2. Accelerating system transitions

Getting to net zero will require major changes in the large-scale systems we use to meet societal needs, including the way we produce and distribute energy, move people and goods, and build our cities.[1,2] Although change in such systems is typically incremental, there have been many dramatic transformations in the past: consider the emergence of a transport system based around the personal automobile,[3] the build-out of electricity systems to provide power for homes and businesses,[4] or the ways computing and the digital economy are altering how we live today. These 'system transitions', which may take several decades, involve interconnected changes to technologies, social practices, business models, regulations and societal norms.[3,5,6]

Transitions are periods of considerable uncertainty, since it is unclear how fast change will come and which approach will pan out. They often have significant distributional impacts.[7] While society may benefit from system change that offers increased service and economy, some enterprises or sectors will contract even as emergent firms and industries expand. Incumbents resist change, and this makes progress bumpy.[8,9] Moreover, there are always multiple ways to apply new technologies, social practices, or business models – that articulate different values and/or provide alternative distributions of benefit. So, transitions inevitably involve struggles over the direction and pace of change.[10,11]

It is no surprise, then, that governments, politics, and policy play an important role in system transitions.[12,13] States may see strategic, military, or commercial advantage in emergent technological systems (consider the development of steam ships, satellites, or the Internet). Changes to regulatory frameworks and property rights are normally required to unleash the potential of new approaches. And actors linked to established and emerging industries contend to influence the direction of policy.

Transitions typically pass through three basic stages: 'emergence', 'diffusion', and 'system reconfiguration'.[14] Emergence is about developing and testing alternatives. Dissatisfaction with the established way of doing things spurs innovators to experiment. At first new technologies are expensive and imperfect, and the designs and business models that will allow widespread adoption are unclear. Novel solutions typically emerge in protected niches – where users are willing to pay over the odds and ignore functional shortcomings. Solar cells, for example, found early applications generating power for spacecraft and in remote locations. As innovators gain experience with the new technology, a combination of favorable circumstances (problems with the existing regime, changes in political or economic context) may allow a more direct challenge to the status quo.[15,16]

During the diffusion phase the new approach gains adherents, improves functionality, and prices fall with economies of scale. Positive feedback loops kick in as consumers become increasingly familiar with the new approach, infrastructure is built out, complementary innovations come to market, and more favorable policy and regulatory frameworks are put in place. As this phase advances, incumbents may become increasingly alarmed by the rapid progress of the challengers and very public struggles may emerge.[17,18]

Eventually, change impacts the overall configuration of the system: sometimes the novel elements are incorporated through realignment, while important features of the previous system remain, but on other occasions a new system almost entirely replaces the old. With this reconfiguration, regulatory and policy frameworks become fully aligned with the new arrangements, linkages to other systems are stabilized, and challengers become the new incumbents.[19,20] These three phases trace out a classic S curve, where a long preparatory phase gives way to widespread deployment and ultimately system transformation (see **Figure 1**).

Approaching the climate challenge from the perspective of system transitions brings to the fore issues that can help the design of transformational pathways and the formulation of supportive policy. In the first place, while it is common to talk about 'the low carbon transition' or 'the energy transition', decarbonizing the economy will actually involve a series of inter-related transitions in an array of sectoral systems (personal mobility, freight movement, agri-food, and so on) [1,2]. Each of these sectors has distinctive dynamics and different obstacles and enabling factors. Moreover, climate change is not the only problem, nor is it typically the most powerful driver of change.

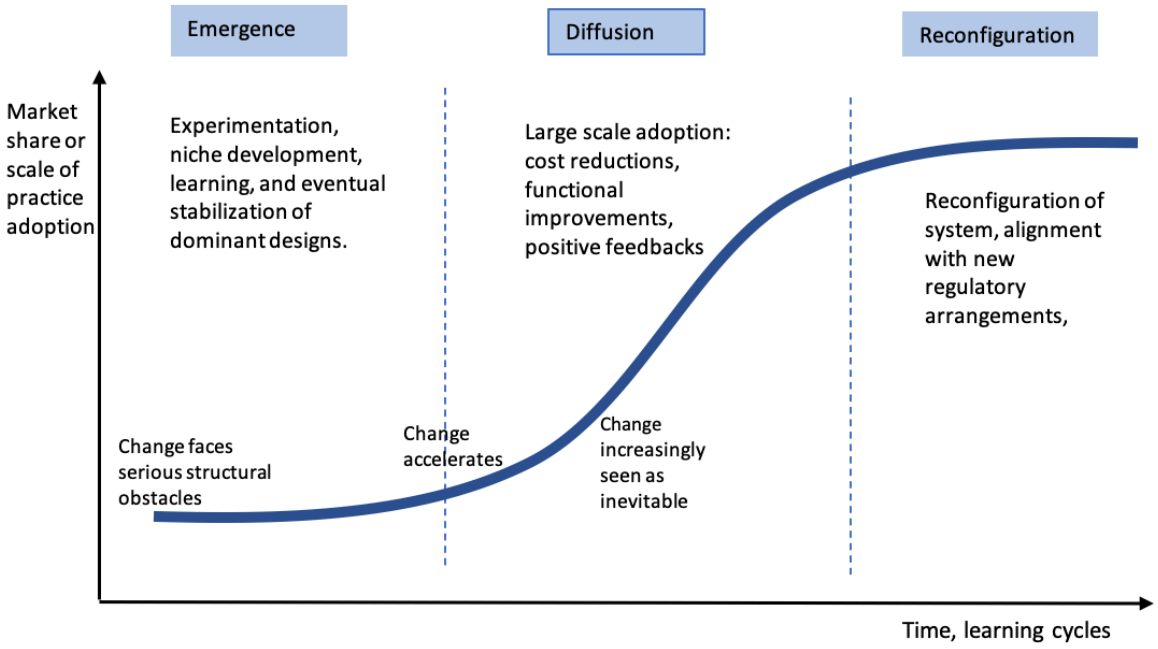

Figure 1. Typical S curve of technology or practice adoption and system transition

Adapted from Victor, Geels and Sharpe, 2019

Some sectors are already being disturbed by powerful disruptive currents (consider autos with electric and autonomous vehicles and ride-hailing apps).[21–23] Integrating low carbon initiatives with solutions to broader challenges is therefore critical. And, since changes big enough to achieve net zero are certain to alter sector norms and the social distribution of costs and benefits, engaging with wider system challenges is unavoidable.

Other policy implications of a transition approach to reaching net zero are that:

- **Accelerating system changes that achieve net zero (and other societal objectives) should be the focus of policy design,** rather than trying to secure the lowest cost incremental GHG reductions by a specified date. In many cases the cheapest or most obvious abatement opportunities are not part of a transformational pathway, and investing in them wastes time and resources that can better be devoted to more strategic efforts.
- **Policy should be attuned to the particularities of the sector and region under consideration.** Only in this way can it empower innovators and target the specific barriers that are preventing change. Agri-food, personal mobility and buildings involve different technologies, actors, and regulatory frameworks, and specific pathways and policy supports are required in each context.
- An **understanding of transition phases (emergence, diffusion, reconfiuration) can help guide the design of the policy mix** at each stage of the transformational process (see Box A). A vast array of policies including R&D support, regulations, tax measures, subsidies and public education can be applied. At a certain point, phase-out measures, which include retirement dates for specific processes, fuels, or technologies, as well as 'just transition' measures to compensate those disadvantaged by change will be required.
- **Innovation policy should be built around core policy goals, including building a net zero economy (it should be 'mission' or 'challenge driven'),[176] rather than simply establishing a generic framework to encourage all innovation**. Indeed, some innovations may be actively driving us in the wrong direction.
- At the appropriate moment **governments must be prepared to back particular technologies, and social and business practices that can accelerate net zero pathways.** Although there is understandable hesitation about 'picking winners', at a certain point it is necessary to focus investment on the most promising options, fund critical infrastructure, reduce uncertainty for private investors, and facilitate economies of scale. Despite the rhetoric about 'letting the market decide' governments have always made choices about technological options – especially large-scale energy technologies. If they had not done so in the past there would be no trans-Canada highway network, nuclear power industry, oil sands development, and so on.[12,13,24,25]
- **While international factors** (including climate agreements, technological advances, globally integrated supply chains, geopolitical rivalries and trade tensions) will impact the pace and orientation of change in key sectors, national governments still retain powerful levers to influence development trajectories.[12,25]

BOX A

Focusing policy to accelerate change at different transition phases

EMERGENCE

POLICY GOAL: encourage emergence of alternatives that can potentially lead to system transformation capable of delivering net zero GHG emissions and other societal goals.

POLICY APPROACH: support portfolio of R&D focused on particular sector/problems; fund experiments and demonstration programs; articulate visions of the most promising alternatives to coordinate actors; facilitate knowledge sharing across target sectors; fund intermediary actors to network innovators and develop best practices; encourage early application niches (for example, through public procurement).

DIFFUSION

POLICY GOAL: accelerate improvement and large-scale deployment of novel approaches that can lead to positive system transformation

POLICY APPROACH: encourage economies of scale, 'learning by doing', and the availability of complementary technologies; support development of standards and codes; support build out of core infrastructure; stimulate demand with purchase subsidies and public procurement; mobilize investment with grants, loans, tax incentives; apply regulations and fiscal measures to raise pressure on incumbents and create market opportunities for new entrants; conduct public education; assist those disadvantaged by changes or less able to enjoy collective benefits

RECONFIGURATION

POLICY GOAL: carry through the transformation of the system to achieve net zero and other societal objectives

POLICY APPROACH: stabilize new institutional and regulatory frameworks; encourage complementarities with other systems; phase out old system elements including compensation, retraining, regional development.