Innovating for Sustainability
Dr. Andrew Hargadon lectures for the SFI Global Sustainability Summer School
Summarized by Catherine Bottrill and Sharon Gourdji

The transformation of modern society from consuming natural resources unsustainably to sustainably necessitates developing new ways of living. This involves a combination of openness, creativity and innovation of new government policies, technologies and behaviours that support and encourage sustainable living. Through the course of the Santa Fe Institute Global Sustainability Summer School we discussed a variety of emerging and possible innovations that if widely adopted could mitigate dangerous climate change. These discussions included: the development of a carbon market, deployment of large-scale renewable energy generation, use of light weight materials, creation of intelligent electricity systems and new consumer preferences.

Three speakers discussed explicitly the innovation process: Andrew Hargadon, Arnulf Grubler and Nebojsa Nakicenovic. This chapter summarises Hargadon's key insights on the innovation processes, which centred on the idea that for invention to be transformative, it must be supported by the appropriate social network to take the idea to reality. Hargadon's discussion complemented those of Grubler and Nakicenovic who later in the course spoke about the significant time it typically takes from the emergence of a technology to its diffusion and widespread uptake across society. The lengthy time associated with the innovation process is a challenge for enabling the transition to sustainable ways of living within the timeframe available for adverting dangerous climate change. An understanding of the innovation process will help society to identify ways of possibly fast-tracking this process, as well as appreciating the constraints on assuming that technological innovation will be the panacea for delivering sustainability.

Andrew Hargadon is a professor in the Graduate School of Management at the University of California, Davis, specializing in entrepreneurship and innovation. His previous experience as a product designer at Apple led him to the study of the history and practice of technological innovation. For example, why do some great ideas and technological solutions sit on the shelf while others become widely adopted throughout society? Dr. Hargadon also founded the Energy Efficiency Center at UC Davis, as well as a Green Technology Entrepreneurship Academy, which has helped to launch green technology companies by linking innovators in academic institutions with the funding agencies, corporations and venture capital firms that can help to get their ideas implemented. In a two talks entitled "Innovation and Sustainability" at the SFI Global Sustainability Summer School, Dr. Hargadon discussed his theories of innovation and how they apply to the particular challenges associated with technology development for sustainability.

The first myth that Dr. Hargadon tries to dispel through his work is the "great man" theory for explaining key inventions in human history, i.e. the lone genius at work in his laboratory who is slightly insane, but also a brilliant problem-solver. Dr. Hargadon uses the stories of Henry Ford and Thomas Edison to dispel this myth, by showing how each of these men relied on their social networks and existing innovations to bring the right idea to market at the right time. Neither of them was an "inventor" in the sense of creating ideas that had never before existed. In fact, Thomas Edison drew on existing innovations in the telegraph and gas lighting industries to develop the electric light-bulb. In addition, Edison worked with someone named Charles Bachelor who was primarily responsible for the 400 patents that came out of the Edison laboratory between 1876 and 1881! Yet in order to maintain the public perception of himself as the lone genius, Edison was not beneath smearing soot on his suit before giving interviews with the press. How these men actually achieved what they are known for (i.e. mass production of cars and the widespread implementation of residential electricity in the United States) is the subject of Dr. Hargadon's first lecture. Dr. Hargadon's second lecture continues to develop the same themes, but focuses more on the process of innovation and its diffusion in society through social networks.

Theory of innovation

A textbook definition of innovation might be the "generation of novel, valuable and non-obvious ideas", although how this actually occurs is the subject of academic debate. Dr. Hargadon relies on a quote from the famous economist Joseph Schumpeter to make the point that we should not misequate invention with innovation. "As long as they are not carried into practice, inventions are economically irrelevant. And to carry any improvement into effect is a task entirely different from the inventing of it, and a task, moreover, requiring entirely different kinds of aptitudes."

In Dr. Hargadon's view, innovation is ultimately about connecting, not inventing. Innovation can be defined as moving existing ideas from where they're known to where they're not known, often in new combinations. This process also relies on two different practices requiring completely different skill sets: coming up with something new (i.e. creativity) and getting it done (or entrepreneurship). For most successful innovation efforts, these two practices have to happen simultaneously, usually in teams where this work can be divided across different kinds of people.

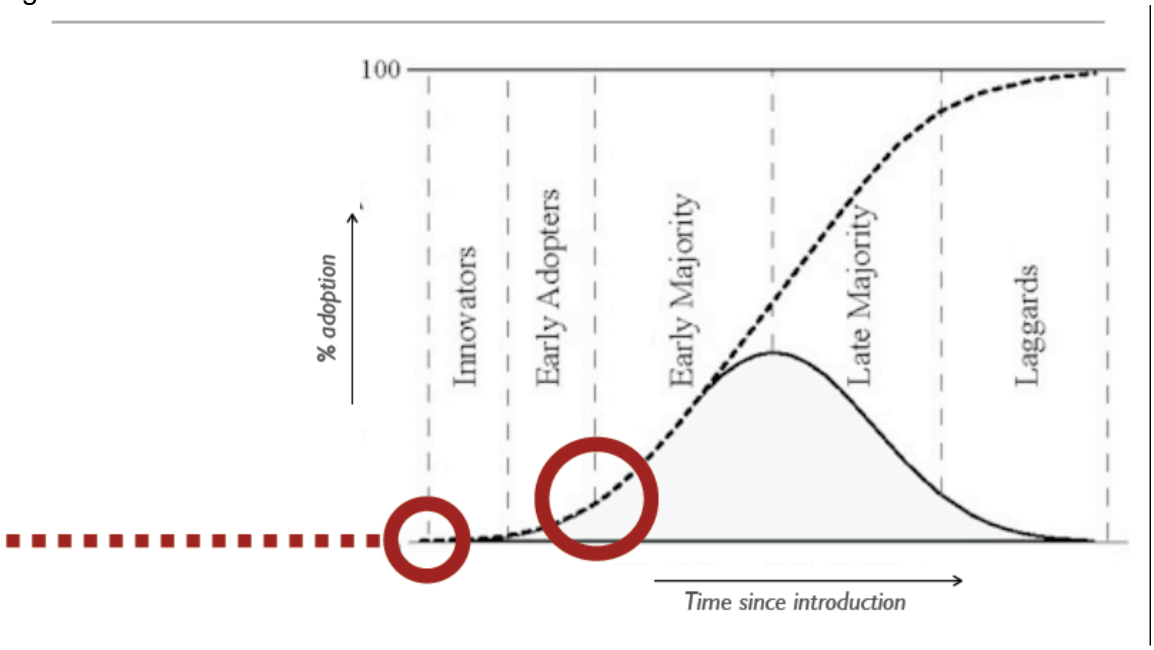
These current theories of innovation counter the tendency of society at large to focus on individuals as the drivers of change. For example, for the last 50 years or so, psychologists have "owned" the concept of creativity and primarily defined it in terms of individual character traits such as tolerance for ambiguity or fluency with new ideas. However, when starting to think about innovation as connecting what's already out there, Dr. Hargadon suggests that creativity should be seen as more than just an innate quality and also as a product of your environment. Humor provides a similar example, where a person's ability to be "funny" frequently depends on the situation where the person is telling the joke.

If one accepts the notion that innovation is ultimately about connecting people and ideas, social network theory, a modification of graph theory from computer science, can be used to map out people's networks, i.e who knows whom and who is talking to whom and how often. "Effective range" is defined as how far apart are the farthest people in a given network. Having a larger effective range increases the probability that someone will be able to take an idea from one corner of their network to another corner where it is not known and highly valuable. When everyone within your network only interacts with other people within this group, the effective range is narrower, lowering the probability of spreading a new idea throughout society at large. According to a number of academic studies, having a larger network is also associated with other personal benefits, such as quicker recovery from colds, less time to find a spouse or a job, resilience to stress, longer lives, etc.

Innovation adoption curve

Inventions widely diffused throughout society will have transitioned through successive innovation adoption stages (Figure 1). Understanding the adoption progression of an invention from its early adoption to its mass diffusion through a population is critical for comprehending the innovation process. There are four key stages in the adoption of an invention: early adopters, early majority, late majority and laggards. The inflection points in the transition from one phase to the next are decisive in determining the diffusion rate and pervasiveness of the invention. An invention has limited significance unless people know of its existence, and it's coming into existence depends on the effective deployment and uptake through a social system rather than the value of the invention in and of itself. Innovation of inventions is about getting things done so that ideas have a realised value within society. Therefore, the social network surrounding the ideas is pivotal for when and how it gets up-taken by members of society.

Figure 1:



The first stage of innovation diffusion is characterised by early adopters who are pioneers of the invention. The task of the inventor group is to identify and target those likely to be willing early adopters of the invention. Early adopters will typically actively seek new inventions, while bearing the risks of invention failure; they will also pay a premium for the satisfaction of being a forerunner supporting a new invention of interest. These adopters are crucial in providing inventors with the ability to test, refine and strengthen capabilities of the invention so that any shortcomings can be resolved. The development of a robust invention with value in the early adopter stage can help the transition to the next stage of innovation diffusion: early majority.

The early majority stage is whereby the invention becomes more widespread as it is accepted as being of beneficial value to adopters. However, as with the first stage, uptake is not dependent solely on the quality of the idea in itself, but also on its strategic placement for uptake within the social system. The early majority is probably the most critical stage for widespread diffusion of the invention, as this is when the critical mass needed for supporting the invention is built. Successful diffusion at this stage requires particular attention be paid in two areas: 1) the social network of the inventor group, i.e. the right combination of strategic relationships are being built to scale deployment of the invention; and 2) the social network of the early adopters is positively exposing the next tier of adopters to the invention. If the social networks in either of these areas are not sufficiently open or built, there is the likelihood that the invention will be stalled in the diffusion process. The structure of social networks for the inventor group will probably have greater implications for the diffusion of the invention than the early adapter group. This is because if there is transitional fail from the first set of early adopters to majority adopters, then a good inventor network may be able to find an alternative route for diffusion of the invention.

The inflection point between early adopters to early majority is a point where the invention is credited to a person or group of people. These people may not actually be the true inventors of the knowledge, but rather they are the individuals associated with bringing the invention to the masses. For example, Al Gore is credited for making the “chatting classes” aware of climate change as a “real” problem. He effectively has been the spokesman for 2,500+ scientists that have published an authoritative scientific evidence base of present and future anthropogenic climate change. His involvement in the agenda resulted in a great proportion of society (i.e. the early majority) accepting that people are causing climate change.

The third stage of innovation adoption, known as late majority, is when the invention has become so ubiquitous that it is normalised within the social system. This is because the invention is widely perceived to hold beneficial value to adopters and also adoption costs are low and the risks are minimal. Successful diffusion at this stage of the invention will be due to the extensive social network of the inventor group, which will have created strong strategic relationships to catalyze the invention to all corners of the social system. The original inventors at the early and late majority stages are likely to represent relatively small components of the social network that is now driving the invention forward, as many other crucial connections will be in operation.

The end tail of the innovation adoption curve is the fourth stage, referred to as the laggard adopter stage. These adopters are typically slow and/or resistant to the uptake of the invention for a variety of reasons, such as they have close social networks, so do not have exposure to or trust of external information sources. The successful diffusion of an invention will not depend on the uptake by laggard adopters because for the most part this group comprises only a relatively small proportion of the social system.

Case studies in successful innovation

Dr. Hargadon draws on historical research to provide three case studies that illustrate his ideas about innovation, social networks and technology diffusion. First, he describes the story of Henry Ford, the Model-T, and the mass production of automobiles in the United States. Then, he discusses Thomas Edison and his "invention" of the electric light-bulb as well as other inventions which came out of his Menlo Park lab in the late 19th century. His third major case study focuses on James Watt and his improvements to the steam engine in 18th century England.

Henry Ford and the mass production of the Model-T

Henry Ford did not invent the automobile. In fact, it had been invented 20 years earlier, and the Ford Motor Company was the 4th auto company started by Henry Ford. However, the Model-T became the car that spread throughout American society in the early 20th century as an affordable purchase for the masses. People in the United States at that time had been clamouring for an affordable car for about 10 years, for one reason due to concerns about streets polluted with horse waste! By perfecting the process of mass production, Ford's factory was able to ramp up production from only 1600 cars per year in 1906 to 265,000 cars per year in 1914.

What is mass production exactly? It consists of four key component technologies:

1) Interchangeable parts, e.g. tires which could fit on any car coming down the line. This technology allowed the production process to achieve higher economies of scale than was previously possible.
2) Continuous flow production, i.e. moving work through a factory in a slow, steady, orderly process. This allowed for barges of iron to arrive at one end of the factory, at the same time that finished cars were emerging from the other end.
3) Assembly line, i.e. people performing a simple task as the work moves past them in the factory. According to Henry Ford, "for 8 hours a day, the men have to become part of the machine."
4) Electric motor, the technology that made all this possible. Prior to Ford, factories were powered by steam engines, which had to be built for the ultimate capacity of the plant, leading to underutilization for most of the plant lifetime. In addition, when the steam engine broke, the entire factory had to shut down to wait for repairs. However, multiple electric motors can be used to power a plant, so that they can always be

> added later as the capacity of the plant grows. In addition, maintenance on one electric motor does not affect production in other parts of the plant.

Ford invented none of these four component technologies for mass production. Instead, his innovation lay in bringing them all together. In fact, interchangeable parts had been previously invented in the machine tool industry for armoury production. When large armies had broken rifles, it was much easier to fix them with interchangeable parts. Continuous flow production was already in use in granaries and breweries at the time, from which Ford bought equipment for his factories. Assembly line production had been notoriously documented in the meat-packing industry by Upton Sinclair's The Jungle, published in 1906. Ford's engineers went to the meat-packing industry plants to study their methods of production, and Ford was famously remembered to proclaim "if they can kill cows and pigs that way, then we can build cars that way!" As for the electric motor, Henry Ford got his start working for the Edison Electric Company where he became very familiar with this technology.

Henry Ford himself was aware of the fact that he was not an "inventor" in the popular sense of the word, but rather a "connector" who relied on his network to pull together ideas from many different existing industries. When called to testify before Congress about the invention of the internal combustion engine, he said "I invented nothing new. I simply assembled into a car the discoveries of other men behind whom were centuries of work... Progress happens when all the factors that make for it are ready, and then it is inevitable. To teach that a comparatively few men are responsible for the greatest forward steps of mankind is the worst sort of nonsense."

Thomas Edison and the invention of the electric light bulb

Thomas Edison's lab opened in 1876 with the public proclamation that it would produce "a minor invention every 10 days, and a major one every 6 months." The first lesson to take away from this statement is that successful innovation requires good public relations! However, Edison's lab was also enormously productive, producing 400 patents and all major inventions that Edison is known for within the next five years of the opening of his Menlo Park lab. While relying on a team of "muckers" who worked for him to actually do the inventing, Edison's genius relied on his ability to take ideas from where they were known, e.g. the telegraph industry, to where they had not yet arrived, e.g. the gas lighting industry.

What were some of the key inventions emerging from the Edison lab? The stock-ticker was the first commercial product successfully developed. This pieced together existing technology in the form of a typewriter, a telegraph line, and a telegraph boy who could type in gold prices in order to relay this information from the floor of the stock exchange to J.P. Morgan's office. The second major invention was the mimeograph pen. This was also originally a component piece of an incoming telegraph machine, only with some wire and batteries added on. This pen with an oscillating needle also was sold to the tattoo industry to become the first electric tattoo needle. Finally, and most famously, Edison is known for the invention of the electric light-bulb. As with many other myths, Edison did not in fact invent the first electric light-bulb. In fact, his patent for the incandescent bulb was turned down by the U.S. patent office, as it had already been invented 35 years earlier. However, Edison saw how his ideas in electric bulbs could be combined with other ideas in electric generation and a good business model (i.e. installing equipment in the house and billing for electricity on a monthly basis) to lead to widespread household use of electricity. As such, Edison gets credit for "inventing" the light-bulb.

Edison's innovation in regards to the light-bulb was primarily in finding ways to put old ideas together, and in turn putting these ideas in a form that could be easily adopted. His stated objective was to "replace lighting with gas with lighting by electricity; not to make a large or blinding light, but to make a small light with the mildness of gas." In fact, he started with a 40 watt lamp, but reduced its size to 15 watt in order to mimic the light produced by existing gas lamps. In a review of the new technology, the New York Post offered the compliment that from the outside, it was impossible to tell if a home was lit by gas or the new electric bulb! This perception was critical to the widespread uptake of the electric light-bulb; Edison's new model gave people their existing behaviour with only subtle changes.

James Watt's steam engine
The importance of the innovation adoption process can also be illustrated well with the historical example of James Watt's invention of the steam engine. The widespread adoption of the steam engine was the result of three critical factors: the drive for energy efficiency, the network supporting Watt and his idea, and the profound differences caused by small changes. Steam engine technology had been around for 50 years already when Watt began working on it. However, the existing engine technology developed by Thomas Newcomen was highly energy inefficient, creating a bottleneck for coal extraction. Therefore, Watt set about using the scientific method to improve the energy efficiency of the engine, as there was already evident demand for early adoption of the technology by the mining industry. He focused on the energy efficiency of the separator condenser element in the steam engine, as he figured by getting the cylinders smaller they could move faster and the engines could be smaller. As a result of cylinder improvements, it would be possible to put the engine in more places and for it to have more applications. However, Watt was not creating revolutionary invention but evolutionary change in steam engine technology.

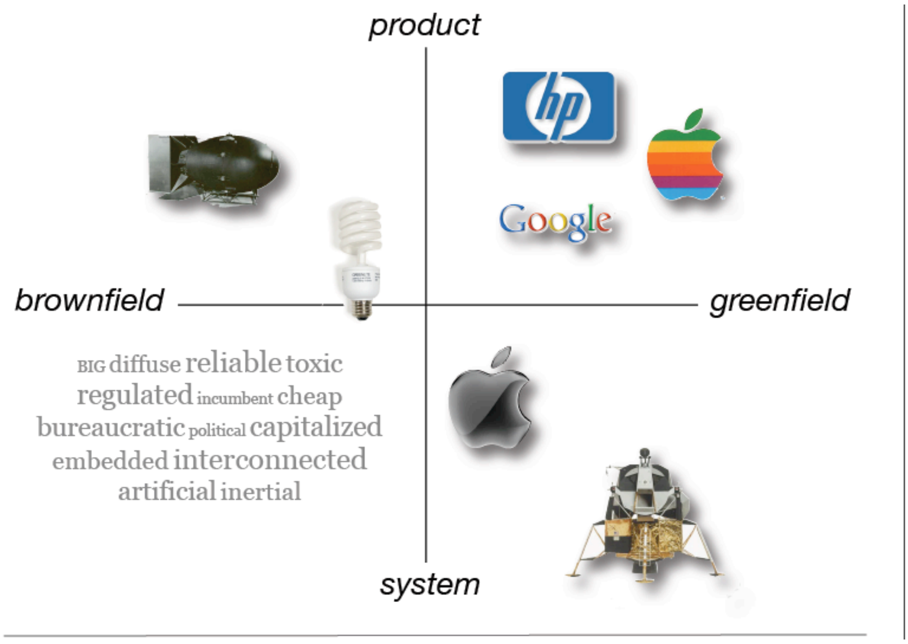
A crucial element for improvements in the steam engine to be successfully adopted was to have the financial investment so that Watt could transform his conceptual ideas into a prototype and then a market product. Initially Watt financed work on the invention himself; however, he quickly ran out of his own financial resources. Recognising he did not have the financial wealth or business acumen for driving his ideas forward, he realised he needed to create the necessary partnerships through his social network. He found an angel investor in John Roebuck to support his work in return for a share of the profits should the invention transpire to be commercially successful. However, even with Roebucks' financial support, Watt realised it was not going to be sufficient especially when Roebucks own financial situation became precarious. By happenstance, Watt met Matthew Boulton when travelling and thought him a strong additional prospective business partner alongside Roebucks. Boulton was a highly successful new industrialist with a business in metal welding various products, which Watt identified as offering a good synergistic relationship for what he was trying to achieve. However, Roebuck was resistant to involving Boulton in the steam engine project despite the case that Watt put forward for them all joining forces. Boulton did though eventually come onboard when Roebuck went bankrupt, as Boulton was able to buy out Roebuck's shares. Boulton had Watt move to his factory where Watt could work with his team of skilled engineers and craftsmen to build a working prototype. In addition, Boulton used his own social network to introduce Watt to James Wilkinson, who had successfully invented a way to bore precise holes into cylinders. This greatly facilitated the construction of a working steam engine prototype. With the working prototype and Boulton's manufacturing facilities, it was possible to meet the early adopter demand already existing in the mining industry.

Challenges in Innovating for Sustainability
After discussing the theory of innovation and social networks and illustrating these with historical case studies, Dr. Hargadon turns to the special challenges associated with innovating for sustainability. Through the example of Thomas Edison, he first stresses the need to find a foothold in the market before any type of revolutionary change can take place. However, introducing "sustainable" products into the marketplace by definition implies the

substitution of existing infrastructure and ways of doing things, which is a much larger challenge than introducing completely new products.

Dr. Hargadon introduced a simple 2x2 framework in order to illustrate the market environments into which different types of innovations are introduced (Figure 2). The vertical axis on this diagram describes the spectrum between a product and a system. Is the innovation a simple product, or does it have to fit into an existing system, e.g. the current electricity generation and distribution system? The horizontal axis shows the spectrum between a Brownfield (or an industry with existing factory infrastructure, unions, etc.) and a Greenfield (a new industry without any of these entanglements). Greenfields are where most success stories of innovation take place, e.g. Google at the start of the internet, or Apple at the start of the personal computer industry. It is much more difficult to innovate within a Brownfields system given the inertia and capital investments associated with current practices. A perfect example is the U.S. auto industry where pension payments to retirees and unionized labor have made it very difficult for the industry to restructure itself to avoid bankruptcy.

Figure 2:



However, Brownfields systems are where innovation for sustainability must occur. These old systems, which are big, diffuse, reliable, toxic, regulated, cheap, bureaucratic, political, capitalized, inertial, etc., are the ones which must be replaced in order to reduce industry-wide energy consumption and other impacts on the environment. So, how can sustainability innovators go about meeting the challenges of designing and innovating for this sector?

Dr. Hargadon introduces three characteristics of designing for sustainable solutions within a Brownfield environment:

1) "Displace current technological solutions and practices with more sustainable ones." This challenge is not about creating new solutions, because often new solutions increase market demand and just end up increasing energy consumption! For example, advances in computing have only increased the demand for more server farms and data storage devices.
2) "Build from existing ideas, people, and artifacts and address existing needs." This comes back to the idea that innovation is about connecting what's already out there,

not inventing new things. It is not enough for an innovator to identify new technical possibilities to solve existing problems; innovators must also build from existing ideas with trained people and existing practices in order to make change happen in a way that is scalable. This is a particular challenge in the gas and electric utility industry, which is already 150 years old! If you think of the poor reliability of the Microsoft Vista operating system, which is the product of a 30-year-old industry, would we tolerate similar reliability in our electric power? Probably not, and the challenge is even more immense to provide this reliability with renewable power in a 150-year-old industry.

3) "Emerge as evolutions in practice but open revolutionary new paths for change." Dr. Hargadon uses the example of the Toyota Prius, the first hybrid electric vehicle, to make this point. The first model of the Prius still required gas, allowing people to continue filling up their tank at the local gas station and avoid the use of an electric plug. However, for the next generation of the car, people started clamouring for a full electric vehicle! The designers of the Prius knew that in order to fit into the existing market and introduce the idea of an electric vehicle, they could not demand a dramatic change in people's current behaviour.

Innovators wanting to implement the three characteristics of successful design for sustainability can use a process that Dr. Hargadon refers to as "netstorming" to increase their chances for successful adoption. Often times a researcher will have a great invention similar to others at a point in time, so the difference between one invention being adopted over another invention is the effectiveness of the inventor's social network for catalysing adoption. Netstorming is the process of identifying the network relationships, skills and expertise that will improve the likelihood of an invention being adopted and diffused through the innovation stages. The first step of netstorming is listing all the incumbent actors in the field that researcher wants to change. The second step is identifying a list of the potential actors, which may yet emerge into the field of interest. Connections between these incumbent and potential actors should be drawn. The third step is defining what each set of actors needs and what they have to offer in supporting the adoption of the invention. An inventor group needs to create the networks that will be most effective in deploying the invention. To improve and increase the diffusion of sustainability inventions, green technology academies have been established to help people construct the right social networks to support the innovation process.

Conclusions

Innovation is a process whereby ideas and people coalesce to bring about a transformative change in society. The embracement and expedition of innovation has a critical role for enabling a transition to sustainable living. However, truly innovative ideas evolve through the opportunities and barriers created by interactions of different actors and circumstances. In his two lectures, Dr. Hargadon presented key innovation concepts that should be appreciated and understood if we are to effectively encourage innovations that fast-track sustainable living. For the lectures, there were three main points to be conscious of in seeking revolutionary innovations for creating a sustainable society: 1) innovation is not about a single original idea, but more the coalescing of ideas; 2) a social network bringing together different types of expertise and skills is needed to turn an idea into reality; and 3) innovation must understand the existing landscape in which it will be introduced and identify how it will enter the market place to provide something needed and desired. So if you have a promising idea for meeting sustainability goals, understand its potential market value, build the right social network then strategically introduce it into the market place.