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Accelerating Innovation in Renewable Energy: Recommendations Based on the Case of Silicon Valley

by

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BIOGRAPHICAL SKETCH

Paulo Filipe Amaral was born on February 12, 1983 in California, where he was raised and completed his undergraduate studies in 2004 at California State University, Stanislaus, receiving a Bachelor of Arts degree in Economics and a minor in Portuguese Studies, *summa cum laude*. Early into the program, and given his passion for the environment, he took an interest in ecological and environmental economics. After a variety of professional experiences, including most recently and after a move to Portugal working as a consultant in the banking sector, he decided to go back to graduate school and further his studies in the field of economics for which he still maintained a keen interest, enrolling in the Master of Economics and Environmental Management program at the School of Economics at the University of Porto.

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I dedicate this effort to Tony.

ABSTRACT

Current renewable energy (RE) technologies are insufficient to satisfactorily address the urgent, time-critical concerns of climate change and energy security. Consequently, there has been a surge in global interest in accelerating RE innovation. Yet, substantial problems confront RE innovation. An emerging and highly useful theoretical framework for studying the processes and problems in innovation is *innovation systems*. This framework emphasizes comparisons between real innovation systems rather than abstract ideals. Many regard Silicon Valley as the quintessential example a high-tech innovation system.

Thus, this dissertation synthesizes new insights and recommendations to overcome the problems confronting RE innovation processes from an examination of the processes and determinants of Silicon Valley's success. The study demonstrates that Silicon Valley is a valid and relevant example. Lessons underscore the importance of policy stability and consistency throughout the system, funding models appropriately adapted to the stage of innovation, an increase in the number and quality of points of contact between agents in the system, and the complementary roles of the entrepreneur and collaborative collective in an optimized culture for RE innovation.

Keywords: Renewable energy, Innovation Systems, Silicon Valley

RESUMO

O estado atual das tecnologias de energia renovável (ER) é inadequado para dar resposta às urgentes preocupações sobre as alterações climáticas e a segurança no abastecimento de energia. Consequentemente, tem havido um aumento no interesse global em acelerar a inovação em ER. No entanto, significativos problemas confrontam o fluxo de inovação em ER. Uma abordagem emergente e altamente útil para estudar os processos e problemas da inovação é sistemas de inovação. Esta abordagem enfatiza comparações entre sistemas de inovação reais ao invés de ideais abstractos. Muitos consideram Silicon Valley o ex-líbris de um sistema de inovação de alta tecnologia.

Assim, a presente dissertação apresenta e produz novas perspetivas e recomendações para superar os problemas que confrontam os processos de inovação em ER, com recurso à examinação dos processos e determinantes do sucesso de Silicon Valley. O estudo demonstra que Silicon Valley é, de facto, um exemplo válido e relevante. As lições retiradas sublinham a importância da estabilidade e consistência de políticas em todo sistema, dos modelos de financiamento adequados ao estado da inovação, do aumento na quantidade e qualidade dos pontos de contacto entre os agentes no sistema, e dos papéis complementares do empreendedor e do coletivo, numa cultura otimizada à inovação em ER.

Palavras-chave: Energia renovável, Sistemas de inovação, Silicon Valley

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1. INTRODUCTION

The voracious consumption of fossil-based energy has fueled our global prosperity for more than two centuries, but has also outstripped earth's absorptive capacity, raising the specter of climate change. Crucial to meeting climate change mitigation objectives, while ‘keeping the lights on’, is the development and deployment of renewable energy (RE) to substitute fossil-based energy production. More than timely, it is urgent that we redouble efforts to add to the body of knowledge that might guide and foster conditions for the acceleration of innovation in RE systems.

By the end of 2010, concentrations of CO_2-equivalent[1] (CO_2-eq) had reached 390 ppm, 39% above pre-industrial levels. The IPCC Fourth Assessment Report (2007) concluded that most of this change is “very likely” the result of increases in anthropogenic greenhouse gas (GHG) generation. Baseline scenarios (‘business as usual’) place the rise in mean global temperatures by 2100 to between 1.1°C and 6.4°C over the 1980 to 1999 average (IPCC, 2007b, IPCC 2012). While the long-term consequences of climate change are poorly understood, its projected impact to earth’s biological systems as well as our human economies is sobering. As with most things, the consensus is that the sooner we act, the less costly it will be to meet climate change mitigation objectives and attenuate adverse consequences. To that end, and in order to limit this temperature increase to between 2°C to 2.4°C, GHG concentrations must be stabilized in the range of 445 to 490 ppm CO2-eq (IPCC 2012).

Electricity generation from fossil fuels accounts for a significant portion of these emissions[2]. Lifecycle GHG emissions from RE technologies are significantly lower than those of fossil fuels, with median values for all RE ranging from 4 to 46 g CO_2-

[1] CO_2-equivalent is a *“standard metric for comparing emissions of different GHGs but does not imply the same climate change responses”. “GHGs differ in their warming influence (radiative forcing) on the global climate system due to their different radiative properties and lifetimes in the atmosphere. CO_2-eq emission is the amount of CO_2 emission that would cause the same time-integrated radiative forcing, over a given time horizon… The equivalent CO_2 emission is obtained by multiplying the emission of a GHG by its Global Warming Potential (GWP) for the given time horizon”*, often 100 years (IPCC 2007a).

[2] For example, total U.S. energy-related emissions of carbon dioxide (CO_2) by the electric power sector in 2011 were 2,166 million metric tons, or about 40% of total U.S. energy-related CO_2 emissions. Of these 40%, coal was responsible for 79% and natural gas for 19% (U.S. Energy Information Administration).

eq/kWh, while those for fossil fuels range from 469 to 1,001 g CO_2-eq/kWh (excluding land use change emissions). Capacity-wise, RE could displace fossil generation, as total global technical potential[3] for RE is substantially higher than present and projected global energy demand. Thus, RE possess clear GHG emission mitigating potential[4]. By substituting much of fossil-based generation capacity with RE, and, furthermore, largely transitioning transportation from combustible fossil fuels to cleanly generated electricity, it is possible for the global economy to transform itself into a low-carbon economy (IPCC 2012). Additionally, while renewables are typically an intermittent energy source, the parameters of production are known such that, as part of a portfolio of strategically placed installations throughout the state (or integrated states) tied into a national (or supranational) grid, RE could offer a reliable source of energy at stable, know factor prices, itself invaluable to business planning and economic growth.

Nevertheless, persuasive reasons for pursuing renewable energy extend well beyond climate change concerns. Indeed, the promise of a "green energy economy" has become itself a political platform, touting economic renewal and job creation "for the 21st century". The prospect of renewables-derived electricity reducing dependence on oil in transportation – and eventually supplanting it – would significantly lessen exposure to the cost risks inherent in procuring this globally bid-up primary energy from politically unstable regions of the world. This would also, of course, mean reduced currency outflows for importing nations and so an improved current account balance, with that money benefiting the domestic economy. However, for oil exporting countries, this would also help support a responsible management of their exhaustible resources. Additionally, even if GHG mitigation were not an objective, demand for RE is projected to continue to grow. Here also, investing in the innovation of RE technologies

[3] Technical potential in this context is *"the amount of RE output obtainable by full implementation of demonstrated technologies or practices"* (IPCC 2012).

[4] Four illustrative IPCC (2012) scenarios *"span a range of global cumulative CO_2 savings between 2010 and 2050, from about 220 to 560 Gt CO_2 compared to about 1,530 Gt cumulative fossil and industrial CO_2 emissions in the IEA World Energy Outlook 2009 Reference Scenario during the same period"*; that is, up to more than 1/3 avoided emissions.

offers a tremendous economic opportunity through the export[5] of technology, related services, and manufactured durables.

However, current *RE technologies are inadequate* to fully meet the challenges and realize the potential benefits (OECD 2011, Bonvillian and Weiss 2009). *Innovation*[6] *is needed*. Further, the innovation process is time-critical, whether we consider the time constraint is planetary (climate change mitigation), policy-based (standards), or market-based (first-to-market, competitive advantage). Thus, *accelerated innovation is needed*. To accelerate innovation in RE, we must understand the processes of innovation itself, where and how it arises, and what problems obstruct its dynamic in RE.

Competitive advantages and innovation capabilities are heavily localized, making the region the appropriate level to study industrial organization and innovation activity (Yu and Jackson 2011). With regard to industrial organization[7], Porter's (1990b) clusters have become a useful reference. As to the specific study of innovation activity, the innovation system (IS) approach is an emerging and highly useful conceptual framework that regards the whole innovation process as *systems*-oriented, emphasizing the interdependency of the agents involved. This approach also emphasizes empirically based "appreciative" theorizing, rather than formal theories, to 'capture processes of innovation, their determinants, and some of their consequences in a meaningful way' (Edquist and Hommen 1999:66).

Silicon Valley is assuredly the world's preeminent empirical model of an accelerated, effectual, and efficient innovation system / high-tech cluster; innovation that serves as the foundation of a truly dynamic and vibrant regional economy. While many comprehensive and thoughtful efforts have been made to understand the reasons for the success of Silicon Valley – often with the goal of guiding efforts to replicate this success in similar technology clusters – the aim of this dissertation is to examine the Silicon Valley experience for its processes and determinants; for guidance in addressing the problems confronting RE innovation systems, and thereby promote robust RE

[5] Most IPCC (2012) RE deployment scenarios show total RE deployment is higher over the long term in non-Annex I countries than in Annex I countries in most scenarios.
[6] Herein, innovation refers to *invention implemented*; ideas successfully brought to market.
[7] Many approaches have evolved to study the dynamic of the regional economy and its innovation activity, and it is important to understand these antecedents, as the literature review shall explore.

innovation systems with high success probability.

The methodology employed is a qualitative, critical analysis of the Silicon Valley experience – with recourse to the essential concepts in the innovation process, namely the forces of industrial clustering and the framework of innovation systems, and their antecedents – to thus synthesize new insights and recommendations to overcome the problems confronting RE innovation processes; thereby, promoting robust and efficient loci of RE innovation.

The dissertation is organized as follows. Section 2 contextualizes and conceptually equips the discussion with a survey of the literature regarding the progression of thought on the economics of concentrated, specialized regions, their competitiveness, and the innovation activity within them; from Marshallian agglomeration economies through to localized innovation systems. Section 3 explores the factors and characteristics critical to the success of the Silicon Valley innovation system. Section 4 analyzes the systemic problems plaguing RE innovation systems. Section 5 briefly discusses the findings and concludes.

The main conclusion presented is that the Silicon Valley model is indeed relevant and can be looked to for concrete guidance in addressing the systemic problems confronting RE innovation systems. Lessons underscore the importance of policy stability and consistency throughout the system, funding models appropriately adapted to the stage of innovation, an increase in the number and quality of points of contact between agents in the system, and the complementary roles of the entrepreneur and collaborative collective in an optimized culture for RE innovation.

2. LITERATURE REVIEW

At a time when we reflexively raise the efforts of enterprise to a global scale, invoke global value chains, and tout the dissemination of communication technologies as de-leveraging the advantages of physical proximity, the role of nations, let alone regions within nations, may seem comparatively unimportant or surpassed in its timeliness. Nevertheless, in firms' ceaseless endeavor to innovate, gain and sustain advantage, the role of location is, as Porter (1990b) points out, always crucial. Paul Krugman (1996) likewise centers on the importance of the regional economies, as opposed to national economies or global companies, as the driving centers of economic activity and wealth creation within the global economy – the 'localization of the world economy'.

Likewise, the process of innovation – especially in high technology – only atypically takes place in isolation. Rather, a myriad of interdependent agents – scientists, researchers, investors, specialized suppliers, producers, etc. – engaging in both market exchanges and non-market knowledge and influence flows, are indispensible to this complex and necessarily concerted activity. Moreover, these exchanges and flows are not unidirectional, but characterized by a multiplicity of learning interactions and feedback loops[1]. Further, these agents interact in a context of established institutions such as laws, rules, regulations, norms, and shared culture.

The conceptual framework that best captures these systemic processes and relations– and so too provides the best instrument for understanding the problems obstructing innovation dynamics – is the emerging conceptual framework of *innovation systems*[2] (Edquist and Hommen 1999, Saxenian 1994). Highly effective innovation systems are characterized by *localization* and so are often approached as *regional innovation systems*, wherein the process of innovation finds its critical mass of agents (Yu and Jackson 2011).

While the dissertation most avails itself of the conceptual framework of innovation systems to study the problems confronting RE innovation, antecedent as well as current

[1] E.g.: consumers engaging with suppliers on product specifications.
[2] Alternatively: systems of innovation.

complementary approaches provide highly useful concepts and insights into the forces and process underpinning economic concentration and the innovative activities therein. The following subsections examine traditional agglomerations economies, through to likewise production-cost driven but more complex modern approaches and clusters, and into networks and systems-oriented frameworks.

2.1 Traditional theories: external economies and agglomeration

Traditionally, regional development and its supporting policies have been approached through the concept of *external economies*. This consists of looking at the productive factors lying outside the individual firm. These 'external economies' are, quite simply, the 'benefit from sharing the costs of common external resources such as infrastructure and services, skilled labor pools, specialized suppliers, and a common knowledge base'. When these factors of production become concentrated in a given geography, or region, the additional benefits of spatial proximity are referred to as *economies of agglomeration*. Once established, the presence of external economies creates a self-reinforcing advantage (Saxenian 1994).

When studying modern economic agglomerations we are in essence studying the ancient, primary organizing principle of society: fragmentation and assignment of roles, or, if you will, specialization and division of labor. While the benefits and efficiencies arising from such organization have long been implicitly understood, Adam Smith is, of course, responsible for the first modern, explicitly economic discussion of this organizing principle, and the wealth it produces by virtue of the gains in productivity and economies, or savings. It is also interesting to note, if in passing, that Smith's characterization of the economic relationship between the city and the country is perhaps more closely aligned to the recent framework of Porter's (1990b) clusters than were the observations of any other economist for two hundred years (Phelps and Ozawa 2003).

Nevertheless, it was Alfred Marshall through his *Principles of Economics* published in 1920 that became the 'father' of the study of industrial organization by producing the now-familiar, original **trinity of external economies**: *labor market pooling*, *inter-firm linkages*, and *technological spillovers*. He explicitly contrasted the "subdivision of functions, or 'differentiation'" in industry with the "integration" that followed; that is, *"a growing intimacy and firmness of the connections between the separate parts of the industrial organism"* (Marshall 1920:241). Thus, he distinguished between *internal economies* within firms, and *external economies* arising outside the firm from the localization of industry (*Ibid.* 266).

In his *Principles,* Marshall first offers a brief historical perspective on the factors of primitive localization[3] and then centers on the agglomeration-reinforcing factors of the three external economies. The principal external economy regards labor, for *"so great are the advantages which people following the same skilled trade get from near neighbourhood to one another"* (*Ibid.* 271). Access to the pooling and availability of specific, skilled labor is a significant advantage to the employers in that industry. From here we begin to see the ever-greater subdivision of work as "subsidiary trades" grow up to supply "implements and materials" to the primary localized industry[4]. Interestingly, he also discusses the advantage of inter-firm mobility[5] afforded by a concentration of like labor – greater ease in breaking off existing associations to form new ones.

Within what we may again refer to as the 'primary' localized industry, another force is in play, a truly impressive force: innovation. Marshall discusses this process as arising from the ether of the external economy, called 'technological spillovers', in the form of non-rival knowledge diffusion. Innovation exists, for in localized industries "the mysteries of the trade become no mysteries; but are as it were in the air" and among the operators of knowledge *"inventions and improvements in machinery and processes and the general organization of the business have their merits promptly discussed: if one man starts a new idea, it is taken up by others and combined with suggestions of their*

[3] Primitive factors include the kinds of resources available in the environment, with family groups operating a family business linked to these resources morphing into villages operating a village business; and later their establishment by royal patronage *in situ* or at another desired location.
[4] Today these are referred to as specialized, or specialty, suppliers. Their importance in innovation systems and in the rise of Silicon Valley shall be noted further on. Among the benefits they produce in the system is a lowering of barriers to entry by supplying specialized equipment that would otherwise have to be produced in-house by large, established firms.
[5] Fundamental to the recombination of ideas and talents, catalyzing invention and innovation.

own; and thus it becomes the source of further new ideas" (*Ibid.* 271). The importance of interaction between the operators of knowledge to 'demystify the mysteries' is clear, and it is possible to infer the role labor mobility and personal and professional networks or linkages in the diffusion of knowledge, which in turn upgrades the competencies of the whole. Also, Marshall implicitly discusses how "good" and "bad" innovations are distinguished. Peers recognize the value of good, or advantageous, innovations, and select these for adoption. Later, they may themselves become innovators upon selected innovations. Marshall indicates a clearly collaborative innovation process. Ultimately, of course, the merit of innovations is determined by success in the market.

2.2 Modern production-cost approaches

Wood and Parr (2005), in discussing the production-cost forces of agglomeration, describe three classifications: scale, scope, and complexity. Each form of agglomeration economy can be both internal to the firm, or exist as externalities. Within a firm, *economies of scale* (economies of horizontal integration) refers to the fact that the marginal cost of production decreases as a function of quantity; *economies of scope* (economies of lateral integration) refers to the fact that the cost of producing two or more products in conjunction within a firm is lower than the cost of producing them in separate firms; *economies of complexity* (economies of vertical integration) refers to a lower final product production cost to the firm when it itself undertakes the various upstream processes necessary to its production rather than if these were undertaken by other firms, contracted in the market.

External to the firm, *scale* refers to the Marshallian advantages of skilled labor pooling (e.g.: availability, reduced cost) and possibility of information spillovers; *scope* refers to when unrelated industries share and benefit from a common infrastructure and access to specialist services not specific to any one industry[6]; *complexity* refers to when *"firms are linked in input-output terms and co-located so as to form a production complex, this co-location resulting in lower production costs"* (*Ibid.* 3). Running parallel to internal

6 For example, in Silicon Valley and similar clusters, access and costs are 'shared' to the key support services of venture capitalists, law firms, accountants, specialized marketing agencies, etc..

agglomeration economies, these external economies of scale, scope, and complexity, when spatially constrained, form the bases of agglomeration economies of the localization, urbanization, and activity-complex types (Parr 2002).

McCann (1995), while still focusing principally on production-cost factors of agglomeration, redirects from Marshallian external economies *per se*. He identifies four types of spatial costs that together determine the economies or diseconomies of agglomeration for a firm or group of firms: *distance-transaction costs* (based on the input-output production function, this includes transport/shipping costs, telecommunications costs, and inter-firm executive travel); *location-specific factor costs* (again, based on factor input costs in the neo-classical production function); *hierarchy-coordination costs* (the need for face-to-face contact with other firms and/or customers for negotiation and coordination of activities). These costs diminish the savings benefits obtained by locating elsewhere with lower factor costs. McCann specifically cites the electronics industry as a prime example, as property, salary and other factor costs are typically lower outside high-tech agglomerations, but whose benefits are diminished by the spatial costs imposed by locating away from the hub of activity. The final cost is *hierarchy-coincidence opportunity costs* (the one demand-side factor McCann identifies, which essentially means firm proximity to market). McCann's distance-transaction costs and location-specific transaction costs drive agglomerations of complexity as described by Parr.

Let us step back slightly with regard to McCann's third point, hierarchy-coordination costs, and think of agglomeration within the firm itself. According to Ronald Coase's (1937) milestone work on the nature of firms, economic activity is centered within a firm when the transaction costs of coordinating production through the market are greater than they would be within a firm. Approaching Coase's concept conversely, the concept of transaction costs has become central to the analysis of economic agglomeration. Co-location reduces inter-firm transaction costs and allows for more steps of the production process to move outside the firm and into the market.

Transaction costs are *"the costs associated with the execution of a transaction, including the opportunity cost incurred when an efficiency-enhancing transaction is* *prevented"* (Milgrom and Roberts 1992:604 in Wood and Parr 2005). Such costs accompany both inter-firm (market) and intra-firm (hierarchy) interactions and include costs associated with determining terms (e.g. price) and costs of coordinating and transmitting information (also termed coordination costs) (Wood and Parr 2005). Hence, economic agglomerations beyond the firm make sense when the economic benefits of reduced inter-firm transaction costs arising from spatial proximity become sufficiently attractive to constitute a determining factor in firm location.

Similarly, Stigler (1951) and more recently Enright (1995) have discussed how the reduced transaction costs associated with the spatial concentration of interrelated economic activities can provide firms with an alternative to reliance on in-firm hierarchical structures[7]. Enright (1995) cites how firms located within a geographic cluster exhibit lower levels of vertical integration than those lying without. This is primarily due to the increased effectiveness (and reduced cost) of the external coordination mechanisms (e.g.: spot markets) available to firms and their coordinating agents, allowing for a greater variety of organizational forms and mechanisms, leading to at-times indistinct firm boundaries[8].

Regarding firm boundaries, Enright (1995) cites the examples of how a single wool textile can pass through five or six firms before it is finished in Prato, Italy, or the hundreds of small firms in Solingen, Germany, that perform a single step in the cutlery production process. Enright also discusses how small, disintegrated firms respond more quickly to incremental changes in technology. Consequently, they are better positioned to take advantage of new technology[9]. Localization also reduces opportunistic behavior, as the news of such behavior is rapidly spread to other firms who then withdraw from and punish the opportunistic firm[10]. Increased levels of cooperation among co-located

[7] Enright (1995:106) also cites external economies in *"access to knowledge of the complex material transformation process and specialized suppliers"*, or access to a proficient labor pool and specialized suppliers. He also notes how *"in many cases suppliers and equipment manufacturers work closely with their local customers to develop and improve products"* and may then *"receive exclusive use of the ideas, inputs and equipment, at least for a short period of time"*. All of these observations are also true for Silicon Valley.
[8] Very much the case in Silicon Valley, with what Saxenian (1994) describes as porous firm boundaries.
[9] Very much the case in Silicon Valley, with its hundreds of nimble, specialized suppliers.
[10] This factor may be less critical nowadays given the ubiquity of firm information online.

firms are also observed, such as bulk purchasing, joint training programs, and industry-specific infrastructure investments.

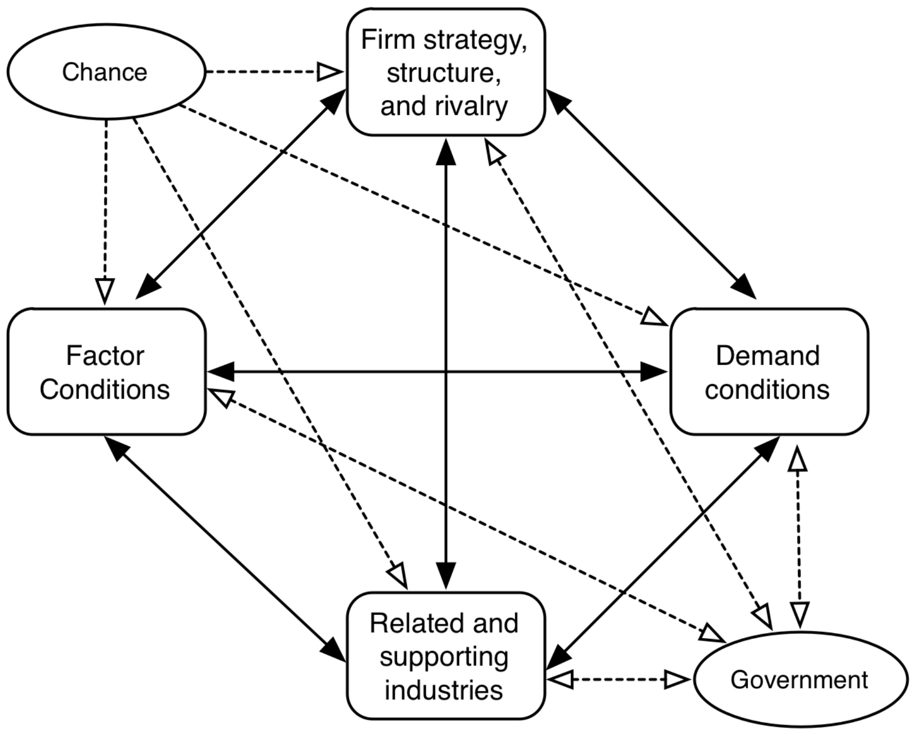
Building on McCann and Enright's emphasis on coordination, or transaction costs, Parr (2002), later joined by Wood and Parr (2005), also discusses the spatial dimension of transaction costs, introducing the concept of *transaction space*. Transaction space approaches transaction cost from the point of view of socio-economic and institutional heterogeneity as it relates to geographic space. Heterogeneity of transaction space refers to the generally increasing differences in language, culture, law, commerce, and institutions confronting transacting agents. Transaction costs decrease, of course, as we approach perfect homogeneity of transaction space. This encourages agglomeration for functions where transactions are highly complex, requiring effective and frequent face-to-face communication, and where product change is frequent, production runs are short and there is high contract turnover; this is very well illustrated by the high-tech production and innovation processes. Routine, low-complexity functions, supported by improved communication technologies, can relocate to low-cost locations over heterogeneous transaction space. The clear implications of this approach on innovation and innovation policy shall be discussed ahead.

2.3 Clusters

The now-common term *cluster*, introduced by the celebrated authority on competition Michael Porter in 1990, is essentially a business term for what economists have long referred to as *agglomeration economies*. Porter (1990b) defines clusters as the amalgam of interconnected firms, suppliers, related industries, and specialized institutions that exist together in a given location. However, Porter distinguishes between the two in that clusters relates the observable phenomena of agglomeration to international competition and strategy.

While Porter generally refers to "national advantage", he is explicit in that the processes of developing competitive advantage are *localized.* He underscores the fact that while *"true competitive advantage in sophisticated industries arises from the ability to create* *and deploy highly specialized knowledge and skills - to deploy labor and capital, and other resources in efficient and imaginative ways"*, its development *"is a localized process, strongly influenced by local institutions, local values, local culture, local history, and local economic conditions"*. Furthermore, whatever of the dimensions of any multi-national enterprise, each must have a home base *"from which emanates the impetus, energy, and insight to improve and upgrade"* (Porter 1990a:190).

Figure 1: Porter's Competitive Diamond Model.



Source: Porter (1990b).

Porter conceptualizes his framework with his Competitive Diamond Model, which demonstrates the relationships between the four determinants of advantage. These are 1) Factor conditions, 2) Demand conditions, 3) Related and supporting industries, and 4) Firm strategy, structure, and rivalry. Taken together, these determinants create a self-reinforcing system that provides both the *resources* to operate and the *pressures* to invest and innovate. To these central determinants, Porter recognizes and adds the not-inconsequential factors of chance and government intervention. Chance is, of course, any shock to the system outside the power of firms to control, such as "pure invention", shocks to demand and supply, actions of foreign governments, wars, etc. Government, for its part, can exert positive or negative influence on the diamond in the form of subsidies, capital market policies, education policies, and, of course, as a significant buyer of goods and services. Ultimately, particular industries will succeed when they exist within a challenging environment that forces them to upgrade and increase their advantages progressively over time.

2.4 Networks and innovation systems

Another interesting approach, quite relevant to our analysis of Silicon Valley, has been to study cluster dynamics and success through the lens of human networks. Regional network-based industrial systems are built around horizontal networks of firms. In such networks, producers specialize, deepening their technical capabilities in particular technologies while maintaining close, but not exclusive, relationships with other specialists – suppliers, skilled contract labor, etc. – who for their part also specialize. Repeated interaction between a multiplicity of agents builds shared identities and mutual trust and reinforces community rules and norms, while simultaneously stoking healthy, competitive rivalries that spur innovation (Saxenian 1994).

The network-based approach aligns well with another important current in the analysis of innovation within an agglomeration or cluster: the concept of *regional innovation systems*, which is simply a regionally focused approach to *innovation systems* (IS).

Developed by authors such as Edquist and Hommen (1999), on the pioneering work of Freeman on national innovation systems in the late 1980s (Foxon *et al* 2005) and greatly advanced by Lundvall (Rutten and Boekema 2007), *innovation systems* is a *systems*-oriented approach to the process of innovation. The traditional *linear* view of technological innovation conceives of a unidirectional flow from basic research to commercial applications that satisfy market needs; this is not a very useful approach, as it does not describe what is empirically observable. In contrast, and at its core, systems perspectives emphasize the interdependencies and interactions between users, producers, and other agents – and their institutional and cultural context – who, through a process of continuous and multilateral engagement in both market exchanges and non-market knowledge and influence flows, together determine the direction and result of innovation. Interactive learning[11] and evolutionary theories[12] shape the framework.

Many, including the OECD, EC, and current Obama administration, have extensively used this approach to study the performance of an economy's innovation processes, identify system problems and provide bases for policy action (Foxon *et al* 2005, Yu and Jackson 2011). The *regional innovation systems* approach recognizes the critical importance of the spatial proximity of related firms and favorable, homogenous institutional structures for successful, accelerated innovation. This concentration of interdependent agents facilitates knowledge spillovers and stimulates adaptation, learning and creation, making the regional level the most appropriate at which to design and implement policies that promote innovation (Yu and Jackson 2011, Rutten and Boekema 2007).

Innovation systems stresses comparisons between real systems rather than against an abstract, ideal system[13]. For its holistic and realistic approach to the innovation process, this concept and this empirical comparison approach will be central to this dissertation's consideration of the problems facing RE. The empirical system that will serve as the basis of comparison is the peerlessly successful innovation system of Silicon Valley, which is characterized by interdependent and densely networked individuals, firms, support institutions, and centers of research, thriving in its uniquely open, entrepreneurial, risk-accepting and failure-tolerating culture.

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[11] Interactive learning theory emphasizes user-producer interaction in the innovation process. It holds that price signal communication does not inform producers about user needs not already served by markets. Non-market, qualitative user inputs are necessary. This is especially true of markets – such as high tech – where products are complex and change rapidly. As we shall see, this certainly characterized the Stanford – Firm and Firm – Military interaction in Silicon Valley. Finally, it is noteworthy that a major concern in the theory is that established "knowledge structures", originally necessary to the process, can later become sources of inertia and resistance to change (Edquist and Hommen 1999). A similar concern is expressed by Enright (1995) regarding agglomeration economies, and by Negro *et al* (2012) and Parrish and Foxon (2009) regarding incumbents in energy technologies innovation.

[12] Evolutionary theory views technological change as an open-ended and path-dependent process where certain mechanisms introduce novelties into the system, and other mechanisms then select from the diversity. Technologies that 'survive' are *"superior in a relative sense, not optimal in an absolute sense, and – contrary to standard economic theory – the system never reaches a state of equilibrium"* (Edquist and Hommen 1999:68).

[13] See points four and nine in Annex 1.

Important efforts to explore the success of Silicon Valley include Saxenian's (1994) comparison between Silicon Valley and Route 128 in *Regional Advantage*, the collections of academic essays edited by Kenney (2000) in *Understanding Silicon Valley* and by Lee *et al* (2000) in *The Silicon Valley Edge*, as well as several other academic papers such as Isaak (2009), Sternberg (1996), Wonglimpiyarat (2006), Gray *et al* (1998), among others.

This literature review has highlighted the forces that promote the spatial concentration of economic activity, and how that concentration of different but related agents is critical to the innovation process. Most approaches are cost-driven, whether they be Marshall's (1920) agglomeration economies where firms seek to benefit from external economies – the sharing the costs of the external resources of infrastructure and services, skilled labor pools, specialized suppliers, and a common knowledge base; Wood and Parr's (2005) classification of economies of scale, scope, and complexity; McCann's (1995) link between distance and transaction costs; or Enright's (1995) direct relationship between the heterogeneity of transaction space and coordination costs. Porter (1990), of course, helped us appreciate the determinants of advantage and relationships between interconnected agents of economic and innovative activity. These insights – particularly those of Marshall and Enright – taken with those of networked and innovation systems will be useful to both understanding and relating Silicon Valley and RE innovation systems.

3. THE SILICON VALLEY MODEL

Silicon Valley is assuredly the world's preeminent example of a high-tech innovation system, whose truly vibrant and prosperous[1] regional economy is supported by the generation of accelerated, effective, and efficiently produced innovations that disrupt existing markets and create entirely new markets with startling regularity.

Figure 2: Silicon Valley and Environs.

Source: Saxenian (1994).

While the term "Silicon Valley" is sometimes rather loosely employed to refer to an indistinctly delimited portion – or all – of the San Francisco Bay Area, or, variously, its technology industry activities, mindset, lifestyle, work ethic or culture, Silicon Valley

[1] Per capita real GDP by Metropolitan Area for Santa Clara – Sunnyvale – San Jose, which corresponds to Silicon Valley, was $90,959 in 2010 (in chained 2005 dollars), the highest in the nation. The corresponding average of all U.S. Metropolitan Areas was $45,557 (BEA). Moreover, this figure continues to rise (Wonglimpiyarat 2006).

does have a generally accepted – though not formalized – geographic delimitation. Lying along the southwestern portion of San Francisco Bay in Northern California and hemmed in by the Santa Cruz Mountains of the Coastal Ranges to the southwest and the Diablo Range to the northeast, Silicon Valley comprises roughly 1,500 square miles, spreading north from its historic center in Palo Alto to San Mateo County and south to Santa Clara County (Saxenian 1994; Kenney 2000).

While it is a physical, geographic region, the Valley is also an industrial district, in the Marshallian mold, a cluster, in Porter parlance, and an innovation system, in emerging insights; however one chooses to label or approach it. Whatever the choice, the Valley's edge arises from factors constituting an environment – framework, if thinking functionally, habitat, if thinking biologically – comprehensive in breadth and optimized to detail for innovation, development, and there-upon-built entrepreneurship. The development of this celebrated environment is highly path-dependent – owing to and conditioned by preceding decisions and events – having evolved largely organically over time and through successive waves of technological innovation; though the Valley does, in fact, owe a great deal to certain external interventions – significantly, government contracts, and some key interactions with the established east coast electronics industry. (Henton 2000, Kenney 2000, Lee *et al* 2000:2-4). Though the Valley's development owes undeniably to a unique time and context-dependent history that cannot be duplicated, valid and practical lessons can be gleaned from an analysis of this innovation system to address the problems confronting existing RE innovations systems.

As discussed above, the development of the Valley is heavily path-dependent. Thus, we shall break out our analysis of the innovation system into a two-strata model:

1) *foundational factors*, which are essentially important historical interactions between key institutions and the respective relationships that evolved and initiated the process of agglomeration; and
2) thereupon-built *reinforcing forces and characteristics* that turbo-charged the Valley's growth.

If in the foundational stratum we are to reduce the birth of the Valley to two causal factors, they are **Stanford University** and the **United States military** in the fist decade of the 20th century. From these, we can abstract the factors *knowledge / know-how* (and know-how supply) and *demand*. Further parsing reveals specific reinforcing dynamisms within these factors, such as the supply of basic R&D, a pivotal leader, adult education of firm professionals, and startup firms on the supply side; and massive, exacting, and sophisticated military procurement and policies such as cross-licensing and second-sourcing on the demand side.

Transitioning out of this ‘inception’, we have in the second stratum the reinforcing factors of support institutions, networks, culture, spinoffs / startups, as well as continued firm-university cooperation, and continued military contracts – which largely underwrote and fundamentally shaped the evolving phenomenon of the Valley.

The first stratum is approached in chronological fashion with the second stratum approach evolving to a more point-by-point consideration of factors and characteristics.

3.1 Foundational factors – Stanford University and the U.S. military

When attempting to understand phenomena, we reflexively turn to its etiology in search of original causation to thus parameterize – excluding the preceding considered immaterial – and thereby focus and refine our study. This is an ungrateful process. Nothing spontaneously appears in time without in some way owing to an event before itself. Nevertheless, it is useful in terms of study to – while discussing prologue insofar as it is legitimate and reasonable – identify a ‘beginning’.

If in this foundational stratum we are to reduce the birth of the Valley to two causal factors, they are Stanford University and the United States military in the fist decade of the 20th century. From these, we can abstract the factors *know-how* and demand, within which further parsing reveals specific reinforcing dynamisms. From this relationship spawned the first firms in what would go on to become the Valley’s backbone and prototype of accelerated innovation and economic growth based on a close cooperation between Research University, Industry, and Military.

While many traditionally consider the birth of Silicon Valley to be the founding of Shockley Semiconductor in 1956 or the earlier 1939 partnership between William Hewlett and David Packard, it would be more accurate to, as Timothy Sturgeon (2000) argues in his fine early-Valley history, retreat further back in history to the founding of the Federal Telegraph Corporation (FTC) in 1909. This is not only historically correct, but enlightening, as that many of the dynamisms and cultural characteristics credited and associated with the economic success of the Valley were already evident then[2].

While the electronics age has its roots in 19th century telegraphy, electrical power, and telephone, the Valley's electronics roots were in turn-of-the-century radio. In 1909, Cyril Elwell, an electrical engineer recently graduated from Stanford University, acquired the U.S. patent rights for the Poulsen arc for radio speech and telegraphy signal transmission, a technology that produced continuous long radio waves within an atmosphere of hydrogen contained by a strong magnetic field. Elwell then turned to Stanford's president, David Starr Jordan, and Civil Engineering Department head, C. D. Marx, to finance the startup[3], which was to be based in Palo Alto and originally named Poulsen Wireless Telephone and Telegraph. After setting up a small demonstration system, the company took on new financiers from San Francisco, was renamed Federal Telegraph Corporation, and began to provide radiotelegraph services in the Pacific.[4] In 1912, Elwell pitched the technology to the Navy, far outperforming the competing East coast-based NESCO firm's unit. The Navy immediately ordered ten thirty-kilowatt arc

[2] These include: the importance of local venture capital; close cooperation between industry and research universities; emphasis on electronic components, advanced communications equipment and military electronics; high levels of inter-firm cooperation; a fertile and tolerated spin-off dynamic; and a unique "Californian" professional culture (Sturgeon 2000). With regard to the paramount spin-off process, although it is commonly first associated with Fairchild Semiconductor (Klepper 2010, Sternberg 1996), it was actually already very much characteristic of FTC decades earlier.

[3] A full thirty years before Stanford Dean Frederick Terman would famously likewise help finance the startup of former students Hewlett and Packard (Leslie 2000).

[4] Notably, arc transmitters were sold to and installed on the fleet of the Pacific Mail Steamship Company, based in San Francisco, which operated between San Francisco and Los Angeles, California, and transpacific to Australia. While the Pacific service was profitable, overland service lost money due unreliable transmission arising from static interference (Sturgeon 2000). This highlighted the technology's sea-based strengths, making an approach to the U.S. Navy natural, beginning the Valley's crucial link to the military.

transmitters for shipboard use. In the period immediately following, the Navy incessantly drove the technology, pushing FTC to develop and supply evermore-powerful transmitters (which it was able to accomplish with the invaluable assistance of the facilities and professors of the Stanford High Voltage Laboratory). With the breakout of World War I, orders surged[5] and employment at FTC went from thirty to three hundred (Sturgeon 2000).

Before the Great War even started, the technology that would supplant the arc transmitter and completely revolutionize radio was perfected in the Valley: the vacuum tube[6]. By 1912, Lee de Forest, a Yale-trained electrical engineer working in the FTC laboratory in Palo Alto, developed vacuum tubes that could be utilized in all three stages of wireless radio communications: signal generation, signal reception, and signal amplification. This technology would *"play a role in the electronics industry of the pre-World War II period analogous to that of the transistor during the postwar period: [it] opened vast and unforeseen new market potential by increasing the capability and reliability of electronic systems while radically reducing their costs, power requirements, and size"* (Sturgeon 2000:23).

Departing momentarily from the dynamic Research University – Industry – Military, let us shift slightly to the dynamic Industry – Spinoff – Military to underscore the early presence and centrality of spinoff activity in the Valley and the role of the military in that process, before focusing on the overall role of the U.S. military in shaping the Valley. This is not yet the fabled spinoff process of Fairchild Semiconductor in the

[5] To illustrate sheer wartime volume at FTC – Shipboard orders included: three hundred two-kilowatt transmitters for merchant marine ships; thirty-kilowatt transmitters for virtually all Navy battleships, a twenty-kilowatt set for a cruiser, a five-kilowatt set for a collier. Shore station orders included: a dual five-hundred-kilowatt station in Annapolis; a two-hundred-kilowatt station in Puerto Rico; a two-hundred-kilowatt set in Sayville, Long Island; a two-hundred-kilowatt set in San Diego; a transpacific five-hundred-kilowatt chain; thirty-kilowatt sets in Alaska; a chain of smaller stations around the Gulf and Atlantic coasts; a pair of one-thousand-kilowatt transmitters in Bordeaux, France; and various army posts around the country took receipt of twenty and thirty-kilowatt sets (Howeth 1963 in Sturgeon 2000).

[6] The vacuum tube was the first three-terminal device, the heart of all electronic devices. In a three-terminal device, electric current between two of the terminals can be controlled by applying an electric current to the third terminal. This constitutes an electric "on/off" switch. By cascading these switches upon each other, very complicated logic circuits are built up. The vacuum tube was replaced by the solid-state transistor, which was smaller, faster, cheaper, and consumed less power. These transistors were built with semiconductor material. A semiconductor is a material that can act as both a conductor and an insulator, that is, capable of both permitting and inhibiting the flow of electrons. Individual transistors on a circuit were in turn replaced by the integrated circuit, which incorporated myriads of ultra-miniaturized transistors and other components in a circuit onto a single silicon substrate (Haviland 2002).

1950s, which spawned the prodigious “Fairchildren” that included Intel. This is the much earlier spinoff process at FTC. Spinoffs included: Magnavox, formed by three FTC employees in 1910 who developed loudspeaker and microphone equipment used by the U.S. Navy, later turning to industry and finally consumer electronics; Litton Engineering, formed in 1932 by employee Charles Litton, went on to become the industry-regarded reference in vacuum tube production equipment and high-powered vacuum tubes highly sought after by the U.S. military for use in ground-based military radar; and Gerhard Fisher, who invented the first metal detector in his Palo Alto garage in 1928, left to form Fisher Research Laboratories in 1936 (Sturgeon 2000). Early on, the Valley was populated by firms from the countless other examples of spinoff activity from this period, quite often resulting from the incentive to satisfy the military’s voracious and ever more discerning appetite for electronics and aeronautical hardware components through World War II, Korea, the Cold War and the Space Race.

Certainly, the Valley would be unrecognizable today were it not for the U.S. military. The U.S. military became the early, central agent in the innovation process in two capacities: as 1) *buyer* and as 2) (indirect) *supplier* of innovation. First, its demand for sophisticated military technologies created a massive, guaranteed, and price insensitive market for the technologies resulting from the various waves of innovation it itself fostered in its second role. In its second and at least as important role, in granting research and development contracts to Stanford University and various independent contracting firms, the U.S. military itself both charted and underwrote the successive waves of innovation to satisfy its own demand for sophisticated new technologies (Sternberg 1996, Gray *et al* 1998). Routinely, these roles converged on the individual firm, with the military agreeing both R&D contracts and subsequent production contracts with the same firm, guaranteeing the firm a market for the products and technologies it developed. Add to this the incentive of cost-plus contracts virtually eliminating all risk; we understand just how favorable the operating circumstances were for the firms in the Valley (Leslie 2000).

Indeed, military policy lowered barriers to entry for new firms and greatly promoted the diffusion of knowledge in the system. With the aforementioned dual R&D and production contracts, the military offered new firms an inexpensive, low-risk entry into new fields with attractive prospects for commercial spinoff[7] (Leslie 1993). Further, and highly significantly, the military policy of second-sourcing[8] its technological products disseminated engineering and manufacturing know-how, upgrading the entire region's engineering community[9], more so still than the cross-licensing of patents[10] among firms. Even after the military's share in the region's turnover decreased, this practice was adopted by civilian costumers who also wanted to guarantee alternative and competitive supply of components (Saxenian 1994). Thus, *"the orders placed by Department of Defense had a deciding influence on the local diffusion of new technological know-how in Silicon Valley"* (Sternberg 1996:211-2).

With regard to the first role, as buyer, World War II and especially the first significant conflict of the Cold War, the Korean War, had a dramatic impact on the Valley by increasing demand for electronics products from local firms such as Hewlett-Packard, Litton Industries[11], Varian Associates[12], Huggins Laboratories[13], Lockheed Missiles and

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[7] To provide a good and representative example, television and radio tube manufacturer Sylvania gained entry into the military market in 1953 with an Army Signal Corps R&D contract to prototype missile countermeasures (originally offered to Stanford, who passed for dearth of resources). Sylvania provided land, a building, and staff, while the army provided equipment and funding. Christened Electronics Defense Laboratories (EDL), the lab was established near Stanford to be close to *"prospective Stanford faculty consultants and newly graduated engineers"* and *"where subcontracts for search receivers, converters, special tubes, and other electronic warfare equipment developed by university researchers could more easily be arranged"*; Terman was heavily influential in determining which contractors earned contracts to mass produce Stanford technology. EDL subsequently grew into one of the largest electronics firms in the Valley. It also spawned several spinoffs such as Microwave Physics Laboratory and Microwave Engineering Laboratories in 1956, Reconnaissance Systems Laboratories in 1957, and Electronic Systems Laboratories in 1964 (Leslie 1993:81). Sylvania / EDL is a good and representative example of the tremendous growth and new-firm creation underwritten by government defense contracting, and facilitated by personal networking and the Stanford-Defense nexus.

[8] Second-sourcing was a policy that ensured that there was a backup supply of critical military components, particularly from small, fledgling semiconductor firms. The military required that suppliers share both technical specifications and detailed manufacturing processes with competing suppliers. Many new firms in the 1960s and 1970s started as second sources and went on to grow and develop their own product lines (Saxenian 1994).

[9] Significantly, knowledge created under government sponsorship was free and available to all. Thus, new West Coast firms could work with the newest technologies unconstrained by East Coast patents, as was the case historically (Leslie 1993).

[10] Semiconductor firms freely cross-licensed their patents to competitors during the industry's first three decades. In the words of Intel founder Robert Noyce: *"Without so doing, no firm could be using the latest technology in all areas"* (Saxenian 1994:45).

[11] Founded in 1932 by Charles Litton, a Stanford graduate of Frederick Terman's tenure (Saxenian 1994). It grew dramatically during early war years and was sold in 1953. New management expanded to satisfy military demand. In just three years, selling almost exclusively to the military, they tripled sales (to $6.2 million) and backlog (to $36 million), and quadrupled employment (to 2,115) on demand for products like pulse magnetrons and tunable klystrons for radar, and tunable continuous-wave magnetrons for jamming and missile guidance systems (Leslie 1993).

Space[14] – the Valley's largest single employer for most of its modern history – and many other smaller contractors. Following on from the Korean War, the Valley continued to be fashioned by the assumptions and priorities of Cold War defense policy and the Space Race (Henton 2000; Leslie 1993; Leslie 2000).

Indeed, moving on from the early technologies already discussed and with distinct military applications in radio and radar, even the succeeding technological wave of the integrated circuit – thought to be civilian-oriented – was itself a product of the military's effort to miniaturize military electronic equipment between 1940 and 1955 (Henton 2000, Sternberg 1996). While integrated circuits would come to have far greater civilian applications than previous technologies, the military, nevertheless, continued to be the primary customer, with its share in the turnover of the Valley's semiconductor industry lying somewhere between 35% and 40% between the years 1955 and 1963 (Sternberg 1996), buying literally all the integrated circuits produced in 1962 at premium prices (Gray *et al* 1998), only falling to below half in 1967 (Leslie 2000).

As Sternberg (1996) states, at this inflection point, successful civilian markets opened up and military share gradually reduced, with Gray *et al* (1998) placing the reduced market share at 10% of all integrated circuit purchases in 1978. Nevertheless, military sales had *"moved firms swiftly along the technological learning curve which allowed unit costs to fall low enough to permit them to penetrate industrial and commercial markets"* (Gray *et al* 1998). Sternberg (1996) and Kenney (2000) argue that while government demand was critical to the genesis of the Valley, it became of minor importance thereafter. As Kenney (2000) states: *"It is entirely possible that the features*

[12] In the late 1930s, the Varian brothers invented the klystron tube at Stanford. Again acting the venture capitalist, the university provided them with $100 in materials and free lab access to develop their technology in exchange for a 50% stake in resulting patents. The klystron became central to central to U.S. antiaircraft and antisubmarine radar during WWII. The university would go on to collect $2 million in royalties. The brothers founded Varian Associates in 1948 (Saxenian 1994). Varian's sales grew from $200,000 in 1949 to $1.5 million two years later to $25 million by the end of the decade, with military tubes accounting for all but a tiny fraction of revenue (Leslie 1993).

[13] Founded in 1948 by former Stanford research associate R.A. Huggins to commercialize technologies developed on his research at Stanford. The firm brought the first travel-wave-tube to market and then expanded with military R&D contracts into other related technologies. By 1961, the firm had turnover of $3.5 million per year (Leslie 1993).

[14] Lockheed Missiles and Space established its laboratory in the Stanford Industrial Park in 1956 and located its manufacturing in nearby Sunnyvale. Its reasons were the same as Sylvania's (Leslie 1993).

initially important for initiation and early growth can at later stages become much less important or even irrelevant. One example is the dramatic decline in the importance of military spending. Today, increased defense spending might paradoxically raise engineering wage costs and divert intellectual resources from the Valley, thus inhibiting its growth. Another inhibitor is U.S. government control on technology exports, which lead to decreased sales. Thus, a once important activity, defense spending probably has evolved to being a burden rather than an accelerator" (Kenney 2000:9).

While it is certainly true that features initially important to early regional growth can later become irrelevant, Gray *et al* (1996) argue more persuasively that in this case, while not nearly as central as before, the military's continued participation in the Valley should not be diminished by researchers, as it continues to be an important player as buyer and indirect supplier of technology[15]. Indeed, the Valley remains one of the leading recipients of defense contracts in the country, in both total dollars and dollars per worker, and more than four times the national average (Leslie 2000, Gray *et al* 1998).

While for purposes of simplicity and abstraction we have reduced the first, foundational stratum to Research University (Stanford) and the United States military, it is necessary to introduce at this point the paramount role of **Frederick Terman** in facilitating non-market knowledge and influence flows between the critical factors of innovation. First as a faculty member, then as dean of the engineering department, and later as president of the university, Terman was an untiring leader, facilitator and advocate in the relationship between the university and industry, the university and the military, and ultimately the military and industry; and he demonstrates the magnitude of impact (a) highly motivated "cross-pollinating" individual(s) can have on an innovation system.

Terman, the son of a prominent Stanford psychologist, had been raised on campus and earned his undergraduate degree there. He went on to MIT to earn his doctorate in

[15] Whatever the latter-day market share, it is unquestionable that defense spending created the technology base for the semiconductor, computer hardware, software, and internet industries (Henton 2000). Further, beyond the continued funding at research universities and associated institutions (such as the Stanford Research Institute), the government funds local national laboratories such as Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, NASA Ames Research Center, and Sandia National Laboratories.

electrical engineering and returned in 1925 as a faculty member of Stanford's engineering department, whereupon – in the mold of the early cooperation between Stanford and FTC *et al*, but on another magnitude altogether – he set about to foster close ties between the university and industry. He launched an aggressive, commercially oriented program in radio electronics, arranging for local industry to donate equipment to his labs, and also looked to them for his real-world research problems. To further involve his students in industry and improve their awareness of its problems and potential job opportunities, he arranged field trips to local firms and invited their engineers to give campus seminars (Leslie 2000). Frustrated by the job prospects of new graduates he advocated entrepreneurship to his students[16] (Gibbons 2000).

Terman returned to Stanford in 1946 from a wartime post at Harvard's Radio Research Laboratory with a renewed vision with regards to the role of the university, envisioning greater protagonism for the university in supporting local technology-based industry, and was determined to avail himself of his new and important government contacts to draw military contracts to the region. He redoubled efforts in encouraging promising students and faculty he recruited to the university to become acquainted with the region's firms and the opportunities these offered. Meanwhile, speaking at industry meetings and though other forms of intense involvement, he encouraged local firms to examine what research being undertaken by Stanford could potentially benefit their businesses (Saxenian 1994).

In his inaugural year back as Dean of the School of Engineering, he wrote: *"The West has long dreamed of an indigenous industry of sufficient magnitude to balance its agricultural resources. The war advanced these hopes and brought to the West the beginnings of a great new era of industrialization. A strong and independent industry must… develop its own intellectual resources of science and technology. For industrial activity that depends on imported brains and second-hand ideas cannot hope to be more*

[16] The most famous example is, of course, most notably when on his encouragement David Packard and William Hewlett commercialized their audio-oscillator, which Hewlett had designed while working on his master's thesis (Saxenian 1994). They founded Hewlett Packard in 1939 and Terman even participated as an angel investor (Gibbons 2000) and arranged an additional bank loan to begin production (Saxenian 1994).

than a vassal that pays tribute to its overlords, and is permanently condemned to an inferior competitive position" (Terman 1947).

Three institutional innovations at Stanford shortly after WWII, all of which continue strongly to this day, reflect Terman's vision and pioneering efforts. First, Stanford established the **Stanford Research Institute** (SRI) in 1946 to conduct defense-related research and assist local industry. Second, the creation of the **Stanford Industrial Park**[17] in 1951 on university land brought important firms closer to the university, facilitating and reinforcing cooperation between the university and industry. Firms would hire faculty[18] as consultants, as well as enjoy access to graduates – promising prospective employees. Third, the **Honors Cooperative Program** in 1953, which allowed local professionals to enroll in graduate courses directly or through a dedicated televised service for off-site learning. This program allowed engineers to stay current in their fields, strengthened ties between industry and the university, and facilitated professional networking (Saxenian 1994; Isaak 2009).

It is noteworthy, therefore, that in his reflections fifty years on, regarding the continued role of Stanford University in the Valley, James F. Gibbons (2000), Dean of Stanford University's School of Engineering from 1984 to 1996, noted three general contributions, which align rather well with the aforementioned. He noted:

1) Transferring technology from its laboratories to commercial companies through licensing of technology and the formation of new companies by students, staff, and faculty. This is the case in the areas of computing and information networking.

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[17] SIP, now Stanford Research Park, became *the* locus of the Valley's activity, with both new firms and large, established East Coast and Chicago firms setting up labs in SIP to be near Stanford's emerging basic research, the SRI, a labor pool of consulting faculty and graduates, and proximity to the nexus of new defense contracts (Leslie 2000). By way of example, new firms that located there include: Varian, Hewlett-Packard, Granger Associates in 1956, Granger spinoff Applied Technologies, Watkins-Johnson, Microwave Electronics Corporation in 1959; East Coast giants that located labs in or adjacent to SIP included: General Electric, Admiral, Zenith, Sylvania, Lockheed Missiles and Space, Philco, Itek, Link Aviation, Kaiser Aerospace, Xerox (PARC), among others. While some of these subsidiary laboratories, unable to make the transition from defense contracting to civilian markets, eventual shut down, they helped create the prototype for the integration of academic, corporate, and military R&D behind the Valley's accelerated expansion (Leslie 1993).

[18] Including Terman himself (Leslie 1993).

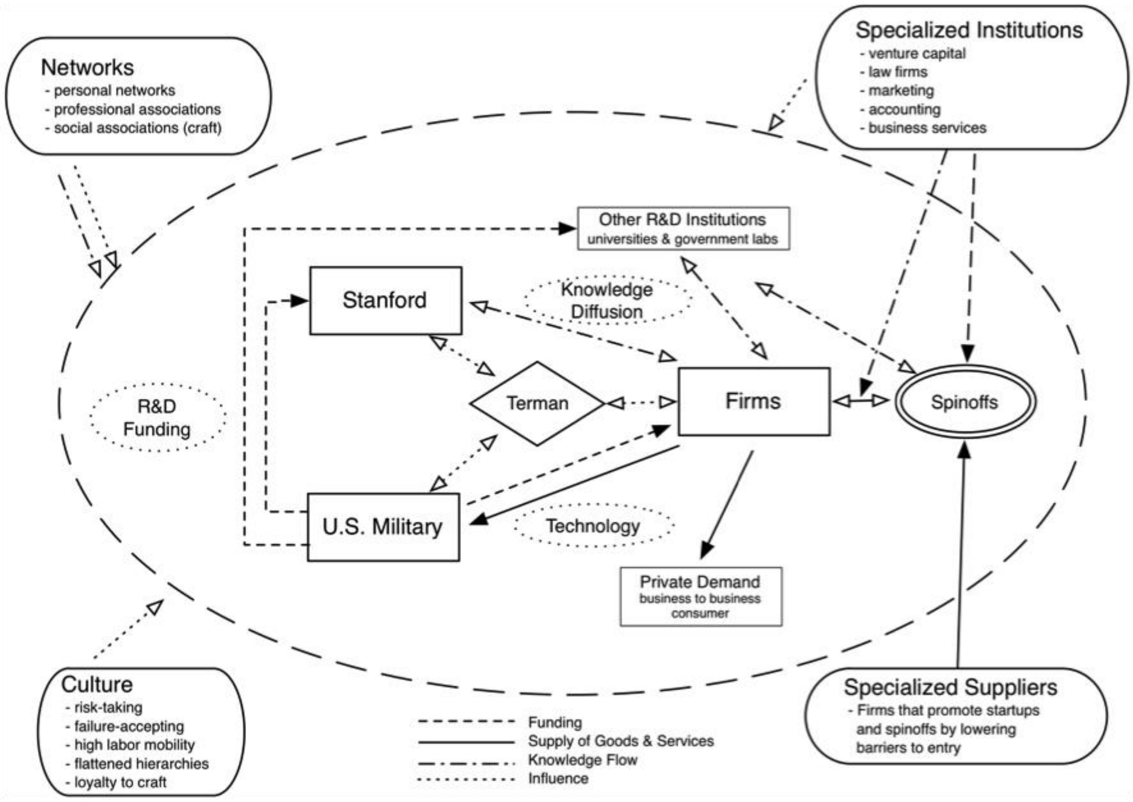
2) Replenishing the intellectual pool every year with outstanding new graduates[19]. This is particularly the case for large, established firms such as those in the semiconductor industry, where most of the development within the industry itself occurs.
3) Providing continuing education to professional, who thereby stay up-to-date on the state of the art with access to Stanford's high-quality distance learning graduate program.

While Frederick Terman provided pivotal leadership in promoting University – Industry symbiosis, he and his efforts did not arise in a vacuum. Indeed, he can better be understood as a catalyst and a promoter of an *extant model, an established pattern*, sharply illustrated by the earlier interaction between previous university president David Starr Jordan, the Federal Telegraph Corporation, and the U.S. military. That early interaction involved close university – industry cooperation in research, early venture capitalism, government intervention as buyer and supplier of research, and a healthy spinoff process.

Having established foundational stratum of Stanford University and the U.S. Military and how their interaction initiated the process of agglomeration and begat the virtuous relationships Research University – Industry – Military and, subsequently, Industry – Spinoff – Military, the next section turns to the second stratum, the reinforcing factors and characteristics that turbo-charged the Valley's growth. Where the present section followed a more chronologically reverent approach, the next will consist of a point-by-point examination of the forces and characteristics credited by the literature to have reinforced the Valley's growth.

[19] To this end, of course, not only Stanford, but the many universities in the San Francisco Bay Area and beyond supply the Valley with new talent. Local institutions include the Universities of California, the California State Universities, private universities, and even the robust Californian community college system (Saxenian 1994).

Figure 3: The Silicon Valley Innovation System mid-20th Century.

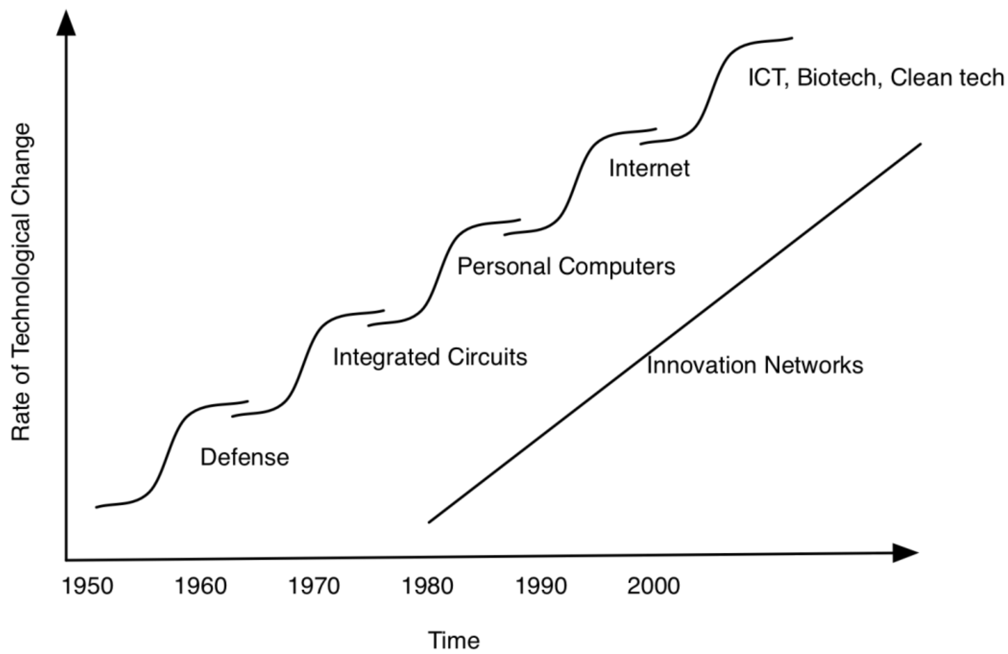


Source: The author's design.

3.2 Reinforcing forces and characteristics

The Valley has spawned successive new industries, as illustrated both in the text above and Figure 4 below. Indeed, what distinguishes the Valley from many other clusters / innovation systems is that the Valley has not remained static, dedicated to a single industry, its generic "high-tech cluster" moniker notwithstanding. The various defense technologies (radar, missile, aerospace) have precious little in common with biotechnology and social networking. This is markedly different from, for example, the relatively monolithic automobile (Detroit) and entertainment (Los Angeles) clusters.

Figure 4: Silicon Valley Waves of Innovation, 1950-2000s



Source: Adapted from Henton (2000) and Wonglimpiyarat (2006).

The generally recognized core dynamism of the Valley's economic growth has been the spinoff and startup processes (Klepper 2010, Kenney and Von Burg 2000) wherein innovative new ideas with high potential economic payoff are quickly financed, developed, and brought to market. But for all the brilliance and risk-taking entrepreneurial disposition of individual agents, what fosters and sustains such a vibrant, firm-spinning ecosystem is what lies beyond individuals and traditional explanations of labor pooling, specialty suppliers, and technological spillovers. *"The essence of Silicon Valley is the cluster of institutions dedicated to creating firms"* (Kenney and Von Burg 2000:221). These institutions include the much-credited venture capitalists and law firms – who provide new firms with much more in terms of guidance and connections than simply money or legal counsel –, accounting, marketing, consulting, and executive search firms that are well-adapted to the needs and culture of the Valley. While *not* foundational factors, responsible for the birth of the region, as the Valley grew in dimension and complexity, these supporting institutions arose, formalized, proliferated, and became evermore specialized to cater to the needs of both existing and, most crucially, fledgling spinoffs and startups (Suchman 2000, Kenney and Florida 2000, Klepper 2010, Ferrary 2011, Saxenian 1994).

3.2.1 Evolving institutions– Venture capital and Law firms

The two most important support institutions in the Valley developed in tandem with the technological entrepreneurial base: venture capitalism[20] (VC) and law firms.

With regard to venture capitalism, Intel's legendary Gordon Moore stated that the 'engineer entrepreneur' combined with venture capital was the essence of creating Silicon Valley (Isaak 2009). Half of the VC firms in the United States are in the Valley, with investment volumes dwarfing all other U.S. regions (Wonglimpiyarat 2006).

While the earliest antecedents of venture capitalism in the Valley stretch back to FTC, with sporadic and informal examples of the activity throughout the first five decades of the Valley, the real beginnings of venture capitalism date to the late 1950s when a few wealthy individuals in San Francisco saw the financial potential of backing technology companies[21]. Arthur Rock was an East Coast venture capitalist who arranged financing for the defectors of Shockley Semiconductor Laboratories with the also-East Coast firm Fairchild Camera and Instrument in 1958[22]. These early VCs were wealthy individuals from business and not technologists themselves. They relied on their intuition. But with the success of Fairchild Semiconductor and its spinoffs, the founders and early

[20] Venture capitalists invest in company stock, becoming equity holders, and so participate directly in the success or failure of a firm. VCs tend to use multi-stage financing to factor in the changing dynamics of a competitive market and as a carrot-and-stick method of encouraging performance and aligning incentives, as progress on the part of the entrepreneurs results in increased valuations of the stock they own (Hellmann 2000).

[21] The Small Business Act of 1958 established the Small Business Investment Corporation vehicle, whereby the government provided up to $300,000 in matching funds for $150,000 in private investments. SBICs were attractive because they allowed for the mobilization of more capital with less personal financial risk. SBICs grew rapidly through the 1960s and were the preferred vehicle until the rules, regulations, and public disclosure requirements associated with SBICs began to outweigh the benefits, where after the limited partnership VC format began to supplant SBICs. SBICs were a crucial stage before formal, freestanding, limited partnership venture capitalism (Kenney and Florida 2000).

[22] Soon thereafter, Fairchild Semiconductor would produce a prolific spinoff process. If FTC was the Big Bang, FS was Inflation. It produced 27 firms between 1966 and 1969, with 124 the family tree by 1986 (Kenney and von Burg 2000). Seeing the potential for himself, Rock moved out to San Francisco in 1961 and would go on to participate in the funding of Fairchild spinoff Intel and many other successful companies (Banatao and Fong 2000).

employees of these wildly successful companies began to look to reinvest their fortunes in the market they understood best, technology[23]. This began informally, as individual investments or in loose associations, but over time, through the 1970s and 80s, venture capitalism began to progressively take on a formalized structure, providing firm creation support services that grew in sophistication apace of the Valley's growing complexity. This is known as path-dependent organizational structural change. (Banatao and Fong 2000, Kenney and Florida 2000, Kenney and von Burg 2000)

"Venture capitalists brought technical skill, operating experience, and networks of industry contacts – as well as cash – to the ventures they funded" (Saxenian 1994:39). Hellmann and Puri (1999 in Hellman 2000) demonstrated that firms who obtained venture capital were faster at bringing their product to market, and that this effect was especially strong with startups pursuing innovation (as opposed to differentiation or imitation), for which first-mover advantage was especially important. This success owes to more than mere financing. Indeed, having emerged generally from the base of successful technology enterprises, being former successful entrepreneurs, these VCs knew the business they were investing in and could comfortably take a more expansive role which included advising on business plans and strategies, serving on boards of directors, helping find co-investors, recruiting key managers. These latter two are examples of the networking role played by VCs, often considered more important for their networks than their money (Kenney 2000). Indeed, networks of human relationships and referrals are central to the VC practice (Kenney and Florida 2000). *"Precisely because venture capital is more than the provision of capital, geographic proximity is important. Indeed, Silicon Valley venture capitalists rarely invest outside the Valley"* (Hellmann 2000).

By virtue of the difficult selection process (VCs sift through scores of applications for each selection), VCs also legitimize the startups they select and later seek to "sell-up"[24]. They play a crucial role in identifying the strengths of a firm and sharing knowledge about it to other potential investors, buyers and otherwise potentially interested agents. This information sharing is especially critical to firms such as Cisco Systems that

[23] This is a process that continues to this day in a virtuous cycle of successful enterprises spawning new VCs who in turn support new successful enterprises (Kenney and Florida 2000).
[24] Acquisitions or IPOs to generate capital gains is the core object of VCs (Ferrary 2011).

practice *open*[25] or *ambidextrous innovation*[26], where exploration is decoupled from exploitation in the innovation lifecycle. Such companies prefer to acquire (*spin-in*) innovative technologies developed in startups or spinoffs, and focus on adapting and commercializing these in an integrated product lines (Ferrary 2011).

It is pertinent to at this juncture to ask: who fulfills or should fulfill this critical facilitating, information-sharing role in RE innovation systems?

In tandem with venture capitalism, the form and function of **law firms** evolved *in response* to the early success of the Valley, and has gone on to turbocharge the Valley's growth as a vital institution in the business services ecosystem that supports new firm creation. Lawyers are generally the first institutional contact for new firms, who turn to them for trusted general business advice and help in both the practical and legal matters of firm structuration. This means that lawyers begin their intervention in the early stages of the structuration process, a time of maximum permeability and malleability, with relatively little conflict and suspicion (Suchman 2000).

Law firms do much more than provide industry-relevant legal counsel and protection, though those in the Valley certainly have come to specialize in areas important to their technology clients, such as intellectual property, licensing, incorporation of startups and trade law. Still, they enjoy a much more expansive role, and like the VC firms they too evolved into influential network brokers (Saxenian 1994). A 1989 study concluded that the form law practiced in the Valley was *"informal, practical, result-oriented, flexible and innovative"*[27], reflecting the culture in the Valley (Friedman *et al* 1989:561) and the needs of its small, high-mortality clients (Suchman 2000).

In his excellent discussion of the role of lawyers in the Valley, Mark Suchman (2000) identifies five roles of the Valley's lawyers: 1) counselor, 2) dealmaker, 3) gatekeeper, 4) proselytizer, and 5) matchmaker.

[25] Open innovation is characterized by porous firm boundaries where *"large companies combine externally and internally developed technologies… to create new businesses"*, interacting strongly *"with different actors in their environment (universities, research labs, customers, exhibitions, venture capital firms, etc.) in search of interesting ideas"* (Ferrary 2011).
[26] Ambidexterity occurs *"at a regional level through inter-organizational coordination"* (Ferrary 2011).
[27] This also applies arranging payment. Startups often cannot afford to pay up front, so lawyers often defer billing or accept stock in lieu of payment (Suchman 2000).

In perhaps their most important capacity, lawyers act as trusted **Counselors**, offering valuable, experience-based business advice to the often young and business-inexperienced entrepreneurs of nascent firms, unable to afford specialized consultants for the many issues involved in the formation, incorporation, and operation of a firm[28] (also Johnson 2000).

As **Dealmakers**, lawyers draw on their business connections to introduce their clients to appropriate transactional partners. They actively procure and facilitate funding for their clients through their well-developed links to the VC community; conversely, in this go-between capacity, they also act as a filter for VCs, evaluating prospective businesses. In this capacity, they 'mediate the flow of scarce resources within the Valley' and provide the critical "brokerage" glue that holds the network together (see also Johnson 2000).

However, in their role as dealmakers lawyers are not mere hubs redirecting contacts and resources, but serve as active **Gatekeepers** of the community. By selectively accepting and referring clients, their influence on resource flows reinforces and institutionalizes desirable community norms and filters out threats to the cohesiveness of the community. Suchman does acknowledge that this introduces the risk of potentially arresting structural innovation (see also Johnson 2000).

As trusted counselors, lawyers are able to encourage their often-inexperienced clients toward certain types of deals and discourage them from others, becoming **Proselytizers**. This is particularly true in transactions with VCs, where they promote confidence, explain conventions, and suppress antagonism, thus easing and expediting negotiations.

The final role, **Matchmakers**, is essentially an extension of the roles of proselytizer and gatekeeper. Lawyers encourage transaction-seeking clients to conform to certain culturally approved models. By formulating understood typologies, they facilitate transactions between agents.

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[28] The cumulative effects of such counseling *"tend to render the organizational community both more isomorphic and more institutionalized over time"*; organizational diversity falls and interorganizational relations become more consistent (Suchman 2000:85). In short, lawyers help standardize, preserve, and guarantee the business culture of the Valley, with corresponding confidence reflected in transactional and operational efficiency gains.

Again, as with VCs, it bears asking: who, or what institution(s) might best fulfilling this critical role in a RE innovation system? Who might knowledgeably link the involved agents, help direct the flow of scarce resources and combination of agents and information, serve as advocate for the industry or specific technologies, and help gate keep the culture / rules and norms of a healthy innovative and entrepreneurial system?

3.2.2 Networks connect the ecosystem

Silicon Valley has a regional network-based industrial system. Hemmed in by bay and mountains into a relatively physically constrained space – early on clustered around Stanford University for access to its human capital, knowledge flow, and military connections – and reinforced by a hierarchically-flattened, open Californian culture, dense social and professional networks have flourished.

Regional network-based industrial systems are built around horizontal networks of firms. In such networks, producers specialize, deepening their technical capabilities in particular technologies while maintaining close, but not exclusive, relationships with other specialists – suppliers, skilled contract labor, etc. – who for their part also specialize. Functional boundaries are permeable within firms, between firms, and between firms and institutions such as business associations and universities. Repeated interaction across a multiplicity of agents builds shared identities and mutual trust while stoking healthily competitive rivalries, promotes the diffusion of ideas, the flow of technical information. Recombination of these agents and ideas spur innovation (Saxenian 1994).

For this reason, the Valley is sometimes referred to as a “knowledge ecology”, where ‘knowledge can leak *out* of a firm… [but] if that firm is an open participant in the ecology, knowledge can also flow back *into* that firm’ with these feedback loops turning the Valley into a thriving ecology (Seely-Brown 2000:xiv).

To understand why, let us use Seely-Brown’s (2000) conceptually useful terms *communities of practice* and *networks of practice*; which in fact describe something quite basic and intuitively understood. Knowledge produced within a firm or research institution is generally produced by teams of people, or communities of practice (cops). Working closely together in their particular area, these cops naturally evolve highly effective communication, a tacit understanding, and know when and when not to trust information or opinions within their group. Firms' value chain comprises many different cops, each with different skills, specialized knowledge and forms of communication. Innovation, which can be understood as the process of bringing new ideas to fruition, or implementation, requires ideas move along that value chain. While communication across functionally different cops within an organization can be difficult – which can often arrest the progression of innovative ideas –, it is rather easy to communicate with functionally similar cops in other organizations. These are networks of practice. We are reminded of Marshall's knowledge "in the air". This cop dynamic also describes the efficient dynamic of start-ups, telling us why they are ideally suited for quick innovation.

We have already examined two major network brokers, venture capital firms and law firms, as well as the professional contacts among like professionals across firms. Yet, it is important to underscore that these professional contacts are quite often also personal contacts. *"Dense networks of social relations play an important role in integrating the firms in the Valley's fragmented industrial structure"* (Saxenian 1994:8). These connections begin informally at university, later on within Valley business associations, firm-to-firm interaction, or other fortuitous meetings. On the importance of constrained geography, Seely Brown (2000:xii) notes that this increases the odds of serendipitous contacts at informal settings at parties, restaurants, sporting events, at children's school, where *"you discover whom you need to meet, who is worth working with, whom you should avoid"*. 'Coupled with density one gets a remarkable petri dish in a culture amazingly open to new ideas, in constant contact, and willing to turn ideas into action'.

3.2.3 Culture

Such is the distinctiveness of the Valley's culture that Silicon Valley is often used to refer to a state of mind rather than the physical place. It is an open and informal culture, interested in new ideas and experiences, much in keeping with the greater Californian culture. This culture is put forward as critical to support and reinforce the unique business ecology that exists in the Valley, which in turn is necessary to support continuous industrial renewal and the rapid development and bringing-to-market of new ideas. Critical elements of the culture herein highlighted are: egalitarian values, risk-taking, failure-acceptance, and labor mobility.

In the open, egalitarian, and hierarchically flattened[29] Valley, there is a greater loyalty to science and craft than firm. Information flows much more freely. In contrast, its East Coast competitor, Route 128, has a Puritanical cultural foundation that emphasizes loyalty to hierarchy, and so is characterized by greater loyalty to firm and an unwillingness to share information. Route 128's inability to keep up with the Valley, despite its significant head start, is in good measure attributed to this culture of rigid social relations and firm-based industrial organization (Saxenian 1994, Isaak 2009).

Isaak (2009) explores the interesting symbiosis / paradox of a stable, mainstream culture, which indeed envelops the Valley, as a necessary foundation for the free-thinking, risk-taking "counter-culture" nevertheless dependent upon the mainstream system's government funding and provisioned stability; macroeconomic and policy. *"The stable, yet tolerant and risk-conducive, political economic framework permits the spirit of Schumpeter's creative destruction to flourish and a hard-driving "cowboy" mentality to motivate entrepreneurs to speculate on making great fortunes through radical new ideas"* (Isaak 2009: 136).

Just as taking risks is encouraged, the failure that often results is tolerated (Wonglingpiyarat 2006, Saxenian 1994, Isaak 2009). Indeed, if it weren't, fear of failure would dissuade many from taking paradigm-shifting risks. Failure is not seen as a black mark; it can even be seen as a 'badge of honor', whence invaluable experience and learning were derived. In fact, failure is a critical element in recycling the region's

[29] Noyce, founder of Intel and former Fairchild founder, rejected social hierarchies, removing all such symbols. Top management interacted directly with all employees, who were expected to "say whatever they thought" and challenge all, including the founders. Everyone received equity in the company. Everywhere former Fairchild employees went they took this ethos (markedly different from the buttoned-down east coast) with them. Hewlett-Packard was also famous for a similar corporate culture, referred to as "The HP Way", characterized by trust in individuals, high autonomy, commonness of purpose (teamwork), and generous benefits. HP pioneered a decentralized organizational structure with semi-autonomous business units (Saxenian 1994).

human resources (Saxenian 1994). As put by John Seely-Brown: *"nurturing seedlings is an inherently protective act. Yet thriving ecologies… grow more robust through death… letting [a firm] die may be more beneficial than keeping it artificially alive. Executives toughened by the experience of failure can be worth more than those who have had none"* (Seely-Brown 2000:xvi).

Of course, the recycling of human resources in the Valley isn't dependent on the failure of firms alone. The culture of labor mobility – made easier by the physical proximity of firms in the valley[30] – is a critical component of the Valley's success. The Valley is characterized by fluid labor relationships, in which *"a colleague might become a customer or a competitor; today's boss could be tomorrow's subordinate"* (Saxenian 1994:36). Also, leaving a firm is not stigmatized. Labor moves from established firms to startups, and startups to established firm (Kenney 2000) in a 'continual shuffling and reshuffling that reinforces the value of personal relationships and networks' (Saxenian 1994). Further, inter-firm mobility is a knowledge-transfer mechanism, whereby information and knowledge circulate rapidly, thereby upgrading the entire region. *"This has important implications, if the competitiveness is considered not at the level of the individual firm but rather at the industrial-regional level"* (Kenney 2000:8).

This consistent culture, within the stable and consistent macroeconomic and policy mainstream that envelops it, creates Enright's (1995) homogeneous transaction space, lowering coordination costs, and accelerating the flows of knowledge, influence, resources, and the other ancillary processes that bring ideas to fruition.

3.2.4 Spinoff dynamic

The archetypal Valley story is that of the university friends who together begin their own startup company in a rented garage that quickly grows into a major firm or is sold up to an established firm for millions. Indeed beyond lore, startups are a real, inextricable and vital mechanism in the firm creation process, and their importance to

[30] Also, the ability to move around within the Valley meant that an employer might change, but one remained equally connected to their personal and professional network.

the Valley's dynamic cannot be understated. Yet, another mechanism of firm creation is at least as important: the spinoff process. The spinoff process is an absolutely fundamental feature in the Valley's model (Sturgeon 2000).

Spinoffs[31] are independent firms that are "spun-out" of a parent firm to focus on a new product or service. Startups formed by key figures that leave an established firm are also commonly regarded as spinoffs. The rate of technological change in the Valley's tech-based industry is not only accelerated by spinoffs, spinoffs are only possible because of the fast-changing nature of technology itself, which prolifically generates inventions and opportunities best exploited within the agile framework of a startup[32] or spinoff[33].

Klepper and Thompson (2010) model the relationship between the quality of a parent firm and the success of its spinoffs in support of the empirical phenomenon that spinoffs consistently outperform other new entrants and disproportionately populate the ranks of the industry's leaders. Separately, in analyzing the spinoff[34] processes in the Valley (and Detroit), Klepper (2010) noted that organizational reproduction (spinoffs) and heredity (the lineage of the spinoffs) were key to the success of the industry and the sustainability of the ensuing growth[35]. Highly successful firms spawned superior spinoff firms, which then clustered around the parent in the nearby geography, creating the beginnings of a cluster. He cites the success of the Fairchild offspring in supporting his argument. In 1975, five of the top ten semiconductor firms in the U.S. were in the Valley: Fairchild, three of its spinoffs, and a second generation Fairchild descendent. In 1980, four of its spinoffs, Intel, Signetics, National, and AMD, represented 32% of the total semiconductor market, in addition to Fairchild's 7%.

[31] While there are several technical definitions describing the various types of corporate restructuring that result in the formation of a new company (Rüdisüli 2005), here the term is used in a broad sense to denote firm emergence from an established firm.

[32] Start-ups might themselves be understood as 'spinoffs' insofar as they are re-combinations of actors and ideas present the innovation system milieu.

[33] Incidentally, spinoffs are key to generating the high capital returns that keep VCs in business.

[34] In his treatment, Klepper defines spinoffs as *"firms whose founders previously worked for another firm in the same industry"* (2010:15).

[35] Noting the importance of organizational reproduction and heredity, Klepper states (2010:29) that *"if agglomeration economies were strongly at work it might have been expected that all kinds of firms would have been superior performers in the clusters, yet the superiority was largely restricted to spinoffs and in particular spinoffs descended from the leaders that entered at the largest sizes"*.

Spinoffs are made possible by the host of specialty suppliers in the Valley, whose ranks they may in turn join. For example, previously, most of the production equipment was made in house. If not for the development of independent firms producing the specialized production and design equipment in the late 1960s, semiconductor spinoffs would have had difficulty getting started (Saxenian 1994). Specialty suppliers quickly became an integral part of the Valley's institutional support structure, promoting and sustaining growth.

In summary, the Valley's origins as a hub of technological innovation lie in university-based research and government military spending in the early 20th century. Small and closely networked firms began to sprout, cluster, and splinter near the university, seeking access to its knowledge and human capital, as well as the influence that secured government contracts. This interaction produced the critical mass necessary for sustained, accelerated innovation. Through successive waves of industry and as demand grew and shifted from public to private, the Valley's firms and support institutions (such as venture capital, law firms, and other business services) co-evolved, growing ever more diverse and specialized to support each stage in the ever-emerging, dynamic and diverse innovation system it has become.

4. RENEWABLE ENERGY INNOVATION

The purpose of the present chapter is to analyze the problems confronting innovation in existing renewable energy clusters, with particular recourse the innovation systems approach discussed in the literature review. The system problems presented herein were formulated from a survey of the literature in renewables innovation. Concurrent with this analysis, we present recommendations to address these problems and boost performance of renewable energy innovation systems based on the lessons revealed in the preceding examination of Silicon Valley.

4.1 Characterization of energy

Energy is often described as a public good. It is essential to all aspects of modern life. Even if, strictly speaking, we classify the explicit benefits of energy (those for which it is transactioned, i.e.: the ability to do work) as a private good, there is no question that the inclusion of externalities changes this simplistic assessment. On one hand, there is the market failure represented in the unpaid costs of negative externalities produced by the generation of energy from fossil sources, most notably the production of climate change-inducing GHGs. On the other hand, the production of renewable energy supplies positive externalities (avoided carbon emissions) that are both nonrival and nonexclusive, allowing for free riders (Wiser and Pickle 1997).

Furthermore, given the natural monopoly, network structure of energy distribution; the political nature of sourcing and provisioning energy; as well as the typical national policies of an affordable, reliable and secure energy system – in support of economic growth and general welfare – it is clear that energy is a commodity that deserves special treatment, including public and public policy attention. For that reason, certainly, the robustness of all aspects of energy system maintenance, renewal, and improvement – including the intelligent management of its upstream and downstream products / externalities – all deserve significant and careful attention, which, as has been argued for innovation generally and will be argued for RE innovation particularly, is best approached through the concept of a regional innovation system.

4.2 Renewable energy innovation vis-à-vis general technology

The innovation process for technology is *"complex and non-linear; complex because it involves a range of actors and factors, and nonlinear because technology innovation occurs through multiple dynamic feedbacks between the stages of the process"* (Narayanamurti *et al* 2009:59). Indeed, as noted with the Silicon Valley case, the innovation system consists of many actors / agents and the relationships among them. These include universities, government agencies, established firms, start-ups and spinoffs, the various support institutions including law and finance, and ever more nowadays, other international institutions.

Nevertheless, the innovation process for renewables is yet more complex. Transitioning to a consideration of renewables innovation problems, it is useful to be mindful of the following factors that, *per* Narayanmurti *et al* (2009), increase RE innovation complexity:

1) ***market failures*** in the form of a) limited and uncertain market signals for energy research, development, demonstration, and deployment, and b) positive externalities of avoided GHG emissions and energy security;
2) ***long time frames*** over which development takes place further hinder the participation of the private sector;
3) significant ***heterogeneity between stages*** of development;
4) competition with ***powerful incumbents*** and technology "lock-in"; and
5) electricity's ***public good nature*** serving as basis for multi-faceted government involvement[1].

[1] For example, governments are interested in assuring the availability of future technology options, reducing risk to the nation and in the sector, developing more appropriate market signals, and even helping create new, desirable markets. Consequently, the government is involved as a major funder and undertaker of energy research, development and deployment, and facilitator of commercialization (Narayanamurti *et al* 2009, IPCC 2012).

4.3 Problems in renewable innovation and lessons from the Valley

Significant problems exist in renewable energy innovation systems (Negro *et al* 2012) and the design of innovation policy (Bonvillian and Weiss 2009) requiring substantial improvements to meet climate change objectives (Narayanamurti *et al* 2009).

Many of the renewables technologies that enable the transition to a more sustainable energy system differ significantly from legacy technologies. For this reason, they are termed disruptive innovations[2], and thus require substantial changes to the various parts of the innovation system, which in turn requires more time and increases the chances of failure. Difficulties that arise in the development of new innovation systems are termed ***system failures***.

In modern innovation policy, such system failures justify policy intervention (Negro *et al* 2012), provided that two conditions are met. First, a *problem exists*, i.e. a situation in which markets fail to achieve socially defined objectives; second, the state and its agencies must also have the *ability* to solve or mitigate the problem (Edquist 2001). The first two system problems discussed – and likely the most critical – in fact relate specifically to the failures of governments. They are:

1) A lack of ***continuity in policy, consistent*** throughout all levels of government
2) ***Poor funding models*** appropriate to stage of development.

4.3.1 Lack of stability and consistency in government policy

Considering the nature of energy – its market failures, public good nature, naturally monopolistic distribution, and its complex innovation processes – and the public goals attached (e.g. climate mitigation) to renewable energy, government clearly has a critical role to play. The essential and overarching nature of this role is to promote a stable and predictable macro environment for confident decision-making and fluid interactions between all agents within the innovation system. Just as uncertainty is detrimental to the functioning of markets, so it is with innovation systems.

[2] A disruptive innovation is one that disrupts an existing market and value network, challenging its incumbents, while creating a new, substitute market and value network (Christensen 1997).

Erratic government policy significantly increases regulatory risk to firms who would otherwise seek to make long-term investment decisions. Misalignment of overlapping and conflicting national, regional, and local standards, regulatory and incentive polices cloud the private sector decision-making process (Negro *et al* 2012). The anticipation of policy volatility (as opposed to policy consistency irrespective of election results) pushes firms to make shorter-term investments in conservative renewables technologies – as opposed to long-term investments in radical innovation - that can be built up quickly to obtain the tax credits and other incentives that are likely to expire or be cancelled in the next cycle of policy destruction and formation (Victor and Tanosek 2011).

Furthermore, renewable energy policies are often written in terms of specific technologies instead of objectives, often with more of a mind to politicking than sound policy making. However, as Bonvillian and Weiss (2009) explains, innovation policy itself must evolve to become technology-neutral[3], pivoting its focus to objectives and a policy framework supporting different types of technology-emergence pathways[4].

Governments desiring a successful RE innovation system should look to Silicon Valley, which "benefited from a mainstream political stability of governance in the U.S. that coexisted with a cultural revolt against that very mainstream" (Isaak 2009:136). This "cultural revolt" was nevertheless part of a consistent Valley culture, within the stable and consistent U.S. macroeconomic and policy mainstream, and promoted Enright's (1995) homogeneous transaction space, which lower transaction and coordination costs, and accelerate the flows of knowledge, influence, resources, and the other ancillary processes that bring ideas to fruition. Governments must promote a stable and predictable macro environment for confident decision-making and fluid interactions between all agents within the innovation system. Furthermore, as happened with the Stanford Industrial Park, large energy technology firms could co-locate subsidiaries with agglomeration-sensitive activities (Gray *et al* 1998) next to loci of learning in industrial parks within a consistent regional innovation system.

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[3] That is, a particular technology should not be favored for politically expeditious reasons, such as appealing to constituents. RE policy should not be codified in terms of specific technologies, but in terms of specific support for emergence pathways and Renewables Portfolio Mandates.

[4] See Annex 2.

4.3.2 Poor funding models appropriate to stage of development

With RE innovation, not only is policy stability essential (Negro *et al* 2012, Victor and Tanosek 2011, Carley 2011), but so too is stable public funding, together with private funding, throughout the innovation process[5] (Narayanamurti *et al* 2012, Chapple *et al* 2010, Victor and Tanosek 2011, IPCC 2012). Furthermore, the models of funding should vary appropriately with the stage of development and the technology-emergence pathway (Bonvillian and Weiss 2009). Government should provide substantial and stable funding support to unguided basic research and radical innovation programs – not established RE technologies – at research universities, institutes, and government laboratories. For innovations closer to commercialization, but for any one of the various reasons that might make it unenticing to private investors, the government should adopt a multi-stage funding approach akin to VC funding, as we shall see below.

With Silicon Valley, we noted the absolutely essential character of stable government defense contracts in the founding and early boom of technological innovation. Toward Narayanamurti *et al*'s (2012) point about the heterogeneity of the various stages of development, in the Valley the government was supportive of the whole system, from research and development on through to demonstration and into production (e.g. cost-plus and two-part contracts). This created a competitive – yet supportive – and open and collaborative (e.g. second-sourcing and the freely available nature of intellectual property generated from government funding) form of accelerated technological innovation. This was particularly true for the Valley's early technologies (e.g. vacuum tubes and microwave electronics) where government purchases accounted for half to virtually all demand, and which were not consumer oriented – quite analogous to the

[5] For example, funding difficulties include the following: 1) It may be difficult for private companies to fully appropriate the returns of investments in some R&D activities, which reduces incentive; 2) firms may be reluctant to take on the risk associated with investing in a new technology that may not ultimately succeed technically or have a market (particularly given the role of policy in forming markets); 3) the timeframes involved in taking a technology from R&D to mature adoption may exceed payback timeframes required by private investors (IPCC 2012). Or, taken another way, the government's role could be understood as filling the *technology gap*, by funding basic research into promising projects, and the *commercialization gap*, which refers to proving technologies by large-scale demonstration and early deployment, before the private sector becomes involved (Victor and Tanosek 2011). Quite analogous to the (unintentional) role the U.S. military played in the Valley with the semiconductor technologies, which transitioned successfully, as an industry, from over 50% government market share to almost entirely private market share.

likewise non-consumer oriented energy generation and transmission technologies, for which, as Narayanamurti *et al* (2012) states, market signals are limited and uncertain.

Furthermore, funding must be directed towards true innovation. Nearly 90% of global investment in clean energy goes toward deploying existing technologies, which are not competitive without government support, and only a fraction goes toward innovation. With more substantial "pull" policies[6], focused "push" funding could achieve more. Larger shares of these scarce research funds must be invested in truly radical leaps forwards (Victor and Tanosek 2011). Additionally, such funding could be managed as VCs manage their overall investment portfolios. A few highly successful technological innovations within a diversified portfolio of risky, ongoing energy programs would 'cover', or compensate for the unsuccessful programs[7]. Also, like a VC, a law firm, or Terman, appropriately knowledgeable and positioned government officials should be actively engaged with the other agents in the system as a resource and facilitator, offering expert advice, brokering useful contacts, and in all ways trying to add value to their investment.

With regard to the criticism that public funding of innovation can create dependency[8] – that is, a tendency to keep technologies at the R&D and first demonstration stages rather than accelerating them through to deployment – the IPCC (2012) notes the use grant-support models that are linked to performance and allow for developers to build a track record. Taking this further, we are reminded of the VC model of funding where financial commitments are made in phases as a carrot-and-stick method of encouraging performance and aligning incentives. Certainly this can be done in a way that transmits

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[6] "Pull" policies include mandates, renewable portfolio standards, and carbon taxes.

[7] It is worth stressing, however, that even then there is benefit to the system. For example, Ruegg and Thomas (2009) reveal that research funded by the U.S. Department of Energy is built upon more extensively by leading wind energy companies than research funded by any other organization. Even when DOE-funded companies ultimately failed, the intellectual property and many of the innovations continued into highly successful wind companies though patent acquisition and human capital migration. It also turned up in many non-wind companies.

[8] Victor and Tanosek (2009:114) state that direct cash grants to "shovel-ready" RE (commercially ready technologies) during the Obama stimulus *"gave few incentives to cut costs so as to make these technologies more competitive in the long haul"*. Dove-tailing perfectly, a scientist with a military products Silicon Valley firm that did *not* survive the transition from military contracts to the private market said, *"The government doesn't train us to do things cheaply"* (Leslie 1993:85). The point to underscore is that the government should be extremely judicious in how it supports mature technologies, wary of stunting technologies by completely insulating them from competition.

the necessary stability to basic RE research, yet exacts increased rates of performance from application development. If a program fails to make progress towards negotiated expectations, the funding entity responsible (e.g. ARPA-E in the U.S.) should have the freedom to pivot in a new direction, closing the program and redirecting the funds and resources (Foxon *et al* 2005). Just as in the high-mortality ecosystem of Silicon Valley, even failure produces knowledge and human talent that are not lost, but recycled in the system in novel reconfigurations to its enhanced health (Bahrami and Evans 2000).

4.3.3 Market bias towards embeddedness, the 'Valley of Death', and externalities

Renewable energies must contend with the ***embeddedness of existing energy systems***, and the resistance of incumbents (carbon lock-in). Fossil fuel technologies benefit from decades of deep integration into the economy, resulting in a large, expensive, and deeply embedded infrastructure, as well as socio-institutional embedding. This makes them cheap, efficient, produced in large quantities and optimally aligned to institutions and customer and firm preferences. The inertia disincentivizing RE innovation is tremendous. In addition, incumbent firms may also deliberately attempt to block their development (Parrish and Foxon 2009).

Another problem is the ***limited and uncertain market signals***[9] for energy research, development, demonstration, and deployment. This is particularly true with regard to overcoming the so-called "Valley of Death", which is the phase in the technology lifecycle just before market introduction and includes demonstration and early market formation. This is an extremely high-risk phase that has difficulty attracting private investment given the high uncertainties about market success coupled with high investment costs (Negro *et al* 2012, Bonvillian and Weiss 2009, IPCC 2011). For this reason, the government is typically attributed the responsibility for bridging this gap.

[9] For example, 'the externalities of greenhouse gas emissions and energy security are not appropriately represented in the market, and thus there is wide-spread belief that the RD&D and deployment that take place are not commensurate with the challenges facing the energy sector and the technical opportunities that are available' (Narayanamurti *et al* 2009:59).

Finally, there are the market failures of unpaid ***negative externalities*** arising from the GHG emissions of legacy, fossil-based electricity production, as well as the largely market-unrecognized and positive externalities of avoided GHG emissions and energy security.

To address such market failures, we could certainly discuss the legitimate – and likely necessary – role of government-promulgated standards, including Renewables Portfolio Standards, fuel consumption standards, cap-and-trade mechanisms, and other environmental regulations. However, let us look again to the Valley and consider the role of the ***entrepreneur***. The Valley has a history of innovative business models[10], a fearless appetite for new forms of entrepreneurship and challenging established institutions and business strategy assumptions (Bahrami and Evans 2000).

Certainly, given the embeddedness of existing energy systems, it can seem a hopeless endeavor for anyone but a strongly politically willed central government. While the majority of the literature, as well as this dissertation, focuses on the changes necessary to institutions, or socio-technical transitions, Parrish and Foxon (2009) position ***sustainability entrepreneurship*** as a critical tool in the transition to a sustainable economy[11]. Sustainability-driven entrepreneurs can *"catalyze co-evolutionary*[12] *changes to institutions and technologies, resulting in larger-scale socioeconomic transitions toward sustainability"*, challenging the lock-in of dominant technologies by increasing selective pressures on other actors within the system (Parrish and Foxon 2009:56).

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[10] E.g.: Reverse markets, where clients advertise their needs to suppliers; "fabless" (no fabrication, design-only) semiconductor companies; so-called networks effects driven models, where a product's value (and profit) rises exponentially with increased market share; etc. (Nevens 2000).

[11] Sustainability-driven entrepreneurship *"employs private enterprise as a vehicle for contributing to environmental quality and social well-being, in addition to satisfying the entrepreneur's own quality-of-life interests"*. They are attributed *gap filling* and *catalytic* functions (Parrish and Foxon 2009:48).

[12] *"Causal mechanisms for co-evolution involve altering selection criteria or changing the replicative capacity of elements"* (Parrish and Foxon 2009:56). *"A successful low-carbon business strategy enhances the selective pressure for [its] institutional niche against its alternatives: for example, by increasing the expectations of other actors within the system that this institutional niche will endure over time and by increasing the dependence on that niche of other actors that follow complementary strategies"* (Parrish and Foxon 2009:57, emphasis added); such as Tesla Motors radically changing the expectations of electrical vehicles in the auto industry.

While not unique to the Valley, this form of entrepreneurship is evident with Tesla Motors in Palo Alto, California, which was *"was founded in 2003 by a group of intrepid Silicon Valley engineers who set out to prove that electric vehicles could be awesome"* and *"accelerate the world's transition to electric mobility"* (Tesla 2012). It has arguably been quite successful at changing the perception of electric cars from underpowered, egg-shaped vehicles to that of, first, high-performance and style, and then, high mass-market potential. Sustainability entrepreneurs, by introducing innovative business strategies or altering the selection criteria, can diminish selective bias against renewable energies and significantly increase selective pressure on existing institutions, and so induce change within the market beyond their market share[13].

4.3.4 Knowledge diffusion

Another significant system problem is poor knowledge diffusion and a lack of understanding between agents throughout the innovation system. In particular, there is poor diffusion of the knowledge created at university into industry, and a converse lack of feedback the from industry to university creates a misalignment between what is produced in basic research and what is needed for applied development in industry. Thus, a potentially highly mutually beneficial dynamic in the system is performing poorly. Poor knowledge flows negatively impact the effectiveness and understanding of the policy, technology, finance and demand communities within the system (Foxon *et al* 2005).

Certainly, we are reminded of the role of Stanford University in Silicon Valley's success. Fred Terman forged close working relationships between Stanford's labs and local industry, directing student research towards answering practical industry problems, and then diffusing that knowledge back into the system. The formation of Stanford Industrial Park, with new and established firms clustered close to university resources, provided a further mechanism for transferring knowledge from university laboratories to local industry. The Honors Cooperative Program allowed working engineers to stay up to date with the newest technologies in their fields, and also kept

[13] See Parrish and Foxon (2009) for a specific energy case study of sustainability entrepreneurship.

the university current on the industry. Likewise, similar university-industry collaboration on firm-incubating research parks and adult education programs should be promoted.

This is critical, given the importance of the dynamic between research universities (institutions) and closely clustered large and small firms in a regional innovation system (Cooke 2010). An excellent example lies in the Californian East Bay, just north of Silicon Valley. Containing the nationally funded research labs Lawrence Livermore National Lab, Sandia National Lab, and Lawrence Berkeley National Lab – housed at University of California–Berkeley –, as well as several large petroleum companies, which lead the state in alternative fuels, the East Bay has by far the densest concentration of any green economy activity in California[14], as measured by location quotient[15]. Energy research and services register an exceptionally high location quotient of 10.5 (Chapple *et al* 2010)[16].

Negro *et al* (2012) also highlights poor diffusion of technical knowledge causing a shortage of skilled staff to support the new technologies, for *"when innovations radically differ from existing ones, [this] requires new educational programs and it takes a long time for the educational system to pick up these changes"*. With regard to quickly qualifying a skilled workforce of engineers and skilled technicians with the competencies necessary for installing and maintaining the newly deployed infrastructures of RE, we can again look to the example of the Valley's (and California's) excellent network of state universities and community colleges. A regional economy, a cluster, an innovation system *must* have a strong and competent

[14] Fifteen entities were responsible for 29% of all Californian clean tech patents between 2000 and 2008, suggesting that large, well-established actors play a significant role in innovation in California's green economy. In particular, the *"involvement of universities such as the University of California and the California Institute of Technology suggests that the resources required to conduct research and develop new energy-related technologies may be so high that small firms and individual inventors are not yet leading the process of innovation in the green economy"* (Chapple *et al* 2010:12).

[15] The location quotient measures the relative share of a particular activity vis-à-vis the local economy. A location quotient of 1 means the activity is in proportion, below or above 1 means the activity has a lower or higher than expected share of a given activity, relative to the size of the economy.

[16] Reinforcing our understanding as to the importance of clusters in the green / renewables innovation process, so central to this thesis, Chapple *et al* (2010) writes: *"green innovation is highly concentrated in a handful of California regions… This clustering provides support for previous work on regional innovation systems and the association between innovation and localization economies"*.

complement of learning institutions ready to supply the necessary knowledge appropriate to all labor segments within the renewable energy value chain.

Of course, one of the best methods for diffusing knowledge and developing new ideas is by employees leaving a firm, combining with other skilled and mobile actors and starting their own firm – the spinoff process, famed in the Valley. The benefits of such a process to radical renewables innovation is implicitly understood, yet let us consider the benefits of the inverse process, also very pronounced in recent years in the Valley and explored in the context of the concept *ambidextrous innovation* – the *spin-in*.

Again, while large firms and institutions have a clear advantage in capital-intensive R&D, small firms demonstrate an advantage in R&D that is more dependent on flexible and skilled labor (Chapple *et al* 2010). We can quite easily imagine co-located firms of different sizes and related varieties benefiting from each other's comparative advantages in an open, regional innovation system with ambidextrous innovation processes so integral the Cisco Systems paradigm (Cooke 2010, Ferrary 2011). Component technology ideas more dependent on skilled labor for development can be quickly financed and developed within the nimble vehicle of a startup that, at an appropriate point in its development, may be acquired by a larger firm (*spun-in*) and integrated into a complex renewable energy technology offering.

4.3.5 Rules and norms of the innovation system

The rules and norms – or culture – of an innovation system can themselves impair the fluid functioning of an innovation system. This is understandable, given the emphasis the innovation systems concept gives to the relations and flow of influence between agents.

Negro *et al* (2012:3843) reveal that the most commonly observed system problem regarding entrepreneurs is how they interact with other entrepreneurs. They "already compete at a very early stage with each other, instead of forming coalitions and alliances" to better influence regulations and help form their respective markets. It is “only after encountering difficulties, disappointments and lack of support from government [that] entrepreneurs select more cooperative strategies”. This type of attitude certainly further arrests the flow of knowledge within the community and the advancement of their technologies to commercial stage.

To be sure, the protection of competitive advantage and intellectual property is of concern to all entrepreneurs hoping to arrange financing and profit on their work, but it is not insurmountable with the proper arrangements (Foxon *et al* 2005). Entrepreneurs could benefit from the example of Silicon Valley, where healthy competition did not take precedence over dedication to the craft, and where extensive cross-firm collaboration among communities of practice and liberal cross-licensing of patents resulted in mutually beneficial cross-pollination and established technical standards, ensuring that the practitioners of the craft benefited from using the very latest technology, and in turn advanced the craft.

Further, given the focus of innovation systems on the free flow of knowledge and influence among actors, it is clear that any such system would benefit from emulating other dynamics and characteristics of the Valley, such as: flattened hierarchies, which increase speed of knowledge flows; labor mobility, openness and collaborative spirit, which lead to the recombination of ideas and talent into new ventures; risk-taking and failure-acceptance, which encourage the development of new ideas and, win or lose, create experience and know-how that is in turn recycled into new projects; and a passion for work and innovation of craft rather than preoccupation with place in established hierarchies of prestige.

Table 1: Renewables Innovation: Systemic Problems and Recommendations

System Problems	Description	Silicon Valley Lessons / Suggestions
Lack of stability and consistency in government policy	Uncertainty arising from short-term energy policies and misalignment across levels of government with regard to RE incentives and standards. This encourages incremental innovations and investment in "safe", conventional RE instead of high-risk, high-reward radical innovation.	Silicon Valley enjoyed a homogeneous transaction space of a unique, shared, innovation-conducive counter-culture enveloped in a stable and consistent U.S. macroeconomic and policy mainstream. Governments must promote a stable and predictable macro environment for confident decision-making and fluid interactions between all agents within the system.
Poor funding models appropriate to stage of development	Funding models must be structured so as to best support the process at each stage, whether it be basic R&D, demonstration, pre-commercial (Valley of Death), or supported commercial.	Stable R&D funding for basic research at research universities and government labs. VC-type, performance-based, multi-stage funding for applied research/ product development. Note: Large, unscrutinizing military contacts at this stage left some Silicon Valley firms unprepared to survive in the private market.
Market bias towards embedded energy systems, resistance of incumbents (Carbon lock-in)	Fossil technologies enjoy advantages of economies of scale, long periods of technological learning and socio-institutional embedding (including exerting influence to maintain status quo). Embeddedness tilts the field against new technology uptake.	Risk-taking entrepreneurship and radically new business models can challenge the status quo, challenging embedded technologies. Sustainability-driven entrepreneurship can alter the selection criteria in a market and place selective pressures on incumbents to change.
Valley of Death	Phase in the development of a technology wherein there is a large, negative cash flow from increasing development costs, but the risks are not reduced enough to attract private investors.	Cost-plus contracts for high-risk and cost development and demonstration. Two-part contracts - R&D and production - assured firms a market for their innovations. However, must be carefully guided by reasonable, established performance-based criteria to avoid dependency and interminable development.
Market Failure	Negative externalities of fossil and positive externalities of RE are inadequately represented in the market.	Innovative business strategies alter selection criteria; can have a significant impact in inducing change in embedded agents through a co-evolutionary process.
Knowledge Diffusion	Gap between the knowledge produced at university and what is needed in industry. Lack of cooperation and strategic direction. Diffusion of technical knowledge in support of new RE systems.	The role of Stanford, Terman, and the adult university programs ensured communication between actors, directed university research to industry problems, and maintained a qualified industry workforce. Educational programs at CSUs and community colleges offered region-relevant educational programs.
Rules and Norms of the Innovation System	Entrepreneurs compete at a very early stage instead of forming coalitions and alliances in order to be more influential.	Healthy tension between collaboration and competition. Open innovation practices. Networks among communities of practice. A loyalty to the craft, flattened hierarchies, labor mobility, risk-taking, and failure-acceptance boost the system.

5. DISCUSSION & CONCLUSION

Climate change and energy insecurity constitute serious threats to the stability and continued viability of our modern society and global economy. Continued myopic dependence on fossil fuels, with its severe yet largely non-market negative externalities, is a dead-end strategy with stark consequences for our closed, planetary system. Beyond the grave concerns to biological and planetary systems as we know them, GHG emissions and cross-national dependency on the very lifeblood of economic activity, energy, increases economic vulnerability, imperils national security, enables distracting and costly geopolitical imbalances, and undermines national sovereignty itself. For these reasons, it is critical to transition to sustainable, secure, and low-carbon energy. To that end, we must endeavor to replace GHG-emitting primary energy sources with renewable energy technologies that will produce clean final energy – primarily electricity – to power our homes, factories, and eventually cars.

To be clear, renewable energy polices are not meant to substitute climate change policies, *"as the most cost-effective carbon mitigation policy is one that prices explicitly the use of carbon-intensive generation"* and *"energy policies are less cost-effective for carbon mitigation because they do not directly address the market failures associated with climate change"* (Carley 2011:289). Addressing the market failure directly would mean putting a price on carbon, via a tax or a cap-and-trade market. Further "pull" methods include Renewable Portfolio Standards, fuel consumption standards, and outright banning of certain generation methods. However, in hand with this, accelerating the supply of energy innovation is critical because "technology supply will assure industry, consumers, and markets that putting a price on energy demand *will work and be affordable*" (Bonvillian and Weiss 2009:56, emphasis added).

Supply of innovation has been the focus of this dissertation. More specifically, accelerated supply, for the provision of innovation is time-critical, whether we consider the time constraint is planetary (climate change mitigation), from policy (meeting standards), or market-based (first-to-market, competitive advantage). With that, however, we also recognized the interest in capturing the economic benefits of innovation in renewable systems within regional and national economies. Industrial clusters are the critical mass at which innovation and competitiveness are achieved and sustained. In this sense, an external (planetary) time constraint is not the disciplining factor. Rather, it is the time it takes to produce innovation and get it to market. If the flow of knowledge and resources among the various agents interacting in the system is obstructed, if the stable policy support framework for the various stages of technological from basic research into mature commercialization are lacking, the system risks failure. Unless the intent is to simply be a buyer of the technology and not reap the benefits of producing it, those looking to stoke regional and national advantage in this emerging industry need to look to the innovation systems within clusters as the vehicle to achieve those objectives.

If innovation in renewable energies must be accelerated, and we wish to capture the economic benefit of such innovations, we must, of course, understand the process of innovation, where and how it arises, and what problems obstruct its dynamic. Modern theory approaches this through *innovation systems*. Highly effective innovation systems are characterized by localization and so are often approached as *regional innovation systems*. A survey of the literature regarding the economics of regions contextualized our discussion, revealing the considered factors driving our progression of thought on innovation and industrial competitiveness; building from Marshallian agglomeration economies though to localized innovation systems.

We saw that innovation systems are *"socio-technical configurations of actors, rules, physical infrastructures and their relations"* (Negro *et al* 2012:3837) including the flows of knowledge and influence in addition to market transactions (Foxon *et al* 2005), and that innovation accelerates when located within the concentrated economic activity of related firms in an industrial cluster, which facilitates knowledge spillovers and stimulates adaptation, learning and creation (Yu and Jackson 2011).

We then took a look at the maximum exponent of an accelerated regional innovation system, Silicon Valley, for *concrete lessons / guidance* as to how we might address system problems, accelerate innovation in RE, and so supply the means to the radical changes we need in a short period of time.

From SV's example, we saw the importance of stable government funding to basic research and universities and government labs, and of consistent and stable policy instrument support throughout the innovation process into mature commercialization. Government aid for applied innovation at the interface between research and private firms support should follow a block-funding approach, holding programs accountable for performance.

Universities have a crucial role in ensuring knowledge flow between themselves and industry, apprising industry of new research, and directing research toward industry problems. These interactions can take place through partnerships on associated industrial parks and professional adult learning programs like Stanford's HCP. But it isn't just about research universities. The success of an innovation system and the competitiveness of a regional economy depends on a skilled and competitive workforce, including scientists and engineers from universities and technicians from community / professional schools. However, this also includes quality agents in support roles within the innovation system, such as lawyers, financiers, and other business service providers.

Further, innovation systems would benefit from emulating the dynamics and characteristics of SV such as: flattened hierarchies, labor mobility, an open and collaborative cross-community of practice spirit, risk-taking and failure-acceptance, which all accelerate the processes of innovation.

Finally, it bears noting that the central preoccupation of any region or nation seeking to create a dynamic innovation system within a renewable energy cluster is not the technology itself, but the conditions under which systemic problems to innovation are minimized and the factors promoting it thrive. As demonstrated, the Valley did not appear spontaneously, but grew over time from a confluence of purposeful complementary factors and reinforcing characteristics. Even at its supposed beginning, with Fred Terman, Shockley and Fairchild Semiconductor, the reunited factors and characteristics were decades in the making. Further, the Valley has not congealed into an IT cluster, but has continued to reinvent itself through successive waves of industry and innovation, branching most recently into bioscience, nanotechnology, clean tech, and other industries. Although a product of its history, regions that are attempting to create the type of dynamism found in SV, can think of renewable energy as their FTC or Fairchild; the beginning of their cluster and a thriving innovation system. If we take the long view of history, a green energy economy is not simply the destination, but a path to regional and national competitiveness, and prosperity.

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ANNEX 1 - Nine characteristics of the *innovation systems* framework

Edquist and Hommen (1999:65-6) formulate the following, very useful, comprehensive list of innovation systems characteristics.

1. ***They place innovation and learning processes at the center of focus.*** This is based on the understanding that technological innovation is a matter of producing new knowledge or combining existing elements of knowledge in new ways. It is thus, in the broadest sense, a "learning process".
2. ***They adopt a holistic and interdisciplinary perspective.*** They are holistic in the sense that they try to encompass a wide array—or all—of the determinants of innovation that are important. They are interdisciplinary in the sense that they include not only economic factors but also organizational, social and political factors.
3. ***They employ historical perspectives.*** Since processes of innovation develop over time and include the influence of many factors and feedback processes, they are best studied in terms of the co-evolution of knowledge, innovation, organizations, and institutions.
4. ***They stress the differences between systems, rather than the optimality of systems.*** They make the differences between systems of innovation the main focus, rather than something to be abstracted away from. This means conducting comparisons between existing systems rather than between real systems and an ideal or optimal system.
5. ***They emphasize interdependence and non-linearity.*** This is based on the under- standing that firms almost never innovate in isolation but interact more or less closely with other organizations through complex relations that are often characterized by reciprocity and feedback mechanisms in several loops. This interaction occurs in the context of established institutions such as laws, rules, regulations, norms, and cultural habits. Innovations are not only determined by the elements of the systems, but also by the relations between them.
6. ***They encompass product technologies and organizational innovations.*** This is based on the understanding that developing a differentiated concept of innovation—one that is not solely restricted to the conventional emphasis on process innovations of a technical nature—is necessary to comprehend the complex relations between growth, employment, and innovation.
7. ***They emphasize the central role of institutions.*** They do so in order to understand the social patterning of innovative behavior—its typically "path-dependent" character—and the role played by norms, rules, laws, etc. and by organizations.
8. ***They are still associated with conceptual diffuseness.*** Thus, further development will involve progressing from the present state of "conceptual pluralism" to a clearer specification of core concepts and their precise content—a gradual selection process in which pluralism and ambiguity will be reduced by degrees.
9. ***They are conceptual frameworks rather than formal theories***. Recognizing that SI approaches are not yet at that stage of development where they are capable of formal (abstract) theorizing leads to an emphasis on empirically based "appreciative" theorizing. Such theorizing is intended to capture

processes of innovation, their determinants, and some of their consequences (e.g., productivity growth and employment) in a meaningful way.

ANNEX 2 - Technology-emergence pathways and corresponding recommendations

Considering technologies follow several pathways to emergence at scale, for which different support instruments should be designed, Bonvillian and Weiss (2009) formulated the following noteworthy categories for common technology-emergence pathways with corresponding suggested support policies:

Experimental technologies
This category includes technologies requiring extensive long-range research. Deployment is far off so that the details of their launch pathways can be left to the future.
Examples: hydrogen fuel cells for transport; genetically engineered biosystems for CO2 capture; and, well into the future, fusion power.

Potentially disruptive technologies
These are innovations that can be launched in niche markets where they will face limited initial competition and can challenge incumbents.
Examples: off-grid wind and solar technologies and LED lighting.

Secondary technologies (uncontested launch)
This group includes secondary (component) innovations that will face market competition immediately on launch from incumbents. They are acceptable to recipient industries if the price is right, but may face built-in disadvantages to incumbents.
Examples: advanced batteries for plug-in hybrids, enhanced geothermal, and on-grid wind and solar.

Secondary technologies (contested launch)
In addition to the barriers facing uncontested technologies, may face economic, political, or other opposition from industries our groups.
Examples: carbon capture and sequestration, biofuels, and fourth-generation nuclear power.

Incremental innovations in conservation and end-use efficiency
These innovations may be implemented in the short term, but may present high initial costs and long payback times.
Examples: improved internal combustion engines, improved building technologies, efficient appliances, improved lighting, and new technologies for electric power distribution.

Improvements in manufacturing technologies and processes
These innovations drive down costs and improve efficiency, but may be dissuasive to investors in the absence of market pressure.

To these, the authors espouse the following support policies:

Front-end technology nurturing
For technology that is far from commercialization along all six pathways.
Actions include: direct government support for long- and short- term R&D, technology prototyping, and demonstrations.

Back-end incentives
To close the gap between emerging and incumbent technologies facing both uncontested and contested launch, incremental innovations in technology for conservation and end use, and technologies for manufacturing.
Actions include: tax credits, loan guarantees, low-cost financing, price guarantees, government procurement programs (including military), new-product buy-down programs, and general and technology-specific intellectual property policies.

Back-end regulatory and related mandates
Actions include: standards regarding energy applications across sectors, regulatory mandates such as renewable portfolio standards and fuel economy standards, and emission taxes.