Part II

Winning and Losing in Nanotech: Case Studies from Developed Countries

CHAPTER 2

Learning from Solyndra

Changing Paradigms in the US Innovation System

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Introduction

The company founder was furious. He had applied for a government loan guarantee to build a factory so that his innovative solar energy technology could be manufactured and sold—before the company ran out of money. And yet two years into the loan application process, he had nothing to show for his application effort.

So on September 8, 2008, Solyndra's CEO Chris Gronet wrote as follows to the head of the US Department of Energy's (DOE) Loan Guarantee Program Office:

> We continue to spend on this project at a very high rate to ensure that we have all of the prerequisites in place for a successful and timely project. I know the intent of the DOE program is to support the expansion of companies like Solyndra that have game-changing technologies that can have a real impact on our energy and global warming issues. But please realize that these delays are now in danger of having the OPPOSITE effect. We are a relatively small company with a small balance sheet and simply cannot afford such delays.

Solyndra did get the loan – nearly a year after this email. The loan was finally signed after the November 2008 election ushered in a new president and a new Secretary of Energy, and after further augmentations to the Loan Guarantee Program. When the loan did come, it was the largest loan guaranteed in this program - USD 535 million. The loan was followed by the arrival of the President of the United States himself, who made a state visit to Solyndra's Fremont, California manufacturing facility in May 2010. The new state-of-the-art plant was built, came on line, and as planned helped cut Solyndra's manufacturing costs in a viciously price-sensitive market.

But three years almost to the day of Gronet's SOS message to DOE, Solyndra filed for bankruptcy protection, having fired nearly all of its 1100 employees with no warning on the eve of Labor Day weekend. Along with Solyndra, a seemingly promising new solar energy technology for the important commercial rooftop market disappeared.

The bankruptcy rapidly became a political football: Republican-led congressional hearings were called, Solyndra executives were subpoenaed by a House of Representatives committee. Photos were published of federal investigators carting off cartons of impounded documents from Solyndra's headquarters. The atmosphere of criminal mystery was deepened when Solyndra executives invoked the Fifth Amendment in order to avoid testifying about their conduct of the business.[1] "Solyndra" had finally become a household name, right at the moment of its death. It was threatening to take the American solar manufacturing sector down with it.

The practical outcomes of this particular bankruptcy have been felt throughout the industry. One commentator claimed that the big winner of the newly-downsized DOE solar program "isn't the American taxpayer or even the House Republicans. It's the Chinese solar industry."(Nocera , 2011) Indeed, the US, having lost its world-leading solar industry in the 1980s, is now busily losing its solar photovoltaic (PV) manufacturing industry for the second time. It had already fallen behind Germany and Japan, smaller countries with inferior insolation, and has now fallen far behind China, whose share of global PV sales went from 6 percent to 48 percent in a few short years.(Nocera ,2011) The precipitous rise of China and decline of the US in solar PV manufacturing has been described as the result of local errors on the part of Solyndra's development process, as part of a natural process of industry consolidation, as the fault of government subsidies – as many things other than what it is, which is a challenge to the current US innovation system.

Just when it seemed that the dust has settled on the September 2011 bankruptcy of Solyndra, Republican presidential nominee Mitt Romney made a campaign visit to the shuttered facility. Solyndra's closed plant, Romney said, is "a symbol of how the president thinks about free enterprise,"; "Free enterprise

[1] See, for example, Matthew Mosk(2011) "Solyndra Execs Stonewall Congress." ABC News. http://abcnews.go.com/Blotter/solyndra-execs-stonewall-congress/story?id=14589597#.T5ZiCY6iNrI .

to the president means taking money from the taxpayers and giving it freely to his friends." (Friedman, 2012) In July, Congressional Republicans introduced a "No More Solyndras Act," further cementing the name as a synonym for government failure in the cleantech arena.[2]

Romney's political score was undermined only one week later, when a solar company aided by his administration in Massachusetts, Konarka, filed for bankruptcy in turn (Schoenberg, 2012).

Presidential politics aside, the failure of Konarka, along with that of many other solar manufacturing companies resting on novel technologies, provides superficial evidence for our hypothesis that Solyndra was not a badly-run anomaly, but a canary in the coal mine of American innovation. The American "National Innovation System" (NIS) has always claimed exceptional prowess at the commercialization of new, high-risk technologies, and yet the dueling solar bankruptcies suggest that this is not always the case. To repeat, then, what are the long-term lessons that we should learn from Solyndra?

In this chapter, we explain why the major interpretations of the Solyndra disaster cover up the real sources of failures like Solyndra's. We argue that Solyndra did not fail because of management errors or dramatic shifts in markets and prices in themselves. More alarmingly, Solyndra did fail by faithfully following the current technology development formula as handed down from the information and biotechnology industries.

There are very high stakes to "getting the failure right" in the Solyndra case. One is whether new photovoltaic technologies, sometimes called "2nd" and "3rd" generation, will garner enough private and public support to continue or even accelerate the remarkable solar installation record of recent years.[3] Another is whether emerging economies, especially those like India's and Brazil's that are suited to solar energy, will develop their own solar manufacturing industries successfully. Towards the end of this chapter, we will address the global implications of the pitfalls of the US NIS in solar energy.

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[2] The bill text, "To limit further taxpayer exposure from the loan guarantee program established under title XVII of the Energy Policy," states that it can be cited as the "No More Solyndras Act" Act of 2005 (Upton, 2012), on line athttp://republicans.energycommerce.house.gov/Media/file/Hearings/Joint/20120712_EP_OI/BILLS-112hr-PIH-nomoresolyndras.pdf.

[3] Pew Charitable Trusts reported that solar installations in 2011 rose to an "unprecedented 29.7 GW of new capacity—10 times the level recorded in 2007." (The Pew Environmental Group, 2012)

A Debate that Insures Defeat

There are two conflicting *policy* interpretations of the Solyndra bankruptcy, and two opposed lessons being drawn from them; that government was the problem, and that government was not the problem. We exclude a common third theory that appears whenever a technology company fails, which is that the company failed because its technology failed—because its technology "wasn't good enough."

Solyndra's bankruptcy has produced a tidal wave of Monday-morning quarterbacking, so we'll pause to explain why we do not accept the critique of Solyndra's technology as such. Not long after the bankruptcy was announced, Bill Joy (2011), a partner at the venture capital firm Kleiner Perkins Caulfield and Byer, said, without naming Solyndra, "The trouble comes if you're not good enough to make a difference. I think a lot of the solar ventures haven't had enough differentiation. They haven't been enough better than the trajectory of the incumbents."[4]

Joy is no doubt right about the sector—*if* we add to his sentence, "not good enough to make a difference *with the industry structure and policy context of the United States after around 2005.*" The quality of Solyndra's technology was, like that of all other technologies, had an *interpretative* fact tied to its social, political, and economic circumstances. It is good or not good enough only in a particular context of time, place, price, quality, and competing product in which it is initially evaluated. Solyndra offers a good example of this principle. Private capital gave its technology repeated thumbs up, as did an especially laborious evaluation for the DOE loan, which lasted through a critical period of nearly three years. We generally do not accept technology critiques outside of their context, but there is no evidence in Solyndra's case that the technology was not "good enough" *in itself* during its process of development.

Back to the two main policy interpretations of Solyndra's bankruptcy. The first interpretation has been advanced by a political Right that already opposes most kinds of government involvement in private enterprise. They have claimed that the bankruptcy of Solyndra, which had received a flagship loan guarantee

[4] "Many have been badly managed, or badly conceived. The trouble comes if you're not good enough to make a difference. I think a lot of the solar ventures haven't had enough differentiation. They haven't been enough better than the trajectory of the incumbents." (Bullis, 2011)For Energy Secretary Steven Chu's categorical denials of influence peddling by George Kaiser, the Obama campaign contributor and principal in Solyndra Lead Investor Argonaut (Solomon and Tracy, 2011).

from the government, proves yet again that the government intrusion in markets is always bad, and that the government has no useful role in energy policy (Los Angeles Times, 2011; Wald, 2011; Wolk, 2011). Energy and Commerce Committee Chairman Fred Upton (R-Mich.) called the loan a "taxpayer rip-off" (Mosk, 2011). Solyndra became a morality play about what happens when government bureaucrats try to "pick winners." The core ideological lesson or argument that governments harm efficient markets was juiced up by the charges of possible political favoritism: one of Solyndra's lead investors was a major Obama campaign bundler with direct access to the President.[5,6]

The second interpretation has come from the mainstream of the Democratic Party and of science policy. This faction already believed that governments have an indispensable role in helping early-stage technology companies cross the "valley of death" from invention to commercialization, a phase where private capital is normally scarce. In this valley, where the technology looks promising but no clear market has emerged that would attract private capital, the government should offer limited help until the company gets on its feet. Currently public sector assistance comes in two main forms: early-stage research funding, and later-stage loan guarantees and tax credits of various kinds. Thus the government role is limited, but this second interpretation values this role highly.

The second interpretation holds, then, that Solyndra had technological merit, was carefully monitored, and engaged in no dubious or illegal practices. It failed because of dramatic changes in global markets, which a properly limited government role cannot control. In Solyndra's case, this took the form of an 80 percent drop in prices of polysilicon, a material used by Solyndra's competitors, which was in turn driven by the mass entrance of Chinese companies into the sector via huge subsidies from the Chinese Development Bank.

This was the interpretation advanced by Department of Energy Secretary Steven Chu when he capably defended the Loan Program in a hearing in

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5 "The problem with politically directed investment isn't merely that bureaucrats are betting with someone else's money on industries they may not understand. Such investment also invites political favoritism for the powerful few at the expense of millions of middle-class taxpayers. Americans need to know the full story of who made or influenced the decision to give Solyndra its loan guarantee, and if political pressure was brought to bear," (Wall Street Journal, 2011)

6 http://www.nytimes.com/2011/11/17/us/politics/energy-secretary-stephen-chu-to-defend-solyndra-loan-to-congress.html?_r=1

mid-November.[7] It was also true for a good journalistic defense of the program (Nocera, 2011) and for one particularly good post-mortem on the clean tech boom. (Eilperin, 2012) This second lesson is that Solyndra is the exception that proves the rule: the American innovation system works, based in part on a modest government role for early-stage companies. But it should not be held responsible for a market "tsunami" like the one Solyndra faced during its formative years.

In short, the Solyndra debacle reinforced a standard debate on the US innovation, which always fields these two limited positions. Either there is *no* governmental role or there is a *limited* role for government in providing bridge funding—large tax credits and loan guarantees--for businesses taking an emerging technology from prototype to mass adoption.

We will not analyze the first position, which denies any useful government role in commercializing emergent technologies. Given its sponsorship by the political Right in the United States, it is politically potent. But it lacks historical evidence and analytical merit. The second position, "early-stage public subsidy," presides over the US innovation system. Its intellectual foundation is sometimes called the *linear model*—a model that has been much criticized in theory, but remains operative in practice.[8] Table 2.1 displays its primary sequence:

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[7] The "linear model" was not invented but was influentially codified by Vannevar Bush (1945), who used the model to win some limited autonomy for scientific researchers from the politics of the funding process. A particularly important later intervention was that of Stokes (1997).Stokes pointed out the problem with calling stage 1 of Table 1 "basic research," showing that much fundamental research aims to address practical problems. Although it is outside the scope of this chapter to analyze this issue, Stokes' research, along with that of the theory of the National Innovation System that followed, as well as "endogenous growth theory" and other neo-Schumpeterian analyses that gathered steam in the 1990s, have not substantially modified the linearity of the model.

[8] Nanotechnology is embodied in the inks that are used in printing PV cells known as "thin-film" on high-speed printing presses. High speed output is the key to the competitive pricing of thin-film solar modules, but this output is difficult to achieve. The technical qualifications of such inks are remarkable: in printing the circuits, there must be a specific ink for every material or component-of-material that is deposited on the fast moving substrate. Each ink must dry before the next feature is printed by the following roller, and as they dry, the particles in the printed feature must react together so as to form the molecular structure of CIGS that is required for module operation. In Solyndra's product, the inks dried and cured into films of material that were no longer nanosized, but the significant science underlying this printing accomplishment was nanotechnological.

Table 2.1: Standard Linear Innovation Model

1. Curiosity-driven research goals
2. (Incremental) public funding
3. Expert-driven research
4. Precompetitive transactions (USD for Intellectual Property)
5. Invention disclosure; Property transactions: patent, license
6. Start up company and private funding
7. Industry development
   - Inter-firm competition
   - Passive government bridging
8. Marketing product to consumers
9. Establishing innovative product in marketplace

The linear model sees limited government intervention primarily at two points: stage 2, "(incremental) public funding" for early-stage research and development (R&D); and stage 7, "modest government bridging," where the government acts essentially as a customer of first or last resort. All the principal development stages (3-6) are private – the research itself, the invention, the creation of intellectual property, and the development for public use are proprietary and shrouded in secrecy. Neither the end-user nor the society as a whole (or social needs as expressed in public policy or otherwise) are present "upstream" as the research and even the development are underway.

This standard linear model supports public funding for early-stage research (stage 2) and some bridge funding when companies must later "cross the chasm" from non-existent or small, unprofitable markets to commercial markets large enough to allow them to cover costs, pay down debt, and meet investor expectations (Moore, 1991). The heavy involvement of the government in stage 2 stands in stark contrast to its nearly total absence during stages 3-6. Government involvement returns in stage 7 but is modest and passive, even if it is cumbersome and intrusive as was the case with Solyndra when Gronet wrote the exasperated email cited above.

The linear model has been widely critiqued, notably by Donald Stokes in the 1990s and Benoît Godin in the 2000s, among others (Stokes, 1997; Godin, 1997) But it remains in practical use, and is widely assumed by policymakers such as Energy Secretary Steven Chu, President Barack Obama, and other leading figures in the American science policy establishment. As we will see, one of its orthodox adherents was the start-up company called Solyndra, whose founders had an interesting idea for a socially-useful, innovative solar technology. Solyndra's solar PV modules involved nanotechnology in the complex process of their manufacture, which requires special inks that enable the high-speed printing of CIGS circuitry. Though Solyndra did not emphasize their use of nanotechnology, the production process required its successful deployment.[9]

Solyndra as a Linear Success Story

To convey an idea of how the linear model operates in practice, we summarize the corporate history of our case study, Solyndra. The bankruptcy was extremely costly in various ways, but one positive effect was that the US Bankruptcy Court for the District of Delaware appointed a Chief Restructuring Officer (CRO), R. Todd Neilson, who was given access to tens of thousands of pages of corporate and government documents. Neilson who wrote a detailed report (Neilson, 2012) has since been made public. Our summary depends on the Neilson report, with its unique level of familiarity with the Solyndra archive. [10]

Chris Gronet founded the company in 2005, sold preferred shares to raise initial capital in 2006, and wrote a pre-application to the DOE Loan Guarantee Program later that year. The theory behind the start-up was simple. Gronet believed he had invented a game-changing or "disruptive" technology. He wanted to commercialize it, had a good sense of the steps and money involved, and engaged in a classic Silicon Valley process of private fundraising.[11]The goal was to build a major manufacturing facility (Fab 2[12] was to have an eventual

[9] Our information about Solyndra's early years is incomplete, and given the legal issues that as of this writing still envelop the company we have not been able to interview principal participants in its development as we had hoped.

[10] Solyndra's first round of financing, in June 2006, was an equal partnership between three established venture capital firms: CMEA Capital, Redpoint Ventures, and U.S. Venture Partners. As is typical with large startup companies, these VC firms then arranged further rounds of funding, each larger than the last, in which the initial firms put up ever-larger sums and brought new VC firms on board. By the time of its DOE loan guarantee, Solyndra had raised nearly 800 million USDof private equity(Fehrenbacher,2009).

[11] "Fab" is the standard Silicon Valley shorthand for fabrication facility, or factory. In this chapter FAB 1 refers to the first manufacturing facility built by Solyndra and FAB 2, the second.

[12] We have attempted to interview all of the founding principals and early-stage executives for the company that became Solyndra but have been unsuccessful, in part because of pending litigation related to the bankruptcy and federal investigation.

420MW / year capacity) and to sell PV tubes on frames to the intermediate market of installers and builders.[13]

What was so disruptive about the technology? In 2005, thin-film modules were seen as cheap but less efficient alternative to polysilicon, whose price had shot up for various reasons. CIGS (Copper Indium Gallium Selenide) had been around for a while (Solar Frontier in Japan was especially experienced with its "CIS" material [Copper-Indium-Selenide]). Gronet used CIGS but in an unusual "elongated" or cylindrical form.

Our assessment of the initial technology is that Chris Gronet had developed a useful innovation that was not in itself a killer app. It addressed and partially resolved three important problems with rooftop installations. The first is the classic problem of reduced effective exposure to the sun of a fixed flat panel. Flat panels lose much of the sun's energy as the sun's angle changes throughout the day, and they are not very effective with diffuse and reflected light. Gronet's cylindrical design sought to capture direct, reflected, and diffuse light all at the same time (Neilson, 2012, 37)

A second major issue with solar systems is "Balance of System" costs (BOS), which can include current-management equipment like inverters as well as complicated brackets and wiring that link modules together and then affix them to the ground or roof. One common problem with flat rooftop modules is their susceptibility to wind damage. Gronet's cylinders were much more aerodynamic than the flat panels, and their greater stability in high winds allowed for brackets that were lighter, cheaper, and easier to install.

The third issue was the cost of the most common material used in photovoltaic modules – polycrystalline silicon, which in the mid-2000s was expensive to manufacture and expensive for module makers to buy [14]Cheaper materials were being tried by various labs and manufacturers, including CIS

[13] At the beginning of 2005, the average contract price for solar-grade polysilicon was between 50 USD and 55 USD per kilogram. This is difficult to calculate with precision as it is different for every module manufacturer, and not always publicly disclosed. This rose steeply in the second half of 2005 and continued to increase steadily until it reached its peak, above 230 USD per kg in August 2008. Prices then fell by the same amount in less than a year(Pedus, 2006; Anon, 2012).

[14] Gronet Technology patents do not declare a "government interest," but this does not exclude the likelihood that the early-stage research, conducted in Stanford University laboratories, for example, was federally funded. Our research on quantum dot patents (unpublished, authors' files) suggests that government interest is disclosed at a lower rate that the actual presence of government funding requires.

thin films as noted above, or, more commonly, CIGS, because gallium is often added as well. CIGS is less efficient than Si, but was cheaper at that time, and Gronet developed a solid, convenient housing for his CIGS thin-film that would protect the photovoltaic layers from degradation while making them easy to install, like a fluorescent light tube.

The evidence we have suggests that Gronet and his partners followed the linear model to the letter. They had performed high-quality academic research that we must assume rested in part on federal funding (stages 1-3).[15] At some point, Gronet and his colleagues decided that their research had commercial potential. For most of the past 30 years, an academic investigator's belief in the commercial potential of his or her line of research generally leads to an invention disclosure to the university's technology transfer office or the pursuit of research sponsorships from relevant firms in the sector, or both (stages 4-5). These stages often interact, and can occur in various orders.[16] In general these transactions and disclosures are confidential, and we have no inside data about these early stages in the life of what would become Gronet Technologies.

But we do believe that CRO Neilson made a reasonable assessment of Solyndra's comparative advantage when he says,

> At the time of its entry into the market, Solyndra's leading competitive advantage was its low BOS (Balance of System) cost, which means the aggregate cost associated with installing and maintaining solar panels. Due to the unique slatted design of the modules, along with their ability to be installed with zero degrees of tilt, Solyndra's panels allowed wind to pass through with minimal resistance. (Neilson, 2012, 38)

Stage 6 involves the establishing of an intellectual property (IP) portfolio. This does not happen at once. IP development is usually iterative, involving

[15] For example, stage 2 might involve an industry sponsorship that advances academic research in a direction with commercial potential, which may involve additional transactions between the firm and an academic lab (stage 4) before the disclosure (stage 5)—or the other way around. When an invention is made in the course of a consulting relationship between a faculty member and an industry sponsor, both the faculty member and the firm may feel no obligation to disclosure the invention to the university.

[16] For a useful analysis of the history of different types of patent continuations and their meaning, seeHegde et al. (2009).

additional patents and the filing of patent continuations.[17] We have evaluated the 16 patents that the US Patent and Trademark Office (USPTO) had assigned to Solyndra.[18] The first four patents were filed in 2005, another eight in 2007, one each in 2008 and 2010, and the final two in 2011. The patents employ mechanical and optical engineering combined with standard Silicon Valley deposition techniques adapted to the more complex geometry of Solyndra's cylindrical modules. Read in sequence, the patents depict the story of how the company encountered problems brought on by the new geometry and found clever ways to circumvent the new difficulties. In our view, they show real ingenuity and seemingly good use of quality patent attorneys.

The linear model we have outlined above elongates the research, discovery, disclosure, and technology transfer period, and reflects a perspective that assumed a starting point in basic research. Stage 7 is often the most difficult stage of all, as disclosed inventions, patents, proofs of concept, prototypes, and small-match samples need to be scaled up and made reliable for commercial markets. Stage 7 can certainly take as long or longer as the first six combined, and in our interviews with solar start-up companies we have found this to be the case. Solving cost problems in a highly competitive environment is extremely challenging with a novel technology or technique, and Solyndra's product had a number of novelties competing for engineering solutions at the same time.

It is highly likely that the company used some of the standard tools of the semiconductor trade for analyzing the results of their depositions and scribing. These would be the tools that evolved out of nanotechnology research: atomic force microscopy, surface enhanced Raman spectroscopy, detailed analyses, and control of sputtering processes. Even with their interesting geometry claims, Solyndra still had to deposit high quality CIGS films where each element is in the right proportion and evenly distributed. This is not easy on flat surfaces, and Solyndra was trying to do it on cylinders. We have two separate reports from experts with knowledge of Solyndra's technical struggles that among other problems their deposition methods broke many cylinders, reducing yields far below suggestions. This problem is undoubtedly only one of the many faced by the company's production groups.

[17] Solyndra may have licensed other patents assigned to others, but we do not have access to this confidential information. We retrieved our list with this embedded URL .

[18] Though a GAO review of the Loan Guarantee Program Office (LGPO) records growing pains and glitches, we see no evidence that the LGPO made unforced errors in the substance of the Solyndra evaluation, even though they did delay it.

We emphasize that these kinds of problems are standard in start-ups, and we have found no evidence that Solyndra faced an anomalous number or that they were below average in finding solutions. They were operating in the middle of one of the world's greatest concentrations of engineering talent, and their strong early funding suggests that they had as good a chance as any company to push CIGS deposition and other needed techniques as far along as it needed to be. Accumulated learning is more important than formal IP to find real solutions in Stage 7, but we find no signs that Solyndra failed to learn rapidly, or of other obvious errors. As we will show below, Solyndra *did* reduce its production costs in line with the price drops among its competitors that were driven in part by the collapse of polysilicon prices after 2008.

In reality, Solyndra appears to have been a highly competent technological operation that proceeded successfully through the early stages of the linear model. I*n the context of the linear innovation model, it did everything right.*

Stage 8: whatever the benefits of the innovative technology; Solyndra's most important *business* advantage (or "value proposition") was, to repeat, that its Balance of System (BOS) costs were much lower than those of its competitors. In 2006, Solyndra claimed its product would cost half of a conventional module per watt per panel (Wp) , owing mostly to savings on the module frames and installations. In particular, the module cylinders would not be as vulnerable to wind damage as the flat panels, so the whole assembly could be lighter, cheaper, and easier to install.

But more obvious retrospective doubts begin to surface for this stage. Solyndra's PV components were not really the cutting edge of the business as such. In spite of its quality technology development process, a skeptic could observe that at the end of 2010, five years since the founding of the company, about USD 1.5 billion of private and federal funds had gone into building a company whose best product was simplified module brackets (Neilson, 2012, 38)

In addition, by 2010 the company was projecting that it would finally break even in 2013. This means that any big-money returns that had attracted the initial investors (whose identity we don't have) were still far in the future (in contrast to the USD 160 million profit that had been projected for 2008–10 when the company was first raising money) .

Solyndra's Fab 1 was up and running until July 2008. In spite and because of this plant, Solyndra has a Net Operating Loss of about USD 385 million by the end of 2008. Given this number, the DOE loan became the crucial funding source for the construction of Fab 2, which was to produce the volume that would generate the revenue needed to generate profits and start paying down losses.

The process of getting the actual loan took almost three years. By early 2009, as noted above, Gronet was anxious and frustrated. But the loan was delayed in part by attempts to make the Stage 8 analysis of markets and future returns as strong as possible, and thus the vetting process was excruciatingly detailed, iterative, and multilateral.[19] The review was based on accounting data furnished by Solyndra, and the CRO's review found this data to be accurate. In other words, all parties, including the private investors, seem to have had complete and honest information, which was hashed out internally and then repeatedly re-analyzed by reputable outside consultants. The company's technological confidence and sales projections were confirmed in the 2008–09 loan review period by DOE's consultants. In contrast to statements made by politicians, the review erred on the side of excessive thoroughness and caution. In short, the innovation system "worked" as it was supposed to.

The DOE loan to Solyndra became final in September 2009 (It was the first under the Obama Administration's stimulus program, which expanded the Loan Guarantee Program [Section 1705 is added to 1703], which had been started under Bush). 2010 was the company's best year, and in the fourth quarter it produced 16.5 MW or almost 90,000 solar panels. In short, the linear model entered Stage 9, putting an innovative product into the marketplace. To repeat, Solyndra appears to have navigated the linear model from stage 1-9 with real success, and with no worse than the usual setbacks and delays.

Solyndra's Final Phase

Nonetheless, company executives and Loan Guarantee Program Office (LGPO) officials spent most of the year 2010 trying to find new infusions of cash so the company could survive while its losses continue to mount. The DOE loan completion can be seen, in retrospect, as the beginning of the end for Solyndra, and we need to explain why.

2010 was a year of endless correspondence among Solyndra management, the private Lead Investors, and DOE's LGPO in the hopes of attracting additional investment: the CRO report offers interesting details, such as DOE's equity

[19] The Venture Capital and other investment communities frequently refer to the stages of funding that they agree to provide to a company as "Tranches." Thus Tranche C refers to the 3rd batch of funding that the investors might agree to provide. In order for funds in a Tranche to be released, the company must meet certain milestones negotiated with the investor or VC before the original deal is signed.

participation. Overall market conditions negated the company's attempts to access public capital markets and Solyndra instead obtained an additional USD 175.0 million of convertible debt financing. Revenues increased to USD 141.9 million in 2010, but the net loss also increased from the prior year to USD 328.6 million. But the company's cash situation was not fixed by the DOE money. Throughout 2010 it got steadily worse.

The year 2011 was even more direr for Solyndra than 2010, in part because both the LGPO and the Lead Investors were increasingly reluctant to put in new money. The simple reasons were the deteriorating market conditions and Solyndra's failure to meet its sales projections. A major restructuring of both the company and its debt was completed in February 2011, in an attempt to clean things up for new investors. Earlier investors, including DOE, were subordinated in the creation of a Tranche C[20] for the investors that the company continued to seek.

The restructuring effort was in vain. Although production costs fell through mid2011 as Fab 2 geared up, it did not fall fast enough. Tranche C stayed unfilled. In August 2011, the Lead Investors (Argonaut and Madrone Partners) confirmed that they have failed to raise another dime from their partners. DOE announced that, under these conditions, it could not get its partner agencies and overseers to modify the loan terms.

In response, Solyndra fired nearly its entire workforce – or 1100 employees – just before Labor Day weekend. It then filed for bankruptcy on September 6, 2011. Two days later, in a final, dramatic humiliation, the Federal Bureau of Investigation (FBI) conducted a surprise raid on Solyndra's shuttered offices, carting out boxes of documents in full view of the assembled media (Leonnig and Stephens, 2011).

The suspicion of criminal wrongdoing made Solyndra a household world. It also finally placed the American solar industry at the center of public attention—in the worst possible way. The nation was treated to the unedifying spectacle of

[20] Industry also tacitly supports this feature of the linear model because it buries the "government interest" in the firm's existing intellectual property in an early—and commercially valueless–stage of development. An obvious example of this view is the pharmaceutical industry's claims about the billions it spends turning a molecule into a life-saving drug, which minimizes the role of Stages 1-3 in development. Minimizing the role of publicly-sponsored research also sidesteps the fact that industry consumes between 40 and 45 percent of US federal R&D funding (National Science Foundation, Indicators 2010, Table 4-1 http://www.nsf.gov/statistics/seind10/pdf/c04.pdf).

two top Solyndra executives pleading the Fifth Amendment rather than testify at a Congressional hearing (Tracy and Perez, 2011). One wag noted that with solar executives trying to dodge self-incrimination as though they were oil executives, the country might finally take solar energy seriously.

From Success to Failure: The Standard Explanation

In assessing this period, neither the Chief Restructuring Officer nor the US Congressional investigation have turned up any wrongdoing on Solyndra's part. CRO Neilson found that Solyndra's estimates of construction costs were reasonable and accurate, all internal accounting was "materially correct" and effectively identical with the one provided by external auditors, Solyndra's disclosures to DOE were complete and accurate, it spent DOE funds as required, and bonus payments were "within materially acceptable limits"(Neilson, 2012, 3 – 4). Similarly, the six-month Congressional investigation turned up no evidence of criminal wrongdoing or of the alleged undue political influence (Samuelsohn, 2012).

As we have already suggested, reading the full CRO report confirms that Solyndra was generally a well-managed company, its executives were honest and intelligent, and that its administrative processes were of at least above-average quality. It seems to have engaged with the exhausting, frustrating loan application process with both speed and skill. In a critical test of the company's competence, the construction of Fab 2 Phase 1 (based on the DOE loan) came in ahead of schedule and under budget (Neilson, 2012, 14).

The company's forecasts of sales and production costs were consistently inaccurate. But there is no evidence to suggest that the excessive optimism of these forecasts was the result of incompetence, delusion, or deception. Inaccurate financial projections are fairly common in industry, particularly in start-ups. Presumably Solyndra's partners could engage in critical interpretation of these projections, and Solyndra did continuously revise them to respond to new data.

If we cannot take the shortcut of explaining Solyndra's failure through wrongdoing or incompetence, where do we turn? The first of the two dominant interpretations of the linear innovation model, the "no-government" explanation described above, blames the sheer presence of the DOE at Stage 7, who allegedly bent market rules as well as some of its own procedures to support a company that free markets wanted to sink. But there is no evidence in the CRO report, or in any of the voluminous media coverage we have reviewed, to suggest that the DOE's involvement with Solyndra distorted or damaged the company's business decisions. The DOE took about a year too long to process the loan application (see the process summary in Neilson, 2012, 81–98), but as noted above, the delay was in large part due to the thoroughness of the review as it attempted to avoid spending public money on a bankruptcy candidate. Correcting this problem logically entails more decisive government involvement in the solar industry rather than no involvement at all.

Moving to the second dominant interpretation ("early stage public subsidy"), also rooted in the linear innovation model, the exemplary instance is offered by CRO Neilson. He blames a combination of foreign governments (China's) and unforeseeable price gyrations (Neilson, 2012, 10–13). We provide a long extract because of the characteristic nature of this explanation:

> Between the buoyant optimism infused in the filing of the original DOE loan pre-application in 2006 and Solyndra's ultimate bankruptcy filing in 2011, the worldwide solar industry experienced a dramatic shift in market conditions. That shift had a particularly drastic effect upon Solyndra and its business model.
>
> In 2008, during the period in which Solyndra first started to produce modules, the price of polysilicon (a critical component of P-Si modules used by competitors) fluctuated between \$250/kg and \$500/kg depending on the data source, due to a shortage in capacity to refine the element to solar grade quality. Consequently, the high price of production materials for crystalline silicon producers led to a higher average sales price per watt ("ASP") for all solar products throughout the market. . . . However, as the price of polysilicon steadfastly dropped, primarily due to the aggressive entry of Chinese manufacturers into the P-Si market, panel manufacturers using polysilicon were able to reduce the cost and price of their panels substantially, and that single component was no longer sufficient to compensate for the disparity between the prices for Solyndra cylindrical modules and the standard costs of the typical polysilicon panels of flat panel producers. Due to these circumstances Solyndra was compelled to reduce its prices in order to remain competitive. Unfortunately, Solyndra's total costs of production, including materials, did not experience a commensurate reduction, which was devastating.
>
> The entry of Chinese manufacturers into the P-Si market between 2009 and 2011, often with subsidized funds from the Chinese government, resulted in a steep drop in production costs for solar manufacturers utilizing P-Si in their products. Because Solyndra did not rely on P-Si in its thin-film solar technology, the company did not benefit from the price declines associated with P-Si products. Solyndra's cost structure remained unaffected while its competitors, who were producing 80% of the world's solar panels, experienced the beneficial results of the steep P-Si price declines. In addition, Chinese producers had access to capital from the China Development Bank, which

> allowed such producers to move their products to market at a much lower cost than their US or European counterparts.
>
> At the time of Solyndra's entry into the market place, the ASP at which the company could sell its modules was approximately $3.30. Had the price stabilized at approximately $3.30 per watt and the government subsidies remained in place, it is possible that Solyndra might have continued its operations and ultimately, may have become a successful company. Given its unique technology, the company may have had a significant impact on the solar industry. However, Solyndra simply could not survive under the market conditions imposed by the precipitous drop in the ASP at which Solyndra could sell its product. At present, the ASP for solar panels hovers at approximately $1.00 per watt. This rapid drop in ASP was probably the single greatest contributor to Solyndra's failure.

Neilson follows the second type of explanation by treating the arrival of Chinese manufacturers of P-Si and of PV modules as an uncontrollable externality against which Solyndra—and US policy—could take now effective action. In the linear model, government action takes place in a pre-competitive research phase (Stage 2), and offers only limited backup—like loan guarantees—in Stage 7.

This standard explanation implies that Solyndra's bankruptcy does not discredit government involvement which is limited to early-stage public subsidy (Stage 2), but reflects a "perfect storm" in markets that was not controlled—for American companies—by sound government intervention. Table 2.2 adapts the abstract linear model from Table 2.1 to show the conceptual underpinnings of this second of the two standard explanations of Solyndra's problems:

Table 2.2: The Linear Model: Solyndra Example

Linear – Solyndra Example
1. Research goals shaped by curiosity and scientific community
2. Grant applications for incremental public funding on various topics
3. Expert research, probably in "Pasteur's Quadrant"
4. Precompetitive transactions for additional funding involving IP confidentiality
5. Gronet's strong IPR – closed portfolio, trade secrets, in-house manufacturing aims at market domination, and high return on investment (ROI)
6. Company formation--Gronet Technologies (2005) becomes Solyndra (2007)
7. Rounds of angel and VC funding attracted by high future ROI based on "closed innovation" model and supplement of government bridging: DOE loan as signal of technology validity to investors
8. Marketing to static, pre-identified niche – which fails
9. Innovative product lost to bankruptcy

The "early stage public subsidy" view adopts a linear innovation model that limits public participation in an otherwise wholly private development structure to Stages 2 and 7. Stage 7 is extremely modest, and in the current US version is restricted to loan guarantees and other passive forms of support for business models that are already in place. Neilson and other defenders of the Solyndra loan (e.g. Energy Secretary Steven Chu) accept this model. The term "linear" captures this sense that each stage, though it may be prolonged and overlapping, occurs in a regular order that moves forward in time and degree of development. Direct government involvement in R&D is, in this view, pre-competitive (Stage 2).

Unfortunately, the linear model obligates Chu, Neilson, and other adherents of the "early stage public subsidy" perspective to treat as externalities the later-stage public subsidies that damaged Solyndra's business model. It also ignores how these later-stage public subsidies enable other countries to capture a majority market share of a high-tech industry in little more than two years. Of course Chu, Neilson, et al. are well aware of Chinese and Taiwanese industry policy to intervene on a massive scale in stage 7 and everywhere else in the cycle, as necessary. But this industrial policy is not treated as something to which Solyndra could or should have responded, since it was outside of the established innovation practice (what we are calling the linear model). Neilson stays inside the linear model when he concludes with his hypothetical remark, "Had the price stabilized at approximately $3.30 per watt, . . . it is possible that Solyndra might have continued its operations and ultimately, may have become a successful company." But the price didn't stabilize there, and the linear model cannot explain why Solyndra didn't respond more effectively to price drops that were driven by factors outside that model—particularly massive Stage 7 government intervention in China .[21]

We will say more about these issues in subsequent sections. Here we offer two interim conclusions:

1. Even the more positive of the two dominant interpretations–the "early stage government subsidy" model–is linear. It rigidly sequences stages and grants a major role for public inputs *only* in the pre-commercial phase—with a minor role for a handful of firms in a bridging phase. Public sector involvement is strictly limited, and indeed is more limited today than it was during the Cold War.
2. Solyndra complied with this model, and played competently and intelligently by its rules.

[21] Authors' interviews with technical personnel not employed directly by Solyndra.

If we blame either government manipulation of market forces (interpretation 1), uncontrollable market forces (interpretation 2), or company malfeasance and incompetence (refuted by the CRO), we let the national innovation system off the hook.

Solyndra's Errors of Orthodoxy

Solyndra made some crucial mistakes, as we will discuss below. But Solyndra's mistakes were, we will argue, the mistakes built into the innovation system itself. We will focus on three of these.

Intellectual Property Restrictions on Research

Our discussion of Solyndra's "forced errors" is in part a speculative reconstruction: the founding figures are off limits, and the public evidence only goes so far. We base our analysis on our own prior research on the sector, including interviews with scientists and technology managers in related firms and laboratories, and on the unusually extensive public archive on Solyndra. We intend this discussion to provoke further analysis of the limits of the current innovation system for commercializing emerging technologies, particularly in socially and environmentally critical domains like 2nd and 3rd generation photovoltaics.

To start with the most obvious problem, Solyndra suffered from an inability to reduce their high costs of production. The cost gap was actually quite a bit larger than generally realized. During its final 18 months, Solyndra had a manufacturing costs of USD 4.28 per watt, and total costs per watt of over USD 6. Its revenues were on an average USD 2.56 per watt. As prices keep falling for competing modules, the company came to lose nearly USD 4 for every watt it sold.

But Solyndra's costs were so high that the company would not have been competitive even if polysilicon prices had remained high. A report of Department of Energy notes that, "[i]n 2010, the average module price for a mid-range buyer dropped 16%, to $2.36/WP ([peak]w) from $2.82/WP in 2009." (Ardani and Margolis, 2011) If this 16 percent drop had not taken place, Solyndra would have earned an additional USD 0.46 per watt—which would have its losses reduce only somewhat from USD 3.92 to USD 3.46 per watt. The CRO reports that Solyndra was receiving an average of USD 2.56 per watt during this period , which put it in the ballpark for per-watt revenues, and yet it continued to lose enormous amounts of money because of its high costs. To address this loss, the Restructuring Plan of early 2011, whose authors were well aware of the falling market prices for polysilicon modules, addressed cost overruns with a goal of per watt increase of 33 percent from the year 2010 to 2012. Yet even this difficult and impressive reduction would not have put Solyndra in the black.

Why did Solyndra have such persistent problems with higher costs? One central reason is that Solyndra never solved core production problems.[22] These issues reduced yield and lowered the final quality of the product. For example, CIGS deposition is difficult on flat surfaces, yet Solyndra needed to deposit on curves. As noted, we have been told off the record that Solyndra's deposition techniques broke more cylinders than expected, and this issue was never fully resolved. Solyndra's unique technology also required one-of-a-kind production equipment that required large amounts of time to troubleshoot. In brief, the production of CIGS cylinders would have required solutions to a number of problems large and small that were never fully identified or understood in advance.

Such problems are common, but difficult and time-consuming to solve. They occur at the science-technology interface. There are often classic examples of work in "Pasteur's Quadrant," where theory ("Bohr's Quadrant,") and experiment ("Edison's Quadrant") are synthesized in a problem-solving focus that nonetheless requires deep analysis (Stokes, 1997) Solyndra appears to have had solid in-house expertise, access to equipment vendor consultants, and the ability to hire short-term specialists from outside. And yet in spite of this knowledge base, Solyndra needed greater innovation capacity than was available to it.

Stages 1-4 of the linear model Solyndra followed describe a typically complex and lengthy research process that culminates in invention disclosures and patenting. Patenting is generally complemented by trade secrecy; patenting is a form of publishing that many small technology companies now avoid.[23] Solyndra followed the standard practice associated with current regime of "strong intellectual property rights," which means not only that disclosures of technical information were minimized, but that problem areas and challenges were not specified in a way that would allow outside experts to respond as they would in a scientific community. Such communities are riddled with rivalries and secrets, of course, but they are not structured around proprietary information

[22] Authors' interviews in the solar manufacturing sector (authors' records).

[23] We have no smoking gun here – an insider saying we had problem X, person A had something like an answer, but we couldn't hire person A. However this is our point: the loss of knowledge can rarely be identified even in retrospect.

and are free to engage in cooperation where mutually desired, while corporate scientists are not.

Much has been made in recent years of "open innovation" in which companies, realizing they lack sufficient in-house knowledge, leverage their own capacities by seeking out those of related firms, including competitors. But even in the accounts of leading proponents, this version of "open" centers on the strategic disclosure of one's IP so as to create a platform or value-chain that revolves around one's own company's business model and products. The idea is to bind one's competitors to one's own IP: this is not a method in which a firm sends out a technical SOS and its rivals offer aid and assistance for the sake of the overall sector and for the good of mankind (Chesbrough, 2003; Phelps and Kline, 2009). Any technical information that appears to add value to the firm is in this model to be concealed. For a start-up company that is pretty much all the information it has. The potential competition is defined as anybody, and the deep expertise in a region like Silicon Valley is ironically also a drawback, because potential aid is potential theft—and on behalf of a highly competent rival.

In the linear model, Stages 5 and 6, the establishing of intellectual property rights and the accompanying start-up company, wholly or in part sever the company from the scientific *ecosystem* in which the company's technology arose. Individual experts often come along with the company—inventors of particular patents and so on—but they are only the fragmentary pieces of a community of practice that is far deeper and richer than any individual embodiment of that practical knowledge. This gap between the leading individuals and the larger research community becomes important when novel challenges arise. If one knew in advance what one would need to know for the entire 5-year arc of technology development, one could hire experts A through Q and have a reasonable chance of success. But one never knows much of what one will need to know later on, and down the road experts R through Z turn out to be indispensable—who may well be out of bounds given the need to protect the company's IP and trade secrets.

Even when outside experts are accessed mid-way in a start-up company's development, this occurs through a system of non-disclosure agreements and guarded communications that can interfere with basic information exchange. Guarded communications are particularly damaging to the process of knowledge creation, in which disclosure of all core issues, data in all possible details, and discussion of minute anomalies many be important in forming and testing new approaches. They inhibit the "deep collaboration" that might offer novel solutions to complex problems that are rife in companies involved in intense stages of development (Raflos, 2007).

A point-by-point demonstration of this flaw lies beyond our data and scope.[24] But our limited information suggests that key Solyndra operations personnel were unable to reach out when it mattered. It may be overstating the problem to say that Solyndra became stranded on an island of its own secrets. But "stealth solar" had by the time of the bankruptcy already become a running joke among journalists covering the sector, and we have heard many solar industry principals complain about reduced discovery in companies that are under great pressure to commercialize quickly. As one senior scientist remarked about Solyndra, "They needed to be more open."

Reflecting this thinking, we propose a general shift from a linear innovation model to our social innovation model, which we call the Social Innovation of Technology (SIT).[25] We start from the middle of the model.

Company formation occurs in both cases. But under our non-linear model for the Social Innovation of Technology, the start-up firm remains embedded in a research ecosystem with which it continues to share information, problems, and potential rewards for solutions. The firm *does* maintain some proprietary information that is essential for its future business ("I'm not going to spend tens of millions of dollars of my investors' money developing a process that I then give away for free," one of our non-Solyndra interviewees said to us.) But

---

[24] "Social Innovation" has meant different things to different people. In sociology and the history of technology, the Social Construction of Technology (SCOT) approach has been an influential theory and methodology that emphasizes social factors in technological development and adoption; it is thus a response to "technological determinism," which sees technological development as inevitable along a "best path," and sees the social consequences as purely derived from technological advancement(Bijker et al., 1987). While SCOT purports to be purely descriptive, more recently scholars have argued for a form of social technological innovation that builds upon the anti-deterministic theory of SCOT and makes it prescriptive. They argue that the technological development process should be informed by human needs and desires. These scholars emphasize the need for public dialog between innovators and those affected by their technologies(Gill, 1994; Chesbroug, 2003; Mulgan, 2007). This approach emphasizes the desirability of mobilizing our current innovation systems for socially positive goals. We wish to go further and suggest an innovation structure (including public policy, public funding, public participation, intellectual property regime and orientation toward social narrative) optimized for this purpose.

[25] "The challenge for the company was educating prospective customers on the total project cost instead of a narrow focus on the ASP of the modules themselves." (Neilson, 2012, 39)

the scope of secret information is sharply *limited*. No less importantly, company principals think systematically about how company's activity can help preserve the health of the sector's research community, its R&D *ecosystem*. Ideally, a firm like Solyndra would help establish an industry consortium like SEMENTECH in the semiconductor industry that would identify crucial technical challenges, establish roadmaps, set common goals, and structure the scope of pooled information that would not be governed by conventional intellectual property rights and trade secrets. Firms in our social innovation model are less likely to become at least partially trapped in their own stealth modes, as Solyndra seems to have been. Technology development remains rooted in the wider community's ongoing basic research.

Table 2.3: Linear vs. Social Innovation of Technology, Stages 5 and 6

Linear Innovation Model	*Social Innovation Model: Social Innovation of Technology*
5. Gronet's strong IPR – closed portfolio, trade secrets, in-house manufacturing-aims at market domination, high ROI	Weak IPR: Gronet operates in research community, open publication, shared articulation of problems and aims
6. Company formation–Gronet Technologies (2005) becomes Solyndra (2007), in competition with all PV rivals	Company formation–Gronet Technologies (2005) becomes Solyndra (2007), in structured collaboration with all PV rivals

VC Capture

Just as stages 5 and 6 can sever a company in the throes of development and production (Stage 7) from the diverse scientific community, so too they can keep a company focused on objectives defined by and through their investors. In particular, the metrics of venture capital can sever a company from evolving user needs and the social forces in which those user needs are evolving.

This is an issue about which news reports and the CRO commented in some detail. Solyndra's founder, Chris Gronet, attracted venture capital to a sales plan addressed to "knowledgeable middlemen" in the rooftop market who were specialist integrators and installers of non-residential systems in an existing market. Venture capitalists and other investors would have asked all of the questions they are trained to ask: how big is this market now? How quickly is it likely to grow? Who is the competition? How will our costs and prices compare? Who will disrupt our technology? What non-consumers are we going to bring into this market? Once a particular consumer market is identified, VC can be particularly useful at establishing benchmarks, devising metrics, measuring progress, and steering the technology as quickly as possible towards the largest markets.

VC focus is less costly for products with an existing mass consumer base. But how does a company build this kind of market for a PV device? Electricity is a commodity, one that people only think about when it fails. PV panels are also commodities, largely indistinguishable devices that lack intrinsic interest, in contrast to consumer devices like personal computers, smartphones, or tablets, and in contrast to consumer durables that are central to daily life (cars, flat-screen televisions, refrigerators, etc). Even assuming the validity of Solyndra's initial claim that its system would have an installed cost of half that of the existing PV systems, Gronet's operation had enormous work to do to get anyone to care. Electricity was still cheaper to buy from the power company than from an allegedly half-cost untried supplier like Gronet Technologies, which sold a product that, for most people, was no more interesting than a circuit breaker panel.

Gronet and his team apparently took far too long to realize that their focus on selling to system installers was too narrow. They had an important warning sign before them, which was the regularity with which customers signed purchase agreements with Solyndra and then declined to fill them. Gronet's strategy ended only when he is let go from the CEO position, in July 2010. His replacement, Brian Harrison, shifted sales towards a direct approach to Wal-Mart, Target, and other mega-roof owners to start building volume sales. We agree with CRO Neilson's view that this was a good idea that came "too late."

But why did it come too late? Gronet and his management team were intelligent, experienced people whose growing desperation must have made them willing to find new customers with a new approach. In fact, it is relatively common for companies in danger to stick with their knitting while trying to knit faster than before. Management analyst Jim Collins calls one phase in a company's typical decline curve the "denial of risk and peril," and an important feature of this phase is a tendency to blame the firm's difficulties on outside factors (Collins, 2009). It is understandable that Solyndra in 2009–10 appears to have focused obsessively on lowering costs of its existing product, casting a watchful eye on falling polysilicon prices, and constantly addressing investor's concerns about evaporating revenues and future returns. But under these circumstances, technological problems and fading investor confidence can become ever more tightly lashed together under challenging market conditions. Price and cost metrics come to overshadow and in fact stand in for deeper, subtler forms of social "pull."

As an example of the sound of VC metrics, we cite leading venture capitalist Vinod Khosla, who was deeply involved in cleantech investment during Solyndra's rise and fall. In a three-part series written for Greentech Media in June 2010, Khosla laid out his rules

> Any company hoping to compete needs high efficiency at a high yield and low cost in the very near term and a clear path to industry leading costs in the near future. For startups, assume a 20 percent cost disadvantage relative to FSLR [First Solar] when starting up and a 10 to 15 percent decline in costs per year from learning.... Then add fundamental technology cost advantages/disadvantages on top of this "learning curve". If costs are not around $0.80 per watt (fully loaded) in 2010–11 at 100 megawatt scale, then I am suspicious the technology can be competitive. Lower balance of system costs (BoS) may allow a technology to be competitive with a few tens of cents additional module cost but not much more.

Two things are noteworthy about this statement. First, it sets an extremely high performance bar, one well beyond Solyndra or any similar company's capability for the period 2010-11. This can only reinforce an obsessive—and perhaps fatalistic—focus on performance improvements, improvements that in themselves will never be enough.

Secondly, Khosla purges all factors other than price competition. He sees PV as an interchangeable commodity that has no public or social dimension, but only cost rivalries with incumbent companies. There is no social, political, cultural, or user context to situate the cost struggle. There is thus no address to the customer other than as someone looking for lowest cost.

Here's how this issue appears in our table, with the orthodox linear approach on the left, and the social approach on the right:

Table 2.4: Linear vs. Social Innovation of Technology, Stages 7 and 8

Linear Innovation Model	*Social Innovation Model: Social Innovation of Technology*
7. Rounds of angel and VC funding attracted by high future ROI based on "closed innovation" model *and* supplement of government bridging: DOE loan as signal of tech validity to investors	Hybrid of proprietary & open IP support broad, complex research and pooled results in which government is investor and partner
8. Marketing to static, pre-identified niche – which fails	Government procurement supports multiple industry and community development; networks provide continuous user narratives and other inputs on the economic and cultural value of the technology

Orthodox stages 7 and 8 can develop a self-reinforcing feedback loop in which the external market becomes a function of technical problem solving that is in turn driven by the investors' entirely legitimate financial goals. The company took production trouble as an incentive to work even harder to produce those modules for a customer whose prior definition had attracted the original investor funds. Neilson suggests that Solyndra didn't broaden its customer address to explain pricing issues, much less than Solyndra's wider social value.[26]

In contrast, stages 7 and 8 of the social innovation model posits a network of relations among the individual company, government agencies, and customers that support continuous communication and dialog about the social and related aims of the technology and its adoption. We believe that Solyndra would have done better financially had they worked with a "sociological imagination" of the society into which their modules were being sold. This would have involved imagining and addressing a wide range of potential users, including the customers of customers of customers. It would have involved Solyndra presenting itself as a central strategist of mass adoption of solar energy by the big box retail industry, and helping them move away from their contribution to the huge American energy footprint.

This more innovative approach would have brought Costco customers into contact not only with Solyndra marketing personnel inside a store on Saturday afternoon, for example, but with Solyndra engineers and executives.[27] Solyndra might have worked with companies like Costco to educate them on the current state of PV technology, explain carefully and tirelessly why their modules represented an advance, and design a plan for touting its expanded use of solar energy to its customers, based on the existing popularity in the United States of renewable energy (Laird and Stefes, 2009). The CRO report offers no evidence that this kind of a client-engineering feedback loop was even contemplated, much less put in place. CRO Nielson expresses some surprise at the persistence of a narrow marketing strategy through mid-2010, but it can be explained in part by the capture of customer contacts by the investors' financial imperatives.

[26] For an early, influential example of this kind of advice see Thomas and Waterman (1982).

[27] In this context, the dumping complaint brought by the main consortium of the US solar manufacturers was a defensive reaction, and though successful, was opposed by another solar industry consortium (representing consumers of modules) (Bradsher et al., 2012).

Aversion to Industrial Policy and Public Funding

All observers of the state of solar agree on two things. The first is that the rapid growth of the solar industry—57 percent average annual growth since 2000–has been "policy driven" – that is, fueled by government incentives and regulations that have increased adoption (Hoffman, 2012). The different installation rates of Germany and the United States makes the point . In 2010, while Solyndra was struggling mightily, the US installed an additional 878 MW of PV solar (Osborne, 2011). Meanwhile,

> In December alone, Germans installed more than 1,000 MW of solar PV, enough solar capacity to generate 1 TWh of electricity under German conditions. While they represent only half that installed in June 2010, the December installations were 50% greater than total solar PV installed in the US in 2010 and as much as that rumored to have been installed in Japan last year. (Gipe, 2011)

The result is that Germany, with about a quarter the population of the US, *had six times the PV capacity of the US* at the end of 2009. The gap widened to almost seven by 2010 (Anon, 2011). This difference—with German solar installations per capita ahead of the US by a factor of nearly 25—cannot be explained by differences in popular support for solar, but by the presence of strong adoption policies and hard renewable percentage targets in Germany, and their absence, on the federal level, in the United States (Liard and Stefes, 2009).

The second point of agreement is that the solar world was revolutionized after the middle of the 2000s by the entrance of China (and Taiwan) into the production of polysilicon and PV cells and modules. Two simple illustrations: between 2004-2010, China's share of global photovoltaic production grew from 7 percent to 45 percent. During the same period, Germany's share fell from 69 percent to 21 percent. Meanwhile, in California, whose California Solar Initiative was the country's most demanding, Chinese companies had nearly 40 percent of the CSI module market by the end of 2010, with Yingli Green Energy pushing its share from 1.2 percent to 17.5 percent in just one year (Woody, 2011).

China revolutionized the solar industry in just a few years. It did not revolutionize it with technological breakthroughs but with a breakthrough in industrial policy. It used a combination of construction loans with zero-interest and/or forgiven principal to expand the capacity of "secondary" technology at an unprecedented rate. It created a large manufacturing ecosystem, continuous improved production quality, built an industry to export, and then added domestic consumption incentives. By 2011, the largest solar companies in the world were "1st tier" Chinese companies, making cells and modules whose high quality explains their mass adoption in markets in California and Germany. China did this with a "red queen" strategy of building flexible, world-class production capacity in distributed, fragmented production markets (Breznitz and Murphee, 2011). While China does not have a centralized, coherent industrial policy on solar or anything else, the sum total of local government policies in technology development has succeeded spectacularly.

A key difference between Chinese and the US solar policy lay in the type of credit provided. In the US linear system, a company like Solyndra counted on a core group of private venture funds (stages 4-6). Public funding came later, in part as a response to shortfalls in private funding. The private funding was patient for a while, but in the period when patience was most necessary, its patience ran out. Public funding—from the DOE—should have been countercyclical, in the sense that Solyndra's failure to find additional private investors would have triggered public bridge funding to fill the gap. Instead, the DOE echoed the private loss of confidence and pulled the plug in lockstep with the private investors. This was particularly unfortunate, since the loan office had held up the Solyndra funding during a crucial period in the company's life cycle, and had done so in part to insure the accuracy of its positive judgment of Solyndra's technology. After this grueling process, one could expect DOE to stand by its own judgment, and yet it did not.

In contrast, China's policy is in effect that of the strategic investor or patient investor. Funding is provided for wholesale construction and implementation, and although the details of the arrangements are often opaque, a certain amount of forgiveness appears to be a routine. The goal is capacity building. This involves a certain amount of waste and inefficiency—many of China's "third-tier" PV and polysilicon companies are now disappearing, and others may well follow (Wang, 2012). But the cost appears to be acceptable to the governments that have set up the partnerships that create it, presumably because of the results. Having created a market glut and driven down prices, China has created a new public policy to absorb the glut. In 2012, China announced the quadrupling of its 2015 domestic solar installations goals (Bloomberg Editors, 2012).

What has been the response in the United States to this monumental building activity? Effectively nothing. Solar R&D saw some substantial one-time stimulus money at DOE, but virtually all of it took the firm of small-scale, early stage R&D funding in combination with several loan guarantee program like the one we've discussed. Much of the funding went to non-renewable energy. The total amount was never on the scale that could actually change the direction of a USD 1 trillion American industry like energy (Laird, 2009). For the original stimulus figures and analyses, see Rotman (2009). Neither the government, nor industry groups, nor some faction of national political leadership, nor a set of university leaders, took it upon themselves to say that the US would not only lead the transition to renewable energy but would articulate a new set of *public* policies that would make it happen. Some venture capitalists and Silicon Valley titans made major statements about the urgency of climate change and the enormous size of the energy markets, but their focus was on entrepreneurial solutions and not at all on public policy—with the partial exception of calls to increase R&D funding in the usual place in the linear model, back in Stage 2 (Doerr, 2007). See also statements by the principals of the American Energy Innovation Council (2012).

In other words, China built the most sophisticated multi-stage innovation model in recent history, and the US had no effective reply. China has gutted the rejuvenating US manufacturing base in PV (It is now doing the same to Germany's). Meanwhile, frontline US companies like Solyndra made no effort to push the US government, local governments, state governments—anyone who would listen—to develop a positive, infrastructure-building response of similar scope and power. This inaction is all the more remarkable because it hurt Solyndra as much or more than it hurt any other entity.[28]

Conclusion

A comparison between the Linear Innovation Model and the one we are advocating, the Social Innovation of Technology (SIT), looks like this:

Table 2.5: Linear vs. Social Innovation of Technology, Stages 1-9

Linear – Solyndra Example	*Social: a Solyndra that could have been*
1. Research goals shaped by curiosity and scientific community	Government funding expresses social goal-decarbornization via multiple technology pathways
2. Grant applications for incremental public funding on various topics	Grant applications for "moonshot" scale funding that "does a job" society wants done
3. Expert research, probably in "Pasteur's Quadrant"	Expert research, with social as well as commercial goals

Contd.

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Contd.

Linear – Solyndra Example	*Social: a Solyndra that could have been*
4. Precompetitive transactions for additional funding involving IP confidentiality	Precompetitive transactions in full socio-cultural context
5. Gronet's strong IPR – closed portfolio, trade secrets, in-house manuf-aims at market domination, high ROI	Weak IPR: Gronet operates in research community, open publication, shared articulation of problems and aims
6. Company formation–Gronet Technologies (2005) becomes Solyndra (2007), in competition with all PV rivals	Company formation–Gronet Technologies (2005) becomes Solyndra (2007), in structured collaboration with all PV rivals
7. Rounds of angel and VC funding attracted by high future ROI based on "closed innovation" model *and* supplement of government bridging: DOE loan as signal of tech validity to investors	Hybrid of proprietary & open IP support broad, complex research and pooled results in which government is investor and partner
8. Marketing to static, pre-identified niche – which fails	Government procurement supports multiple industry and community development; networks provide continuous user narratives and other inputs on the economic and cultural value of the technology
9. Innovative product lost to bankruptcy	Individual company rests on developed cleantech ecosystem

We are not proposing China as the example of the SIT model. China has, however, adopted many of its features. It takes a "moonshot" approach to a major social imperatives, one whose "job" is abundantly clear (Stage 2). Its approach to IPR is flexible (Stages 4 and 5), to put it tactfully, but the upside is that China very quickly adopts good ideas regardless of their origin and is famously successful with high rates of process innovation (Breznitz and Murphree, 2011). It has a better shot than does the United States at the support of individual companies in a stable manufacturing ecosystem (Stage 9, via Stages 6-8). And it is acquiring other people's expert research (Stage 3) in part by bankrupting them, while it builds its own research capacity.

Low- and middle-income countries are more likely to avoid Solyndra-like disasters and rapidly develop renewable energy industries if they practice social rather than linear innovation. They cannot blindly follow the particular version of social innovation practiced by China, which in any case has many undesirable elements, particularly its political authoritarianism and labor exploitation. But these countries can benefit from avoiding the big three mistakes that we have found in the Solyndra bankruptcy, which are deeply entrenched, systemic preferences in the innovation system for:

1. Strong intellectual property rights at the expense of continuing basic research.
2. Venture capital over strategic investment, particularly public investment.
3. Market forces over visionary industrial policy.

If the Solyndra bankruptcy and its benighted political aftermath can help shift global innovation practice from the linear to the social model, it will not have been in vain.

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