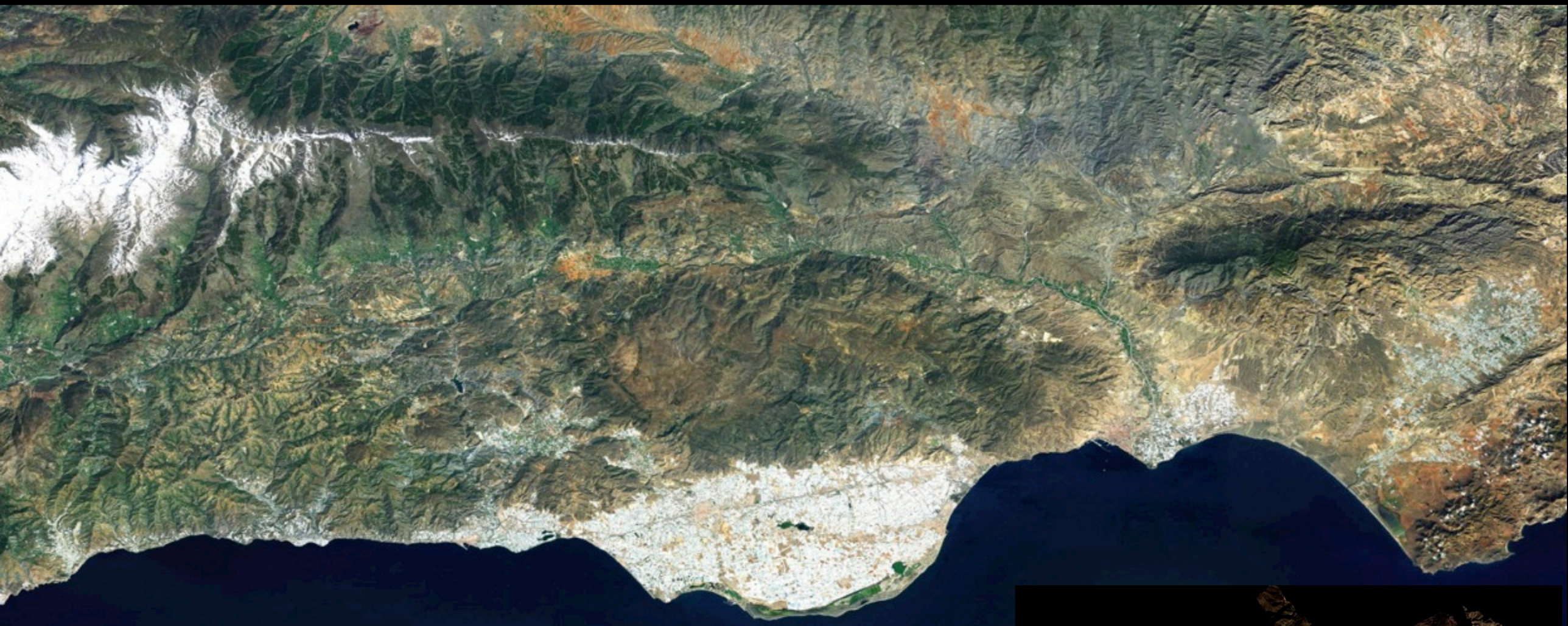
Mohelnikova, J. (2009). Materials for reflective coatings of window glass applications. Construction and Building Materials 23, 1993–1998.

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



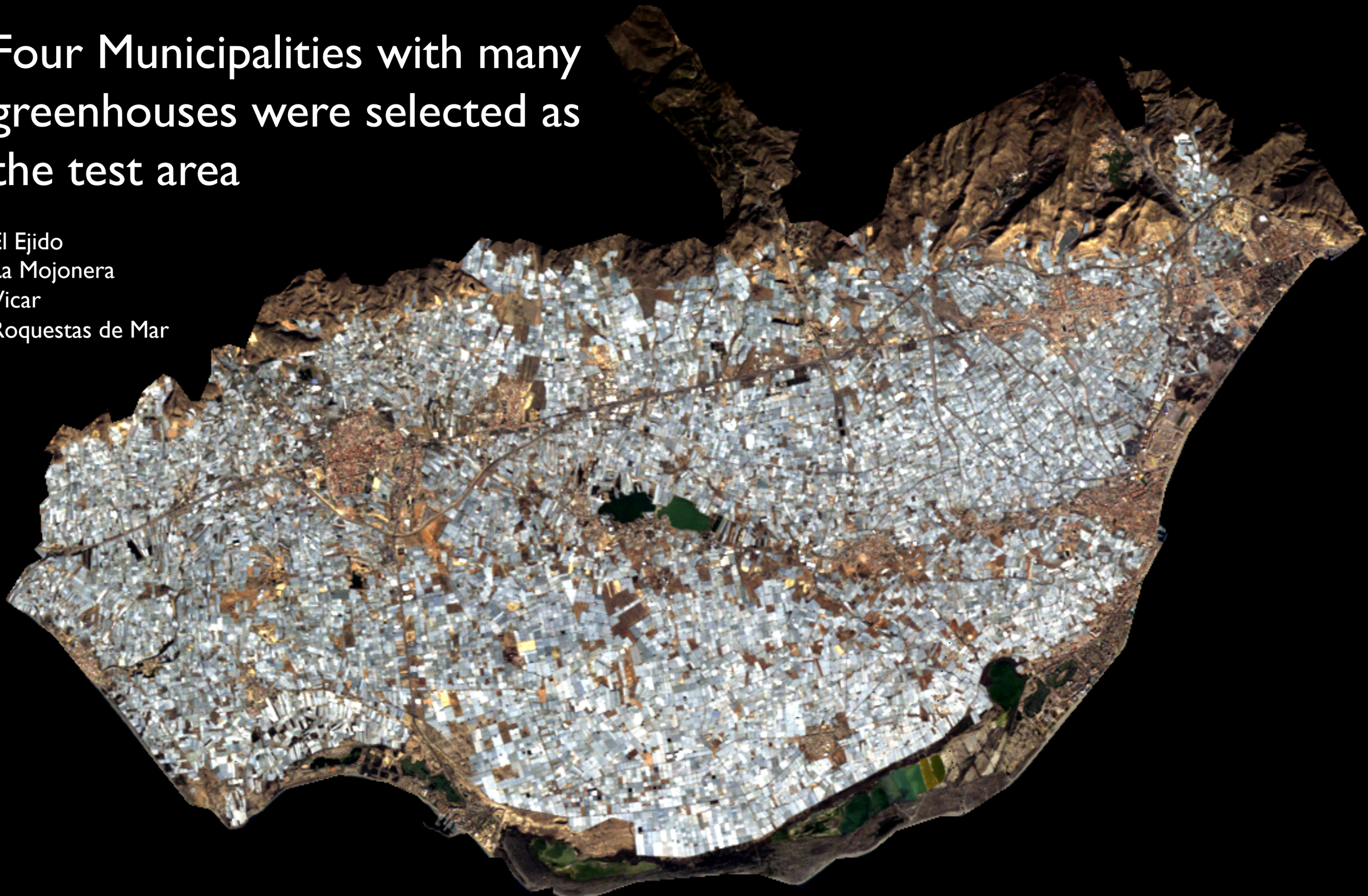
Four Municipalities with many greenhouses were selected as the test area

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

Selection of the Test Area

Selection of the Test Area

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

Date of Image	Total Area of Sample (m2)	Greenhouse Area of Sample (m2)	Pixels Classified as Greenhouse in Sample	Area Classified as Greenhouse in Sample (m2)	Ratio of the Actual Greenhouse Area to the Pixel Estimate
Nov 12, 2006	31250860	22865897	22450	20205000	1.1317
Feb 16, 2007	31250860	22865897	22695	20425500	1.1195
May 7, 2007	31250860	22865897	24675	22207500	1.0296
Jun 24, 2007	31250860	22865897	23803	21422700	1.0674
Aug 11, 2007	31250860	22865897	22711	20439900	1.1187
Aug 27, 2007	31250860	22865897	22773	20495700	1.1156
Jul 15, 2009	31250860	22865897	23898	21508200	1.0631
Dec 6, 2009	31250860	22865897	22550	20295000	1.1267
Feb 24, 2010	31250860	22865897	22734	20460600	1.1176
Oct 22, 2010	31250860	22865897	23055	20749500	1.1020
Dec 9, 2010	31250860	22865897	22401	20160900	1.1342

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

This is likely the result of mixed pixels.

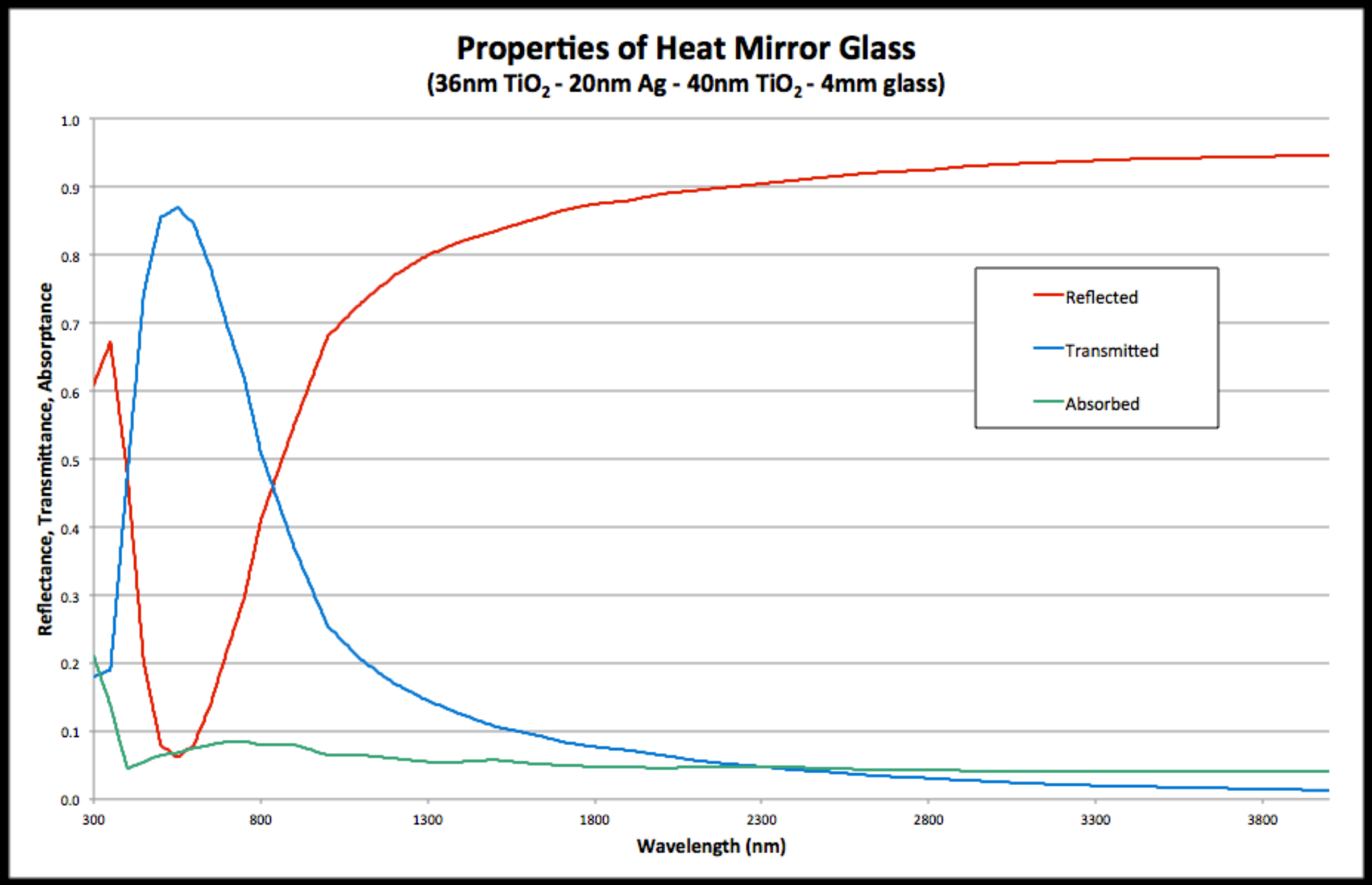
Comparison of Classified Area to Actual Area

Date of Image	Ratio of the Actual Greenhouse Area to the Pixel Estimate	Pixels Classified as Greenhouse in Whole Scene	Estimated Area of Greenhouses in Whole Scene (km2)
Nov 12, 2006	1.1317	154203	157.1
Feb 16, 2007	1.1195	159570	160.8
May 7, 2007	1.0296	182469	169.1
Jun 24, 2007	1.0674	163495	157.1
Aug 11, 2007	1.1187	151282	152.3
Aug 27, 2007	1.1156	153301	153.9
Jul 15, 2009	1.0631	156442	149.7
Dec 6, 2009	1.1267	146004	148.0
Feb 24, 2010	1.1176	161521	162.5
Oct 22, 2010	1.1020	169620	168.2
Dec 9, 2010	1.1342	144671	147.7
			156.9

Applying these underestimations to the 11 images, the area of greenhouse roof in Almeria is around 156.9 km

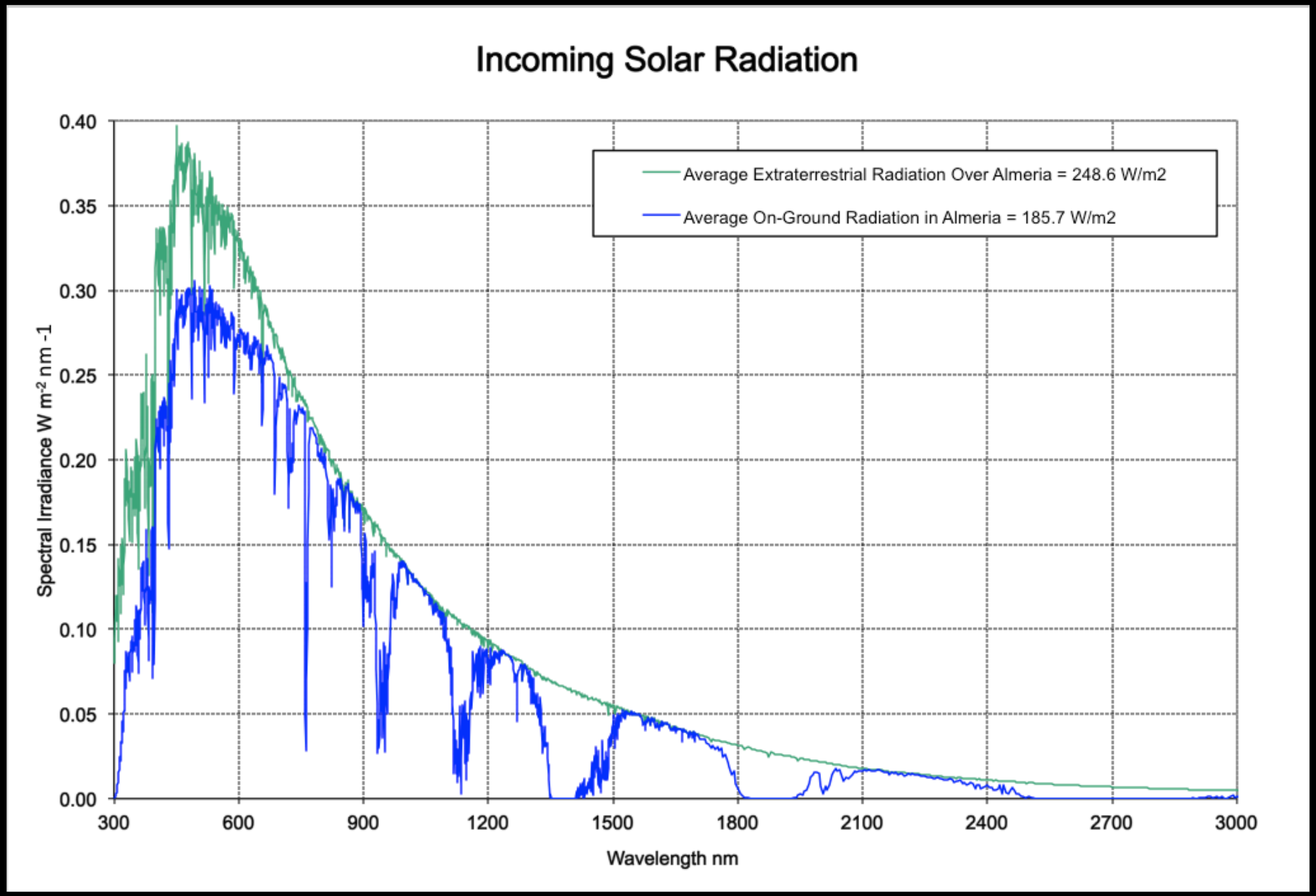
Part 11: Calculating the Portions of Sunlight Going to Electricity Generation and Plant Growth

Spectral Properties of Low-E (Heat Mirror) Glass Were Converted Over Into Excel



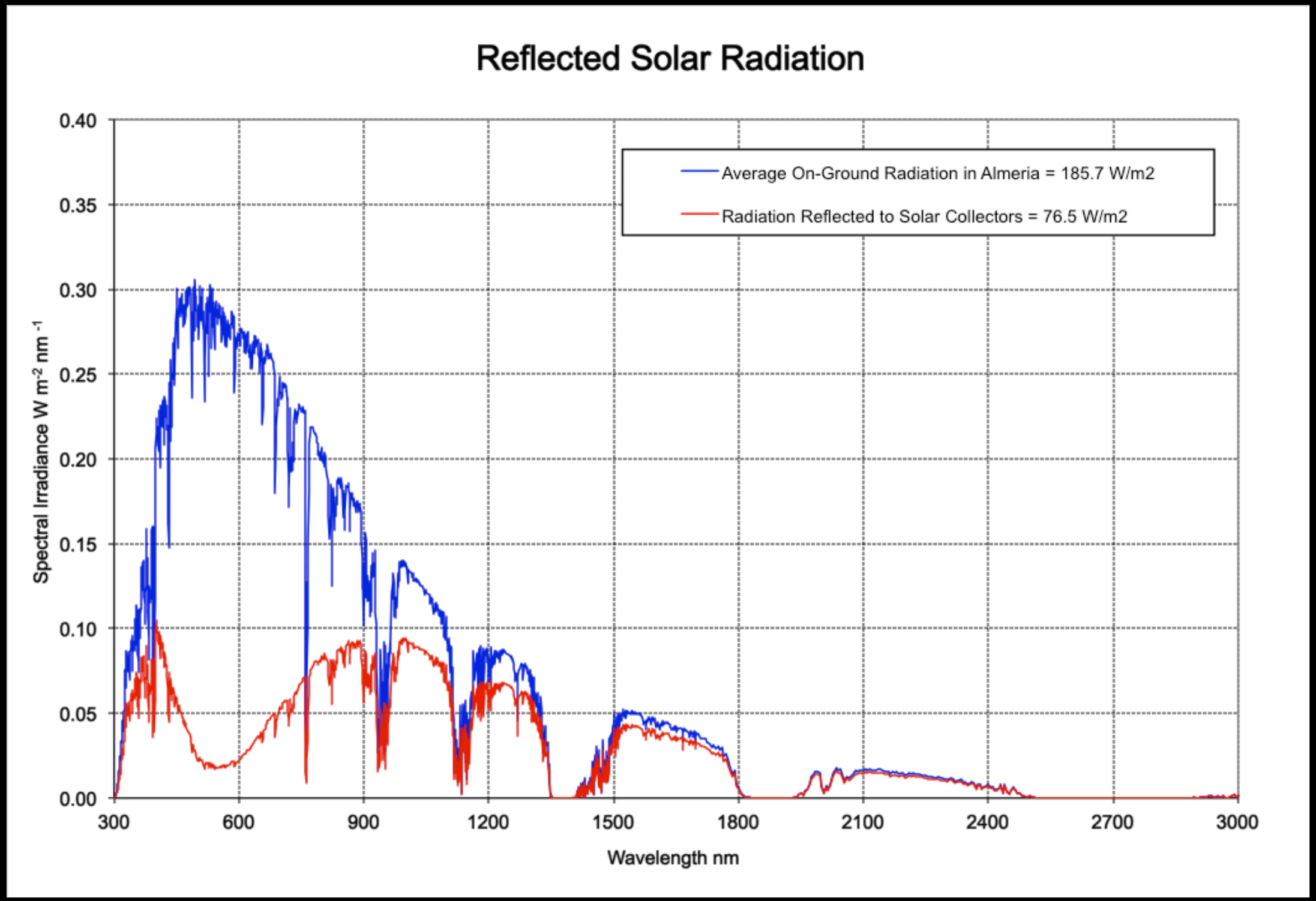
Mohelnikova, J. (2009). Materials for reflective coatings of window glass applications. Construction and Building Materials 23, 1993–1998.

Total Incoming Radiation Into Almeria was Obtained



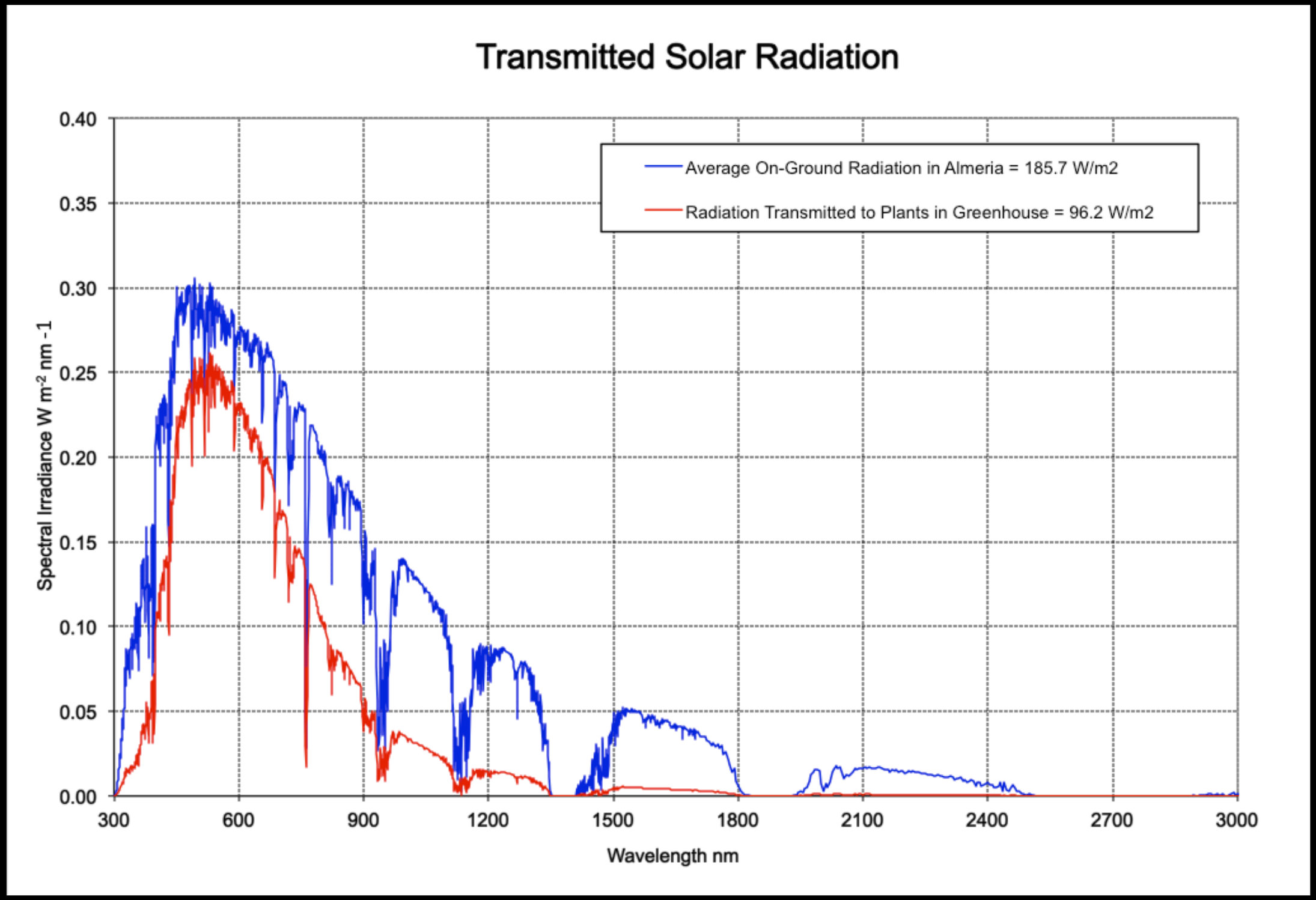
Mohelnikova, J. (2009). Materials for reflective coatings of window glass applications. Construction and Building Materials 23, 1993–1998.

The Reflected Portion Was Calculated



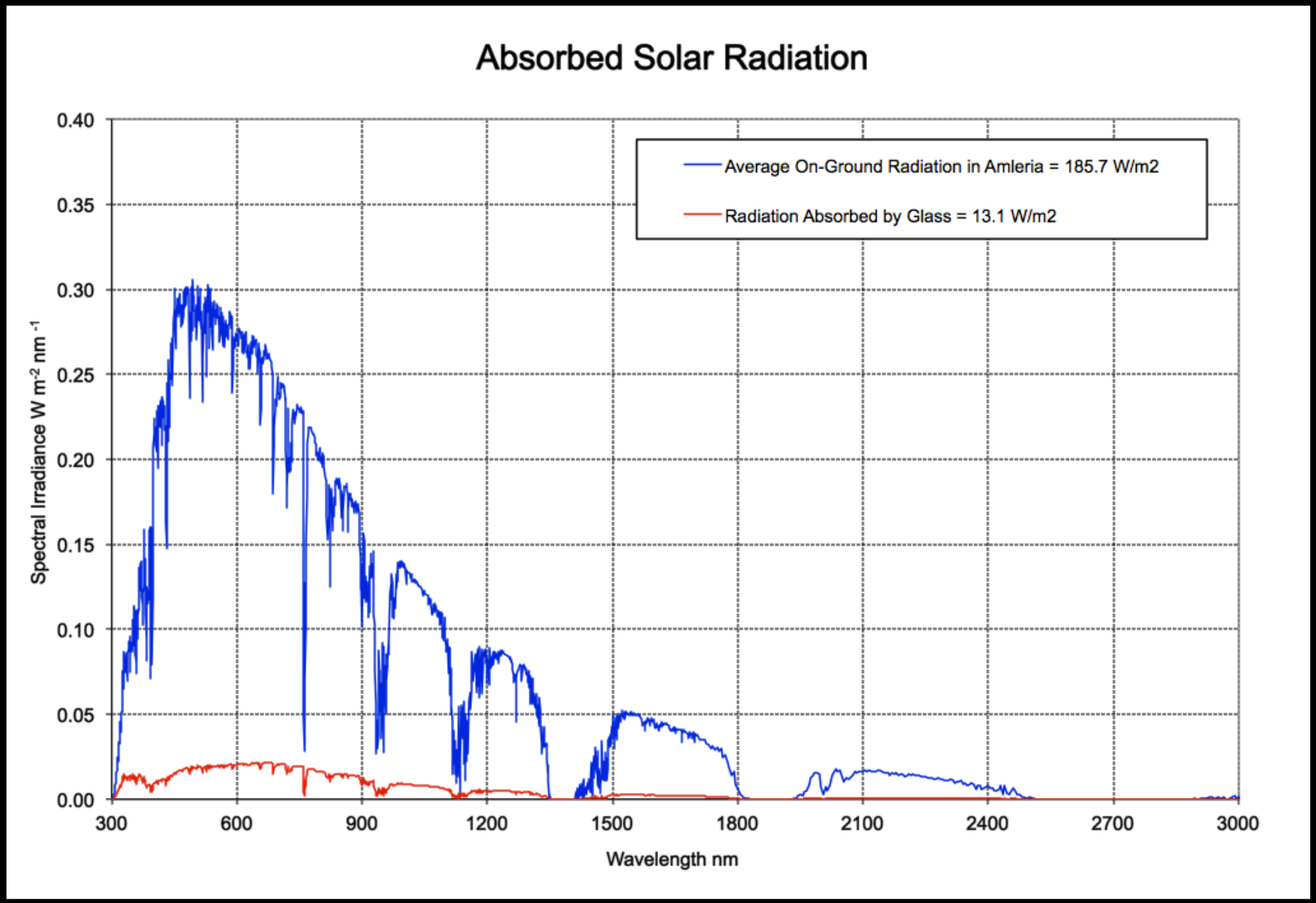
Mohelnikova, J. (2009). Materials for reflective coatings of window glass applications. Construction and Building Materials 23, 1993–1998.

The Transmitted Portion Was Calculated



Mohelnikova, J. (2009). Materials for reflective coatings of window glass applications. Construction and Building Materials 23, 1993–1998.

The Absorbed Portion Was Calculated



Mohelnikova, J. (2009). Materials for reflective coatings of window glass applications. Construction and Building Materials 23, 1993–1998.

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 = 4.45 kWh/m2/day = 185.72W/m2	**185.72**
Process Occurring for Electricity Generation	**Resulting W/m²**
Portion Going to Pre-Heating Water for Electricity Generation	76.4
16% will strike elements of the greenhouse that do not reflect energy[1]	12.2
84% of the light will actually strike the glass[1]	64.2
At peak performance, 62% of energy will be lost in the conversion to electricity[2]	39.8
At peak performance, 38% of sunlight can be converted into electricity[2]	24.4
10% can be lost due to not operating at peak performance	2.4
Final Conversion of Solar to Electricity	**22.0**

On the Scale of Almeria	
Watts coming out of Almeria on Average	3446745448
Gigawatts coming out of Almeria on Average	**3.45 GW**

For comparison, the power consumption of NYC in 2004 was 5 GW[5]

[1]Mills D., Morrison, G. (1998). Compact Linear Fresnel Reflector Solar Thermal Power Plants. Solar Energy Vol. 68, No. 3, pp. 263–283

[2]Mills D., Morrison G., Pye J., Le Lièvre. P. (2006). Multi-tower Line Focus Fresnel Array Project. Journal of Solar Energy Engineering. Vol. 128

[5]New York City Energy Policy Task Force. (2004). New York City Energy Policy: An Electricity Resource Roadmap. A Report to Mayor Michael R. Bloomberg. http://www.nyc.gov/html/om/pdf/energy_task_force.pdf

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

Peak Incoming Solar Radiation = 900 W/m^2	**900**
Process Occurring for Electricity Generation	**Resulting W/m^2**
Portion Going to Pre-Heating Water for Electricity Generation	370.5
16% will strike elements of the greenhouse that do not reflect energy[1]	59.3
84% of the light will actually strike the glass[1]	311.2
At peak performance, 62% of energy will be lost in the conversion to electricity[2]	192.9
At peak performance, 38% of sunlight can be converted into electricity[2]	**118.3**

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]

[1]Mills D., Morrison, G. (1998). Compact Linear Fresnel Reflector Solar Thermal Power Plants. Solar Energy Vol. 68, No. 3, pp. 263–283

[2]Mills D., Morrison G., Pye J., Le Lièvre. P. (2006). Multi-tower Line Focus Fresnel Array Project. Journal of Solar Energy Engineering. Vol. 128

[6]The Energy Blog: About Parabolic Trough Solar. http://thefraserdomain.typepad.com/energy/2005/09/about_parabolic.html

2) Greenhouse System Generates Electricity on its Own

Average Incoming Solar Radiation = 4.45 kWh/m2/day = 185.72W/m^2	**185.72**
Process Occurring for Electricity Generation	**Resulting W/m2**
Portion Going to Pre-Heating Water for Electricity Generation	76.4
16% will strike elements of the greenhouse that do not reflect energy[1]	12.2
80% of the light will actually strike the glass[1]	64.2
At peak performance, 87% of energy will be lost in the conversion to electricity[2]	55.9
At peak performance, 13% of sunlight can be converted into electricity[2]	8.3
10% can be lost due to not operating at peak performance	0.8
Final Conversion of Solar to Electricity	**7.5**

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]

[1]Mills D., Morrison, G. (1998). Compact Linear Fresnel Reflector Solar Thermal Power Plants. Solar Energy Vol. 68, No. 3, pp. 263–283

[2]Mills D., Morrison G., Pye J., Le Lièvre. P. (2006). Multi-tower Line Focus Fresnel Array Project. Journal of Solar Energy Engineering. Vol. 128

[5]New York City Energy Policy Task Force. (2004). New York City Energy Policy: An Electricity Resource Roadmap. A Report to Mayor Michael R. Bloomberg. http://www.nyc.gov/html/om/pdf/energy_task_force.pdf

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

Incoming Solar Radiation = 900 W/m2	**900**
Process Occurring for Electricity Generation	**Resulting W/m2**
Portion Going to Pre-Heating Water for Electricity Generation	355.7
15.5% will strike elements of the greenhouse that do not reflect energy[1]	55.1
80.5% of the light will actually strike the glass[1]	286.3
At peak performance, 87% of energy will be lost in the conversion to electricity[2]	249.1
At peak performance, 13% of sunlight can be converted into electricity[2]	**37.2 GW**

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]

[1]Mills D., Morrison, G. (1998). Compact Linear Fresnel Reflector Solar Thermal Power Plants. Solar Energy Vol. 68, No. 3, pp. 263–283

[2]Mills D., Morrison G., Pye J., Le Lièvre. P. (2006). Multi-tower Line Focus Fresnel Array Project. Journal of Solar Energy Engineering. Vol. 128

[6]The Energy Blog: About Parabolic Trough Solar. http://thefraserdomain.typepad.com/energy/2005/09/about_parabolic.html

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.

Mohelnikova, J. (2009). Materials for reflective coatings of window glass applications. Construction and Building Materials 23, 1993–1998.

1) Greenhouse System is Used to Grow Tomatoes

Average Incoming Solar Radiation = 4.45 kWh/m2/day = 185.72W/m^2	**185.72**
Process Occurring for Biomass and Food	**Resulting W/m^2**
Portion Going to Producing Biomass Transmitted Through Glass and Slipping Through Mirrors	102.3
32.03% is outside the wavelength usable by photosynthesis (700nm-4000nm)	32.8
67.97% is inside the wavelengths usable by photosynthesis (300nm-700nm)	69.6
86% is lost due to light not striking chloroplasts, degrading short-wavelength photons, etc.	59.8
14% is converted into biomass[3]	9.7
40% of biomass is consumed by the plant[3]	3.9
60% of biomass is used to build the plant[3]	5.8
Conversion factor of photosynthesis wattage to kg/yr is 1.07 W/kg/yr	6.3 kg/m^2/yr
Tomatoes allocate 57–59% of their biomass to their fruit[4]	**3.6 kg/m^2/yr**

On the Scale of Almeria	
Kilograms of total biomass being produced	981,119,478 kg/yr
Kilograms of tomatoes being produced	**569,049,297 kg/yr**

[3]Hall D. and Rao K, Photosynthesis Cambridge University Press, UK. 211 pp. ISBN 0521-43622-2

[4]Heuvelink, E. (1995). Effect of plant density on biomass allocation to the fruits in tomato (Lycopersicon esculentum Mill.). Scientia Horticulturae Volume 64, Issue 3, Pages 193-201

2) Greenhouse System is Used to Grow Algae Producing Biofuel

Average Incoming Solar Radiation = 4.45 kWh/m2/day = 185.72W/m^2	**185.72**
Process Occurring for Biomass and Food	**Resulting W/m^2**
Portion Going to Producing Biomass and Food	102.3
32.03% is outside the wavelength usable by photosynthesis (700nm-4000nm)	32.8
67.97% is inside the wavelengths usable by photosynthesis (300nm-700nm)	69.6
86% is lost due to light not striking chloroplasts, degrading short-wavelength photons, etc.	59.8
14% is converted into biomass[3]	9.7
40% of biomass is consumed by the plant[3]	3.9
60% of biomass is used to build the plant[3]	5.8
40% of remaining biomass is used for plant components other than oil	2.3
60% of remaining biomass is converted into oil that can be used as biofuel	**3.5**

On the Scale of Almeria	
Watts of total biofuel being produced	529469251
Gigawatts of total biofuel being produced	**0.53 GW**

[3]Hall D. and Rao K, Photosynthesis Cambridge University Press, UK. 211 pp. ISBN 0521-43622-2

[4]Heuvelink, E. (1995). Effect of plant density on biomass allocation to the fruits in tomato (Lycopersicon esculentum Mill.). Scientia Horticulturae Volume 64, Issue 3, Pages 193-201

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

Average Incoming Solar Radiation = 4.45 kWh/m2/day = 185.72W/m^2	**185.72**
Process Occuring for Absorption by Desalination Equipment	**Resulting W/m2**
Total energy being converted to heat within the greenhouse and coming out of the greenhouse's CSP	132.4
10% will be lost to the air, soil and equipment as hot water is passed through pipes and transfers mediums	13.24
90% will be available to desalinate seawater	119.17
Given heat capacities of seawater, this amount that can be brought over the boiling point from an initial 18°C	4.8E-05 kg/s/m^2
Assuming sea temperature is 18°C and water will be returned at 50°C, some energy will be lost	2.3E-06 kg/s/m^2
Seawater that could be desalinated (kg/s)	4.5E-05 kg/s/m^2
Seawater that could be desalinated (kg/day)	**3.91 kg/day/m^2**

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 = 185.72W/m^2	**185.72**
Process Occurring for Absorption by Glass, Ground and Air	**Resulting W/m2**
7.0% is absorbed by the glass itself	26.24
50% of light falls through spaces between the glass and is absorbed	6.12
Hot water moving through pipes transfers heat to the system	13.24
Total energy absorbed by ground and air	**45.60**

On the Scale of Almeria	
Watts Being Lost to Ground and Air on Average	7156142693
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

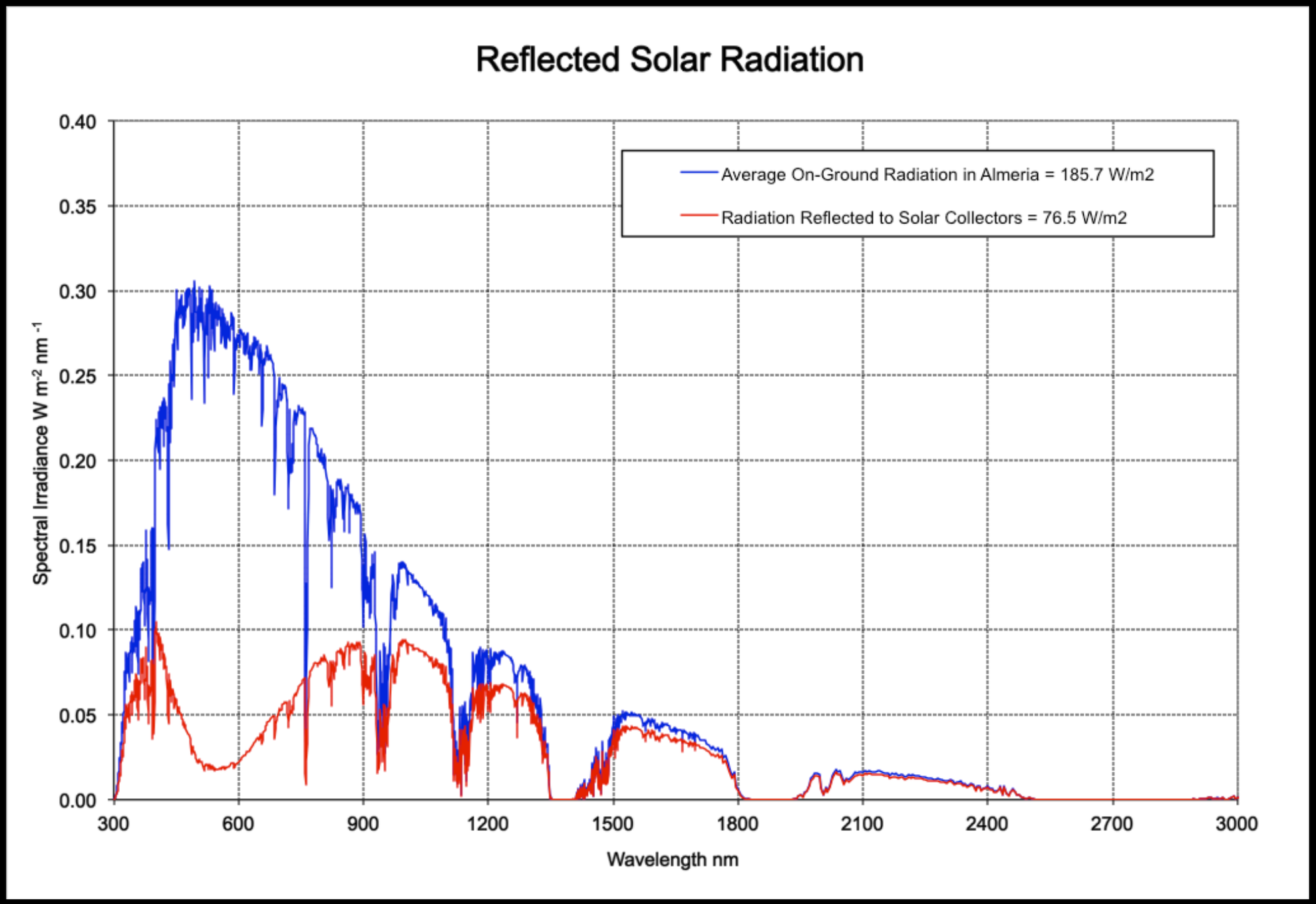
Type of Energy/Product Produced	W/m2	GW Over all Almeria
Electricity	22.0	3.45
Tomatoes (energy)	3.4	0.53
Desalinated Water	111.7	17.53
Waste Heat Placed in the Sea	7.0	1.16
Waste Heat Absorbed by Glass, Air, and Ground	45.6	7.16
TOTAL	185.7	29.83

Efficiency of Electricity and Tomatoes = 13.7%

Efficiency of Electricity, Tomatoes, and Desalinated Water = 73.8%

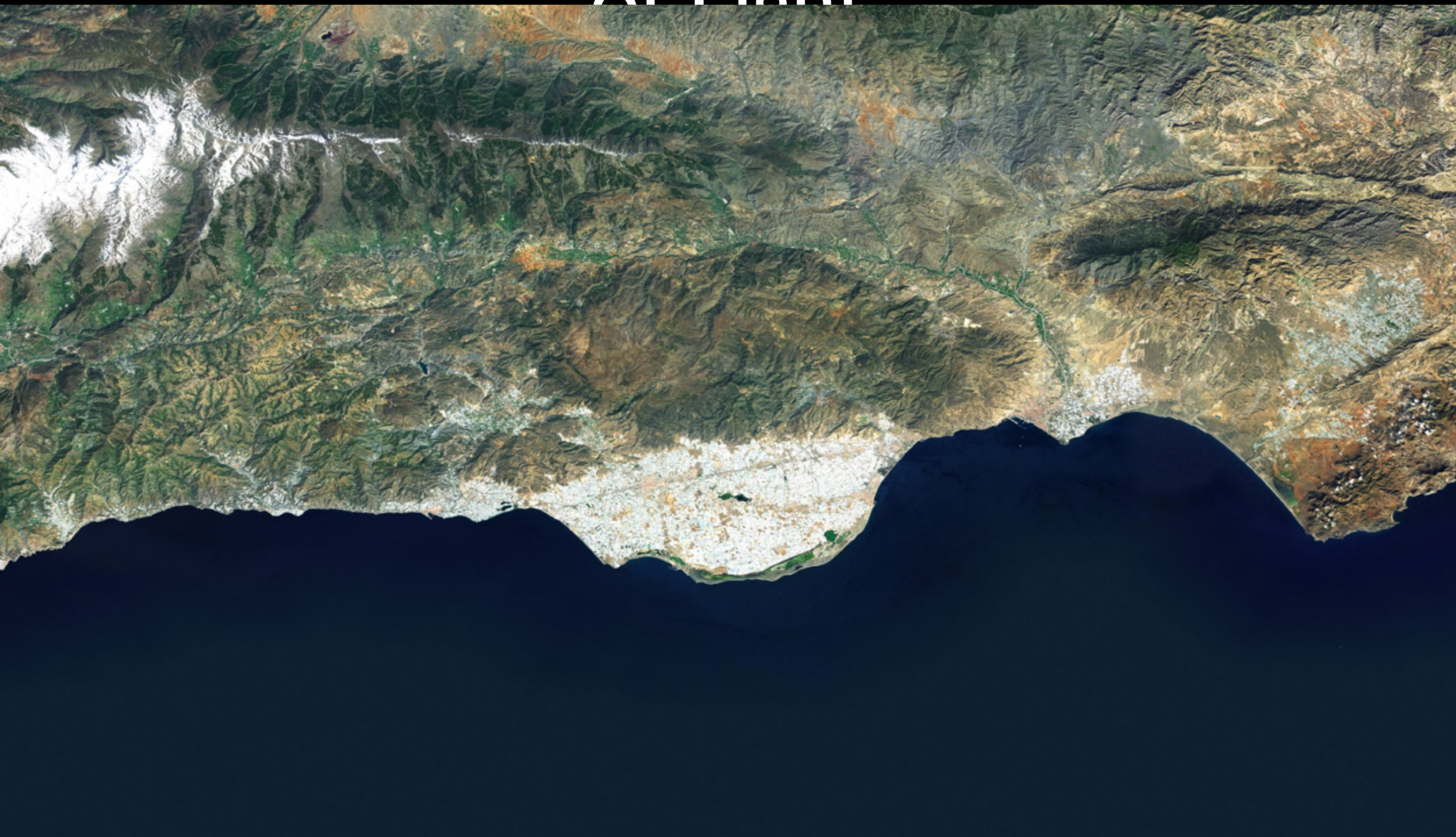
Argument Supporting Design: Almeria Albedo Analysis

Some Visible Light That Could Nourish Plants is Reflected



18.9% of visible light (300nm-700nm) is reflected

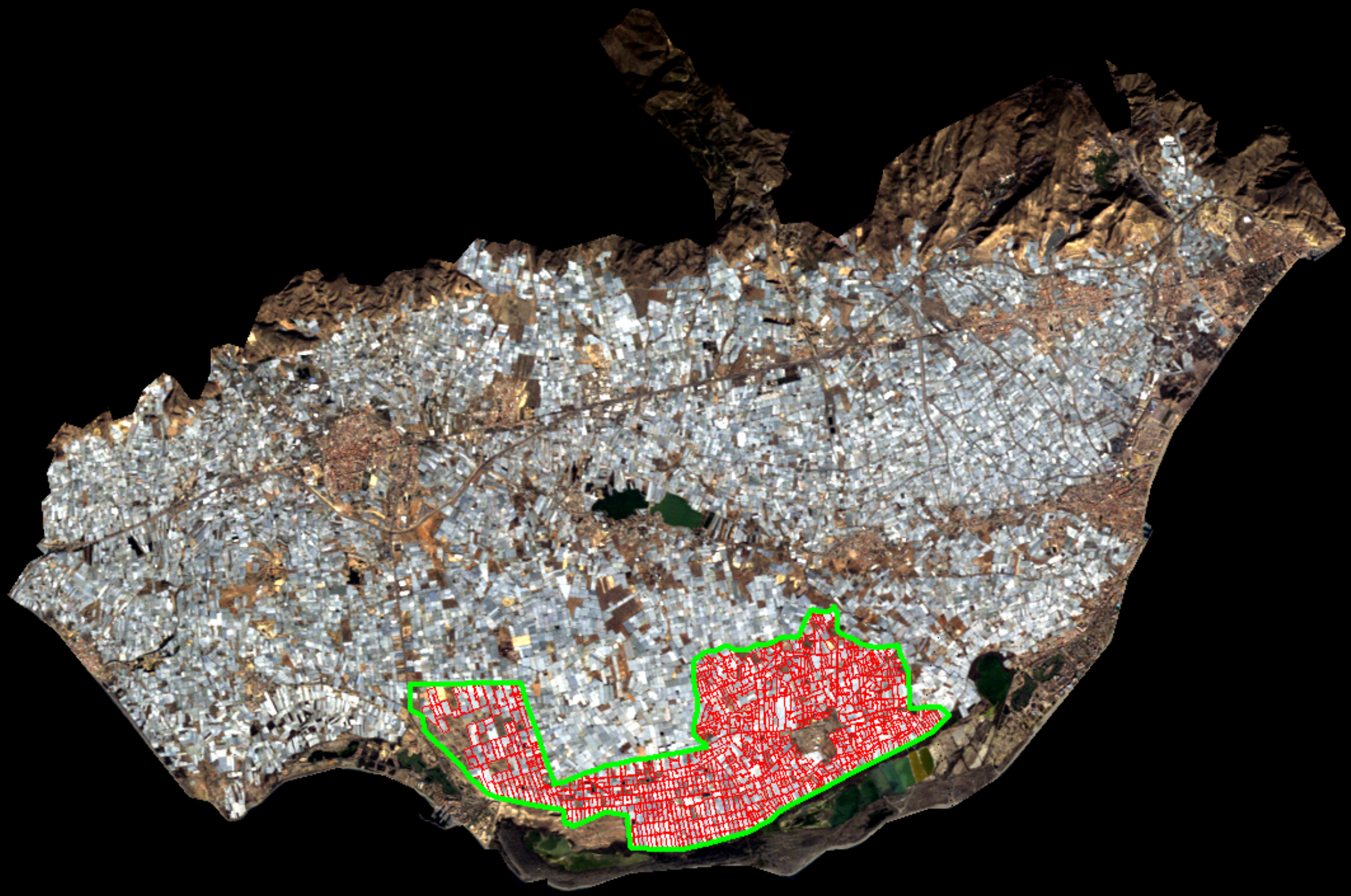
However, the Present Greenhouses Already Reflect a Lot of Light



However, the Present Greenhouses Already Reflect a Lot of Light

However, the Present Greenhouses Already Reflect a Lot of Light

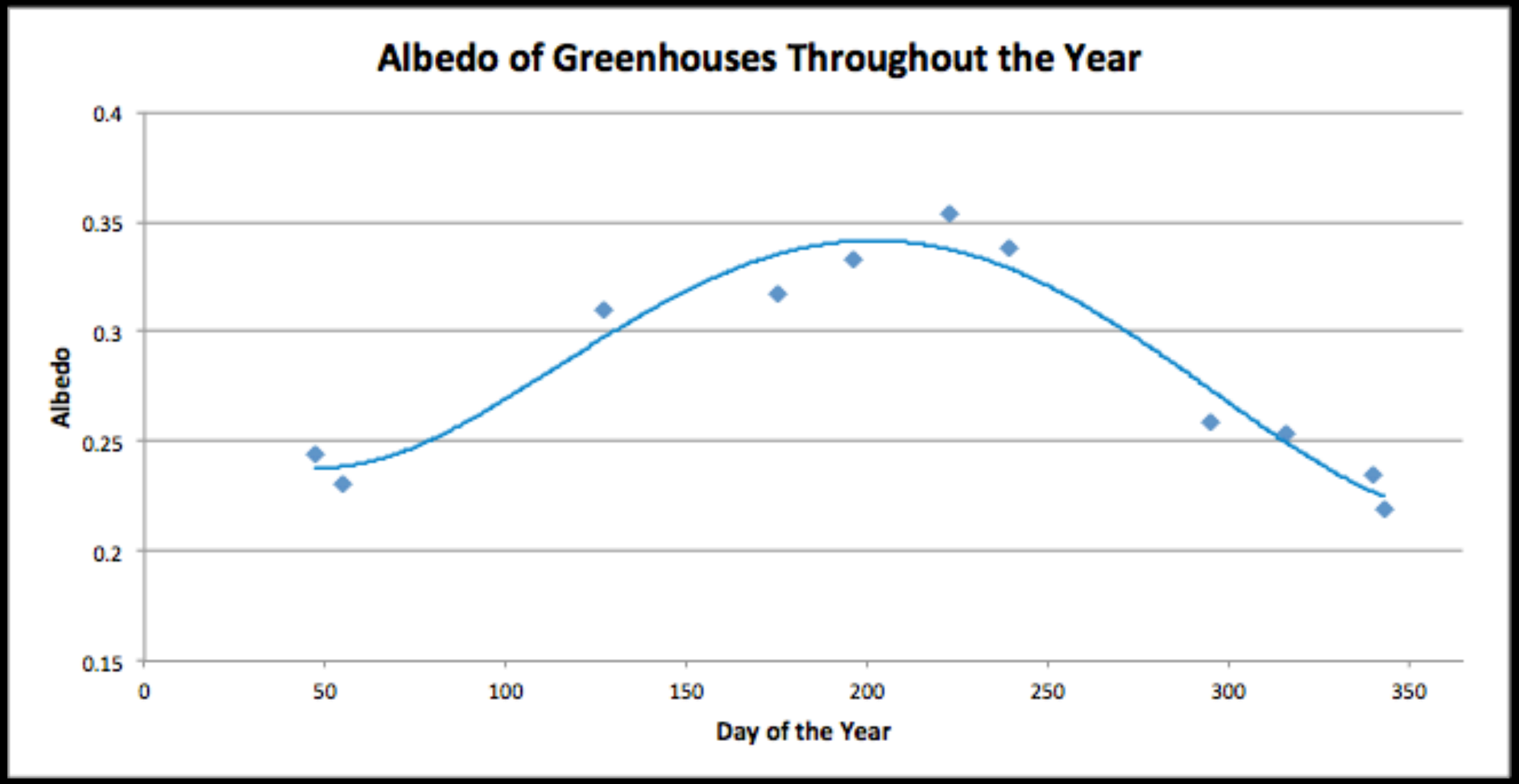
LANDSAT Albedo of the Greenhouse Sample Was Analyzed



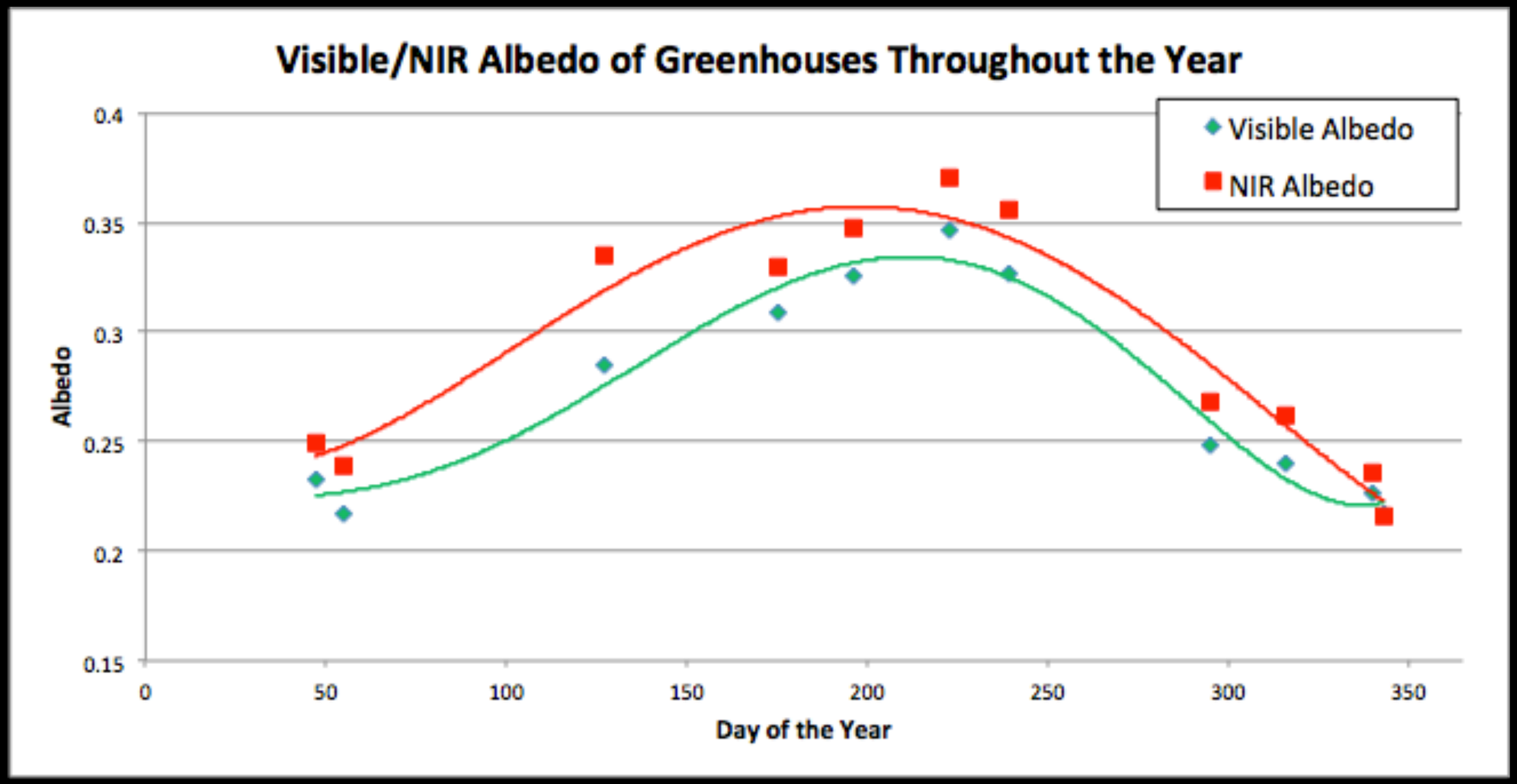
Average Albedo of the Eleven LANDSAT Images

Date of Image	Broadband Albedo	Visible Albedo	NIR Albedo
Nov 12, 2006	0.25	0.24	0.26
Feb 16, 2007	0.24	0.23	0.25
May 7, 2007	0.31	0.28	0.33
Jun 24, 2007	0.32	0.31	0.33
Aug 11, 2007	0.35	0.35	0.37
Aug 27, 2007	0.34	0.33	0.36
Jul 15, 2009	0.33	0.33	0.35
Dec 6, 2009	0.23	0.23	0.24
Feb 24, 2010	0.23	0.22	0.24
Oct 22, 2010	0.26	0.25	0.27
Dec 9, 2010	0.22	0.22	0.22
Average	**0.28**	**0.27**	**0.29**

Annual Albedo Cycle Over the Eleven LANDSAT Images



Visible and NIR Albedo Cycle Over the Eleven LANDSAT Images



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?)