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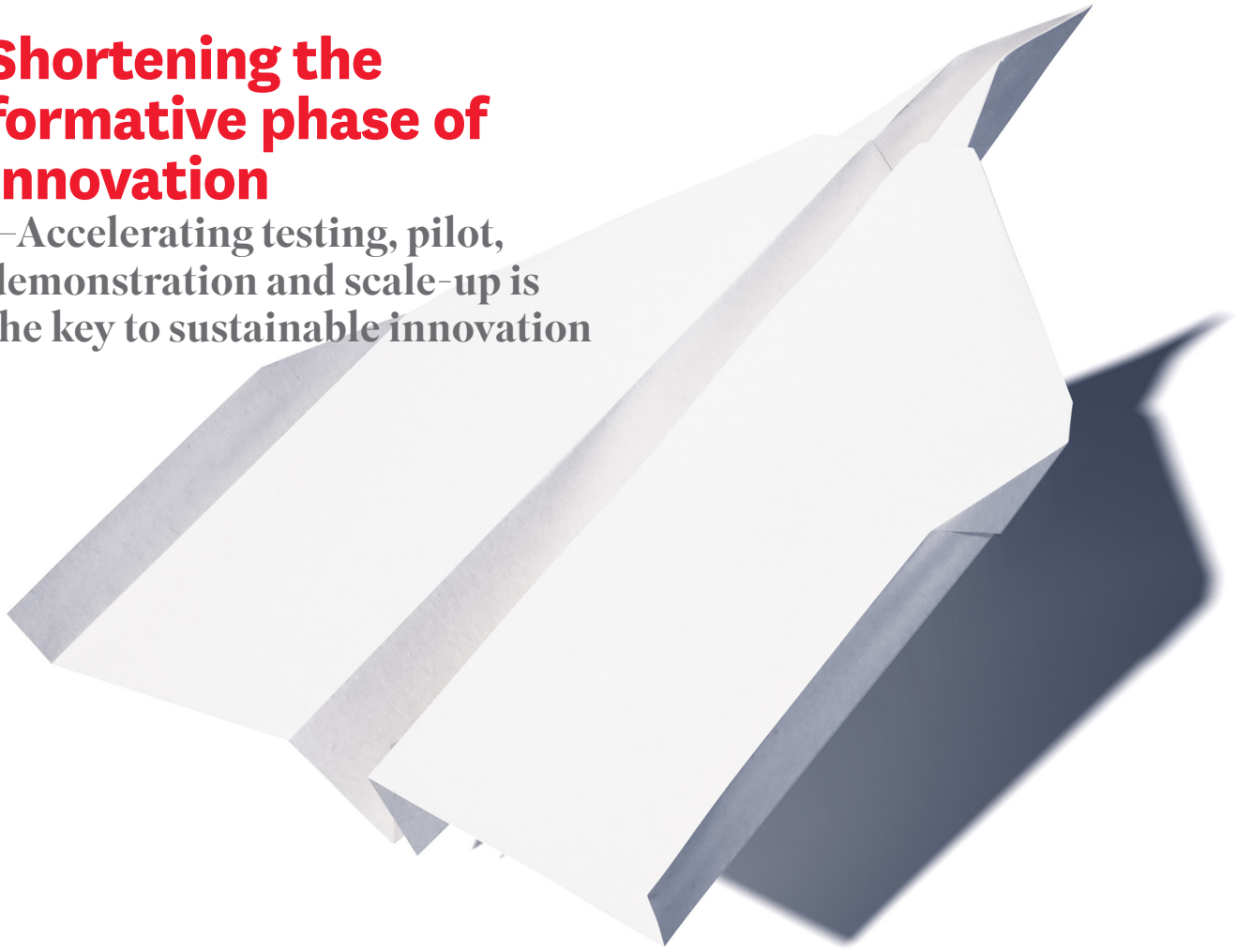


Shortening the formative phase of innovation

—Accelerating testing, pilot, demonstration and scale-up is the key to sustainable innovation

By Markus Gustafsson, Johan Frishammar, Daniel Enström och Fredrik Engström

To manage the transition to a sustainable and circular economy, new products and technologies must be invented. However, initial innovation alone is not sufficient. Equally important is shortening the subsequent "formative phase" through which innovation and technology is upscaled. This article defines formative phase, explain why it is so important and delineates how it can be shortened by means of more effective technology scale-up.

Sweden–like the rest of the world–is facing an enormous challenge in transcending into a more circular and sustainable economy. United Nations climate change body IPCC states we have 12 years of leeway in reaching global targets for limiting the temperature increase to 1.5 degrees. Complying with the Paris agreement therefore requires widespread development and diffusion of low-carbon technologies. Emissions must be cut dramatically, and new sustainable technologies must be developed and diffused within short timeframes.

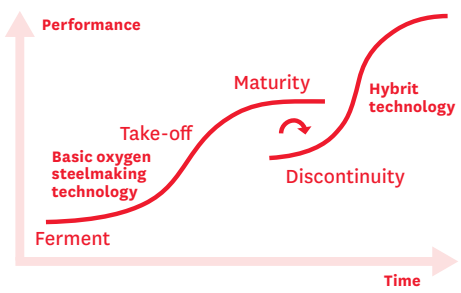
On a positive note, many companies and industries now take climate change seriously. They act proactively, realizing that sustainable technologies and products not only mitigate climate change but are critical to their survival and competitive advantage. For example, the latest generation of data center technology procured by Facebook is dramatically more energy efficient than the prior generation, and the Hybrit project holds the promise for fossil free steel production. Similar initiatives occur also in other industries, such as the ongoing electrification of cars and the transformation of the energy system.

These transformations require innovation in 1) the products and services of firms but also in 2) the underlying process technologies and production methods to produce goods and services. However, there is a bias in thinking about sustainable innovation. We–academics, companies, policy makers and the general public–think too much about initial innovation and too little about the formative phase in which products and technology is scaled up to mass market volumes. We celebrate the first product launch, first-mover firms and individual entrepreneurs but often forget about the subsequent development and scale-up. A new sustainable technology or product by a single firm will not accomplish much, but millions of products by thousands of firms will. The bottleneck is often not the lack of innovations, but rather the long timeframes for the subsequent formative phase of technology development. Recent research shows the formative phase is often 20-30 years and sometimes longer.

What is the "formative phase" and why is it so important?

The formative phase occurs *after* an initial innovation. The formative phase comprises the early technology development phase that sets the stage for a technology to emerge and become established. In other words, it is the development that happens *before* a technology can grow rapidly and take off. The formative phase is so important because it is here that industrial capacity is created which enable subsequent large-scale diffusion.

The concept of the technology S-curve is helpful to explicate "formative phase". Think of steel manufacturing. The dominant technology for steelmaking is "Basic oxygen steelmaking" which was invented in 1948 and still account for about 70% of global steel output. This technology is now at the maturity phase. If the Hybrit technology under development by Vattenfall, LKAB and SSAB succeeds, it will imply a new technology for steel manufacturing which will create disruption and discontinuity by means of sustainable innovation. This new technology can draw on the learnings from the old, including core competences of incumbent iron- and steel manufacturing companies.



The formative phase is lengthy; in fact, depressingly lengthy from a sustainability perspective. Recent research shows it is often 20-30 years. Therefore, we need to ask what could be done to shorten it so that sustainable technologies can reach the mass market faster.

To shorten the formative phase, improve the innovation system for the specific technology at hand

New sustainable technology is never developed in isolation. Rather, it is embedded in a technological innovation system which performs a set of important functions. Weaknesses in these functions may stall or lengthen the formative phase. For example, ill-functioning markets or lack of infrastructure for pilot- and demonstration activities may constitute weaknesses. However, a system may also have strengths, for example excellent knowledge development and access to required resources.

One example was Vattenfall's carbon capture and storage project in Schwarze Pumpe where a 1.5 billion euro investment was cancelled just after the pilot phase, but before the demonstration phase, in 2016, because current environmental legislation was not sufficiently aligned to the technology. By contrast, the recent major investment decision into battery technology by Northvolt may be an example of a project aligning with extent system strengths. There is currently world-class research on this technology conducted by Swedish universities and institutes, and valuable complementary resources exist by the presence of mining companies, world-class equipment manufacturers (like Epiroc, ABB) and potential customers (like Volvo cars, Scania, etc.). In addition, many of the minerals- and metals required, including several so-called rare earths, reside in Sweden. Together, this forms an ecosystem of actors and complementary resources around the technology. Table 1 defines the functions of an innovation system and delineates some key challenges for each function.

A technological innovation system is dynamic and evolves over time. A good example is complex products and systems, like wind power technology. The recent major investment in Markbygden outside Piteå, by Svewind, with up to 1100 wind turbines, benefits from new inventions in rotors, powertrain, encapsulation and digital sensors and connectivity which has made this technology increasingly competitive over time.

That said, an innovation system needs to deal with technical-, market-, and institutional uncertainty as it evolves. Important functions at the beginning of the formative phase may be knowledge creation, entrepreneurial experimentation and initial market formation. Later on, resource

Innovation system function	Definition	Examples of key challenges
Knowledge development and diffusion	How knowledge is genereated, combined and shared to allow innovation to progress (including R&D and learning efforts)	Too little funding for basic R&D, lack of networks for knowledge diffusion, too little learning among actors
Influence on directionality	How new actors allocate activities and investments between competing technologies and designs, and incentives to enter	Industry investments goes largely to incumbent and fossil-based technology, inadequate incentives to enter into the new actor network, lack of visions and goals
Entrepreneurial experimentation	Acts of probing into new technologies and applications by taking risks	Too little risktakning from industry actors, limited support by government
Market formation	Organization of markets, from demonstation projects to niches to bridging markets to mass markets	Lack of pilot- and demonstration facilities, Insufficient governmental support to create niche markets, Industry failures in creating mass markets
Legitimization	Socio-political process of creating a network of diverse actors who works to strengtheing the technology and system	Too few actors, key actors missing, absence of certain roles (e.g. for coordinating a network by means of network management)
Resource mobilization	The process of drawing in human capital, financial capital and complementary assets from the outside	Lack of human resources, lack of financial resources, Investments too small to meet needs

mobilization, legitimization and mass market formation may be more nuanced as technology development matures, production capacity increases and new value chains are formed.

Technology factors also influence the length of the formative phase

Characteristics of the technology *per se* may also greatly influence the length of the formative phase, as will the principles for *how* technology is developed. First, *substitutability* matters. Technologies which are not readily substitutes for incumbent technologies require longer formative phases as e.g. seeking legitimization will take more time, as will creating user demand. Diffusion processes are simply slower for non-ready substitutes. Second, *technological complexity* matters in so far as highly complex technologies have longer formative phases. For example, Hellsmark and colleagues show that advanced biorefinery technology in Sweden had a very long formative phase. However, if urgency of development is high, even highly complex technologies can be developed in relatively short timespans (The Apollo programme is one example, and nuclear technology is another, the latter with a post-hoc estimated formative phase of 13 years). The *need for infrastructure* must also be considered, in so far as technology strongly dependent on idiosyncratic infrastructure have longer formative phases. A technology's *relative advantage* also matters; if the technology is highly competitive over existing alternatives, the formative phase may be shorter. The same is true if *compatibility* is high, i.e. if the new technology have a strong alignment with existing value- and supply chains. Similarly, if a new technology aligns with existing laws and legislation, the formative phase may be quicker. Finally, *how* innovation is conducted should matter a lot. A great example is the "Open compute project", an organization which shares designs of data center technologies among companies such as Facebook, IBM, Nokia, Google and Microsoft. These companies share non-core knowledge. After all, a data center is just about infrastructure. They also draw on their DNA from software development, including rapid and agile prototyping, which is a development logic vastly quicker and very different from that of development of physical products.

Implications

The formative phase for most technologies are long, lasting on average 20-30 years. The formative phase needs be shortened, and technology development accelerated, to achieve large-scale diffusion of sustainable technology. Better knowledge about the formative phase allows companies, investors and policy makers to make better decisions on investments, location, technology- and product development not only by understanding firm-internal invention of products and technology but also the subsequent formative phase in which products and technology is scaled up to mass market volumes. This allows companies to better address sustainability proactively. We conclude in five bullet points, abbreviated in the word NORTH:

***N**urture sustainable innovation and accelerate it by better understanding the formative phase of the innovation process, like in the example of Hybrit.*

***O**rganize the innovation system so as to overcome weaknesses (to the extent possible) and reinforce system strengths. Development of biorefinery technologies in Sweden is an example.*

***R**euse! Development logic and ideas can be "borrowed" from the software paradigm and applied to the development of physical products as this may accelerate development of new technology, like in the data center example with Facebook.*

***T**echnology-specific factors matter a lot for the duration of the formative phase. For example, aligning with existing value chains and complementary resources as in the case of the Northvolt investment in battery technology.*

***H**elp by government in the form of policy initiatives can facilitate development of new sustainable technology, for example by subsidizing demand for new sustainable technology or by R&D subsidiaries. Such support has benefitted the project in Markbygden in wild power technology. However, policy frameworks can also overturn investments, such as in the Schwarze pumpe project by Vattenfall.*

ADDITIONAL READINGS

> Hellsmark, H., Mossberg, J., Söderholm, P. & Frishammar, J. (2016). Innovation system strengths and weaknesses in progressing sustainable technology: The case of Swedish biorefinery development. *Journal of Cleaner Production 131: 702-715.*

> Bento, N. & Wilson, C. (2016). Measuring the duration of formative phases for energy technologies. *Environmental Innovation and Societal Transitions 21: 95-112.*

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