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Chapter 4 Venture Capital and Clean Technology

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Introduction

The threat of climate change has focused considerable attention on the need for reducing anthropogenic carbon emissions, predominately by reducing fossil fuel usage. That attention has brought equally considerable human and financial capital to bear on generating innovations in what has become known as the clean technology (Clean Tech) industry. However, changing the existing energy infrastructure, including both coal- and gas-fired power plants and diesel- and gasoline-powered engines, represents a monumental undertaking. In addressing climate change, three options are generally recognized: mitigation of emissions, adaptation to changing environmental conditions, or suffering the consequences of deterioration. Innovation has become the primary means, in the public eye and in public policy, for pursuing both mitigation and, increasingly, adaptation. Indeed, the recent and dramatic innovations driving the information technology revolution have placed the entrepreneur and his or her financier, the venture capitalist, at the center of new policies for driving innovation. This chapter considers the wisdom of such a placement, focusing particularly on the applicability of venture capital to fostering innovation in Clean Tech.

Energy systems are literally at the core of all political economies and are thoroughly integrated into our everyday lives. Whether the steam engine and its relationship to the industrial revolution or the petroleum industry and the mass consumption society; energy production, delivery and use have played central roles in their respective historical epochs. Due to its impact on the global ecosystem, there has been an increased questioning during the last decade of whether the current energy regime is sustainable and of the possibility of transitioning to a new energy regime less dependent upon fossil fuels. Those advocating a transition to clean technology believe this can only be accomplished by the discovery and commercialization of technological innovations. What are the mechanisms and who are the agents for financing this hoped-for transition? For a number of reasons, many have come to believe that venture capital is the ideal financing mechanism for such a transition (Wüstenhagen and Teppo 2006; for an alternative perspective, see Kenney 2010; Hargadon and Kenney 2012; Lange et al. 2011).

Advocates of venture capital as the financing mechanism draw upon the centrality of VCs in financing the information technology revolution (e.g., Perez 2002). Venture capitalism co-evolved with the emergence and growth of entrepreneurial activity in the information and communications industry, particularly in regions such as Silicon Valley (Kenney 2011). The success venture capitalists experienced in funding the development of ICT giants including Apple, Cisco, Intel, Oracle, and many more firms, also formed the basis of what many, perhaps, euphemistically have termed a New Economy (Gordon 2000). This remarkable record of success in ICT, combined with the modest but significant success in the biomedical fields, is attractive. And yet these advocates rarely consider that there have been other sectors within which venture capitalists initially invested but soon abandoned due to a lack of returns. This paper identifies the boundary conditions for successful VC investment and compares these conditions with the characteristics of clean technology in general, and the solar industry in particular, to establish the viability of innovation driven by VC investment success.

Some believe the existing energy system can only be overturned by a process of Schumpeterian creative destruction initiated by entrepreneurs. Given the sheer scope of change required, the momentum of the existing energy system, and the power of entrenched interests; given the recent emphasis in many nations upon austerity; and given the faltering confidence in the ability of governments to invest in long-term public projects, direct government action appears unlikely. In this environment, the prospect of a self-financing clean technology revolution is appealing. Schumpeterian creative destruction—the virtuous cycle of successful innovations emerging, attracting new human and financial capital, propagating further innovation and investment that opens new economic spaces—appears an attractive alternative for action at the scale required. Given venture capital's prominent role in the last such wave of destruction, the information technology industry, policy makers are turning to the venture capital model as a means for funding new firms whose success could affect an energy transition and possibly unleashing a new and similar wave of economic and employment growth.

Utilizing an appreciative model of the boundary conditions for successful VC investment developed in Hargadon and Kenney (2012), we consider the possibilities for investing in clean technologies and the likelihood of VC-backed firms replacing today's energy system, or, at least, important parts of it. In this exploration, we pose the question of whether

Schumpeterian creative destruction will be the dominant mode for the clean technology change process. In particular, we pose three questions: first, is clean technology an industry and, if so, how? Second, what are the boundary conditions for venture capital's investment success, a critical component of opening new economic spaces? And third, where in Clean Tech might these conditions hold (with a deeper exploration of one area, solar power)?

1 Is Clean Technology an Industry?

To investigate the potential role of venture capital in Clean Tech, building upon other chapters in this book, we ask whether clean technology is a coherent industry, or set of industries, joined by some unifying principle and whether this principle, like digitization was for the information and communication technologies or molecular biology for biotechnologies, is sufficiently powerful to provide large numbers of opportunities for venture investing.. This is important because all previous long-wave expansions were based on a group of emerging industries and technologies, invariably one of these new technologies was a new energy source or production system.

While the media, many observers, and government policy-makers refer to Clean Tech as a single industry, determining whether this is, in fact, the case is important analytically. The difficulty with considering Clean Tech as a single industry or technology is immediately apparent by the fact that the definitions of clean technologies themselves are both broad and vague. Patel (2006), as an extreme, goes so far as to suggest that Clean Tech, as a term, is simply a creation of the VCs and has little merit beyond this. More pragmatically, Phillip Cooke (2008) examines a variety of definitions before accepting Joel Makower's definition of Clean Tech as "a diverse range of products, services and processes that harness renewable materials and energy sources and substantially reduce the use of all resources and dramatically cut or eliminate emissions and waste." If this definition is accepted, the sheer breadth of technologies, markets and production processes violates the earlier definitions of an industry as a group of firms competing in a market or sharing similar knowledge bases, labor pools, and other linkages.

This diversity is illustrated in Table One which catalogues industries that are considered by the Clean Tech Group, a Clean Tech investment consultancy, as being part of clean technology. The sheer diversity of markets and knowledge bases involved in Clean Tech are remarkable. Using a broad definition, Chapple et al. (2011: 8) identify 194 different 8-digit SIC codes as part of the CT economy. To be certain, the firms in these SIC codes do not consider themselves as part of a single industry, do not compete in similar markets, and do not share technologies, labor markets, or suppliers. In the absence of a clear definition, even establishing the number of Clean Tech firms is difficult. For example, Karen Chapple et al. (2010) include existing firms in industries as diverse as environmental consulting and waste recycling, including automotive recycling facilities. The inclusionary approach is not without justification as some of the greatest benefits for energy conservation and environmental protection can be expected from improving existing activities, which Chapple et al. (2010) and others refer to as "process" improvements – in other words, undertaking existing activities either more efficiently or with less effect on the environment. But it is not without its problems either, we must be very careful making generalized claims about industry attributes without a clear definition of what designates an industry.

[Table 1]

Defining industries and their boundaries has attracted much attention in economics, management, and sociology, much of which has considered the problem of firms that span industrial boundaries (e.g., Ruef and Patterson 2009; McKendrick and Carroll 2001). Sociologists have generally treated industrial boundaries as socially defined: i.e., who do the participants or significant outsiders such as financial intermediaries define as their competitors or members of their industry (see, for example, Porac et al. 1995). In this sense, in some of the sociological literature, the creation of industry categories has somewhat of a voluntaristic cast, if key internal members (for instance, through forming trade associations) or external audiences label a set of firms as an industry, this is sufficient to make it legitimate (DiMaggio 1988). The reasons for a set of organizations becoming an industry can vary. For example, the government agencies can, in effect, mandate groups of firms as being an industry by regulating them through a common entity. To illustrate, Russo (2001) documents the emergence of an independent power generation industry that was enabled by government policy requiring that existing utilities purchase power from independents. In this illustration the independent power industry is contiguous with independent firms selling power to the utilities. In this case, common knowledge base, supplier relations, or labor forces have no bearing on industry membership – it is defined by the work product. Since the other dimensions such as power generation technologies were not part of the definition, they may vary considerably, though their output is undifferentiated electrons. Here the market and industry are synonymous, but the activities and even the organizational forms, e.g., for-profit firms, non-profit firms, cooperatives, etc. by which the electrons are produced can vary dramatically.

In economics, a more standard definition of an industry is a group of firms sharing similar technologies and producing a roughly similar product. For example, an industry could consist of firms producing a somewhat differentiated product, say semiconductors, but selling to different customers. Thus, the firms might be somewhat different markets, but they would be members of the same industry. Here, the industry is determined by having a similar product and technologies. Such definitions of industries suggest a certain coherence in terms of activities and products. In contrast, while both bus and railroad firms provide transportation services, they are considered to be in different industries even though they compete. The relatedness of Clean Tech firms and sectors can also be measured though product-space analysis, a technique determining the relationship between related inputs and finished products in terms of SIC codes. Using this technique and, as discussed in earlier chapters, Mark Huberty and Georg Zachman (2011) found that for six Clean Tech products, solar photovoltaic, wind turbines, nuclear power plants, nuclear reactor parts, electric meters, and electric meter parts, the respective value chains were almost entirely unrelated. The implications of the lack of common suppliers is that there are likely to be few general synergies and probably relatively little knowledge-sharing between the sectors, this is despite the fact that all of the six products are related to the electric grid and three of them generate electricity.

While the previous paragraphs suggested that technology synergies are likely to be limited, undoubtedly some Clean Tech companies participate in the same value chains. To illustrate the significance of this observation from a VC perspective, successful investments in the personal computer industry created demand for the following related products for which startups could be formed to provide: small magnetic storage devices (e.g., Seagate, Shugart Associates, Tandon), software (Borland Software Corporation, Lotus Development Corporation, Microsoft, WordPerfect), data communications devices and software (Novell, Synoptics, 3Com), and many more. It is this concatenating process, evidenced in the Personal Computer industry that drives powerful waves of creative destruction. Yet we believe there will be far fewer opportunities in Clean Tech to fund the creation of entirely new value networks composed of new firms because fewer entirely new industries composed of new firms are likely to emerge. Consider, for example, if the all-electric automobile were to become the dominant personal transportation vehicle, would a similar process to what happened in the PC be triggered? In certain limited respects this may be occurring. Venture capitalists have invested in electric automobile startups such as Tesla and Fisker and firms such as A-123 Systems, a battery maker. At a macro-level, if the only new firm-to-new firm relationships are between assemblers and battery makers, then the new value network is quite truncated. The lack of Schumpeterian creative destruction potential is further illustrated when we consider that only a few contracts between the new assemblers and battery makers have emerged. So, for example, in 2010 A-123 Systems signed a contract to supply Fisker Automotive with battery packs, but for its S series roadster Tesla adopted lithium-ion cells produced by Japanese electronics giant Panasonic Corp., which also has a strong relationship with Toyota, which is beginning to make electric cars. Of course, here the largest obstacle is that existing auto and battery producers are competing in exactly the same economic spaces and they have enormous complementary assets. While, from an analytical perspective, the success of a movement to an all-electrical vehicle economy would be a major technical transformation and offers suppliers of all types business opportunities, whether startups can build their productive capacity sufficiently rapidly so as to out-flank incumbent firms in adjacent industries is unclear and depends upon the speed with which it will occur, the ability of the incumbents to internalize the shift, and the types of technological developments necessary. For Zysman and Huberty (2010), the firms most likely to drive new economic growth are those providing new goods and services – and it is among them that VCs search for investment opportunities. However, here once again, the firms must display the characteristics VCs desire for justifying investment.

Ultimately, one must acknowledge that both public perception and policy are directing human and financial capital towards Clean Tech, and these factors alone warrant some defining characteristics. For the purposes of this analysis, we use the nature of the innovation challenge as the common attribute of the Clean Tech industry. In all cases, companies differing by technology, by market, or by production processes are identifiably engaged in a similar effort to displace extant fossil fuel-based technologies and practices with lower carbon alternatives. This definition does not resolve the major concerns we have about the ill-defined bundling of so many diverse firms, technologies, and markets into a singular category so much as recognize the singularly common characteristic among them. As we'll discuss later, it is this singular commonality which also challenges the potential role of venture capital investing.

2 Venture Capital Investments and Outcomes

Successful VC investing is predicated upon selling previous investments to others and achieving a significant capital gain (Zider 1998). These gains are the key to the VC's compensation and their ability to continue raising capital. The key skills for a venture capitalist are discovering, investing in, and assisting an entrepreneur or team of entrepreneurs to organize a firm capable of exploiting a newly emerging market or an existing market on the verge of being disrupted. The risks of making VC investments are many and, in fact, the dominant condition for VCs is uncertainty. There are many vectors of uncertainty. It is possible that the emerging technology does not work, that the investee firm is ill-suited to exploiting the opportunity or a market never appears or it fails to grow sufficiently fast. Another vector of uncertainty is related to the entrepreneurial team and its management capabilities. Economists have proposed understanding VC investment decisions through agency theory where presumably the investor, the principal, cannot be sure about the commitment of the agent, the entrepreneur (Lerner 1995). It is more likely that the various vectors of uncertainty are of greater significance to the investment's outcome than any agency-related contractual problems. In case of negative outcomes, it is more likely that the venture falls victim to what Stinchcombe (1965) termed the "liability of newness," which refers to the problems new firms face at their inception. In fact, the practice of VC investment has evolved routines, norms, and even contracts to cope with this generalized uncertainty and high mortality rates (on contracts, see Suchman and Cahill 1996).

The high mortality rates among young firms with concomitant large losses mean that VCs must be extremely selective in their investment choices. To build a new firm capable of the rapid growth that will increase its value sufficiently to offset the losses, venture capitalists must commit significant tranches of capital with little prospect of recovery should the firm fail. Because of the nature of the VC business, they must push their portfolio firms to grow extremely rapidly – long-term (slow) growth is an undesirable investment outcome. The dilemma every VC faces is that they should not invest in firms that will fail or have minimal success, but they must not miss the firms that have the potential to grow extremely rapidly – of course, the result is unknown *ex ante*. Given these conditions, venture capitalists undertake a due diligence process before deciding in which firms to invest (Tyebjee and Bruno 1984). Because the diligence process is itself iterative, entrepreneurs continually hone their business plans, and in conjunction with venture capitalists develop a collective vision of how the firm should evolve (von Burg and Kenney 2000). Even after agreeing to invest, fund disbursement is staged, thus as more information emerges, the VCs can recalibrate their investment, as they discover more about the technology, market, and management team.

Once the investment is made, the venture capitalist(s) become partners in the venture and are expected to commit significant time to each portfolio firm by serving on its board of directors, making introductions, helping craft overall strategy, assisting in the recruitment of members of the management team, and monitoring the growth of the firm (Florida and Kenney 1988; Gompers and Lerner 2001; Kaplan and Stromberg 2004). Because seasoned venture capitalists have been involved in a number of startups, they can provide valuable advice on avoiding the myriad pitfalls a rapidly growing firm can experience. However, because venture capitalists aim to profitably liquidate their investment and their first loyalty is to their capital, their goals and interests can clash with those of the founder.

The particular economic conditions of markets, in addition to differences among individual ventures, determine the success of venture capital-backed ventures. In other words, not all markets are susceptible to transformation by small firms. In one study that examined which firms developed the most important innovations of the 20th century, new firms contributed almost half of the innovations. These contributions, however, were greatest in immature industries where new entrants could expand in a relatively uncontested fashion (Acs and Audretsch 1988). As Joshua Lerner (2009: 60) argues, venture capital has had "relatively little impact on those [industries] dominated by mature companies… venture investors' mission is to capitalize on revolutionary changes in an industry, and the well-developed sectors often have a relatively low propensity for disruptive innovation." While these observations are useful, in the energy sector, the more relevant question is whether incumbents in neighboring sectors have the complementary assets and sufficient time to enter the emerging sector.

Ultimately, when judging whether a financial vehicle can support a particular genre of organizations, the question is whether the organizations and their markets have the characteristics necessary to meet a set of criteria. The key factors for a venture capital investment can be reduced to three interdependent criteria—rapidly growing markets, scalable technologies and ventures, and large and rapid pay-offs. When these criteria are not sufficiently satisfied, then those investment opportunities are unlikely to receive venture capital. Finally, because VC is risk capital, it is entirely possible for VCs to initiate investing in a particular sector, but evidence must accumulate during the investment life-cycle validating the initial investment. If information emerges suggesting that the returns will not be as great as expected, the flow of capital to particular firms or an entire sector can be cut-off. Though it is certainly possible to initially receive venture capital investment, particularly if there is significant public attention, ensuring continued investment is more difficult. We briefly expand upon these criteria below and then apply them to a few of the most salient clean technologies.

Large and Rapidly Growing Markets. VCs aim to invest in markets on the verge of creation (or disruption) that will allow their portfolio firms to grow rapidly by attracting customers. This growth depends on (1) the particular value proposition of the portfolio firm that is sufficiently compelling that customers rapidly adopt its new service or product or willingly migrate from incumbent technologies and competitors, and (2) on the market conditions that enable such new adoption or migration. In the former case, the particular offerings (and their value propositions) vary across competing firms in any given market, and it falls to the venture capital investors to discern the differences when investing in a particular industry. The latter case, however, derives from market and technology conditions and thus remains largely constant across all new and existing firms competing in a particular industry. For example, early internet firms such as Netscape, Yahoo!, Excite, and Amazon benefited from the rapid arrival of new users to the Internet, a new platform upon which they could offer their services (and one where there were quite literally no competing incumbents). Such moments may also occur in existing markets, when a technological or other discontinuity is sufficiently large enough, occurs rapidly enough, or is legally protected in ways preventing incumbents' reactions.

For early-stage ventures, a market must have the promise of growth in ways that allow new ventures to scale which, in turn, justifies valuations permitting outsized returns to investors. The returns on venture capital investments depend on the market value of a new company (via IPO or acquisition) and, in new ventures, such valuations are typically multiples of revenues (rather than earnings) that reflect the anticipation of continued rapid growth. For this reason, investments have concentrated in particular industries or industry sub-segments undergoing rapid transformation, growth, or experiencing massive discontinuities. These sectors naturally change over time. Ultimately, the success of venture capital is predicated upon having investment opportunities with large enough potential markets and concomitant returns to compensate for the risks.

The recent burst of VC investment in clean technologies was based on a belief that there would be rapid and widespread adoption in existing markets. This rush to invest was remarkable because, since World War Two, with the exception of the biomedical fields, outside the information technologies, such transformational growth has been the exception rather than the rule. Because during the last decade growth in the OECD energy markets has stagnated (0.14% annual growth rate), the adoption of CTs is predicated on the rapid replacement of existing technologies. While some CTs have experienced rapid growth in deployment global terms, wind and solar (PV) technologies still contribute just 0.23% and 0.01% of total power generation, respectively.

A number of obstacles limit the growth rate of Clean Tech firms: the long lifecycles of existing energy systems limit the number of customers turning over in a given year; the high capital costs limit the risk-tolerance of those customers; and the shared infrastructure and economies of scale enjoyed by existing systems make it extremely difficult for new technologies to compete on cost. In many cases, to make significant inroads in these markets, clean technology ventures must displace entrenched competitors with a relatively undifferentiated product—watts of electricity or joules of power. The differentiation the CT firms depend upon is an economic externality – in contrast to the competitor carbon-based fuels – the CTs do not produce global climate change gases. However, if the cost of the externality is not internalized into the price, then most CTs are more expensive compared to existing power generation, which competes at its variable costs. Much of the current growth in CT deployment is because governments have mandated favorable feed-in tariffs for CTs, however due to the global economic crisis many nations are decreasing the tariffs, thereby changing the relative cost of the energy generated by CTs. Simply put, the markets in which clean technology ventures hope to compete are large on an absolute scale, but the *relative* arrival of new customers (or churn of old customers) willing to adopt is small, limiting the growth and diffusion of emerging technologies and thus limiting the growth of the new ventures promoting them.

Scalability. Should new ventures have the good fortune of experiencing rapid growth in customer demand, a second boundary condition emerges. Rapid turnover in customers through either new arrivals (a growing market), technological obsolescence (a churning market), or radical change in market structure (e.g., deregulation) creates the conditions for ventures to grow rapidly. Two dimensions of scalability then become important. First, the new venture and its underlying production technologies must be able to scale as fast or faster than the market growth so that it can outpace later-arriving new entrants or slower-reacting incumbents. Unless new companies can emerge and become dominant players by scaling faster than competitors (new ventures and incumbents), there is little advantage to investing significant venture capital in them. In markets such as the information and biomedical technologies, the returns on equity are relatively decoupled from returns on assets. In other words, the value of a company (and its growth) is exponentially larger than its capital requirements to achieve that growth. Thus scalability is a dominant feature of the information technology sector, and for successful VC investing it is a prerequisite.

Second and related, ideally the new ventures must be able to provision the rapidly growing market without a correspondingly growing need for capital investment; this scalability is a function of both the venture and the technical and market conditions. For example, software, along with internet services, can increase production of goods and services without a corresponding increase in capital assets. The online retailer Amazon.com illustrates how financial assistance can enable a company to scale with a rapidly growing market. Amazon.com's infrastructure, though at times strained, was able to scale with the growth of internet shoppers leaving little room for later ventures or major retailers to enter that particular segment. It is this type of growth for which venture investing is optimized. To displace incumbent systems on which markets currently depend, emerging clean technologies must be able to scale in terms of both capacity and quality. Even if a new technology does have the potential to scale in this way, the costs of achieving this scale in clean technologies rarely reflect the same ratios of investment to growth as historically seen in the information and communication technologies. Energy supply technologies, such as solar, wind, or biofuels, find that investments in R&D, while equivalent to similar investments in information and biomedical technologies, are considerably smaller than the investments needed to commercialize those technologies. Biotechnology firms solved the scaling problem by licensing their technologies, usually proprietary patented drugs, to incumbent pharmaceutical firms that had the requisite financial prowess to conduct expensive clinical trials, scale production, and manage distribution. This model worked because patents ensured that pharmaceutical firms would pay enormous sums for the rights to a candidate drug or would acquire the entire firm at an enormous premium. Most technologies in Clean Tech, in general, do not have the same intellectual property protection as pharmaceuticals, but have similar scale up costs.

The costs of scaling production, distribution, and installation for clean technologies like wind, solar, or biofuels, often runs to ten times the costs of initially developing the technology. Similarly, achieving even a fraction of the production volumes needed for additional low-carbon technology capacity requires large-scale construction or reallocation of manufacturing capacity. And because the energy sector is both heavily regulated and central to the provision of other goods and services, new technologies must meet very stringent cost, quality, and reliability expectations before they can enter (let alone scale rapidly) to serve the mass market. Indeed, both purchasing and financing decisions demand performance histories of not only the technologies under consideration but also the companies supplying those technologies and guaranteeing their performance. Most importantly, those costs grow relatively linearly with the revenue growth of the company. For example, Russ Landon, a managing director at the investment bank Canaccord Adams in Boston, compared clean technology startups to IT startups: “the capital requirements for energy startups are huge" (Kirsner 2010). While $25 million may develop a new biofuel production process, an additional $250 million is needed to create a production plant (and each new plant requires equivalent asset investments). In terms of pools of money, even the largest venture capital funds are relatively small (less than $1 billion per fund and, say, $3.5 billion under management). Even with syndication, opportunities requiring over $500 million are rarely attractive as the potential losses are too great. The Solyndra case, which went into bankruptcy after nearly $1 billion in private venture capital and $500 million in additional federal loan fund guarantees, provides a useful illustration. Similar high up-front capital costs are also a reason venture capitalists will not invest in firms intending to manufacture semiconductors or build state-of-the-art data centers.

Scalability (and sheer size of the required investment), like market growth, is thus a critical factor in the ability of venture capital-backed ventures to create new economic spaces sustaining rapid industrial transformation. By growing rapidly (and relatively cheaply) in pace with growing markets, scalable ventures can provide extremely high returns to early investors. Not all technologies or firms (or their industries) are capable of scaling rapidly, nor do all technologies and ventures necessarily experience dramatically decreasing unit costs as they scale. Absent these advantages, early investors risk the high likelihood of being diluted or even washed-out as the company grows.

Rapid and Large Value Creation. As noted before, the valuation of new firms and, hence, the returns for the VC investors who backed them, requires not only a growing firm, but also the promise of a growing market that will allow the new venture to scale with it. The returns on venture capital investments, in other words, depend on the market value of a new company (via IPO or acquisition) and, in new ventures, such valuations are typically multiples of revenues (rather than earnings) that reflect the anticipation of continued rapid growth. The high growth rates of markets and relatively low costs of scaling-up thus typically differentiate the industries attracting venture capital. Contrast this with the relatively slow change and enormous scale-up costs in most energy markets and it is difficult to envision more than a few clean technology companies generating the growth in revenues and market share, and corresponding growth in equity value, sufficient to reward venture capital investors. Of course, a mania associated with clean technology may be sufficient to ensure capital gains for the venture investors able to reach an IPO or positive trade sale for their portfolio firms but, thus far, the IPOs have had lackluster results. For example, A123 Batteries, a venture capital-backed company, went public in September 2009 priced at $13/share, with investors at that price suffering an immediate dilution of $8.37 per share. After the 180 day lock-up period, when insiders were able to sell, the stock dropped. As of June 2012, following a spate of production problems associated with scaling up, the company now trades at $0.91. The now bankrupt A123 proved to be a marginal investment for the venture capitalists and particularly bad investment for the public. Similarly, the electric car manufacturer Tesla went public in June 2010 at $17 per share, by June 2012 it is valued at $27.90 per share, despite accelerating losses and sales of under 2,000 total automobiles in 6 years of operation. Many of these firms are unprofitable and, revenues are growing at less than 15 percent per year. The incumbent photovoltaic firms are experiencing revenue and profit growth rates of 20 percent, but they are no longer dependent upon VCs.

In sum, the interplay of these three interdependent characteristics of markets—growth, scalability, and rapid payoffs—determine whether venture capital financing can successfully open new economic spaces by funding early-stage ventures in particular sectors and at particular moments. Absent a favorable constellation of characteristics, it is difficult for individual ventures to effectively transform markets by growing sufficiently in size and valuation to validate previous venture investments and attract the ones necessary to create a self-sustaining industrial transformation. Worse, because venture capital uses these criteria not only to identify new ventures but also to shape their strategies, augmenting venture capital's role when these criteria are absent can be counter-productive. Driving high–growth strategies in low-growth markets; rapidly scaling when the cost of growth outpaces the resulting equity value; or attempting to exit quickly in sectors where valuations recognize low-growth and low scalability may hinder the success of individual firms. In markets with these conditions using public monies to amplify individual venture investments may equally amplify the negative effects and destroy a promising venture.

3 CT Markets Analyzed

Innovation in clean technologies poses challenges that may be fundamentally different from those challenges venture capital-backed startups are best suited to overcome. In developed nations, clean technology innovations must penetrate existing markets and displace incumbent energy systems or find small niches within which they can patiently develop footholds. In existing markets there is an installed capital stock that incumbents can treat as a sunk cost, making competition economically difficult for emerging ventures and technologies that must compete with the variable cost of the continuing operation of existing plants. Alternatively, conquering niche markets, which is a frequent path for new technology adoption, may not permit sufficiently rapid growth to justify VC investment particularly since success neither in the niche markets nor a later ability to breakout from them is guaranteed. Given these constraints, how well does a venture capital-driven model of innovation fit with aspirations for a clean technology revolution?

As of 2012, venture capital funds continue to invest in the various clean technologies. But the amount and number of deals was declining significantly not only in the U.S. but also globally. In the case of the U.S., in Quarter Two, 2012 the amount invested, $1 billion, had decreased by 11 percent, but the number of deals had dropped by 42 percent suggesting early stage and follow-ons were becoming scarcer. Moreover, there were four deals in excess of $60 million, which indicates that the venture capitalists were concentrating their investments – again suggesting that the sector was experiencing difficulties (PriceWaterhouseCoopers 2012). Given the disappointing performance of clean technology firms in achieving IPOs, after IPO performance, or being acquired at good multiples, venture capital investment will almost certainly wane unless performance on these dimensions improves. Given that the stock market by 2012 was near decade-long highs and government subsidies for clean technologies were beginning to decline, but clean technology IPOs and positive mergers were becoming less frequent, the forecast for clean technology appears cloudy. Investment in clean technology will continue for the duration of the existing funds. The reckoning will come when the clean technology venture capital firms seek to raise new funds. This is likely to be difficult.

To illustrate the structural reasons for the low returns, this section introduces a methodology for assessing the relative fit of particular markets and technologies to the boundary conditions identified in the previous section. Table Two illustrates such an examination. Note that the evaluations apply to new ventures in these sectors, and not the deployment of established technologies, typically funded with project financing. In other words, the installation of wind energy, reflecting the installation of wind turbines, reflects the growth of incumbent firms funded by project (or debt) financing and thus does not reflect the conditions for startup ventures in wind. For reasons of space, the evaluations of individual sectors are not presented in detail. Rather, Table Two serves as an illustration of evaluating the general sectors of CT and the potential value of VC investing in each, and to note when (and why) particular niche technologies or markets may make such investment viable and effective. We then evaluate one sector, solar power, as an example.

Solar Photovoltaics

According to one report, the market for solar photovoltaics globally, while having slowed down in 2011, grew 139 percent from 2009 to 2010 (Solarbuzz 2011). Even if markets slow significantly, the large and rapid growth criteria is being met, though the large number of competitors in the market means that recent solar startups are competing with existing firms; some of whom are incumbents. The scalability criterion is more problematic as solar photovoltaic technology requires large capital-intensive fabrication facilities that can cost hundreds of millions of dollars each. For example, Solyndra, which went bankrupt in August 2011, received a $525 million loan guarantee from the federal government to build one fabrication facility. As another example, the established firm, First Solar, recently completed a fabrication facility in Germany that cost $282 million (Whitmore 2011). Moreover, if demand increases sufficiently, First Solar would have to build another facility at roughly the same cost. In other words, costs of production increase roughly in line with demand, though there is likely some learning and scale economies in the production process.

From 2005 to 2007, at the height of a global warming frenzy in the media some VC-backed photovoltaic firms made public stock offerings. Two successful photovoltaic IPOs were Sunpower and First Solar. Sunpower was established in 1984, had a number of owners, and went public in 2005. First Solar was established in 1990, purchased by a VC firm in 1999, and then had stock sold to the public in 2006 (First Solar 2006). In 2007 GT Solar Technologies, a photovoltaic production equipment maker founded in 1984, was able to make its IPO, but in 2011 changed its name to GT Advanced Technologies (ElectroIQ 2011). One remarkable feature of these successes is that on average it took two decades until the firms were able to undertake their IPOs. Though they are now industry leaders, these "gestation" periods are longer than the life of VC's funds and thus unprofitable. In terms of initial public stock offerings, the criteria of large and rapid pay-offs have been unmet not only in terms of rapidity, but also, only a few photovoltaic firms have been able to make initial public stock offerings. For the other exit path, trade sales, there have been only a few sales and the returns to investors from such sales have been marginal (Lange et al. 2011).

In 2011, there was a glut of solar modules on the global market driving down prices, but also making the competitive environment more difficult for fledgling firms. The result was a number of bankruptcies. The situation was further compounded by the turbulent stock markets in 2011, which meant the ability for any firms, but particularly those that appeared to be uncompetitive, to raise public monies was virtually nil.

4 Discussion and Conclusion

This paper has identified a set of structural causes, stemming from economic conditions that explain both the success and limitations of venture capital-backed firms in creating self-sustaining industrial transformations. These causes suggest venture capital is an ill-suited investment vehicle—let alone policy framework—for fostering a clean technology revolution. Yet, venture capital investing remains active within clean technology.

The promise and success of venture capital in fueling Schumpeterian creative destruction is undeniable in the information and biomedical technologies. However, generalization from these cases without understanding the structural and market conditions in which venture capital investing has traditionally helped open new economic spaces and brought about industrial transformations can be misleading. Because industries differ in terms of their market conditions, maturity, and technological trajectories, not every industry provides the same conditions for, or responses to, venture capital investing.

Some have recently argued that the venture capital model can be adjusted to account for the conditions we have identified as constituting a fundamental blockage (Marcus et al. 2012). These authors suggest that the venture capitalists are making larger investments with longer time horizons with presumably lower risks and also smaller investments at earlier stages. Finally, they suggest that the venture capitalists are investing more at the intersection between clean energy and the information technologies. Whether this will overcome the obstacles we have identified is, of course, unknown at this time. It is also possible that venture capitalists will find clean technology niches within which to invest. However, we do not believe that during the next decade venture capital will find clean technology to be a field that provides enormous capital gains. Also, the firms supported by venture capital investment are unlikely to make a significant contribution to addressing the global climate change trajectory.

Given the political economic changes expected to result from global warming and the possibility that peak oil has been reached, there are ample opportunities for innovation and entrepreneurship in clean technology. Many clean technology businesses can and should grow using self-financing and investments from friends and family, and the Danish wind turbine industry is a classic case of such growth (Garud and Karnoe 2003). In Denmark, there was no need for venture capital. The technology was developed in use, as both performance and reliability advanced together. There is every reason to believe that the desire to decrease carbon emissions will offer many such opportunities. Large existing multinationals such as General Electric, Siemens, Alstom, Hitachi, and Toshiba in energy and Toyota, Daimler, Nissan, General Motors and others in transportation are leveraging their competences to produce clean technology solutions. In addition, existing small and medium-sized firms, which have strong technical abilities in various machinery industries and in components and subcomponents of larger energy solutions, will respond to these business opportunities.

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Table 1: Industry Segments according to the Cleantech Group:

Energy Generation	Energy Storage	Energy Infrastructure	Energy Efficiency
• Wind	• Fuel Cells	• Management	• Lighting
• Solar	• Advanced Batteries	• Transmission	• Buildings
• Hydro/Marine	• Hybrid Systems		• Glass
• Biofuels			• Other
• Geothermal			
• Other			
Transportation	**Water & Wastewater**	**Air & Environment**	**Materials**
• Vehicles	• Water Treatment	• Cleanup/Safety	• Nano
• Logistics	• Water Conservation	• Emissions Control	• Bio
• Structures	• Wastewater Treatment	• Monitoring/Compliance	• Chemical
• Fuels		• Trading & Offsets	• Other
Manufacturing/Industrial	**Agriculture**	**Recycling & Waste**	
• Advanced Packaging	• Natural Pesticides	• Recycling	
• Monitoring & Control	• Land Management	• Waste Treatment	
• Smart Production	• Aquaculture		

Table Two: Clean Tech Energy Sector Compared on the Basis of Criteria for VC Investment

Industrial Sector	Large and Rapidly Growing Markets	Scalability	Large and Rapid Payoffs
Solar photovoltaics	0	0	-
Solar central thermal	0	-	-
Solar facility installation	-	-	-
Wind energy	-	-	-
Biofuels/Ethanol	-	-	-
Geothermal	-	-	-
Advanced lighting (LED)	0	0	0
Energy management (SW/HW)	0	+	0
Energy storage	0	-	-
Transportation	-	-	-
Recycling	0	0	0
Smart grid (T&D, metering)	+	-	0

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