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Organization Environment 2013 26: 31 originally published online 24 January 2013

DOI: 10.1177/1086026612474956

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Organization & Environment

26(1) 31–60

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DOI: 10.1177/1086026612474956

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Abstract

If venture capital's role in clean energy is to be more transformative in creating a sustainable society then the trends we reveal in this paper must gain momentum, but whether these trends will continue to gain momentum is not certain. We therefore encourage organization and natural environment scholars to follow up on the claims we make in this paper and pursue the questions we raise further. This paper reviews both the potential and the limitations of venture capital (VC) as a source of funding for clean energy. We provide preliminary evidence that venture capitalists (VCs) have been adjusting their operating procedures to accommodate clean energy. First, they have been investing larger amounts of money for longer periods of time. Second, they have started to avoid funding high risk production, distribution, and installation manufacturing and production companies and to a greater degree have been funding companies that focus on the intersection between information technology and energy. Third, besides making bigger bets, stretching out their timetables, and avoiding high risk and capital intensive companies, they have been experimenting with investments in companies with very risky technologies. Were these companies to succeed in commercializing these technologies the impact on the natural environment would be very great. We challenge organization and natural environment scholars to take up questions like these and others that deal with clean energy funding. 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 our economy and society in a more sustainable direction?

Keywords

venture capital, clean energy, disruptive innovation, organizations and natural environment, Department of Energy, private equity, high tech, pension funds, solar energy, storage

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This article addresses the potential and limitations of venture capital (VC) as a source of funding for clean energy. For the purposes of this article, clean energy is defined as solar and wind energy; biofuels; energy efficiency; alternative modes of transportation like hybrid, 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 United States will continue to be an economy and a society largely dominated by fossil fuels (U.S. DOE, 2010). In the DOE's base case, use of natural gas expands from 25% to 26%, coal use declines from 21% to 20%, reliance on petroleum falls from 37% to 32%, energy use grows slowly in response to greater energy efficiency, and renewable energy increases from 8% of U.S. primary energy consumption to just 15%.

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 21, 2012, "is some kind of disruptive technology that takes off on its own, the way the Internet . . . took off" (Leonhardt, 2012). Such a technology, like the Internet, might be partially or even entirely funded by venture capitalists (VCs). The goal of this article therefore is to analyze the critical role that VCs can play by taking promising technologies—perhaps developed in government, university, or corporate labs, on which entrepreneurs have seized and around which they have started to build businesses—and providing 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 health-care, 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 are generally involved in the earliest stages of a start-up's development while corporate and investment bank VCs compete with private equity. In this article, our main interest is private equity VC, a category that does about 80% of VC transactions as listed in Thomson Reuter's VC database. Well-known examples are Sequoia Capital, which financed Apple, and Kleiner Perkins Caufield & Byers (KPCB), which financed Genentech. Clean energy investment differs from traditional VC by virtue of the need to lengthen the time horizon of involvement in investments—in both directions, that is, more investment and involvement in firms at an early stage of technology development and with firms in a late stage of technology commercialization. Consequently, clean-tech VC investing requires changes to the traditional VC approach. In this article, we provide preliminary evidence suggesting that VCs indeed may be in the process of partially adapting to the requirements of clean energy investing. We challenge organization and natural environment scholars to verify and extend our preliminary findings and we provide many additional suggestions for organization and natural environment research into this topic.

To undertake the type of research we are suggesting, background is needed on VC and the role it can play in the commercialization of clean energy technologies. The next section of this article therefore discusses the role VC can play in clean energy. The following section provides a review

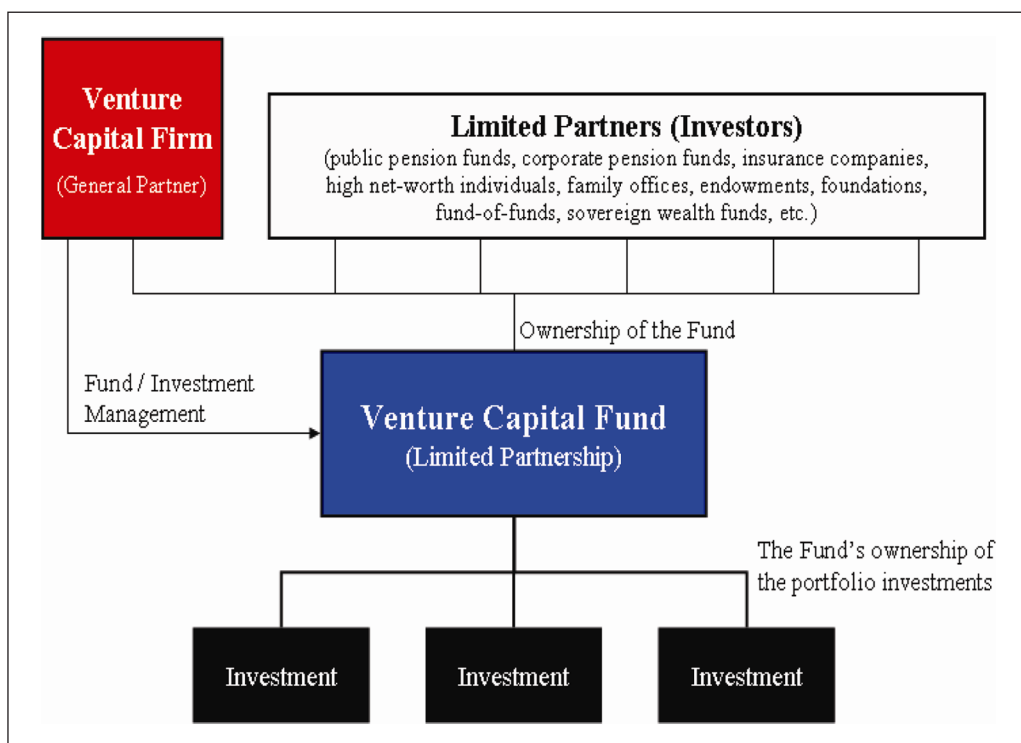


Figure 1. The typical organization of private equity venture capital.

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

of the VC industry, how it arose and works, what it does and has achieved, and what it does not do and therefore is incapable of achieving. Then, we trace 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. We do an initial evaluation of the commitments of VCs to clean energy, which we hope will be followed up by additional research. We try for a first-cut answer to the question of the extent to which VCs can further the cause of clean energy. In the final section of this article, we consider the role of VC in comparison to other funding sources. The questions we raise in this section should be of fundamental importance to organization and natural environment scholars.

- Among a number of possible funding sources, what role is VC best suited to play?
- How would it need to change in order to play a more significant role?
- What would have to happen for VC to stimulate a major breakthrough, one that was of the magnitude of the Internet in transforming our economy and society in a more sustainable direction?

Venture Capital and Clean Energy

How does VC work? VCs function as general partners (GP) in investment funds that they create (see Figure 1). They raise money from groups such as university endowments, pension funds, insurance companies, private companies, and individuals who are limited partners (LPs) in funds that generally have a 10-year life span between raising money and exiting from the

investments made (Yuklea, 2009). Their role is to find promising start-ups, nurture their development, and look for potential exit opportunities either through initial public offering (IPO) on a stock exchange or through acquisition by another company. For the services that the VCs render, they are entitled to 20% of the profits if the start-ups achieve successful exits. In the meantime, they earn management fees of 1% to 2.5%.

Entrepreneurs draw on basic and applied research, which often comes from university, government, and corporate labs, to establish their businesses. They typically obtain initial resources from themselves as well as family, friends, and angel capitalists, but often there is a gap between start-up and large-scale deployment of products and services, a gap that proves to be the "valley of death" for many entrepreneurs. VCs normally provide entrepreneurs with funding during the interval when entrepreneurs' ideas have to be vetted and tested and their commercial viability proven. In filling this gap, VCs take on great risk in that the entrepreneurs they support frequently fail. 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 GPs or LPs nor the original start-up team earn a great deal. The average annual 2002-2012 returns to LPs were just 4.41% per year, though if this time period is extended to 1997-2012 to include the Internet bubble, these returns go up to 30.95% per year (Cambridge Associates LLC., 2012).

The spectacular success of VCs in the late 1990s contributed to the high-tech boom that 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 start-ups the VCs support can have as large an impact on sectors such as transportation, power generation, home construction, and manufacturing as the companies that they funded earlier had on sectors such as communications, media, entertainment, and retail. That this is the promise embodied in VC-backed clean energy start-up firms does not necessarily mean that this promise will be realized. VCs today are in trouble. Returns on investment have been declining. Funds raised are no longer what they once were at the end of the 1990s and the start of the 21st century. All VC investments, including those in high-tech firms, have gone down.

This situation presents a number of important research topics that organization and natural environment can endeavor to explore. First, the analogy between clean energy and high tech may be flawed for a number of reasons. The *substitution* problem with clean tech is greater than it was with high tech (Lovins & Rocky Mountain Institute, 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. Analyzing the substitution problem is a challenge that organization and natural environment scholars can take up.

Second, *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 & Newell, 2011). Most of the 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 always been conducive to a large-scale shift to clean energy. While the United States has clumsily designed subsidies that get renewed periodically if at all, other countries like Germany have had more consistent policies that have yielded better results (Marcus, Aragon-Correa & 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 & Bilharz, 2006). Clearly, more research by organization and natural environment scholars on the role that government plays in clean energy is needed (Marcus, 1984; Marcus & Geffen, 1998)

Third, 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. Without a greater expectation of return on investment, 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 (Kenney, 2011). This task is not one that VC can take on by itself. It requires *partners*. Without partners, it is less likely that the United States will achieve, let alone move beyond, DOE's modest clean energy projections. Thus, another challenging research topic that organization and natural environment scholars can take up is to analyze and understand the partnering process in clean energy. For example, how is cross-sectoral leadership created in this domain (Marcus, Shrivastava, Sharma, & Pogutz, 2011)?

Fourth, for VCs to fund disruptive and radically transformative clean energy technologies, they also need to get more involved in *exploration*, while maintaining their involvement in *exploitation* (March, 1991). Clean energy must lengthen the time horizon of involvement of its investments in both directions—in firms at early stages of technology development (exploration) and in firms at later stages of technology commercialization (exploitation). Here the challenge for organization and natural environment scholars is to integrate and extend the already large management literature on the explore–exploit issue (Farjoun, 2010).

Fifth, we know that 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 [NVCA], 2011). Another potential contribution to be made by organization and natural environment scholars would be to determine whether a continuation of this trend will be primarily *contingent on the financial rewards available*, the returns that clean energy investments garner compared to the returns available from other VC investment categories, or whether other factors will play a role.

Sixth, organization and natural environment scholars can also investigate whether 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.

Finally, clean energy investing requires *changes to the traditional VC approach* to investing. No doubt VCs will continue to invest if they get positive feedback, monetary and institutional, but this feedback is not likely to be sufficient (Aldrich & Fiol, 1994; Deephouse, 1996; DiMaggio & Powell, 1983; Lounsbury & Glynn, 2001; Navis & Glynn, 2010; Rao, 1994; Zimmerman & Zeitz, 2002). We suggest that organization and natural environment scholars study how and in what ways the investment model should change.

We provide some evidence in this article suggesting such adjustments are occurring in this model that may allow VCs to invest more in clean energy than otherwise would be the case. Indeed, VCs may be in the process of adapting to the requirements of clean energy investing. Organization and natural environment scholars can contribute to our understanding of how such adaptations are occurring. We propose that organization and natural environment scholars further test the preliminary evidence we assemble in this article. This evidence suggests that the more clean energy becomes a part of the VC world, the more VCs adjust their operating procedures to accommodate the category by becoming more patient in the use of their capital, bringing greater focus to the intersection between information technology and energy, and experimenting more with investments in very risky technologies. If the VC role in clean energy is to be more transformative, we believe it is because these trends will gain momentum, but it is not certain how deep these adjustments are and whether they will continue into the future. The challenge is for

organization and natural environment scholars to further examine these trends. The payoff would be large and make contributions to both academic scholarship and the cause of replacing fossil fuels with more environmentally sound alternatives.

The Role of Venture Capital in Society

These suggestions constitute a substantial agenda for future research on this important topic. This type of research is worthwhile because of the important role that VC plays in society. For organization and natural environment scholars, VC plays an important role because it is society's essential technology gatekeeper, one that has helped to create waves of technological innovation that have transformed both industries and society at large. New ventures not only depend on technological knowledge, they also require entrepreneurial and managerial know-how, which VCs provide. They are not the content specialists but carry with them the knowledge of how to select profitable ideas, how to fund them, and how to lead them to a profitable exit. Prominent companies that VCs have supported include Google, eBay, Amazon, Intel, Sun Microsystems, Microsoft, Medtronic, Home Depot, Starbucks, Federal Express, and Whole Foods. High-tech companies in which VCs have invested, such as semiconductors, 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 & 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 United States have been created by VCs. Their data show that a very high percentage of start-ups that have the aspiration to become major businesses but are unable to secure VC funding fail within 3 years.

Venture capitalists fund highly innovative ideas that may threaten established products and services. 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). If entrepreneurial firms fail, banks do not have sufficient hard assets to hold as collateral and repossess. 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. VCs speed up this process. Without VC funding, entrepreneurial firms would not have the wherewithal to grow their businesses and diffuse their technologies on a wide enough basis to provide themselves and society the full benefits of the services of which they are capable. Such firms 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 start-up firms need in order 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 start-ups 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 United States. It provides the United States with a distinct advantage in global competition as it has attracted talented entrepreneurs and investors from throughout the world. The growth of this form of investing came about because of a variety of factors that coalesced in the second half the 20th century, including the 1979

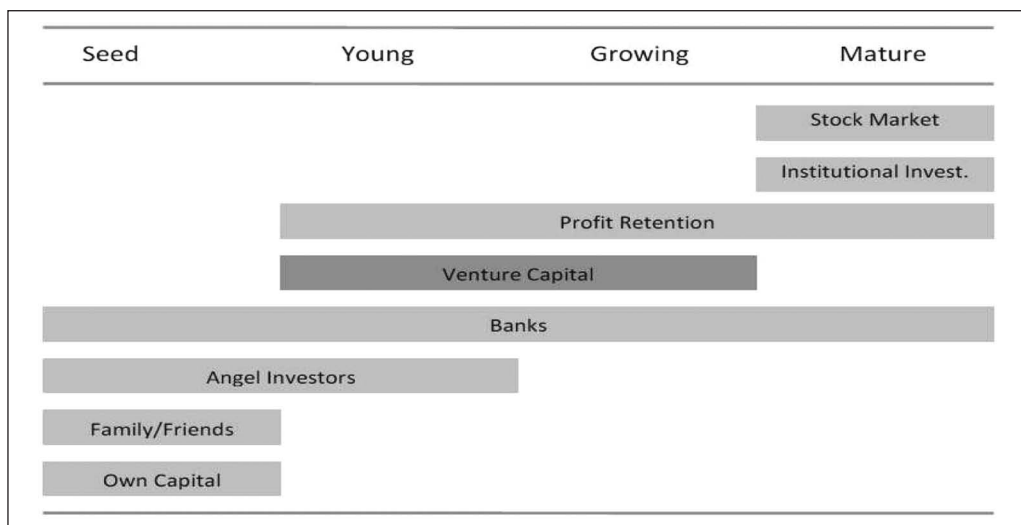


Figure 2. The role of venture capital in the maturing of entrepreneurial businesses.
Source: Ghosh and Nanda (2010).

changes to the Employee Retirement Income Security Act, which permitted pension funds to allocate up to 10% of their portfolios to riskier investments like VC (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 VCs 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 start-up firms that the VCs 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 on 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, VC is also not the first 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 an aspiring entrepreneur might be to obtain a grant from the government, a small bank loan, or 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.

Venture capitalists play an intermediate role in the innovation process by trying to assist in developing technologies that have been conceived of 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 start-ups 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 & 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. VC firms but may be less prevalent among VC 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 start-up. The assessments tend to involve face-to-face meetings and communications with the start-up's founders' previous backers, suppliers, and competitors. They seek to do a careful screening of the start-up's financials and closely inspect its business plan. The number of start-ups 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 start-ups 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 shortcuts, gut feelings, and subjective impressions in order to make their decisions. Getting funding from a VC is never easy. Typically, only 10 out of 100 business plans that come to a VC's attention get a serious look, and only 1 of these 10 is funded. The chances of being funded by the more prominent and prestigious VC firms are even lower. Start-ups that successfully scale this barrier understand that they have cause to celebrate, as obtaining funding from a well-regarded VC legitimizes start-ups 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 they can never 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% of a typical VC's investments do not pay off. More than 70% of a portfolio's returns derive from just 8% of the investments made. Despite the extensive experience many VCs have, their disappointments are frequent (Gompers & 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 10 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 3 or 4 times their first investment for follow-up financing. The evaluation of whether a start-up is deserving of follow-up funding takes place in stages (NVCA, 2011) on an annual or semiannual basis. The main stages of VC follow-up funding after the seed stage are early stage and expansion. The definition of a seed or start-up company is that it has a concept under development that is not fully operational. Early-stage companies have a product or service in testing or in pilot production. In some instances, the product or service may be commercially available and generating revenues. Expansion or later stage companies have 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 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 outside 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% of the capital gains in addition to the return of their principal, while the GPs earn the remaining 20%. Besides the payoffs from successful IPOs or acquisitions, the incentives for the VC's are the management fees they charge. The GPs thus have a guaranteed return whether or not the LPs get anything back. A typical goal is to exit an investment within 7 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 VC has made a disproportionate contribution to jobs, market value, and economic growth in the United States (Gompers & Lerner, 1998, 1999, 2001a, 2001b; Lerner, 2002), overall returns to LPs in the past 10 years are estimated to be 0.5 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 VC 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 & 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, head count, and fund-raising slipped. The 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. 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.

Venture Capital 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, VCs started to make more investments in clean energy companies. According to figures compiled by the NVCA (2011), starting in 2005-2006 the energy sector experienced a particularly sharp increase in the percentage of investments, reaching more than 16% of the total investments that VCs made in 2008 and weathering fairly well the great financial crisis of that year and the next. According to the NVCA, the average annual investment that VCs 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 on 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 categories, had the largest share of VC investment in the United States (see Figure 3).

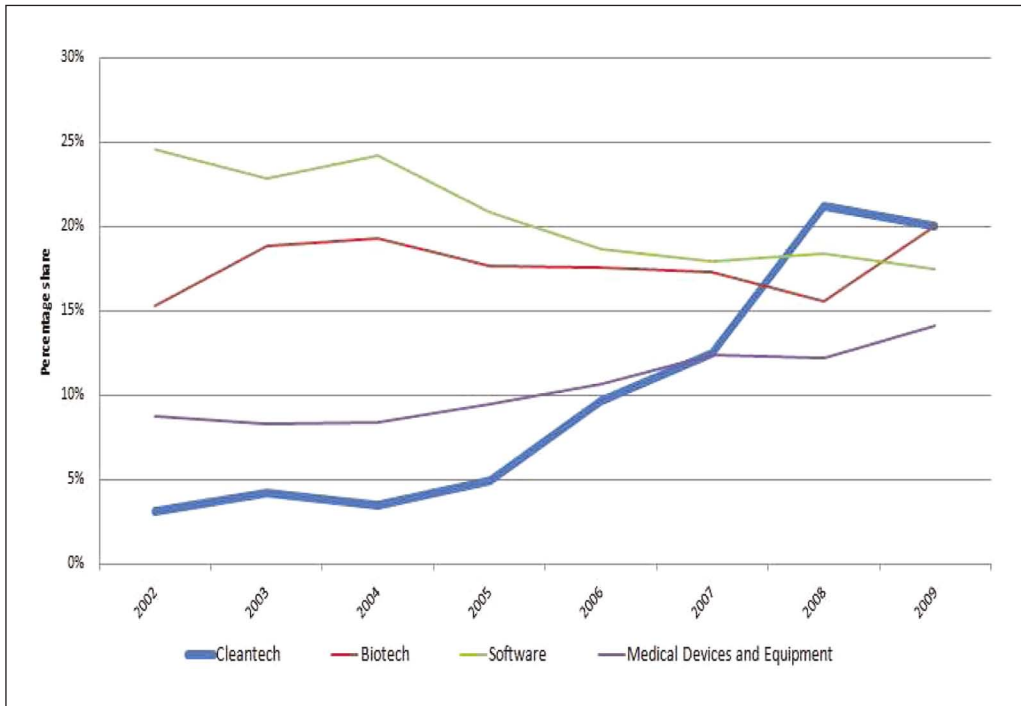


Figure 3. The share of various venture capital investment categories in the United States.

Source: Cleantech Group (<http://research.cleantech.com/>).

Matthew Nordan (2011), a VC investor at Venrock, has combined a number of sources to trace clean tech's rise (see Figure 4). In the baseline period, 1995-1999, a total of \$100 to \$200 million was invested in 30 to 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. Nordan argues that when the bubble burst, VC firms had to find other avenues for their investments. Some went into nanotechnology, but others entered clean tech. By 2005, an investment level of \$800 million had been reached. This estimate of clean-tech investment is very consistent with that of NVCA (2011). In the next 3 years, clean-tech financing increased by more than 50% annually. In 2008, clean-tech financing went up to more than \$4.5 billion. This figure is considerably less than the NVCA estimate for the category it calls energy. However, Nordan (2011) points out that seed funding began to decline, dropping off by 29% between 2007 and 2008. 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 article, we will return to this issue of the decline of seed funding.

What accounts for the rise of clean energy as an investment category? There were many contenders for VC funding. 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

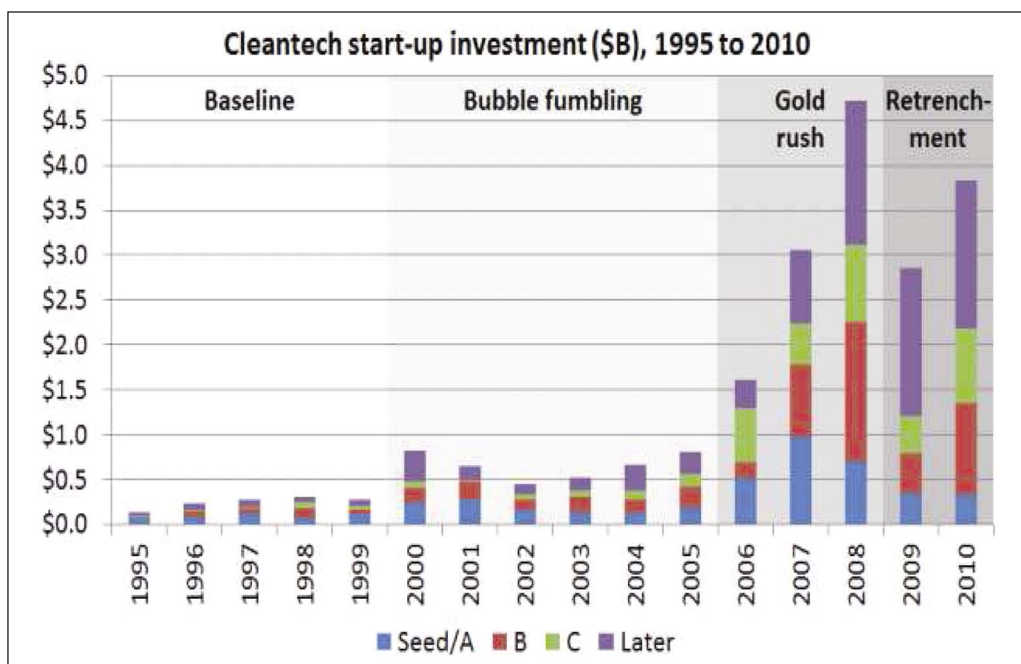


Figure 4. Trends in clean-tech investing.

investment categories (Abrahamson & Fairchild, 1999). Social construction 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. Nordan (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. We believe that successful well-publicized exits also help explain the clean investment takeoff. Our explanation mixes the symbolic (Strang & Macy, 2001) and economic reasons (Arthur, 1994) to explain the rise of clean energy (Marcus, Ellis, Malen, Drori, & Sened, 2011). Organization and natural environment scholars should take up this question of what legitimizes a new category of funding with potential impacts for the sustainability of society.

The Legitimacy of a New Category

We offer some preliminary observations and hypothesis and then further describe clean energy's ascent as a VC investment category. Prior to arising as an investment category (Santos & Eisenhardt, 2005, 2009), technologies, products, and processes are "untested and incompletely understood" (Tushman & Anderson, 1986, p. 444). Product definitions are unclear (Hargadon & Douglas, 2001). The firms that compete tend to be incompletely formed, resource poor, and without clear or well-established identities. The challenges that they face to be viewed as acceptable, appropriate, desirable, and legitimate (Suchman, 1995) are large. These challenges have to be overcome for a new category to be considered legitimate. Significant departures from past trends, what Tushman and Anderson (1986) call "punctuated equilibrium," when a category that has languished in relative obscurity becomes legitimate, are not that common (Gaba & Meyer, 2008; Greve, 1995; Rogers, 2003).

We argue that a process of social construction has to interact with objective conditions in order to confer legitimacy on a new VC investment category like clean energy. For legitimacy to be conferred on a new investment category, there must be both social construction (Khaira, 2010; Rao, 1994, 1998; Rao & Singh, 2001; Rao, Zald, & Morrill, 2000; Rindova, Pollock, & Hayward, 2006; Russo & Earle, 2010) and learning from problem-driven search (March, 1991; Offerman & Sonnemans, 1998). Normative ideas of social construction have to be combined with performance-driven ideas of positive feedback and effectiveness. The argument from social construction is that legitimacy is largely a cognitive process conferred by mental associations. By virtue of the connections that new market participants make with experienced deal makers, the experienced deal makers come to see a new category as legitimate (Sorenson & Audia, 2000; Sorenson & Stuart, 2001; Stuart, Hoang, & Hybels, 1999). The rational argument, on the other hand, rests on the new market's potential to deliver performance. There must be concrete indicators of success, real signs that investors will realize a return on their money. Zuckerman (2011) proposes that arguments about legitimacy swing back and forth between these two lines of thought but that even social constructionists like Berger and Luckmann (1966) do not to deny that the performance assessment plays a role. Following in the footsteps of the adaptive emulation school (Strang & Macy, 2001; Strang & Still, 2004), we argue that both social construction and symbols of success are important.

In accord with the social constructionist point of view, we believe that the legitimacy of a new investment category like clean energy ultimately derives from the close ties that entrepreneurs form with experienced VC investors. Amid the uncertainty that a new category presents, observers rely on the associations that participants in a new category have with the experienced investors to judge the new category's suitability and feasibility. These ties with experienced investors function as a surrogate for the investment category's quality (Stuart et al., 1999). In this way, prominent backing from organizations with prior deal-making experience works to confer legitimacy. Before the new investment category's legitimacy is fully achieved, there also must be signs of objective verification. The endorsement the category receives from associations with prominent prior deal makers is not enough. Thus, we hold that whether the new category like clean energy is viewed as legitimate also depends on a capacity to exhibit the signs of investment success. Without this positive feedback (Arthur, 1989, 1994, calls it "increasing returns"), legitimacy will not be completely realized. We would posit that the impacts of the symbols of success in turn are moderated by the media (Deephouse, 2000; Pollock & Rindova, 2003; Rindova, Pollock, & Maggitt, 2008; Zuckerman, 1999, 2000). The media's moderation means that there is a perceptual element in how success symbols affect legitimacy. For their influence to be fully felt, the symbols must be publicized broadly. Without the spread of this knowledge, the effects of the symbols on legitimacy will be of lower magnitude.

Associations With Established Venture Capital Organizations

Associations with reputable external actors (Hsu, 2006; Hsu & Hannan, 2005; Zuckerman, 1999) help move the legitimization process forward by framing the unfamiliar with the familiar and making a new market category more understandable. By not going it alone (Scott, 2001), the new category becomes viable and real to external parties who judge it. VCs come to believe that entrepreneurs who are participating in the new category have assimilated the essential qualities they need to succeed: the informal as well as formal methods they must rely on to conduct transactions, manage and execute deals, and do well in a competitive environment where few survive. Because of their associations with experienced actors, it appears as if the entrepreneurs are less risky candidates to receive the VC investment. Isomorphism (Deephouse, 1996; DiMaggio & Powell, 1983; Greve, 1998) with standard industry practices provides

legitimacy. By being in accord with accepted scripts, they gain credibility. Conformity suggests possession of requisite abilities to compete against others vying for VC's money.

Ties formed by start-ups with experienced deal makers enable these entrepreneurial firms to better understand the culture that launched previous innovative companies and technologies for several reasons (Sorenson & Audia, 2000). Such ties allow start-ups to observe and imitate practices (Jaffe, Trajtenberg, & Henderson, 1993; Saxenian, 1994) that have spawned previous successes. Start-ups also benefit from VC experience in bringing products to the market as they become better positioned to learn from the suppliers, customers, and consultants who work with the experienced deal makers (Baum & Ingram, 1998). Established deal makers are in a position to put entrepreneurial firms in touch with the critical collaborators (Brown & Duguid, 1991) and to gain access to customers, technologies, and talent. With this structure in place (Tripsas, 2009), there is the presumption that the entrepreneurs with these connections know what to do, as compared to firms lacking such relationships. The legitimacy of new investment categories is augmented by connections between firms in the new category and established VCs. Ties with established deal makers (Hsu & Hannan, 2005) build confidence that the entrepreneurs are legitimate (Hannan & Freeman, 1993). The entrepreneurs obtain from the VCs an implied endorsement (O'Rourke, 2009; Russo & Earle, 2010; Scott, 2001; Suchman, 1995). Their chances for success are similar to other organizations that have been associated with these experienced deal makers in the past. The hypothesis that organization and natural environment scholars could explore is that legitimacy is conferred on a new VC category by its associations with organizations that have had prior deal-making experience.

Signs of Success

Clean energy entrepreneurs increase stature through association with high-status organizations. These entrepreneurs are in the same league as the companies these VCs have funded in the past (Khaire, 2010). Proximity to choosy deal makers with strong evaluation skills suggests that those who associate with them are distinctive (Stuart et al., 1999). These appearances, however, could be deceiving if there were not something else—concrete symbols of success that sustain them. The issue is more than just being in the same league as the proven VCs: It is in answering the VCs' need for a return on their money. Because VCs need a sufficiently large return to make future investments, they carefully monitor their portfolios to weed out underperforming elements (Lerner, 2002). They require objective verification that the decisions they make are good ones—proof that they are on the right track. Without proof of this payoff, the VCs are less inclined to stick with a category. Thus, calculative and instrumental rationality must be added to the social constructionist argument we so far have made about what confers legitimacy on a new investment category. To justify the decisions they make, VCs must have confidence that they will earn a good return. Kenney (2011) maintains that this is the Achilles' heel of clean energy investment. The category has to hold its own against the other categories in which the VCs can invest. The hypothesis that organization and natural environment scholars could investigate is that legitimacy is conferred on new VC category by symbols of deal-making success. For VCs, successful investments are those from which they have profitably exited, most frequently through an IPO or an acquisition of the entrepreneurial firm.

Finally, one more element must be added—the role of media coverage as a channel for carrying the discourse about deal making success forward. We argue that the success symbols without the flow of information media coverage generates would be less influential in building the image, reputation, and legitimacy of the clean energy market category (Deephouse, 2000; Elsbach, 1994; Pollock & Rindova, 2003; Rao, Greve, & Davis, 2001; Rindova et al., 2008; Zuckerman, 1999, 2000). Interpretive accounts of success found in the media catalyze the flow of information

<i>Percentage annual return</i>	2002	2003	2004	2005	2006	2007	2008	2009	<i>Time period average</i>
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%

Figure 5. Returns to different categories of venture capital investment: 2002-2009.

Source. National Venture Capital Association (2011).

and increase the growth of a new market category's legitimacy and the extent to which it is generally accepted as a viable investment category (Elsbach, 1994; Zuckerman, 1999). The media thus play an important role in the legitimization of new investment categories. Understanding the role of the media in establishing the legitimacy of investment in clean-technology firms also constitutes an important avenue of research for organization and environment scholars.

A Historical Sketch

The rise of clean energy as an investment category in the historical context of the first decade of the 21st century can be seen as a combination of associations with established deals makers and signs of deal-making success—as we show in the brief historical sketch that follows. Early VC investments in clean energy, those that took place in 2001-2004, were spurred by specialist firms dedicated nearly entirely to this type of investment. Examples of such VC firms include Nth Power, EnerTech Capital, SJF Ventures, Rockport Capital Partners, and NGEN Partners (Cleantech Group, 2012). The only non-clean tech-dedicated VC who did a large number of these deals during this period was Draper Fisher Jurvetson. 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, with most firms more than doubling the number of deals in which they participated as compared with the prior period. The leadership from firms specializing in clean energy cleared the path for other VC firms to move in this direction. They established the niche and provided it with its initial endorsement.

After the fact, we also 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 VC 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 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. An outcome of the financial returns was that by 2005, at

least 18 of the largest U.S. pension funds started to show 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.

The transition from the specialist VCs to high-prestige generalists was spurred by the pension funds. Once the pension funds endorsed the category, high-prestige VCs came on board with their own endorsements. Among the high-prestige VCs who gave their endorsement to clean energy, the most important were KPCB and Khosla Ventures, a breakaway from KPCB, which led all VCs in number of clean deals carried out in this period (Cleantech Group, 2012). Draper Fisher Jurvetson continued to be very active. The start-ups' ties to these well-regarded VCs cast a positive shadow. Proximity to choosy deal makers with strong evaluation skills suggested that the start-ups were investment candidates that were comparable to the VC's prior successes (Khaire & Wadhvani, 2010). Nonspecialist investors with the bulk of their investments in other categories then 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 were also influenced by the actions of the prestigious firms whose moves they imitated.

At the same time, overall clean energy spending was expanding, which provided another type of external validation. Clean energy investment was growing because of these mutually reinforcing trends. Bloomberg New Energy Finance (2010) estimates that overall clean energy spending in 2009 was \$165 billion. This figure was far higher than the \$2 billion plus that VCs invested. About 9% of the \$165 billion was corporate R&D money, 6% was government R&D money, and 11% was invested in clean energy stocks. But most important was the large amount being spent on clean energy projects—more than 70% of the \$165 billion was invested this way. These investments suggested that the market for clean energy was substantial. In 2009 alone, about 50 gigawatts (GW) of clean energy generation capacity (excluding hydro) was added worldwide, an increase of 40 GW from 2008, and nearly as high as the 83 GW 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.

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 4 times what it was in 2004 (NVCA, 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 et al., 2012). The United States, China, and South Korea, in particular, increased their clean energy spending. On April 22, 2009, less than 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, bio-fuels, 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 10 years, it was estimated that China might spend 4 to 6 times as much. Given these moves by global governments, it was not surprising that while total venture activity was down, clean energy as a percentage 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

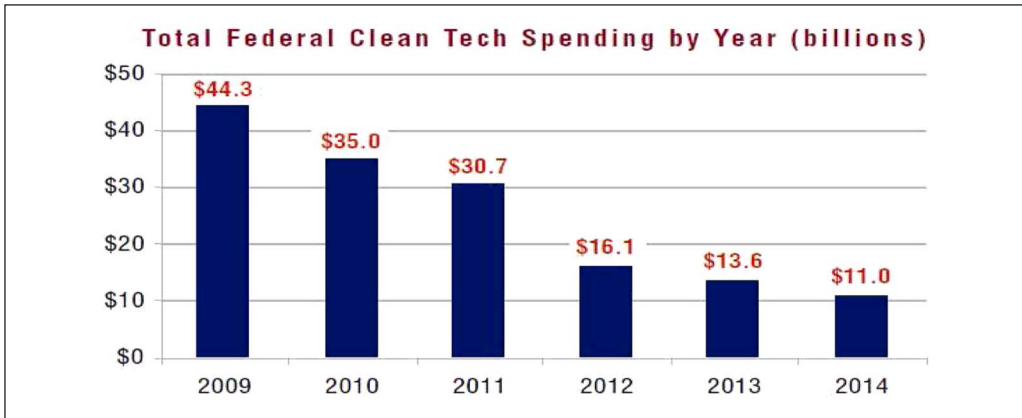


Figure 6. U.S. government spending on clean tech.
Source: Jenkins et al. (2012).

gradually decline (see Figure 6). They will be largely exhausted by the end of 2014 and therefore could not be depended on to give a long-term boost to clean energy investing.

The Impact of Clean Energy Venture Capital Investment

We have exhaustively examined the rise of clean energy as an investment category. The reasons for its rise can be further analyzed by organizational and natural environment scholars. Now we turn to another important topic—the impact of this investment. The evidence we assemble here regarding the impact of the past decade of investment in clean energy is preliminary. However, we hope that this also can help spur further research. Was this investment a net plus on the road toward a sustainable energy economy? Or, did early returns fuel a bubble in technologies that were not ready for commercialization and, in so doing, actually stunt the long-term growth of the sector? Has the actual technological progress in specific clean technology areas benefited or been harmed by recent investment trends?

According to DOE's (2010) reference case model, published in 2010, by the year 2035, though there will be less emphasis on foreign imports, the U.S. economy and society will remain dominated by fossil fuels. DOE's projections were based on the assumption that "revolutionary or breakthrough technologies" will play no role. Shale gas will 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 will constitute no more than a third of all vehicles. Fuel efficiency standards largely will be counterbalanced by the tendency of drivers to drive more. The electricity mix will gradually shift to renewables and natural gas, which will make up the majority of capacity additions. Nonetheless, as much as 40% of electricity will still be generated by coal. 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 United States be altered by a breakthrough or by a series of breakthroughs (Abernathy & Clark, 1985; Tushman & Anderson, 1986) in the technologies that VCs fund?

Table 1 shows a group of companies that were seeking VC funding in 2010. To create this group of companies, the first author of the article reviewed the results of an assignment he gave to sections of his MBA classes that year. He divided the students into groups and asked them to respond to the following dilemma:

Table 1. Clean Energy Companies Seeking Venture Capital Funding in 2010.

Name	Description
Prism SolarTechnologies	Solar: Photovoltaic 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 third-generation dye solar cells that work in low-light conditions
ReGen Power Systems	Efficiency: Stirling engines that reduce heat and energy loss in steam power generation
Planar Energy Devices	Storage: Solid-state electrolyte batteries that have 3 times the energy density
Gravity Power	Storage: Long-lasting, low-maintenance, environmentally sound pumped storage
SBAE Industries	Biofuels: Genetic sequencing and cultivation of algae to enhance feedstock potential
Graphene Energy	Storage: Nanotech ultracapacitors that increase battery life
Tour Engine	Transportation: Cylinder and 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 to 20 times thinner photovoltaic film that achieves high performance, low cost
WindAid	Wind: Low-cost wind due to reduced mechanical belts, gears, and lubrication
ZenithSolar	Solar: More efficient modular and easily scalable high-concentration photovoltaic 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 and other products that sit on building envelope
AlgaeCake Technologies	Biofuels: Algae bioreactor that uses solar energy to produce feedstock

Your group has been hired by a VC that is known for investing in clean energy. It has a list of clean start-ups 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 available from the authors. The list was assembled from companies that were found on the Cleantech Group website. Among the student choices, the 20 companies in Table 1 stand out. They figure prominently as promoting unconventional, potentially breakthrough technologies that offer simple design, offer power generation and power saving, are small in scale, and are 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 nanotech ultracapacitors.
- 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, have still 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 3 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 to 20 times thinner film that achieves high performance at low cost, and 3G Solar is moving in the same direction with an inexpensive third-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.

If some or all of these companies succeeded, the DOE's (2010) projections could prove to be underestimates of what is possible. The problem with this scenario is that these companies, which are just a sample of the companies that have potentially game-changing technologies, have received little or no VC funding (see Table 2). One hears repeatedly in the VC community that VC firms do not fund "science experiments." The companies they fund must be near to

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	21 Ventures
ReGen Power Systems	5,000,000	Quercus Trust, 21 Ventures
Planar Energy Devices	4,000,000	Battelle Ventures, Innovation Valley Partners
Gravity Power	2,250,000	Quercus Trust, 21 Ventures
SBAE Industries	1,220,000	Allegro Investment Fund, PMV, Capricorn
Graphene Energy	500,000	Quercus Trust, 21 Ventures
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	

commercial stage and close to delivering a high rate of return to investors. We noted before the stagnancy in seed funding. 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 lists some of the most highly funded U.S. clean energy companies (Cleantech Group, 2012). Overall it can be said that these companies are developing more mature clean technologies as compared to the cutting-edge clean technology companies listed in Table 1. Most of these are first- and second-generation technologies that are closer to commercialization than the companies listed previously. Many of these technologies are already 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 a large number of suppliers. Silver Spring Networks'

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
MiaSol ^Â ©	Thin-film photovoltaics	470,000,000	DTE Energy Ventures, Gabriel Venture Partners
Boston Power	Lithium batteries	344,960,000	Venrock Associates, 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

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 (light-emitting diodes) today can be purchased at any Home Depot or Walmart. While not widely adopted at this point, they are very close to taking off. These clean-tech firms 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. The funding for the mature clean-tech firms, by any standards, is very high. It exceeds by more than 3 times the \$40 million to \$50 million that VCs typically invest in a company in order to move it to successful exit (Ghosh & Nanda, 2010). Nonetheless, the question still remains whether mature clean-tech firms, even after all this money has been invested, will do well. Many of them, like Fisker, which 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 (2010) reference model, more cutting-edge clean-tech companies will have to succeed. The VCs would have to move outside their comfort zone. Because most of the start-ups they fund frequently fail, it is not so easy for them to fund innovative and transformative companies in the current economic climate of a global slowdown and continued uncertainty about the future. In the current economic climate, they must find and fund entrepreneurial firms with higher chances of near-term success. Meeting the DOE's modest goals for 2035 hinges on the mature clean-tech firms doing well. These companies 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. Going beyond these modest goals is contingent on cutting-edge clean-tech firms succeeding as well. However, without support from VC investors, this success becomes more challenging.

Given the importance of VC to technology development generally but the current attitudes of VCs to investing in entrepreneurial clean-technology firms, we make two somewhat

contradictory claims, the validity of which we hope will be the subject of future investigation by organization and natural environment scholars. The first claim is that to exceed the DOE's (2010) projections, not only must enough already well-funded companies deliver but also a sufficient number of companies with great innovative promise 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 gains in efficiency and renewable energy generation that the United States is capable of achieving.

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? This is the final, but perhaps most important, challenge we raise for organization and natural environment scholars.

Private Investment

It is possible that angel investors or private investment like Quercus can take up the slack and accomplish what conventional VC cannot. There is in our society a plethora of wealthy persons with large accumulated fortunes who 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 providing sufficient funding to the cutting-edge clean-tech firms that truly need it.

Government

There is 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 not taking place only in the United States. The subsidies for renewable energy in Europe that have opened up markets for wind and solar will also be decreasing. 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 United States and elsewhere, such a tax is almost unthinkable.

Another important development to consider is the growing involvement of the Chinese government in clean energy. Chinese government spending in the clean-technology space is already

having an impact on the trajectory of clean-tech development. This spending has contributed to 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. Chinese investment has been targeted at opportunities in manufacturing products for mass markets. Chinese firms have ramped up capacity to make first-generation wind turbines and solar cells for these markets. These firms 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 overcapacity, which may sour them on clean energy. Even if Chinese investment in clean tech is maintained, the target is likely to be finding ways to meet the vast domestic need for power. This means that investments will be more focused on scaling up existing proven technologies even in the clean space as opposed to providing funding for potentially game-changing technologies whose viability remains in doubt.

Corporations

Another possibility is that well-established companies sitting on large cash reserves will provide funding for far-reaching clean energy innovation. However, many of these companies face a genuine conflict of interest. Their business models depend on 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 start-ups, 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 large corporations, with 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 start-ups. Companies like Intel and Google have been especially active as VCs, and GE, along with firms like Siemens, has been responsible for a disproportionate number of clean energy acquisitions. Nonetheless, whether this pattern of investing will continue if the sector hits a dry spell and investments returns slip remains an open question. 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 noncapital intensive sectors (Ghosh & Nanda, 2010). Typical investments are below \$15 million per investment round. Historically, VCs have

Table 4. A Comparison of All Venture Capital Funding and Clean Energy Venture Capital 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)	Percentage dollar amount	No. of deals	Percentage no. of deals	Average (\$) investment (millions)	Dollar (\$) amount (millions)	Percentage dollar amount	No. of deals	Percentage no. of deals	Average (\$) investment (millions)
Seed	22793.12	5.1	6,653	11.5	3.43	185.73	0.9	197	13.4	0.94
Early stage/ Series A	95521.43	21.4	16,689	28.9	5.72	3186.4	15.2	546	37.2	5.84
Expansion/ Series B	218098.59	48.8	23,286	40.35	9.37	5789.1	27.6	352	24.3	16.44
Later stage/ Series C and greater	118398.34	26.5	11,072	19.2	10.69	11810.46	56.3	372	25.4	31.75
Total	446810.38		57,700		7.74	20971.69		1,467		14.3

Source. National Venture Capital Association (2011) and the Cleantech Group (2012).

preferred to make relatively small investments in firms with low capital intensity, as are typical in the high-tech and med-tech sectors. These preferences work to discourage VCs from investing in clean energy and may not be easy to change. At a minimum, one would expect VCs to increasingly avoid high-risk clean energy production, distribution, and installation manufacturing and production companies and to focus on start-ups that emphasize the intersection between energy and information technologies areas. A number of clean-tech companies do fit this description. Silver Spring Networks focuses on smart metering and the use of software, and Bridgelux focuses on advanced lighting and heating. Although VCs may fund the back or front ends of the solar energy supply chain, they are unlikely to become heavily involved in manufacturing. Recent Cleantech Group (2012) reports suggest that such a pattern exists in clean energy VC—VCs are indeed investing more in energy efficiency and the intersection between energy and information technology. But there is evidence of a countertrend. Whether individually or as part of packages put together by syndicates, some start-ups have obtained very large sums of money from VCs 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 VCs have ever supplied a start-up. The Cleantech Group 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, Nordan (2011) 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 draw on data from the NVCA (2011) and the Cleantech Group (2012) comparing seed, early-stage, and later stage funding of clean energy to average VC investment across all sectors from 1995 to 2009 (see Table 4). 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. 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 in 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 start-ups through the demonstration stage but of also helping them 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- to 10-year exit periods that VCs favor.

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. The long development time associated with clean-tech firms as compared to high-tech firms compounds this problem. As a result, less money is left for new promising innovative start-ups, and early-stage R&D in this field is often left to academic institutions. Later stage clean-tech funding grew in 2009 and 2010 while early-stage funding contracted. These trends provide support for the idea that VCs are increasingly funding companies like Fisker, a firm trying, but failing, to manufacture another version of the plug-in hybrid. Will funding for mature clean-tech companies like Fisker that are absorbing a higher proportion of the VCs' efforts dwarf the funding that cutting-edge firms can receive? Ten firms could survive on the funding that Fisker so far has obtained. If this trend continues, breakthrough and game-changing clean energy technology will be underfunded 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 thinking about how clean-tech VC investment has differed from traditional VC investment. If we shift our focus from the dollar amount invested in clean energy deals to the *number* of deals, a different story emerges. From 1995 to 2009, clean energy had a higher percentage of seed and early-stage deals than VC as a whole. More than half these deals were in early stages, while less than half of all VC 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. This notable change to the traditional VC investment approach 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 firms from other categories in which VCs invest. There are many examples of the chicken and egg problem. For instance, which comes first, the electric car or the charging stations on which those cars depend? The interdependence of the infrastructure and clean technologies reliant on that infrastructure 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. In other words, the traditional VC approach of making many small bets is extended to less mature firms by increasing the number while decreasing the size of the bets. 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 start-ups may lack sufficient resources, even in the event they are able to procure funding (Thomson, 2010).

This analysis requires additional verification. This is an important area of research for organization and natural environment scholars. More important, it raises a critical issue concerning any

transition to a cleaner sustainable future—namely, how and from what sources might firms developing societally important but less technologically mature technologies procure funding for those technologies. The fact that such technologies are less mature makes funding increasingly problematic. However, the societal importance of those technologies increases the imperative to promote their development. Governments have traditionally funded basic science; however, in the current environment of fiscal austerity among developed countries, the extent to which government is able or willing to play this role in the promotion of clean technology development may be restricted. Examining how funding for these important technologies may be promoted constitutes an important area where organization and natural environment scholars can make an academic as well as a practical contribution.

Active at Both Ends of the Spectrum

Based on the preliminary work we have done, our proposals would be consistent with the kinds of adjustments VCs are making. That is, they should be breaking 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 conducting trials and experiments to determine if more disruptive technologies and business models really work. They can maintain their involvement in more mature companies, while supporting more innovative firms. Indeed, while fewer funds are being formed, the size of individual funds investing in clean energy 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 what VCs had raised in the past for clean energy. 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 solely in later stage companies.

Conclusions

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 LPs that invest in VCs and allow them to assemble large blocks of money, VCs are not in a position where they can justify lower profits. In the case of other investment categories, when returns did not meet expectations, VCs discontinued investments in those sectors—nanotech investment being a prominent example. The reasons that the VC industry exists—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 article, we have traced the successful takeoff of clean energy VC investment but have also noted that its future potential depends on the capacity of VCs to adapt existing norms in order to accommodate the specific characteristics of clean energy technology firms. VCs need to modify their expectations and financing patterns to make additional room for this type of investing. The two main changes that might be advocated, and we see evidence of taking place, is that VCs must show greater patience and invest more in late-stage companies while, at the same time, not losing sight of the many truly innovative and pioneering early-stage companies that require assistance. But we remain concerned that cutting-edge clean-tech companies are not obtaining sufficient funding in the present era of tighter resources. These conditions may work to the detriment of society, which needs to move beyond DOE's (2010) modest projections for a clean energy future. The direction in which we would hope VCs would move would be 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.

We encourage organization and natural environment scholars to pursue the many questions we have raised further. Throughout the article, we have raised research questions that organization and natural environments could pursue but surely we have not exhausted this topic. Other examples of this research might include distinguishing energy-efficient improvements, which might have relatively lower needs for capital, including VC, from renewable energy technologies, which might have relatively higher needs for capital. Along this continuum, might there be combinations of efficiency and renewables, such as passive solar construction, that are in between those extremes, or different levels and types of complimentary infrastructure, including regulatory and/or promotional policy, which would provide more fine-grained analysis? Valuable research would include multisectoral and/or multinational collaborative investments, rather than just for-profit U.S. VCs and start-ups. We encourage research along these lines and additional research of this nature as we think that the funding of clean energy innovation that will bring the global economy toward greater sustainability is of the utmost importance.

Acknowledgments

The authors would like to thank Steve Lydenberg, Don Geffen, Ari Ginsberg, and Mazhar Islam for comments on earlier drafts of this article.

Authors' Note

This article was prepared for the Harvard University Initiative for Responsible Investment Conference: The Societal Function of Investment Asset Classes: Implications for Responsible Investment, October 4, 2012.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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