EECA INSIGHTS

Government Leadership

Innovation and the transition to a low carbon future

Why we have to choose our way now and where to focus for emissions reductions at scale

July 2021

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Citation

Energy Efficiency and Conservation Authority 2021

Innovation and the transition to a low carbon future
- Why we have to choose our way now and where to focus for emissions reductions at scale

Wellington, New Zealand

ISBN: 978-1-99-115222-0

Published in July 2021 by

Energy Efficiency and Conservation Authority (EECA)

Wellington, New Zealand

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Innovation and the transition to a low carbon future

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Executive summary

Innovation can be defined as "*the application of 'better solutions' that meet new requirements, unarticulated needs, or existing market needs.*" (World Design Organisation)

The innovation lens is central to transitioning to a low-carbon economy, as there is a "new requirement" (as per the innovation definition) for the whole economy to decrease GHG emissions.

In essence, **the transition to net zero-emissions means finding sustainable ways to solve all the problems we currently solve with fossil fuels**. The adoption of low-carbon technologies will be crucial, but non-technical innovations such as changes in practices or behaviours will be required too.

Given the central role of innovation to help us transition, this paper investigates the barriers to low-carbon innovation and how to address these to accelerate the transition.

Some challenges common to innovation in general become pivotal when a low-carbon lens is applied, and addressing the innovation diffusion chasm stands out as the biggest priority when it comes to emissions reductions in New Zealand. Innovation in the energy space takes time to mature and diffuse and low-carbon innovations are facing an uphill battle due to the "carbon lock-in" effect.

Low-emission innovations which are commercially available today have the greatest potential to reduce emissions by 2030 and beyond. Indeed, by 2050, these technologies are projected to continue to account for the majority of emissions reductions on an annual basis. In contrast, innovations at demonstration or prototype stages can be expected to decarbonise currently hard-to-decarbonise sectors over a longer timeframe. **The clear implication of this is that New Zealand's emissions reductions commitments in 2030 and 2050 will mostly have to be met by technologies that are in-use today.**

This paper concludes by introducing a framework and a methodology for identifying low-carbon innovations which will deliver emissions reductions at scale. The framework is based on the three levers which act on emissions reductions: the use of low-carbon fuels, increasing the efficiency of processes, and practice changes which allow us to do more with less. Our proposed methodology based on this framework allows for the identification of emissions reductions opportunities which will achieve impact. These are the commercially available innovations which must be supported to bridge the diffusion chasm.

The main purpose of this paper is to spark a dialogue with relevant stakeholders keen to collaboratively address the challenges of reducing emissions. This paper outlines areas EECA sees as requiring focus in accelerating innovation for emissions reduction, based on our insight so far:

- **Provide predictable and long-term signals** to give market actors the confidence to undertake the necessary investments. Innovation takes a lot of time.
- **Provide incentives across all stages of the innovation cycle:** Ensure there is continuity in support, with a specific focus on bridging the diffusion chasm.
- **Consider the country's long-term competitive advantage resulting from wide adoption of innovation** when assessing the costs/benefits.
- **Upscaling firms' "absorptive capacity" of innovations** is a key part of a crosscutting effort.
- **International collaboration is key given New Zealand is mostly a technology-taker, and efforts should be made to ensure NZ's society can access the most relevant solutions.** This could include trade agreements as a bridge to importing low-emission technologies such as electric vehicles or high temperature heat pumps.
- **Agencies need to think through their actions with an end-to-end mind-set:** It is better to support a solution up to the point it makes a real difference than support many solutions that have potential but provide no follow-up. Picking winners is necessary.
- When an agency's mandate prevents it from acting end-to-end, **partnership with other agencies and organisations should be sought to create a pipeline of innovation with cross-government support.**
- **Focus on impact:** When resources are limited, focus on achieving real-world change. This is preferable to a profusion of early stage wins (e.g. patents) which fail to result in actual implementation (commercial projects) and therefore have no impact on emission reductions.
- **Allow support for non-technical innovation**: Selection criteria for government support should leave options open or specific support policies should be created and ring-fenced.

1 What this think piece is (and isn't) about

1.1 Purpose

The purpose of this paper is to:

a) Highlight the central role of innovation in transitioning to a net zero-emissions economy.

b) Outline some of the overarching issues that need addressing in order to achieve meaningful emissions reduction.

c) Propose a framework and a methodology for identifying low-carbon innovations which will deliver emissions reduction at scale.

1.2 Scope

Given the wide-ranging nature of the topic, the scope of this paper is:

a) **Mitigation** rather than adaptation. The current rate of global emissions will lock-in temperature rise above 1.5°C within a decade,[1] but the full impact of these emissions will happen several decades later, with the multiplier effect of tipping points.[2] This difference in timing between mitigation and adaptation means they can't be considered from the same innovation-lens perspective.

b) **Focus on the later steps of the innovation cycle:** science, research and the fundamental infrastructure underpinning it (physical and data) is a pre-requisite to innovation, however it takes a long time for any new and original breakthroughs to be translated into wider adoption and uptake at commercial scale. As such, direct emission reductions will need to come from later steps of the innovation cycle to meet target timeframes.

c) **All sectors.** The perspective and broad framework proposed could apply to any sector, although there is a focus on the energy sector.

d) **All emissions.** This includes a consumption-based perspective as well as the production-based targets required to meet Nationally Determined Contributions (NDCs). It also includes all greenhouse gases.

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[1] Emissions Gap Report 2020 | UNEP - UN Environment Programme

[2] Maximum warming from a particular CO_2 emission is estimated to occur about 10 years after the emission. Then, the complex interactions between climate and other earth systems can further delay the full consequences of this increase in temperature: e.g. sea level rise, melting of permafrost, and vegetation changes such as forest die-back.

1.3 Framing definitions

The following definitions are provided as context for this discussion. The words “technology” and “innovation” are often misused interchangeably, however for the purposes of this paper we have defined each of these terms below.

Technology can be the knowledge of techniques, processes, or it could be embedded in machines to allow for operation without detailed knowledge of their workings.

Technologies must be “invented” and then developed before the process of application can begin.

Innovation can be defined as the application **of “better solutions” that meet new requirements, unarticulated needs, or existing market needs.**[3]

Such innovation takes place through the provision of more effective technologies, products, processes, services, or business models that are made available to markets, governments, and society.

Non-technical innovation, such as novel business models, are as important as new technologies. This is especially important for sectors of the economy where technological solutions are far from being commercially available.

Working with these definitions, innovation is a broad concept that emphasises application, whereas technology and invention are more specific to the early stages of the innovation cycle. This is an important distinction because the barriers to an economy-wide transition to low-carbon, brought about through innovation, are not the same as the barriers that apply to technology development.

[3] World Design Organisation https://wdo.org/glossary/innovation/

2 The central role of innovation in addressing climate change

This section examines the innovation lifecycle, and describes the central role of innovation in addressing climate change.

2.1 Innovation has a lifecycle

Innovation is a dynamic and complex process following a lifecycle. The figure below outlines the varied stages of innovation and highlights the proportional shift in drivers from "technology push" to "market pull":

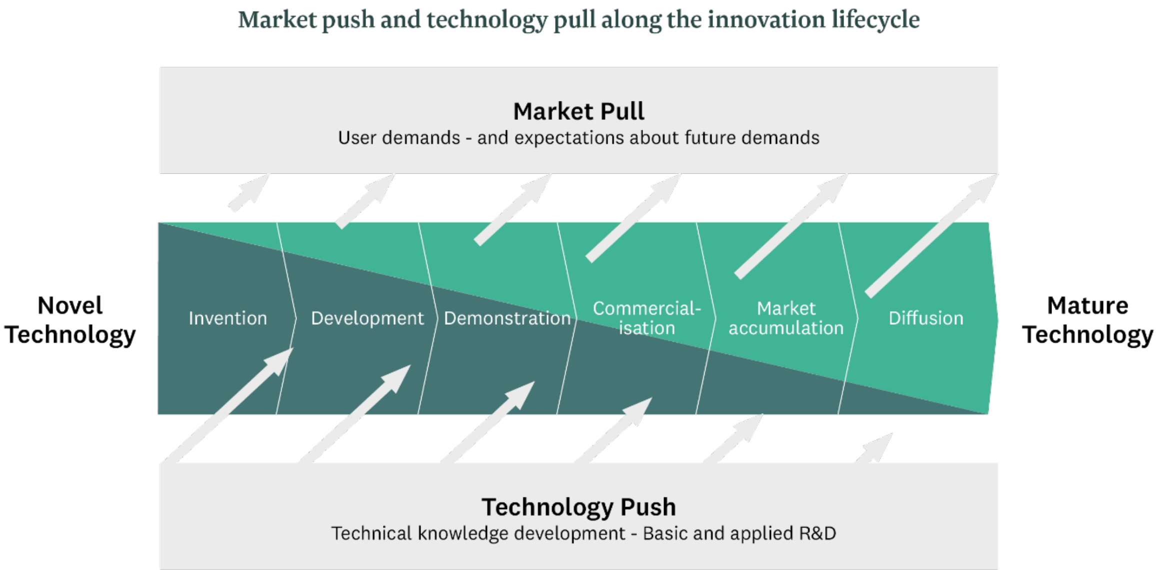

Figure 1: The innovation lifecycle. Adapted from Grubb et al. "On order and complexity in innovations systems: Conceptual frameworks for policy mixes in sustainability transitions"[4].

It is important to highlight here that:

a) There is still a need to push, even in the later stages of the lifecycle.

b) The "technology push" means that some actors (public or private) decide to support the innovation.

c) This illustrates relative proportion, rather than volume of support. The costs tend to increase as the innovation progresses through its lifecycle, and therefore a smaller proportion of "push" might still require higher levels of financial support.

[4] Michael Grubb, Will McDowall, Paul Drummond, On order and complexity in innovations systems: Conceptual frameworks for policy mixes in sustainability transitions, Energy Research & Social Science, Volume 33, November 2017, Pages 21-34.

2.2 Innovation is hindered by gaps in support

The "valley of death" of innovation

The investment space following pre-commercialisation is often described as the "valley of death". In this stage of the innovation cycle, technologies often fail to become commercially viable due to a lack of funding. Usually suppliers of these pre-commercial technologies cannot afford to pay the first commercial-scale installation in full, and it represents a high risk for the first taker of the innovation. Reaching commercialisation requires an adopter to attempt to address the barriers associated with the technology/innovation.

It also requires appropriate funding to provide 'patient finance'. This is the vital role of green banks, doing the due-diligence and accepting a higher level of risk. That due diligence is then a public good, unlocking and catalysing private financing sources for the next installation. Such examples routinely provide a commercial return to government, which allows the bank to be self-sustaining. Socialising the risk of innovation but privatising the rewards is not sustainable.

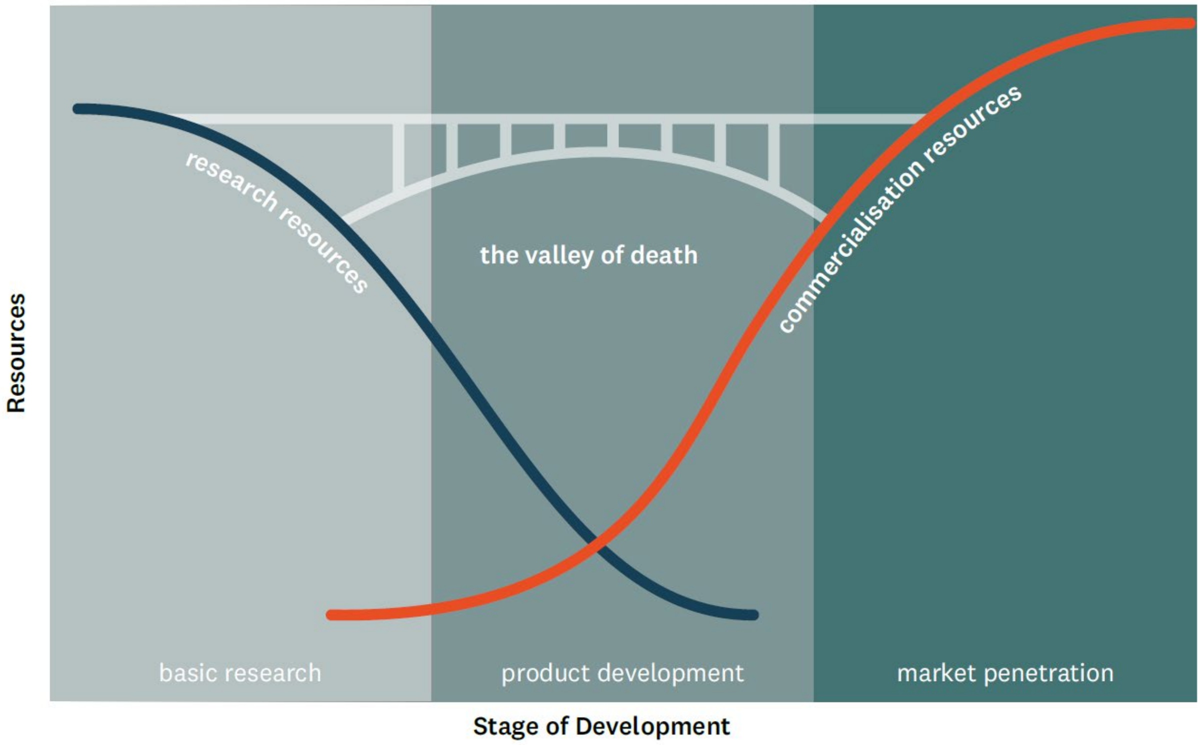

Figure 2: The Valley of Death. Adapted from Markham et al. (2010), referenced by Joannes Barend Klitsie et al., "Overcoming the Valley of Death: A Design Innovation Perspective".

The innovation "diffusion chasm"

Further on in the innovation cycle, a point described as the "diffusion chasm" may be reached. Here, market-specific barriers such as supplier availability, capacity, and capability limit the innovation's uptake. It is through multiple demonstrations that these market barriers are addressed, and lessons and information is shared within the market, resulting in the wider diffusion of the innovation.

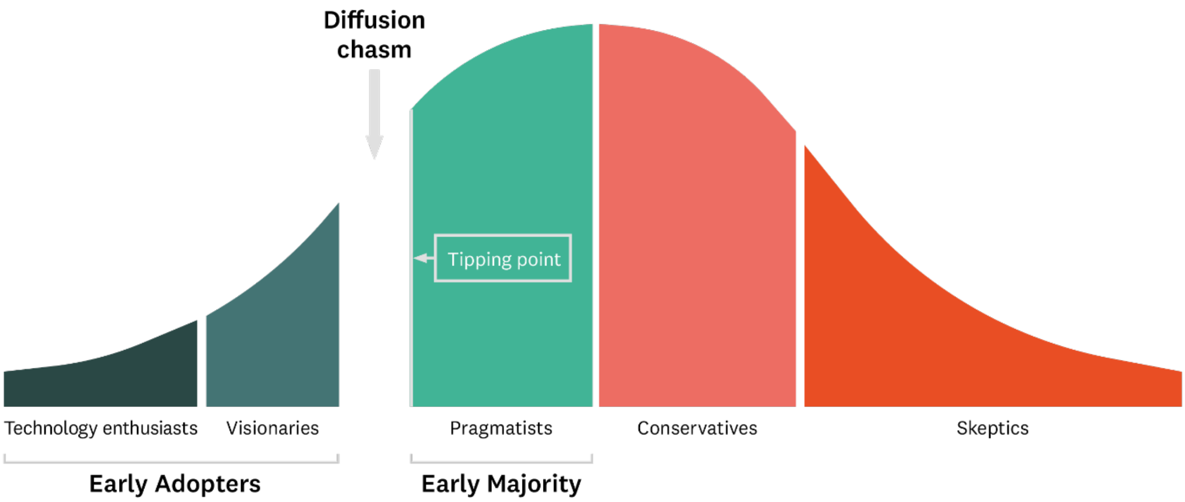

Figure 3: Crossing the Chasm. Adapted from Geoffrey Moore, 1992. The abscissa shows time, and how adoption starts with the technology enthusiasts and finishes with the skeptics. The ordinate shows rate of adoption, which is fastest for the pragmatists. The tipping point is reached when the chasm has been bridged.

We will return to discuss the chasm when discussing the New Zealand strategic perspective, as we believe this chasm is the most significant and urgent barrier to address to achieve emissions reductions targets.

2.3 Innovation involves risk, which shifts, but remains high, up until adoption by markets

At early innovation stages, the likelihood of failure is high but capital requirements are low. As the innovation progresses through the cycle, the likelihood of failure reduces progressively but the level of capital commitment increases simultaneously, resulting in a risk level[5] that is similar, or even higher, than the earlier stages. To ensure innovation is successful, support should be sustained across all steps. Support that is restricted to early stages is highly inefficient if the innovation has no pathway to reach the market and subsequently fails.

[5] Risk is the result of two components: Probability (or likelihood) and Gravity (or severity).

2.4 Innovation is about problem solving

Innovation is about problem solving: It can be about solving a new problem or solving an existing problem in a more efficient way.

The "problem to solve" approach is well known in entrepreneurship literature and can help build a consistent plan. For example, battery makers are not actually in the battery market, but in the "portable energy" market, and it just happens that currently batteries are a relevant option to provide portable energy for some uses. That might change in the future, as happened with the photography market where electronics replaced film as a solution for recording photons.

In practice, all problems that have traditionally been solved using fossil fuels now need to be solved with low-carbon alternatives. The transition to a net zero emissions economy should therefore focus on the question: *What is the most efficient low-emissions solution available to solve this problem?* However, a significant part of the public discussion seems to revolve around "one-size-fits-all" solutions relying on a single technology or fuel pathways.

If a government sets the direction for innovation, it should be addressed problem-by-problem, as there is no silver bullet. It will take a wide array of solutions.

2.5 Innovation is disruptive

For some problems, the solution is to adopt commercially available technologies at scale, while for others, practices need to change. Often a combination of the two will be required. A good example of this is transport, where adopting commercially available technologies means the adoption of electric vehicles to replace petrol and diesel engines, and where practice change represents a shift from cars to public transport. Such practice changes can be incremental and still result in significant transformation with time.

However, some activities carry inherent emissions that may not be sufficiently mitigated by progressively adopting new technologies or changes in practices and these activities will need to be replaced altogether at some point in time. Oil and coal extraction are obvious examples, but ruminant-based proteins may also fit in this category. In these cases, government can enable a strategic pivot if the industry is unable to adopt change fast enough, by paving the way for alternative fuels and alternative protein industries.

2.6 Innovation takes time, especially for new energy technologies

Bringing new technologies to market can take decades. The fastest energy-related examples from the last decades include consumer products like LEDs and lithium ion batteries, which took 10-30 years from the first prototype to mass market. Moreover, these examples required massive support from governments of the largest economies in the world.

From prototype to mass market: Solar PV[6]

The first demonstrations of PV cells were made in the 1950s in USA by Bell Labs, which was granted the right to spend a portion of AT&T and Western Electric's operating budget on risky and basic R&D, in line with its government-regulated telecommunications license. This resulted in USA leading in the technology throughout the 1970s under the supervision of the National Aeronautics and Space Administration (NASA), which had sizeable public R&D funds, which resulted in them using PV in satellites and shuttles. The oil shocks of the 1970s spurred Japan and USA to increase their public funding for PV research in a quest for more secure energy sources. In USA, companies that spun off from government-regulated laboratories, found niche business opportunities for PV. In Japan, companies like Sharp were also aided by government support for innovation to build production facilities and they too found market niches.

Throughout the 1980s and 1990s, PV for electricity production was uncompetitive except for off-grid customers. Suppliers in USA, then Japan and then Germany were, however, able to scale-up as a result of government procurement and incentive policies in these countries. As the potential became more apparent to researchers, R&D funding increased, the number of patents accelerated, and costs fell. Of particular significance in helping to create a market were government feed-in tariff programmes, first in Germany in the 1990s, then in Italy, Spain, the United States, China and India by the 2010s. These programmes, backed by rising deployment targets, targeted grid-connected systems and provided the guaranteed scale-up needed for global supply chains. At this point, patenting peaked, and the market consolidated around a dominant design.

Even though the development of solar PV to this point took around 60 years, progress would almost certainly have been slower if these countries – and others not mentioned here – had not shared the responsibility for these innovation stages.

[6] Energy Technology Perspectives 2020 - Special Report on Clean Energy Innovation - Accelerating technology progress for a sustainable future, IEA, 2020.

2.7 Innovation with available technologies is required for emissions reductions at scale

The time available to reduce emissions and limit global warming to less than 1.5°C to avoid triggering climate-change tipping points is much shorter than the time needed to take an innovative technology from demonstration to mass market, even with widespread support from governments.[7]

The graph below portrays the role played by emissions reduction technologies under the IEA's "sustainable development scenario"[8], with the 2030 and 2050 timelines added here.

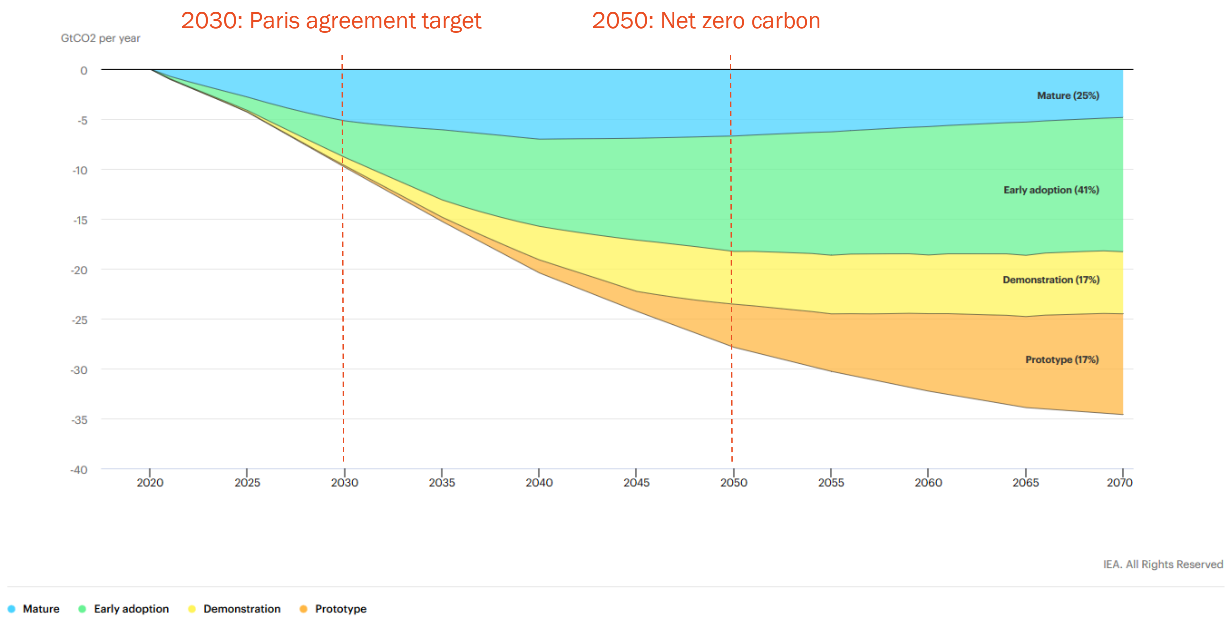

Figure 4: Global energy sector CO_2 emissions reductions by current technology readiness category in the Sustainable Development Scenario relative to the Stated Policies Scenario, 2019-2070.[9]

Commercially available low-emission innovations (mature or at early adoption stages, respectively in blue and green on the graph) have the greatest potential to reduce emissions by 2030 and beyond. Indeed, by 2050, these technologies are projected to continue to account for the majority of emissions reductions on an annual basis. In contrast, innovations at demonstration or prototype stages (shown in yellow and orange on the graph) can be expected to decarbonise currently hard-to-decarbonise sectors over a longer timeframe. The clear implication of this is that New Zealand's emissions reductions commitments in 2030 and 2050 will mostly have to be met by technologies which are in-use today.

IEA's "ETP Clean Energy Technology Guide" lists individual technologies and their respective Technology Readiness Level (TRL).[10] It provides a good snapshot of the available technologies and the difference each

[7] Cf. footnotes 1 and 2.

[8] Energy Technology Perspectives 2020 - Special Report on Clean Energy Innovation - Accelerating technology progress for a sustainable future, IEA, 2020.

[9] IEA, Paris, https://www.iea.org/data-and-statistics/charts/global-energy-sector-co2-emissions-reductions-by-current-technology-readiness-category-in-the-sustainable-development-scenario-relative-to-the-stated-policies-scenario-2019-2070

[10] https://www.iea.org/articles/etp-clean-energy-technology-guide

can make in the limited timeframe. Pathways such as hydrogen, carbon capture and storage, and biofuels may not make a significant contribution before 2030. In order to meet the Paris Agreement NDCs, we should therefore focus greater resources on progressing commercially available technologies which will have a greater impact. Looking at commitments beyond 2030 is the rationale for ongoing support for science, and research and development of technologies which are currently at the demonstration or prototype stage.

In focusing greater resource on commercially available technologies, many of which will be imported, some will argue that this is a lost opportunity to invest in early stage NZ-based technologies. We offer three points in return: First, this should not be an either/or decision, as NZ needs to invest more in all areas[11]; Second, and as above, commercially available technologies are required to deliver the emissions reductions we have committed to; and Third, there are supply-chain and economy-wide benefits to adopting innovative technology, whether or not it is imported.

2.8 Innovation support should address carbon lock-in

Carbon lock-in[12] is an example of a path dependency that innovation support related to climate change should specifically address.

Daniel Rosenbloom, World Resources Institute, Breaking Carbon Lock-In through Innovation and Decline[13]

Studies have identified a range of self-reinforcing mechanisms that promote path dependency:

1. *the sunk costs associated with current technologies and infrastructure (e.g., long-lived physical capital);*
2. *accumulated experience with established technologies and institutions (e.g., human capital);*
3. *self-fulfilling expectations about the persistence of these arrangements (e.g., common perceptions that carbon-intensive practices are somehow natural);*
4. *the benefits of moving in a set direction (e.g., standardization); and*
5. *positive feedback between an institutional setup and its beneficiaries (e.g., vested interests).*

[11] In its "Low-emissions economy" report the Productivity Commission advice was for New Zealand to "*Devote significantly more resources to low-emissions innovation and technology*" to reduce emissions and realise economic benefits for New Zealand.

[12] Karen C. Seto, Steven J. Davis, Ronald B. Mitchell, Eleanor C. Stokes, Gregory Unruh, Diana Ürge-Vorsatz, Carbon Lock-In: Types, Causes, and Policy Implications, Annual Review of Environment and Resources 2016 41:1, 425-452.

[13] Daniel Rosenbloom, World Resources Institute, Breaking Carbon Lock-In through Innovation and Decline, https://www.wri.org/climate/expert-perspective/breaking-carbon-lock-through-innovation-and-decline

The diagram below, adapted from Rosenbloom, illustrates how these path dependencies unfold. In the notional example given, decision making in favour of choices G, L and Q is driven by sunk costs (mechanism 1), vested interests (5), and learning (2).

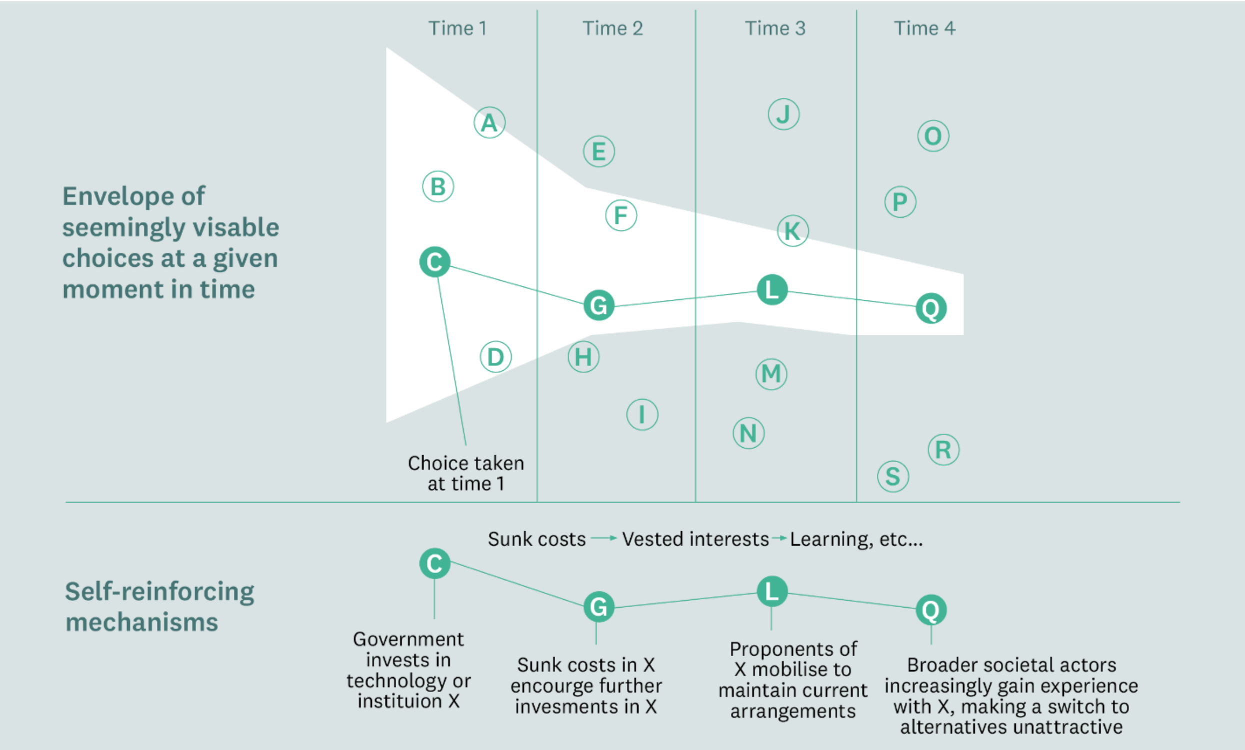

Figure 5: Illustrative Path-Dependent Process, adapted from Rosenbloom et al., 2019.

These natural mechanisms create very strong forces against change that diverges too significantly from business as usual. Therefore, the narrative that the required innovation will happen by itself, provided an enabling environment exists, is misleading: A carbon lock-in means the environment will be enabling for innovations that reinforce or at least don’t challenge the current path, but will prove an uphill battle for innovations diverging from it. This means higher risks, more barriers to overcome, and ultimately more development time required for low-carbon innovations to achieve adoption and commercial sustainability.

This means that low-carbon innovations need an extra level of support to succeed. This is illustrated by the examples of solar PV, batteries, or wind energy, which have benefited from strong support from several countries over a long period of time to achieve the success we know today.

3 Overarching innovation issues for New Zealand to address

To achieve a low-emissions economy, we need to address two main problems:

1. Commercially available emissions reduction technologies are being adopted too slowly. The timeframe for action is closing, "here and now" is better than an uncertain potential.
2. For emissions without clear technological solutions the rate of changing practices is too slow. Adopting new ways of doing things, from production processes to consumers' behaviours is required. New business models, new technologies to inform more conscious consumption, and new kinds of regulations are valuable innovations to address this issue.

3.1 The diffusion chasm in New Zealand

The figure below maps energy-related support funding available in New Zealand, along the Technology Readiness Level[14] scale.

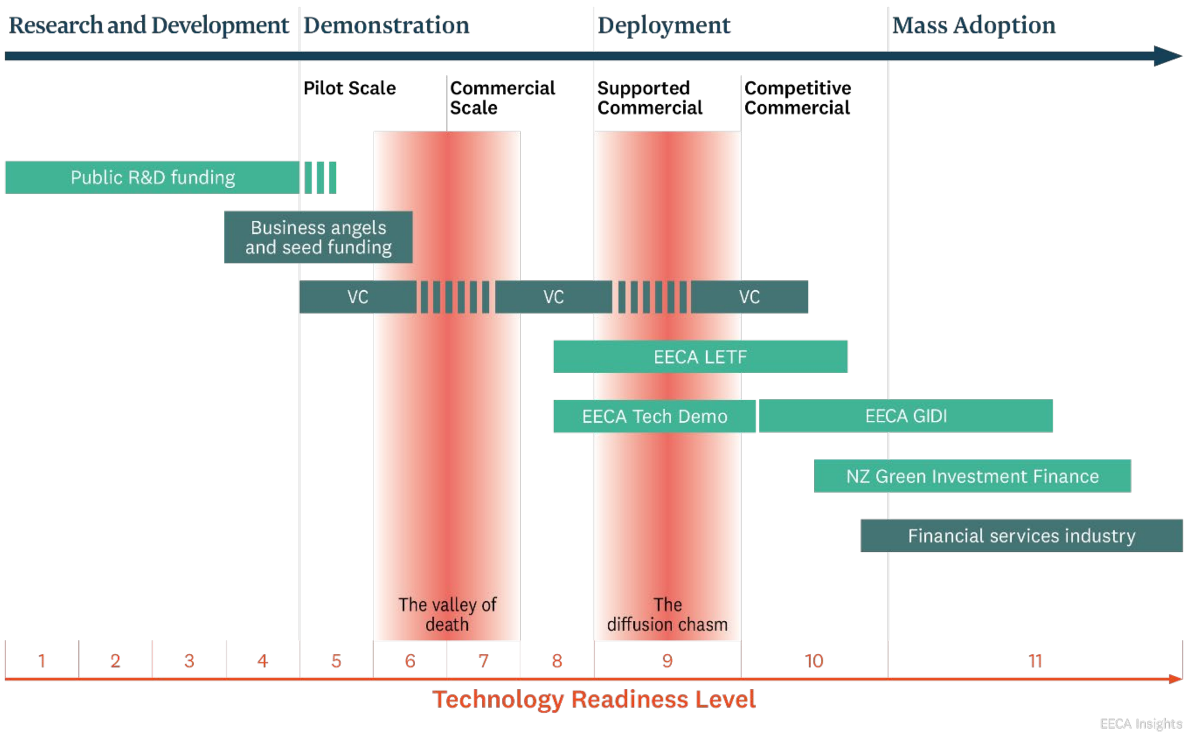

Figure 6: Energy-related support funding[15] available in New Zealand. Light green boxes indicate public funding and dark green boxes indicate private funding. Note that boxes do not indicate the scale of funding available. VC = venture capital, LETF = Low Emissions Transport Fund, GIDI = Government Investment in Decarbonising Industry.

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[14] Cf. footnote 10.

[15] Other organizations which support energy-related innovation, but do not provide financial backing, are acknowledged but not included within the scope of the figure. This includes, for example, Ara Ake.

While this view may not be exhaustive, the valley of death and the diffusion chasm are apparent, as there are limited funding options to progress through these phases. For example, while venture capital may provide support from TRL 5 to TRL 10, these funds are "exit driven", and often provide insufficient support to cross the valley of death and the diffusion chasm. Investors with a long term view valuing emissions reduction potential as well as financial return are therefore required.

EECA's funds, in particular the Low Emissions Transport Fund and the Technology Demonstration fund, are shown as crossing the diffusion chasm. This highlights the relevance of these funds to the low carbon transition, but the point to make is that these funds are relatively small in magnitude, and, as noted in Section 2.1, the funding required to progress an innovation increases through the lifecycle. In other words, crossing the diffusion chasm requires more support in dollar terms than crossing the valley of death.

Crossing the valley of death may require other funding and support mechanisms. The recently established Ara Ake is working to support innovations from demonstration to early deployment (TRL 5/6 to TRL 8/9), however Ara Ake does not provide financial support and so is not highlighted in the figure.

Based on the critical timing issue raised above, addressing the diffusion chasm is the biggest priority when it comes to emissions reductions in New Zealand. Once the diffusion chasm is bridged, an innovation's adoption rate can grow very quickly. This means that government support policies can focus on early adoption until a tipping point or critical mass is reached and the markets take over most of the growth.

3.2 What could innovation for climate change look like in New Zealand?

As outlined above, the transition to a low-carbon future implies accelerated and scalable adoption of innovation across the whole economy. Based on this, an approach would be based on the following key points.

1. **Support and accelerate large-scale adoption of low-emissions innovations**

   Without commercial projects being implemented or physical changes in how we use resources, there will not be meaningful GHG emissions reductions.

2. **Enable this adoption through a major upscaling of business' "absorptive capacity"**

   Businesses' ability to adopt innovative technologies and practices must be enabled through financial and non-financial support mechanisms.

3. **Consider that New Zealand will mostly be a technology and innovation taker**

   The scope and multi-faceted nature of the economic transition requires a global effort and no country can fully transition by itself – especially if relatively small and remote.

   This calls for active partnership with other countries, at national but also regional and local levels.

4 A framework and a methodology

Previous sections in this paper have examined the innovation lifecycle, described the central role of innovation in addressing climate change, and highlighted the overarching innovation issues for New Zealand to address. This has included a focus on the importance of bridging the diffusion chasm.

This section introduces a framework based on the three levers which act on emissions reduction, and a methodology for identifying low-carbon innovations which will deliver emissions reduction at scale. These are the innovations which must be supported to bridge the diffusion chasm.

4.1 A framework proposal

The driving forces that technology and innovation need to influence are:

1. **Emissions intensity**

   Switching to low-carbon fuels will reduce the emissions from each unit of energy used.

2. **Efficiency**

   Increasing the efficiency of processes will increase output per unit of resources consumed.

3. **Consumption and practices**

   Put simply: Doing more with less.

The objective is:

The combined changes on each of these three levers leads to a fast-enough improvement to keep our GHG emissions below our remaining budget.

Every innovation with potential to reduce emissions acts on one (or several) of these three levers. When analysing at the New Zealand level, pulling only one lever is not enough to stay within the carbon budget. Therefore, any technology and/or innovation policies should consider these three levers to maximise emissions reduction potential.

Taking transport as an example:

- Switching to electric vehicles would reduce emission intensity, because electricity has lower emissions than petrol or diesel (expressed as kg CO_2-e / kWh of fuel).
- Switching to electric vehicles would also act on the efficiency lever, because EVs are more efficient than internal combustion engines (expressed as km / kWh).
- Greater use of public transport, or car sharing, are examples of the consumption and practices lever. For example, a car with two persons instead of one will have half the emissions (expressed as kg CO_2-e / passenger km) even if there has been no improvement in the emissions intensity or efficiency. Mode shifting to public transport could also be considered to increase system efficiency (expressed as passenger km / kWh).

This way of breaking down the problem is similar to the approach taken by the New Zealand's Ministry of Transport, leading to their framework "Avoid-Shift-Improve"[16].

Below are further examples to illustrate in practical terms the application of this framework, with the main goal of avoiding missed opportunities. This is by no means an exhaustive list.

Category of problems to solve	Emissions intensity	Efficiency	Consumption and practices
Electricity	Increase rate of renewable energy	Energy efficient appliances	Artificial intelligence Energy Storage
Transport	EV, Hybrid vehicles	Public transport, Rail Driver assistance Tyre pressure monitoring systems	Lighter vehicles Car sharing Improved logistics Urban form
Buildings	Switch from fossil fuel to electricity	Building retrofits	Use of low-carbon building materials Changes in use practices
Food production	Methane inhibitor/vaccine for ruminants Low-emissions feeds	Production per unit of inputs (milk/cow feed)	Waste reduction Reduced Nitrogen fertiliser use Low-emissions feeds

[16] New Zealand's Ministry of Transport, Transport Emissions: Pathways to Net Zero by 2050, Green Paper, https://www.transport.govt.nz//assets/Uploads/Discussion/Transport-EmissionsHikinateKohuparaDiscussionDoc.pdf

4.2 A methodology for impact

Based on the three levers framework outlined previously, here is a proposed methodology to identify low-carbon innovations which will deliver emissions reductions at scale.

A. List and define the problems. Start with the crosscutting ones.

B. Use the three levers framework to identify options available for each problem.

C. Assess the options based on technology readiness, emissions reduction potential, and specific barriers to wider diffusion.

D. Where there are clear winners, set a direction and develop support mechanisms to increase the rate of adoption.

E. Where there are not clear winners to solve a specific problem, focus on behaviour and practice change.

A. List and define the problems. Start with the crosscutting ones

For example, "Transport" fits well with a category of problems to solve:

- *What are the most efficient low-emissions solutions available to transport people from home to work?*
- *What are the most efficient low-emissions solutions available to transport people on long distances?*
- *What are the most efficient low-emissions solutions available to transport goods long distances?* …

In contrast, "Businesses" is not a very helpful framework to list problems and identify the options available: Business is just a form of organisation, which faces a wide-ranging series of problems, (including transport ones for example).

Hence the importance of starting with problems that sit across the economy, such as transport, buildings or electricity generation. Subsequently, more specific families of problems, containing only the specific problems to solve by a specific sector, can be addressed.

B. Use the three levers framework to identify options available for each problem

For each problem listed, identify the available options:

- *Which options would be less carbon intensive? (fuel switching)*
- *Which options would allow a more efficient use of resources? (mainly energy efficiency)*
- *Which behavioural or practice changes could reduce the resources requirement per unit of service/well-being?*

Some options may overlap between several levers: this is not a problem, as the main goal of this framework is to avoid missed opportunities. At this step, the apparent likelihood of these options does not matter, as the main goal is to allow and trigger blue-sky thinking.

C. Assess the options

The options are then assessed against several criteria which should include at least the following:

- Timing: What is the option's Technology Readiness Level? (*see Appendix 1*) What is the likelihood that the option will deliver emissions reduction at scale in the available timeframe?
- Potential: What amount of emissions reduction can reasonably be expected from the option?
- Barriers: What are the specific barriers to a wide diffusion of this option? Which barriers could a government intervention influence? How hard or easy is it going to be? Will this be enough or are other major barriers beyond government's influence?

These criteria are key to avoid dead ends and wasting time and resources on options that will not deliver any meaningful emissions reductions.

D. Where there are clear winners, set a direction and develop specific policies to increase pace of adoption

Based on the previous criteria, it is likely that clear winners will be identified for some problems. It is important to remember that this is about "the best we have got", not waiting for the perfect solution that might never come.

Several winners might need to be picked for a problem. Perhaps because a single option's emissions reduction potential is insufficient, or the problem's uncertainties are too high which calls for diversification to cover the risk of underachievement.

Each option will have its own set of barriers with differing importance. However, the whole portfolio of options will present a finite set of barriers that can then be addressed through a finite set of policies.

How these support policies and government interventions will be grouped to address barriers for several options is well beyond the scope of this document, but some useful insights can be drawn from experiences in other countries.

E. Where there are no clear options to solve a specific problem, focus on behaviour change

For some problems, there are no options with a credible and timely potential for emissions reductions. Therefore, achieving the required emissions reductions needs other interventions relying on communication, regulation or incentives to influence the behaviours and practices of people and businesses.

4.3 Guidelines to think about innovation support policies

Based on the insights highlighted in this paper, we conclude with the following guidelines, as included in the Executive Summary:

- **Provide predictable and long-term signals** to give market actors the confidence to undertake the necessary investments. Innovation takes a lot of time.
- **Provide incentives across all stages of the innovation cycle:** Ensure there is continuity in support, with a specific focus of bridging the diffusion chasm.
- **Consider the country's long-term competitive advantage resulting from wide adoption of innovation** when assessing the costs/benefits.
- **Upscaling firms' "absorptive capacity" of innovations** is a key part of a crosscutting effort.
- **International collaboration is key given New Zealand is mostly a technology-taker. A lot of efforts should be made to ensure NZ's society can access to most relevant solutions.** E.g. trade agreement as a bridge to importing low-emission technologies such as electric vehicles or high temperature heat pumps.
- **Agencies need to think through their actions with an end-to-end mind-set:** It is better to support a solution up to the point it makes a real difference than support many solutions that have potential and but provide no follow-up.
- When an agency mandate prevents it to act and think end-to-end, **partnership with other agencies/organisations should be sought to create a pipeline of innovation with cross-government support.**
- **Focus on impact:** When resources are limited, focus on achieving real-world change. This is preferable to a profusion of early stage wins (e.g. patents) which fail to result in actual implementation (commercial projects) and therefore have no impact on emission reductions.
- **Allow support for non-technical innovation**: selection criteria for government support should leave options open or specific support policies should be created and ring-fenced.

Appendix 1: Opportunities and priorities for New Zealand

In this paper, innovation is meant as the process of adopting change in general. It argues that government should pick winners to ensure change at pace.

Below is a suggestion of "safe picks" for winners with commercial availability and well accepted potential for significant impact, but still at a low adoption stage.

These innovations could therefore benefit from some form of support to boost their adoption.

Based on the rationale conveyed in this paper, this is a mix of commercially available technologies and practices changes. These suggestions are not an exhaustive list of available options. They won't substitute to more profound changes to the way we live (urban form), eat (changes in diet), travel (less and slower) and use resources (sustainably):

Heat, Industry and Power

Priorities: Energy efficiency first, process shifts and electrification.

- Energy efficiency technologies
- High temperature heat pumps
- Electro-technologies able to substitute to process heat
- Shifting off-road diesel to electric and hybrid or other renewables
- Demand flexibility

Buildings

Priorities: Electrification of buildings, improve energy performance, smart demand management, and decarbonisation of the construction sector.

- Heat pumps for space and water
- Low-carbon materials alternative for buildings
- Modularity, prefabrication
- Higher performing windows (double glazing, low-emissivity coatings)
- Heat and moisture exchange panels
- LED
- Design: Dynamic simulation, design specifically adapted for wood as the main material
- Demand management
- Thermal storage: Hot and cold for large buildings
- Smart building management systems

Transport

Priorities: Electrification of light transport, mode shift and low-carbon logistics.

Road

- EV and hybrid uptake policies
- Car ownership rate reduction
- Car efficiency policies (g/km)
- EV trucks for short distance (<12 ton)
- Low carbon logistic policies (trucks to train)
- Platooning and road trains
- Dynamic charging, or Electric road systems (ERS)
- Enabling infrastructures: Fast charging, smart grid
- Telematics

Public transports and Rail

- Electric buses
- Facilitate public transport use
- Facilitate multi-modal transport
- Advanced liquid biofuels for trains

Sea

- Electric short-sea ships and ferries
- Alternate Maritime Power (AMP, or "cold ironing")
- Hull coating to reduce drag

Primary sector

Priorities: Practices shift and transition away from animal proteins.

- Off-road diesel to electric (e.g. Tractors)
- Regenerative agriculture practices uptake policies
- High efficiency indoor cropping
- From animal proteins to plant-based proteins and/or alternative proteins
- Sustainable management of marine resources

Appendix 2: Technology Readiness Level (TRL) scale

Various Technology Readiness Level (TRL) scales have been developed to represent a technology's stage of development from the idea (TRL 0) to commercial application (TRL 9) and even beyond as a commercially available technology continue to evolve in the market before reaching full maturity.

This paper uses the TRL scale from the IEA, as below.

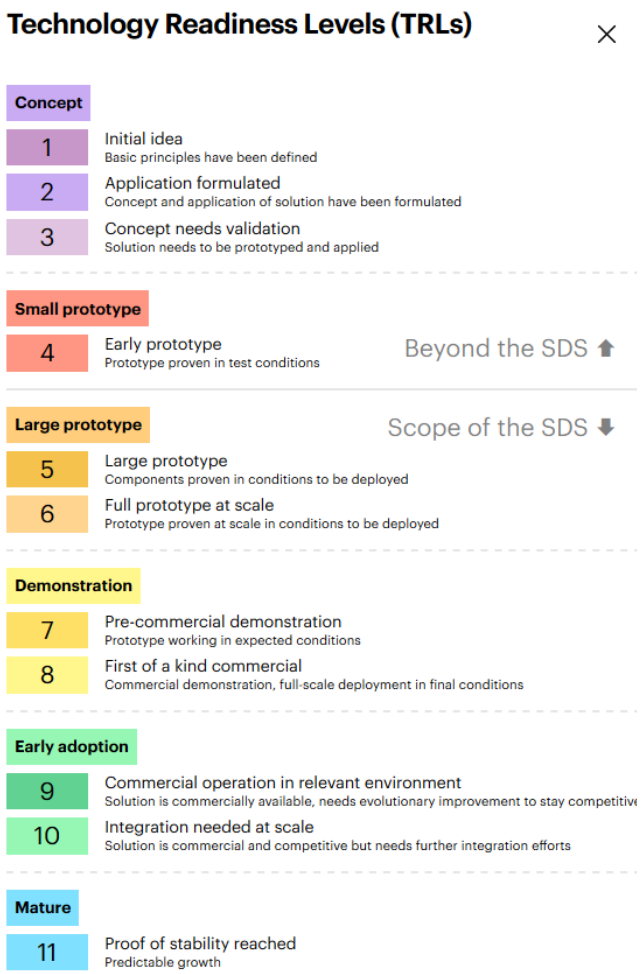

Figure 7: Technology Readiness Level scale from IEA. https://www.iea.org/articles/etp-clean-energy-technology-guide