**Making Serious Inroads into Achieving Global Climate Goals: Disrupting Innovation Driven by Governmental Regulatory Targeting, Not Slow Guided Incremental Innovation Involving Incumbents is What is Needed to Transform the Industrial State***

Nicholas A. Ashford, MIT
Ralph P. Hall, Virginia Tech

**Abstract**

Strategic Niche Management and Transition Management have been promoted as useful avenues to pursue in order to achieve both specific product or process changes and system transformation by focusing on technology development through evolutionary and co-evolutionary processes, guided by government and relevant stakeholders. However, these processes are acknowledged to require decades to achieve their intended changes, a timeframe that is too long to adequately address many of the environmental and social issues we are facing. An approach that involves incumbents and does not consider targets that look beyond reasonably foreseeable technology is likely to advance a model where incumbents *evolve* rather than being *replaced* or *displaced*. Sustainable development requires both disruptive technological and institutional changes, the latter including stringent regulation, integration beyond coordination of disparate goals, and changes in incentives to enable new voices to contribute to integrated systems and solutions. This paper outlines options for a strong governmental role in setting future sustainability goals and the pathways for achieving them.

## Introduction

This paper traces the strengths and weaknesses of the evolutionary/co-evolutionary processes of Transition Management (TM) and Strategic Niche Management (SNM) in achieving sustainable development. These approaches mirror Ecological Modernization (EM) in their focus on learning processes within the firm and among firms in an evolving technological regime which hope to change and accelerate innovation processes in order to achieve more sustainable technologies (Ashford, 2002a). Their proponents reject revolutionary and disruptive changes brought on by government fiat (Rotmans, Kemp and van Asselt, 2001a), although, curiously, in earlier work some of them acknowledged the potential of regulation to change technological trajectories dramatically (Schot, Hoogma and Elzen, 1994).

This paper argues that regulation-induced technological innovation has a much greater potential in making the significant changes required to achieving sustainable development by encouraging disrupting innovation, especially from new entrants displacing incumbents. TM and SNM processes are argued to be “too little, too late.” Nowhere is this more evident than in the area of global climate disruption. Attempts in the Netherlands to coach more sustainable energy production and use through TM and SNM are contrasted with President Obama’s new climate change initiative by regulating emissions from coal-fired power plants. Progress that is too little and too late has been made internationally through evolutionary processes. It is time to embark on a different pathway.

Unsustainable systems, such as energy production and use, agriculture, and transportation consist of inter-connected components and economic actors characterized by technical (and political) “lock-in” [1] which is difficult to change. Strategic stringent regulation of those components, if conceived in an integrated fashion, are argued to be a more successful pathway to sustainability, even if greeted by political resistance.

* Updated from an earlier paper: Ashford and Hall 2015, presented in August 2015 at 6th International Sustainability Transitions (IST) Conference. Sustainability Transitions and Wider Transformative Change Historical Roots and Future Pathways, Falmer, Brighton, UK.

In the remainder of this paper, we address the theories of system innovation, the strengths and weaknesses of the TM and SNM approaches, the argument in favor of a stronger role for government than mere guidance, regulation-induced technological innovation as a more viable alternative to achieving more sustainable development, and finally the importance of diffusion (as opposed to innovation) in achieving sustainable development. The debates of which approaches are more likely to succeed predictably reflect the disciplinary orientations of the opposing camps, centering around evolutionary, neoclassical, and ecological economists, and sociologists, on the one hand, and legal scholars and political scientists on the other. So-called technology policy experts occupy both domains.

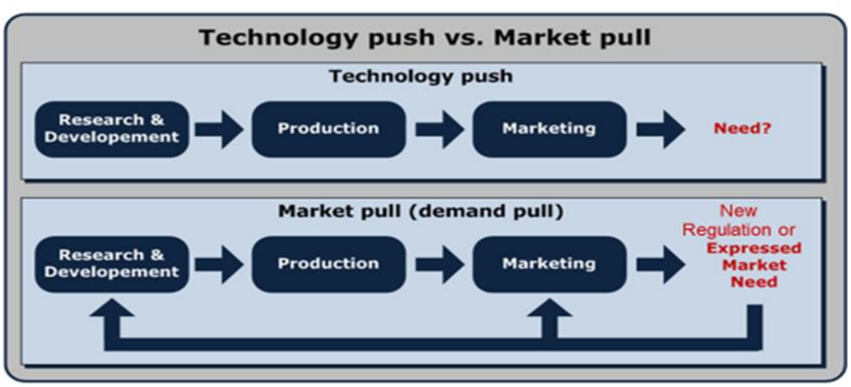
**The Innovation Process: Distinguishing Singular Product and Process Changes from Systemic Innovation**

Much faith and hope in transforming industrial systems has been placed on the concept of innovation. After all, the root of the word implies change. The innovation process is acknowledged to encompass three related and interactively-connected activities: invention, innovation, and diffusion. Invention is the first working prototype of a technology; it can involve a product, a process or a manufacturing/services system. Innovation is the first or new market application, while diffusion refers to proliferation of the innovation throughout an industry. When the innovation is then used in other industries, applications, or national contexts, we often also use the term technology transfer to describe diffusion. Finally, if significant adaptation is required in a new context, it is sometimes referred to as a separate innovation.

While governments, as well as the private sector, generally devote significant resources to create innovations, especially in saleable products although process innovations also receive attention, it is important for our purposes to distinguish what motivates a particular innovation and who provides the financial capital to spur both innovation and diffusion.

Innovation may occur driven by technology push forces, or by market pull (see Figure 1). Industrial sectors routinely engage in the R&D necessary to develop saleable technologies with the hope that the market will absorb them, even in the absence of nascent market demand. This occurs naturally (as an evolutionary process) and can take decades, and traditional industrial policy providing government assistance is often said to "grease the wheels of innovation" in hopes of the nation enjoying financial rewards (see the discussion below).

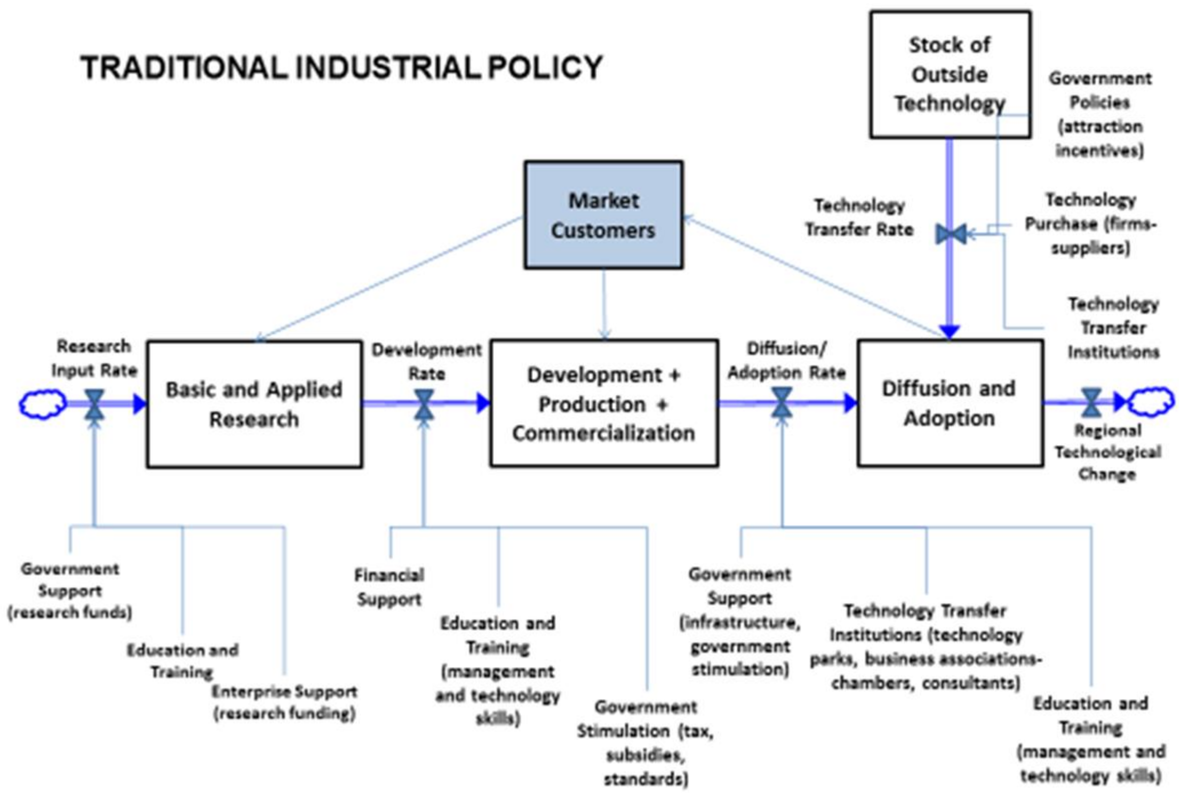
**Figure 1 – Technology Push v. Market Pull Innovation**




Source: Adapted from http://en.wikipedia.org/wiki/File:Technology-Push_Market-Pull.png

The role of the government in promoting innovation is presented in Figure 2, indicating all the traditional ways in which innovation might be stimulated (Ashford and Hall 2011a).

**Figure 2 – Traditional Industrial Policy Interventions**




Source: Ashford and Hall (2011a)

The interventions depicted in the figure are of course familiar to those involved with traditional industrial policy that focuses on singular product or process changes. System innovations, discussed below, such as the transportation system or the agricultural system necessarily involve multiple economic actors interacting in larger venues and this model does not adequately represent the complexity involved in system transformations. Technology push innovations are pursued by profit-seeking firms and by countries seeking to enhance domestic and trade revenues (capital supplied by firms and subsidized through R&D innovation programs & cost-sharing through business tax deductions – and in the case of trade and aid, Export Credit Agencies, Sovereign Wealth Funds and Overseas Development Grants).

In contrast, there are often nascent or express market needs demanding to be satisfied. Market pull innovations can also be pioneered (Jänicke and Jacob 2005) by firms recognizing an unmet societal or market need and direct their innovative efforts towards that end. Often the demand is difficult to assess and can wane over time. An example is the need for a better chemotherapeutic approach to cancer, or increased concern for finding a cure for Alzheimer's Disease. Often, the R&D need is cutting-edge and financially risky. Government often supports the initial forays into research as exemplified by the development of computers, aircraft, and the Internet (Mazzucato 2014).

When it comes to stimulating innovation (and diffusion) of system transformations – or technologies that have remained unchanged for decades -- there seems little doubt that government setting of specific medium- to long-term mandatory targets, plus economic support, is indispensable for achieving transformations within a reasonable period of time (Ashford et al, 1985; Pelkmans and Renda 2014). Regulation and mandated targets essentially collectivize public demand or needs through the setting of standards and requirements. Costs are imposed on the private sector with cost-sharing achieved through business and R&D deductions. Sometimes subsidies are provided. Governments need to understand the different forces giving rise to innovation and diffusion, and not succumb to traditional industrial policy if serious transformations – especially involving the displacement of incumbents or system changes involving many different economic actors – is what is needed. In the last decade, the concept of co-evolutionary innovation has been introduced by Dutch researchers injecting government and stakeholder guidance in the selection process entailing strategic niche management and transition management (Grin et al., 2010). This co-evolutionary process is advocated for system innovation, but its promoters admit the transformations can also take decades to achieve. A previous criticism of depending on these co-evolutionary processes to achieve systemic sustainable transformations can be found in Ashford and Hall (2015).

We certainly believe that system transformations are key to achieving system transformation involving technological, organizational, institutional, and societal innovations among a disparate collection of economic actors, but a much more directive role for government to meet the challenges is needed through an integrated approach utilizing regulations, targets, and appropriate economic signals. The government must take on the role of trustee for the needed transformations – and trustee of the technologies and firms of the future, often not yet represented at the negotiation table -- not of referee, teacher, or generator of consensus.

Finally, one of the bottlenecks in commercialization of useful technologies may come late in the innovation cycle. The innovation literature emphasizes the importance of *deployment* - the step in which a technology moves from bench-top or lab to actual commercial use in practice. Semantic preferences differ as to whether this is described as the last step in the innovation activity or the first step in diffusion. Semantics aside, what is important is that the R&D to accomplish this transition is not basic research, but truly *applied* research, a distinction glossed over in discussions of innovation policy. Barriers to deployment are often influenced by incumbents whose technologies compete with the new technology and seek to delay or prevent its entry.

## Theories of System Innovation

When we move beyond product and process innovation into system changes, in addition to the wide range of instruments that can be used to guide technological development (in the product and process contexts), there are a number of theories that describe the process of technological innovation. Box 1 shows how the various schools of economic, historical, and sociological thought differ in their approaches to conceptualizing technological development. The description of these approaches draws on the work of Luiten (2001), Moors (2000), and Partidario (2003). In each description, the role of government is identified.

The theories of technological innovation shown in Box 1 provide an indication why focusing on government intervention in the process of technological innovation is important, even necessary. In addition, although the policy instruments above have been listed in a general form, we should recognize that the success of a particular instrument in directing or stimulating technological development is context sensitive (Wallace, 1995).

Understanding the role of societal (or cultural) change and how new technology forms can regulate social behavior is essential (Winner, 1977, 1986, 1992). If society is unwilling to accept (or buy) a new technology, then that technology will not be diffused sufficiently to affect the overall system (unless it is imposed by regulation). It is also important to consider whether new forms of technology are supporting the satisfaction of fundamental human needs for (1) safety, security, and sustenance; (2) competence, efficacy, and self-esteem; (3) autonomy and authenticity; and (4) connectedness (Kasser, 2002). Indeed, because meeting human needs lies at the center of sustainable development, perhaps greater attention should be paid to the impact of technology on needs fulfillment.

Asking whether a new technology form is likely to be diffused sufficiently to affect the overall system is critical for sustainable development. In Europe, and more specifically in the Netherlands [2], there is a growing body of research that looks into how society can transition (that is, transform) to sustainable forms of development through system innovation (Elzen, Geels and Green, 2004; Kemp and Rotmans, 2005; Grin, Rotmans and Schot, 2010; Elzen, 2002).

A “transition” (or transformation) is described as “a long-term change process in an important sub-system encompassing various functional systems (for example, food production and consumption, mobility, energy supply and use, etc.) in which both the technical and the social/cultural dimensions of such systems change drastically” (Elzen, 2002, p. 1). A “system innovation” is described as “a set of innovations combined in order to provide a service in a novel way or offering new services. System innovations involve a new logic (guiding principle) and new types of practices” (Rennings et al., 2003, p. 14). Geels (2004, pp. 19-20) describes a system innovation as consisting of three important aspects: (1) technological substitution, which includes the emergence and diffusion of new technology that replaces existing technology; (2) the co-evolution of technological and social systems, where both types of systems are continually interacting and changing; and (3) the emergence of new functionalities, where a new product or service provides a new functional characteristic. It follows that a “sustainable” system innovation would provide economic, environmental, and social benefits with the offering of new products, processes, or services.

An important characteristic of research focusing on system innovation is the recognition that the relationships among sets of technologies are dynamic, complex, and nonlinear, and that these technologies are socially embedded. This focus supports the idea of dynamic, as opposed to static, efficiency and the importance of considering the fourfold co-evolution of technology, institutions, organizations, and society. Because the evolutionary economic and quasi-evolutionary approaches to technological innovation (Box 1) make technology and innovation explicit and adopt a system approach, the frameworks developed to assess system innovation are built on these theories. Because neoclassical economic theory treats technology as exogenous, it does not provide fertile ground for considerations of system innovation.

Briefly, evolutionary economics focuses on the process of technological innovation from the perspective of the survival of the fittest – that is, its roots are Darwinian and Schumpeterian [3] Nelson and Winter (1982, 1977) were the first to develop an economic theory in which the evolutionary theory of technological innovation was embedded. Their theory is based on two independent processes: variation and selection. In addition, because technology is treated as being socially embedded, the ideas of path dependency or lock-in and bounded rationality play important roles in the analysis of technological innovation. The evolutionary model of technological innovation was later extended by focusing on the sociological aspects of the evolutionary approach (Rip, 1992; van de belt and Rip, 1987). The so-called evolutionary approach treats the variation and selection of technology as non-independent events (Moors, 2000). Thus, the focus is on how technological variations are influenced by the selection environment.

The field of evolutionary economics is beginning to emerge as an important framework for understanding how modern economies work. Development is conceived as an evolutionary process. In general, evolutionary theory views innovation as a dynamic, interactive process of variation and selection where institutions and actors continually influence and learn from each other.

Evolutionary theory has five important characteristics that differ from the neoclassical economic approach (Butter, 2002; OECD 1997). First, because the process of innovation is uncertain and is based on risk taking, there is no rational maximization behavior or optimal solution. Performance objectives can be achieved in many different ways through the creation of entirely new products, processes, or services. Thus, the selection of an optimal outcome using a specific form of technology ignores the possible emergence of new, disruptive ideas. Second, because innovation is a state of constant change and is not predictable, there is no one point of equilibrium. Third, technology is made explicit and is treated as a system of interacting sub-technologies designed to achieve an overall objective. Fourth, innovation is made explicit as a dynamic and interactive process of variation and selection. Finally, the technological (or physical) and social (including institutions) structure of a system is made explicit. This enables economic performance to be considered as a function of the facilitating structure – that is, the infrastructure, institutions, financial system, geographic location, and other factors.

There are currently three important frameworks that can be used to develop initiatives to stimulate system innovation for sustainable transformations. Kemp (2002), Kemp, Loorbach, et al. (2007), and Kemp and Rotmans (2005) propose "strategic niche management" and "transition management" – a quasi-evolutionary approach – for achieving system changes necessary for sustainability. Butter (2002) suggests a three-layered approach for "green system innovation" based on a combination of evolutionary theory and national systems of innovation [4]. Ashford (2002c) argues for integrating rather than coordinating government interventions in order to bring about the needed technological, organizational, institutional, and social transformations to achieve significant sustainable system change. A role for government is anticipated by all three of these commentators, but to different degrees and in different ways.

**Strategic Niche Management and Transition Management**

The concept of strategic niche management (SNM) emerged from the two opposing views of the *technological fix ideology* (or technological optimism) and the *cultural fix paradigm* (Hoogma et al., 2002). The former argues that the benefits associated with technological progress are likely to far outweigh costs, and that a technological solution can be found to all problems. The latter suggests that the technology itself is actually part of the problem and that real solutions will have to come from *social* and *cultural* change. Therefore, SNM was created to "allow for working on both the technical and the social side in a simultaneous and coherent manner" (ibid., p. 3).

Kemp (2002, p. 10) describes SNM as the "creation and management of a niche for an innovation with the aim of promoting processes of co-evolution." The idea is that a new product will be used by *real* users (by society, industry, or government), and its use will promote interactive learning and build a product constituency. The underlying notion is that new technologies will be introduced in a socially embedded manner. It is important to realize that SNM is primarily focused on product innovation, not process innovation. However, its proponents argue that process innovation will be part of technological regime transformations (see the discussion of regime change below). SNM also enables institutions and organizations to adjust the technological development and deployment process to stimulate the adoption and diffusion of a new product.

A key element of the SNM concept is that technological change occurs in a co-evolutionary manner – that is, technologies evolve within institutional networks. Saviotti (2005) suggests that two important general points can be made about the co-evolution of technologies and institutions: “First, the emergence of new technologies increases the division of labor in the economy, but in the meantime creates new coordination problems. One of the roles of co-evolving institutions is to provide coordination. Second, although the firms producing and using the new technologies compete, other co-evolving institutions are in a complementary relationship with the main technology” (ibid., p. 30). Saviotti’s comments highlight the complexity that surrounds the introduction of a new technology and provide weight to Kemp’s arguments for the creation of protective niches in which promising technology can be tested and developed. The ability to experiment with new technology through demonstration projects that help users and suppliers learn about new possibilities is a vital component of SNM.

The process of experimentation is likely to achieve one of two outcomes: regime optimization [5] or regime shifts [6]. These two outcomes can be described as sustaining or disrupting changes, respectively (see the earlier discussion). A technological regime is defined as “the whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, established user needs, regulatory requirements, institutions and infrastructures” (Hoogma et al., 2002, p. 19). In general, the type of technologies that are suitable for experimentation should be ones that hold the potential to bridge the gap between existing and new (sustainable) technological regimes (Kemp, 2002). This type of technology is referred to as “pathway technology.” In essence, SNM is a bottom-up, initially nondisruptive process where once the niche for experimentation has been established by government policy/regulation, the new technology form evolves from interactions among society, government, nongovernmental organizations, and industry. The emphasis is on multistakeholder governance rather than on government as the dominant actor.

Transition management (TM) is a model of co-evolutionary management of transformative change in societal systems through a process of searching, learning and experimenting (Rotmans and Kemp, 2008) [7]. Managing means adjusting, adapting and influencing rather than using a command-and-control approach. There are persistent problems for which there are no immediate solutions. By transforming the persistent problem into a visionary challenge, TM explores a range of possible options and pathways through the carrying out of a diversity of small-scale experiments. Based on what is learned from these, the vision, agenda, and pathways are adjusted. Successful experiments are continued and can be scaled up, and failed experiments are abandoned, until convergence is reached. Rather than focusing on a single, available solution, TM explores various options and is aimed at guiding variation-selection processes into more sustainable directions, with the long-term aim of selecting the most sustainable option(s) and paths based on learning experiences. TM is meant to be a mutually supportive vehicle for both sociotechnical and policy changes.

It is debatable whether Kemp’s description of the latter strategy will result in disrupting innovation. Kemp (2008, p. 374) acknowledges that “faced with sustainability problems, [incumbent] regime actors will opt for change that is non-disruptive from the industry point of view, which leads them to focus their attention on system improvement instead of system innovation." Whether the concept could hold particular merit for system innovation in a specific context remains to be seen. If revolutionary change – or a technological regime shift – can occur via a stepwise system innovation process, SNM can be a useful tool that can be applied to large-scale engineering systems, such as the transportation system (Hoogma et al., 2002; Hoogma, Weber and Elzen, 2001), but that is a big "if." It depends on, among other things, the extent to which incumbents dominate the process.

Opponents of SNM argue that one of the shortcomings of the technique is that at some point the "probe and learn" ideology needs to become action and transformation, and Kemp's theory is unclear on how transformation will occur (Smith, 2003). Further, if niches grow within or alongside existing regimes, they are unlikely to have radically different practices and rules, which raises the question whether the new products, processes, or services will offer significant benefits. A final point raised by Smith (2003) is the fact that the localization of niches may run against the nationalization or globalization ideology of mainstream government and business institutions. Thus, an important question is whether the "transformative potential" of SNM will be inhibited by these powerful forces (ibid.).

Vergragt (2005) raises a slightly different concern from that of Smith (2003). He argues that if the role of government is to legitimize the transition process – including its own reform and the abolition of existing institutional and economic barriers to sustainable development – then a quandary exists because the national government may in fact be part of the problem rather than part of the solution. Therefore, an important question is who will manage the transition process. Quist and Vergragt (2004) also question whether an emerging niche market will survive once its protection mechanisms are removed. On the other hand, Grin et al. (2010, p. 83), in stating that "[m]uch of the cited research focuses on explaining the limited success of the [SNM] experiments studied," references Hommels et al. (2007, p. 85) who are described as arguing that "part of the problem might be that SNM focuses too much on providing protection."

In critiquing the TM approach, Tukker et al. (2008) comment that transition management of innovation neglects the role of the consumer and the importance of demand-side policies influencing consumption. It should be noted that regulation is both a supply-side policy and a demand-side policy intervention; it defines the allowable characteristics and places constraints on the nature of products and on their manufacturing, use, and disposal.

Dewulf et al. (2009), in analyzing transition management in the context of other theories of change management – especially intervention by government – question whether transition management is the "only model in town." Dewulf et al. (2009, p. 12) observe that "a distinctive trait of transition management appears to be the assumption of an overarching position of (governmental) transition managers who can apply management tools, niche-building machinery, and engineering devices from a privileged, knowledgeable and external position ... towards a clear and one-dimensional target." The government participates along with other stakeholders, rather than take a more directive role reminiscent of command-and-control regulatory involvement. The process is characteristically Dutch, using the so-called "polder consensus-seeking model." Dewulf et al. (2009, p. 4) argue that transition management can take a relatively long time – twenty-five to fifty years – whereas collaboration theory in practice focuses on reaching an agreement and effectuating change in a few years' time. Given the existence of relatively short-term "tipping points" in sustainability challenges, e.g., global climate disruption, endocrine disruption, and rapidly changing financial landscapes, the benefits of transition management may come far too late. Collaborative processes, of course, have their own drawbacks.

Ashford (2002c) argues that although Kemp acknowledges that regulation can be a useful tool to stimulate radical (system) changes, his faith in the formation of strategic niches and stepwise change *within* the original technology regime is not likely to result in disrupting forms of technology that are necessary for sustainable development. The problem is that firms are likely to resist initiatives or regulations that threaten their market position and to focus instead on activities that maintain the status quo. Thus, a reliance on evolutionary or even co-evolutionary change rather than revolutionary change is not likely to support the emergence of new market entrants who play an important role in introducing radically different (and potentially more sustainable) forms of technology (Reinhardt, 1999). Berkhout et al. (2004) make a case similar to that of Ashford. They argue that the tendency of critical social groups has been to target the "incumbent regime, rather than its potential successor, ... represents a direct antithesis of the bottom-up niche-based model" (ibid., p. 61). The lesson appears to be that attempts at normatively-driven sociotechnical transitions (that is those forms most pertinent to the transition management project) do not follow exclusively the pattern described by the niche-based model, but instead imply much greater attention to macro-level processes (public opinion, government policy, the structure and scope of markets) and their capacity to influence and induce innovation at the micro- and meso-level.

Jacob (2005), while generally supportive of decoupling economic growth from environmental degradation through ecological modernization, raises questions similar to those of Ashford and Berkhout et al. and asks whether SNM's experimental arena is likely to capture and maintain the necessary political (and financial) support for a real transition. Further, Jacob (2005) argues that although "discourse and persuasion" are useful tools, they are unlikely to resolve any opposing core beliefs held by the actors. Thus, bargaining and making trade-offs are likely to play an inevitable role in any decision-making and transition process.

Finally, continuing from Smith's (2003) earlier reservations about the ability of SNM to bring about the needed transformations, Smith and Kern (2007) comment on its limited success in energy policy in the Netherlands. They describe how Kemp and Rotmans persuaded the Dutch government to adopt SNM as a central strategy in its Fourth National Environmental Policy Plan (NMP4) in 2001. It should be noted, however, that the environmental successes of earlier Dutch National Environmental Policy Plans (NEPPs) were premised on the government setting clear future targets but negotiating ways of achieving those targets with stakeholders. The approach later adopted in its NEPP was to negotiate both targets and pathways with stakeholders. Existing industrial stakeholders may not represent the interests or capacity of future technology providers who are likely to displace them.

The NMP4 focuses on restructuring production and consumption systems over a thirty-year period to achieve a reduction of one-twentieth in both resource and energy use. Smith and Kern (2007) describe and critique the SNM approach in the context of the Netherlands:

> By creating policies that support niche experiments in sustainability, whilst other policies place incumbent systems under concerted pressure to become sustainable, the transitions approach seeks to facilitate the transformation of systems ([citing] Smith, Stirling, et al. (2005)). The "S" curve moves the niche "pre-development" phase, through "take off" along an "acceleration" phase, and culminates in "stabilization" around the new structure of sustainable socio-technical practices ([citing] Rotmans et al. (2001b)). (Smith and Kern 2007, p. 6).

> [SNM] offers the prospect of reinvigorating ecological modernization without challenging cherished components. Thus, market-based instruments and win-win regulations, both advocated within ecological modernist discourse, remain key policy tools amongst a portfolio that can help guide transitions. The power of innovation to decouple environmental degradation from economic growth remains as a foundation. The dominant ecological modernization discourse is repackaged in the transitions approach [8]. (ibid., p. 7).

> Many commentators applauded this co-operative, long-term approach. ... Others were disappointed. The [NMP] plans interpreted ecological modernization technocratically. ... The plans were weakened by compromises within government and with business that translated into relatively undemanding targets. (ibid., p. 8).

> In our view, deeper, more profound envisioning exercise and transition debates will happen in civil society arenas, removed from the messy compromises of government and the economic imperatives of business. What the transitions discourse and ecological modernization lack is an account of how such initiatives become a power base for change. Neither identifies the social agents that can ensure the radical components of a discourse that can carry through to institutionalization. (ibid., pp. 18-19).

A more sympathetic view of transition management is expressed by Meadowcroft (2005, p. 486), who characterizes its proponents as appreciating the "regulatory dimensions" of technological evolution. Although he acknowledges that transitions under transition management may well take more than twenty-five years, that continued economic growth may be possible only at the expense of the environment, and that the role of government in solving environmental problems has been underestimated, Meadowcroft (2005, p. 492) decries governments being "confined to a top/down and expenditure/regulatory framework" and puts some faith in transition management. More recently, Meadowcroft (2009) comments on the importance of addressing the politics surrounding the implementation TM toward sustainability goals.

Shove and Walker (2007) provide four cautionary concerns:

> Transition managers' efforts to develop and work towards shared societal or environmental goals are all very well but techniques like those of multi-stakeholder involvement in foresight exercises, or methods of public participation and deliberation are never "neutral" and never evacuated of power and strategic behavior. ... Initiatives of this kind can be experienced as processes of co-option, the effect of which is to neuter rather than embrace dissent. In addition, and in any event, it is important to remember that stakeholders' visions of the future are always and inevitably shaped by the systems and social environments they inhabit today. (ibid., p. 765).

> Thoroughly systemic, thoroughly co-evolutionary models of social and environmental change undoubtedly challenge conventional approaches to problems of sustainability. In so far as they embody these ideas, strategies of transition management imply a necessarily radical overhauling of theory and orientation, but our caution is that such techniques can also be incorporated into political business-as-usual, albeit with a little more frequent revisiting of goals and a somewhat longer term horizon. (ibid., p. 767).

> How should those concerned with sustainability respond to the increasingly rapid, powerful and expertly orchestrated diffusion of unsustainable technologies, practices

> and images? Is the subtle modulation of reflexive governance capable of stemming and diverting unforeseen transitions of this kind, or are more robust counter measures required? (ibid.).
>
> [Concerning transitions in practice:] First ... there is almost no reference to the ways of living or to the patterns of demand implied in what remain largely technological templates for the future. Second, and because large-scale technological examples command so much attention, commentators take it for granted that policy and corporate actors are the key players – even if the involvement of other groups and interests is vital. ... Third, the transition management literature consequently draws upon a narrow (perhaps necessarily narrow) slice of what is in fact a much wider debate about social systemic change. (ibid., p. 768).

The publication of this critique stimulated a response by Rotmans and Kemp (2008) and a counter-response by Shove and Walker (2008), illustrating just how important the issue of transition management is becoming in the sustainability debate.

In spite of initial reservations about the success of TM-inspired reincarnation of long-term policy design, some of its critics are cautiously optimistic about its future use (Shove, 2010; Voss, Smith and Grin, 2009). We, however, remain skeptical because (1) the time framework for success is far too long given the challenges of sustainable development, (2) there is too much potential for capture of future agendas by incumbents, even if they change somewhat, and (3) without clear and certain long-term targets characteristic of backcasting, long-term investments by new entrants leading to discontinuous change necessary for radical technological change are unlikely to be made. Backcasting in incremental steps is not long-term backcasting, and while it introduces flexibility and mid-term corrections, it does not provide certain targets toward which to innovate. Again, we find it difficult to be optimistic that step-wise changes made toward uncertain futures involving incumbents will lead to radical, disrupting changes. Ecological modernization or reflexive governance arose historically because governments were not willing to exercise courage at setting long-term goals that challenge incumbent forces and agendas. Second generation policy design operating under the soft euphemism of accommodation and learning has serious weaknesses.

In a more recent critique of the policy implications of SNM, Grin et al. (2010, p. 91) offer:

> The research discussed indicates that SNM is not a silver-bullet solution that will bring about transitions towards sustainable development, if only because experimenting will not be sufficient. SNM should be seen as a useful addition to existing policy instruments that have neglected the value of experiments. Other more traditional instruments for inducing sustainable innovation, such as market incentives, various forms of regulation and technology forcing also have to play a role.

Finally, Grin et al. (2010, p. 84) distinguish the potential effectiveness of TM and SNM:

> We acknowledge that TM addresses some factors that SNM underplays. While SNM develops an evolutionary approach that builds on and leverages the dynamic forces of market competition, aimed at overcoming lock-in and promoting socio-technical diversity, TM suggests a more ambitious approach of goal-oriented modulation that places more emphasis on the role of strategic envisioning. In that respect, TM introduces the notion of “transition experiment” which is supposed to be different from regular innovation experiments (van den Bosch and Taanman, 2006).

**A Stronger Role for Government**

Government has an important role to play in creating winning forces and visions for sustainable transformations (Ashford, 2000, 2002c, 2005). Depending on the type of transformation required, the roles of government should encompass the following (Ashford 2002b, pp. 18-19):

- "The direct support of R&D and incentives for innovation through appropriate tax treatment of investment;
- the creation and dissemination of knowledge through experimentation and demonstration projects;
- the creation of markets through government purchasing;
- the removal of perverse incentives of regulations in some instances and the deliberate design and use of regulation to stimulate change in others;
- the training of owners, workers, and entrepreneurs, and educating consumers;" and
- the direct creation of meaningful, rewarding, and satisfying jobs.

It should be clear how these roles relate to the ideas embedded in SNM and TM approaches, but we envision a much stronger role for government in stimulating technological innovation. Government should go beyond simply creating a favorable investment climate. "Without deliberate design, significant changes – even system changes – are unlikely to improve competitiveness, environment, and employment at the same time" (Ashford, 2002b, p. 18). As discussed in the next section, *stringent regulation* (focusing on environmental, health, and safety issues) is essential to stimulate significant technological changes, and such regulation may in fact be necessary to create niches that facilitate the entry of new firms and organizations into a new market.

Others who support the view that stringent (or "properly conceived") regulation is necessary for environmental innovation include Foxon et al. (2004), Huber (2004b), and Jänicke (1990). For instance, Huber (2004a, p. 447) comments that "strict environmental performance standards ... [remain] by far the most effective controls instrument for environment and innovation alike (which is not astonishing given the fact that environmental standards are, or immediately translate into, technical standards)." Perhaps what is astonishing is the largely absent mention of government regulation in the SNM and TM literature. See Pelkmans and Renda (2014) for a recent review of the stimulating effects of regulation on innovation.

Ashford et al. (2002) argue that an *evolutionary* (or incremental) pathway is insufficient to achieve factor ten or greater improvement in a system's performance. Further, because changes in sociotechnical systems (such as the transportation or energy system) are difficult, the "creative use of government intervention is a more promising strategic approach for achieving sustainable industrial transformations than the reliance on the more neo-liberal policies relying on firms' more short-term economic self-interest" (ibid., p. 10). Hence relying on Christensen's (1997) approach to radical disrupting innovation is seen as being unlikely to result in "system" transitions toward sustainable development; however, disrupting forms of technological change are likely to continue.

In addition, Ashford et al. (2002) state that governments should work with stakeholders to define future targets – while ensuring that their agendas are not captured by incumbent firms – and then use their position as trustee to "represent the future generations and the future technologies to 'backcast' what specific policies are necessary to produce the required technical, organizational, and social transformations" [9] (ibid., p. 10).

It is likely that an evolutionary pathway is insufficient to achieve factor ten or greater improvements in eco- and energy efficiency and reductions in the production and use of, and exposure to, toxic substances. Such improvements require more systemic, multidimensional, and disruptive changes. We have already asserted that the capacity to change can be the limiting factor, and that this is often a crucial missing factor in optimistic scenarios.

Successful management of disruptive product innovation requires initiatives and input from outsiders to produce the expansion of the design space that limits the dominant technology firms. Especially in sectors with an important public or collective involvement, like transportation, construction, and agriculture, this means that intelligent government policies are required to bring about necessary change.

Rigid industries whose processes have remained stagnant also face considerable difficulties in becoming significantly more sustainable. Shifts from products to product-services rely on changes in the use, location, and ownership of products in which mature product manufacturers may participate, but this requires significant changes involving both managerial and social (customer) innovations. Changes in sociotechnical systems, such as transportation or agriculture, are even more difficult. Thus, as Ashford et al. (2002) argue, the creative use of government intervention may be a more promising approach to realizing industrial transformations than relying on shorter-term economic interests.

This is not to say that enhanced analytic and technical capabilities on the part of firms and cooperative efforts and improved communication with suppliers, customers, workers, other industries, and environmental/consumer/community groups are not valuable adjuncts in the transformation process. But in most cases, these means and strategies are unlikely to be sufficient by themselves for significant transformations, and they will not work without clear mandated targets to enhance the triple goals of competitiveness, environmental quality, and enhancement of employment/labor concerns.

Government has a significant role to play, but the government cannot simply serve as a referee or arbiter of existing competing interests, because neither future generations nor future technologies are adequately represented by the existing stakeholders. And new stakeholders are only marginally likely to be brought into development by incumbents, notwithstanding the wishful thinking of SNM and TM advocates.

Government should work with stakeholders to define far-future targets, but without allowing the incumbents to capture the agenda. It has to go beyond its historical focus on coordinating public- and private-sector policies. It must be multidimensional and directly address the present fragmentation of governmental functions. This means that the various policies must be mutually reinforcing and the targets must be clear.

**Regulation-Induced Innovation as an Alternative Pathway to Achieving Sustainable Development**

In a longer article the authors have argued that regulation – properly fashioned – can transform products and processes which confers both economic and health, safety, and environmental benefits as well as costs (Ashford and Hall, 2011a). In contrast, classical economic analysis of the relationship between health, safety, and environmental regulation and competitiveness maintains that stringent regulation increases production costs, diverting resources from R&D, and consequently hinders innovation. This assumption was challenged first in the late 1970s at

MIT and made popular in 1991 by the so-called 'Porter hypothesis' (Porter, 1991; Porter and van den Linde, 1995).

The Porter hypothesis and the relevant literature indicate that environmental, health, and safety regulation can induce dramatic innovations, not only by spurring the development of new products or services by incumbent producers, but also by creating conditions in which new producers can enter the field. Regulation can do this when firms have, or are induced to have, the willingness, opportunity, and capacity to innovate. This literature, and the insights gleaned from it, provide an important set of clues for how regulation can be used to foster sustainability.

Based upon his research into the competitive advantage of nations, Porter (1991, p. 168) claimed that "[s]trict environmental regulations do not inevitably hinder competitive advantage against foreign rivals; indeed, they often enhance it. Tough standards trigger innovation and upgrading." He observes, "[p]roperly constructed regulatory standards, which aim at outcomes and not methods, will encourage companies to re-engineer their technology. The result in many cases is a process that not only pollutes less but lowers costs or improves quality. … Strict product regulations can also prod companies into innovating to produce less polluting or more resource-efficient products that will be highly valued internationally" (ibid.). Porter‘s hypothesis is that firms which respond to stringent regulation by developing new technologies have a 'first mover' advantage and can capture the market for their products/services. Comparison of national competitiveness with good environmental governance and private sector responsiveness supports the Porter hypothesis. Good economic management and good environmental management are related and firms which succeed in developing innovative responses to environmental challenges benefit both environmentally and economically.

Earlier empirically based work on this concept, dates back twelve years before Porter‘s work to research undertaken at MIT (Ashford, Heaton and Priest, 1979; Ashford, Ayers and Stone, 1985; Ashford and Heaton, 1983; Ashford, 1993). This earlier work showed how stringent and focused regulations in the U.S. chemical producing and using industries had the effect of stimulating fundamental product and process innovations. The MIT studies revealed that *environmental and health and safety regulation* – if appropriately designed, implemented, and complemented by economic incentives – can lead to radical technological developments that can significantly reduce exposure to toxic chemicals in the natural and working environments, and in consumer products. Examples include regulation-induced replacement of poly-chlorinated biphenyls used in transformers by a silicone-based fluid, a new polymerization process for polyvinylchloride, and textile weaving innovation eliminating the need for a formaldehyde-containing resin that imparted permanent press properties to cloth.

A limitation of Porter‘s hypothesis is that it focuses on how incumbent firms respond to more stringent regulations, but it ignores the important dynamics of new entrants (van de Poel, 2000). Porter and van den Linden (1995) argue that regulation, properly designed, can cause a regulated firm to undertake innovations that not only reduce pollution – which is a hallmark of production inefficiency – but also save on materials, water, and energy costs, conferring what Porter calls 'innovation offsets' to the innovating firm (and what Ashford and his MIT colleagues called ancillary benefits'). This can occur because the firm, at any point in time, is sub-optimal. If the firm is the first to comply with regulation in an intelligent way, other firms will later have to rush to comply and do so in a less thoughtful and more expensive way. Thus, there are 'learning curve' advantages to being first and early.

Given Porter‘s focus on 'innovation offsets' – i.e., the cost savings due to induced innovation that could exceed the cost of the regulation (Porter and van den Linde, 1995) – he is mainly concerned with the costs to incumbent firms. However, it is possible to differentiate between 'weak' and 'strong' forms of the regulation-induced innovation hypothesis – a distinction that Porter does not make. In its weak form, as Porter observes, firms subject to more stringent regulation respond with product and process innovations. However, while environmental and worker health and safety improvements may be realized, the offending products and processes are only incrementally changed.

In contrast, in the strong form of the regulation-induced innovation hypothesis, stringent regulation can stimulate the entrance of entirely new products and processes into the market, thereby displacing dominant technologies. In this situation, unless incumbent firms have both the willingness and the capability to produce and compete with the new forms of technology, they too are likely to be displaced from the market (Christensen, 1997). Figure 3 below provides a simple diagram of the likely technological responses to the strong and weak forms of the regulation-induced innovation hypothesis. Empirically-based examples were researched by Ashford and his colleagues in their work.

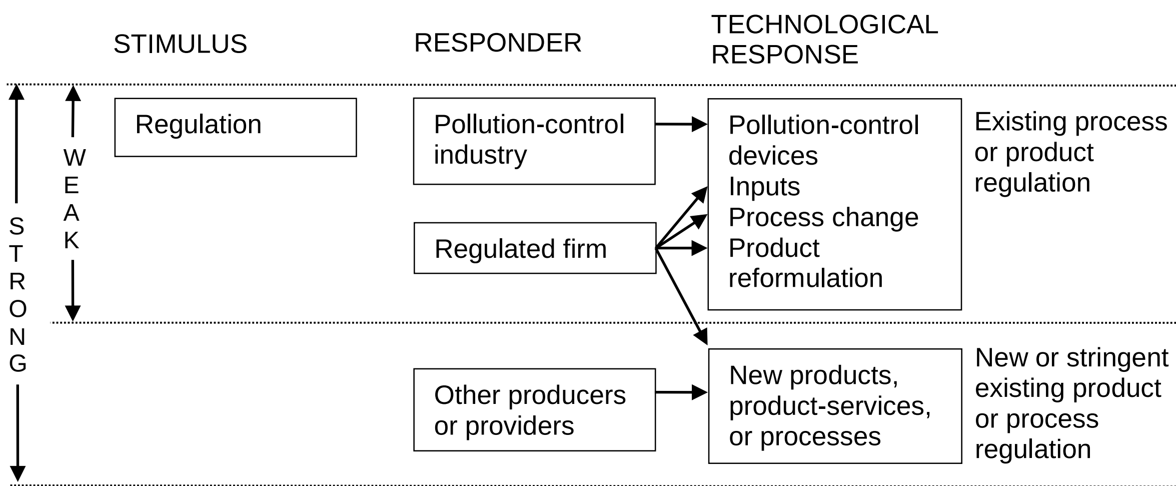



Figure 3: A model for regulation-induced technological change for 'weak' (Porter) and 'strong' (Ashford/MIT) forms of the regulation-induced innovation hypothesis

While some question whether environmental regulation does generate a positive effect on innovation (Robinson, 1995; Walley and Whitehead, 1994; Jaffe and Palmer, 1997), their analyses tends to miss the essence of the 'strong' form of the regulation-induced innovation hypothesis. Although it is likely that stringent regulation will not stimulate technological innovation in most firms, some firms are likely to rise to the challenge and become technological leaders in the process. Hence, the "evidence is necessarily anecdotal" (Ashford, 1999, p. 3). The Schumpeterian notion of 'waves of creative destruction' leading to succeeding advances in technological development describes the process by which dominant technologies are being continually displaced as new technologies become available.

The design challenge facing government is how existing undesirable technologies can be retired (or displaced) through a combination of regulation and market incentives. These ideas thus challenge the notion that incumbent firms will reinvent themselves in a significant way and should have a major role in setting the targets for future regulation. Incumbents will not set targets they do not expect that they can meet.

With regard to the ‘weak’ form of the regulation-induced innovation hypothesis, ambitious environmental policies in developed nations can lead to the formation of ‘lead markets’ for environmental technologies (Jänicke and Jacob, 2005). However, the evidence suggests that “the international diffusion of environmental innovations must be accompanied by international policy diffusion, or the adoption by other countries of the induced innovation must be economically reasonable” (Beise et al., 2003, p. 1). Both of these factors make it difficult to predict with certainty whether an ambitious environmental policy is likely to create a lead market for the international diffusion of innovations. The uncertainty surrounding the likely impacts on national industries of more stringent environmental [and health and safety] regulation is seen as one reason why governments hesitate to implement such policies (Blazejczak and Edler, 2004).

Stringent regulation can stimulate new entrants to introduce *entirely new products and processes* into the market – products and processes that will displace dominant technologies. One of several vivid examples is the displacement of Monsanto‘s PCBs in transformers and capacitors by an entirely different dielectric fluid pioneered by Dow Silicone. Regulation can thus encourage disrupting innovations by giving more influence to new customer bases, in which demands for improvements in both environmental quality and energy use and efficiency are more sharply defined and articulated. Of course, industries that would fear being displaced by new entrants would not be expected to welcome this regulation. This explains in part their resistance to regulation and their propensity to try to capture regulatory regimes, surreptitiously or through direct negotiation with government (Caldart and Ashford, 1999).

In principle, regulation can be an effective and proper instrument for government to guide the innovation process. Well-designed regulation that sets new rules changes the institutional framework of the market. It can thus be an important element in creating favorable conditions for innovation that will enhance environmental sustainability and create incentives for the development of powerful lead-markets, which pull innovation towards that sustainability (Jänicke and Jacob, 2004). With regard to regulation, what seems to matter is not only the stringency, mode (specification versus performance standards), timing, uncertainty, focus (inputs versus product versus process) of the regulation, and the existence of complementary economic incentives, but also the inherent innovativeness (usually in new entrants) or lack of it (usually in the regulated firms) that the regulation engenders.

In order for innovation to occur, the firm (or government itself) must have the *willingness*, *opportunity/motivation*, and *capability/capacity* to innovate (Ashford, 2000). These three factors affect each other, of course; but each is determined by more fundamental factors.

*Willingness* is determined by (1) attitudes towards changes in production in general, (2) an understanding of the problem, (3) knowledge of possible options and solutions, and (4) the ability to evaluate alternatives. Improving (3) involves aspects of capacity building through the diffusion of information, through trade associations, government-sponsored education programs, inter-firm contacts, and the like. Changing attitudes towards changes in production (1) often depends on the attitudes of managers and on the larger culture and structure of the organization, which may either stifle or encourage innovation and risk taking. Factors (2) and (4) depend on internal intellectual capacities. In the context of disrupting innovation by firms representing the dominant technology, willingness is also shaped by the [rare] commitment of management to nurture new approaches that are at odds with its traditional value network or customer base.

*Opportunity and motivation* involve both supply-side and demand-side factors. On the supply side, technological gaps can exist between the technology currently used in a particular firm and the already-available technology that could be adopted or adapted (known as diffusion or incremental innovation, respectively), or alternatively the technology that could be developed (i.e., significant sustaining or disrupting innovation). Consciousness of these gaps can prompt firms to change their technology, as can the opportunity for cost savings. Regulatory requirements can also define the changes that would be necessary to remain in the market. On the demand side, three factors could push firms towards technological change. These are (1) opportunities for cost savings or expansion of sales, (2) public demand for more environmentally-sound, eco-efficient, and safer industry, products, and services, and (3) worker demands and pressures arising from industrial relations concerns. The first factor could result from changes in the customer value networks. However, all these factors may stimulate change too late in the dominant technology firms, if new entrants have already seized the opportunity to engage in developing disrupting innovations.

*Capability or capacity* may actually be the most important and limiting factor and can be enhanced by (1) an understanding of the problem, (2) knowledge of possible options and solutions, (3) the ability to evaluate alternatives, (4) resident/available skills and capabilities to innovate, and (5) access to, and interaction with, outsiders. Knowledge enhancement/learning (2) can be facilitated through deliberate or serendipitous transfer of knowledge from suppliers, customers, trade associations, unions, workers, and other firms, and the available literature. The skill base of the firm (4) can be enhanced through educating and training operators, workers, and managers, on both a formal and informal basis, and by deliberate creation of networks and strategic alliances not necessarily confined to a geographical area, nation, or technological regime.

Interaction with outsiders can stimulate more radical and disrupting changes. This last method of enhancing the capacity of firms to undertake technological change involves new ‘outsider' firms and stakeholders with which the firm has not traditionally been involved. Capacity to change may also be influenced by the innovativeness (or lack thereof) of the firm as determined by the maturity and technological rigidity of a particular product or production line (Ashford et al., 1985; Ashford, 2000). Some firms find it easier to innovate than others. The heavy, basic industries, which are also sometimes the most polluting, unsafe, and resource-intensive industries, change with great difficulty, especially when it comes to core processes. New industries, such as computer manufacturing, can also be polluting, unsafe (for workers), and resource and energy intensive, although they may find it easier to meet environmental demands. Government should not miss the opportunity to loosen the creative forces that bring about innovative changes that can simultaneously benefit the economy, the environment, and the general welfare.

## The Importance of Diffusion in Achieving Sustainable Development

Although technological innovation is crucial to achieve long-term sustainable development and fosters adaptive transformations, the preoccupation of scholars with innovation, in contrast with diffusion, may contribute to under-deployment or lack of development of policies that promote diffusion. The diffusion of technology is essential for enhancing sectoral and national revenues, as well as promoting more sustainable industrial, agricultural, transportation, and construction practices. There are many existing technologies that could contribute to the reduction of health, safety, and environmental problems and improve labor productiveness, but they either encroach on vested interests in maintaining current practices or may impose costs on firms, on consumers, or on both. In many cases, “environmental technologies” are process technologies rather than products and may confer proprietary benefits on their designers, who may not want others to have them. Environmental technologies are also difficult to organize into a market.

The slow pace of widespread technology adoption (diffusion) is not due to the fact that the "discovery" of solutions to health, safety, and environmental challenges is lacking, nor is there a need for co-evolutionary approaches. Rather, what is missing is political and private-sector will for technology adoption. This may be as true for cleaner technologies as for so-called end-of-pipe technologies. After all, if the health, safety, and environmental harms that come from a technology are not internalized in the price of a manufacturer's activities, products, or services, why should he or she care if it is "cleaner"? Technology-diffusion forcing by government supported by significant demand by consumers, citizens, or workers through the tools of regulation, taxes, legislation, and stakeholder participation is likely to speed up the pace of change towards sustainable development. In sum, government needs to play a strong role in stimulating both disrupting innovation and the diffusion of technology. Otherwise, SNM and TM by themselves are likely to be too little and too late.

**Box 1: Theories of Technological Innovation and the Role of Government**

*Neoclassical economic approach:* Technological development is *exogenous*, and technology is treated as a black box. Using this approach, a rational actor will attempt to maximize the production function. Government intervention corrects underinvestment by stimulating fundamental R&D and supporting universities.

*Evolutionary economic approach:* Technological development is *endogenous* and is a path-dependent process of variation and selection. Technology is described as evolving from a firm's knowledge base. Technological development tends to occur along known directions, favoring path dependency and lock-in. The role of the government is to generate variation within an entrepreneurial climate that enhances innovation.

*Systems-of-innovation approach:* Technological development is a process of interactive learning and includes not only R&D and knowledge production but also the transfer, exchange, and use of knowledge and the demand for knowledge. The aim of technological development is to optimize the use of knowledge generated by a system of related and linked actors. The role of the government is to maintain the institutional knowledge infrastructure of universities and research institutes.

*Industrial-networks approach:* Technological development takes place in a process of interactions between actors who perform activities and have access to different resources. Thus technology (innovation) is the result of interactions between firms. No explicit attention is given to directing technological development. The role of the government is to build and renew local knowledge-intensive networks and to stimulate cooperation.

*Social constructivism approaches:* Technological development is led by a process of social interaction that is directed by the values and beliefs of interest groups and actors (including government). The role of the government is to understand and articulate specific positions during negotiations and to develop networks that support social interaction.

*Quasi-evolutionary approach:* Technological development is a process of co-evolution at different levels of analysis (micro, meso, and macro). Hence technology is an object in a co-evolutionary learning process. The *technological regime*[a] guides, but does not fix, R&D activities. The role of the government is to influence the rules of a technological regime to facilitate learning processes among the various actors, and to establish *niches* of protected learning.

*Large-technical-systems approach:* Technological development is the process of solving critical problems of a technical (or engineering) system. Technology is seen as part of an expanding technical system. Critical problems – or *reverse salient* – of the technical system have to be solved before the system can expand. The role of the government is to avoid causing or strengthening reverse salients and to reinforce the capacities or possibilities of system builders.

Sources: Luiten (2001), Moors (2000), and Partidario (2003).

[a] Rip and Kemp (1998, p. 340) define a technological regime as "the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems – all of them embedded in institutions and infrastructures."

**Notes:**

1. For an in-depth discussion of lock-in and path dependency, see Ashford and Hall (2011a).

2. This concept has generated considerable academic and government interest. It was the subject of five annual international conferences, the latest held in Brighton, the UK in August of 2015 entitled The International Sustainability Conference 2015, see http://www.sussex.ac.uk/spru/IST2015@sussex.ac.uk

3. For an excellent discussion of evolutionary economics see Grin et al. (2010), Chapter I.3 and especially pp. 35-42.

4. For a discussion of Butter's approach see Ashford and Hall (2011b), pages 351-354.

5. An example of regime optimization is the development/deployment of highly efficient vehicles that use the improved internal combustion engine as a base.

6. Hoogma et al. (2002) provide the following examples of innovations that have regime-shift potential: battery-powered vehicles, telematics for traffic management, car sharing, smart cards, individualized self-service rental systems, dial-a-ride services, and bicycle pools.

7. Kemp (2008, p. 375) comments: "The management of institutions can be done through the … use of three coordinating mechanisms: markets, hierarchy, and structure." "The basic steering mechanism is modulation, not dictatorship or planning and control" (ibid., p. 377), and "The long-term goals for functional systems are chosen by society either through the political process or in a more direct way through a consultative process" (ibid.). Kemp endorses market-based instruments, and although he does not explicitly mention regulation, it is clear that he rejects a regulation as the main steering approach; this is in line with his commitment to evolutionary approaches and strong commitment to markets. This parallels the recent contribution of ecological economists Beddoe et al. (2009, p. 2488), who also ignore regulation as a mechanism to achieve sustain-able transformations and instead rely on cultural evolution to "push our society toward the adoption of institutions that best fit the new circumstances." "Creating a sustainable future will require an integrated, systems level redesign of our socio-ecological regime focused explicitly and directly on the goal of sustainable quality of life rather than the proxy of unlimited material growth" (ibid., p. 2483).

8. Hey et al. (2007) and Jänicke and Jacob (2005) have been especially critical of relying on market-based instruments for achieving sustainable transformations, advocating, like Ashford, strong regulatory approaches.

9. The backcasting approach enables policy makers to look back from a desirable future to create strategies that they hope will enable the future visions to materialize. This approach is in contrast to current planning processes that develop strategies based on forecasts.

10. See the special issue of the Journal of Cleaner Production devoted to strategies for promoting diffusion (Montalvo and Kemp, 2008).

**References:**


Ashford, N.A. 1993. Understanding Technological Responses of Industrial Firms to Environmental Problems: Implications for Government Policy. In Fischer, K. and Schot, J. (Eds), *Environmental Strategies for Industry: International Perspectives on Research Needs and Policy Implications,* pp. 277-307. Washington, D.C.: Island Press.

---. 1999. Porter Debate Stuck in 1970s. *The Environmental Forum* (September/October, 1999): 3.

---. 2000. An Innovation-Based Strategy for a Sustainable Environment. In Hemmelskamp, J.; Rennings, K. and Leone, F. (Eds), *Innovation-Oriented Environmental Regulation: Theoretical Approach and Empirical Analysis,* pp. 67-107. New York: Physica-Verlag Heidelberg.

---. 2002a. Government and Environmental Innovation in Europe and North America. *American Behavioral Scientist* 45(9): 1417-1434.

---. 2002b. An Innovation-Based Strategy for a Sustainable Environment. In Hemmelskamp, J.; Rennings, K.; Verlag, F.L.S. and Heidelberg (Eds), *Innovation-Oriented Environmental Regulation: Theoretical Approach and Empirical Analysis,* pp. 67-107. New York.

---. 2002c. Technology-Focused Regulatory Approaches for Encouraging Sustainable Industrial Transformations: Beyond green, beyond the dinosaurs, and beyond evolutionary theory. Paper read at 3rd Blueprint Workshop on Instruments for Integrating Environmental and Innovation Policy, 26-27 September, 2002, at Brussels.

---. 2005. Government and Environmental Innovation in Europe and North America. In Weber, M. and Hemmelskamp, J. (Eds), *Towards Environmental Innovation Systems,* pp. 159-174. Heidelberg: Springer.

Ashford, N.A.; Ayers, C. and Stone, R.F. 1985. Using Regulation to Change the Market for Innovation. *Harvard Environmental Law Review* 9(2): 419-466.

Ashford, N.A.; Hafkamp, W.; Prakke, F. and Vergragt, P. 2002. Pathways to Sustainable Industrial Transformations: Cooptimising Competitiveness, Employment, and Environment. Cambridge: Ashford Associates.

Ashford, N.A. and Hall, R.P. 2011a. The Importance of Regulation-Induced Innovation for Sustainable Development. *Sustainability* 3(1): 270-292.

---. 2011b. *Technology, Globalization, and Sustainable Development: Transforming the Industrial State*. New Haven: Yale University Press.

Ashford, N. A. and R. P. Hall (2015). "Making Serious Inroads into Achieving Sustainable Development: Is Strategic Niche Management/Transition Management Sufficient to Transform the Industrial State?" Conference: 6th International Sustainability Transitions (IST) Conference. Sustainability Transitions and Wider Transformative Change Historical Roots and Future Pathways, At Brighton, University of Sussex Campus (Falmer), UK August 2015. Available at: https://www.researchgate.net/publication/280839263_Making_Serious_Inroads_into_Achieving_Sustainable_Development_Is_Strategic_Niche_ManagementTransition_Management_Sufficient_to_Transform_the_Industrial_State

Ashford, N.A. and Heaton, G.R. 1983. Regulation and Technological Innovation in the Chemical Industry. *Law and Contemporary Problems* 46(3): 109-157.

Ashford, N.A.; Heaton, G.R. and Priest, W.C. 1979. Environmental, Health and Safety Regulations and Technological Innovation. In Hill, C.T. and Utterback, J.M. (Eds), *Technological Innovation for a Dynamic Economy,* pp. 161-221. New York: Pergamon Press, Inc.

Beddoe, R.; Costanza, R.; Farley, J.; Garza, E.; Kent, J.; Kubiszewski, I.; Martinez, L.; McCowen, T.; Murphy, K.; Meyers, N.; Ogden, Z.; Stapleton, K. and Woodward, J. 2009. Overcoming systemic roadblocks to sustainability: the evolutionary Design of worldviews, institutions, and technologies. *PNAS* 106(8): 2483-2489.

Beise, M.; Blazejczak, J.; Edler, D.; Jacob, K.; Janicke, M.; Loew, T.; Petschow, U. and Rennings, K. 2003. The Emergence of Lead Markets for Environmental Innovations. Berlin: Forschungsstelle fur Umweltpolitik (FFU).

Berkhout, F.; Smith, A. and Stirling, A. 2004. Socio-technological regimes and transition contexts. In Elzen, B.; Geels, F.W. and Green, K. (Eds), *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy,* pp. 48-75. Cheltenham: Edward Elgar.

Blazejczak, J. and Edler, D. 2004. Could Too Little and Too Much Turn Out to be Just Right? On the Relevance of Pioneering Environmental Policy. In Jacob, K.; Binder, M. and Wieczorek, A. (Eds), *Governance for Industrial Transformation. Proceedings of the 2003 Berlin Conference on the Human Dimensions of Global Environmental Change,* pp. Berlin: Environmental Policy Research Centre.

Butter, M. 2002. A Three Layer Policy Approach for System Innovations. Paper read at 1st Blueprint Workshop, Environmental Innovation Systems, January 2002, at Brussels.

Caldart, C.C. and Ashford, N.A. 1999. Negotiation as a Means of Developing and Implementing Environmental and Occupational Health and Safety Policy. *Harvard Environmental Law Review* 23(1): 141-202.

Christensen, C.M. 1997. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Cambridge: Harvard Business School Press.

Dewulf, A.; Termeer, C.; Pot, W.; Werman, R. and Breeman, G. 2009. The Value of Theoretical Multiplicity for Steering Transitions Towards Sustainability. In *Paper presented at the First European Conference on Sustainability Transitions, Amsterdam, 4-6 June 2009*.

Elzen, B. 2002. Transition to Sustainability through System Innovation:Summary report from workshop and follow-up activities. Forum on Science and Technology for Sustainability, http://sustainabilityscience.org: Workshop held 4-6 July 2002, University of Twente, the Netherlands.

Elzen, B.; Geels, F.W. and Green, K. (Eds). 2004. *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy*. Cheltenham: Edward Elgar.

Foxon, T.; Makuch, Z.; Mata, M. and Pearson, P. 2004. Innovation Systems and Policy-Making Processes for the Transition to Sustainability. In Jacob, K.; Binder, M. and Wieczorek, A. (Eds), *Governance for Industrial Transformation. Proceedings of the 2003 Berlin Conference on the Human Dimensions of Global Environmental Change,* pp. 96 - 112. Berlin: Environmental Policy Research Centre.

Geels, F.W. 2004. Understanding system innovations: a critical literature review and a concept synthesis. In Elzen, B.; Geels, F.W. and Green, K. (Eds), *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy,* pp. 19-47. Cheltenham: Edward Elgar.

Grin, J.; Rotmans, J. and Schot, J. 2010. *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change*. New York: Routledge.

Hey, C.; Jacob, K. and Volker, A. 2007. Better Regulation by New Governance Hybrids? Governance Models and the Reform of European Chemicals Policy. *Journal of Cleaner Production* 15(18): 1859-1874.

Hommels, A.; Peters, P. and Bijker, W.E. 2007. Techno therapy or nurtured niches? Technology studies and the evaluation of radical innovations. *Research Policy* 36(7): 1088-1099.

Hoogma, R.; Kemp, R.; Schot, J. and Truffer, B. 2002. *Experimenting for Sustainable Transport: The approach of Strategic Niche Management*. London: Spon Press.

Hoogma, R.; Weber, M. and Elzen, B. 2001. Integrated long-term Strategies to induce Regime Shifts to Sustainability: The approach of Strategic Niche Management. Paper read at Paper presented at the conference, Towards Environmental Innovation Systems, 27-29 September, 2001, at Garmisch-Partenkirchen, Germany.

Huber, J. 2004a. Environmental Policy Shift Through Technological Innovation. In Jacob, K.; Binder, M. and Wieczorek, A. (Eds), *Governance for Industrial Transformation. Proceedings of the 2003 Berlin Conference on the Human Dimensions of Global Environmental Change,* pp. 438 - 447. Berlin: Environmental Policy Research Centre.

---. 2004b. *New Technologies and Environmental Innovation*. Cheltenham: Edward Elgar.

Jacob, K. 2005. Management of Industrial Transformation: Potentials and Limits from a Political Science Perspective. In Lehmann-Waffenschmidt, M. (Ed). *Innovations towards Sustainability. Conditions and Consequences,* pp. Berlin: Springer-Verlag.

Jaffe, A.B. and Palmer, K. 1997. Environmental Regulation and Innovation: A Panel Data Study. *Review of Economics & Statistics* 79(4): 610-619.

Jänicke, M. 1990. *State Failure: The Impotence of Politics in Industrial Society*. Pittsburgh: The Pennsylvania State University Press.

Jänicke, M. and Jacob, K. 2004. Lead Markets for Environmental Innovations: A New Role for the Nation State. *Global Environmental Politics* 4(1): 29-46.

---. 2005. Ecological Modernisation and the Creation of Lead Markets. In Weber, M. and Hemmelskamp, J. (Eds), *Towards Environmental Innovation Systems,* pp. 175-193. Heidelberg: Springer.

Kasser, T. 2002. *The High Price of Materialism*. Cambridge: The MIT Press.

Kemp, R. 2002. Integrating Environmental and Innovation Policies. In *International workshop on Industrial Innovation and Environmental Regulation: Toward an Integrated Approach, 6-7 September, 2002*. Maastricht.

---. 2008. Transition Management for Sustainable Consumption and Production. In Tukker, A.; Charter, M.; Vezzoli, C.; Stø, E. and Andersen, M.M. (Eds), *System Innovation for Sustainability: Perspectives on Radical Changes to Sustainable Consumption and Production,* pp. 369-390. Sheffield: Greenleaf Publishing.

Kemp, R.; Loorbach, D. and Rotmans, J. 2007. Transition management as a model for managing processes of co-evolution towards sustainable development. *The International Journal of Sustainable Development and World Ecology* 14: 1-15.

Kemp, R. and Rotmans, J. 2005. The Management of the Co-Evolution of Technical, Environmental and Social Systems. In Weber, M. and Hemmelskamp, J. (Eds), *Towards Environmental Innovation Systems,* pp. 33-55. Heidelberg: Springer.

Luiten, E.E.M. 2001. Beyond energy efficiency: Actors, networks and government intervention in the development of industrial process technologies. Utrecht University, Utrecht.

Mazzucato (2014) *The US Entrepreneurial State: Debunking Public vs. Private Sector Myths.* New York and London: Anthem Press.

Meadowcroft, J. 2005. Environmental Political Ecomomy, Technological Transitions, and the State. *New Political Economy* 10(4): 479-498.

---. 2009. What about the politics? Sustainable development, transition management, and long term energy transitions. *Policy Sciences* 42(4): 323-340.

Montalvo, C. and Kemp, R. 2008. Diffusion of cleaner technologies: Modeling, case studies and policy. *Journal of Cleaner Production* 16(1): Supplement 1: S1-S184.

Moors, E.H.M. 2000. Metal Making in Motion: Technology Choices for Sustainable Metals Production. Delft University of Technology, Delft.

Nelson, R.R. and Winter, S.G. 1977. In Search of Useful Theory of Innovation. *Research Policy* 6: 36-76.

---. 1982. *An Evolutionary Theory of Economic Change*. Cambridge: Harvard University Press.

Organisation for Economic Co-operation and Development (OECD). 1997. New Rationale and Approaches in Technology and Innovation Policy. Paris: OECD.
Partidario, P.J. 2003. "What-if": From path dependency to path creation in a coatings chain: a methodology for strategies towards sustainable innovation. Delft University of Technology, Delft.
Pelkmans, J. and Renda, A. 2014. Does EU regulation hinder or stimulate innovation? : Special Report, the Centre for European Policy Studies, No. 96, November 2014. Available from http://www.ceps.eu.
Porter, M.E. 1991. America's Green Strategy. *Scientific American* 264(4): 168.
Porter, M.E. and van den Linde, C. 1995. Green and Competitive: Ending the Stalemate. *Harvard Business Review* 73(5): 120-134.
Quist, J. and Vergragt, P. 2004. Backcasting for Industrial Transformations and System Innovations Towards Sustainability: Relevance for Governance? In Jacob, K.; Binder, M. and Wieczorek, A. (Eds), *Governance for Industrial Transformation. Proceedings of the 2003 Berlin Conference on the Human Dimensions of Global Environmental Change,* pp. 409-437. Berlin: Environmental Policy Research Centre.
Reinhardt, F. 1999. Market Failure and the Environmental Policies of Firms: Economic Rationales for "Beyond Compliance" Behavior. *Journal of Industrial Ecology* 3(1): 9-21.
Rennings, K.; Kemp, R.; Bartolomeo, M.; Hemmelskamp, J. and Hitchens, D. 2003. Blueprints for an Integration of Science, Technology and Environmental Policy (BLUEPRINT). Mannheim: Zentrum für Europäische Wirtschaftsforschung (ZEW).
Rip, A. 1992. A Quasi-evolutionary Model of Technological Development and a Cognitive Approach to Technology Policy. *Rivista di Studi Epistemologici e socioli Sulla Scienza e la Tecnologia* 2: 69-103.
Rip, A. and Kemp, R. 1998. Towards a Theory of Social-Technical Change. In Rayner, S. and Malone, E.L. (Eds), *Human Choice and Climate Change, Volume II,* pp. 329-401. Columbus: Battelle Press.
Robinson, J. 1995. The Impact of Environmental and Occupational Health Regulation on Productivity Growth in U.S. Manufacturing. *Yale Journal of Regulation* 12: 388-434.
Rotmans, J. and Kemp, R. 2008. Detour ahead: a response to Shove and Walker about the perilous road of transition management. *Environment and Planning A* 40: 1006-1011.
Rotmans, J.; Kemp, R. and van Asselt, M. 2001a. More Evolution than Revolution: Transition Management in Public Policy. *Foresight* 3(1): 015-031.
Rotmans, J.; Kemp, R.; van Asselt, M.; Geels, F.; Verbong, G. and Molendijk, K. 2001b. Transitions & Transition Management. The case for a low emission energy supply. In *ICIS working paper: I01-E001. Maastricht.*
Saviotti, P.P. 2005. On the Co-Evolution of Technologies and Institutions. In Weber, M. and Hemmelskamp, J. (Eds), *Towards Environmental Innovation Systems,* pp. 9-31. Heidelberg: Springer.
Schot, J.; Hoogma, R. and Elzen, B. 1994. Strategies for Shifting Technological Systems: The Case of the Automobile System. *Futures* 26(10): 1060-l076.
Shove, E. 2010. Questions Often, Sometimes and Not Yet Asked. *Theory, Culture & Society* 27(2-3): 277-288.
Shove, E. and Walker, G.P. 2007. Caution! Transitions ahead: politics, practice and transition management. *Environment and Planning A* 39: 763-770.
---. 2008. Transition Management™ and the politics of shape shifting. *Environment and Planning A* 40: 1012-1014.
Smith, A. 2003. Transforming technological regimes for sustainable development: a role for alternative technology niches? *Science and Public Policy* 30(2): 127-135.

Smith, A. and Kern, F. 2007. The transitions discourse in the ecological modernisation of the Netherlands. Working Paper. SPRU (Science & Technology Policy Research), University of Sussex, UK.

Smith, A.; Stirling, A. and Berkhout, F. 2005. The Governance of Sustainable Socio-technical Transitions. *Research Policy* 34(10): 1491-1510.

Tukker, A.; Charter, M.; Vezzoli, C.; Sto, E. and Andersen, M.M. 2008. *System Innovation for Sustainability: Perspectives on Radical Changes to Sustainable Consumption and Production*. Sheffield: Greenleaf Publishing.

van de belt, H. and Rip, A. 1987. The Nelson-Winter-Dosi Model and Synthetic Dye Chemistry. In Bijker, W.; Hughes, T.P. and Pinch, P. (Eds), *The Social Construction of Technological Systems: New directions in the sociology and history of technology,* pp. 135-158. Cambridge: The MIT Press.

van de Poel, I.R. 2000. On the Role of Outsiders in Technical Development. *Technology Analysis and Strategic Management* 12(3): 383-397.

van den Bosch, S. and Taanman, M. 2006. How Innovation Impacts Society. Patterns and Mechanism Through Which Innovation Projects Contribute to Transitions. Paper presented at Innovation Pressure Conference , March 15-17, 2006, Tampere, Finland.

Vergragt, P. 2005. Back-casting for Environmental Sustainability: From STD and SusHouse towards Implementation. In Weber, M. and Hemmelskamp, J. (Eds), *Towards Environmental Innovation Systems,* pp. 301-318. Heidelberg: Springer.

Voss, J.-P.; Smith, A. and Grin, J. 2009. Designing long-term policy: rethinking transition management. *Policy Sciences* 42(4): 275-302.

Wallace, D. 1995. *Environmental Policy and Industrial Innovation. Strategies in Europe, the U.S. and Japan*. London: Earthscan Publications Ltd.

Walley, N. and Whitehead, B. 1994. It's Not Easy Being Green. *Harvard Business Review* (May/June): 46-52.

Winner, L. 1977. *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought*. Cambridge: The MIT Press.

---. 1986. *The Whale and the Reactor*. Chicago: The University of Chicago Press.

--- (Ed). 1992. *Democracy in a Technological Society*. Dordrecht: Kluwer Academic Publishers.

Nicholas A. Ashford is Professor of Technology & Policy and Director of the Technology & Law Program at the Massachusetts Institute of Technology. He holds both a Ph.D. in Chemistry and a Law Degree from the University of Chicago. Dr. Ashford also is visiting scientist in Occupational and Environmental Health at the Harvard School of Public Health and teaches intensive courses in Sustainable Development, and European & International Environmental Law at Cambridge University, UK and at the Cyprus University of Technology. He recently co-authored Environmental Law, Policy and Economics: Reclaiming the Environmental Agenda (2008, MIT Press). He can be reached at nashford@mit.edu. His web site is: http://ashford.mit.edu

Ralph P. Hall is an Assistant Professor in the School of Public and International Affairs at Virginia Tech. He holds a PhD in Technology, Management, and Policy from MIT and a MEng in Civil Engineering from the University of Southampton. Dr. Hall has over a decade of academic and professional experience in applying the concept of sustainable development to large-scale infrastructure systems with a specific emphasis on transportation, water supply, and sanitation systems. He is the Research Chair for the U.S. Transportation Research Board (TRB) Committee on Transportation and Sustainability. Dr. Hall can be reached at rphall@vt.edu. His web site is: http://ralphphall.wordpress.com/