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INNOVATION PRIORITIES TO DELIVER CLIMATE NEUTRALITY

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The European Green Deal sets out an exciting vision for the EU. Delivering climate targets alongside economic growth will be a major challenge and will only be achieved through innovating in all aspects of our lives. The innovations required will not happen without support from EU funds. However, the financial support available is constrained, particularly given the costs of responding to the COVID-19 crisis. A new process is required to prioritise effort and ensure money is spent wisely.

Innovation priorities fall into two categories:

- *Incremental*: Deployment activities that must be accelerated to keep decarbonisation on-track.
- *Breakthrough*: Questions that must be answered to create high value future pathways to net zero.

An independent centre of technical expertise should be established to produce a rigorous science-based assessment of innovation priorities. In the absence of such analysis, it will be necessary to rely on an intuitive understanding of the challenges and opportunities ahead.

This paper undertakes an intuitive assessment to identify key priorities for energy (including buildings), transport, industry and agriculture and land use. It also identifies important issues that cut across sectors[1].

Context

The EU has adopted a net zero greenhouse gas emissions target for 2050 and is starting to consider how the broader policy agenda can be aligned with this decision. The proposed European Green Deal (EGD) has an important role to play in driving policy alignment, as well as moving the discussion beyond simple technical delivery and towards economic opportunity.

EU innovation policy must be central to the overall package designed to deliver net zero and to support the goals of the EGD. Whilst the basic technologies already exist to make significant progress towards net zero, many are in the early stages of development, have very high costs, or are difficult to deploy at the rate necessary. Equally important, success is likely to depend on major changes in the behaviour of EU citizens and when and how this might happen remains unknown. Innovation will be essential in improving existing technologies and their deployment potential, opening new technology pathways, and creating the attractive new lifestyle choices that will be needed to command public support for the transition.

Innovation covers a broad range of activities from fundamental research revealing entirely new technical possibilities to small, incremental improvements in the design and marketing of mature products driven by competition and the commercial imperative. It also relates to important aspects of the transition beyond the technological: social, regulatory, policy, etc. In this paper, we define two broad innovation areas:

> *Incremental:* Referring to areas where it is already possible to deploy technologies or approaches at scale but where significant on-going

[1] This paper was written as the COVID-19 crisis was emerging. COVID-19 will raise its own research questions, including about interactions between pandemics and responding to other crises such as climate change. At the time of writing, this did not change our conclusions about the appropriate response to climate change – indeed we hope the thoughts expressed here can be helpful and complementary to the response to COVID-19.

'learning by doing' will be necessary to improve performance, reduce costs and support lifestyle change.

> *Breakthrough:* Where knowledge gaps exist and new solutions are required if net zero is to be delivered in a technically, economically, and politically acceptable way.

EU innovation funding resources are finite and must be allocated to priority innovation needs. This paper sets out an approach to identifying innovation priorities and provides an early assessment of what these priorities might be in the 4 key sectors of the economy: energy (including buildings), industry, transport, and land use and agriculture.

It sits alongside two other papers: an overarching framing paper which defines broad principles for EU research and innovation policy to ensure alignment with the EGD, and a paper which proposes a governance framework that will support efficient targeting of the EU research and innovation budget.

Innovation priorities to deliver net zero

The net zero policy challenge is characterised by two important features: the extent of the changes required and the timescales over which these must be achieved. This is a challenge unlike any previously undertaken by the EU and we cannot rely on traditional policy approaches to deliver success. Innovation policy will be extremely important. We not only need to answer difficult technical questions, we need to find new ways to influence social norms and lifestyle choices. And we need to do this quickly.

The EU approach to innovation has previously focused on technology, relied on 'bottom-up' mechanisms to identify priorities and left the diffusion of new products throughout society to market processes. All of these must change. There must be a greater focus on overcoming the key obstacles to achieving net zero and new processes implemented to rapidly amplify and deploy solutions.

The accompanying policy brief on EU research and innovation governance highlights the importance of establishing a centre of technical expertise – the Clean Economy Observatory – that maintains latest up to date knowledge of technological and social developments. A centrally held understanding of technology cost and deployment potentials will allow coherent decisions about future infrastructure needs including identifying those choices that can be left to a later date when more information will be available. It will also be able to identify the innovation priorities that will guide EU research and innovation activities and ensure the most effective allocation of available funds.

Innovation priorities will fall into two categories:

> Deployment activities that must be accelerated to keep decarbonisation on-track – this will involve incremental innovation created, for example, through 'learning by doing'[2].

> Questions that must be answered to create high value future pathways to net zero – these are the major breakthroughs required overcome current technical, economic, or political barriers on the path to net zero.

The E3G paper on innovation governance recommends that the Clean Economy Observatory would play a critical role in the first of these by assimilating and sharing learning across the EU and beyond. The second category should be managed as stand-alone 'innovation missions' with the objective to identify solutions within timescales consistent with delivering the net zero target.

In the absence of a rigorous science-based assessment of innovation priorities that could be delivered by an organisation such as the Clean Economy Observatory, it will be necessary to rely on an intuitive understanding of the challenges and opportunities ahead. This paper adopts such an approach guided by the priority categorisation described above. The following sections propose priorities for the four key emitting sectors – energy (including buildings), transport, industry, and agriculture – as well as identifying where cross-sectoral approaches can deliver benefits across the economy.

Energy (including buildings)

Significance

The decarbonisation of the energy system, and the use of energy in buildings, is hugely important for the overall net zero delivery challenge. Not only are these sectors significant sources of greenhouse gas emissions, but electrification is a core decarbonisation strategy for other sectors. It is, therefore, not only important to adopt technology and supporting processes that can produce, convert, store and use energy at close to zero or even negative emissions, but to do so as demand for clean energy (largely electricity) increases.

[2] 'Incremental' should not be associated with small emissions reductions since incremental gains in combination can add up to a step-change in emissions reduction.

Fortunately, many technological solutions already exist which give the option for early progress through rapid deployment. However, there are significant social and political barriers which act as a major obstacle to the deployment of these technologies at scale, especially within the built infrastructure. Also, electricity systems are not currently designed to accommodate large proportions of variable renewable generation sources (wind and solar,) which are the renewable technologies with the broadest deployment potentials, and there are no current international examples to demonstrate how this can be achieved[3].

Incremental innovation requirements

Deployment mechanisms have already driven incremental improvements in the cost and performance of renewable energy technologies, especially wind and solar power generation. It is likely that significant further progress is possible as deployment proceeds. This form of deployment driven innovation can be applied to other important large-scale technologies that have proven functionality, such as carbon capture and storage, HVDC transmissions connections, concentrating solar power and information and communication technologies to improve power grid operation (smart grid). Also, the rapid deployment of wind and solar electricity generation will require major improvements in system balancing capability which has historically been provided by fossil-fired power generators. System operators must ensure efficient grid operation through developing alternative balancing resources, such as demand response, interconnector trading and battery storage. Indeed, improvements in battery performance represents a particularly important area for incremental innovation.

However, many of the important opportunities for deployment driven innovation lie within buildings. There is huge scope to improve the cost and performance of technologies that reduce energy consumption, ensure that it is low carbon and allow it to be controlled to provide added comfort and services for the grid. The key obstacle to unlocking this learning potential involves the social acceptance barriers that must be overcome to allow these technologies (e.g. district heating and heat pumps) to be deployed. This, in turn, will require a programme of large-scale pilots to test new approaches to citizen engagement and supporting regulatory and market models.

[3] The only countries with more than 30% of electricity produced annually by variable renewable sources are Uruguay and Denmark, both of which benefit from high levels of interconnection with large neighbouring power systems - REN21 (2018). Ireland, which has high wind capacity, currently limits non-synchronous generation and net interconnector imports to 65% of demand, although the UK's National Grid is currently considering how to operate the system at 100% 'low carbon' (i.e. including nuclear) by 2025.

The increasing integration of sectors that have previously been treated independently (especially electricity, heat and transport) will require new approaches to system planning and this, in turn, will depend on improved system modelling capability and regulatory models that support efficient investment and system operation. This represents another important aspect of deployment driven innovation in the energy sector.

Breakthrough innovation requirements

Wind and solar generation technologies have huge potential to provide cheap low carbon electricity. However, there are significant drawbacks – including the variable nature of the power produced and the negative impact on the local environment. Alternative renewable energy technologies exist that have the potential to be more reliable and/or controllable – such as deep geothermal, wave, tidal, and 'floating' offshore wind turbines capable of operating in deep water – but these are currently too expensive to be deployed at scale. Significant breakthroughs are required for these to represent a credible alternative renewable technology option.

The required rapid deployment of wind and solar electricity generation will create significant imbalances between production and demand that cannot easily be bridged through existing approaches to energy storage or demand management – for example, the difference between winter to summer heating loads or coping with prolonged windless periods in winter. New long duration seasonal electricity and thermal storage technologies are likely to be essential for net zero emissions to be cost-effectively delivered[4].

Electrification has huge potential to support decarbonisation of other sectors. However, this requires the identification and development of new process synergies. For example, concentrating solar power has the potential to create the high temperatures required for many industrial processes. Also, hydrogen can be produced via electrolysis using surplus renewable electricity and used to provide energy for industrial processes, power generation or transportation such as shipping. However, producing hydrogen efficiently and in high quantities will require new fast ramping and low-cost electrolysis techniques as well as significant additional dedicated renewable generation capacity.

[4] Hydrogen produced through electrolysis has the potential to provide this service, but this is likely to be a scarce resource given the range of alternative needs that it can meet.

Finally, new fabrics and materials should be developed that would reduce energy demands from the built infrastructure to zero or even turn them into net producers of energy. This would create new low-cost pathways towards net zero.

Proposed innovation priorities

Improving social engagement to the degree that will allow refurbishment of the built infrastructure is a priority deployment activity that must be accelerated to keep decarbonisation on-track. This will require a major programme of large-scale deployment pilots in a variety of situations to test different approaches to engaging property owners, including individuals and businesses. Another critical deployment activity involves the **connection of a range of flexible resources to the power grid to allow efficient integration of high levels of variable renewable generation**.

Currently, there are no cost-effective ways to enable all power requirements to be produced by variable renewable generation and new solutions are required to establish this as a credible decarbonisation pathway. A mission is, therefore, required to develop **long duration and high capacity power storage technologies**. Similarly, **high capacity and low-cost electrolysis technologies** will open the potential to produce large volumes of hydrogen that will create high value options to abate sectors where no credible alternatives exist.

Transport

Significance

Transport is the only sector where emissions continue to rise, largely due to increased air travel and use of private cars. A key challenge lies in decarbonising hard to abate sectors, namely aviation and shipping. Indeed, varying combinations of electricity and zero emission fuels such as hydrogen and synthetic fuels will need to be pursued to decarbonise these sectors. Advanced biofuels will also have a role to play in decarbonising aviation and shipping. However, the energy system is not currently set up to accommodate the required level of renewable energy generation, low carbon fuel production and smart vehicle charging. Similarly, most vehicles currently for sale have not been designed to run on electricity and low carbon fuels.

Cultural trends for increased car and low-cost airline use have created a key challenge to the decarbonisation of the transport system. The transport system is central to the way people live their lives and to economic growth. Therefore, clean transport solutions will need to meet individual and business needs. A cultural change is required to generate a modal shift from legacy cars and air travel to other modes of transport. However, this will depend on attractive alternatives to be provided at affordable rates, such as rail travel and mobility as a service. This would not only generate economic benefits from the reallocation of spending on oil imports to domestically produced technologies and services, it would also reduce illness and premature deaths arising from poor air quality.

Incremental innovation requirements

Incremental improvements in cost and performance have occurred through the deployment of transport technologies, notably of batteries, fuel cells and electric vehicles (EVs). Significant emissions reduction can be achieved from deploying zero emission transport solutions such as electric vehicles, high-speed trains, and light railways. Meanwhile, advanced biofuels can be used to decarbonise aviation and shipping until zero emission designs are commercialised. Measures to improve operational efficiency through digital technologies, such as smart traffic management, vehicle fleet logistics improvements and predictive maintenance, would reduce emissions further. This requires policy action to introduce new incentives on transport operators to decarbonise their fleets. Indeed, public policy has an important role to play in driving innovation through improving CO_2 performance standards, restricting and ultimately banning legacy vehicles, moving freight into railways and waterways, and providing fiscal incentives.

A rapid deployment of zero emission energy infrastructure for transport will also be important, including providing the required infrastructure for the electrification of transport. This will require additional renewable energy generation capacity and charging infrastructure for cars, heavy goods vehicles (HGVs) and ships. Electric trucks powered by overhead wires could be deployed as an alternative to HGVs, although future improvements in battery range would enable fully electric long-haul trucks. In addition, the growing demand for electric ships will become a driver for expansion of onshore power supply at ports. Rapid deployment of electric transport solutions will require integrated cross-border planning of the transport and energy sectors to ensure last mile connectivity, standardised charging equipment, improvement in system balancing capability and the smart integration of EVs as power system resource through vehicle-to-grid services. As such, electrified modes of transport will complement variable renewable energy sources.

Developing an improved understanding of transport needs and how these might change through transport data analysis and modelling will be critical for planning the future transport system. Behavioural and demand-side measures will be needed to accelerate the social acceptance of new transport solutions and generate a switch away from car and air travel. These may include workplace and school shared vehicle travel plans, incentives for public transport and carsharing, reversing company car policies and public campaigns. Cities and local authorities will also play a crucial role in delivering a sustainable transport system. Indeed, city-level demonstration of integrated and smart urban transport with transit-oriented and mixed-used development will be key to generate a shift from cars to active and public transport while developing healthy and liveable cities.

Breakthrough innovation requirements

New fuel production technologies face several regulatory and financial barriers. However, technical developments in the clean production of hydrogen and synthetic fuels produced from electrolysis and direct air capture will have huge potential to decarbonise the hard to abate sectors and replace heavy fuel oil. Currently, electrolysis for hydrogen production is expensive and new low-cost solutions are required.

New vehicle designs are expensive to develop but will be required to decarbonise the hard to abate parts of the transport system. Indeed, new aircraft designs such as electric aircrafts could provide an alternative to the use of other low carbon fuels. New ship propulsion and energy storage designs could enable fully electrified ship fleets for shorter ranges, while ship designs based on hydrogen and ammonia could decarbonise tankers and container ships. These innovations will require research into next generation battery technology to improve battery range, durability and recycling while reducing the dependence on rare raw materials. Also, hydrogen fuel cells will need to be developed for the hard to abate sectors and non-electrified rail routes.

Innovations in transport solutions could create more sustainable outcomes and it is important to identify and build demand for such innovations. Autonomous, connected, and shared vehicles with smart traffic management systems have the potential to improve the efficiency of the transport system and generate economic benefits. New concepts for mass transit could revolutionise the transport system and compete with medium and long-haul air travel. However, such technologies will need to be proven at scale and will require regulatory and financial incentives.

Proposed innovation priorities

Existing low carbon transport solutions, such as **electric vehicles, smart charging, and high-speed trains at the national level, as well as cycling and walking infrastructure in urban areas**, must be deployed at scale. However, this requires last mile connectivity to enable a shift away from current modes of transport.

Considerable culture change will be needed to accelerate the switch from cars and planes to other transport modes. This will require an **improved understanding of changing transport needs and the development of new mobility solutions**. Such data would enable the planning and deployment of transport infrastructure along with the demand-side measures to drive behaviour change.

Finally, the hard to abate sectors will pose a challenge for the decarbonisation of the transport system. New **fuel and fleet solutions for heavy transport, including shipping and aviation**, will need to be deployed to accelerate the decarbonisation of these sectors. Meanwhile, regulatory and financial barriers will need to be removed to nurture the market for clean transport solutions.

Industry

Significance

The major challenge with industrial emissions lies in the ability to achieve deep decarbonisation, especially in process-based industries using high grade heat. Mitigation levers used in other sectors (energy efficiency, fuel switching, material efficiency and CCS) can only achieve a certain amount of progress and, ultimately, it will be necessary to transform the materials that are being produced.

Industry is the backbone of the EU economy and the transition to low carbon approaches will provide the engine for continued economic growth in a decarbonised future. However, industrial assets often last 20-30 years or longer and many are due for renewal in the next few years. It is crucial that the EU makes the right investments now to lay the groundwork for clean production technologies to be deployed over the next decade and innovation will be essential if this objective is to be realised.

Incremental innovation requirements

Significant reductions in emissions can be achieved through the application of existing technologies and approaches. For example, whilst improvements in production efficiency have been a focus of energy intensive industries for some time, smaller enterprises have often paid little attention to the opportunities that exist. In addition, most industrial organisations can benefit from applying existing technologies (e.g. digitalisation) to improve material efficiency through, for example, prolonging product lifecycles, changing designs and reducing waste. Also, there are opportunities to exploit cross-sector synergies through, for example, waste heat recovery.

Around half of current industrial emissions arise from direct combustion of fossil fuels. Carbon capture and storage is an existing technology that could be deployed now. Capture technologies can be combined with the transport and storage infrastructure to create low carbon industrial hubs. These hubs should be designed to allow the progressive reduction of emissions in line with the net zero objective such that ultimately the industries can move away from burning fossil fuels and towards low-cost hydrogen produced from surplus renewable electricity.

It is important to start now with the development of industries to produce new low carbon products and services that will become the mainstay of the net zero economy. Public policy has a key role to play in building these new markets through education programmes, public procurement policies and clean purchasing mandates.

Breakthrough innovation requirements

The net zero economy will require the development of a range of new materials that involve new production processes, have longer lives and reduce waste (e.g. cellulose fibres to replace plastics). There is a particularly important requirement to develop new low carbon concrete and cement chemistry. Also, maximum use must be made of existing materials and new recycling and sorting technologies will be required (e.g. decontamination of steel).

Whilst carbon capture technology may not be required in the long-term to capture the emissions from fossil fuel combustion, new production processes (e.g. concrete, aggregates, carbon fibre) may create greenhouse gases that could be captured and stored using this infrastructure. Indeed, a whole range of materials may be produced using electrolysis (power to 'x') giving rise to carbon emissions that require capture and storage.

New approaches to provide alternative sources of high-grade heat is a key requirement for industry in a net zero future. This may involve direct electrification solutions or burning hydrogen produced using surplus renewable electricity and advanced electrolysis techniques.

Proposed innovation priorities

It is important that progress is made now in the decarbonisation of industrial processes and not deferred until major technical breakthroughs emerge. The priority should be on driving production innovation through **reducing demand for high-emitting products through implementing efficiency measures, material savings and using public policy to drive switching to alternatives**.

However, major breakthroughs will be required. The **development of new cement and concrete chemistry** and **providing high-grade heat from low carbon** sources appear the most important requirements.

Land use and agriculture

Significance

The share of greenhouse gas emissions from agriculture and land use is growing, largely due to increasing demands for food and changing attitudes to food waste. There is a high proportion of non-CO_2 emissions from soil and livestock which will be difficult to abate without changes to consumption patterns. Stimulating the necessary culture change therefore represents a critical innovation requirement.

This is the only sector that can offer large scale, cost effective carbon sequestration through ecosystem restoration and changes in land management. Also, there is the potential to significantly improve public health through moving away from meat products towards a plant-based diet.

Incremental innovation requirements

It is important to start now with developing an improved understanding of consumers' dietary needs and how these might be changed. Continued development and refinement of existing plant based and/or cultured meat alternatives will be an important aspect of this process.

Existing technologies can be applied now to reduce agricultural impacts. Farmers can be encouraged to conserve and enhance soil and other potential carbon sinks and to convert to alternative feedstocks with lower supply chain emissions. Digitalisation and artificial intelligence can be applied to implement precision farming techniques and degraded land can be reclaimed to create new agricultural opportunities.

Breakthrough innovation requirements

It will be necessary to reverse many recent cultural trends including the demand for food transported over long distances and increases in food waste. This will require a radically different mechanism to align farming and consumer needs and to adopt more circular approaches. This major cultural change will need to be supported by a range of technical developments. These include new fertilisers to improve and enhance soil quality and new uses for wastes (e.g. capturing CO_2, producing high quality compost, biofuels).

Ultimately, there is the potential for advances in precision fermentation to produce a variety of 'lab grown' foods including protein. Scaling of these production techniques has the potential to dramatically reduce the land and water footprint currently involved in meat production.

Proposed innovation priorities

Reversing current cultural trends that are leading to increasing emissions from the agricultural and land use sector represents the key innovation priority. Immediate progress is required to develop an **improved understanding of consumers' dietary needs and how these might be changed**. This can be accompanied by **incentives for farmers and landowners to develop the carbon sequestration potential of their land** through, for example, exploring new approaches to ecosystem restoration.

This on-going behavioural analysis of farmers and consumers to drive the transition towards low carbon diets should be accompanied by research aimed at identifying credible pathways towards **replacing animal proteins with plant and fermentation products**.

Cross cutting issues and priorities

It is important that innovation priorities are not developed independently for each of the sectors. The previous sections highlight several areas where innovations can spill-over from one sector into another. For example, improved hydrogen production through electrolysis can have applications in electricity, heat, industry, and transport sectors. Also, improved uptake of electricity control systems in premises can support the more efficient charging of electric vehicles. Moreover, there are technological breakthroughs that could be transformative across all four sectors and beyond, including innovations in **connectivity, remote monitoring, predictive analytics, and 3D printing and design**.

It is also necessary to emphasise the importance of social, regulatory, and political innovation acting alongside technological innovation. For example, new thinking is required to **support decarbonisation in those regions with particularly significant transition challenges**. The analysis of social and cultural change must prioritise consumers in these regions and they could be priority locations for large-scale innovation pilots and tests of new technological solutions.

Summary of recommendations

The analysis set out above highlights the wide range of innovation needs associated with delivering a net zero objective. Prioritisation of innovation spending is, therefore, essential. Whilst such prioritisation should be the subject of an on-going rigorous science-based assessment, initial allocation of funds must be based on a more intuitive analysis. Our initial recommendations for innovation prioritisation are summarised below.

Figure 1: Innovation Prioritisation

Sector	Incremental	Breakthrough
Energy (Including Buildings)	Improving social engagement and power system balancing	Long duration and high capacity power storage and high capacity and low-cost electrolysis
Transport	Deploying existing technologies (e.g. EVs, smart charging and high-speed trains) and improving understanding of societal transport needs	New fuel and fleet solutions for heavy transport, including shipping and aviation
Industry	Reducing demand for high-emitting products (efficiency, material savings, public policy)	New cement and concrete chemistry and providing high-grade heat from low carbon sources
Agriculture and land use	Understanding how to change the way dietary needs are met and incentives for farmers and landowners to implement the carbon sequestration measures	How to transition towards low carbon diets and identifying credible pathways towards replacing animal proteins

Delivering on this innovation agenda will require a new approach from EU policy makers. The accompanying framing paper sets out the overarching principles that now need to be followed.