Solar Power Limitations and U.S. Energy Needs

The Six Power Estimates

by

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Purpose

The intent of this paper is to answer the question, “Is solar energy a viable power source to meet United States (U.S.) energy needs?” Solar power prices and cost benefit considerations are not part of this paper, nor are ecological considerations, nor are the cost of installing and maintaining any of the solar power equipment over time. This paper is purely to provide the realities of the available incident solar power and the current capabilities of the 2012 solar power arrays. This paper should be used as a source for follow on cost benefit analysis, sustainment considerations over time, investment strategy and identification of the main scientific and manufacturing limitation to solar power that should drive research and development investments.

This paper presents six sets of calculations based on the U.S. 2011 energy consumption rates and the solar power science of 2012[(1)]. The six sets of calculations presented are; Maximum theoretical power, Minimum area using maximum realistic power, Maximum realistic power, Minimum area using realistic total power, Best effort power and a Tesla S sedan electric automobile example.

Maximum theoretical power

This calculation is the total potential power collection using 100% efficient solar cells covering all of America with no power reductions due to solar cell performance loss over time, or loss caused by battery storage and retrieval or loss due to power conversion or A/C wire transmission. The power is reduced by the latitude of the collection area (L) the day time rotation reductions in longitude (L) and the time when the cells rest at night (N). All numbers are rounded up in favor of the solar power production.

<u>Executive result</u>

The total energy that is theoretically possible if we converted every piece of U.S. soil to solar cell collection areas with 100% collection and efficiency with no losses to any factor is 4.936×10^{22} joules = 4.678×10^{19} btu which is 480 times the U.S. consumption in 2011.

Naturally, to completely cover the U.S. in solar cells and collect all of the incident energy would be a catastrophic event causing rapid cooling, loss of all plant and animal life and unacceptable changes in weather patterns. It is however, a point of theatrical discussion of the energy delivered to the continental U.S. for further dialog.

Minimum area using maximum theatrical power

This calculation provides the area needed in square kilometers and a selected state that would be of equal area that would be converted into solar cell fields to power the U.S. energy needs if the maximum theoretical power numbers are used.

<u>Executive result</u>

The area needed to power the U.S. using maximum theoretical power with 100% collection and efficiency with no losses to any factor is 16,807 square kilometers, or approximately 80% of New Jersey. This is the minimum theoretical area that would power the 2011 U.S. energy needs.

This collection and efficiency are unachievable using the manufacturing and technology limits of 2012 however, it is a point of theatrical discussion of the optimum manufacturing and physical perfection of the solar cell and future design field area requirements.

Realistic total power

This calculation uses current technology solar cell performance covering all of America with no power reductions due to solar cell performance loss over time. The power is reduced by the limited frequency (F) of the solar cell conversion band, the limited efficiency of the best perming cell (E) the latitude of the collection area (L) the day time rotation reductions in longitude (L) and the time when the cells rest at night (N). The power is reduced by the conversion from direct current (DC) to alternating current (AC) losses and AC wire transmissions losses. All numbers are rounded in accordance with scientific significant digits.

<u>Executive result</u>

The total energy that is theoretically possible if we converted every piece of U.S. soil to solar cell collection areas with realistic (FELLN) power and reductions for A/C conversion and wire transmission loss is 3.083×10^{20} joules/year = 2.921×10^{17} btu/year or just over **three** times the needed 2011 power.

Naturally, to completely cover the U.S. in solar cells and collect all of the incident energy would be a catastrophic event causing rapid cooling, loss of all plant and animal life and unacceptable changes in weather patterns. It is however, a point of realistic discussion of the energy delivered to the continental U.S. for further dialog.

Minimum area using realistic total power

This calculation provides the area needed in square kilometers and the selected States that would be of equal area that would be converted into solar cell fields to power the U.S. energy needs if the realistic power numbers are used.

<u>Executive result</u>

The area needed to power the U.S. using maximum realistic (FELLN) power with reductions for A/C conversion and wire transmission loss is 2,757,137 km^2 , or approximatley 34.1 % of the total continental U.S. and would consume these states;

Arizona	295,234 km^2

California	423,970 km^2
Colorado	269,837 km^2
Idaho	216,632 km^2
Nevada	286,367 km^2
New Mexico	315,194 km^2
Oregon	255,026 km^2
Utah	219,887 km^2
Washington	184,827 km^2
Wyoming	253,348 km^2
Total	2,720,322 km^2

Best effort power

This calculation is the amount of power produced if the U.S. made a "best effort" by converting 6.3% of all continental U.S. Federal land into solar cell collection areas. The power is reduced by the limited frequency (F) of the solar cell conversion band, the limited efficiency of the best perming cell (E) the latitude of the collection area (L) the day time rotation reductions in longitude (L) and the time when the cells rest at night (N). The power is also reduced by conversion from direct current (DC) to alternating current (AC) losses and AC wire transmissions losses. All numbers are rounded in accordance with scientific significant digits.

<u>Executive result</u>

The total energy with the U.S. best effort of converting 6.3% of continental possible if we converted every piece of U.S. Federal land into solar cell collection areas with realistic (FELLN) power and reductions for A/C conversion and wire transmission loss is 3.832×10^{15} btu/year or 3.9% of 2011 U.S. energy needs.

Tesla electric automobile

This calculation is the square kilometers and acres needed to power a Tesla S sedan used to commute 25 miles each way with a solar cell field 15 miles outside of Los Angeles, CA. The Tesla Company S sedan factory specifications are used for power consumption rates. The "realistic total power" assumptions (FELLN) are used without losses due to conversion to AC power however the power is reduced by direct current (DC) wire transmission losses over 15 miles. The Tesla Battery conservation and battery retrieval numbers and efficiencies are assumed included with the specifications of the Tesla S.

<u>Executive result</u>

To power the Tesla S sedan in Los Angeles, California using only solar panels, each owner will need to purchase and sustain 3.73 acres (122 meters x 122 meters area) or 15,000 m2 of solar cell coverage for a 25 mile (50 round trip) daily commute.

Executive Summary

Solar power is not currently ready for *deployment* as a viable, clean energy alternative due mainly to the manufacturing limitation of the solar cell itself. The frequency limitation in absorption (7nm) across the energy field of 2000nm makes the cell capable of only capturing 1.7% of the available energy.

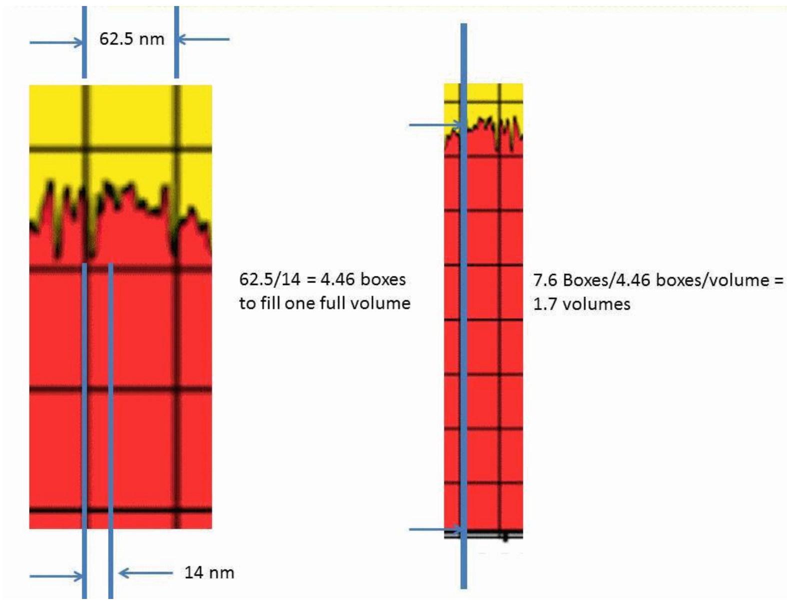


Diagram 13. Expanded 14 nm view while calculating the ratio of power collection to actual power available [21]

Executive Recommendation

1. Perform a solid cost benefit analysis of *deploying* the current restricted solar cells against the cost effectiveness of alternate green energy (nuclear and hydroelectric) and fossil fuel power cost effectiveness.

2. Redirect federal and state funding from *deployment* of these very limited solar cells wasting tax resources trying to harness energy with only 1.7% capture potential per dual filament.

3. Use federal, university and state resources to focus on research and development of better manufacturing processes that will liberate electrons on 70% of the viable frequency bands (250nm – 2000nm) with a 70% efficiency rate.

4. Calculate a threshold for viability of *deployment* of the new improved cell with a required frequency band of abortion and the efficiency of conversion based on the cost/benefit analysis from paragraph 1.

5. Provide guidelines for current cell capability for *deployment* of solar cell viability such as remote locations, low power needs and off-grid applications.

6. Fund *deployment* of current proven high capacity, clean power sources such as nuclear and hydroelectric power.

7. Use the six power estimates as a means of comparison for how year-by-year scientific and manufacturing process are improving. Re-calculate the six power estimates to measure the impact of leaps in capability and test for viability of deployment against the criteria set in paragraph 5.

8. Do a solid environmental impact statement coving the manufacturing and disposal of used solar cells against the use of traditional fossil fuel power production.

9. Check congressional testimony to validate if theoretical numbers were briefed to congress urging the funding of *deployment* rather than scientific, manufacturing research and development efforts.

All six calculations conform to the assumptions outlined in the *Methodology, Theory* and *Calculations* portion of this paper.

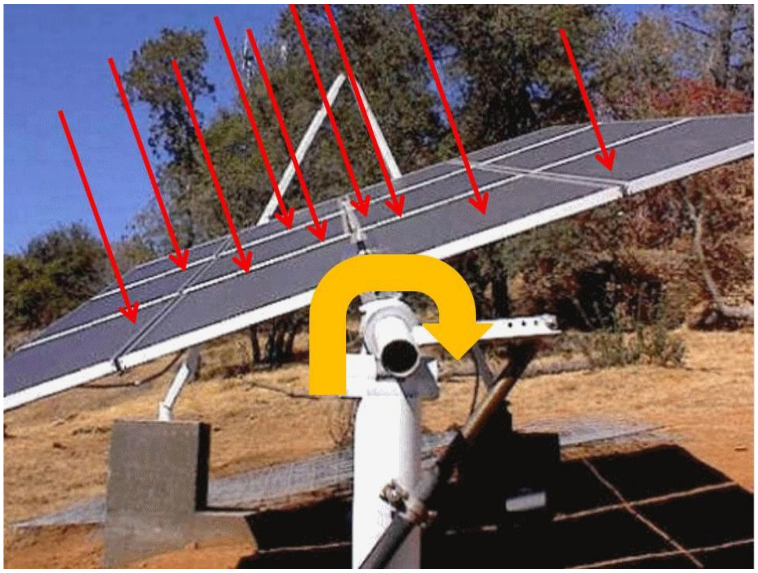
Methodology

Solar energy is a constant source of power that arrives to the earth from the sun. In real time, the amount of energy arriving to the earth is a function of several factors to include the atmosphere, weather, rotation of the earth, location in latitude of the collection area, the size of the collection area, the intelligent design of the collection arrays, the bandwidth of the collected frequencies and the efficiency of the solar cells themselves.

The distribution of that energy to remote customers is also constrained by several factors to include direct current (DC) battery storage and retrieval, conversion of the DC power to alternating current (AC) and losses due to power line transition. All of these factors are considered in this paper with the best industry and scientific real world numbers.

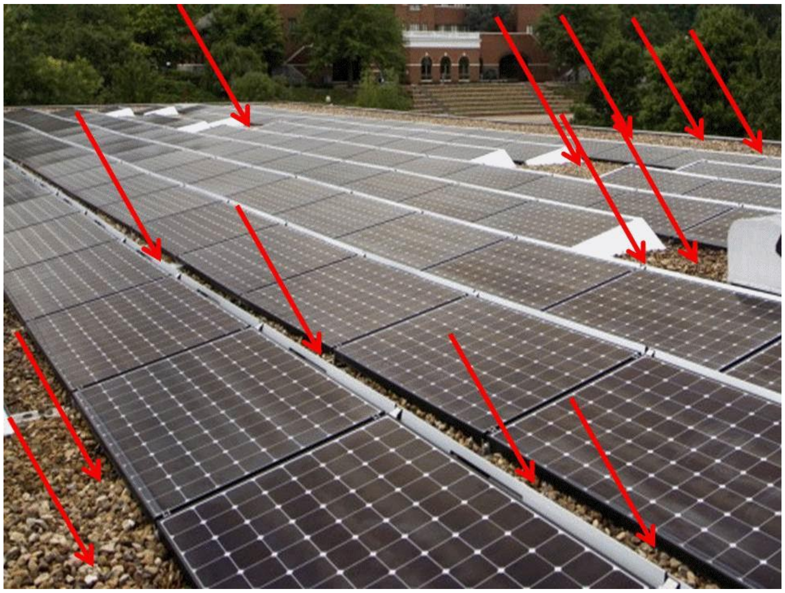
Assumptions

1. Every collection field has an intelligent design that rotates the face of the solar panel to ensure a ninety (90) degree angle of the striking surface to the arriving energy.



Picture 1. A variable angled array rotating perpendicular to the arriving energy [2]

2. The intelligent field design captures all of the arriving energy in the collection area and no energy is wasted striking the ground regardless of pathways or design gaps.



Picture 2. Areas of arriving energy missing collectors [3]

3. The large distance from the earth to the sun makes the arriving energy parallel with other pieces of arriving energy. See diagram 1.

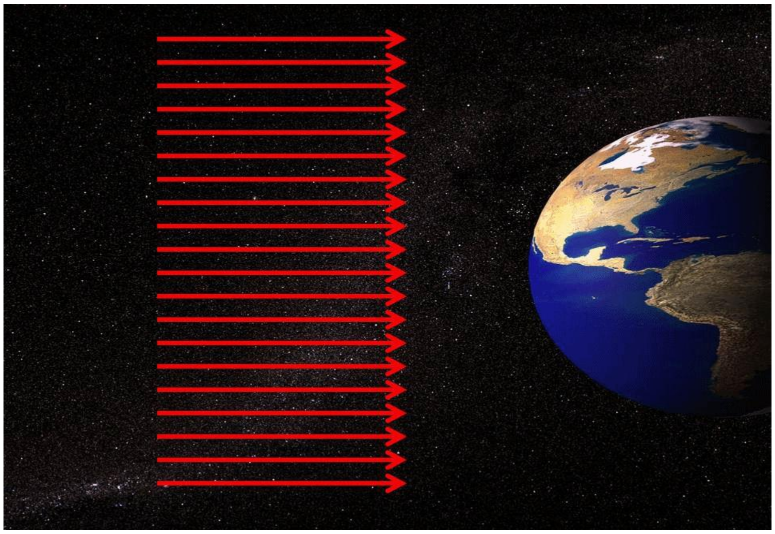


Diagram 1. Solar energy in parallel lines [4]

4. Since the energy travels in parallel lines from the sun to the earth, the perpendicular area of the collection field determines the amount of solar energy intercepted.

5. The amount of power collected is reduced when the collection area is tilted as in diagram 2.

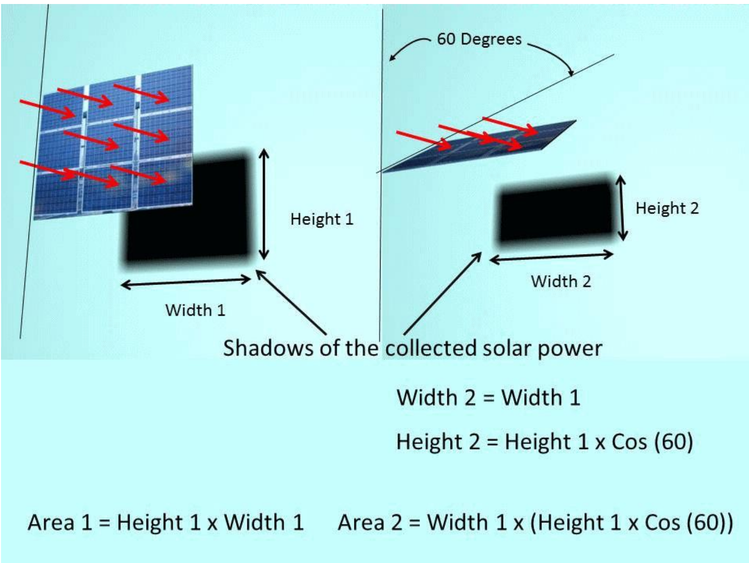


Diagram 2. The effective collection area is reduced in height by the cosine of the tilt angle [5]

6. The collection area is tiled as the location of the collection site increases in degrees of latitude. See diagram 3.

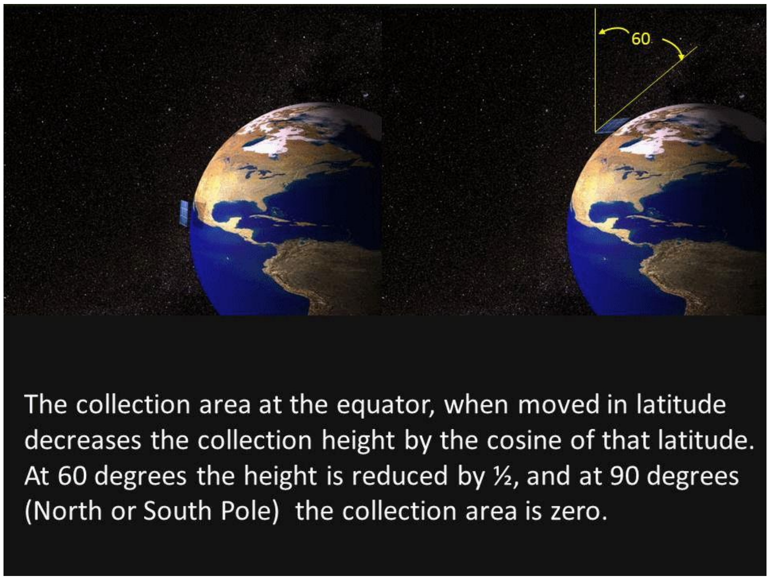


Diagram 3. Decrease in effective collection area at higher latitudes [6].

7. The amount of power collected is reduced when the collection area is rotated. See diagram 4.

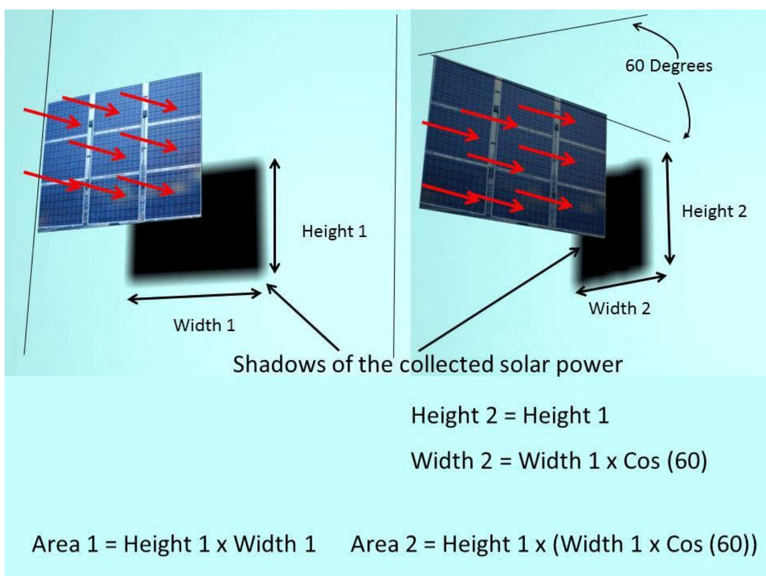


Diagram 4. The effective collection area is reduced in width by the cosine of the rotated angle [7].

8. The collection area is rotated as the earth revolves past noon in degrees of longitude. See diagram 5.

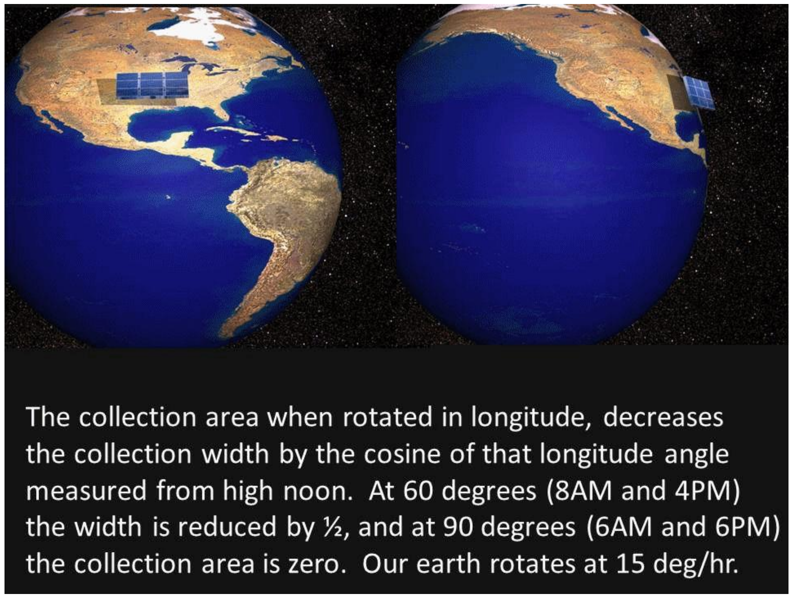


Diagram 5. Decrease in effective collection area at morning and afternoon longitudes [8]

9. Solar power is very limited near the north and south poles as well as early morning, late afternoon and night time. The formulas presented in assumptions 3-8 can effectively estimate collection changes throughout the time of day as well as the location of the collection site in degrees of latitude.

10. The earth is tilted at 23% from the perpendicular axis of the orbit plane. In the northern hemisphere therefore we can add 23% to the latitude at winter solstice, and subtract 23% at summer solstice.

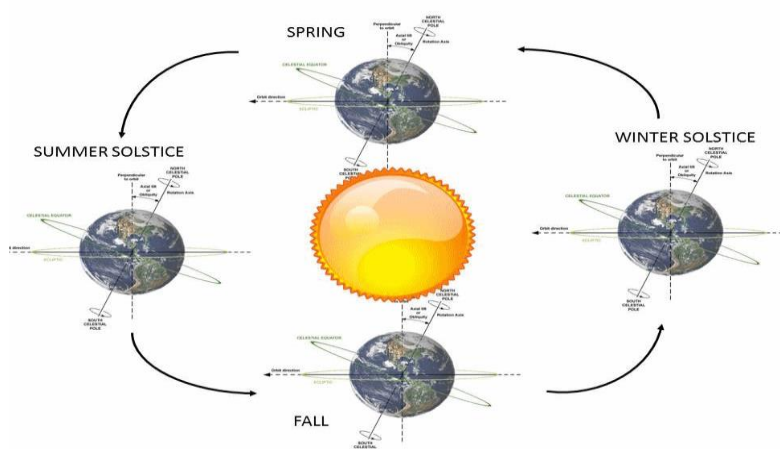


Diagram 6. Orbital tilt axis is constant throughout one year [9]

This paper provides a yearlong average of the changes in apparent latitude from the tilted axis by calculating the collections areas with an upright earth (no tilted axis).

11. The earth axis wobbles in the same manner as a top wobbles when it spins. The changes in latitude caused by this wobble are assumed negated with the upright earth axis calculations.

Theory

1. The arriving solar energy is spread evenly across the collection area of the earth. The total possible collection area of the earth is calculated by taking the value of (pie) times the radius squared or:

$(\pi * R^2)$.

Diagram 8. Radius of the earth used to calculate the km^2 collection area [12]

a. Radius of the earth Re = 6378.145km [10]

b. Pie = 3.141593 [11]

c. The collection area is therefore:

$3.141593 * (6378.145 \text{ km})^2 = 127{,}802{,}308.04 \text{ km}^2$

2. The solar energy striking the surface of any collection area is reduced by several factors, the most significant of these are listed in diagram 9 below. The metric prefix P is for peta, or 10^{15}, or quadrillion (quads) or 1000000000000000. W is for watts. [13]

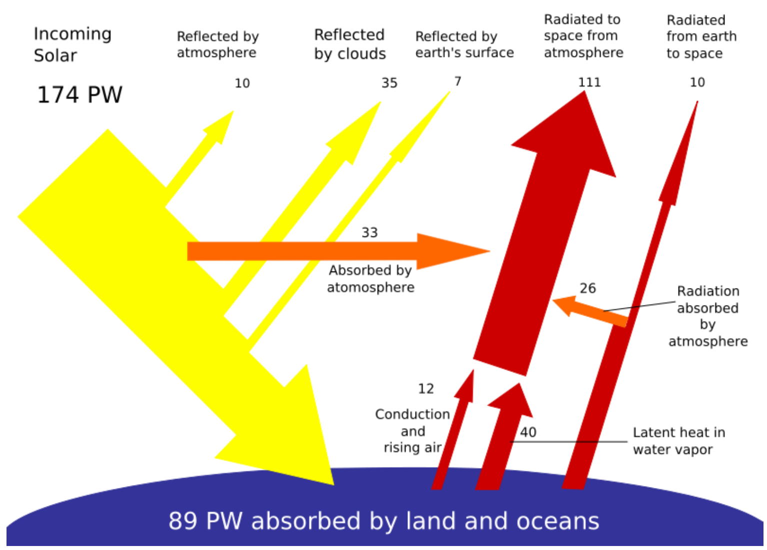


Diagram 9. NASA - The balance of power in earth sun systems [14]

3. The earth receives 174 petawatts (PW) of incoming solar radiation in the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The surface of the earth and the oceans together

intercept 89 PW of power on 127,802,308.1 km^2 of area. The power arrival rate per square kilometer is then:

a. 89×10^{15} Watts/ 127,802,308.1 km^2

b. 696388049.354 Watts/km^2

c. The rate of total energy arriving on the earth is therefore:

6.963×10^8 Watts/km^2

(Note; this rate is only possible on a flat disc that is perpendicular to the rays, and is only available at the equator at high noon. This rate is decreased by ½ at 60 degrees of latitude as well as 8am and 4pm.)

4. Most of the other frequencies of solar energy striking the earth's surface are spread across the visible and infrared ranges with a small part in the ultraviolet. [15] The energy striking the surface of the earth is colored in red in diagram 10 below.

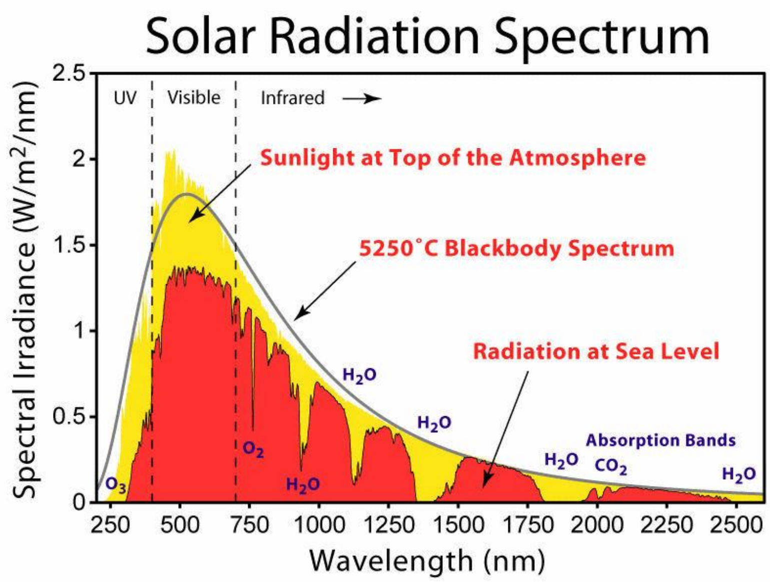


Diagram 10. Wavelength and arriving radiation at sea level. [16]

5. Scientists are constantly trying to invent solar cells that cover all of the frequencies of the arriving red frequency area with varying levels of success. Most solar cells operate in the width of the frequencies within the bands of 400nm–1050 nm with different levels of absorption and efficiency [17]. The best frequency performance of the current technology solar cells are around 500 nm. See diagram 11 below.

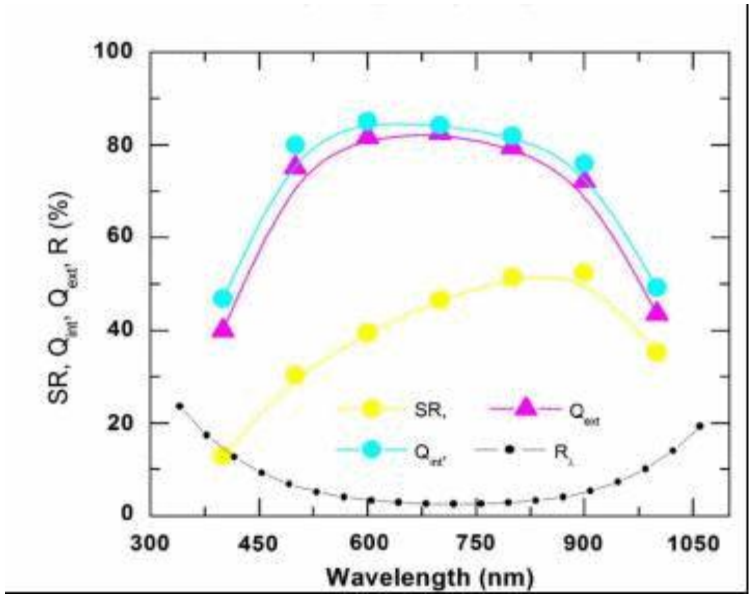


Diagram 11. Spectral response (SR) and internal (Qint), external (Qext) efficiency and reflectivity of solar cells[18] .

6. Each individual solar cell has a very small frequency band of absorption due to the material matrix needed for photons to liberate electrons. The top performing solar cell in the world is currently from Boeing Spectrolabs^tm in both the width of absorption and efficiency of transforming the solar energy into electric power. The maximum frequency band of absorption of a single filament is 7 nm with 125 nm frequency spacing between the subsequent filaments giving the top performing solar cell 14 nm of absorption[19].

The relative amount of arriving power that can be transformed into electricity by frequency limitations is estimated by using the area graph in diagram 12. The total area of the arriving red energy is 95.2 volumes and the area bounded by the 14 nm is 1.7 volumes.

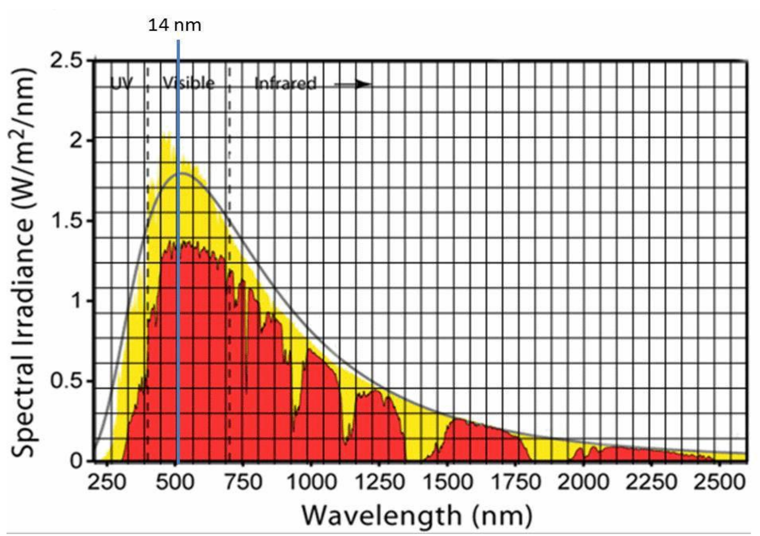


Diagram 12. The 14 nm collection band of the top performing two filament solar cell [20]

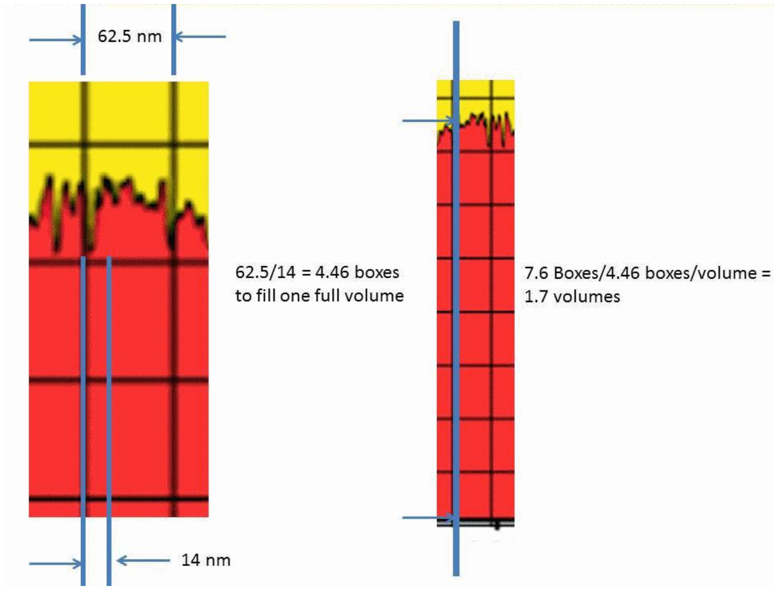


Diagram 13. Expanded 14 nm view while calculating the ratio of power collection to actual power available [21]

a. Volumes in the frequency constrained collection = 1.7

b. Volumes of the total arriving red energy = 95.2

c. The percentage of power that is collectable is therefore:

   1.7/95.2 = 0.017 or 1.7%

d. Therefore the max collectable energy with current cellular frequency limitations are 1.7% of the total arriving energy is;

   696388049.354 Watts/km2 x .017 = 11838596.8 Watts/km2

e. Frequency limited potential (F) for solar cell collection =

   $F = 1.183 \times 10^7$ Watts/km^2

7. The solar cell power output is a function of the efficiencies of the cells to convert the frequency limited power to direct electrical current. Diagram 13 below shows various companies and their solar cell product efficiencies. In 2010 the highest performing cell converts 41.6% of the arriving energy into electricity [22].

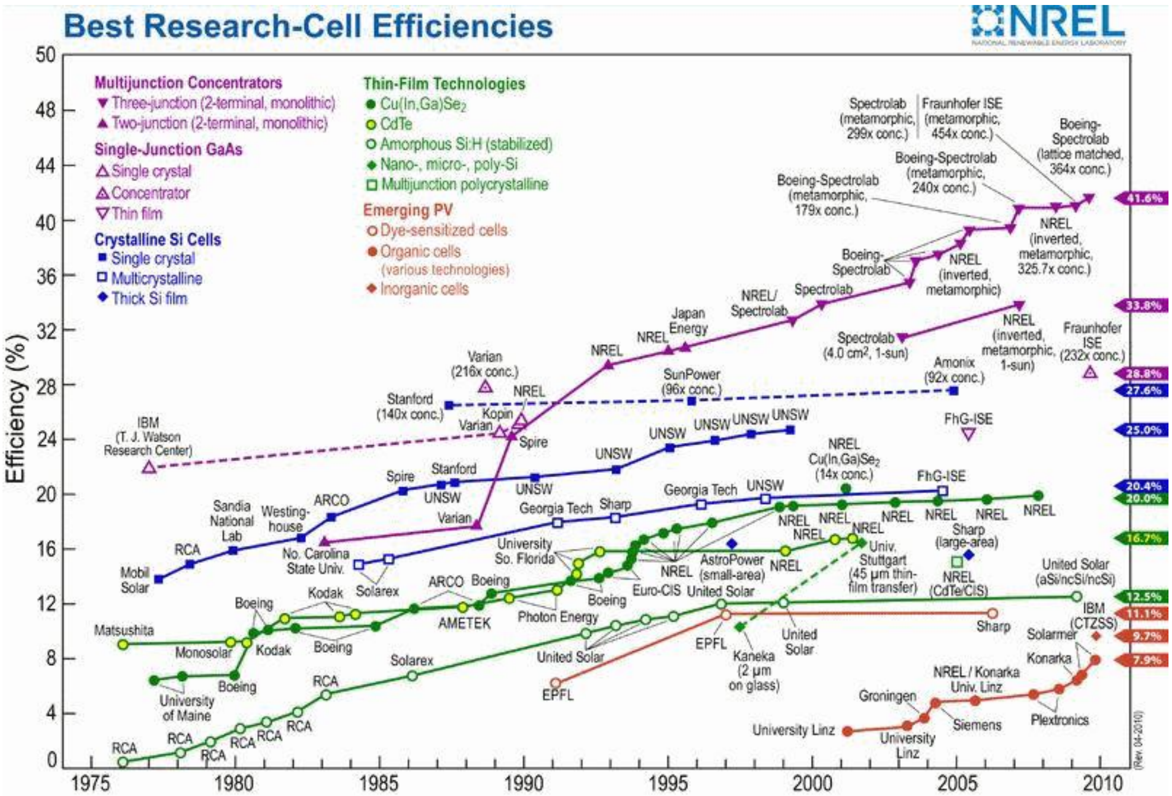


Diagram 14. Historical solar cell performance and efficiencies by company and type [23]

a. Therefore the max collectable frequency limited power is reduced by a efficiency (E) factor of 41.6% or:

F power is 1.183×10^7 Watts/km^2 x .416% = FE = 4924856.26 Watts/km^2

b. Frequency and efficiency (FE) limited solar cell collection rates are therefore;

(FE) = 4924856.26 Watts/km^2.

8. The frequency-efficiency (FE) potential is reduced by the northern latitude of the continental U.S. To estimate the loss due to our northern altitude, we will use 39 degrees north as median latitude to estimate for positional power reduction.

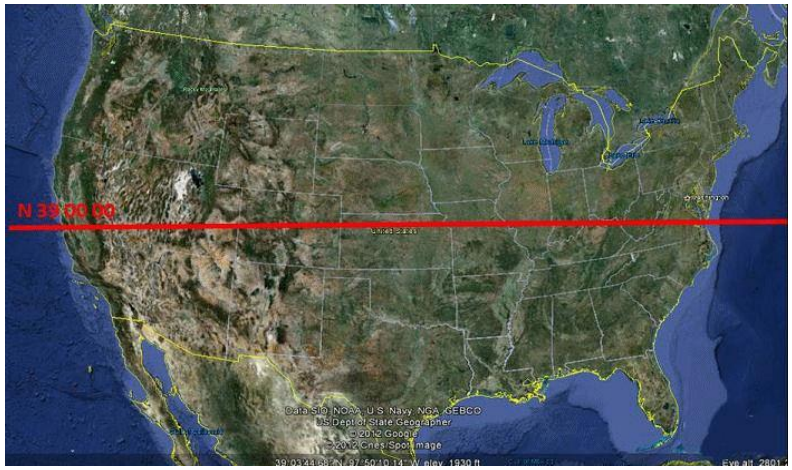


Diagram 15. 39 Degrees North Latitude [(24)]

a. See diagram 3 for an explanation of reduction due to latitude (L)

b. New collection area is reduced by the cosine of 39 degrees Cos (39 deg) = 0.777 or:

   FE= 4924856.26 Watts/km2 x (.777) = FEL = 3826613.32 Watts/km2

c. Therefore the frequency – efficiency – latitude (FEL) limited solar cell collection rates are;

   FEL = 3826613.32 Watts/km2.

9. The frequency – efficiency – latitude (FEL) collection rates are also reduced by the rotation of the earth in longitude. The earth rotates at 15 degrees/hour [(25)], and diagram 5 will be used to calculate the reduction per degrees of longitude away from high noon.

a. The ratio of how much the collection area is reduced must be calculated for each hour, as the cosine function is not linear. Therefore chart 1 below compares the collection area against the hours of exposure.

Time of day	Degrees of rotation	Cosine angle effect	FEL x Cosine angle effect
Noon	0 Deg	100%	3826613.32 Watts/km2 x 1 hr
1PM	15 Deg	96.5%	3692681.85 Watts/km2 x 1 hr
2PM	30 Deg	86.6%	3313847.13 Watts/km2 x 1 hr
3PM	45 Deg	70.7%	2705415.61 Watts/km2 x 1 hr
4PM	60 Deg	50%	1913306.66 Watts/km2 x 1 hr
5PM	75 Deg	25.8%	987266.23 Watts/km2 x 1 hr
6PM	90 Deg	0 %	0 Watts/km2 x 1 hr
Total 6 Hours	90 Deg	Non-linear	16439130.80 Watts-hrs / km^2

Chart 1. Power changes with longitudinal rotation [26]

b. The actual power delivered in the six hours from high noon is therefore 16439130.80 Watts-hrs /km^2.

c. The baseline power delivered at high noon without the earth's rotation for the same six hours is FEL = 3826613.32 Watts/km2 x 6 hrs or 22959679.92 Watts-hrs /km2.

d. Given the two different exposure to power ratios we can calculate the loss due to rotation during the daytime by taking the actual Watt-hrs/km^2 divided by the theoretical Watt-hrs/km^2 or:

<u>16439130.80 Watts-hrs /km2</u> = 71.6% (all units cancel)
22959679.92 Watts hrs /km2

e. Therefore the FEL power rate is reduced during 12 hours of morning to evening by longitude (FELL) as:

f. FEL Power is 3826613.32 Watts/km2 x 71.6% (L) = FELL =

FELL = 2739855.13Watts/km2

10. Additionally there is no power delivered during night time, so 50% of the time, the solar cells rest. Therefore the day power rate FELL is reduced by night N by 50% and therefore:

a. FELL = 2739855.13Watts/km2 x .50 = FELLN = 1369927.56 Watts/km2

b. Frequency, Efficiency, Latitude, Longitude and Night (FELLN) power (Realistic power) is then what can be collected per square kilometer of collection panels in the continental U.S.

<u>FELLN = 1369927.56 Watts/km^2</u>

Calculations

This paper presents six sets of calculations based on the U.S. 2011 energy consumption rates and the solar power science of 2012[1]. The six sets of calculations presented are; theoretical power, minimum area using maximum theatrical power, realistic power, minimum area using realistic power, best effort power and a Tesla S electric automobile example.

Theoretical power

1. "Theoretical power" calculations convert all of the incident available power from the sun striking the continental U.S and converting directly into electrical power.

a. The total rate of solar power striking the surface of the earth at the equator at high noon is 6.963×10^8 watts/km^2

b. This power rate is reduced by latitude (see theory para 8.) by 0.777 or:

Max power = 6.963×10^8 Watts/km^2 x .777 = 541093514.348058 Watts/km^2

L (Lat) power is therefore = 5.41×10^8 Watts/km^2

c. L power rate is reduced by the rotation in longitude (see theory para 9) by .716 or:

L power = 5.41×10^8 Watts/km^2 x .716 = 387422956.273209528 Watts/km^2

LL power is therefore = 3.874×10^8 Watts/km^2

d. LL power rate is reduced by the resting period at night (see theory para 10) by .5 or:

LL power is therefore = 3.874×10^8 Watts/km^2 x .5 = 193711478.136604764 Watts/km^2

LLN power is therefore = 1.937×10^8 Watts/km^2

e. The continental U.S. covers 8,080,464.3 km^2 [27] therefore the max theoretical energy collection rate is the rate per square kilometer times the actual square kilometers available or;

1.937×10^8 Watts/km^2 x 8,080,464.3 km^2 = 1565278683583065.31 Watts

1.565×10^{15} Watts = max theoretical collection rate in the continental U.S.

f. A watt is one joule per second or; watt = 1 joule/second[23]

g. There are approximately 31536000 seconds in a single year (365 days x 24 hours/day x 60 min/hour x 60 sec/min = 31536000 seconds (note - sidereal time is ignored for this paper)

h. The total theoretical energy collected is the joules per second multiplied by the total seconds in a single year or;

1.565×10^{15} Watts = 1.565×10^{15} j/s or

1.565×10^{15} j/s x 31536000 seconds/year = 49362628565475547616160 joules/year or;

4.936×10^{22}joules/year

i. One British Thermal Unit (btu) is equal to 1055.18 joules [(23)]

j. Converting from joules to btu we divide the joules by the conversion or;

$$\frac{4.936 \times 10^{22} \text{ joules}}{1055.18 \text{ joules/btu}} = 4.678 \times 10^{19} \text{ btu}$$

k. The total energy used by the U.S. in 2011 was 97.3 Quarillion Btu or 97.3×10^{15} Btu or 9.73×10^{16} btu[(28)]

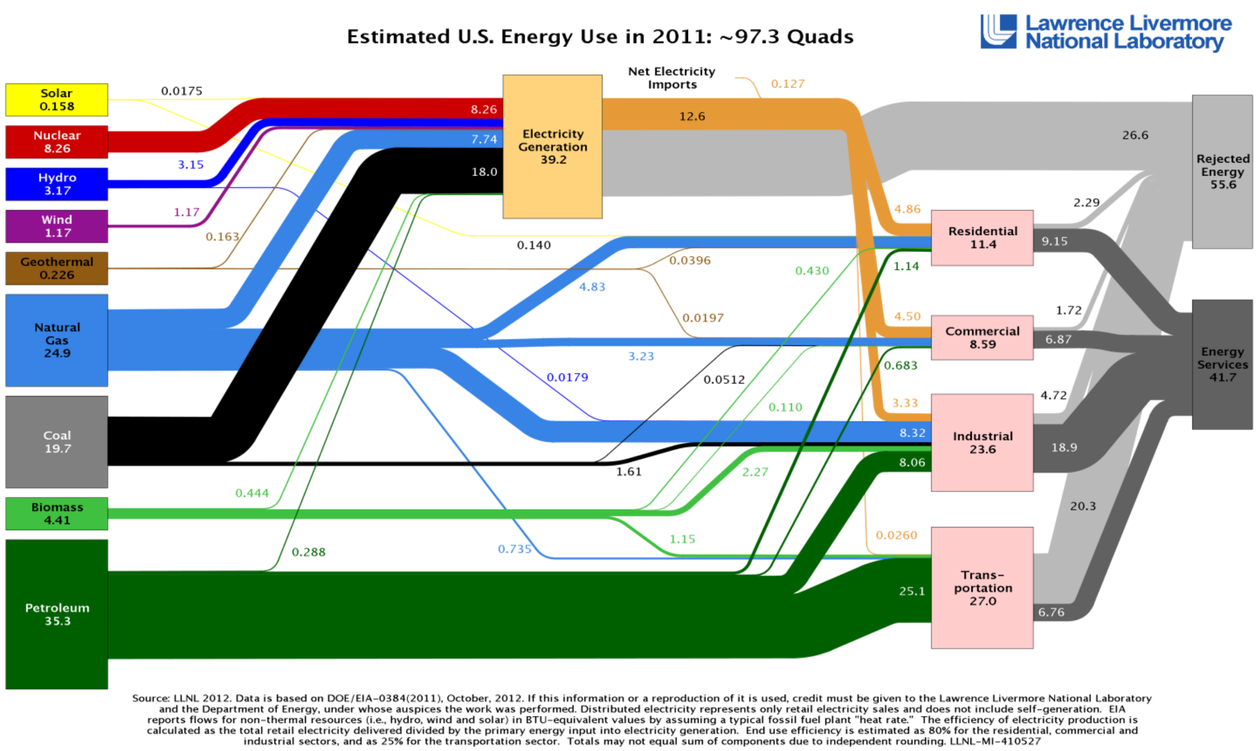


Diagram 15. Estimated U.S. Energy use for 2011[29]

l. Calculating the total ratio of theoretical power to actual power is a ratio or;

$$\frac{\text{Max theoretical power is } 4.678 \times 10^{19} \text{ btu}}{\text{Max energy used is } 9.73 \times 10^{16} \text{ btu}} = 480.78 \text{ times}$$

2. The amount of maximum theoretical power is 480.78 times the energy used in 2011. However, this theoretical power does not have the real world limitations of the narrow frequency band of absorption of the solar cell itself, or the efficiency of the cell, or the conversion of the D/C power to A/C power or the wire transfer losses over distances. Naturally, completely plowing under the U.S. would be a life ending event in America, as well as cooling and disturbing weather pattern changes.

Minimum area using maximum theatrical power

1. This calculation provides the area needed in square kilometers and a selected state that would be of equal area that if converted into solar cell fields will provide the U.S. energy if the maximum theoretical power (max potential) numbers are used.

a. From paragraph 1.k. the total energy needed to power the U.S. in 2011 is 9.73×10^{16} btu

b. One British Thermal Unit (btu) is equal to 1055.18 joules [23]

c. Converting from btu to joules we multiply the btu by the conversion or;

9.73×10^{16} btu x 1055.18 joules/btu = 102669014000000000000 joules or

1.027×10^{20} joules used in the U.S. in 2011

d. To convet the needed energy into a power rate we divide the power by time. From paragraph 1.g there are approximately 31536000 seconds in a single year. Therefore

$$\frac{1.027 \times 10^{20} \text{ joules to power the U.S. in 2011}}{31536000 \text{ seconds}} = 3255613077118.2 = \text{j/s} = \text{watt}$$

3.256×10^{12} watts

e. From paragraph 1.d. the maximum theoretical power per square kilometer is LLN power = 1.937×10^{8} watts/km^2

f. To calculate the area needed to provide the power rate we divide the 3.d. by 3.e. or;

$$\frac{3.256 \times 10^{12} \text{ watts}}{1.937 \times 10^{8} \text{ watts/km}^2} = 16{,}807 \text{ km}^2$$

2. The area needed to power the U.S. using maximum therotical power is 16,807 square kilometers, or apporoximaty 82% of New Jersey. This number shows the potentail for solar power to be a viable energy source for the future of American power needs. The significant factors that are not included in this calculation are the limited freqency bands that the 2012 solar cells and the efficiecny of the solar panel itself.

Realistic total power

1. This calculation uses current technology solar cell performance covering all of America with no power reductions due to solar cell performance loss over time. The power is reduced by the limited frequency (F) of the solar cell conversion band, the limited efficiency of the best perming cell (E) the latitude of the collection area (L) the day time rotation reductions in longitude (L) and the time when the cells rest at night (N). Additionally, the power is reduced by direct current (DC) to alternating current (AC) losses and AC wire transmissions losses. All numbers are rounded in accordance with scientific significant digits.

a. FELLN power is 1369927.56 watts/km2

b. Tranfroming the direct current power from the solar cells to alternating current requires a DC to AC power converter. The most effiecnt power converter tranfers 96% of the power to from DC to AC(30) therefore the AC uploaded power to the lines are:

   1369927.56 watts/km2 x .95(24) = 1315130.46 watts/km2

c. Delivering power to the remote ares of the U.S. requires AC high power lines that deliver 92% of the uploaded power(31), therefore the AC delivered power is:

   1315130.46 watts/km2 x .92 = 1209920.02 watts/km2

d. Using the total area of the continental U.S. from paragraph 1.e 8,080,464.3 km^2

e. Therefore the total power rate using realistic solar cell performance is the rate times the area or:

   1209920.02 watts/km2 x 8,080,464.3 km^2 = 9776715527465.286 watts or 9.776×10^{12} watts or joules/second

f. The total seconds in a single year = 31536000 sec

g. The total possible energy is therefore the rate of power multiplied by the time of delivery is;

9.776×10^{12} joules/second x 31536000 seconds = 308318500874145259296 joules or 3.083×10^{20} Joules

h. One British Thermal Unit (btu) is 1055.18 joules so converting joules to btu:

$\frac{3.083 \times 10^{20} \text{ Joules}}{1055.18 \text{ joules/btu}}$ = 292195171320670652.6 btu = 2.921×10^{17} btu

i. The total energy used by the U.S. in 2011 was 97.3 Quarillion btu or 9.73×10^{16} btu.

j. The ratio of power avaio be to the power needed is therefore:

$\frac{2.921 \times 10^{17} \text{ btu}}{9.73 \times 10^{16} \text{ btu}} = 3.003$

2. Using realistic numbers for actual 2012 technology solar cell performance, if we converted all of the continental U.S. into a solar cell field, we could only generate 3.003 times the amount of energy used in 2011.

Minimum area using realistic total power

This calculation provided the area needed to power the U.S. using realistic (FELLN) power with reductions for A/C conversion and wire transmission loss. This is the minimum realistic area that would power the U.S. in 2011 using 2012 technology.

a. FALLN power reduced by AC conversion and AC wire loss is 1,209,920.02 watts/km2 (see paragraph 1.c)

b. The total energy used by the U.S. in 2011 was 97.3 Quarillion btu or 9.73×10^{16} btu

c. We convert btu to watts by the ratio of 1 btu = 1055.18 joules

9.73×10^{16} btu x <u>1055.18 joules/btu</u> = 105201446000000000000 joules or 1.052×10^{16} joules

d. 1.052×10^{16} joules need to be distributed over one year to arrive at a power rate, so we divide by seconds.

1.53×10^{16} joules/31536000 seconds = 3335915969051.1 j/s or watts or 3.33×10^{12} watts

e. Then we use realistic power to calculate the area needed to generate the needed 3.33×10^{12} watts

$$\frac{3.33 \times 10^{12} \text{ watts}}{1209920.02 \text{ watts/km2}} = 2{,}757{,}137 \text{km}^2$$

k. The ratio of needed U.S. soil to generate the U.S. power needs then the needed soil divided by the actual soil or;

$$\frac{2{,}757{,}137 \text{ km}^2 \text{ needed area to generate U.S. power}}{8{,}080{,}464.3 \text{ km}^2 = \text{area of the U.S.}} = .341 = 34.1\ \%$$

3. Therfore, using realistic solar power numbers, 2,757,137 km^2 is the required amount of area needed in the U.S. to generate the 2011 power needs. This is 34.1 % of the total land in the continental U.S.

2,757,137 km^2 is approximately the same area needed from the following states [(31)];

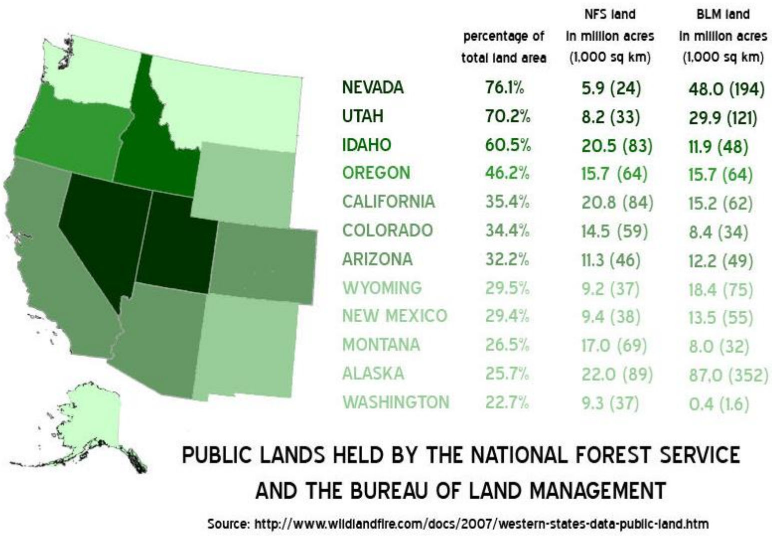
Arizona	295,234 km^2
California	423,970 km^2
Colorado	269,837 km^2
Idaho	216,632 km^2
Nevada	286,367 km^2
New Mexico	315,194 km^2
Oregon	255,026 km^2
Utah	219,887 km^2
Washington	184,827 km^2
Wyoming	253,348 km^2
Total	2,720,322 km^2

Chart 2. States needed to be converted to meet 2011 power demands [(32).]

Best effort power

This calculation is the total energy delivered by converting 6.3% of western continental U.S. federal land into solar cell collection areas using realistic (FELLN) power and reductions for A/C conversion and wire transmission loss.

1. The western U.S. has an extensive amount of federal land in the national forest service and bureau of land management, see chart one below.



	percentage of total land area	NFS land in million acres (1,000 sq km)	BLM land in million acres (1,000 sq km)
NEVADA	76.1%	5.9 (24)	48.0 (194)
UTAH	70.2%	8.2 (33)	29.9 (121)
IDAHO	60.5%	20.5 (83)	11.9 (48)
OREGON	46.2%	15.7 (64)	15.7 (64)
CALIFORNIA	35.4%	20.8 (84)	15.2 (62)
COLORADO	34.4%	14.5 (59)	8.4 (34)
ARIZONA	32.2%	11.3 (46)	12.2 (49)
WYOMING	29.5%	9.2 (37)	18.4 (75)
NEW MEXICO	29.4%	9.4 (38)	13.5 (55)
MONTANA	26.5%	17.0 (69)	8.0 (32)
ALASKA	25.7%	22.0 (89)	87.0 (352)
WASHINGTON	22.7%	9.3 (37)	0.4 (1.6)

Chart 3. Western U.S. National Forest and Bureau of Land Management Reserves [33]

a. The total amount of national forest serviceable land is 580,000 km^2.

b. The total amount of bureau of land management land is 1,102,100 km^2

c. Therefore the total amount of western U.S. Federal usable land for solar power conversion is 1,682,100 km^2

d. 6.3% of the total usable land is therefore;

   1,682,100 km^2 x .063 = 105,972.3 km^2

e. FALLN power reduced by AC conversion and AC wire loss is 1,209,920.02 watts/km2 (see paragraph 1.c)

f. Therefore the delivered power is the rate per area times the area or;

   1,209,920.02 watts/km2_ x 105,972.3 km^2 = 128218007335.446 watts or

   1.28 x 10^{11} watts

g. Taking the delvery rate aover one year long period is

   1.28 x 10^{11} joules/sec x 31536000 seconds/year = 4043483079330625056 joules/year or;

   4.043 x 10^{18} joules/year

h. We convert btu to joules by the ratio of 1 btu = 1055.18 joules

$\frac{4.043 \times 10^{18} \text{ joules/year}}{1055.18 \text{ joules/btu}}$ = 3832031576916379 btu/year or;

3.832×10^{15} btu/year

i. The total energy needed is 9.73×10^{16} btu/year (see Theortical 1.e.)

j. The ratio of best effort to 2011 power needed is therfore

$\frac{3.832 \times 10^{15} \text{ btu/year}}{9.73 \times 10^{16} \text{ btu/year}}$ = 0.039 or roughly 3.9% of American power needs

2. The best effort power when converting 6.3% of all western U.S. federal land is 3.832×10^{15} btu/year or **3.9%** of 2011 U.S. energy needs.

Tesla electric automobile

This calculation provides the square kilometers and acres needed to power a Tesla S sedan used to commute 25 miles each way using a solar cell field located 15nm outside of Los Angeles CA.

10. The Tesla S sedan consumes power at different speeds and internal settings. This paper uses the power consumption rates from a Motortrend magazine test drive from Los Angeles to San Diego with the following results;

a. 233.7 miles traveled[34]

b. Consumed 93 % of the largest battery available (85-kW-hr option) [34]

c. Used 78.2 kW-hrs of electricity [34]

d. Converting to joules used, we take out the hour portion by;

78.2 kW-hrs = 78,200 W-hrs = 78,200 joules/second x hrs
(78,200 j/s x hrs) x 3600 seconds/hrs = 281,520,000 joules used

e. Converting to joules per mile;

281,520,000 joules used = 1,204,621.31 joules/mile or 1.24×10^{6} joule/mile

f. The battery storage and efficiency is listed by Tesla at 86% [35], so there must be more energy delivered from the field or:

$\frac{1.24 \times 10^{6} \text{ joules/mile}}{.86}$ = 1400722.4 joules/mile or 1.40×10^{6} joules/mile

g. Commuting 25 miles both ways (50 miles) the energy needed to travel that distance is therefore;

1.40×10^6 joules/mile x 50 miles = 70036122.67 joules or 7.00×10^7 joules

h. DC power loss to tranport the energy over a 25 mile direct current line is 8.6% loss[(28)] or the power needed to be generated is then;

$\frac{6.02 \times 10^7 \text{ joules}}{.086}$ = 814373519.46 or 8.14×10^8 joules

i. Assuming the time of charging is dawn to dusk (longitudinal rotation, latitude and night reductions are already compensated for in FELLN power) therefore we use 6am to 6pm collection or 11 hours.

11 hours (FELLN power) x 60 minutes/hour x 60 seconds/minute = 39,600 seconds

j. Calculating the rate of energy (power) is then the energy divided by the time of generation needed from the solar field or;

$\frac{8.14 \times 10^8 \text{ joules}}{39{,}600 \text{ seconds}}$ = 20,564 j/s or watts or 20.6 kw delivery system

k. FELLN power is 1369927.56 watts/km^2 (No AC conversation loss or AC wire transmission losses) to calculate the area needed to generate the 50 mile commute.

$\frac{20{,}564.7 \text{ watts}}{1369927.56 \text{ watts/km}^2} = 0.015 \text{ km}^2$

l. Changing to meters is then;

0.015 km^2 x (1000 meters/km)^2 = 15,000 m^2 = 122 meters x 122 meters area needed

j. One international acre is defined as 4046.8564224 m^2 therefore;

$\frac{15{,}000 \text{ m}^2}{4046.8564224 \text{ m}^2\text{/acre}} = 3.73 \text{ acres}$

11. To power the Tesla S sedan in Los Angeles California with only solar panels, each owner will need to purchase and sustain 3. 73 acres (122 meters x 122 meters area) or 15,000 m^2 of solar cell production for a 25 mile (50 round trip) commute.

Summary

1. Solar power is not currently ready for employment as a viable clean energy alternative, due mainly to the manufacturing limitation of the solar cell itself. The frequency limitation in absorption (7nm) across the energy field of 2000nm makes the cell capable of only capturing 1.7% of the available energy.

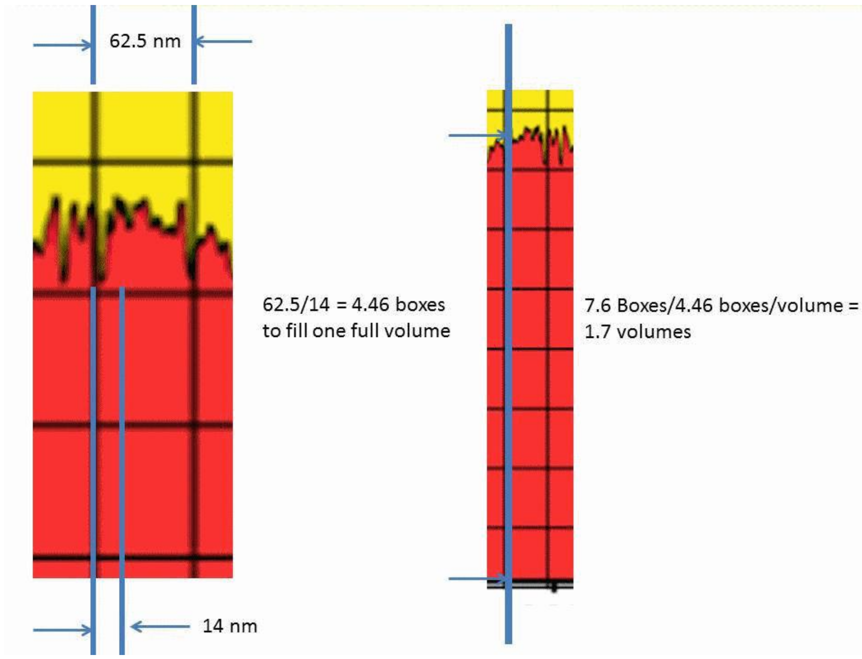


Diagram 13. Expanded 14 nm view while calculating the ratio of power collection to actual power available [21]

2. Perform a solid cost benefit analysis of *deploying* the current restricted solar cells against the cost effectiveness of alternate green energy (nuclear and hydroelectric) and fossil fuel power cost effectiveness.

3. Redirect federal and state funding from *deployment* of these very limited solar cells wasting tax resources trying to harness energy with only 1.7% capture potential per dual filament.

4. Use federal, university and state resources to focus on research and development of better manufacturing processes that will liberate electrons on 70% of the viable frequency bands (250nm – 2000nm) with a 70% efficiency rate.

5. Calculate a threshold for viability of *deployment* of the new improved cell with a required frequency band of abortion and the efficiency of conversion based on the cost/benefit analysis from paragraph 1.

6. Provide guidelines for current cell capability for *deployment* of solar cell viability such as remote locations, low power needs and off-grid applications.

7. Fund *deployment* of current proven high capacity, clean power sources such as nuclear and hydroelectric power.

8. Use the six power estimates as a means of comparison for how year-by-year scientific and manufacturing process are improving. Re-calculate the six power estimates to measure the impact of leaps in capability and test for viability of deployment against the criteria set in paragraph 5.

9. Do a solid environmental impact statement coving the manufacturing and disposal of used solar cells against the use of traditional fossil fuel power production.

10. Check congressional testimony to validate if theoretical numbers were briefed to congress urging the funding of *deployment* rather than scientific, manufacturing research and development efforts.

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