THE PROMISE AND PITFALLS OF VENTURE CAPITAL AS AN ASSET CLASS FOR CLEAN ENERGY

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ABSTRACT

Clean tech investment differs from traditional venture capital (VC) sectors by virtue of need to lengthen the time horizon of involvement in investments--in both directions, that is, more investment and involvement in firms at an earlier stage of technology development and with firms in a later stage of technology commercialization. Consequently, clean tech VC investing requires changes to the traditional VC approach. In this paper, we provide some evidence that suggests that these changes are occurring, that VCs indeed may be in the process of adapting to the requirements of clean tech investing. This paper reviews both the potential and limitations of venture capital as a source of funding for clean energy. It tries to paint an accurate picture of the realities of VC funding of clean energy as it has evolved during the last decade. In this paper, we provide preliminary evidence that suggests that the more clean energy becomes a part of the VC world the more venture capitalists are adjusting their operating procedures to accommodate this category of investment. The evidence suggests that a number of adjustments are taking place. First, because of a fixed pool of resources, VCs are investing larger amounts of their money for longer periods of time. Second, they increasingly have been avoiding high risk clean energy production, distribution, and installation manufacturing and production companies and funding the back and front ends of the solar energy supply chain and startups that focus on the intersection between energy and information technologies areas. Third, besides making bigger bets, stretching out their timetables, and avoiding high risk and capital intensive companies, they have been experimenting more by investing in a greater number of firms in risky technologies whose commercialization is less imminent. If the VC role in clean energy is to be more transformative we believe it is because that these trends will gain momentum, but how deep these adjustments are and whether they will grow in the future is not certain.

For the purposes of this paper, clean energy will be defined as solar, wind, biofuels, energy efficiency, alternative modes of transportation like hybrids, electric, and fuel cell vehicles, and supportive technologies such as storage and smart grid. What they have in common is the potential to reduce noxious emissions, lower the chances of climate change, decrease U.S. dependence on an imported commodity from unstable regions, build new industries, and create jobs. Under current projections of the Department of Energy (DOE) by the year 2035 the U.S. still will be an economy and society largely dominated by fossil fuels (U.S. Department of Energy, 2010). In the DOE's base case, use of natural gas expands from 25 to 26 percent, coal declines from 21 to 20 percent, reliance on petroleum falls from 37 to 32 percent, energy use grows slowly in response to greater energy efficiency, and renewable energy increases from 8 percent of U.S. primary energy consumption to 15 percent. Though clean energy use grows in the DOE scenario, its impact is not transformative. What might alter this prediction would be a series, or even a single, major clean energy leap forward. "Our best hope," according to Benjamin Strauss, a scientist quoted in the *New York Times* on July 22, 2012, "is some kind of disruptive technology that takes off on its own, the way the Internet…took off" (Leohardt, 2012). Such a technology, like the Internet, might be partially or even entirely funded by venture capitalists (VCs).

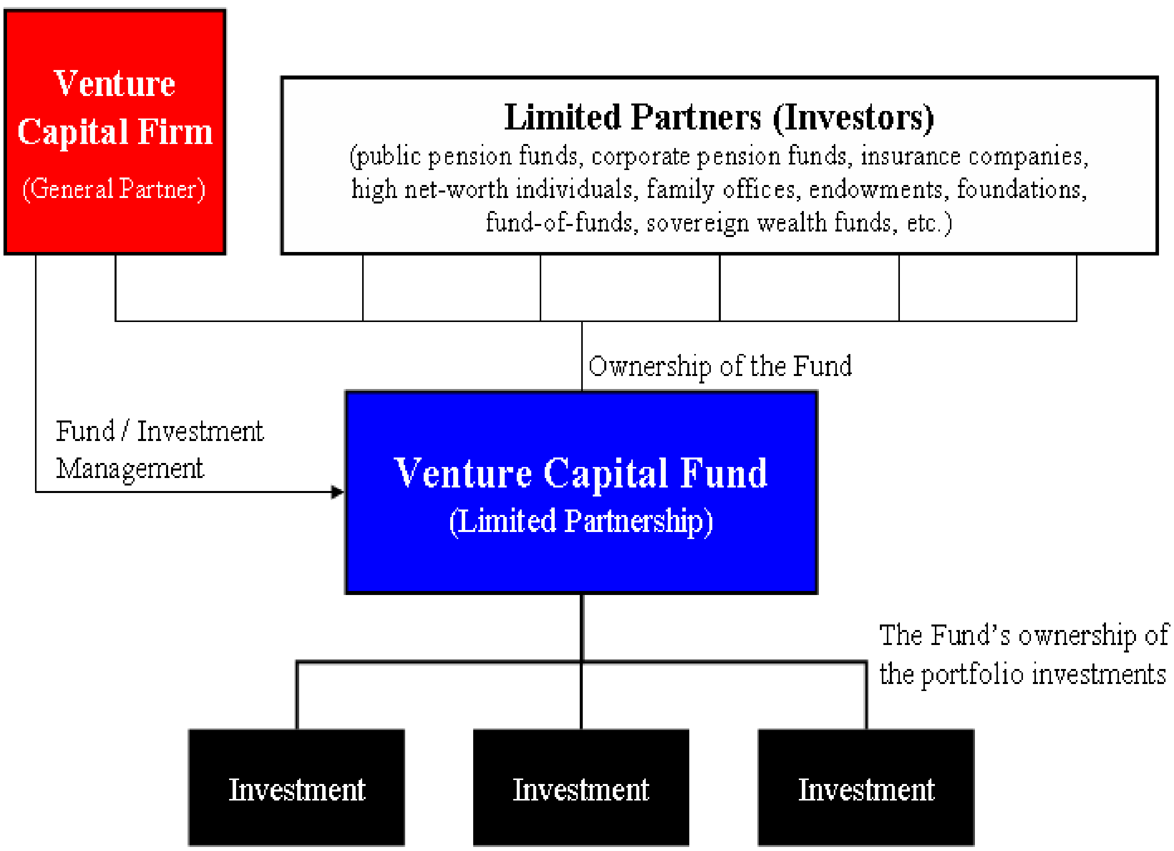
The critical role the VCs can play is to take promising technologies, perhaps developed in government, university, or corporate labs, which entrepreneurs have seized upon and around which they have started to build businesses, and provide the entrepreneurs with the resources they need to move toward full-scale commercialization. As Ghosh and Nanda (2010) comment:

> The emergence of new industries such as semi-conductors, biotechnology and the Internet, as well as the introduction of several innovations across a spectrum of sectors in healthcare, IT, and new materials have been driven in large part by the availability of venture for new startups. Unlike other forms of funding, a key aspect of venture capital is that it facilitates the provision of funding to startup firms despite the huge risks associated with unproven technologies….Since startups with new technologies rarely have internal cash flow to draw upon and are too risky to get debt finance, they depend critically on the provision of venture capital for their survival (p.1).

There are different types of VCs—angel investors who generally are involved in the earliest stages of a startup's development and corporate and investment bank VCs that compete with private equity. In this paper, our main interest is in private equity VC, a category that does about 80 percent of VC transactions as listed in Thomson Reuter's VC data base (Thomson ONE Banker). Well known examples are Sequoia Capital which financed Apple and Kleiner, Perkins, Caulfield, & Byers (KPCB) which financed Genentech.

In this instance VCs function as general partners (GP) in investment funds that they create (see Figure 1 on the next page) and raise money from such groups as university endowments, pension funds, insurance companies, private companies, and individuals who are limited partners (LPs) in the funds (Yuklea, 2009). The funds generally have a 10 year lifespan between raising money and exiting from investments made. In the meantime the VCs earn management fees of 1- to 2.5 percent. Their role is to find promising startups, nurture their development, and look for potential exit opportunities either through initial public offering (IPO) on a stock exchange or acquisition by another company. For the services that the VCs render they are entitled to 20 percent of the profits if the startups achieve successful exits.

Figure 1: The Typical Organization of Private Equity Venture Capital



Source: http://en.wikipedia.org/wiki/Venture_capital

The VC role is unique among investor class types. In establishing their businesses, entrepreneurs draw on basic and applied research, which often comes from university, government, and corporate labs. Initial financial resources are typically provided by the entrepreneurs themselves as well as family, friends, and angel capitalists. But there is a gap between starting an entrepreneurial firm and the large-scale deployment of its products and services. This gap proves to be the "valley of death" for many entrepreneurs. In this interval, the entrepreneurs' ideas have to vetted and tested and the commercial viability of their ideas proven. The role of VCs is to provide entrepreneurs with funding during this juncture. In filling this gap, VCs take on great risk in that the entrepreneurs they support frequently fail. The complete write-off of investments with no or little return to investors is common. Even if an exit occurs, it may not be very successful and neither the general or limited partners nor the original startup team earn a great deal. The average annual 2002-20012 returns to LPs were just 4.41 percent per year, though if this time period is extended to 1997-2012 to include the Internet bubble these returns go up to 30.95 percent per year (Cambridge Associates LLC,. 2012).

The spectacular success of VCs in the late 1990s contributed to the high tech boom which so dramatically transformed the global economy. The promise of VC investment in clean energy firms is that this class of investors can have a similarly transformative impact on the global economy with respect to how energy is generated and used. That is, they will discover and cultivate companies of comparable stature and quality that have the capacity to usher in a Schumpeterian revolution of far reaching proportions, a revolution embodied in the firms the VCs support but that spills over beyond these firms to society at large. The startups the VCs support can have as large an impact on such sectors as transportation, power generation, home construction, and manufacturing as the companies that they funded earlier had on such sectors as communications, media, entertainment, and retail.

That this is the promise embodied in VC backed clean energy startup firms does not necessarily mean that this promise will be realized. The analogy between clean energy and high tech may be flawed for a number of reasons. First, the substitution problem with clean tech is greater than it was with high tech (Lovins, 2011). Clean energy must substitute for an infrastructure already in place, not create a new one. The energy infrastructure has long replacement lead times—anywhere from 15 years for motor vehicles to 50 years for power plants to 100 years and more for some manufacturing facilities and buildings. Moreover, the government's involvement in clean energy, unlike its involvement in high tech during its heyday, has been and will remain intense. The government played a major role in the early research and development leading up to the high tech revolution (Henderson and Newell, 2011). Most of this money was in the form of defense spending, but by the 1990s, when so many high tech companies took off, this was less of a factor. The government's involvement in clean energy, on the other hand, remains intense, but this involvement has not been always been conducive to a large-scale shift to clean energy. While the U.S. has clumsily designed subsidies which get renewed periodically if at all, other countries like Germany have had more consistent policies that have yielded better results. (Marcus, Arragon-Correa, and Pinske, 2011). It is well-recognized that German laws, like the Feed-In tariff, have been extremely important in opening up markets for clean energy (Wüstenhagen and Bilharz,, 2006).

Because of the substitution problem and the role of government, clean energy is handicapped as a category of VC investment in comparison to high tech. There are limits to how much backing VCs can give to clean energy. Unlike the costs of scaling up production, distribution, and installation of high tech or software, the costs of scaling up production, distribution, and installation of clean energy technologies such as wind, solar, or biofuels are extremely high (Hargadon and Kinney, 2012).This task is not one that venture capital can take on by itself. If the VCs cannot take up this task it will be harder for the U.S. to achieve, let alone move beyond, the DOE's relatively modest clean energy projections of being no more than marginally less dependent on fossil fuels. This paper therefore reviews both the potential and limitations of venture capital as a source of funding for clean energy. It tries to paint an accurate picture of the realities of VC funding of clean energy as it has evolved during the last decade. Our view is that it will be difficult but not impossible for venture capitalists to fund disruptive and radically transformative clean energy technologies. Clean tech investment differs from traditional VC sectors by virtue of need to lengthen the time horizon of involvement in investments—in both directions That is, more investment and involvement in firms at an earlier stage of technology development and with firms in a later stage of technology commercialization. Consequently, clean tech VC investing requires changes to the traditional VC approach. In this paper, we provide some evidence that suggests that these changes are occurring, that VCs indeed may be in the process of adapting to the requirements of clean tech investing. We provide preliminary evidence that suggests that the more clean energy becomes a part of the VC world the more venture capitalists are adjusting their operating procedures to accommodate this category of investment.

The preliminary evidence we provide suggests that a number of adjustments are taking place. First, because of a fixed pool of resources, VCs are investing larger amounts of their money for longer periods of time. The capital for scaling up production, distribution, and installation of clean energy technologies that otherwise would come from public equity markets and established companies has been blocked because of a weak IPO market and the reluctance of established firms to invest. Because these routes have been blocked, VCs, out of necessity, are becoming more patient in the use of their capital.

Second, they increasingly have been avoiding high risk clean energy production, distribution, and installation manufacturing and production companies and funding the back and front ends of the solar energy supply chain and startups that focus on the intersection between energy and information technologies areas, companies that depend on the use of software, smart metering, and advanced lighting and heating. Third, besides making bigger bets, stretching out their timetables, and avoiding high risk and capital intensive companies, they have been experimenting more by investing in a greater number of smaller bets in risky technologies whose commercialization is less imminent.

If the VC role in clean energy is to be more transformative we believe it is because that these trends will gain momentum, but how deep these adjustments are and whether they will continue into the future is not certain. Total numbers of clean energy deals and dollar amount invested have remained relatively steady in recent years despite the downward drift in the economy (National Venture Capital Association, 2011). Whether this trend continues will be determined by the returns that clean energy investments garner compared to the returns available from other VC investment categories. Regardless of whether the number of deals and dollar investment in clean energy declines, grows, or remains steady, the trend will be toward greater specialization as fewer, better funded, and apparently better-informed, and/or highly motivated VC firms capture more of the market share in clean energy VC investment.

The next section of the paper provides a review of the VC industry, how it arose and works, what it does and has achieved, and what it does not do and is incapable of achieving. The following section traces the types of commitments that VCs have made to clean energy, why they have made these commitments, what is the character of these commitments, and how deep they are. The commitments of this asset class to clean energy are then evaluated. What can they achieve and what are they less likely and less able to achieve? In the final section we consider the role of venture capital and other possible funding sources for clean energy. Amongst a number of possible funding sources, what role is venture capital best suited to play? How would it need to change to play a more significant role? What would have to happen for venture capital to stimulate a major breakthrough, one that was of the magnitude of the Internet in transforming the economy and society?

The Role of Venture Capital in Society

Venture capital in the U.S. is said to be society's essential technology gatekeeper, one that has helped to create waves of technological innovation that have transformed both industries and society at large. Prominent companies that VCs have supported include Google, E-bay, Amazon, Intel, Sun Microsystems, Microsoft, Medtronic, Home Depot, Starbucks, Federal Express, and Whole Foods. In particular it is argued that the high tech companies in which venture capitalists have invested such as semi-conductors, personal computers, biotechnology, software, nanotechnology and artificial intelligence have created spillovers that have established new industries, revitalized economies, and benefited society as a whole (Florida and Kenney, 1988). Gompers and Lerner (1999, 2001a, 2001b) have argued that up to a third of the total market value of all public companies in the U.S. has been created by VCs. Their data show that a very high percentage of startups that have the aspiration to become major businesses do not attract VC funding and fail within three years.

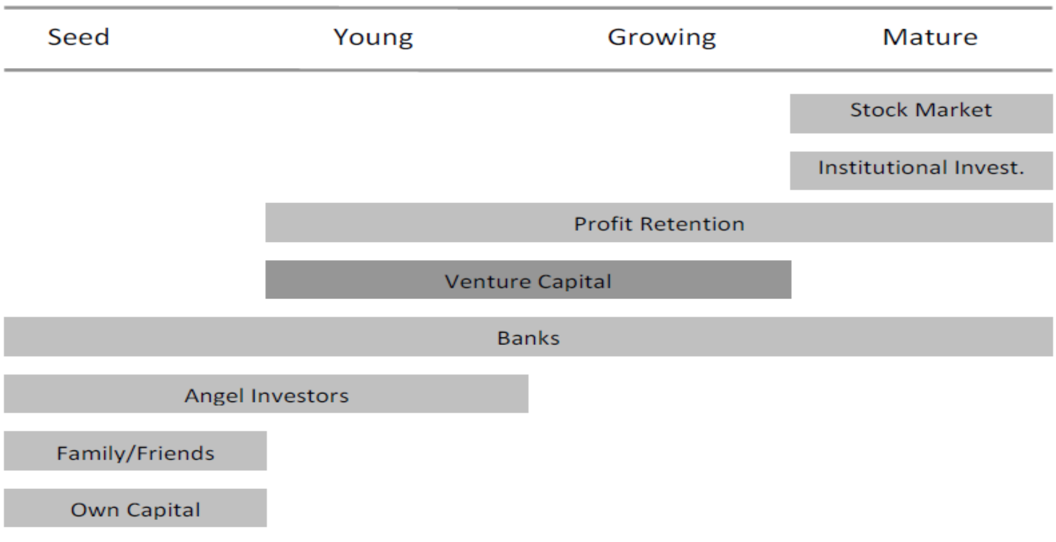
VCs fund highly innovative ideas that may threaten established products and services. The ideas that they fund are outside the mold of the ideas that banks typically finance. If entrepreneurial firms fail banks do not have sufficient hard assets to hold as collateral and repossess. A lack of funding is generally viewed as a major barrier to the progress that entrepreneurial firms otherwise could make (Amit, Brander, & Zott, 1998; Bygrave, 2004). VCs are supposed to remove this barrier. Without their funding the entrepreneurial firms could fail. They would begin small and remain so or take far longer to become big, even if their businesses were based on innovations with high growth potential. Without VC funding, entrepreneurial firms would not have the wherewithal to grow their businesses and diffuse their technologies on a wide-scale enough basis to provide the full benefits of which they are capable of providing to themselves and society. They would lack the resources, for instance, to hire the staff they need and to do the product development that is necessary for them to achieve market growth. If their technologies and business models show enough promise, they cannot rely just on the capital of their founders and the founders' early backers and profits earned from early activities to expand rapidly and boost the scale of their operations.

VCs are supposed to provide the capital that high potential startup firms need to take-off. In doing so, VCs are held accountable by their investors to deliver sufficient return to justify continued support. Though the espoused aim of VCs is to fund disruptive technologies, these technologies must have broad global market appeal and be scalable in a reasonable time frame. In most cases, VC investments are likely to fail but these losses are more than made up for by their successes which earn very high returns. In contrast, banks are unable to tolerate such high volatility. In addition VC firms often provide startups with financial management and even technological advice that can play a crucial role in the struggling firms' successes**.**

Venture capital is a unique institution whose origin is mostly in the U.S. It provides the U.S. with a distinct advantage in global competition as it has attracted to the U.S. talented entrepreneurs and investors from throughout the world. The growth of this form of investing came about because of a variety of factors which coalesced in the second half the 20th century including 1979 changes to the Employee Retirement Income Security Act (ERISA), which permitted pension funds to allocate up to 10 percent of their portfolios to riskier investments like venture capital (NVCA, 2003) and reductions in the capital gains tax rates. The establishment of the NASDAQ as a secondary stock market was another important development inasmuch as it provided the companies that venture capitalists funded with another profitable exit option. Moreover, the VC industry benefited from significant technological developments that took place, notably in microelectronics, which created market opportunities for the entrepreneurial firms they funded. As a result of these developments, VCs were able to raise money from large investors such as pension funds and endowments and to move this money to select startup firms that the venture capitalists had identified as having particularly high promise.

In most models of innovation neither VCs nor the entrepreneurs they fund are the original sources of the basic research upon which the entrepreneurs rely to grow their businesses (see Figure 2). Typically, basic research is backed by the government and carried out by universities, national laboratories, private corporations, and/or inventors and other especially gifted people who operate in their homes and their garages. For most entrepreneurial firms, venture capital is also not the original source of their financing. Typically they rely on the founders' own resources and start with the backing of funds they get from family and friends. The next step for aspiring entrepreneur might be to procure a grant from the government, obtain a small bank loan, or obtain help from an "angel" investor. Today, a growing number of angel investing groups collectively explore investment opportunities that VCs ignore or reject for various reasons. Since individuals risking typically about $10,000 are more willing to take a higher risk than VCs they are playing an interesting role. Several such groups specialize in clean energy.

Figure 2: The Role of Venture Capital in the Maturing of Entrepreneurial Businesses



Source: Ghosh, & Nanda, 2010

VCs play an intermediate role in the innovation process in trying to assist in developing technologies that have been conceived elsewhere become ready for scale-up. VC funds help the entrepreneurial firms in which they invest take steps that are preliminary to full-scale commercialization. As we have pointed out, as technologies move to the final stages of commercialization, private equity markets, acquisitions, and debt markets take over. Thus, the specific niche of the VCs is to take promising ideas that entrepreneurial companies present to them and to help prepare these companies for ultimately going public or becoming acquired. VCs generally oversee and manage the startups they fund in a more intensive way than an entrepreneurial firm's prior backers. The risks are high and to control for them, VCs become actively engaged, taking a board seat and regularly meeting with management in order to help the company and assure that it is accountable to investors (Hellmann and Puri, 2002). VCs put the companies they fund in touch with potential collaborators. They provide access to customers, technologies, and creative talent. This style of intensive oversight, management, and involvement by the VCs is especially prevalent among U.S. venture capital firms, but may be less prevalent among venture capital firms located in other parts of the world. This style of intensive oversight, management, and involvement by the VCs generally is viewed as having a positive impact on entrepreneurial firms resulting in higher growth rates, more patents, and better performance than in non-VC financed companies (Gompers & Lerner, 2001a; Kortum & Lerner, 2000).

VC firms attempt to carry out exhaustive analyses before they fund a startup. The assessments tend to involve face to face meetings and communications with the startup's founders' previous backers, suppliers, and competitors. They seek to do a careful screening of the startup's financials and closely inspect its business plan. The number of startups looking for funding always exceeds the amount of money available. The alternatives from which VCs have to choose are many, and, on the surface, all the startups may look good. Thus, it may be hard for the VCs to decide which of these alternatives are better. Hence, despite their efforts at due diligence, VCs often have no choice but to resort to short cuts, gut feelings, and subjective impressions to make their decisions. Getting funding from a VC never is easy. Typically, only 10 of a 100 business plans that come to a VC's attention get a serious look, and only one of these 10 is funded. Among the more prominent and prestigious VC firms the chances of being funded are even lower. Startups that successfully scale this barrier understand that they have cause to celebrate as obtaining funding from a well-regarded VC legitimizes startups in the eyes of potential investors, partners, competitors and customers (Mangiart & Sapienza, 2000).

VCs attempt to determine if there will be sufficient returns to justify an investment but never can be sure. The expected return must be high to justify the many failures. As we noted earlier, just a few of a VCs investments actually pay off. Ghosh and Nanda (2010) estimate that 60 percent of a typical VC's investments do not pay off. More than 70 percent of a portfolio's returns derive from just 8 percent of the investments made. Despite the extensive experience many VCs have, their disappointments are frequent (Gompers and Lerner 2004). In the end, VCs reject many good ideas, and many of the ideas that they do fund do not pan out.

VCs provide transitional funding to entrepreneurial firms that show promise and need cash to take off. Generally they provide funding for a period of no more than ten years or until the entrepreneurial firm is ready for an IPO or acquisition. At that point in time, the VC, its investors, and the entrepreneurial firm are in a position to achieve a substantial payoff for the risks they have taken. As noted previously, each fund that VCs create is a separate partnership that they form only after they have the obtained necessary commitments from investors. The money is drawn from a pool of money that investors make available to the VCs. Besides the general stipulations found in the fund's charter, the investors have little say in the subsequent decisions the VC makes.

Typically, VCs reserve three or four times their first investment for follow-up financing. The evaluation of whether a startup is deserving of follow-up funding takes place in stages (National Venture Capital Association, 2011) on an annual or semi-annual basis. The main stages of VC follow up funding after the seed stage are early stage and expansion. The definition of a seed or startup company is that it has a concept under development that is not fully operational. The definition of an early stage company is that it has a product or service in testing or pilot production. In some instances it may be commercially available and generating revenues. The definition of an expansion or later stage company is that it has put the product or service into production and made it commercially available, the company is likely to be showing revenue growth, but still may not be making a profit. Refinancing is conditional on a company achieving the technical or market milestones that VCs establish. Abandonment after initial funding is not at all that unusual. This method of funding allows VCs to be more informed before they provide additional backing, thus helping them better separate out investments that are likely to succeed from investments that are not likely to succeed. Financing by stages is considered to be an important way for the VCs to mitigate the outsize risks they are taking.

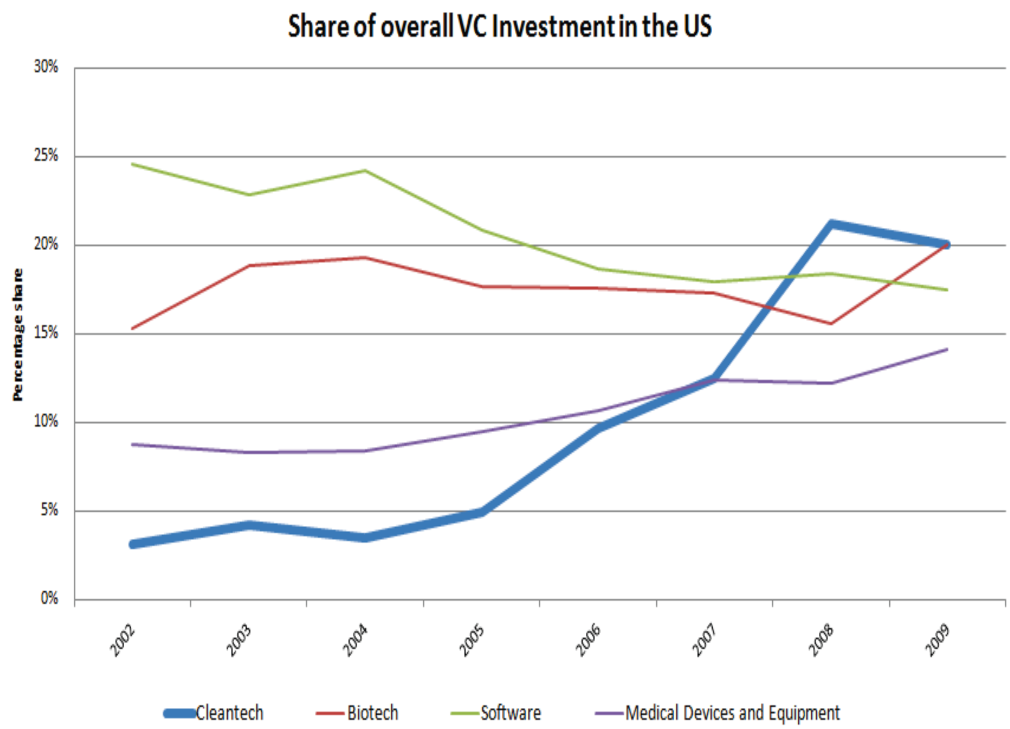
As noted, VCs are referred to and legally considered as the GPs in an investment, while pension funds, endowments, individuals, and corporations, and other investors are the LPs (Yuklea, 2009). For the LPs, the incentives consist entirely of the likely capital gains. LPs earn 80 percent of the capital gains in addition to the return of their principal while the GPs earn the remaining 20 percent. Besides the payoffs from successful IPOs or acquisitions, the incentives for the VC's are the management fees which they charge. The GPs thus have a guaranteed return whether or not the LPs get anything back or not. A typical goal is to exit an investment within seven years, but this goal often is not achieved (Kenney, 2011). For every major success a VC firm has, it has many failures.

The aim of VCs is to invest in the leading companies of the future. To achieve this goal, they take on excessively high risks in the hope they will realize outsized gains. Though studies have shown that venture capital has made a disproportionate contribution to jobs, market value, and economic growth in the U.S. (Gompers and Lerner, 1998, 1999, 2001a, 2001b and Lerner, 2002), overall returns to LPs in the last 10 years are estimated to be .5 percentage points below the average annual return to the Dow Jones Industrials during this period and just slightly above the S&P (Cambridge Associates LLC., 2012). One must return to the Dot.com era to observe truly spectacular venture capital returns to investors. Financial disturbances play havoc in the industry. If the stock market is weak and few IPOs are being executed the VCs' business model is challenged (Kortum and Lerner, 2000). The 2001 meltdown of the tech economy greatly harmed VCs. In the decade that followed and they never fully recovered. Capital under management, headcount, and fundraising slipped. The National Venture Capital Association (NVCA), the main industry trade group, does a yearly assessment of the industry. In 2011, it commented that though IPOs picked up from previous years and a record number of companies were acquired, total available investment proceeds continued to be low (National Venture Capital Association, 2011). The number of VC firms, funds, and professionals involved in the industry had declined substantially from what they had been in the year 2000. Many VC firms shut their doors.

VC Investments in Clean Energy

At the same time that VC's experienced a decline, their investments in clean energy were growing. From a relatively small beginning in 2001-2004 venture capitalists started to make more investments in clean energy companies. According to figures compiled by the NVCA, starting in 2005-2006 the energy sector experienced a particularly sharp increase in the percentage of investments, reaching more than 16 percent of the total investments that VCs made in 2008 and weathering farily well the great financial crisis of that year and the next (National Venture Capital Association, 2011). According to the NVCA (2011), the average annual investment that venture capitalists made in the energy sector in 2001-2004 was $429 million, in 2004 this number jumped to $720 million, in 2005 it escalated to $1.823 billion, and by 2008 it had reached $6.250 billion. Slipping to $3.375 billion in 2009 it rebounded in 2010 to levels higher than it had achieved in 2007. Figures such as these, compiled by different groups, sometimes appear differently depending upon how they have been assembled and what they classify as clean energy, but the overall trend is unmistakable. Clean energy, as a category of VC investment, took off in the first decade of the 21st century. The Cleantech group, which also collects data, estimates that by 2008 clean tech as whole, which includes air and water pollution as well as some agricultural categores, had the largest share of VC investment in the U.S (see Figure 3).

Figure 3: The Share of Various VC Investment Categories in the U.S.

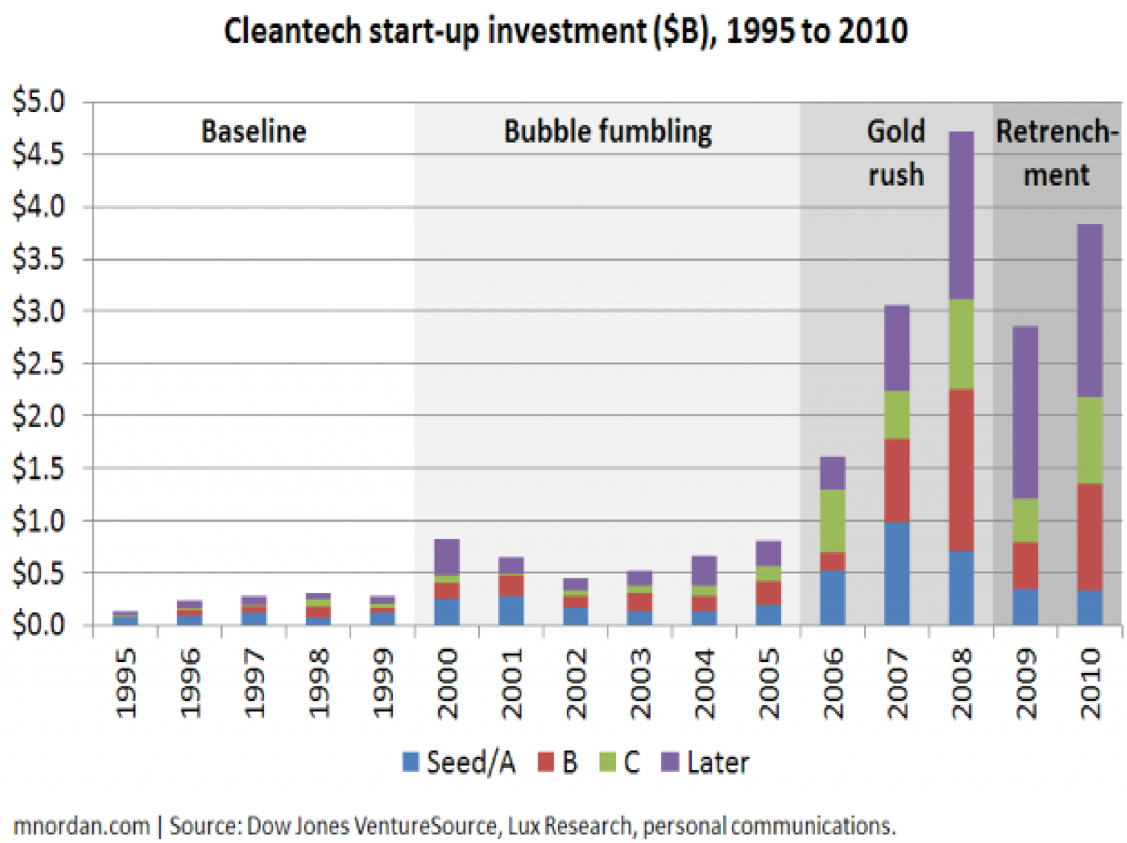


Source: Cleantech Group http://research.cleantech.com/

Matthew Nordan (2011), a venture capital investor at Venrock, has combined a number of sources to trace clean tech's rise (see Figure 4). In the baseline period, 1995-99, from $100 to $200 million was invested in 30-50 deals annually – this was a period when the VC industry as a whole grew dramatically from about $7 billion invested per year to more than $50 billion so that clean tech lost market share to other VC investment categories**.** At the peak of the Internet bubble, the year 2000, an all-time record of just about $100 billion was invested mostly in Internet companies. When the bubble burst, Nolan argues that VC firms had to find other avenues for their investments. Some went into nanotechnology but others entered clean tech. By 2005 it had reached an investment level of $800 million. This estimate of clean tech investment is very consistent with that of NVCA (2011). In the next three years, clean tech financing increased by more than 50 percent annually. In 2008, clean tech financing went up to more than $4.5

billion. This figure is considerably less than the NVCA (2011) estimate for the category it calls energy. However, Nolan points out that seed funding began to decline, between 2007 and 2008 dropping off by 29 percent. Following the 2008 financial crisis, clean tech financing fell by a third and seed funding dropped in half, returning to 2006 levels, but in 2010 a recovery in clean tech financing took place. Clean tech investing did not reach a new peak but it did soar above 2007 levels. Nevertheless, seed funding continued to be stagnant. Later in this paper we will return to this issue of the decline of seed funding.

Figure 4: Trends in Clean Tech Investing



For now we would like to explore what accounts for the take-off of this category. There were many contenders for VC funding at this time. What led VCs to choose clean energy over software, biotechnology, semiconductors, medical devices, telecommunications technology, and electronics that had longer track records and were better established? Gompers and Lerner (1998, 1999, 2001a, 2001b) suggest that VCs tend to get on bandwagons and become enamored of fashionable new investment categories. Fashion (Abrahamson & Fairchild, 1999) plays an important role in this industry because information is incomplete and difficult to access, future market conditions are hard to predict, and performance is hard to track. Nolan

(2011) attributes the rise in funding to three solar companies (Q-Cells, SunPower, and Suntech) that went public, all at valuations around $1 billion, in 2004. Marcus et al. (2012) find that successful well-publicized exits help to explain the clean investment take-off. These factors mix symbolic (Strang,& Macy, 2001). and economic reasons (Arthur, 1994) to explain the rise of clean energy. We would like to place them in their historical context during the first decade of the 21st century.

***Leadership from Firms Specializing in Clean Energy*.** Early VC investments in clean energy, those that took place in 2001-2004,were spurred by specialist firms dedicated nearly exclusively to this type of investment like Nth Power which did 20 deals, EnerTech Captial which did 12 deals, SJF Ventures which did 10 deals, Rockport Capital Partners which did 9 deals, and NGEN Partners which did 7 deals (Cleantech Group, 2012). The only non-dedicated venture capitalist who did a large number of these deals during this period was Draper Fisher Jurvetson which did 9. In the next period, 2005-2008, when clean energy investment rapidly grew, the specialist firms continued to be very active. Almost all of them increased the number of deals that they did. Nth Power did 32 deals, Rockport Capital Partners did 25 deals, EnerTech Capital did 24 deals, NGEN Partners did 18 deals, VantagePoint Capital Partners did 19 deals, and Braemer Energy Ventures did 18 deals (Cleantech Group, 2012).

***Returns to Investors*.** Though it could not have been known with certainty at the time, after the fact we can see that clean energy delivered good returns to investors. In 2002-2004 after the high tech bubble burst VC energy investments did well in comparison to other venture capital investments. According to the NVCA (2011), VC energy investments did twice as well as investments in other VC categories in these years (See Figure 5). Not every year, however, yielded the same outstanding results. By 2005 the information technology category made a strong comeback and clean energy investments were trailing investments in other categories. Nonetheless, in 2007 the energy category again did very well, tying with information technology as the best performance category. For the entire 2002-2009 period, the NVCA (2011) estimates that the average VC category yielded returns of 17% per year, the energy category yielded returns of 19% per year, while information technology, the traditional mainstay of VC investment, yielded returns of 28% per year.

Pension Fund Preferences. By 2005, at least 18 of the largest pension showed an interest in the category (O'Rourke, 2009). Large and prestigious institutional fund managers were explicit about their preference for clean energy allocations. For instance, CalPER's GreenWave initiative dedicated $200 million to this area in 2004, and its sister fund CalSTERs dedicated $250 million to it in 2005. The reasons for the interest of the pension funds varied. Some touted the environmental benefits. Others perceived clean energy mainly in economic terms, as a growth and profit opportunity, while still others envisioned its win-win character—it was both good for society and good for the pension funds' bottom lines.

Figure 5: Returns to Different Categories of Venture Capital Investment: 2002-2009

Percentage annual return	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Time period average**
All VC Categories	10%	12%	14%	15%	9%	13%	26%	37%	**17%**
Energy	26%	47%	13%	9%	7%	22%	12%	14%	**19%**
Information Technology	9%	17%	20%	31%	21%	22%	48%	54%	**28%**

Source: National Venture Capital Association (2011)

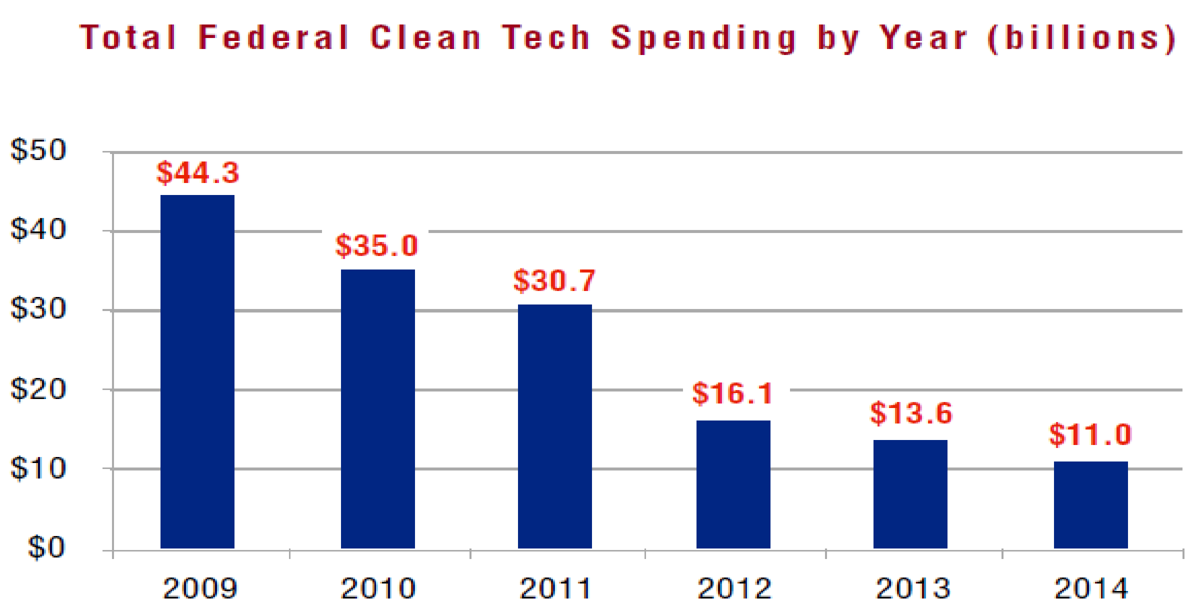
High Prestige VC Endorsements. The transition from the specialist VCs to high prestige generalists was spurred by the pension funds. Among the high prestige VCs who gave their endorsement to clean energy, the most important were Kleiner Perkins Caulfield & Buyers (KPCB) which did 30 clean energy deals in the 2005-2008 period, and Khosla Ventures, a breakaway from KPCB, which led all VCs in number of clean deals carried out in this period with 38 deals (Cleantech Group,. 2012). Draper Fisher Jurvetson continued to be very active with 30 deals. The startups' ties to these well-regarded venture capitalists cast a positive shadow. Proximity to choosy deal makers with strong evaluation skills suggested that the startups were good investment candidates (Marcus, Malen, and Ellis, 2012). They might be in the same league as the VC's prior successes (Khaire and Wadhwani, 2010). Non-specialist investors with the bulk of their investments in other categories also picked up interest. They justified their investments as a type of diversification to round out their portfolios and hedge themselves against contingencies such as high energy prices or the passage of U.S. climate change legislation but they also were influenced by the actions of the prestigious firms whose moves they imitated.

A Growth in Overall Clean Energy Spending. Another type of external validation was that overall clean energy spending was expanding. Bloomberg New Energy Finance (2010) estimates that overall spending in 2009 was $165 billion, a number far higher than the $2 billion plus that VCs invested. About 9 percent of the $165 billion was corporate R&D money, 6 percent was government R&D money, and 11 percent was invested in clean energy stocks. But most important was the large amount being spent on clean energy projects—over 70 percent of the $165 billion was invested this way. These investments suggested that the market for clean energy was real and substantial. In 2009 alone, about 50 gigawatts (GW) of clean energy generation capacity (excluding hydro) was added worldwide, an increase of 40GW from 2008, and nearly as high as the 83GW of fossil-fuel generating capacity that was added that year (Bloomberg New Energy Finance, 2010). Though the absolute number for fossil fuel generation was more, the growth rate for clean energy was greater.

Government Support. After the financial crisis of 2008, clean energy investment made a rapid comeback with 2010 being the second highest annual investment total for clean energy ever and more than four times what it was in 2004 (National Venture Capital Association, 2011). What helped the category rebound in 2010 was the rapid growth in government involvement. Globally, governments committed close to $190 billion to clean energy in various parts of their stimulus packages (Jenkins, J. et. al. 2012). The U.S., China, and South Korea in particular, picked up their clean energy spending. In April 22, 2009, four months after Obama took office, he declared that clean energy technologies that either seek energy efficiency or harness power from renewable sources such as solar, wind, biofuels, and smart power grids, and electric vehicle propulsion would be a linchpin of the stimulus. More than $90 billion of the $787 billion U.S. stimulus was set aside for this purpose. In announcing its own stimulus, the government of South Korea almost matched this number. Over the next ten years it was estimated that China might spend four to six times as much. Given these moves by global governments it was not surprising that while total venture activity was down, clean energy as a percent of the total held its own. Thus, government was an important factor in sustaining the rise of clean energy in a period when it otherwise may have seriously fallen-off. The problem with government spending was that the commitments made in 2008 were set to gradually decline (see Figure 6). They would be largely exhausted by the end of 2014 and therefore could not be depended upon to give a long term boost to clean energy investing.

Among VC investors in clean energy, by 2011, a distinct trend had emerged. The number who had made at least some investment in clean had never been large. Over the entire 2000-2010 period the Thomson Reuters data show that no more than 8 percent of VC firms had ever invested in a clean energy startup. By 2009, although neither the number of deals nor their dollar volume was declining substantially, the number of VC investors involved in the sectors was (See Figure 7). In 2008 and 2009, Ghosh and Nanda, 2010) report that about a quarter of U.S. clean energy deals were carried out by *just five* clean energy investors. There was growing concentration among VCs who make clean energy investments. The trend also has been toward growing specialization. In 2011, the largest clean energy investors, each of whom did from 11 to 37 transactions, were KPCB, Draper Fisher Jurvetson, Rockport Capital, General Electric, New Enterprise Associates, Chrysalix, Khosla, VantagePoint, Braemer, and Oak Investment Partners. Fewer, better funded, and apparently better-informed, and/or highly motivated venture capital firms had maintained or increased their commitments.

Figure 6: U.S. Government Spending on Clean Tech



Source: Jenkins et. al., 2012

The Impact of Clean Energy VC Investment

Now we turn to the impact of this investment. According to DOE's reference case model, published in 2010, by the year 2035, though there would be less emphasis on foreign imports, the U.S. economy and society still would be dominated by fossil fuels (U.S. Department of Energy, 2010). DOE's projections were based on the assumption that "revolutionary or breakthrough technologies" would play no role. Shale gas would offset declines in other natural gas sources, and more hybrid, plug-in hybrid, all electric, and fuel cell vehicles would be on the road, but they would constitute no more than a third of all vehicles. Fuel efficiency standards largely would be counterbalanced by the tendency of drivers to drive more**.** The electricity mix gradually would shift to renewables and natural gas as they would make up the majority of capacity additions, but as much as 40 percent of electricity still would be generated by coal.

Possible Alteration of the Reference Case Model. Under the assumption that there will be no meaningful change in government policy such as a robust carbon tax, to what extent might these significant but relatively modest changes in the energy production system of the U.S. be altered by a breakthrough or by a series of breakthroughs (Abernathy and Clark, 1985; Tushman and Anderson, 1986) in the technologies that venture capitalists fund? Here is a group of companies that were seeking VC funding in 2010 (see Table 1). To create this group of companies Professor Marcus reviewed the results of an assignment he gave to sections of his MBA classes in that year. He divided the students into groups asked them to respond to the following dilemma: "Your group has been hired by a VC that is known for investing in clean energy. It has a list of clean startups that are seeking funding. Your group can recommend up to four of these companies to add to the VC's portfolio. Which companies would you choose and why?" The full list of companies from which the students could choose is found in the appendix to this paper. The list was assembled from companies that were found on the Cleantech Group website. Among the student choices the 20 companies found in Table 1 stand out. They figure prominently as promoting unconventional, potentially breakthrough technologies that offer simple design, power generation and power saving, small in scale, and more distributed than conventional options whether they be renewable, efficiency, fossil, or nuclear (Lovins, 2011). The technologies are environmentally friendly and can be applied in multiple applications in many locations without losing their effectiveness. In almost each instance they would be called a third generation renewable or energy efficiency technology. For example:

- Conventional wind generation is limited to large-scale turbines, the bigger the better, which must be built in high intensity wind locations and typically require the construction of new transmission to bring the power to populated areas where the energy is most needed. Ocean based wind has similar liabilities. WindAid, however, reduces costs by simplifying the turbine's design, Magenn Power delivers wind power from high altitude locations, and Coriolis Wind has a concept that will work in low speed wind environments.

- Conventional ideas about energy storage tend to center on the lithium battery, but Powerthru focuses on the flywheel, Planar Energy Devices on solid state electrolyte batteries, Gravity Power on pumped storage, and Graphene Energy on nano-tech ultra-capacitors.

- Today's biofuels made from corn and other material that can be eaten have been heavily criticized for the challenges they pose to the food supply, ProteRec, in contrast, is examining how to break down cellulosic material so that there will be no need to rely on materials like corn that are used for food and SBAE Industries, Algae Cake Technologies, and Galten Biodiesel are exploring algae and jatropha as alternatives to food-based fuels.

- Thick and thin film solar photovoltaics,(PVs), though they have made rapid progress, still have not reached price parity with conventional power generation technologies. Prism Solar Technology, therefore, is trying to improve PVs with a concentrator that increases energy collection by as much as three times, and ZenithSolar is moving in this direction with a modular and easily scalable high concentration PV system that is up to 5 times more efficient. Uriel Solar is going beyond thick and thin films with a 10-20 times thinner film that achieves high performance at low cost and 3G Solar is moving in the same direction with an inexpensive 3rd generation dye solar cells that work in low light conditions

- Another limitation of thick and thin film solar PVs is that they must be attached to a building's rooftop. Pythagoras proposes putting solar devices in windows and on other parts of the building envelope and not just on rooftops.

- Power generation facilities remain big and centralized. ReGen Power Systems is looking into an entirely different method of power generation – a low temperature Stirling engine that can be deployed in a decentralized way.

- Alternative vehicles are moving away from the internal combustion engine toward electric and fuel cell alternatives. Tour Engine is returning to the internal combustion engine and trying to determine how to extract greater engine efficiency and emission reduction through cylinder and piston management.

- Huge amounts of energy are lost when people go about their day to day activities in moving from place to place. Innowatech is pursuing a whole new concept in energy efficiency that involves capturing and harvesting the mechanical energy that is released from passing vehicles, trains and pedestrians.

Table 1: Clean Energy Companies Seeking VC Funding in 2010

NAME		**DESCRIPTION**
Prism SolarTechnologies	solar	*PV concentrator that improves energy collection by as much as 3 times*
Galten Biodiesel	biofuels	*advanced high yield production and cultivation of biodiesel from jatropha*
ProteRec	biofuels	*synthetic biocatalytic enzymes and processes that substantially lower costs*
3GSolar	solar	*inexpensive 3rd generation dye solar cells that work in low light conditions*
ReGen Power Systems	efficiency	*Stirling engines that reduce heat & energy loss in steam power generation*
Planar Energy Devices	storage	*solid state electrolyte batteries that are 3 times the energy density*
Gravity Power	storage	*long lasting, low-maintenance, environmentally-sound pumped storage*
SBAE Industries	biofuels	*genetic sequencing & cultivation of algae to enhance feedstock potential*
Graphene Energy	storage	*nano-tech ultra-capacitors that increase battery life*
Tour Engine	transportation	*cylinder & piston management that improves engine efficiency*
Magenn Power	wind	*turbine that generates energy from high-altitude sources*
Powerthru	storage	*award winning flywheel energy storage*
Uriel Solar	solar	*10-20 time thinner PV thin film that achieves high performance, low cost*
WindAid	wind	*low cost wind due to reduced mechanical belts, gears, & lubrication*
ZenithSolar	solar	*more efficient modular & easily scalable high concentration PV system*
Innowattech	efficiency	*harvesting mechanical energy from passing vehicles, trains, pedestrians*
Coriolis Wind	wind	*scalable small turbines for low wind speed environments*
Pythagoras	solar	*solar window & other products that sit on building envelope*
AlgaeCake Technologies	biofuels	*algae bioreactor that uses solar energy to produce feedstock*

If some or all of these companies succeeded, the DOE's projections could prove to be underestimates of what is possible. These projections might be seriously off the mark. There is the potential to generate wind energy at higher altitudes if a company like Magenn Power succeeded. Smaller and cheaper turbines are possible if a company like WindAid succeeded or turbines that work in low wind speed environments could become common if a company like Coriolis Wind succeeded. If companies like Galten Biodiesel, SBAE Industries, AlgaeCake Technologies, and Protrec succeeded, the sources of biofuels could be expanded and their conversion into useable products made simpler, easier, and less costly. Fundamental advances could be made to overcome energy storage problems that plague the generation of intermittent wind and solar power if companies like Gravity Power and Powerthru succeeded.

The battery problems that limit the range of electric powered vehicles could be addressed if companies like Planar Energy Devices and Graphene Energy succeed. If companies like (Prism Solar, 3GSolar, Uriel Solar, ZenithSolar, solar energy efficiencies could rise significantly and costs could go down. The envelopes of buildings -- their windows, walls, and roofs – could be covered with solar cells that would make the buildings largely energy self-sufficient if a company like Pythagoras succeeded. Less wasteful, more decentralized power production could take place if a company like ReGen Power Systems succeeded, Not all cars would have to be hybrids, plug-ins, or fuel-cell vehicles as significant improvements could be made in the internal combustion engine if a company like Tour Engine succeeded, and the waste energy cars, trucks, and people create could be better captured if a company like Innowattech succeeded. The problem with this scenario is that the companies listed in Table 1, which are just a sample of the companies that have potentially game-changing technologies, have received relatively small amounts or no VC funding (see Table 2).

Table 2: Funding of Clean Energy Companies in 2012

NAME	**Total $ Paid In Capital**	**Major Investors**
Prism SolarTechnologies	13,035,000	Rudd Klein Alternative Energy Ventures
Galten Biodiesel	10,000,000	Capital Partners
ProteRec	10,000,000	Evergreen, Israel Cleantech, Pitango
3GSolar	5,700,000	21Ventures
ReGen Power Systems	5,000,000	Quercus Trust, 21Ventures
Planar Energy Devices	4,000,000	Battelle Ventures, Innovation Valley Partners
Gravity Power	2,250,000	Quercus Trust, 21Ventures
SBAE Industries	1,220,000	Allegro Investment Fund, PMV, Capricorn
Graphene Energy	500,000	Quercus Trust, 21Ventures
Tour Engine	0	
Magenn Power	0	
Powerthru	0	
Uriel Solar	0	
WindAid	0	
ZenithSolar	0	
Innowattech	0	
Coriolis Wind	0	
Pythagoras	0	
AlgaeCake Technologies	0	

One hears repeatedly in the VC community that VC firms do not fund "science experiments." The companies they fund must be near to commercial stage and close to delivering a high rate of return to investors. We noted before the stagnancy in seed funding (See Figure 4). According to trends that the CleanTech group follows, a shortfall in early stage VC clean energy funding for entrepreneurial companies like those discussed above has taken place. These companies are finding it increasingly difficult to access financing through traditional VC routes. The funding that the companies with potentially breakthrough technologies are receiving is coming more from private investors that are outside the VC mainstream like Quercus Trust. Quercus funds ReGen Power Systems, Gravity Power, and Graphene Energy (see Table 2). An estate planning fund established by David Gelbaum, who earned most of his money at a very young age from stock prediction algorithms, Quercus has invested about $400 million in about 40 clean energy companies (Woody, 2010). Quercus is more of an angel. It is not a traditional VC.

Table 3 is a list of some of the most highly funded U.S. clean energy companies (Cleantech Group, 2012). Overall it can be said that their technologies are less cutting edge than the technologies of the companies in Table 1. Most of these are first and second generation technologies which are closer to commercialization than the companies listed previously. Many of these technologies already are available, in commercial use, or nearly in commercial use. All the major auto companies have plans to introduce plug-in hybrids. BrightSource Energy already has 2.4 GW of power under contracts with Southern California Edison and Pacific Gas & Electric Company. FirstSolar, another company that specializes in thin film solar, has been in existence since 1999 and has installed 5 GW of modules. The lithium battery is ubiquitous in laptops and is found in many hybrid and electric vehicles. Boston Power does not enter an empty space – it faces serious competition from a host of companies including Shenzhen, the Chinese company with the world's leading market share and an established U.S. firm like Johnson Controls. The biodiesel market already is quite well developed, with Europe being the world's largest user and there being many large number of suppliers. Silver Spring Networks' meters, which provide communications between a local utility and a building or manufacturing site, simplify the collection of information for billing and help the utility with outages, but they are less helpful to an owner who wants to carefully monitor and control his or her power consumption and conserve energy. LEDs, today can be purchased at any Home Depot or Wal-Mart. While not widely adopted at this point, they are very close to taking off. The companies in Table 3 are pursuing relatively mature technologies on the verge of common availability, not experimenting with potential breakthrough technologies that have longer routes to go before they are widely adopted.

Table 3: Highly Funded U.S. Clean Energy Companies in 2012

Name	**Short Description**	**Total $ Paid In Capital**	**Major Investors**
Fisker Automotive	Plug-in hybrids	989,817,856	Advanced Equities, KPCB,
BrightSource Energy	Solar thermal plants	535,771,860	VantagePoint Capital Partners DTE Energy Ventures,
MiaSolÃ©	Thin-film PVs	470,000,000	Gabriel Venture Partners Venrock Associates,
Boston-Power	Lithium batteries	344,960,000	TPG Biotechnology Partners
Elevance Renewable Sciences	Biodiesel fuel	294,000,000	TPG Growth, Materia, Cargill Foundation Capital, JVB Properties
Silver Spring Networks	Electric metering	277,800,000	NCD Investors, Contra Costa Capital, WR Holdings, Warburg Pincus, APEX Venture Partners
Suniva	Silicon cells	224,400,000	New Enterprise Associates
Bridgelux	LED solutions	213,900,000	Chrysalix Energy Venture Capital, Google, Idealab, ACME Group

The funding for the companies in Table 3, by any standards, is very high. It exceeds by more than three times the $40–$50 million that VCs typically invest in a company to move it to successful exit (Ghosh and Nanda, 2010). Nonetheless, the question still remains whether the companies in Table 3, even after all this money has been invested, will do well. Many of them, like Fisker that has seen mishap after mishap with its test vehicles, have been very challenged at they try to move to wide scale commercialization.

We argue that to exceed the projections found in the DOE reference model, more Table 1-like companies will have to succeed. The VCs would have to move outside their comfort zone. Because most startups they fund so often fail, it is not so easy for them to fund innovative and transformative companies in the current economic climate of a global slowdown and continue uncertainty about the future. In the current economic climate, they must find and fund entrepreneurial firms with higher chances of near term success. Just to meet DOE's reference case projections at least some of the near-to-commercialization Table 3 companies will have to succeed, but to go beyond these projections a number of the more disruptive and innovative Table 1 companies must be successful. Meeting DOE's modest goals for 2035 hinges on the more conventional firms represented in Table 3 doing well. Going beyond these modest goals is contingent on the more innovative clean energy companies in Table 1 doing well. The companies in Table 3 are promising modest improvements and technological advances, yet many of them may fail to deliver. This reality makes it very hard for VCs to facilitate a large-scale clean energy revolution.

Given that this is the case, we can make two somewhat contradictory claims. The first is that to exceed DOE projections, not only must enough already well-funded companies deliver, but a sufficient number of companies with great innovative promise also must be successful. However, a more far-reaching claim is that companies with this type of promise are going to leapfrog the well-funded firms. If they leapfrog these companies, it will make the success of the more conventional companies less relevant. In this case, the more innovative companies are in competition with the less innovative companies. They stand for different energy futures and are competing for the same funding. Beating DOE projections depends on the more innovative companies prevailing over the less innovative companies. If too much investment is made in the more conventional companies it will crowd out investment in the more innovative ones. Another cycle of substituting long lived energy infrastructure will have to occur before these technologies are in common use. The commercialization of more innovative technologies, if it takes place at all, could be delayed by a century or more. The failure of innovative companies to thrive because of insufficient funding today bounds the gain in efficiency and renewable that the U.S. can make.

The Dilemma of Funding Disruptive Innovation

The funding limits under which VCs operate thus pose the following dilemma—if VCs are not in a position to help fund potentially game changing technology on a large-scale basis then who can provide this type of funding?

Private investment. Is it possible that angel investors or private investment like Quercus can take up the slack and accomplish what conventional venture capital cannot do? There is in our society a plethora of wealthy persons with large accumulated fortunes that will have to invest their money somewhere. What is the likelihood that they will move in great numbers and invest a large percentage of their money in clean energy? Though their wealth is large, it may not be equal to the magnitude of the task. Probably the bulk of this wealth will go into other channels. Only a small number of wealthy individuals will devote themselves to clean energy in the way that David Gelbaum has. To the extent that this money is invested in clean energy it will be in well-known and well-regarded VC funds that may not be sufficiently funding innovative Table 1 companies.

Government. There is also little likelihood that fiscally constrained governments will take up the slack. As indicated earlier, the U.S. government is phasing down funding in this domain. This downsizing is taking place not only in the U.S. The subsidies for renewable energy in Europe that have opened up markets for wind and solar also will be going down. A sufficiently large carbon tax phased in over a number of years, replacing these subsidies, would help governments with their fiscal problems and provide a more stable and effective stimulus to clean energy spending, but given the current political climate in the U.S. and elsewhere such a tax is almost unthinkable. But there is another important development to consider—the growing involvement of the Chinese government in clean energy. The involvement of the Chinese government already has been having an impact. It has contributed to the outcome of Chinese companies having the largest share of clean energy IPOs in recent years. The problem with the Chinese government taking up the slack is its predilection to commercialize mature technologies. That is, the Chinese government is not likely to encourage and fund experimental firms in a significant way. Neither the Chinese government nor Chinese companies have shown much of an interest in this type of company. The Chinese see opportunities in manufacturing products for mass markets. They have ramped up capacity to make first generation wind turbines and solar cells for these markets. They responded extraordinarily well to the subsidies available for renewable energy in Europe, surprising the world by how quickly they could expand manufacturing to meet the needs of this market in particular. Their rapid response to the demand created by government subsidies, indeed, created a global glut in wind turbine production and solar cells manufactured. As European subsidies are phased out and Europe faces the prospect of a long recession, Chinese companies are confronting the dilemma of dealing with the over-capacity, which may sour them on clean energy. If they do not reduce their investment they will concentrate on meeting a vast hunger for power domestically, sticking with what currently works to supply their domestic market rather than going out on a limb and providing funding for game changing technology which may or may not

Corporations. Another possibility is that well-established companies sitting on large cash reserves will fund this type of far reaching clean energy innovation. However, many of these companies face a genuine conflict of interest. Their business model depends upon conventional forms of generation and consumption. It would not be in their interest to heavily fund alternative energy. To give but the most striking example, Exxon-Mobil has heavily touted its research in petro-algae in television ads but the amount of money it devotes to exploring this technology is miniscule in comparison to the amount it spends on technologies that will allow it to extract residual oil from tar sands. Without being cynical one can say that Exxon-Mobil’s forays into petro-algae are a public relations gimmick. More to the point, the company has been completely inactive in acquiring clean energy startups, unlike large pharmaceutical companies which regularly tap the VC market for new business opportunities. One must ask the question of how suited large incumbent companies are for fundamental innovation. With some exceptions, it is unlikely that these companies, with their legacy businesses to protect and sustain, can be major catalysts of innovation. Nonetheless, some large and established companies have been active in the corporate clean energy VC market and the market for clean energy startups. Companies like Intel and Google have been especially active as venture capitalists and GE along with firms like Siemens has been responsible for a disproportionate number of clean energy acquisitions. The question is will these companies’ involvement in these activities continue if the entire sector hits a dry spell and investments returns slip. Though some corporation are likely to continue to show an interest in clean energy, the corporate sector as a whole is not likely to sufficiently expand its involvement and take up more of the slack in funding disruptive and game changing technology.

Venture capitalists. This brings us back to the VCs themselves. Can they adjust their business model so that they can be more hospitable hosts to the long term risks associated with breakthrough technologies? VCs tend to be most comfortable investing in non-capital intensive sectors (Ghosh and Nanda, 2010). They prefer to keep their investments below $15 million per investment round. They have favored information and medical technology companies that meet these criteria. Their preferences for low capital intensive, relatively small investments in the high tech and med tech sectors would discourage VCs from investing in clean energy and these preferences may not be easy to change. At a minimum, one would expect the VCs increasingly to avoid high risk clean energy production, distribution, and installation manufacturing and production companies and to focus on startups that emphasize on the intersection between energy and information technologies areas, companies that depend on smart metering and the use of software, like Sliver Spring Networks, or advanced lighting and heating, like Bridgelux (see Table 3). They also might fund the back or front ends of the solar energy supply chain, but they are not likely to get heavily involved in manufacturing. Recent Cleantech (2012) group reports suggest that such a pattern exists in clean energy venture capital—VCs are indeed investing more in energy efficiency and the intersection between energy and information technology.

But there is evidence of a counter-trend. Whether individually or as part of packages put together by syndicates, Table 3 shows startups that have obtained very large sums of money from venture capitalists. They have been funded at these levels despite the fact that their businesses involve high stakes, risky, capital intensive manufacturing. The funding for Fisker Motors, for instance, approaches $1 billion, an amount that is at the very highest ranges of the funding venture capitalists have ever supplied a startup. The Clean Tech Group (2012) reports that a late-stage bias continues to push average deal size to amounts greater than past funding for other investment categories. At the same time, as we previously noted, Nolan reports a steep decline in seed and early stage funding (see Figure 4) from a 2007 high of close to $1 billion to less than $300 million in 2010. The latter is hardly sufficient to fund highly innovative firms.

In a preliminary effort to try to understand what has been taking place, we drew on available data from the National Venture Capital Association (2011) and the Cleantech Group (2012) and compared seed, early stage, and later stage funding of clean energy and all VCs from 1995-2009 (See Table 4). The post-2009 data would have been worth including but there was missing information on the clean energy side. We found that average clean energy deals in later stages and expansion received considerable more funding than VC deals as a whole in these stages. The average later stage clean energy deal received $31.7 million in financing, while the average later stage VC deal obtained $10.69 million, a ratio of almost three to one in favor of the clean energy deal. The average clean energy expansion deal obtained $16.44 million in financing, while the average expansion VC deal received $9.37 million, a ratio of about two to one in favor of the clean energy deal.

Table 4: A Comparison of All VC Funding and Clean Energy VC Funding by Stage: 1995-2009

	ALL VENTURE CAPITAL 1995-2009 (National Venture Capital Association Data)					**CLEAN ENERGY VENTURE CAPITAL 1995-2009** (Cleantech Group Data)				
	Dollar ($) Amount (millions)	Percent Dollar Amount	No. of Deals	Per-cent No. of Deals	Average ($) Invest-men (millions)	Dollar ($) Amount (millions)	Percent Dollar Amount	No. of Deals	Per-cent No. of Deals	Average ($) Invest-men (millions)
Seed	22793.12	5.1	6653	11.5	3.43	185.73	0.9	197	13.4	0.94
Early Stage/ Series A	95521.43	21.4	16689	28.9	5.72	3186.4	15.2	546	37.2	5.84
Expansion/ Series B	218098.59	48.8	23286	40.35	9.37	5789.1	27.6	352	24.3	16.44
Later Stage/ Series C and Greater	118398.34	26.5	11072	19.2	10.69	11810.46	56.3	372	25.4	31.75
Total	446810.38		57700		7.74	20971.69		1467		14.3

Sources: National Venture Capital Association (2011) and the Cleantech Group (2012)

Consistent with these findings is that the average clean energy seed investment was financed at a considerably lower level than the average VC deal. It obtained average funding of $.94 million, while the average seed VC deal as a whole obtained funding of $3.43, a ratio of about one to three *against* the average clean energy deal. These data are line with a late stage bias. A reason late stage companies have diverted cash away from early stage companies has been that traditional exit routes, whether public markets or acquisitions, have been blocked because of poor economic conditions. Thus, by virtue of necessity VCs have taken up the role of not just nurturing startups through the demonstration stage but of helping them to move toward later stages of commercialization. The number of years firms get clean energy funding has been stretched out. Often it is greater than the 5-10 year exit periods that VCs favor. As investors have been providing additional money for unplanned follow on rounds, the dollar amounts available for early stage clean energy deals has been lower. The problem with this trend is that in a zero-sum world the more money VCs provide to firms to which they have been committed for a long time the less money they have available to fund small and more innovative firms. With VCs locked up for long periods funding technology that is nearly mature, they have less money left to invest in potentially breakthrough and disruptive technologies.

Hargon's data in Figure 4 show the same trend that later stage clean tech funding grew in 2009 and 2010 and early stage funding contracted. Concretely this trend connotes that the VCs increasingly are funding companies like Fisker, a firm trying, but failing, to manufacture another version of the plug-in hybrid. Will funding for companies like Fisker that are absorbing a higher proportion of the VCs 'efforts dwarf the funding that technologically more advanced firms can receive? Ten advanced firms can survive on the funding that Fisker so far has obtained. If this trend continues breakthrough and game changing clean energy technology will be under-funded and the ability of the U.S. economy to break the choke hold that fossil fuels have on life and society in the next 20 to 25 years will be reduced (Thomson, 2010).

However, there is another way of looking at Table 4. If we switch from dollar amount invested in clean energy deals to the *number* of deals, a different story emerges. From 1995-2009 clean energy had a higher percentage of seed and early stage deals than venture capital as a whole. More than half these deals were in early stages, while less than half of all venture capital deals were in these stages. We surmise from this observation that VCs have done more clean energy deals at early stages but have feebly financed them. The money for early stage clean energy innovation is spread broadly but not deeply. The investment funnel is longer than in other categories of VC investment. The adaptation of the VCs' business model to clean energy might be a function of the relative lack of maturity of earlier stage clean energy companies in comparison to the maturity of early stage non clean-energy companies that VCs usually fund. Maturity is not just at the technological level but encompasses issues of cost, market acceptance, and societal readiness. Commercializing new clean energy technologies is difficult. They need substantially more complementary infrastructure than the other categories in which VCs invest. There are many examples of chicken and egg problems. Which comes first, for instance, the electric car or the charging stations upon which they depend? The interdependence of innovation in the energy system adds risk to investments VCs make in clean energy. To hedge against this risk, a strategy of making many small investments in a large number of less mature companies, as well making a small number of large bets in a few mature companies, makes sense. Though lowering the investment amount in less mature companies to compensate for the nascent nature of their technologies is reasonable, it means that many promising startups are without sufficient resources (Thomson, 2010).

Active at Both Ends of the Spectrum. Our recommendations are consistent with the kinds of adjustments VCs are making. That is, they should break norms and boundaries they apply to other investment categories and continue to show a willingness to invest larger amounts of money for longer periods of time in clean energy. Besides making bigger bets and stretching out timetables they must continue to show a willingness to experiment and make a large number of small bets in risky companies with products and services whose commercialization is not as imminent. This approach might be the best that can be expected given current economic conditions and funding constraints. But were economic conditions to improve and funding constraints to loosen, then the VCs would have the opportunity to fund a backlog of promising beginning stage companies that has built up because in the interim it has been so difficult for these companies to find financing.

VCs have to be active at both ends of the spectrum. If economic conditions improve and some of their early investments do well in comparison to other categories of VC investment, then the VCs will be able to raise larger funds for clean energy and achieve a better mix. They will be able to both fund firms for a longer time and at a deeper level and they also will be able to fund more risky and innovative entrepreneurial companies for a shorter time and at a thinner level. VCs can be equally active at the end point of commercializing technologies and at the start point of conducing trials and experiments to determine if more disruptive technologies and business models really work. They can maintain their involvement in more mature companies, while still supporting more innovative firms. Indeed, while fewer funds are being formed, fund size in clean energy industry has been growing. Ghosh and Nanda (2010) report that KPCB and Khosla Ventures both upped their typical fund raising goals for clean energy funds and that KPCB raised $500 million and Khosla $750 million. These amounts exceeded those VCs had raised in the past for clean energy (See Table 5). Once such large funds are established the important point is that a sufficient amount of their money should be set aside for seed and early stage entrepreneurial companies as well as for the late stage companies. It should not be invested just in the late stage companies.

Table 5: Size of Clean Energy Funds: 1995-2008

Period	Average	Median	Smallest Fund	Largest Fund
1985-1994	$42	$39	$5	$130
1995-2001	$57	$47	$2	$320
2002-2008	$194	$147	$1.6	$6,000

Source: Ghosh, & Nanda, 2010

The espoused aim of VCs is to fund disruptive technologies, but that generally recognized model in the industry is not one that is likely to be particularly effective in the clean energy domain unless a conscious effort continues to be made to be active at both ends of the spectrum. That disruptive technology that VCs fund also must have global market appeal and scalability in a reasonable time frame is a well known constraint under which VCs operate, but these standards are very hard for clean energy companies to meet in the current economic and political climate. To fund clean energy companies it would be unrealistic to expect VCs to suspend their well-tested business model totally. Given the expectations of the limited partners that invest in VCs and allow them to assemble large blocs of money, VCs are not in a position where they can justify lower profits. In the case of other investment categories, nanotech would be an example, when returns did not meet expectations, VCs discontinued their investments. The reasons that the VC industry exists—both to provide the potential for outsize gains to investors *and* to fund new ideas that cannot not be financed with traditional bank financing, highly innovative ideas that threaten established products and services—are not in perfect harmony. The time period for the launch of the new companies that the VCs fund is not short but it is not infinite. What VCs hope to achieve is that some of the companies they support will be able to create highly successful businesses in less than 10 years.

In this paper we have traced the successful take-off of clean energy venture capital but also have noted that its future potential depends upon its capacity to adapt its norms to accommodate to the needs of clean energy. VCs need to modify their expectations and financing patterns to make additional room for this type of investing. The two main changes we advocate and see evidence of taking place is that VCs should show greater patience and invest more in late stage companies, and at the same time not lose sight of the many truly innovative and pioneering early stage companies that require assistance. But we remain concerned that innovative and truly pioneering companies are obtaining insufficient funding in an era of tighter resources and that this would be to the detriment of society which needs to move beyond DOE's modest projections for a clean energy future. The direction in which we hope VCs will move is to allow for more risk at the end of the spectrum that can produce potential breakthrough technologies that truly have the capacity to move us beyond fossil fuel dependence.

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APPENDIX: Clean Energy Start Ups Seeking VC Funding in 2010

3G Solar
Advanced Solar Power (ASP) Ltd.
AES Wind
Afikim Electric Mobilizers
AFSK Good Heat (Hom Tov)
Algaecake Technologies Corp.
Amcor Solar Energies
AORA Ltd.
Aora Solar (FKA EDIG Ltd.)
B2U Solar
BrightSource Industries Israel
BrightView
BTP (Biofuel Turnkey Plants)
Building Turbines, LLC
C.En (Clean Energy)
Carnegie Power
Cellaris
CellEra
CES - Computerized Electricity Systems
Chi Sage Systems
Chromagen solar energy
Coriolis Wind
CQM
Crytec
Current Motor Company
Development One, Solutions, Inc.
DiSP (Distributed Solar Power)
Distibuted Solar Power
Diverse Energy Ltd.
Domoteck
EcoThermics Corporation
Elspec Engineering
EMME (fka Home Comfort Zones, Inc.)
Energtek
Ener-t Global
EnStorage
EVO Electric Ltd.
eWind Systems, Inc.
Fastransit
Fisher Coachworks
Fountainhead
FriCSo
Galten
Genesis Motors Corporation
Geomage
Georgia Alternative Fuels
GJ Senergy Cooling Systems
Global Energy
Gravity Power
Graphene Energy
Green Automotive
Green Horizons
Green Socket
GreenFuel Technologies
GreenJobs, Inc.
GreenSun Energy (GSE)
GridPlex
GSystems
HCL CleanTech
HelioFocus
Industrial Learning Systems, Inc.
Infinia Corp.
Innowattech
International WoodFuels
IQWind
KLD Energy Technologies Inc.
LaunchPoint Technologies, Inc.
Leviathan Energy Wind Turbines, Ltd.
Leviathan Energy, Inc.
Lightech Electronic Industries
Lontra
Lumenergi, Inc.
Magenn Power, LLC.
MagPower Systems, Inc.
Medis Technologies
Menolinx Systems
MetroLight
MIDCorp
Millennium Electric TOU
Minicy Catom
Moench Inc.
MST
National Biodiesel (NBI)
NCON Corporation
NextCAT, Inc.
NiDan Control Systems
Nordic Windpower
Nova Green Inc.
NRG International
NTS Energie
Olivebar
Oxycom Fresh Air BV
P&E AUTOMATION
Paper Battery Company
Pentadyne Power Corp.
Phoebus Energy
Planar Energy Devices
Portus
Power Panel
Powersines
Portus
Powerthru
Prat Energy Industries
PROterec
Primafuel
Prism Solar Technologies
Pythagoras Solar
Quadra Solar Corporation
Rand Solar Energy Systems
ReGen Power Systems
R-Box LLC
ReDriven
Redwood Renewables
Remco Solid State Lighting Inc.
R-Jet Engineering
Royal Wind
RPI Solar
SAGE Electrochromics, Inc.
SATEC
SBAE Industries
SDE Energy & Desalination
Sempa Power Sytems Ltd
Shekel Technologies
Shirasol
Smart Energy
SN Tech Inc.
SolarEdge
Solarium Power Private Ltd.
SolarPower
Solexant Corp.
Starfield Controls
Starpoint Solar
TechnoSpin Wind
Telkoor Power Supplies
Thermorise Inc.
Tigo Energy
Tour Engine
TransAlgae
TrickleStar
Turbo Trac Systems Inc.
UniBatt
Uriel Solar
Verdiem Corp.
Vision Motor Cars, Inc.
VoltAir Wind Power Inc.
Wattminder Inc
WindAid
XP Vehicles, Inc.
Yaroke Energy Solutions
ZenithSolar