Residential Photovoltaic Solar - Options and Expectations

Randy Dunton
March 2012

Note: this document is for purposes of education only – copyrighted materials contained herein remain the property of the respective owners
Historic market drivers and costs of solar photovoltaic energy
Our energy needs and future outlook (yikes!)
Solar policies and the role of industry and government
Solar power system examples
The effects of aging, shading, and temperature
Options for PV systems for suburban living – design & cost benefits
Brief overview of the Solar PV market drivers

- In 1960 PV modules were approximately $1000 per watt, PV remained dormant – the world ran on cheap & abundant fossil fuels.
- The oil crisis in the late 70’s, the nuclear disaster in Chernobyl, and global warming sparked a renewed interest in alternatives.
- With proper government incentives in Japan and Germany, the industry fueled the exponential ramp in automated manufacturing capability, production grew exponentially for over a decade, reducing costs dramatically.
- With today’s recent Chinese competition - the retail price in 2012 has dropped to ~ $1 per watt for a module: a 1000x reduction in 50 years.
PV market growth is rapid, prolonged, and world-wide; 2011 = 67MW (recession-proof; 01, 08)

The United States and China, the largest consumers of energy, have yet to face the inevitable fact that traditional energy resources are unsustainable

After the Fukushima disaster most of Japan’s nuclear power plants are now offline, we should expect to see even greater growth worldwide

Figure 1 - Evolution of global cumulative installed capacity - 2000-2010

- PV market growth is rapid, prolonged, and world-wide; 2011 = 67MW (recession-proof; 01, 08)
- The United States and China, the largest consumers of energy, have yet to face the inevitable fact that traditional energy resources are unsustainable
- After the Fukushima disaster most of Japan’s nuclear power plants are now offline, we should expect to see even greater growth worldwide

Graph courtesy of European Photovoltaic Industry Association (EPIA)
There is a magic cross-over point called *grid-parity* where the economics are in favor of PV

Depending on where one lives (solar radiation) and also depending on how much one pays for energy - this cross-over point has been achieved (e.g. Hawaii, California)

- Hawaiians pay 30-40 cents/kWh
- Arizonans pay 10-15 cents/kWh
- Washington State pays ~6 cents/kWh
- We are just starting - renewables are in their infancy (~1%) as contributors to the utility energy mix

- Utility-scale PV power plants consisting of 100’s of thousands of modules are becoming more common, especially in the south-western USA (e.g. Mesquite Solar 150MW)

- Utility PV power plants are built in very short time as compared to nuclear (10 years), however upfront costs are high as compared to gas or coal - and power output varies with the weather, making it intermittent – storage is the next challenge
Our energy needs

“It is not necessary to change. Survival is not mandatory.”

--W. Edwards Deming, American statistician, professor
The long term trends are all very alarming
- Peak production has occurred twice now (USA, global)
- Replacing oil and coal will be monumental undertakings and will take decades of *concerted* effort
- The longer we wait the more difficult, risky, and expensive it will become
- The USA has 2% of the world’s reserves - we require 25% of the oil produced - no amount of drilling will fix this
The choice of current energy sources is unsustainable, economically and environmentally.

The world’s population has grown by a factor of 3 in the last 6 years and our energy demand by a factor of 7.

China and India joining industrialized life results in explosive new demand.

Each year energy demand grows by ~2% - and is expected to grow by 30-50% by 2020, almost doubling by 2050 from 2010.

Per capita the USA uses 6x the energy of 1950 levels.

Why is solar PV so exciting and important right now? Is it not too expensive?

**PV is an expensive energy form - it would seem**

- However solar and wind are the only known viable energy options worldwide to replace the majority of oil for transportation and coal/gas for electricity
- The USA spent ~ $4 trillion on Iraq alone attempting to “secure” the oil pipeline
- The world is addicted to cheap oil, addicts must have what they need at almost any cost…
- Over 100’000 people perished in the war on Iraq – over oil…
- Extracting the last ½ of the oil reserves is proving to be very costly from a human, monetary, moral, and environmental point of view
- Coal, the other big dependency the world has, creates the worst forms of pollution: CO2, SOx, NOx, heavy metals

**Incentives for solar and wind?**

- **Worldwide the PV industry, as well as the other renewable energies require financial incentives to be viable ($46B ¹)**
- **However - all energy production has a form of direct subsidy, even oil, coal, and gas ($557B ²), it just much less apparent**
- **The indirect cost of oil - considering pollution and war? (we spend ~65$/barrel on the middle east oil for US troops ³)**

---

¹ Bloomberg New Energy Finance
² International Energy Agency (EIA)
³ “oil panic and the global crisis” (S. Gorelick)
Why is solar PV so exciting and important right now?

Suburban PV has two unique advantages over all forms of energy; solar modules fit on rooftops, close to the load

- By bringing energy production and consumption together - something fossil fuel power plants and other renewable energy can't do – suburban PV is *distributed generation* (DG) without the transmission losses incurred with grid power
- Being *distributed*, PV actually competes with retail power delivered by the utility – not wholesale (enforced by law: *net metering*)

Imagine a world with solar on every possible rooftop - and electric vehicles in every garage

- Every person becomes an energy entrepreneur
- The sun never sends a bill
- No wars over energy, no environmental disasters
Role of Government and Industry

- Physics & technology dictates where energy can be harvested, however energy is politically driven.
- Most people agree that the government’s role is to protect its citizens – long and short term.
- One wise way is to set policies – through which industry will react: with solutions for the benefit of the citizens.
- Industry’s role is to become profitable (short term mindset).
- “the market” cannot plan or execute far reaching goals – energy transition will take decades; oil, hydro, and nuclear were all government driven initially.

How it works - state level: Renewable portfolio standards (RPS) set goals: AZ 15% by 2025, CA 33% 2020, etc. – driven in AZ by the Arizona Corp. Commission (ACC)
  - AZ Utilities required by law to comply – renewable energy credits (REC) purchased from homeowners by the utility – net metering is a law
  - AZ: No sales tax and no property tax increase for PV systems

Predictions of the future of PV

- Hard to predict the future, here is one insider’s viewpoint:
- Suntech’s founder & CEO Dr. Zhengrong Shi runs the largest PV manufacturing operation in the world. 2011 sales were $3.1 B.
- Suntech has manufacturing in Goodyear AZ

Q: How big can solar get?

A: “Today it’s only about 1% of the global energy market. In many markets we already are price competitive. I think in five years' time solar won't need subsidies and that will help accelerate growth. By 2050, 25% of our electricity will come from solar.”
Brief tour of the various types of solar power plants
Photovoltaic (PV) systems

- The most visible and costly system component, common to all Photovoltaic (PV) systems, is the PV array

- *Arrays* consist of *modules*, which are electrically connected to produce a calculated voltage, current, and power output

- PV cells produce DC power, and in most cases *modules* produce DC power as well

- DC energy can be stored in batteries, directly power DC loads, or be converted to AC power by *inverters* to power AC loads with the excess energy sold back to the electric utility
One very popular system in suburban neighborhoods is the grid-tied system sometimes known as grid-connected or utility-interactive system.

It operates as one of many power generators in parallel feeding the utility grid, modular in nature a number of these may be connected in parallel even on one premise.

they will not operate without the presence of a grid; a common misconception is to assume that somehow the PV will supply power to a home when the grid is down – there is no storage.
Details of the grid-tied system

- Grid tied systems consist of a “flat-plate” array and an “inverter” that feeds the utility grid (and loads)
- Other than some safety disconnect equipment, conduit, and racking, the system is not much more than the inverter and the array
- This system requires very little maintenance and lasts 25 or more years

- System costs are ~$4/W (2012), and after rebates and incentives close to 1/2 to 2/3 of that
- Residential Systems range in size from 3KW to 15KW (DC)
- Commercial systems are generally 100KW to 1000KW, e.g. schools and stores
- Utility scale are 100’s of MW

---

Photo courtesy of Solar City, SolarWorld, SMA, Eaton

Mar. 2012 Residential PV - options and expectations © - Randy Dunton V1.0
Concentrating collectors focus the sun’s energy into an intense radiation through reflective surfaces or lenses – and must track the sun.

- high-efficiency solar cells: concentrating PV (CPV)
- working fluids: concentrating solar thermal (CST) that transfer thermal energy (a.k.a. Concentrating Solar Power CSP)
A concentrating collector can take many forms, the two popular ones:

- Heliostats
- Mirrored lens (trough)
- In both cases steam is generated to run a turbine and a generator
The sun’s radiation is used to heat a large body of air under an expansive collector zone, which is then forced by the laws of physics (hot air rises) to move upward through large turbines generating electricity.

In the 1980s, a solar chimney power plant was demonstrated to work in a pilot project in Spain.

Able to generate power day and night.

EnviroMission is planning a 200MW plant in Arizona; 1000m high and 7000m diameter, $750M (est.) ($3.25/W).

No water!
Effects of shade, heat, aging on PV systems

Images courtesy of American Solar Electric
Shade and heat

- Modules perform less than nominally rated at higher temperatures: -0.5% / degree Celsius
- E.g. a 200W module will produce ~160W in the summer heat – this part of normal system design
- Keeping the array well ventilated is good practice (>4” off the roof)
- Shade is the performance killer
  - 50% to 90% power loss if module is partially shaded
- A proper system design starts with sun-path analysis and shading considerations (site survey)
Module aging

- PV systems age very well in AZ – 15 year old power plant from SRP is running reliably without issues
- Long-term aging is ~ 0.4% to 0.7% 2) per year
- Studies show that module power drop ~4% 1) over 11 years

- What causes aging?: there is no conclusive data yet, it seems UV causes cell p-n junction degradation, additionally internal hot-spots and internal module electrical resistance reduces the power

Notes:
1) Source “COMPARISON OF PV MODULE PERFORMANCE BEFORE AND AFTER 11-YEARS OF FIELD EXPOSURE” (A.M. Reis et. al.)
2) "DEGRADATION ANALYSIS OF WEATHERED CRYSTALLINE-SILICON PV MODULES" (C.R. Osterwald et. Al.)
Example Systems:

- Off-grid 1.5HP pool pump with 1.3KW array
- 3.9KW grid-tied generator
Off-grid pool pump (1.3KW)

- Running a load directly from the array is simple and the most efficient type of system
- DC motor efficiency (~90%) is greater than common 1-phase AC motors (56%)
- 1.3KW of PV power can run the 1.5HP pool pump to filter the pool (30’000G) 1.5x to 2x per day
- Pool is filtered during the day; best time to run pump to avoid algae growth, less chemicals and longer running times in the summer, automatically runs less during winter with shorter days
- Pump is very quite and manufactured in Safford Arizona (Sun Pumps)
- Smaller pools use 1 to 1.5 HP motors and 2-4 modules
Off-grid pool pump (1.3KW)

Cost & benefit breakdown:

- Pump ~$1100, PV array ~$1300, other electrical equipment ~$300
- Hardware for roof (rails) ~$600
- Labor (est.) ~$2500
- Total costs: ~$5700 (less for smaller systems)
- 30% ITC (federal) = $1800, price of system ~$4000 (not including financing)
- Saves $60-70 per month
- 6 year simple payback compared to existing AC pool pump

(4% interest, 4% inflation of energy)
Grid-tied 3.9KW generator - design

Array, sensors, support equipment, rails and standoffs with flashing, tie into grid via breaker
• The array performance depends on tilt and azimuth – if the array is not pointed in the ideal way a loss of performance will occur

• E.g. if the roof resulted in an array tilted at 20 deg. and the array azimuth is 115 degrees from north one would experience a ~10% loss in energy production
Grid-tied 3.9KW performance: PVWatts

- NREL’s PVWatts (V1.0) is a simple and accurate tool that provides a good estimate of energy and value with a few system inputs
- (e.g. tilt and azimuth of array, system efficiency (~85%), location)

Compared with actual data (3.8KW, 20 tilt, 115 azimuth, 85%)
- Feb 2012: ~17kWh/day = 29 days x 17kWh/day = 493kWh
- Sept 2011: ~19 kWh/day = 30 days x 19 kWh/day = 570kWh

http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/
Cost trends continue down; with $1/W modules, and lower margins than 2011, expect to pay around $4/W in 2012

Leasing is popular, and prepaid lease is near $2/W
• Payback is complex; long timeframes, large upfront costs, cost of money, opportunity cost of money, inflationary cost of energy - e.g. simple payback: $9K in 14 years
• Choose variable you are comfortable with, try this great tool from Kyocera: http://www.kyocerasolar.com/calculate-your-savings.php
Reference materials

• Energy: “Crude the incredible journey of oil”
  • http://www.abc.net.au/science/crude/

• Energy “Fuel”
  • http://thefuelfilm.com/

• Energy “Crude Awakening”
  • http://www.oilcrashmovie.com/

• Role of government & renewable energy policy
  • Carbon War: Global Warming and the End of the Oil Era (Jeremy Leggett)

• PV system design
  • Photovoltaic Systems (James P. Dunlop)
outline

• Historic market drivers and costs of solar photovoltaic energy
• Our energy needs and future outlook (yikes!)
• Solar policies and the role of industry and government
• Solar power system examples
• The effects of aging, shading, and temperature
• Options for PV systems for suburban living – design & cost benefits
Backup information
Calculating PV performance by hand

To answer the question: “how much energy will a PV system produce on my house?”

- We can examine the following items:
  - Roof area pointing generally south (~20 degree pitch)
  - Use Rule of thumb to calculate power: 10W/ft² generated AC power (at noon) for silicon PV (assume array is 12% efficient)
1) Calculate roof area and power

- Using Google Earth you measure the size of area on roof for the array

- E.g. ~30 feet x ~15 feet leaving some area around the array to walk = 450 square feet

- 450 square feet of array x 10 Watts per square foot = 4500 Watts AC
2) energy per day

Google search: “NREL insolation” NREL’s radiation resource maps show that a “Flat Plate tilted at latitude” has an annual average daily irradiation level or peak sun hours of 6-7 hours.

Using 6 peak sun hours we multiply this by 4500 W to get average daily energy production of 27 KWh.

Power (kW) x Time (h) = Energy (kWh)

3) energy per month and value

- 27 KWh per day with an average of 30 days per month = 810 KWh of energy delivered per month

- At an average of $0.12 per KWh
  - $97.2/month

![Bar chart showing kWh usage for different months in 2009 and 2010.](chart.png)
The RPS (renewable portfolio standards) varies from state to state.

- For example, California has committed to producing 20% of its electricity needs with renewable energy by 2010, Arizona 15% by 2025.
- RPS is one tool for a government to direct industry and consumers towards a sustainable future, Hawaii is in a hurry since their electric grid is oil based.

**Pro-solar policy and tools**

The RPS (renewable portfolio standards) varies from state to state.

- For example, California has committed to producing 20% of its electricity needs with renewable energy by 2010, Arizona 15% by 2025.
- RPS is one tool for a government to direct industry and consumers towards a sustainable future, Hawaii is in a hurry since their electric grid is oil based.
A photon is a unit of electromagnetic radiation from the sun.
Photons contain various amounts of energy depending on their wavelength.
Certain wavelengths can be absorbed by the semiconductor material.
Photons transfer their energy to electrons in the semiconductor material, forcing electrons to move to the “N-layer” in the semiconductor.
Given that electrons are negative in charge, this creates a voltage potential.
The photovoltaic effect produces free electrons that must travel through conductors in order to recombine with electron voids, or “holes”, this is the electric current which produces power.
Micro-grid – small communities

Eigg Electric (Scotland) is a community owned company which provides electricity for all island residents from the renewable sources of water, sun, and wind

- PV array: 10KW
- Four wind turbines: 24KW
- Hydro: 100KW
- Diesel generators: 140KW
- A number of AC-coupled SMA Sunny Island battery inverters create a 3-phase AC mains for the island
- 11KM of AC grid wiring

- Power is capped, 5KW residence, 10KW for businesses
- Currently adding more solar PV for the mild dryer summers

Video: (9:54) Eigg Electric

http://www.youtube.com/watch?v=l3n-6YHquno&hl=en&fs=1

Photos courtesy of islandsgoinggreen.org

http://islandsgoinggreen.org/about/eigg-electric/
Installation and geographies

- Germany is the world leader so far – it is time for China and the USA to step up to the adoption as top world energy consumers.

Source: data and graph courtesy of European PhotoVoltaic Industry Association

Figure 22 - 2010 global cumulative installed capacity share (MW, %)