Solar Power Generation in the US:
Too expensive, or a bargain?

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Abstract

This article identifies the combined value that solar electric power plants deliver to utilities' rate payers and society's tax payers. Benefits that are relevant to utilities and their rate payers include traditional, measures of energy and capacity. Benefits that are tangible to taxpayers include environmental, fuel price mitigation, outage risk protection, and long-term economic growth components.

Results for the state of New York suggest that solar electric installations deliver between 15 to 40 cents per kWh to ratepayers and taxpayers. These results provide economic justification for the existence of payment structures (often referred to as incentives) that transfer value from those who benefit from solar electric generation to those who invest in solar electric generation.

Introduction

"Economically viable" solar power generation remains a remote and elusive goal for the solar energy skeptics because the cost of unsubsidized solar power appears to be much higher than the cost of conventional generation. Indeed, it does take a revenue stream of around 20-30 cents per kWh to justify a business investment in small to medium distributed solar electrical generation today. Large centralized solar installations in the southwestern US are below a breakeven range of 15 cents per kWh.

A mix of federal and state incentives, whether tax-based, or ratepayers-levied, can make solar an attractive investment in many parts of the US; feed-in-tariffs (FITs) have been particularly effective in

Europe and Asia. Without incentives, however, the needed revenue stream for solar generation is still considerably higher than the least expensive way to generate electricity today, i.e., via unregulated, mine-mouth coal generation. This large apparent "grid-parity gap" can hinder constructive dialogue with key decision makers and constitutes a powerful argument to weaken political support for solar incentives, especially during tight budgetary times.

In this paper, we approach the apparent grid parity gap question on the basis of the full value delivered by solar power generation. We argue that the real parity gap – i.e., the difference between this value and the cost to deploy the resource -- is considerably smaller than the apparent gap, and that it may well have already been bridged in several parts of the US. This argumentation is substantiated and quantified by focusing on the case of PV deployment in the greater New York City area. Since this is not one of the sunniest places in the US, this paper should serve as an applicable case to other regions and/or solar technologies.

Solar Resource Fundamentals

It is useful to first review a couple of fundamental facts about the solar resource that are relevant to its value.

Vast potential: First and foremost, the solar energy resource is very large (Perez et al., 2009a). Figure 1 compares the current annual energy consumption of the world to (1) the known planetary reserves of the finite fossil and nuclear resources, and (2) to the yearly potential of the renewable alternatives. The volume of each sphere represents the *total* amount of energy recoverable from the finite reserves and the *annual* potential of renewable sources.

While finite fossil and nuclear resources are very large, particularly coal, they are not infinite and would last at most a few generations, notwithstanding the environmental
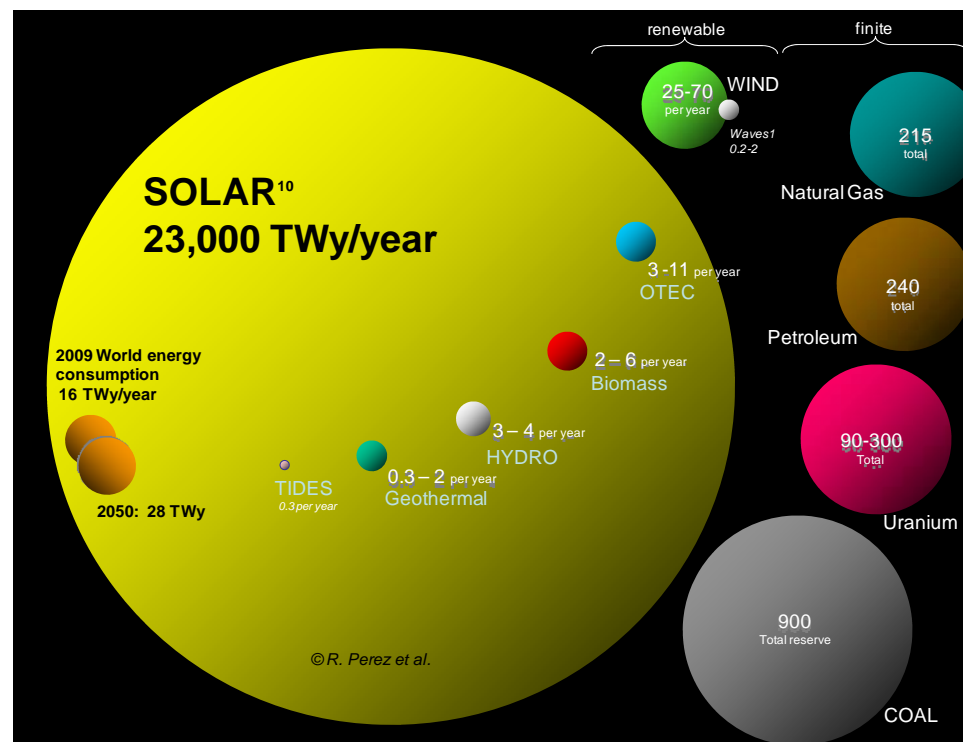

Figure 1: Comparing finite and renewable planetary energy reserves (Terawatt-years). Total recoverable reserves are shown for the finite resources. Yearly potential is shown for the renewables (source: Perez & Perez, 2009a)

impact that will result from their full exploitation if now uncertain carbon capture technologies do not fully materialize. Nuclear energy may not be the carbon-free silver bullet solution claimed by some: putting aside the environmental and proliferation unknowns and risks associated with this resource, there would not be enough nuclear fuel to take over the role of fossil fuels[1].

The renewable sources are not all equivalent. The solar resource is more than 200 times larger than all the others combined. Wind energy could probably supply all of the planet's energy requirements if pushed to a considerable portion of its exploitable potential. However, none of the others – most of which are first and second order byproducts of the solar resource -- could, alone, meet the demand. Biomass in particular could not replace the current fossil base: the rise in food cost that paralleled recent rises in oil prices and the demand for biofuels is symptomatic of this underlying reality.

On the other hand, exploiting only a very small fraction of the earth's solar potential could meet the demand with considerable room for growth. Thus, leaving the cost/value argumentation aside for now, logic alone tells us, in view of available potentials, that the planetary energy future will be solar-based. Solar energy is the only ready-to-mass-deploy resource that is both large enough and acceptable enough to carry the planet for the long haul.

Built-in peak load reduction capability: For a utility company, Combined Cycle Gas Turbines (CCGT) are an ideal source of variable power generation because they are modular, can be quickly ramped up or down and answer the question: "*is power available at will*?" As such CCGT have a high *capacity value*.

Solar generators, distributed PV in particular, are not available at will[2], but they often answer a similar question: "*is power available when needed*?" and as such can capture substantial *effective capacity value* (Perez et al., 2009b). This is because peak electrical demand is driven by commercial daytime air conditioning (A/C) in much of the US reaching a maximum during heat waves.
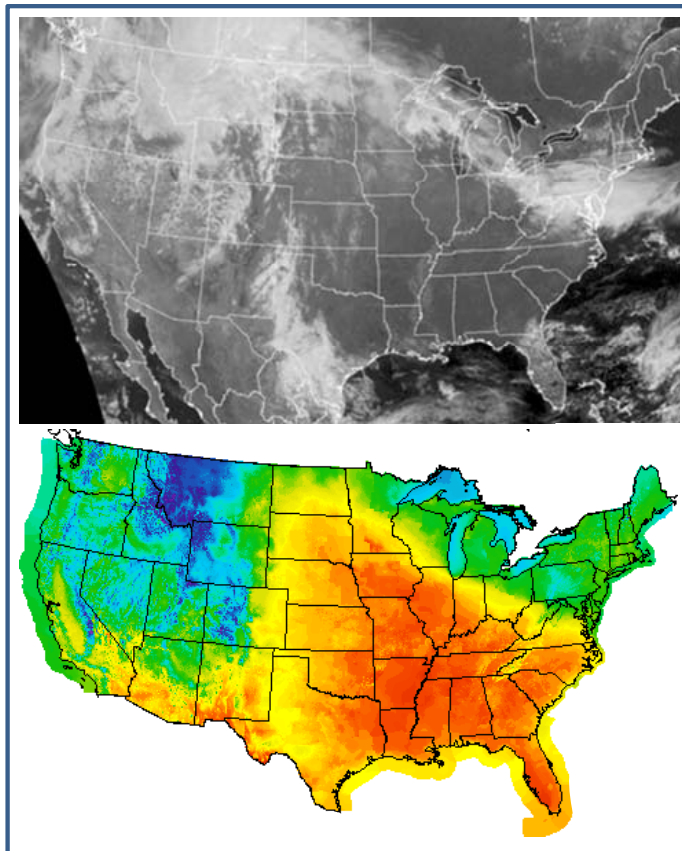

Figure2: Cloud cover during a heat wave in the US

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[1] Of course this statement would have to be revisited if an acceptable breeder technology or nuclear fusion became deployable. Nevertheless, short of fusion itself, even with the most speculative uranium reserves scenario and assuming deployment of advanced fast reactors and fuel recycling , the total finite nuclear potential would remain well below the one-year solar energy potential (ref1)

[2] Concentrating Solar Power (CSP) technology has several hours of built-in storage and could be partially available at will.

The fuel of heat waves is the sun; a heat wave cannot take place without a massive local solar energy influx. The bottom part of Figure 2 illustrates an example of a heat wave in the southeastern US in the spring of 2010 and the top part of the figure shows the cloud cover at the same time: the qualitative agreement between solar availability and the regional heat wave is striking. Quantitative evidence has also shown that the mean availability of solar generation during the largest heat wave-driven rolling blackouts in the US was nearly 90% ideal (Letendre et al. 2006). One of the most convincing examples, however, is the August 2003 Northeast blackout that lasted several days and cost nearly $8 billion region-wide (Perez et al., 2004). The blackout was indirectly caused by high demand, fueled by a regional heat wave[3]. As little as 500 MW of distributed PV region-wide would have kept every single cascading failure from feeding into one another and precipitating the outage. The analysis of a similar subcontinental-scale blackout in the Western US a few years before that led to nearly identical conclusions (Perez et al., 1997).

In essence, the peak load driver, the sun via heat waves and A/C demand, is also the fuel powering solar electric technologies. Because of this natural synergy, the solar technologies deliver hard-wired peak shaving capability for the locations/regions with the appropriate demand mix -- peak loads driven by commercial/industrial A/C -- that is to say, much of America. This capability remains significant up to 30% capacity penetration (Perez et al., 2010), representing a deployment potential of nearly 375 GW in the US.

Renewable energy breeder: The mainstream (crystalline silicon PV) solar electric technology has a proven record of low degradation (<1%/year) and long life (Chianese et al., 2003). After 50 years of operation, a well-built PV module should still generate at least 60% of its initial rating. In addition, the energy embedded in the manufacture a PV system today would be recovered in less than 3 years if it operated in a climate representative of the central US. Several other PV technologies and CSP are capable of producing tens of times their embodied energy during their operating lifetime.

Thus, in effect, solar generators are efficient *energy breeders*, and after a startup period relying on finite energies for initial deployment, a solar economy could easily supply the energy necessary to fuel its own growth.

Too Expensive?

When posing the cost/value question, it is important to identify the relevant parties: i.e., who pays for, and who receives what.

 The three parties involved in a solar electric transaction can be summarized as:

   (1) The investor/developer who purchases/builds a plant;

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[3] The High A/C demand in the northeast required large power transfers (7 GW) from the South and West into the Northeast. These transfers and the inattention of the grid operators caused power lines to overload and disconnect, leaving fewer and fewer energy transfer paths open as the afternoon progressed, until the point when the last major link, near Cleveland, failed and the path closing failure accelerated exponentially, leaving the northeast as an electrical island disconnected from the rest of the continent with 7 GW power generation deficit – the text book example of a blackout. The solar resource region-wide at the time of the blackout was nearly ideal, representing a text-book example of heat wave conditions (Ref3)

(2) The utility and its ratepayers who purchase the energy produced by the plant;[4]
(3) The society at large and its taxpayers who contribute via public R&D and tax-based incentives and receive benefits from the plant.

The transaction is often perceived as one-sided in favor of the investor/developer whose return on investment – e.g., the necessary 20-30 cents breakeven cash flow-equivalent for distributed PV -- is forced upon the two other parties. However, these parties do receive tangible value from solar generation.

Value to the utility and its ratepayers accrues from:

- Transmission (wholesale) energy, 6-11 ¢/kWh: energy generated locally by solar systems is energy that does not need to be purchased on the wholesale markets at the *Locational-based Marginal Pricing* (LMP). Perez & Hoff (2008) have shown that in New York State, the value of transmission energy avoided by locally delivered solar energy ranged from 6 to 11 cents per kWh, with the lower number applying to the well-interconnected western NY State area, and the higher number applying to the electrically congested New York City/Long Island area. This is more than the mean LMP in both cases (respectively 5 and 9 cents per kWh) because solar electricity naturally coincides with periods of high LMP.

- Transmission capacity, 0-5 ¢/kWh: because of demand/resource synergy discussed above, PV installations can deliver the equivalent of capacity, displacing the need to purchase this capacity elsewhere, e.g., via demand response (Perez & Hoff, 2008). In the above study, Perez et al. calculated the effective capacity credit of low penetration PV in metropolitan New York and showed that PV could reliably displace an annual demand response expense of $60 per installed solar kW, i.e., amounting to 4.5 cents per produced solar KWh[5].

- Distribution energy (loss savings), 0-1 ¢/kWh: distributed solar plants can be sited near the load within the distribution system – whether this system is radial or gridded – therefore, they can displace electrical losses incurred when energy transits from power plants to loads on distribution networks (this is in addition to transmission energy losses). This loss savings value is of course dependent upon the location and size of the solar resource relative to the load, and upon the specs of the distribution grid carrying power to the customer. A detailed site-specific study in the Austin Electric utility network (Hoff et al., 2006) showed that loss savings were worth in average 5-10% of energy generation. In the case of New York this would thus amount to 0.5-1 cent per kWh.

- Distribution capacity, 0-3 ¢/kWh: As with transmission capacity, distributed PV can deliver effective capacity at the feeder level when the feeder load is driven by industrial or commercial A/C, hence can reduce the wear and tear of the feeder's equipment – e.g., transformers -- as well as defer upgrades, particularly when the concerned distribution system experiences growth. As above, this distribution capacity value is highly dependent upon the feeder and

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[4] Sometimes this entity may be replaced by a direct customer as is done in power purchase agreements (PPAs) however, because the utility grid is always the buffer/conduit of solar energy generation, PPA or not, the "big-picture" cost value equation remains the same.
[5] 1 kW of PV in New York State generates on ~ 1,350 KWh/year. Therefore $60 per kW per year amounts to 4.5 cents per kWh produced.

location of the solar resource and can vary from no value up to more than 3 cents per generated solar KWh (e.g., see Shugar & Hoff, 1993, Hoff et al., 1996, Wenger et al., 1996 and Hoff, 1997).

- Fuel price mitigation, 3-5 ¢/kWh: Solar energy production does not depend on commodities[6] whose prices fluctuate on short term scales and will likely escalate substantially over the long term. When considering figure 1, it is hard to imagine how the cost of the finite fuels underlying the current wholesale electrical generation w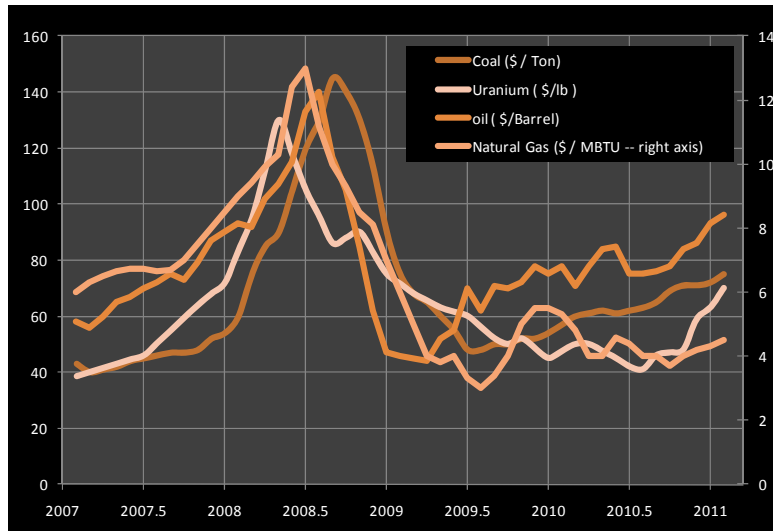ill not be pressured up exponentially as the available pool of resources contracts and the demand from the new economies of the world accelerates. The cost of oil may be the most apparent, but all finite energy commodities, including coal, uranium and natural gas, tend to follow suit, as they are all subject to the same global energy demand contingencies. Even before the 2011 Middle East political disruptions,

Figure 3: Finite energy commodity price trends 2007-2011

in a still sluggish economy, energy commodity prices had ramped up past their 2007 levels when the world economy was stronger (see fig. 3). Solar energy production represents a very low risk investment that will probably pan out well beyond a standard 30 year business cycle (Zweibel, 2010). In a study conducted for Austin Energy, Hoff et al. quantified the value of PV generation as a hedge against fluctuating natural gas prices (Hoff et al., 2006). They showed that the hedge value of a low risk generator such as PV can be assessed from two key inputs: (1) the price of the displaced finite energy over the life of the PV system as reflected by futures contracts, and (2) a risk-free discount rate[7] for each year of system operation. Focusing on the short term gas futures market (less than 5 years) of relevance to a utility company such as Austin Energy, and taking a stable outlook on gas prices beyond this horizon, they quantified the hedged value of PV at roughly 50% of current generation cost -- i.e., 3-5 cents per kWh in the context of this article, assuming that wholesale energy cost (see above) is representative of generation cost.

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[6]Conventional energy is currently required for the manufacture of solar systems but, as argued above, this input will eventually be displaced because of the resource's breeder effect.

[7]Discount rates are used to measure the present decision-making weight of future expenses/revenues as a function of their distance to the present. A high discount rate minimizes the impact of future events such as fuel cost increases, while a low rate gives more weight to these events (e.g., see Ref 15). From an investor's stand point, the discount rate represents the return of a hypothetical investment against which to benchmark a particular venture. Low risk investments are characterized by low return rates (e.g., T-bills) while high risk ventures require high rates to attract prospective investors.

There are additional benefits that accrue to the society at large and its tax payers:

- Grid security enhancement, 2-3 ¢/kWh: because solar generation can be synergistic with peak demand in much of the US, the injection of solar energy near point of use can deliver effective capacity, and therefore reduce the risk of the power outages and rolling blackouts that are caused by high demand and resulting stresses on the transmission and distribution systems. The capacity value of PV accrues to the ratepayer as mentioned above. However, when the grid goes down, the resulting goods and business losses are not the utility's responsibility: society pays the price, via losses of goods and business, compounded impacts on the economy and taxes, insurance premiums, etc. The total cost of all power outages from all causes to the US economy has been estimated at $100 billion per year (Gellings & Yeager, 2004). Making the conservative assumption that a small fraction of these outages, say 5-10%, are the of the high-demand stress type that can be effectively mitigated by dispersed solar generation at a capacity penetration of 20%, it is straightforward to calculate that the value of each kWh generated by such a dispersed solar base would be worth around 3 cents per kWh to the New York tax payer (see appendix).

- Environment/health, 3-6 ¢/kWh: It is well established that the environmental footprint of solar generation (PV and CSP) is considerably smaller than that of the fossil fuel technologies generating most of our electricity (e.g., Fthenakis et al., 2008), displacing pollution associated with drilling/mining, and emissions. Utilities have to account for this environmental impact to some degree today, but this is still only largely a potential cost to them. Rate-based Solar Renewable Energy Credits (SRECs) markets that exist in some states as a means to meet Renewable Portfolio Standards (RPS) are a preliminary embodiment of including external costs, but they are largely driven more by politically-negotiated processes than by a reflection of inherent physical realities. The intrinsic physical value of displacing pollution is very real however: each solar kWh displaces an otherwise dirty kWh and commensurately mitigates several of the following factors: greenhouse gases, Sox/Nox emissions, mining degradations, ground water contamination, toxic releases and wastes, etc., which are all present or postponed costs to society. Several exhaustive studies emanating from such diverse sources as the nuclear industry or the medical community (Devezeaux, 2000, Epstein, 2011) estimate the environmental/health cost of 1 kWh generated by coal at 9-25 cents, while a [non-shale[8]] natural gas kWh has an environmental cost of 3-6 cents per kWh. Given New York's generation mix (15% coal, 29% natural gas), and ignoring the environmental costs associated with nuclear and hydropower, the environmental cost of a New York kWh is thus 2 to 6 cents per kWh. It is important to note however that the New York grid does not operate in a vacuum but operates within – and is sustained by -- a larger grid whose coal footprint is considerably larger (more than 45% coal in the US) with a corresponding cost of 5-12 cents per kWh. In the appendix, we show that pricing one single factor – the greenhouse gas CO_2 – delivers at a minimum 2 cents per solar generated PV kWh in New York and that an argument could be made to claim a much

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[8] Shale natural gas is believed to have a higher environmental impact than conventional natural gas, including greenhouse gas emissions (Howarth, R., 2011).

higher number. Therefore taking a range of 3-6 cents per kWh to characterize the environmental value of each PV generated KWh is certainly a conservative range.

- Long Term Societal Value, 3-4 ¢/kWh: Beyond the commodity futures' 5-year fuel price mitigation hedge horizon of relevance to a utility company and worth 3-5 ¢/kWh (see above), a similar approach can be used to quantifying the long term finite fuel hedge value of solar generation, from a societal (i.e., taxpayer's) viewpoint in light of the physical realities underscored in figure 1. Prudently, and many would argue conservatively, assuming that long-term, finite, fuel-based generation costs will escalate to 150% in real terms by 2036, the 30-year insurance hedge of solar generation gauged against a low risk yearly discount rate equal the T-bill yield curve amounts to 4-7 cents per kWh (see appendix). Further, arguing the use of a lower "societal" discount rate (Tol et al., 2006) would place the hedge value of solar generation at 7-12 cents per kWh (see appendix). Taking a middle ground of 6-9 cents per kWh, the long term societal value of solar generation can thus be estimated at 3-4 cents per kWh (i.e., the difference between the societal hedge and short-term utility hedge already counted above).

- Economic growth, 3+ ¢/kWh: The German and Ontario experiences, where fast PV growth is occurring, show that solar energy sustains more jobs per kWh than conventional energy (Louw et al., 2010, Ban-Weiss et al., 2010, and see appendix). Job creation implies value to society in many ways, including increased tax revenues, reduced unemployment, and an increase in general confidence conducive to business development. Counting only tax revenue enhancement provides a tangible low estimate of solar energy's multifaceted economic growth value. In New York this low estimate amounts to nearly 3 cents per kWh, even under the extremely conservative, but thus far realistic, assumption that 80% of the manufacturing jobs would be either out-of-state or foreign (see appendix). The total economic growth value induced by solar deployment is not quantified as part of this article as it would depend on economic model choices and assumptions beyond the present scope. It is evident however, that the total value would be higher than the tax revenues enhancement component presently quantified.

Cost: It is important to recognize that there is also a cost associated with the deployment of solar generation on the power grid which accrues against the utility/rate payers. This cost represents the infrastructural and operational expense that will be necessary to manage the flow of non-controllable solar energy generation while continuing to reliably meet demand. A recent study by Perez et al. (2010) showed that in much of the US, this cost is negligible at low penetration and remains manageable for a solar capacity penetration of 30% (less than 5 cents per KWh in the greater New York area at that high penetration level). Up to this level of penetration, the infrastructural and operational expense would consist of localized (demand side) load management, storage and/or backup operations. At higher penetration, localized measures would quickly become too expensive and the infrastructure expense would consist of long distance continental interconnection of solar resources, such as considered in projects such as Desertec (Talal et al., 2009).

Bottom line

Table 1 summarizes the costs and values accruing to/against the solar developer, the utility/ratepayer and the society at large represented by its tax payers. The combined value of distributed solar generation to New York's rate and tax payers is estimated to be in the range of 15-41 cents per kWh. The upper bound of the range applies to solar systems located in the New York metro/Long Island area and the lower bound applies to very high solar penetration for systems in non-summer peaking areas of upstate New York. In effect, Table 1 shows that grid parity already exists in parts of New York -- and by extension in other parts of the country -- since the value delivered by solar generation exceeds its costs. This observation justifies the existence of (or requests for) incentives as a means to transfer value from those who benefit to those who invest.

TABLE 1

	Developer/Investor	Utility/Ratepayer	Society/Taxpayer
Distributed solar* system Cost	20-30 ¢/kWh		
Transmission Energy Value		6 to 11 ¢/kWh	
Transmission Capacity Value		0 to 5 ¢/kWh	
Distribution Energy Value		0 to 1 ¢/kWh	
Distribution Capacity Value		0 to 3 ¢/kWh	
Fuel Price Mitigation		3 to 5 ¢/kWh	
Solar Penetration Cost		0 to 5 ¢/kWh	
Grid Security Enhancement Value			2 to 3 ¢/kWh
Environment/health Value			3 to 6 ¢/kWh
Long-term Societal Value			3 to 4 ¢/kWh
Economic Growth Value			3+ ¢/kWh
TOTAL COST / VALUE	**20-30 ¢/kWh**	**15 to 41 ¢/kWh**	

* Centralized solar has achievd a cost of 15-20 cents per kWh today. However less of the above value items would apply. The distribution value items would not apply. Transmission capacity, and grid security items would generally be towards the bottom of the above ranges, while penetration cost would be towards the top of the ranges because of the burden placed on transmission and the possible need for new transmission lines -- nevertheless, a value of 14-30 cents per kWh could be claimed.

<u>Conservative estimate</u>: It is important to stress that this result was arrived at while taking a conservative floor estimate for the determination of most benefits, and that a solid case could be made for higher numbers particularly in terms of environment, fuel hedge and business development value. In addition, several other likely benefits were not accounted for because deemed either too indirect or too controversial. Some of these unaccounted value adders are worth a brief qualitative mention:

- No value was claimed beyond 30 year life cycle operation for solar systems, although the likelihood of much longer quasi-free operation is high (Zweibel, 2010)
- The positive impact on international tensions and the reduction of military expense to secure ever more limited sources of energy and increasing environmental disruptions was not quantified.
- The fact dispersed solar generation creates the basis for a strategically more secure grid than the current "hub and spoke" power grid in an age of growing terrorism and global disruptions concerns was not quantified.
- Economic growth impact was not quantified beyond tax revenue enhancement.
- The question of government subsidies awarded to current finite energy sources (i.e., displaceable taxpayers' expense) was not addressed.

Tax payer vs. rate payer: Unlike conventional electricity generation, the value of solar energy accrues to two parties. This may explain why the perception of value is not as evident as the above numbers would suggest. In particular, public utility commissions are focused on defending the interests of utility ratepayers, and if only the utility/ratepayers' value is considered, the case for solar is marginal at best (4-25 cents of value per kWh). However, focusing on the ratepayers' interest alone ignores the fact that ratepayers and the taxpayers are one and the same. Supporting one to the exclusion of the other ends up penalizing the whole person.

Tangible Value: Another reason why perception of value is not evident is because those who pay for the costs that solar would displace are often not aware of these costs. For the ratepayers items (energy & capacity), the tradeoff is obvious, but not so for the other items. However, costs are incurred in many indirect, diffuse, but nevertheless very real ways -- e.g., insurance premiums, higher taxes to mitigate impacts, deferred costs (environment, future replacements of short term infrastructures, energy increases), and missed economic growth opportunities.

Stable value: One of the characteristics of the solar resource is its ubiquity and stability: it is present everywhere and does not vary much from one year to the next although short term variability (clouds, weather, seasons) often tend to overshadow this perception (Hoff & Perez, 2011). Similarly, the value delivered by solar generators is very stable and predictable.

The two primary factors that do determine value per kWh produced are (1) location and (2) solar penetration[9]. Location is important because the value delivered by solar generation in terms of transmission and distribution energy and capacity, as well as blackout protection is location-dependent: a system in winter-peaking rural upstate New York will deliver less value than a system in a growing commercial sector of Long island. Penetration is important, because some of the benefits, in particular the capacity benefits, tend to erode with penetration; and the cost to locally mitigate this erosion increases (see, Perez et al., 2010).

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[9] Technology and solar system specs (e.g., array geometry) are also relevant: highest value in NYC would be for systems delivering near maximum output at 4 PM – i.e., fixed tilt, oriented SW.

Therefore, if one were to design an effective system to provide solar generation with the fair value it deserves from rate/taxpayers, it would have to be a stable and predictable system that accounts for the location and penetration factors. Auction-based SRECS could be engineered to meet these criteria, but a smart value-based FIT that is stable and tunable by design, appears to be a more logical match[10].

Very high penetration solar?

Some of the benefits identified in this article apply roughly up to 30% solar penetration. This already represents a 375 GW high-value solar deployment opportunity for the US -- a very large prospective market with a large national payoff; but what happens beyond that point? At very high penetration, the issues facing solar would become similar to wind generation's issues, albeit with a much smaller and more [aesthetically] acceptable footprint. Many of the value items mentioned above would remain (long-term, wholesale energy, fuel price hedge, environment) while others would not (regional and localized capacity). The solutions envisaged today, including large scale storage and continental/international interconnections to mitigate/eliminate weather, seasons and daily variability, are currently on the drawing board (e.g., Perez, 2011, Lorec, 2010, Talal et al., 2009).

Final Word: The Value of Solar

It is clear that some possibly large value of solar energy is missed by traditional analysis. Most of us recognize this in our perception of solar as more sustainable than traditional energy sources. The purpose of this article is to begin the quantification of this value so that we can better come to terms with the difficult investments we may make in solar despite its apparent grid parity gap with conventional energy. Society gains back the extra we pay for solar. It gains it back in a healthier, more sustainable world, economically, environmentally, and in terms of energy security.

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APPENDIX

Grid security enhancement: 20% US penetration would represent roughly 250 GW of solar generating capacity. Using a New York-representative production level of 1,350 kWh per KW per year, the solar production would thus amount to 375 billion kWh/year, worth $5-10 billions in outage prevention value under the conservative assumption selected here, amounting to 2-3 cents per kWh.

Estimating solar CO2 mitigation value: The value of solar generation towards CO2 displacement may be gauged using several different approaches.

(1) By starting from the carbon tax /cap-and-trade penalty levels that are being envisaged today -- at $30-40/ton of CO2 (e.g., Nordhaus, 2008). Given the energy generation mix in a state like New York, each locally displaced kWh (i.e., solar generated) would remove 500-600 grams of CO2, and thus would be worth nearly 2 cents.

(2) By starting from the figure of 1.5% of world GDP per year advanced by the IPCC as the minimum necessary to prevent a runaway climate change (IPCC, 2007). 1.5% of GDP represents $900 billions. Global CO2 emissions are ~ 30 billions tons. Displacing 2/3^{rds} of these emissions to bring us back to a 1960's level, and again, and taking New York's current generation mix as an emission reference amounts to a value of 3 cents for each kWh displaced by solar generation.

(3) Also by starting from the 1.5% GDP figure, but recognizing that solutions to displace green house gases need to be primed and encouraged before they can be effective and reach their mitigation objectives. If we assume, very conservatively, that solar energy represents only 10% of the global

warming solution[11] and should thus be fully encouraged to the tune of 0.15% GDP, then given the current installed solar capacity of 20-30 GW and the current installation rate approaching 20 GW annually worldwide, encouraging the development of solar would amount to distributing ~ 150 cents per kWh to each existing and new solar system. This value would then decrease gradually over the years as the installed solar capacity grows, ultimately reaching a value commensurate with points (1) and (2).

Long term fossil fuel price mitigation/ societal value: The long term fuel price mitigation value of a solar kWh is the present value of the difference between what one would have to pay for energy escalating over the life of the solar system and what one would have to pay if energy cost remained constant. Under the assumptions of this article – 150% increase of finite energy in 25 years and a present value assessed using a yearly low risk discount rate equal to the T-Bill yield curve, this difference is about 60%. Hence, taking the solar-coincident wholesale generation cost of 6-11 cents as gauge of current energy production cost, the long term mitigation value of a solar kWh is 4 to 7 cents per kWh. Interestingly, this estimate is commensurate with the International Energy Agency's contention that a CO_2 tax worth $175 per ton should be necessary to encourage the development of renewables and displace fossil fuel depletion (Tanaka, 2010) while mitigating their depletion and keeping their long term prices near the present range. Based on the New York's generation mix, $175 per ton amounts to 9-10 cents per kWh. It is important to remark that alternative and less conservative approaches can be considered and defended to determine the value of the low risk/long life solar investment to society. In particular, comparing the difference between solar savings assessed with a business as usual discount rate and a societal discount rate provides a measure of the long term society's benefit that is not taken into account using short-term oriented business as usual approaches. Even when using a very modest business-as-usual discount rate of 7%, the present value of conventional generation appears reasonable: future operating costs increase but do not matter much because they are discounted – at 7% the weight of expense/revenue 30 years into the future in terms of present-decision making is discounted by nearly 85% (at 10% discount rate, the weight would be discounted by over 95%). However, this practice heavily penalizes future generations. It also penalizes solar: Solar power plants are upfront-loaded with relatively high installation costs, and the quasi free energy they will produce for the long term is not valued as it should, since it is heavily discounted. Nevertheless, the intergenerational, long-term societal value of present-day solar installation is very real. As a remedy to this dichotomy, "societal" discount rates are sometimes used by governments to justify investments which are deemed appropriate for the long term well being of the society (Tol et al., 2006) – solar generation clearly fits this definition. Comparing a 2% societal discount rate and a 7% business-as-usual rate and calculating the value of solar as the present difference of the two alternatives, the societal hedge value of solar energy generation would be 7-12 cents per kWh.

Tax revenue enhancement: The German experience indicates that each MW of PV installed implies 10-15 module manufacturing jobs, 8-15 installation jobs and 0.3 maintenance jobs, as confirmed by recent numbers from Ontario (Louw et al., 2010, Peters, 2010). Solar jobs represent more than ten times

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[11] Given the potentials shown in Figure 1, it is probably much higher than that. A higher percentage would yield a higher solar value.

conventional energy jobs per unit of energy produced – i.e., ten new solar jobs would only displace one conventional energy job.

Although these numbers may be skewed by the fact that a still expensive and nascent solar industry is overly job-intensive, a quick reality check reveals that the relative higher price of the solar technology today also implies a higher job density: the necessary 20-30 c/kWh solar revenue stream underlying discussions in this article corresponds to a turnkey cost of $4 million per solar MW. In the case of PV, this cost can be assumed to divide evenly between technology (modules/inverters) and system installation (construction, structures) representing $2M per MW for each. Conservatively assuming that 50% of technology and 75% of installation costs are directly traceable to solar-related jobs and assuming a job+overhead rate of $100K/year, this simple reality check yields 10 manufacturing and 15 construction-related jobs. Demonstrating that the solar job density of the solar resource is higher than that of conventional energy is also straightforward to ascertain from first principles: comparing a $4/Watt turnkey solar system producing 1,500 kWh/KW/year to a $1/Watt turnkey CCGT producing 5,000 kWh/kW/year, and assuming that the job density per turnkey dollar is the same in both cases, yields 13 times more jobs for the solar option per kWh generated.

As the turnkey cost of solar systems expectedly goes down, the job density will of course be reduced, but, more importantly, so will the necessary breakeven revenue stream.

For now, given the premise of this paper -- a required solar energy revenue stream of 20-30 cents per solar kWh -- let us calculate the value that society receives under this assumption.

The following assumptions are used for this calculation:

- Each new solar MW results in 17 new jobs. There are 2 new manufacturing jobs (it is assumed that 80% of the manufacturing jobs are foreign - and do not generate any federal or state tax revenue) and there are 15 new installation jobs.
- Solar systems are replaced after 30 years, so the amount of jobs corresponding to each installed MW is the present value of a 30 year job replacement stream. With a discount rate of 7%, 17 jobs times an annualized factor of 0.08 translates to 1.36 jobs per MW per year.
- System maintenance-related jobs amount to 0.3 jobs per MW[12] (German experience)
- The total amount of sustained jobs per MW is therefore equal to 1.66.
- Assuming that ten solar jobs displace one conventional energy job, the net sustainable new jobs per solar MW are therefore equal to 1.49 (90% of 1.66).
- The salary for each solar job is $70K/year.
- Current federal and New York tax rates for an employee making $70,000 per year pays a combined effective income tax rate of 23%.
- 1 MW of PV generates 1,500,000 kWh per year.

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[12] This corresponds to a very reasonable O&M rate of 0.5% under the assumptions of this study.

- Finally, direct job creation translates to the additional creation of indirect jobs. It is conservatively assumed that the indirect multiplier equals 1.7 (i.e. every solar job has an indirect effect in the economy of creating an additional 0.7 jobs).[13]

Putting the pieces together, the tax benefit from job creation equals about 3 cents per kWh.

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[13] Indirect base multipliers are used to estimate the local jobs not related to the considered job source (here solar energy) but created indirectly by the new revenues emanating from the new [solar] jobs.