Engineering Economic of Alternative Energy Sources

S. Frank Waterer – EE, Fellow
Schneider Electric Power Systems Engineering

Schneider Electric

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- The focus of this presentation is the present a brief summary of the basic engineering economics associated with the installation and use of wind turbine generators, photovoltaic array panels, and large battery storage units as the alternative energy sources.
- The conventional power sources referred to within this presentation are the typical utility owed and operated generating power plants.
- Portions of the subject matter in this presentation are also applicable to other alternative energy sources as bio-mass, geothermal, wave generation.

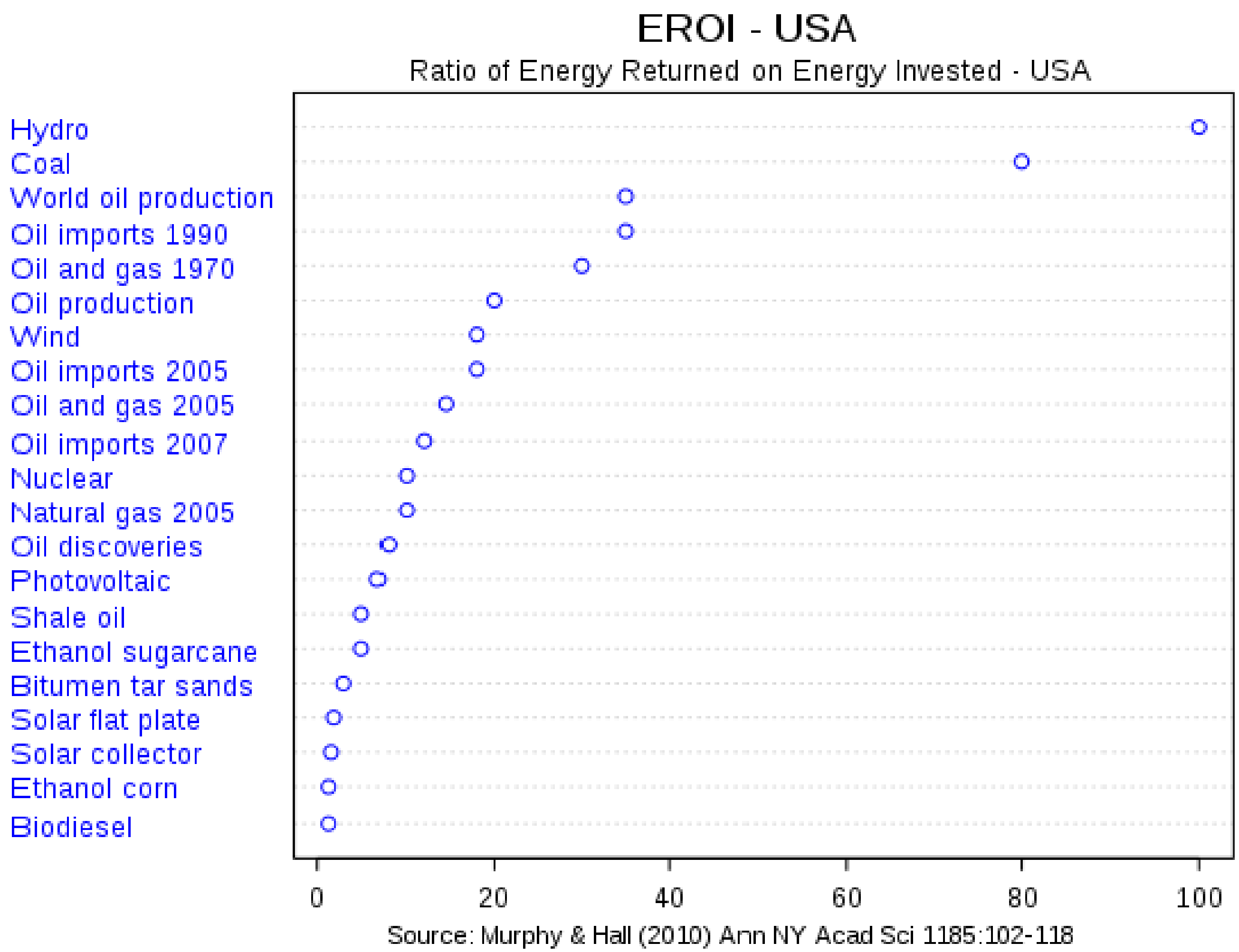
Sources of Energy

- **Sun**
- **Human labor**
- Wood (Made the expansion of the human race possible)
- Domestic animals
- Flowing water (Supplied the power for mass scale manufacturing)
- Windmills (For pumping water and powering grist mills)
- Exothermic reactions between chemicals and metals
- **Coal (Supplied the power for the Industrial Revolution)**
- Whale Oil (Lighting)
- Petroleum Oil (Lighting and heat generation, then transportation, then electricity production)
- Electricity for nuclear reaction
- **Electricity from Photovoltaic (aka; Solar Panels)**
- **Electricity from Wind Turbine Generators**

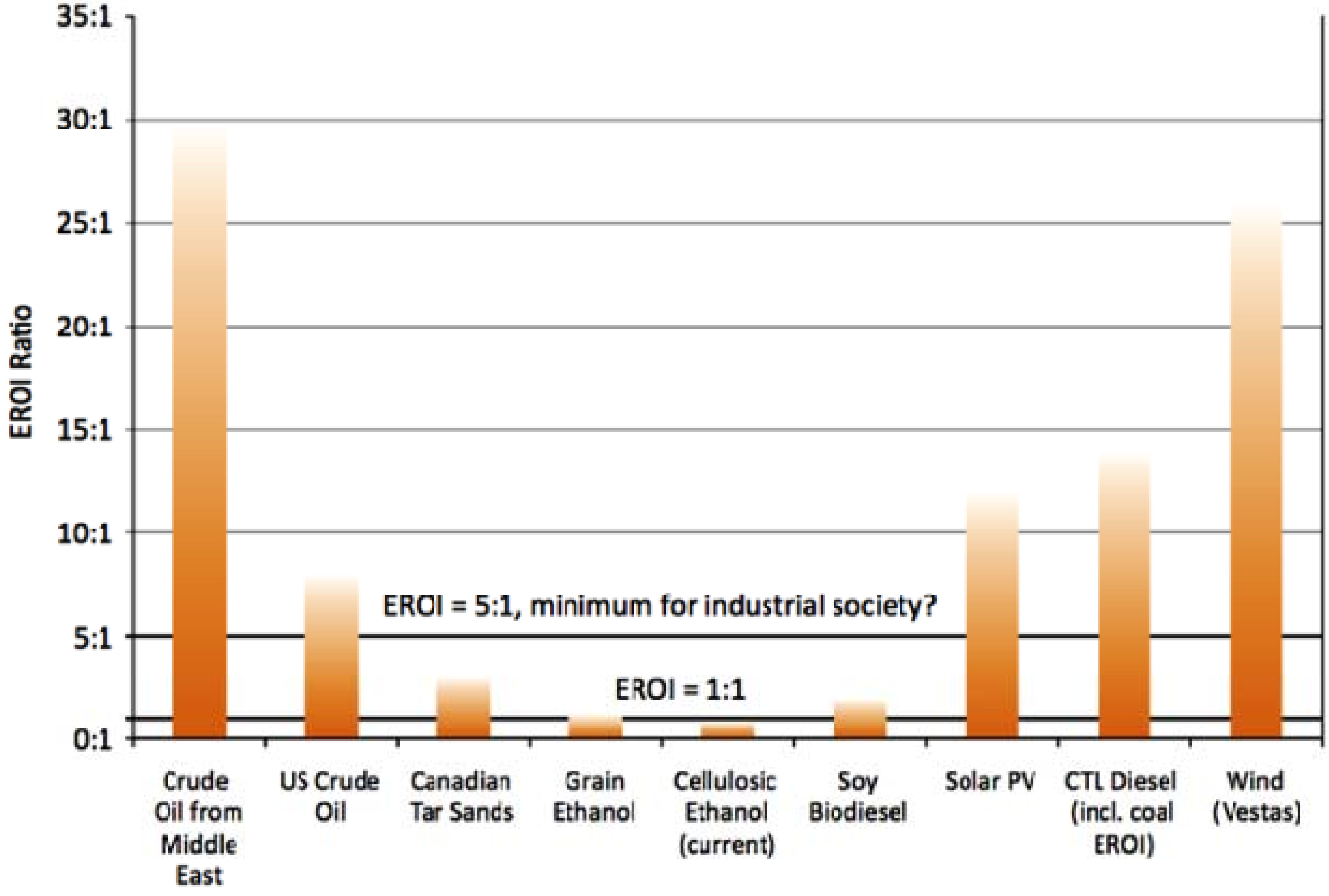
Energy Return on Investment (EROI)

- **Energy must be consumed or utilized to produce energy.**
- The energy remaining and readily available for use after the consumption and utilization of production is referred to as the 'net energy'.
- The ratio of total energy used to produce energy versus the total energy produced is called the "energy return on investment" or EROI.
- EROI is NOT the same thing as "conversion efficiency" as the feedstock in the conversion processes of a electric power plant or petroleum refinery. (Conversion efficiencies are always less than 100%
- **True EROI covers ALL real expenses and expenditures of energy** (i.e.; human labor, materials, manufacturing, transportation, necessary infrastructures, maintenance, repairs, replacement components and parts, intermittency, variability, etc…)
- Total Gross Energy Yield ÷ Total Gross Energy Expended = EROI
- **The minimum EROI required to operate and maintain an average industrial society is estimated at 5:1**

Energy Return on Investment (EROI)



Energy Return on Investment (EROI) [S1]



Alternative Energy Sources - EROI

- Note: The EROI data concerning wind and solar power in the previous two slides are skewed considerably more positive than the real terms and actual results because the factors of intermittency, variability, economic subsidies, tax credits, maintenance cost, replacement cost, and the future cost for the necessary expansion of the transmission and distribution capacities and grid interconnections were excluded as variables in the available EROI calculations and statistics. **Therefore, the true EROI of ALL real expenses and expenditures of energy in the Academy of Science studies concerning wind and solar energy sources were NOT factored into data as important variables.**

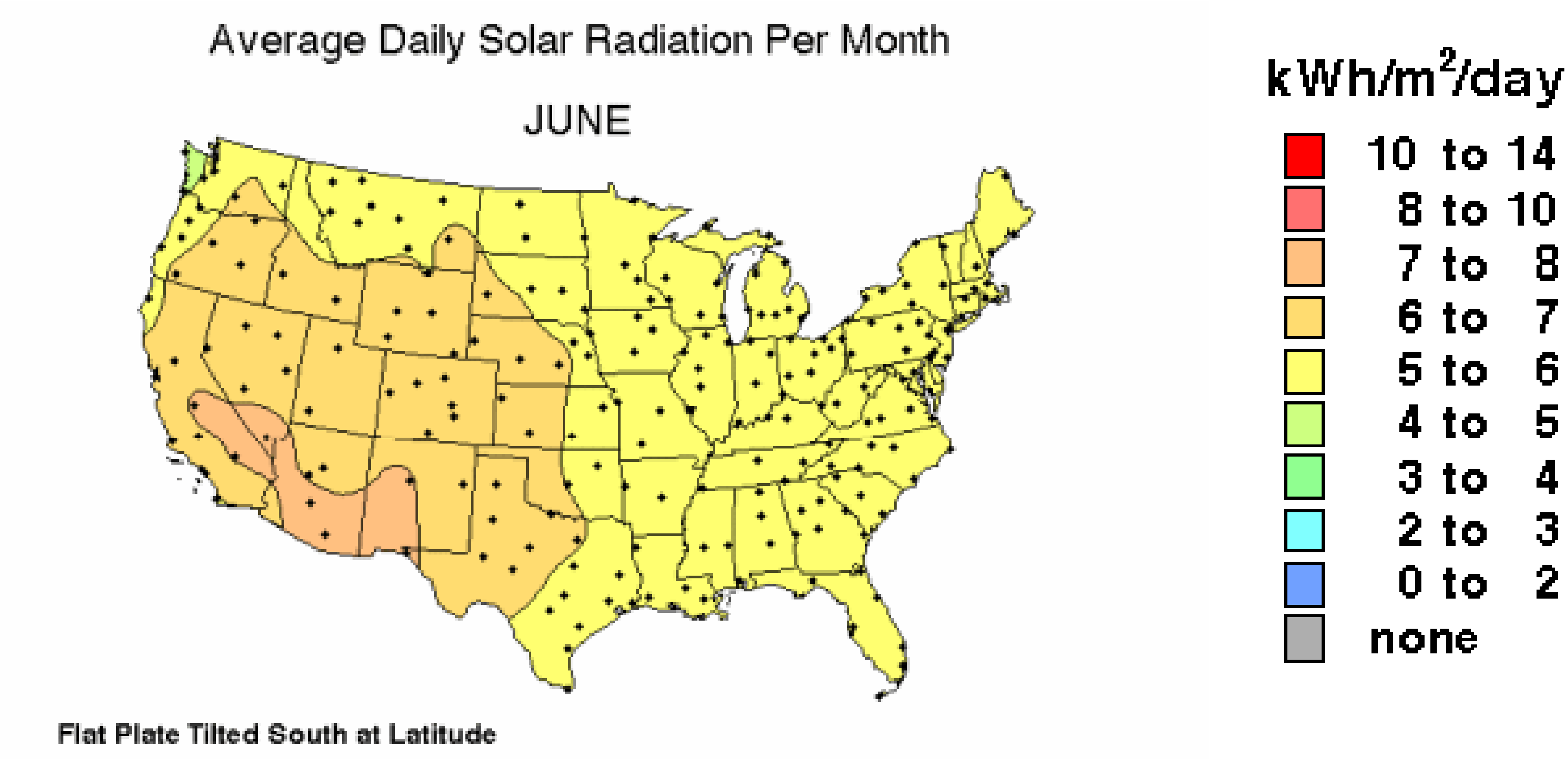
Electrical Power Generation Capacity Factors vs. Intermittency and Variability [S2]

- Solar energy and wind power can only respectively be produced when the sun is shining and the wind is blowing. This creates inherit technical challenges to balance variable availability of power from these two source with immediate demands for power.
- The problem of available supply from these two alternative source is less problematic when their supply contribution are a very low proportion of the total load demand.
- Combined total output from solar energy and wind power generation makes up less than 3% of total world wide electrical power demand. [S2]
- The problem of available supply from these two alternative source will be significantly more problematic when their supply contribution are 5% or higher of a total proportional load demand.
- An indication of the intermittency and variability challenges can be expressed in the **"capacity factors"** (i.e.; the average % of time in a year the a power source is producing full available capacity).

Electrical Power Generation Capacity Factors in the USA [S2]

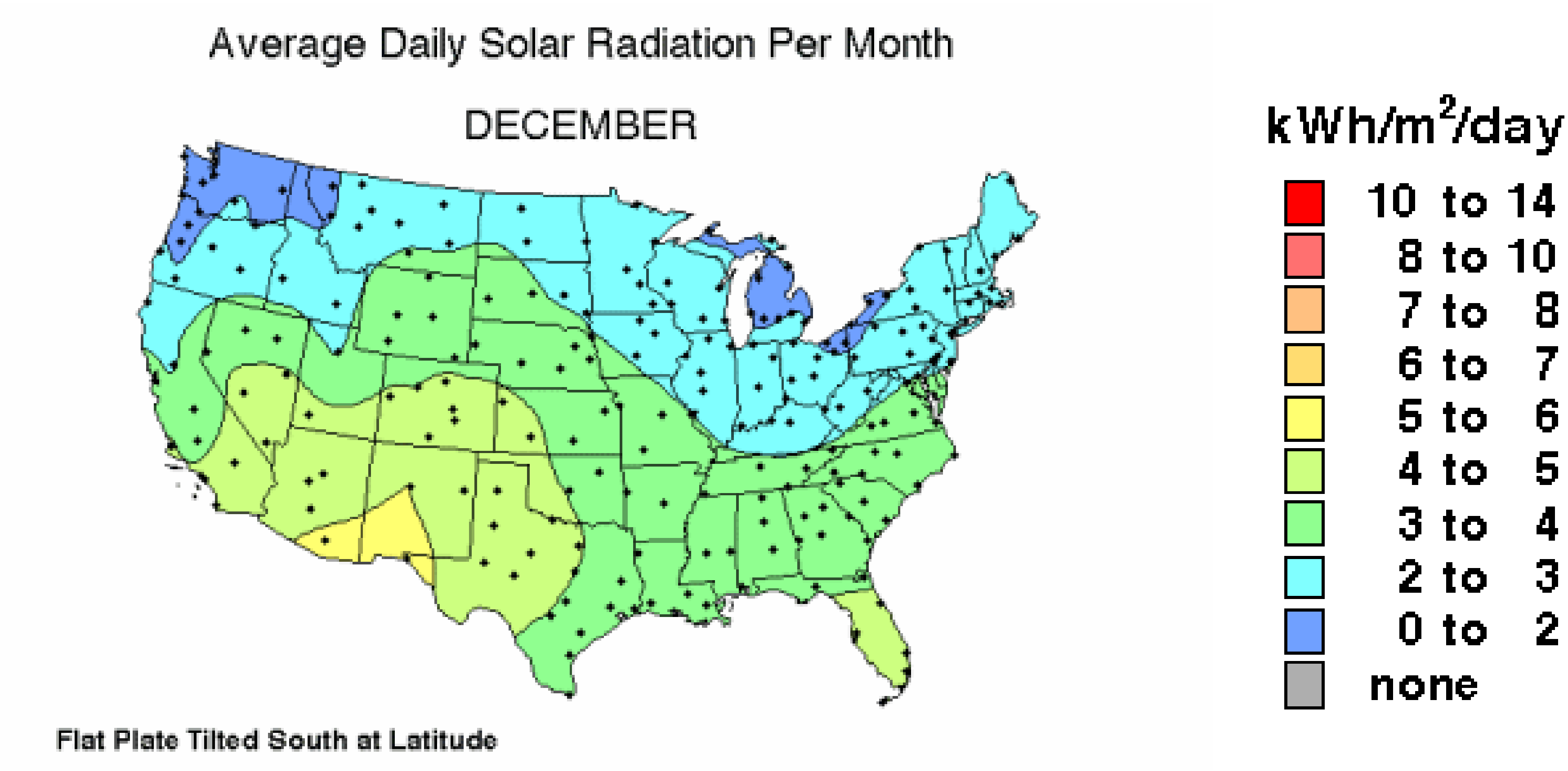
Generation Type	Capacity Factor per year of Total
● Nuclear Power	● 60% - 100%
● Coal	● 70% - 90%
● Geothermal	● 70% - 90%
● Hydropower	● 30% - 80%
● Natural Gas	● ~ 60%
● Wind	● 20% - 40%
● Photovoltaic	● 12% - 19% (can be higher if viable storage battery were available)

Electrical Power Generation Capacity Factors vs. Intermittency and Variability [S2] [S6]



KWH you can expect per day for each square meter of solar panel surface area.

Electrical Power Generation Capacity Factors vs. Intermittency and Variability [S2] [S6]



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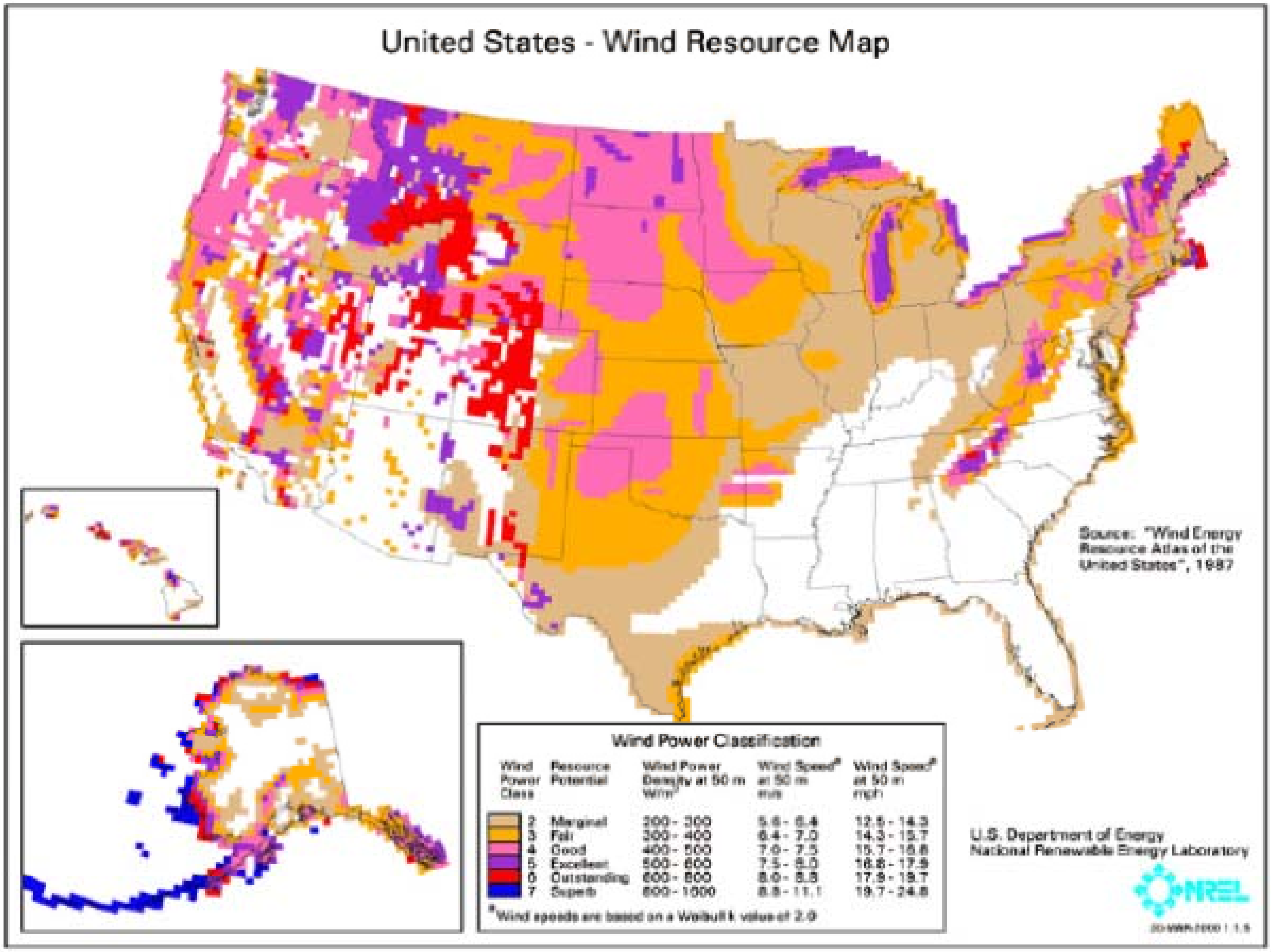


Energy Density vs. Space [S2]

- 'Energy Density' (ED) means the amount of energy contained in any unit of energy potential or source. (i.e.; ED = energy/mass or volume)
- The more dense an energy source the less land or space necessary for its utilization
- The specific physical reason that energy from coal and nuclear power are the overwhelming sources of energy in electrical generation is because their respective energy density is very small.
- One single gigawatt (1000 megawatt) coal fired power plant requires between 1 – 4 km^2 (square kilometers) of land.
- (1 km^2 = ~0.386 mi^2 = 247 acres) and (4 km^2 = ~1.54 mi^2 = 988 acres)
- A photovoltaic array field that can produce a gigawatt will require up to 50 km^2 of land. (~ 19 mi^2 = 12160 acres = The land area of a small US city.)
- A wind farm that can produce a gigawatt will require up to 150 km^2 of land (~ 60 mi^2 = 38400 acres = The land area of a medium sized US city.)

Energy Density vs. Space

- The Roscoe Wind Farm in Roscoe, Texas was completed in 2008 and presently is reported to be the largest capacity wind farm to date on the planet. The farm consist of 627 separate wind turbines and a total installed capacity of 781.5 MW. This wind farm is located about 200 miles west of Fort Worth and spans considerable portions of four Texas counties and covers nearly 100,000 acres. (100000 acre = 156.25 mi² = 404.7 km²) **[Over 100X the land area of the largest 1GW coal fired plant]**

- The Horse Hollow Wind Energy Center is reportedly the second largest wind farm on record and is also located in the State of Texas. This wind farm has 421 separate wind turbines that generate a total capacity of 735 megawatts. The wind turbines are spread across 47,000 acres of land in Taylor and Nolan County, Texas. (47000 acre = 73.44 mi² = 190.2 km²) **[Nearly 50X the land area of the largest 1GW coal fired plant]**

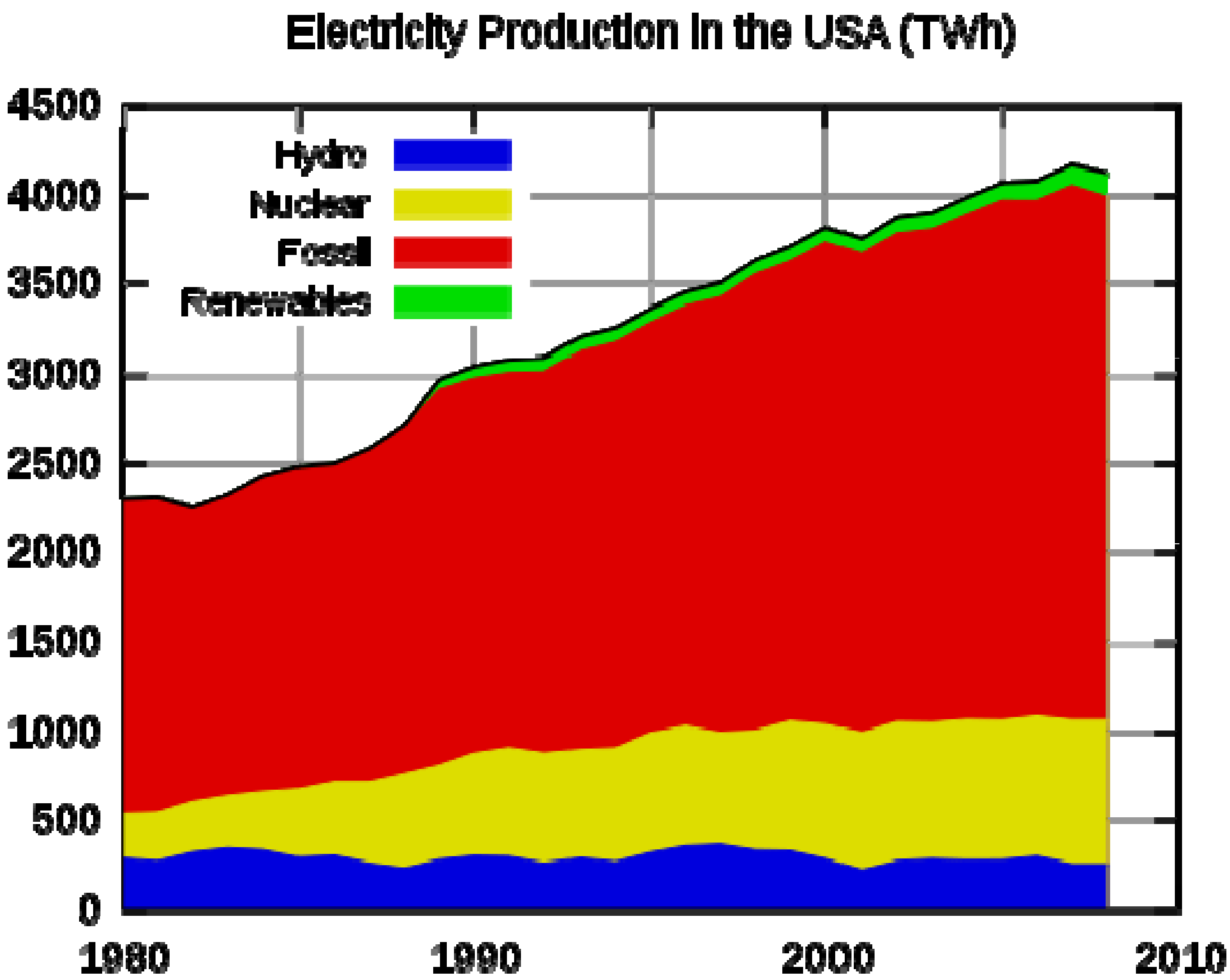
Energy Density vs. Space

- The total land area of the 50 States of the USA is 9,158,960 km²
- Total electricity consumption in MW·h/yr within the USA in 2009 was 3,741,485,000 [2009 was the lowest consumption rate of electricity in the past decade] (Source: US Department of Energy)
- 3,741,485,000 MW = 3,741,485 Gigawatts
- If a photovoltaic array field that can produce one gigawatt requires up to 50 km² of land, then total number of photovoltaic array fields necessary to generate 3,741,485 gigawatts of electrical power will require up to 187,074,250 km² of land area or **20.4 times the total land area of all 50 States of the USA**
- All calculations falsely assumed that sufficient volumes of direct sunlight were shining directly overhead on flat surface solar panels 24 hours a day and 365 days/year.

Energy Density vs. Space

- The total land area of the USA is 9,158,960 km²
- Total electricity consumption in MW·h/yr within the USA in 2009 was 3,741,485,000 (per DoE)
- 3,741,485,000 MW = 3,741,485 Gigawatts
- If a wind farm that can produce one gigawatt requires up to 150 km² of land, then number of wind farms necessary to generate 3,741,485 gigawatts of electrical power will require up to 561,222,750 km² of land area or **61.3 times the total land area of all 50 States of the USA**.
- All calculations falsely assumed that sufficient volume and velocity of wind is blowing through each wind farm at a greater than necessary steady state rate 24 hours a day and 365 days/year.

Energy Density vs. Space as of 2008



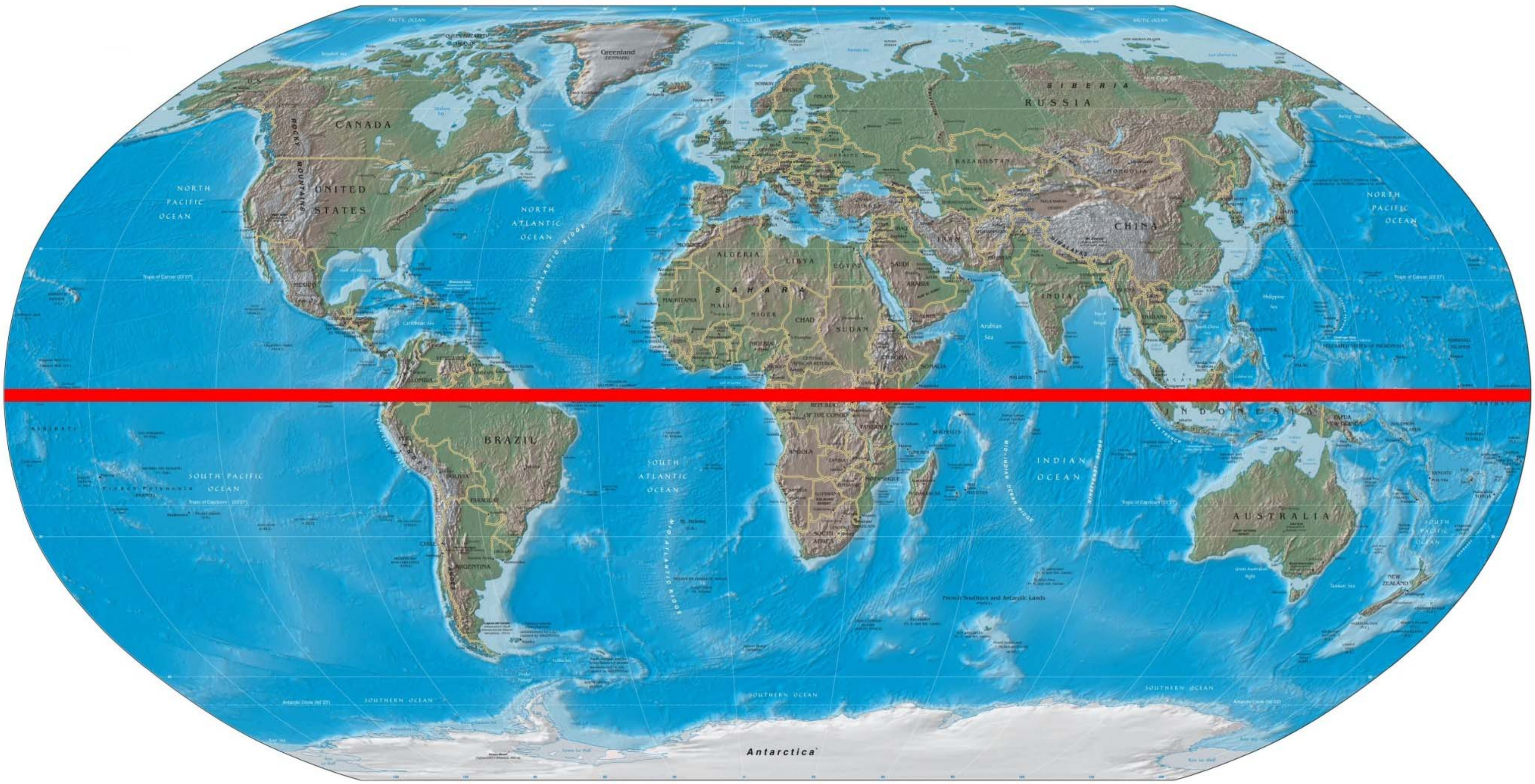
Energy Density vs. Mass

- The limiting capacity factor for photovoltaic systems is the lack of viable energy storage mean as in charging batteries when the sun is brightly and directly shining and discharging the batteries to convert Vdc to Vac when the sunshine is inadequate or when it is dark.
- The limiting factor for battery installation and use is "battery density". The theoretical limit of battery density is 3MJ/kilogram**.**
- The best available technology to date for storage batteries lithium-ion cells.
- It requires 4.74 pounds of lithium-ion cells to produce one megawatt of power for one second.
- To be able to store and discharge **1000 megawatts (1 gigawatt) of energy for only one hour would require 17,052,632 pounds of lithium-ion cells. Cost: ~$30BILLION USD)** . (NOTE: The added weight for the required cell casings, storage racks, and foundation supports is not part of the equation.)
- **The required scale of mass and cost are specifically why massive energy storage facilities supplied by solar panel arrays are economically and technically problematic at present.**

Site Preparation for a Solar Photo-Voltaic (SPV) System

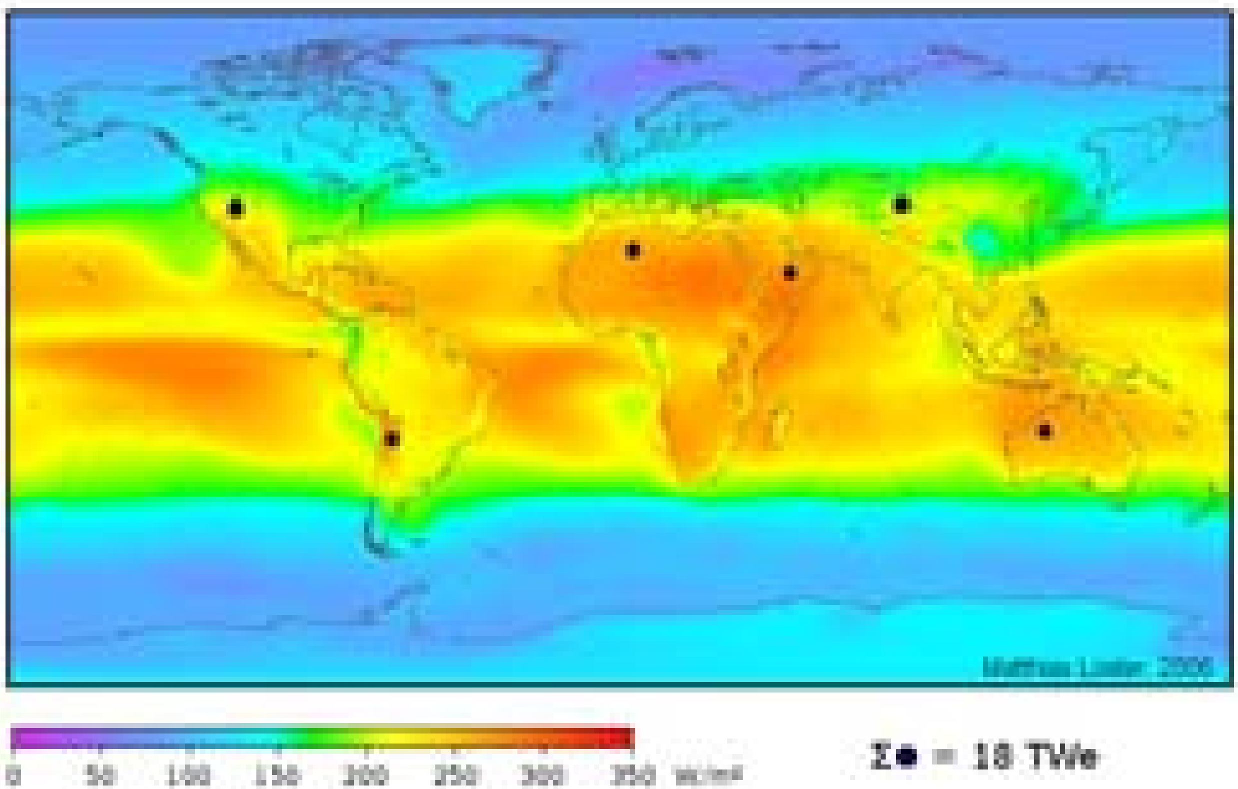
- **The idea location for a SPV System is on a very large, flat, barren, and geologically stable location on the equator with a gentle constant breeze and mild temperatures.**
- However, most of the worlds solar panels are physically located in the northern hemisphere. Consequently, intermittency and variability of sunlight will always be a challenge.
- Because of the massive amount of space required to install large capacity photovoltaic fields the selected site has to be relatively flat, have abundance sunlight at the selected site around the period of the summer solstice, free of obstacles or structures that might cast shadows, and located at some appreciable distance from inhabited areas for the available space, and with a mild wind.
- There must be space remote enough to the north of the solar array field to install inverters, transformers, and power distribution or transmission towers. Can not cast shadows.

Site Preparation for a Solar Photo-Voltaic (SPV) System



Average insolation showing land area (small black dots) required to replace the world primary energy supply with solar electricity. 18 TW is 568 Exajoule (EJ - is equal to 1018 joules per year). Insolation for most people is from 150 to 300 W/m^2 or 3.5 to 7.0 $kWh/m^2/day$.

Sites Planned for a Solar Photo-Voltaic (SPV) Systems



Average insolation showing land area (small black dots) required to replace the world primary energy supply with solar electricity. 18 TW is 568 Exajoule (EJ - is equal to 1018 joules per year). Insolation for most people is from 150 to 300 W/m² or 3.5 to 7.0 kWh/m²/day. [S10]

Installation of Smaller Solar Photo-Voltaic (SPV) Systems (1MW) [S1][S4]

- Total area requirement is about 12000 square meter or 140000 square feet (approx 3 acre). [Ideal – best case scenario]
- Site preparations for smaller SPV sites are the same for large SPV sites.
- There must be space between installed panels (wind loading) for air circulation to keep the panels at optimum temperatures to acquire maximum performance.
- **Typical Solar Panel Specification**

  Peak power generation per panel: 75 Watts/panel
  Minimum number of panels needed: 13000
  Average dimension of each panel: 2 feet x 4 ½ feet
  Average Use Life of PSV: 20+ years (with idea conditions)
  Ideal expected % degradation of panels per decade = 8-9% [The worst expected % degradation is 1.5% - 2% per year]

  Average Installation Cost: ~ $8k USD per panel in the USA with an average ROE of 33.5 years.

Installation of Smaller Solar Photo-Voltaic (SPV) Systems (1MW) [S4]

- **BATTERIES**
  Batteries for maximum panel output (~75%)

  Total capacity: 24V-30000Ah or 48V-15000Ah
  Number of batteries: Depends on the size
  Maximum use life of a battery: no more than 6-7 years under ideal conditions
  Warranty: 2 years, (possible 3 years with maintenance contract)
  Cost: $27 USD to $41 USD per watt
  Total battery cost: ~ $30,000,000 USD (does not include storage facility)

- **INVERTER**
  Sine-wave inverter of 0.9 kW.
  Cost: $50 USD per watt
  Total cost: ~ $30,000,000 USD (does not included building, maintenance cost, cooling requirements, or use life lost rates)

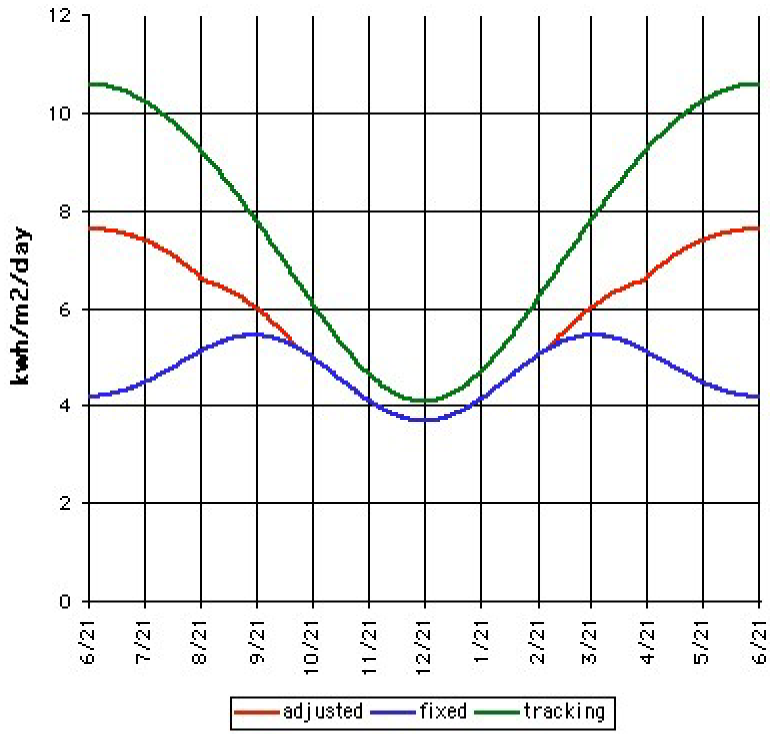
For larger scale SPV systems (3MW, 5MW, 10MW, etc.) multiply every value by the respective rate of scale.

Installation of Smaller Solar Photo-Voltaic (SPV) Systems (1MW) [S4]

- **SOLAR POWER MOUNTING:**
  - **FIXED SPV: Solar panels are oriented towards true south and are fixed at an angle equal to the latitude of the place for optimum power generation throughout the year.**
  - **SPV TRACKING:**
    - Single tracking SPV's track the sun in East-West direction during the day.
    - Double tracking SPV's track the sun in East-West direction during the day and North-South during the year seasonal variations.
    - **Tracking enhances the power output by about 30%, at the cost increase of 30%**
    - Tracking is not always recommended for solar farms because of installation and maintenance cost

SPV TRACKING [S4]

- **kWh output vs. adjusted, fixed, & tracking panels**



Available Necessary Materials vs. Scale of Production [S3]

- Alternative energy sources (solar and wind) require the use of rare earth materials as indium, gallium, and neodymium in the final manufactured products
- Current technology production of solar photovoltaic panels require large quantities of gallium. Thin film panels to reduce over all weight are made mainly of copper, indium, gallium and selenium. [Standard solar panels are flat and made from silicon.]
- Thin film and more flexible solar conversion technology require a considerable amount of indium. (Indium is an important component in flat screen monitors and there is a greater consumer demand for flat screen PC monitors and TV sets than for solar panels.)
- A 2007 study found that at current rates of consumption the know reserves of indium would only last 17 years [S5]
- Neodymium is required in the manufacture of windmill turbine generators for the production of the necessary permanent magnets.
- China is the dominant world resource (over 95%) of all rare earth minerals.
- In 2009, the Chinese government announced restriction on the export of rare earth materials to encourage investment exclusively within China of all industries using rare earth element. (i.e., flat screen monitors & TVs, solar panels, permanent magnets)
- Most of the finished manufactured products associated with solar panels and wind turbines generators used within the USA are imported from China. [S9]
- **Although the USA incurred the cost and performed most all of the present R&D for the solar industry, over 90% of the production, manufacturing, and profitability went overseas.** In the solar industry material cost, labor rates, and production expenses are the deciding variables. **Consequently, the USA can not economicly compete with China in these areas.**

Partial List of Faltered or Bankrupt “Green Energy” Companies as of October 2012** (page 1 of 3) [S12]

- Evergreen Solar ($25 million)*
- SpectraWatt ($500,000)*
- Solyndra ($535 million)*
- Beacon Power ($43 million)*
- Nevada Geothermal ($98.5 million)
- SunPower ($1.2 billion)
- First Solar ($1.46 billion)
- Babcock and Brown ($178 million)
- EnerDel’s subsidiary Ener1 ($118.5 million)*
- Amonix ($5.9 million)
- Fisker Automotive ($529 million)
- Abound Solar ($400 million)*
- A123 Systems ($279 million)*
- Willard and Kelsey Solar Group ($700,981)*

Partial List of Faltered or Bankrupt “Green Energy” Companies as of October 2012** (page 2 of 3) [S12]

- Johnson Controls ($299 million)
- Brightsource ($1.6 billion)
- ECOtality ($126.2 million)
- Raser Technologies ($33 million)*
- Energy Conversion Devices ($13.3 million)*
- Mountain Plaza, Inc. ($2 million)*
- Olsen’s Crop Service and Olsen’s Mills Acquisition Company ($10 million)*
- Range Fuels ($80 million)*
- Thompson River Power ($6.5 million)*
- Stirling Energy Systems ($7 million)*
- Azure Dynamics ($5.4 million)*
- GreenVolts ($500,000)
- Vestas ($50 million)

Partial List of Faltered or Bankrupt "Green Energy" Companies as of October 2012** (page 3 of 3) [S12]

- LG Chem's subsidiary Compact Power ($151 million)
- Nordic Windpower ($16 million)*
- Navistar ($39 million)
- Satcon ($3 million)*
- Konarka Technologies Inc. ($20 million)*
- Mascoma Corp. ($100 million)

*Bankrupt

- As of October 2012 the losses totaled 7.435 BILLION $USD at the expense of the US Taxpayers. This sum excludes the amount these failed 'Green Energy" companies received in state, local, and federal tax credits and subsidies.

**Available and reliable data on the total number of faltered or bankrupted 'Green Energy" companies that received federal taxpayer money stopped being readily available from the DoE after October, 2012.

Risks to Production Rate of Scale [S3][S9]

- Ready availability of materials at a desirable or predicable rate
- Large expected price increases
- Potential supply disruptions
- Uneven geographical distribution of available production and reserves (i.e.; Indium is an important component in flat screen monitors)
- The USA is completely import dependent on all rare earth elements
- By the year 2030 at present increased rates of manufactured produces the demands for gallium is expected to exceed known available resources by 600%.
- By the year 2030 at present increased rates of manufactured produces the demands for indium is expected to exceed known available resources by 300%.
- Prices of the silicon used in conventional solar panels from China fell dramatically, declining 30 percent in 2011 and over 50% since 2010. (per Bloomberg New Energy Finance)

Irony of Alternative Energy Production [S3][S9]

- The manufacturing of all alternative energy produces are completely dependent and reliant on fossil fuels for the mining of raw materials, all transportation needs, site preparations, manufacturing, construction, modifications, maintenance, decommissioning, and deposal.
- No alternative energy source can reproduce itself
- The total of all possible alternative energy sources can only be employed to marginally supplement fossil fuel based energy sources unless the USA returns to a pre-industrial age.
- The material input requirements and energy scarcities to produce alternative energy produces will likely constrain the development and manufacturing of alternative energy produces
- All present “shortages” of coal, oil, and natural gases are man made. At present there are 3.5 centuries of known coal reserves in the USA and recent geological discoveries indicate that the USA has more oil reserves than Saudi Arabia.

Sources

[S1]

P. J. Meier and G. L. Kulcinski, Life-Cycle Energy Requirements and Greenhouse Gas Emissions for Building-Integrated Photovoltaics, Fusion Technology Institute (2002); National Renewable Energy Laboratory, What Is the Energy Payback for PV? DOE/GO-102004-1847 (2004); Vasilis Fthenakis and Erik Alsema, "Photovoltaics Energy Payback Times, Greenhouse Gas Emissions and External Costs," Progress in Photovoltaics 14, no. 3 (May 2006), 275–280; Luc Gagnon, "Civilisation and Energy Payback," Energy Policy 36, no. 9 (September 2008), 3317–3322; Cutler Cleveland, "Net Energy from the Extraction of Oil and Gas in the United States, 1954–1997," Energy 30 (2005), 769–782; Charles A. S. Hall et al., "Peak Oil, EROI, Investments and the Economy in an Uncertain Future," in Biofuels, Solar and Wind as Renewable Energy Systems, David Pimentel, ed. (Springer Science, 2008); Vestas Wind Systems, Life Cycle Assessment of Offshore and Onshore Sited Wind Power Plants Based on Vestas V90-3.0 MW Turbines (Denmark, 2005); Alexander E. Farrell et al., "Ethanol Can Contribute to Energy and Environmental Goals," Science 311 (January 27, 2006).

Sources

[S2]

Renewable Energy Research Laboratory, University of Massachusetts at Amherst, Wind Power: Capacity Factor, Intermittency; National Renewable Energy Laboratory, Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts, NREL/SR-550-34440 (Golden, CO: NREL, 2003).

[S3]

The Post Carbon Reader: Managing the 21st Century's Sustainability Crises, Richard Heinberg and Daniel Lerch, eds. (Healdsburg , CA: Watershed Media, 2010)

[S4]

SOURCE: http://www.lgreenventures.com/solarfarm.html

Sources

[S5]

Earth's Natural Wealth: An Audit, David Cohen, New Scientist, Volume 23, pages 34-41, (May 2007)

[S6]

The relative sizes of wind turbine generators are defined and establish by the US Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) based on standards develop by the International Electric Commission (IEC).

[S7]

Wind Farm Collector System Grounding, IEEE PES Transmission and Distribution Conference 2008, Steven W. Saylors

[S8]

Wind Turbine Lightning Protection Project, 1999-2001, National Renewable Energy Laboratory (NREL), Brian McNiff, May 2002, NREL/SR-500-31115

Sources

[S9]

China Benefits as U.S. Solar Industry Withers

The bankruptcies of three American solar power companies in the last month, including Solyndra of California on Wednesday, have left China's industry with a dominant sales position — almost three-fifths of the world's production capacity — and rapidly declining costs.

http://www.nytimes.com/2011/09/02/business/global/us-solar-company-bankruptcies-a-boon-for-china.html

[S10]

http://en.wikipedia.org/wiki/Solar_power

[S11]

GE Guts Offshore Wind-Power Plans

General Electric, the U.S.-based industrial giant and leading manufacturer of wind-power turbines, is scaling back efforts to expand its presence in the offshore wind power market. The rationale: there is no meaningful offshore wind market to speak of – at least not yet.

http://www.forbes.com/sites/williampentland/2011/09/10/ge-guts-offshore-wind-power-plans/

[S12]

http://blog.heritage.org/2012/10/18/president-obamas-taxpayer-backed-green-energy-failures/

Questions?

Contact Information

S. Frank Waterer – EE, Fellow

Schneider Electric Engineering Services

2979 Pacific Drive Suite “E”

Norcross, Georgia 30071

Phone: 770-734-1368

Email: frank.waterer@schneider-electric.com