Global innovation needs assessment

Energy and land use synthesis report

October 12, 2021

Funded by:

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Analytics by:

:vivideconomics

The findings and views expressed across this project do not necessarily reflect the view of ClimateWorks, the Government of the United Kingdom or Mission Innovation.

The Global Innovation Needs Assessments

The Global Innovation Needs Assessments (GINAs) is a first of a kind platform for assessing the case for low carbon innovation. The GINAs take a system wide perspective, explicitly modelling the impact of innovations across the global economy. Uniquely, the analysis quantifies the economic benefits of low carbon innovation and identifies the public investment levels — from research and development to commercialization — needed to unlock these benefits. The analysis is divided into 3 Phases: Phase 1 on global energy and land use, Phase 2 on global industry, and Phase 3 on regional deep dives. This synthesis report forms part of Phase 1.

The analyses do not assess all relevant technologies nor do they evaluate all relevant factors for policy judgements. Instead, the work is intended to provide a novel evidence base to better inform policy decisions. The Phase 1 analysis looks across a broad range of climate mitigation technologies in energy and land-use, ranging from demand response to protein diversification, to model the economic value of related innovation investment. Later phases expand the research. As with all technologies, there are risks and potential downsides to their adoption, and some remain controversial. Which innovations to invest in is ultimately a policy judgement, and this analysis does not provide policy recommendations to invest in any specific technologies.

The Global Innovation Needs Assessments project is funded by the ClimateWorks Foundation and the UK Foreign, Commonwealth & Development Office. Analysis was conducted by Vivid Economics. Thank you to the UK Department for Business, Energy and Industrial Strategy (BEIS) analysts and the Mission Innovation Secretariat who were consulted on aspects of the work, and for BEIS support for the 2017-2019 Energy Innovation Needs Assessments which developed the methodological approach taken here.

The GINAs will release key outputs ahead of COP26, with additional outputs expected in 2022

October 12th
- Energy and land-use synthesis report
- Quantitative estimates of innovation benefit and spending need
- Selected innovation area reports

Phase 1: energy and land-use launch

Phase 1: energy and land use update at COP 26 in Glasgow

November
- 13 innovation area reports* across energy and land use
- Co-benefits report
- Methodology annexes

Q1 2022
- Expansion of GINAs to cover energy intensive industry
- Innovation area reports covering energy intensive sectors, industrial CCS, and circularity
- Expansion of GINAs to cover further CDR, particularly DAC (subject to funding)

Phase 2: industry & CDR

Phase 3: regional deep dives

Q3 2022 (subject to funding)
- Regional analysis of innovation benefits and needs

The innovation area reports cover: In energy: wind power, low carbon hydrogen, solar power, low carbon fuels, nuclear power, flexible power system, buildings, power CCS, zero carbon road transport. In land use and agriculture: protein diversity, decarbonizing agrochemical inputs, yield enhancing technologies, irrigation

A suite of Phase 1 outputs is available on the GINA website

1. Energy and land use synthesis report – *slide based summary for policymakers and executives*

Synthesis of the findings across the innovations considered in energy and land use

2. Energy and land use & agriculture innovation reports – *in depth quantitative analysis for industry and policy analysts*

Wind power
Offshore and onshore wind turbines

Low carbon hydrogen
Electrolysers and gas reforming with CCS

Solar power
Utility-scale and distributed PV

Low carbon fuels
2nd generation biofuels, synthetic fuels (H_2 + CO_2)

Nuclear power
Small modular and large-scale advanced reactors

System flexibility
Battery storage, power-to-X, demand response

Buildings
Heat pumps, building fabric

Power CCS
CCS in power generation (coal, gas, and biomass)

Zero-carbon road transport
Battery electric vehicles, fuel cell electric vehicles

Protein diversity
Cultured meat and new plant-based proteins

Decarbonizing agrochemical inputs
Innovative fertilisers and pesticides

Yield enhancing technologies
Digital agriculture and vertical farming

Irrigation
Improved irrigation methods and systems

These energy and land use technology areas were selected for their potential for further innovation and magnitude of the associated system benefits. Their selection here is because they could play a key role in a net zero pathway, and evaluating the returns on innovation investment will help inform decisions about that role: it does not imply that an optimal net zero pathway necessarily includes each of these technologies. Analysis of additional technologies, including for industrial sectors, are forthcoming. Further technical notes on the projects' selection approach is provided in the methodology annex on the GINA website.

3. Co-benefits of innovation report – *qualitative analysis of the environmental and other non-economic benefits of net zero innovation*

4. European case study – *Analysis of jobs and growth benefits in Europe specifically*

5. Methodology annex– *A description of the modelling approach taken for analysts*

Contents

The Global Innovation Needs Assessments has produced a suite of outputs. For the full set of materials please visit: https://www.climateworks.org/report/ginas/

Executive summary

The Global Innovation Needs Assessments aim to raise the ambition for innovation support

No project has quantified the payoffs, public benefits or business case of Net Zero innovation globally

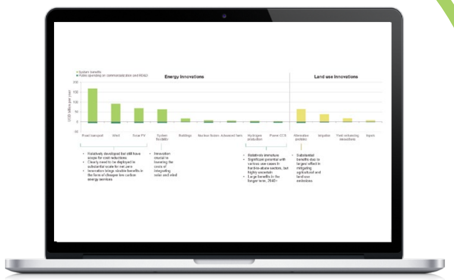
While the IEA, OECD, and IRENA have all published reports on innovation priorities, these efforts do not quantify the payoffs from making these investments.

The UK's Energy Innovation Needs Assessment (EINA) project, which Vivid Economics led from 2017-2019, demonstrated that a whole system assessment of the public benefit is possible to do robustly.

This study provides a first of a kind quantitative analysis of innovation benefits and needs, in order to raise the global ambition for innovation spending. It includes

- A global benchmark for innovation spending
- An evidence base on the value of innovation
- A framework for country National Innovation Plans
- A starting point for international collaboration

The GINAs provide a broad evidence base, across a suite of outputs



Synthesis and innovation area reports

Synthesis report covering the key messages across the project, overall benefits, and overall spending needs

14 standardized innovation area reports across energy and land use covering
- System interactions
- Innovation opportunities and benefits
- Business opportunities (jobs and GVA)
- Innovation spending needs

First of a kind quantification of benefits and spending needs

Quantified spending needs for both RD&D and commercialization

Quantified benefits including
- Savings from reduced decarbonization costs
- Market size of low carbon supply chains
- GVA and jobs supported by innovative manufacturing activities

Co-benefits of innovation for decarbonization

Innovation for decarbonization provides key further benefits including
- Ecological and Biodiversity benefits
- Climate adaptation benefits
- Nutritional benefits

Targeted briefs available on the website set out key benefits

The GINAs is a first-of-a-kind assessment on the benefits and spending requirements of net zero innovations

The GINAs draws on the best available models and evidence base for net zero innovations

- World's largest open source energy system model
- Methodology co-developed with BEIS in 2018 for the EINAs
- Same model trusted by UN PRI, the IIGCC, and WBCSD
- 2 advisory panels of leading innovation experts on energy and land use
- Leading global land and water-use model, used across major IPCC scenarios
- **440** innovations in underlying database
- **2,700** technologies covered in the model
- **21** regions covered
- **150+** literature sources of cost estimates reviewed
- **50+** IPCC, IEA, NGFS scenarios for benchmarking

… and consider the least-cost way for the world to achieve net zero with these innovations

Future demand for final energy services and food

Technologies across the energy and food systems

Cost-optimization models
Energy model (VESM) ↔ Land use model (MAgPIE)

Net Zero with Low innovation expensive decarbonization in the absence of innovation support

Net Zero with High innovation rapid cost reduction and growth in deployment due to innovation

Quantitative outputs:

- Deployment scale (e.g. hydrogen production capacity, EV fleet)
- Public benefits of innovation (system cost reduction across scenarios)
- Business opportunities (market size, GVA, jobs for each technology)
- Public RD&D and commercialization spending ($ billion per year)

Net zero innovation makes options affordable and available for mass market deployment

01 Net zero innovation means moving technologies to mass market deployment

- Energy technologies historically require 2-4 decades to mature
- Net zero requires mass deployment and rapid growth now and in 2030s
- Innovation support is necessary to bridge this gap

02 It requires roaring commercialization in the 2020s and increased RD&D…

- Commercialization spending is low today. Starting from a low base, it increases 8x to $46 bn/year
- RD&D spending, for the technologies considered in the GINAs, increases 3x to $35 bn/year

03 Accompanied by a set of market creation policies to accelerate uptake

- Commercialization kick starts supply chains and drives down costs through learning by doing
- However, commercialization funding only provides a small % of total investment required on a net zero pathway

04 Innovation unlocks affordable decarbonized energy and food …

- Innovation accelerates and deepens cost reductions for key technologies
- Cumulatively across the system, decarbonization costs can reduce by up to $2.7 trillion per year by 2050

05 … adds jobs and growth in new value chains …

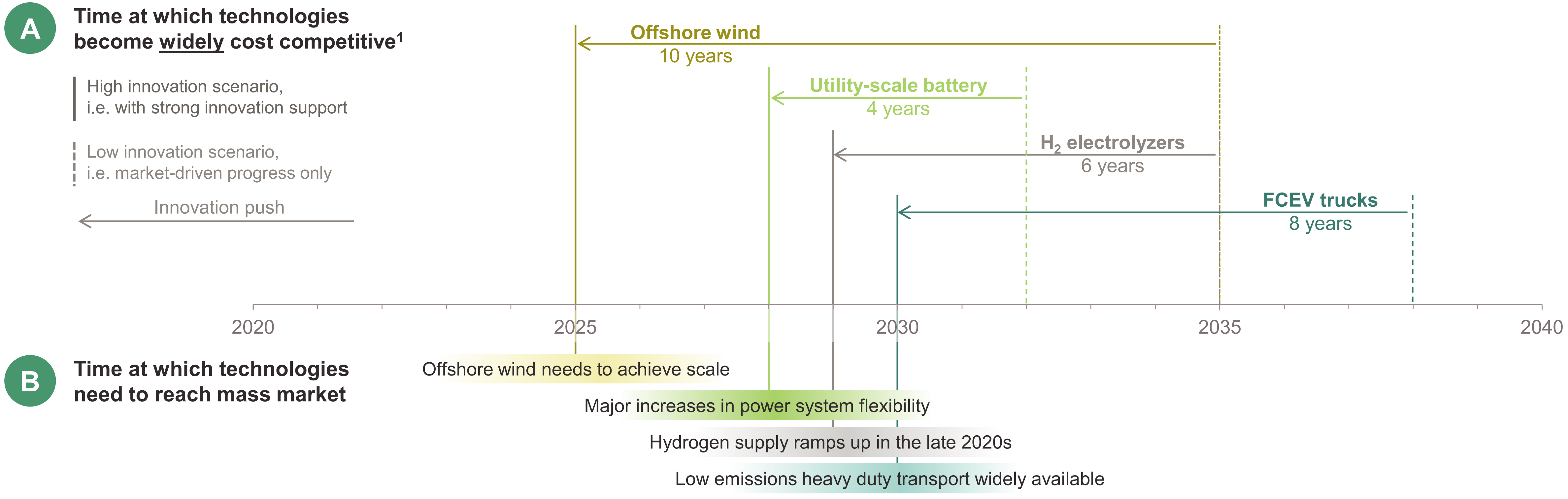
Innovation could further support value chains worth $3.4 trillion by GVA and support 37 million FTE jobs in 2050.

06 … and safeguards nature and health

Innovations protect natural resources by reducing land use and water consumption, avoiding pollution, improving biodiversity, and better health of human society.

1 Net zero innovation means supporting low carbon options to move rapidly through to mass market deployment

Historically, it takes 2-4 decades to fully commercialize a technology after demonstration.
A rapid transition to net zero would require supporting low carbon innovations to achieve market scale much earlier.

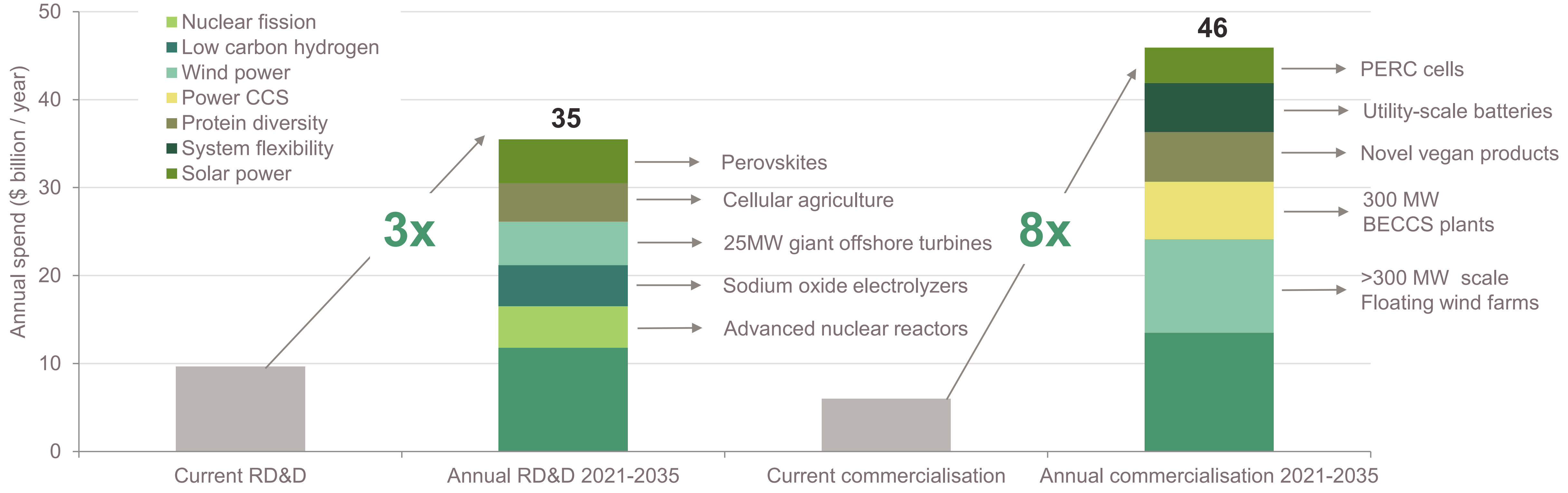


(1) Based on technology costs for the global level. Cost competitiveness defined as levelized costs falling within 10-15% difference of the emissions-intensive alternative, subject to a carbon price.

Note: Further detail for technologies and innovation areas, including their potential role in a net zero system as well as a discussion of alternatives, is provided in focussed reports on each innovation area

2 This requires roaring commercialization in the 2020s as well as increased RD&D

While RD&D spend increases 3x, the larger change required for net zero innovation is large scale funding for commercial scale deployment of key technologies



Note: Current RD&D spending for energy innovations is based on a subset of technologies in the IEA RD&D database that lies within the scope of the GINAs. Current commercialization spending is not tracked consistently globally and is estimated by Vivid Economics using available public spending data for wind, solar, CCS and hydrogen. Additional information on the method is reported in the annex.
Note: Further detail for technologies and innovation areas, including their potential role in a net zero system as well as a discussion of alternatives, is provided in focussed reports on each innovation area

3 Commercialization support should be accompanied by a wider set of market creation policies to accelerate uptake

Proven technologies with some small scale projects

Examples:

- Hydrogen electrolyzers
- Floating offshore wind
- Small modular nuclear reactors
- Hydrogen fuel cell trucks
- Gas CCS with Allam cycle
- Utility scale lithium-ion batteries and flow batteries

Policies to support innovations *after* the RD&D phase

Commercialization policies
Supply side funding for commercial scale deployment of immature technologies, in immature markets, to drive down costs

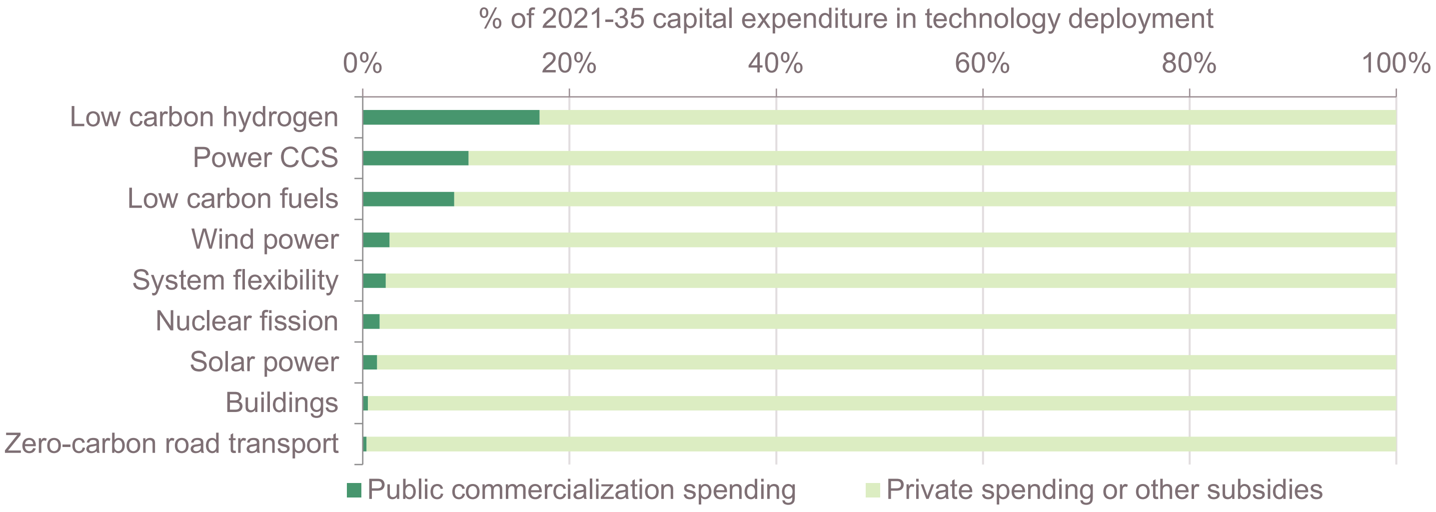
e.g. direct procurement, CfDs, subsidies

Kicks start commercialization, ~5% of investment

Market creation policies
Establish viable markets for technologies

e.g. carbon pricing, low carbon fuel standards, mandates and bans, tax credits

Drives ~95% of deployment investment



Mature technologies in well-developed markets

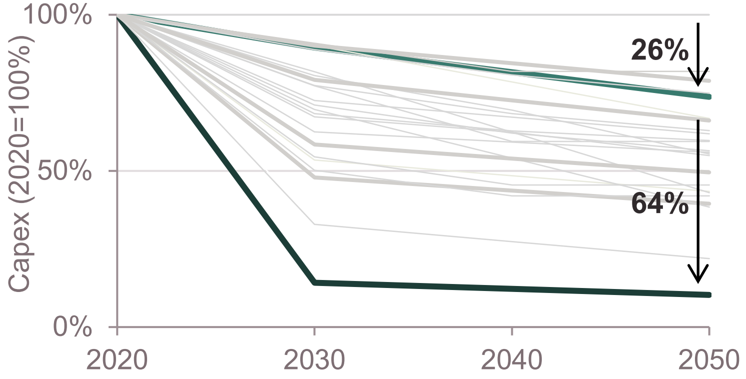
Examples:

- Current solar PV technologies
- Current onshore wind technologies

Note: Further detail for technologies and innovation areas, including their potential role in a net zero system as well as a discussion of alternatives, is provided in focussed reports on each innovation area

4 Innovation unlocks affordable decarbonized energy and food

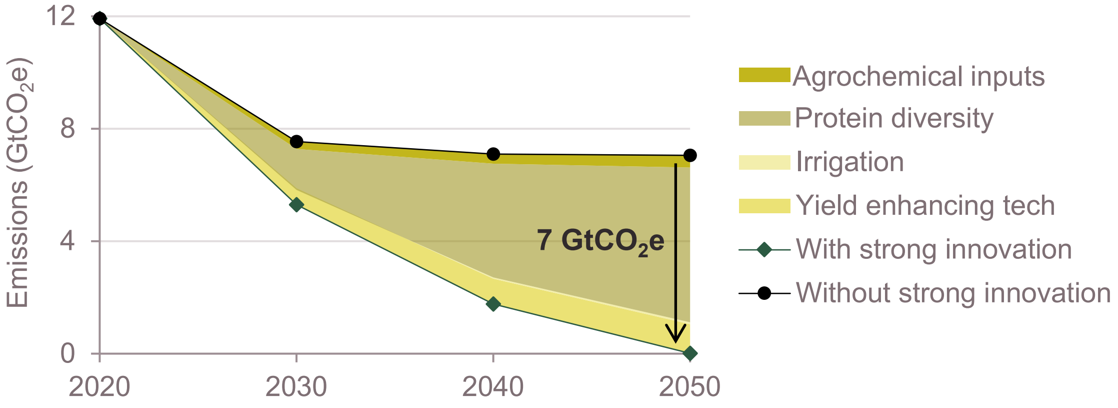
1. Energy innovations reduce the costs of clean energy technologies, making it cheaper to mitigate energy emissions



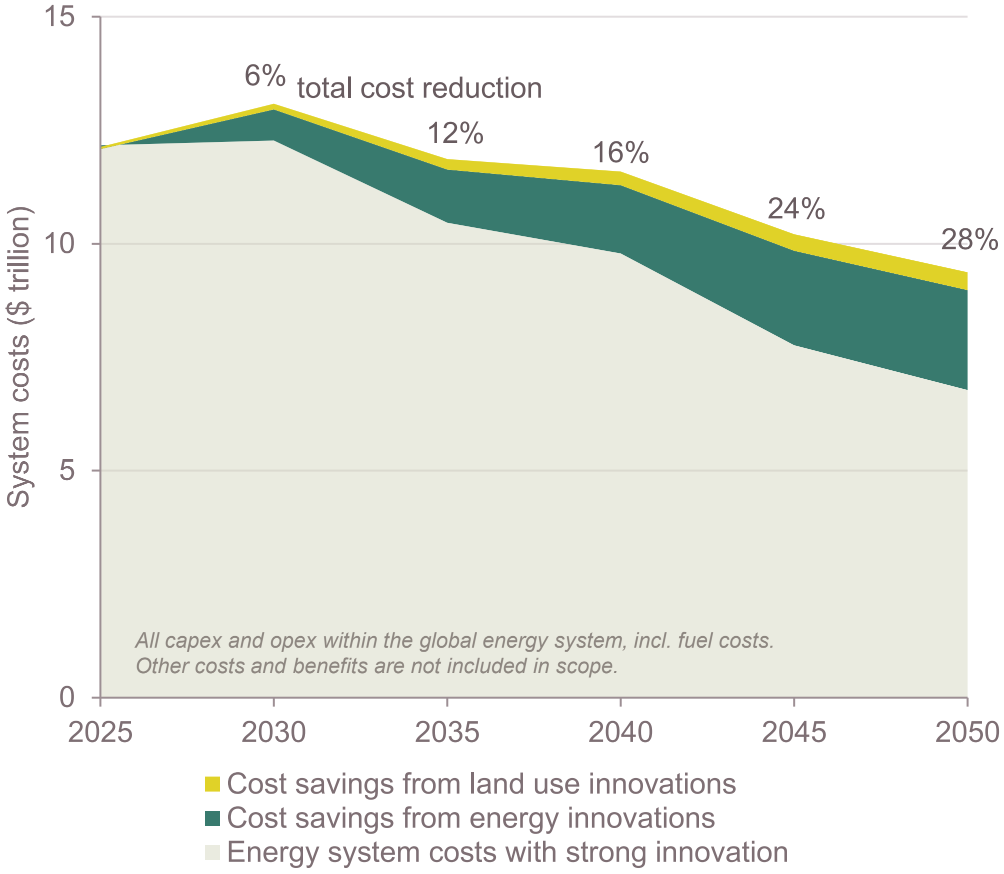
Cost decline scenarios constructed from 160+ studies in techno-economics.

For example, for hydrogen electrolyzers, the installation costs per kW **drop by 26% in the low innovation scenario** and a **further 64% in the high innovation scenario.**

2. Land use innovations reduce agricultural and land use emissions by up to 7 $GtCO_2e$ per year in 2050, creating room in the carbon budget



3. Energy and land use innovations combined could reduce the costs of decarbonising the economy by 28%, with savings around $2.7 trillion per year by 2050.



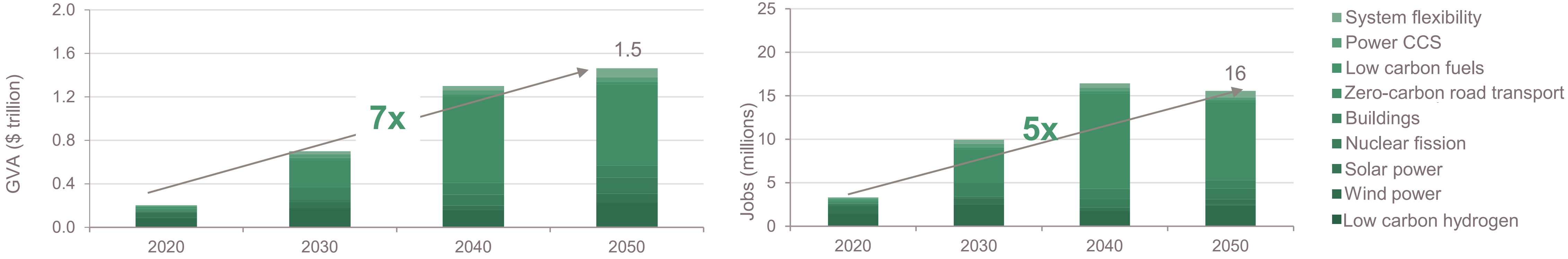
Note: Further details on the methodology on how energy and land use innovations are translated into system benefits are provided in slide 20, 24 and the methodology annex available on the GINA website

5 Innovation unlocks high value economic activity in low carbon supply chains supporting over 37 million jobs & worth $3.4 trillion

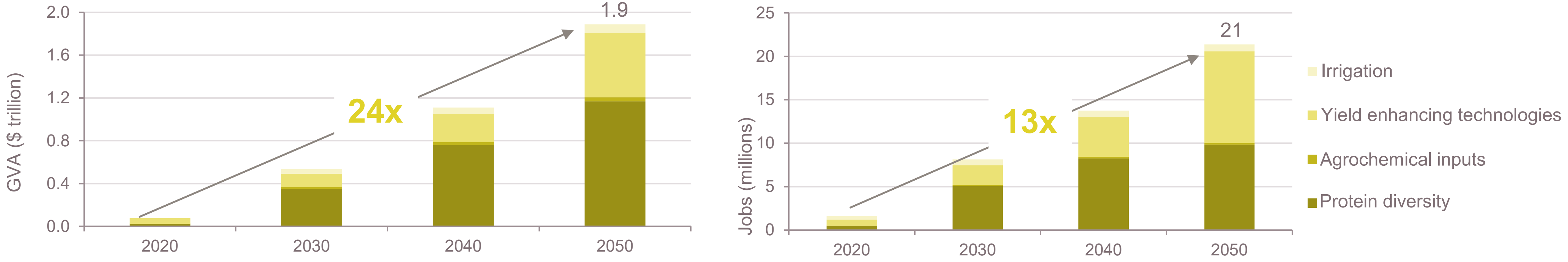
Innovation is key to scaling high value economic opportunities (GVA $3.4 trillion) within large low carbon supply chains

- The analysis captures innovative parts of the supply chain which centre around manufacturing
- Innovation helps ensure a competitive advantage and drive growth in high value sectors. This helps provide sustainable employment opportunities in high quality jobs

Energy



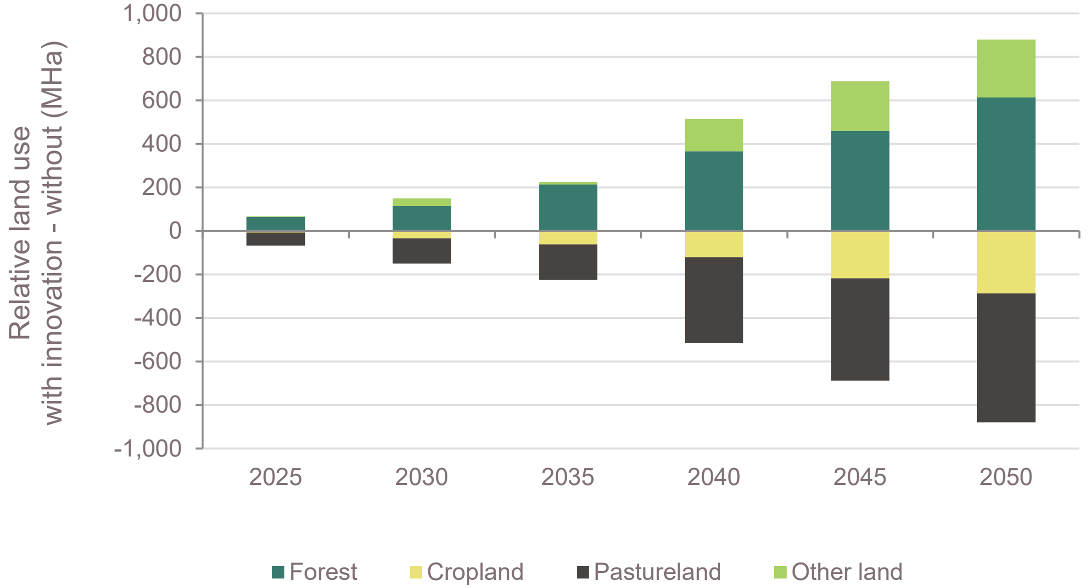
Land use



Note: Further detail for technologies and innovation areas, including their potential role in a net zero system as well as a discussion of alternatives, is provided in focussed reports on each innovation area

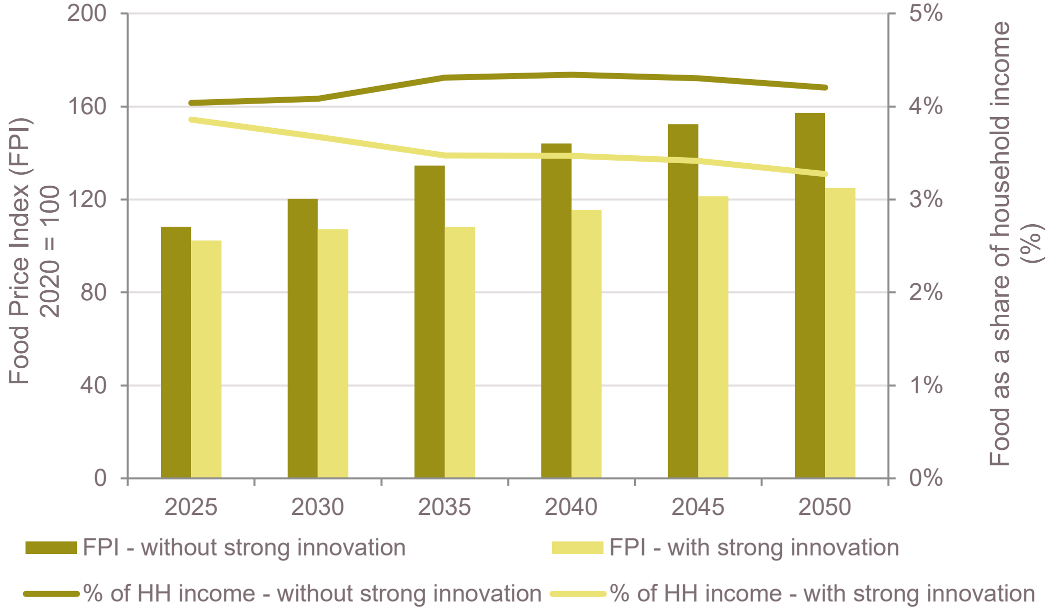
6 Safeguards nature and health

Innovation improves efficiency of agriculture, enabling land and resource sparing



Improvements of the end-to-end efficiency of food systems, such as increased yields, higher input use efficiency, and growth in low emissions alternative protein **could spare up to 880 MHa of land for nature, equivalent to about 5% of global land area.** This land sparing enables restoration of natural habitats, reduced water demand, decreased agrochemical runoffs, and improved biodiversity

Innovation improves food security by easing cost increases and improving resilience



- Smaller increases in average food costs improve food security and inclusion among the poorest households, reducing malnutrition and famine
- Innovations enable wider uptake of climate resilience measures and can reduce food production's exposure to physical climate hazards, contributing to food security

Part 1: The value unlocked by pushing low carbon innovation

In the GINAs, we consider 3 categories of benefits of low carbon innovation

Affordable energy and food

Innovation reduces the cost of decarbonisation, driving down final energy and food prices for consumers.

- **Land use & agricultural innovation** reduces the competition for land easing pressure on food prices and enabling more widespread use of low cost decarbonisation through nature based solutions
- **Energy innovation** directly reduces costs (e.g. cheaper hydrogen) as well as indirectly reducing whole system costs (e.g. reduced need for higher cost abatement options)

Jobs and Growth

Innovation unlocks valuable supply chains and high skilled jobs. The low carbon economy will be large, with supply chains worth many trillions $. This work identifies **manufacturing segments** of the supply chain, which countries could attract by commercialising key innovative technologies

Nature and Health

Beyond decarbonisation, **innovation facilitates the protection of nature and biodiversity** by dramatically reducing the land footprint required for agriculture and by reducing agrochemical runoffs that pollute waterways and damage habitats.

By potentially lowering food prices in a net zero scenario, innovation helps **improve food security and equity outcomes in low-income countries.** Innovations that contribute to agricultural adaptation also **reduce exposure to the physical impacts of climate change**.

Note: The list of benefits of innovation considered in the GINAs is not exhaustive

The innovation areas of focus for Phase 1 were selected based on the scale of their potential system benefits

Areas of focus for the GINAs

The GINAs focus on innovations which
- **could provide the largest potential benefits** to the system between now and 2050; and,
- **play a potentially important role in a net zero scenario** based on credible current evidence

The chosen areas of focus **do not imply**
- The technologies will necessarily play major roles in achieving net zero globally. This will depend on political choices and inherently uncertain innovation processes
- Technologies and innovation which are not areas of focus cannot play a major role in achieving net zero

Filters applied for selection

1 **Technologies are at least at demonstration stage today**
- Includes e.g., synthetic fuels and next generation of electrolysers
- Excludes e.g., nuclear fusion

2 **Technologies play a material role in 1.5C scenarios from credible institutions**
- Includes e.g., solar power
- Excludes e.g., tidal stream and geothermal which are only applicable in specific geographies

3 **Technologies have plausible substantial scope for innovation**
- Excludes e.g., hydropower

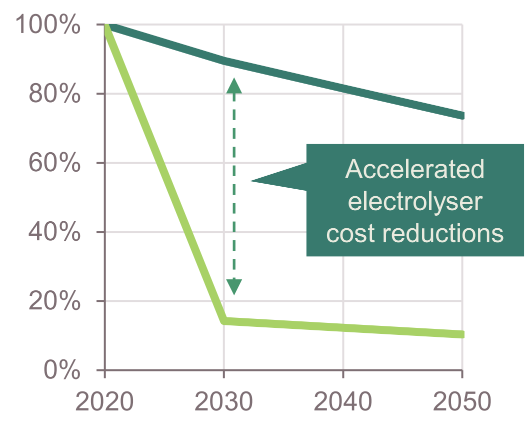
- Today's evidence base on the potential of decarbonization technologies can help guide decisionmakers guide innovation. However, innovation is inherently uncertain and not fully predictable. Unexpected breakthroughs will occur, as well as disappointments in development. Our understanding of the potential benefits **will change** and the GINA methodology can be applied to map innovation potential and benefits of new technologies, or technologies for which expectations have substantially changed.
- Further detail on how GINA's areas of focus were selected is set out in the methodology annex available online

Energy innovation provides system wide benefits, making low carbon energy affordable

Affordable energy and food

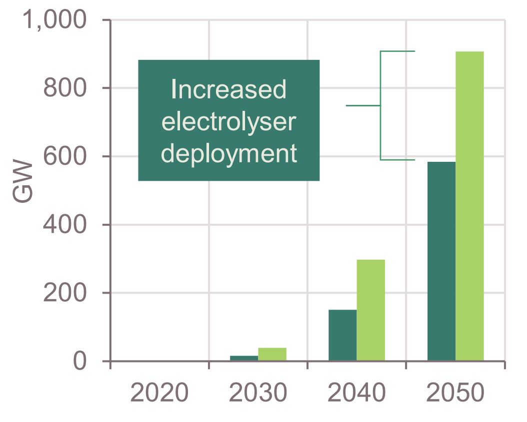
Innovation reduces costs and other barriers….

- Research and innovation leads to technological and process improvements.
- This reduces deployment barriers and unlocks accelerated technology cost reductions for technologies across different TRLs.



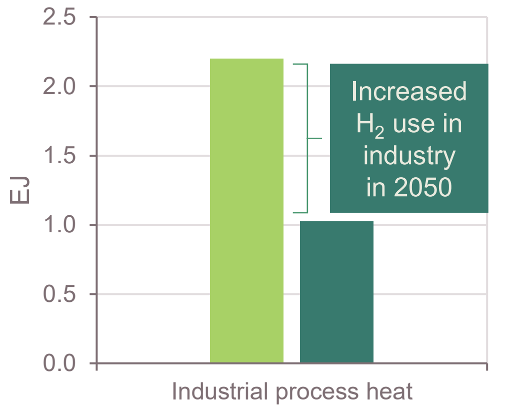
….increasing technology deployment….

- Lower costs increase returns and potential profits, increasing investment and deployment.
- Lower technology cost increase deployment in a cost minimized decarbonization pathway.



…enabling wider system cost reductions….

- Lower costs and increased deployment of related downstream or synergistic technologies (e.g. increased FCEVs when hydrogen becomes cheaper, or increased solar when battier become cheaper).
- Reduced deployment of other more expensive mitigation technologies.



….and ultimately reducing low carbon energy costs

- The combination of high deployment of low-cost technologies and indirect system impacts reduces the overall cost of decarbonization to the energy system.
- Consequently, this reduces energy costs.

28%

The system costs reduction between 2020 and 2050 from innovations in energy and land use cumulatively

The largest benefits accrue in technologies which can provide energy services more cheaply than fossil fuel competitors

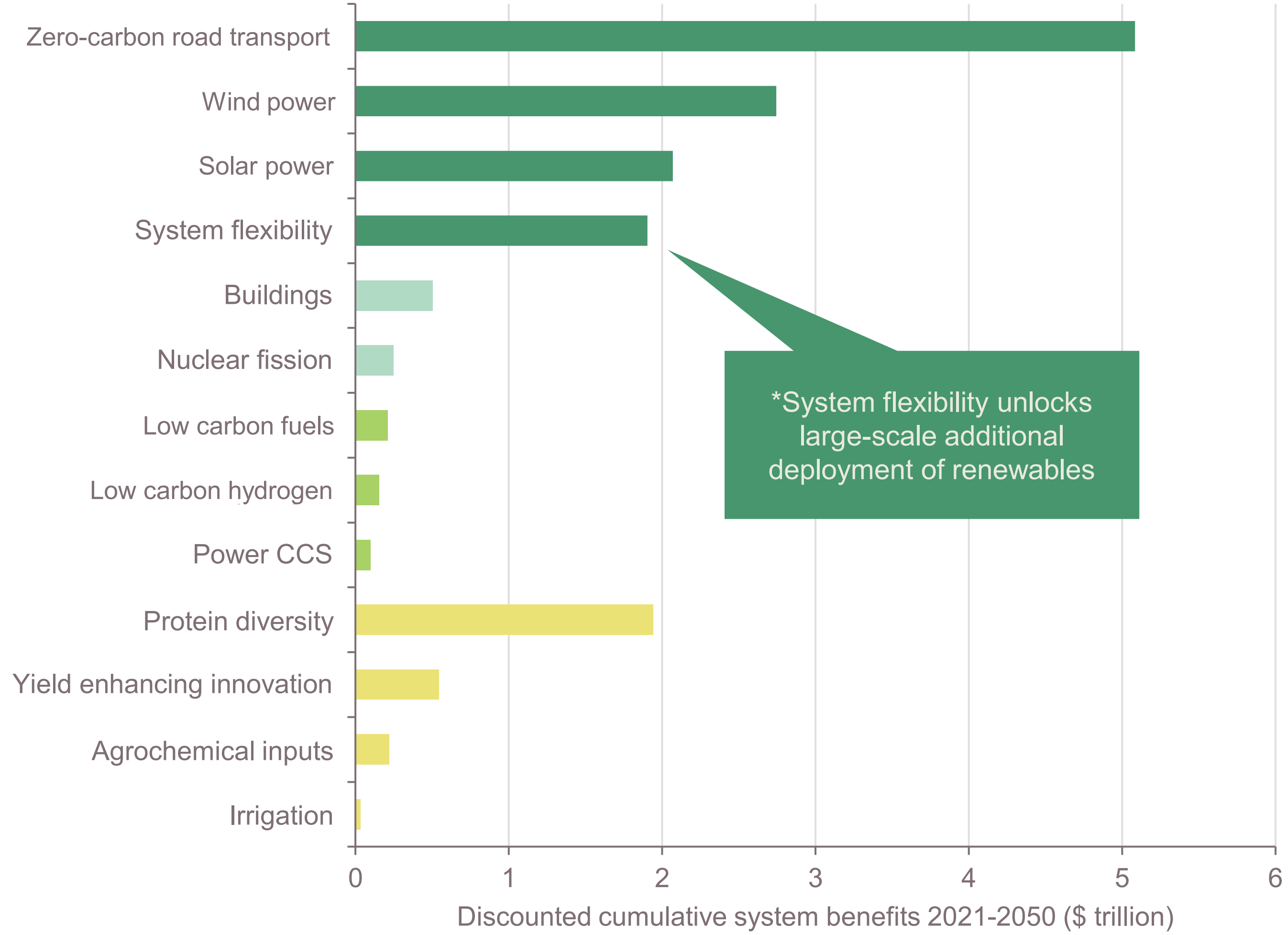
Affordable energy and food

Zero-carbon road transport, variable renewables and flexibility* provide large system benefits early in the century because of the scale of their deployment and costs which drop below fossil fuel competitors.

Nuclear fission uptake remains modest even with high innovation due to renewables' cost-competitiveness. **Buildings**' innovation largely involves removing non-cost barriers, which have a limited impact on system benefits.

Innovation in **low carbon fuels, hydrogen and power CCS** most delivers benefits in the long term and hence the discounted benefits between 2020-2050 are modest.

Within innovation in agriculture and land use, **protein diversity** provides the largest system benefits, driven by the large scale CO_{2e} abatement they can drive.



Note: Cumulative system benefits are discounted at a 5% annual rate and in total amount to around $16 billion. In comparison, the undiscounted cumulative system benefits across technologies amount to $45 billion. Using a discount rate implicitly increases the value of the system benefits that accrue in the short term relative to those materialising close to 2050. However, the order of technologies based on system benefits is the same with both methodologies. An in-depth exploration of discounted and undiscounted system benefits per technology can be found in each individual technology report.

Note: Further detail for technologies and innovation areas, including their potential role in a net zero system as well as a discussion of alternatives, is provided in focussed reports on each innovation area

The system benefits from innovation in less mature technologies accrue in the longer term

Affordable energy and food

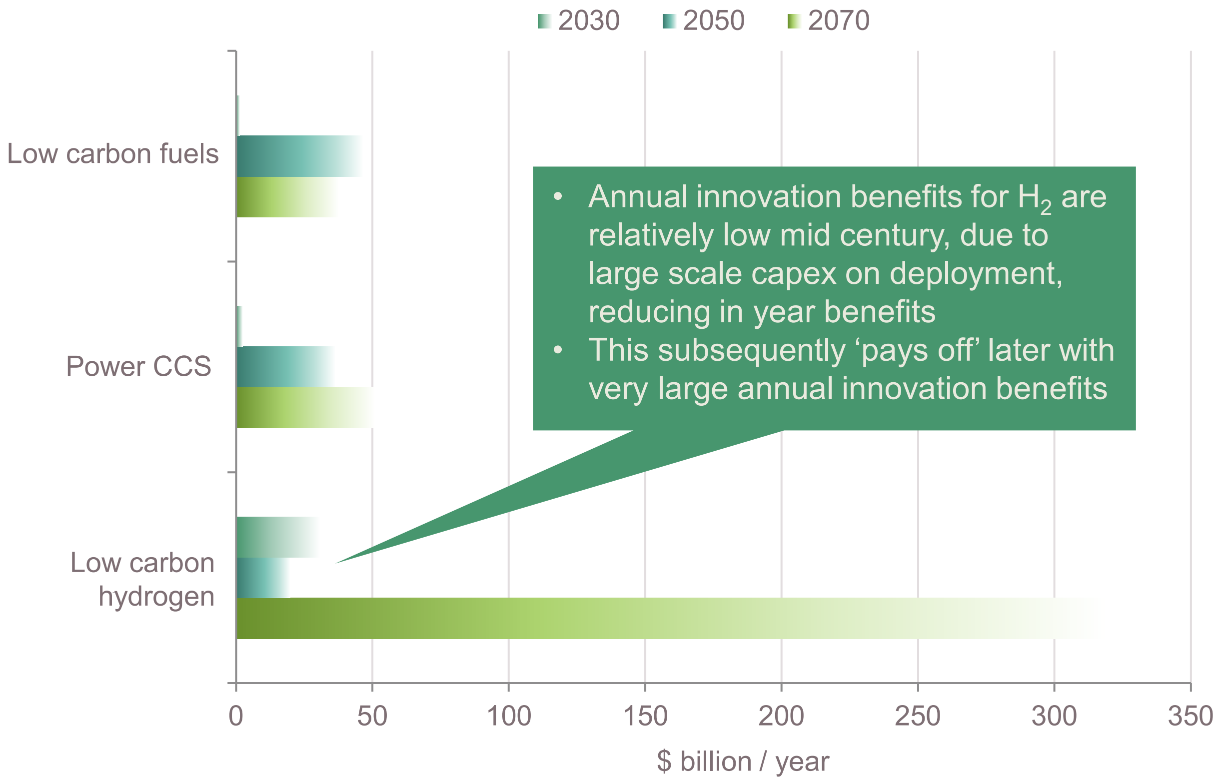
Even with widespread innovation, low carbon fuels are only taken up at scale by the middle of the century, when supply chains for low cost feedstock (hydrogen, biomass, CO_2) are available at scale, and key demand sectors like aviation need to deeply decarbonize. Hence benefits mainly accrue in the long term.

Deployment of power CCS plants at globally relevant scales mostly occurs in the late 2030s and 2040s, thanks to reduced costs of capture technologies and increased demand for negative emissions (through BECCS). Consequently, most benefits accrue in the long term.

Hydrogen innovation accelerates and lowers cost of hydrogen take-up in ‘core’ hydrogen applications such as high temperature heat in industry. The system benefits of innovation are most pronounced in the long term, when low cost green hydrogen helps drive more widespread take-up of hydrogen beyond ‘core’ hydrogen uses such as high temperature heat in industry.

The system benefits from innovation in less mature technologies today primarily accrue in the longer term

**note – in year benefit estimates are subject to significant uncertainty, they are presented here to illustrate a trend over time only*

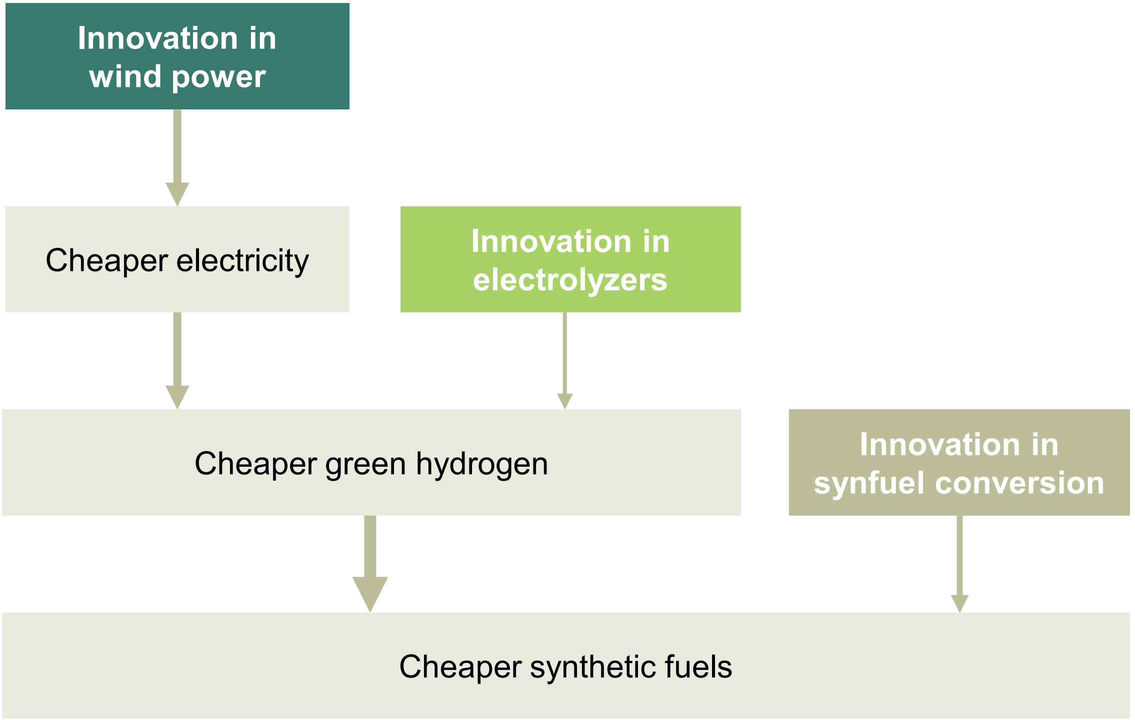


Note: Further detail for technologies and innovation areas, including their potential role in a net zero system as well as a discussion of alternatives, is provided in focussed reports on each innovation area

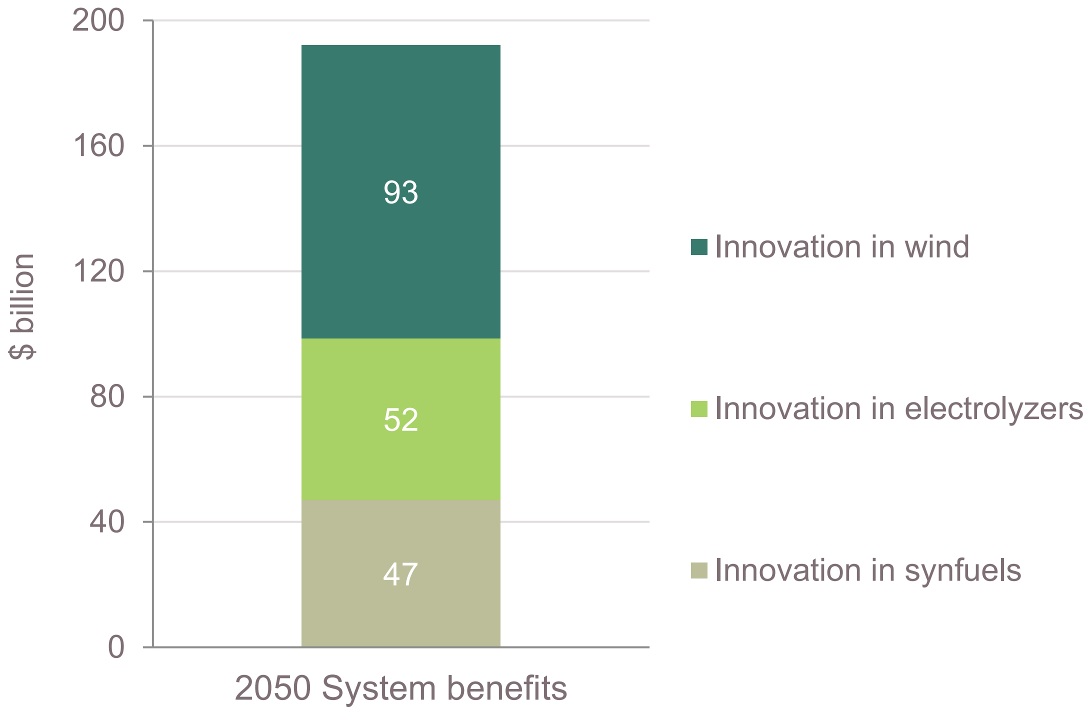
Innovations in one technology can substantially enhance the value of innovations in another

Affordable energy and food

Stronger innovation in wind power and electrolyzers enable cheaper production of synthetic fuels, enhancing the system benefits of innovation in synfuel conversion technology



This amplifies the system savings attributed to synthetic fuels by close to 4x

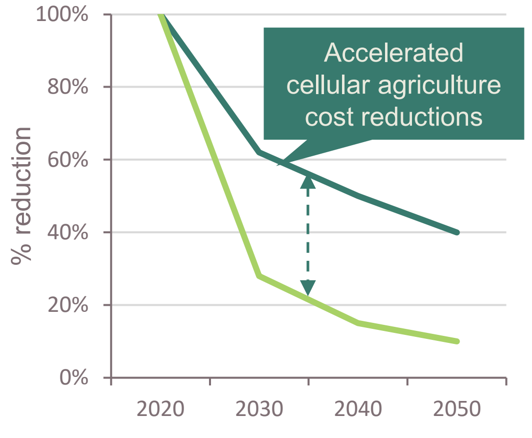


Land use innovation reduces land system emissions and keeps food affordable in a net zero scenario

Affordable energy and food

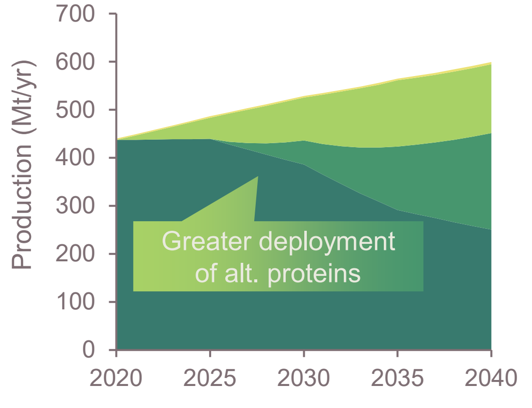
Innovation reduces costs and other barriers….

- Research and innovation leads to technological and process improvements
- Commercialization support and agricultural extension expands markets, accelerating cost reductions and unlocking economies of scale



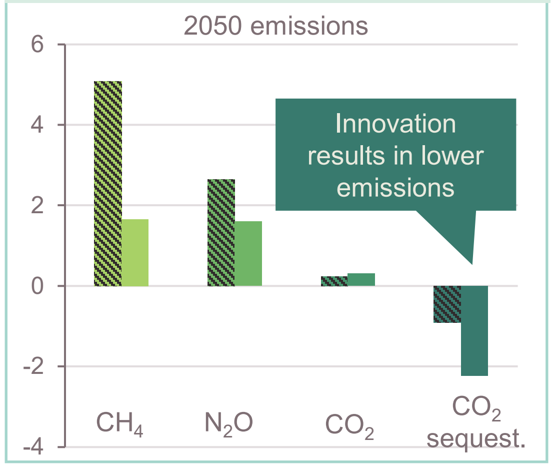
….increasing technology deployment….

- Lower costs increase returns and potential profits, increasing investment and deployment
- Lower technology costs increase consumer and farmer adoption of new technologies



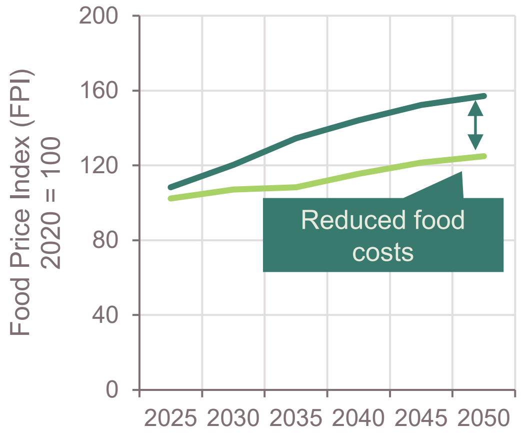
…reducing emissions….

- Technology uptake reduces land system emissions both directly and indirectly by reducing agriculture's land footprint, enabling carbon-rich ecosystem restoration
- Reduced land system emissions reduces need for untested and expensive mitigation in energy



….and alleviating pressure on food prices

- Easing land competition and improving climate adaptation in agriculture also moderates food prices
- Less expensive food improves health outcomes and equity impacts in developing countries



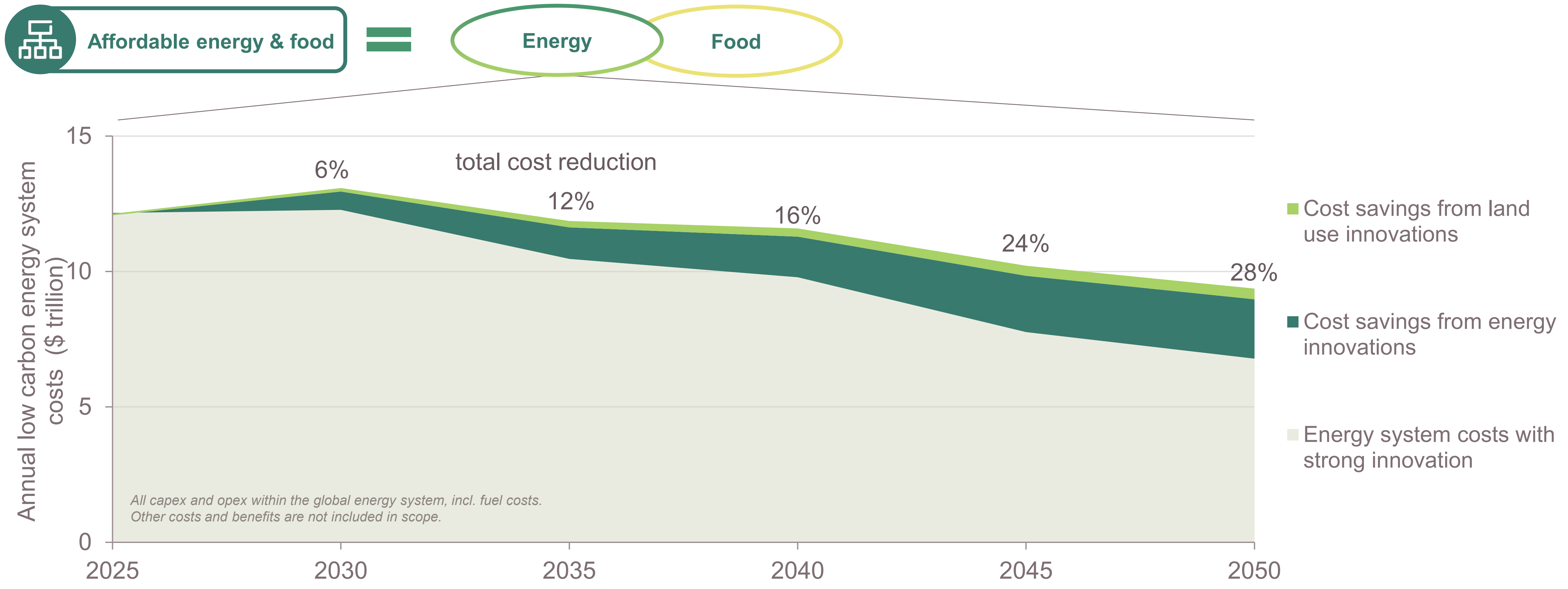
Innovations that reduce reliance on animal agriculture and reduce land footprint have the largest climate benefits

	Cumulative emissions reduction to 2050 ($GtCO_2e$)	Net agricultural land potentially spared by 2050 (MHa)
Protein diversity would provide substantial climate benefits, with early uptake dominated by plant-based alternatives before cellular agriculture becomes competitive in the long term. Emissions reductions are especially pronounced for **methane from fewer ruminants** and **negative CO_2 emissions from natural ecosystem restoration** of former pasturelands.	97	640
Yield-enhancing technologies reduce CO_2 emissions from cropland-expansion-driven deforestation, especially in the 2020's and 2030's. Yield growth is especially important in tropical countries, first to prevent deforestation, then later to unlock negative emissions from habitat restoration. Much of this growth can come from adoption of existing technologies, so agricultural extension and technology transfer programs are critical.	24	230
Decarbonized agrochemical inputs are one of the few ways to decrease N_2O emissions from the land system, especially as fertilizer consumption is expected to continue to expand with growing populations and incomes. Maximizing the fertilizer's efficiency after application so that usage can be minimized is particularly important for land system outcomes.	9.5	0.5
Innovation in **irrigation** provides only modest benefits, since much of the climate benefit comes from greater deployment of existing technologies. **The primary benefit of innovation in irrigation is in water savings** and improved environmental outcomes.	0.5	6

Net zero innovations in energy and land use reduce system costs by 28% by 2050, $2 trillion per year, by 2050

Affordable energy and food

Annual savings from energy and land use innovations increase progressively from $0.5 trillion in 2030 to around $2.5 trillion in 2050, making it cheaper to decarbonize the global economy

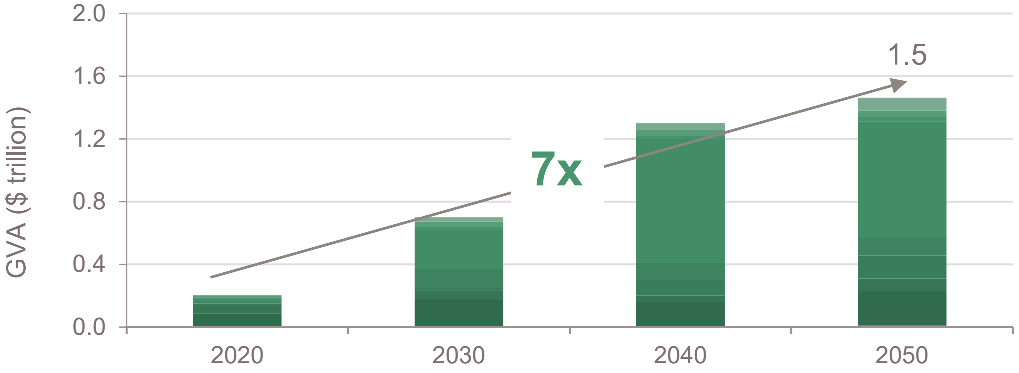


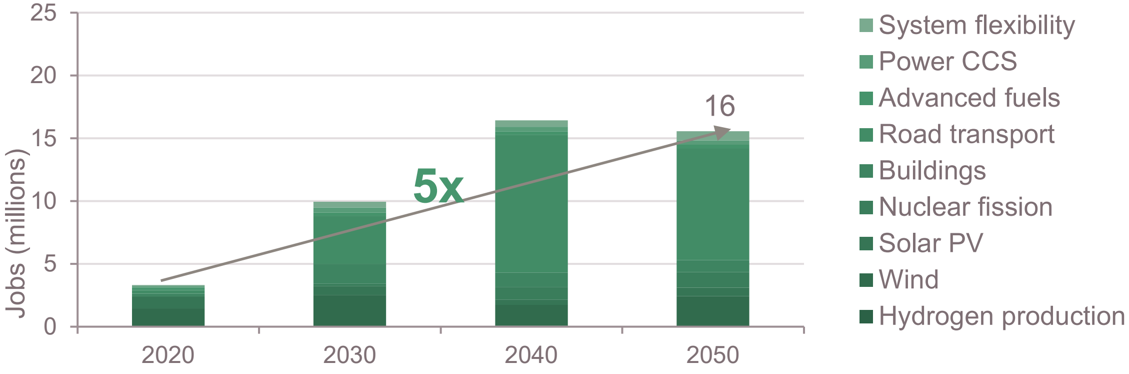
Innovation unlocks high value economic activity in low carbon supply chains supporting over 37 million jobs and worth $3.4 trillion

Innovation is key to capturing trade exposed and high value supply chains (GVA $3.4 trillion) within large low carbon supply chains

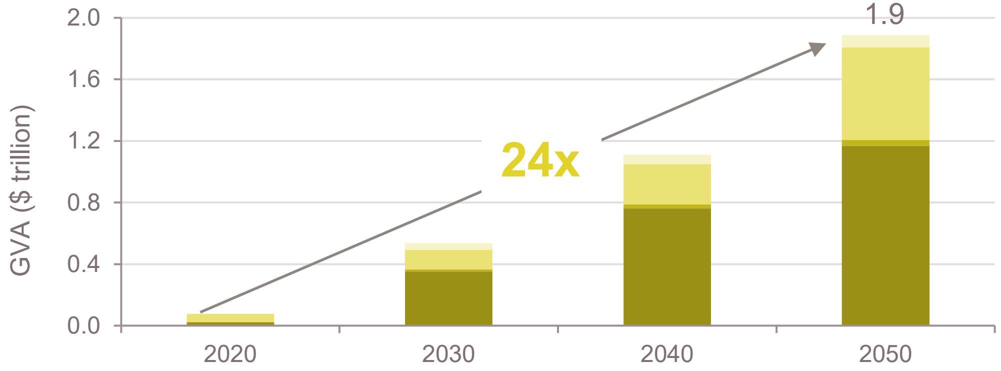
- The analysis captures innovative parts of the supply chain which centre around manufacturing and are trade exposed
- Innovation helps ensure a competitive advantage and drive growth of national industries and long-term employment opportunities in high value sectors and high quality jobs

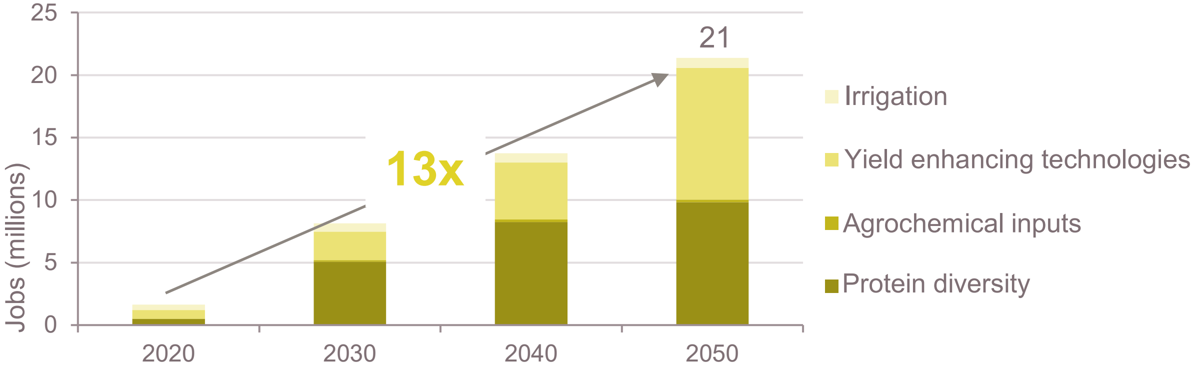
Energy





Land use





Note: Further detail for technologies and innovation areas, including their potential role in a net zero system as well as a discussion of alternatives, is provided in focussed reports on each innovation area

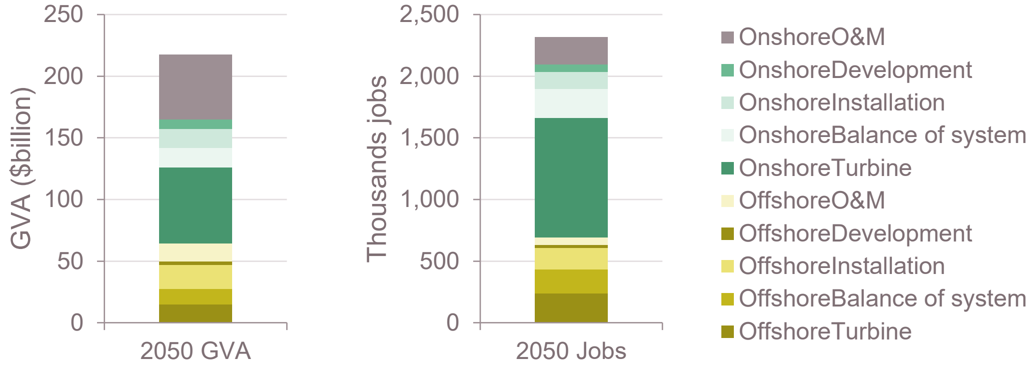
Wind jobs deep dive: Innovation helps develop a competitive edge in high value parts of the supply chain

Economic benefits

Innovation in wind power provides substantial opportunities for manufacturers, service providers, and win project developers

	2050 Market size	Innovation Opportunities	Trade exposure
Tier 2/ Tier 3 suppliers	~$200b	Small	High
OEM and service providers	~$400b	Large	High
Wind project developers	~$400b	Large	Medium
Utilities	N/A	Medium	Low

Wind developers and their suppliers could provide over $200 billion in gross value added (GVA) in 2050 and support 2.3 million jobs



Support for innovation can help establish domestic supply chains to serve a global market.

Case study: Denmark

- Wind energy has a long history in Denmark, which is home to some of the world's largest wind turbine manufacturers such as Vestas, Siemens, and Ørsted, with the industry generating $18 billion in revenue and employing 30,000 workers in 2019.
- The Danish government was the first European country to bring in large subsidies for onshore wind, including capital grants in the 1980s and feed-in-tariffs in the 1990s. Significant RD&D subsidies for the industry continued today. This has laid the foundations for the wind industry.
- Having demonstrated offshore wind technologies in the 1990s, the Danish government paid for the utility scale wind farms with turbines from Ørsted (then DONG Energy) in the late 1990s. This proved critical to achieve scale and drive down costs for the company.
- As a result, Ørsted gained a first-mover advantage as the pipeline of offshore wind projects grew significantly in Europe in the 2000s. Today, it has close to 25% global market share for offshore wind turbines.

Land use innovations benefit nature and health beyond climate, enhancing the public investment case

880 MHa of habitat restoration could stabilise and begin to reverse biodiversity loss.

The expansion of extractive agricultural practices has been a primary driver of catastrophic habitat and species loss over the past century. Land sparing from innovation can start to reverse this.

Innovation can also enable regenerative practices-polyculture cropping systems can be made easier with emerging precision agriculture tools.

Food prices have important just transition and food security impacts.

The current food system's emissions intensity means that decarbonization can drive price increases. While some price rebalances are appropriate, they must be managed carefully to avoid harmful impacts on the poorest and most vulnerable. Innovation eases land competition and eases the pressure on prices, improving food security outcomes.

Runoffs from animal agriculture and fertiliser application severely damage ecosystems both terrestrial and marine. Innovations that reduce waste streams are critical to biodiversity.

Reduced pollution helps ecosystems…

…and improves human health.

There are ~3 million cases of agrochemical poisoning in the developing world annually (WHO), and millions more suffer lower air and water quality as a result of agricultural waste.

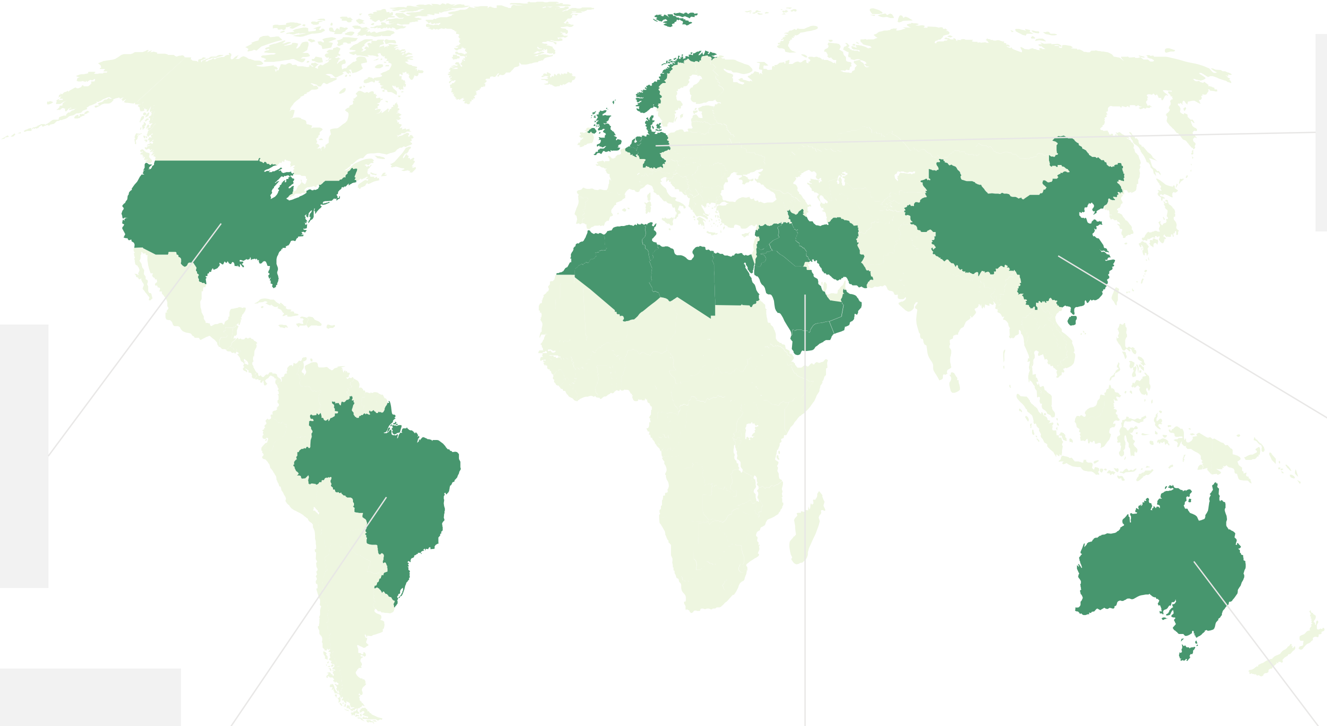
Innovation would reduce agriculture's water footprint.

Agriculture is responsible for ~70% of all freshwater withdrawals globally. With climate change altering the distribution of water resources, conserving water to meet environmental needs is increasingly important. Innovation, especially in irrigation systems, could help reduce the environmental risks of water shortages.

Innovation can increase food system resilience.

Climate adaptation in agriculture is increasingly critical for both human health in the developing world and supply chain resilience. Deployment of irrigation and precision agriculture tools can help make extensive agriculture more resilient, while innovations like vertical agriculture and alternative proteins can help diversify supply chains and reduce physical risk exposure.

Different innovations will benefit different regions given difference in their economies, land, and energy systems, for example:



Northern Europe

North Sea countries benefit disproportionately from CCS and H2 innovation

US

A large aviation industry, and low-cost renewable/H_2 potential makes synfuels particularly beneficial

China

Rapid transition away from coal make wind and solar innovations (coupled with flexibility) particularly valuable

Brazil

Large agricultural sector as well as reforestation potential make agricultural productivity innovations particularly valuable

Australia

Abundant solar resource provides substantial H_2 export opportunities to Asia

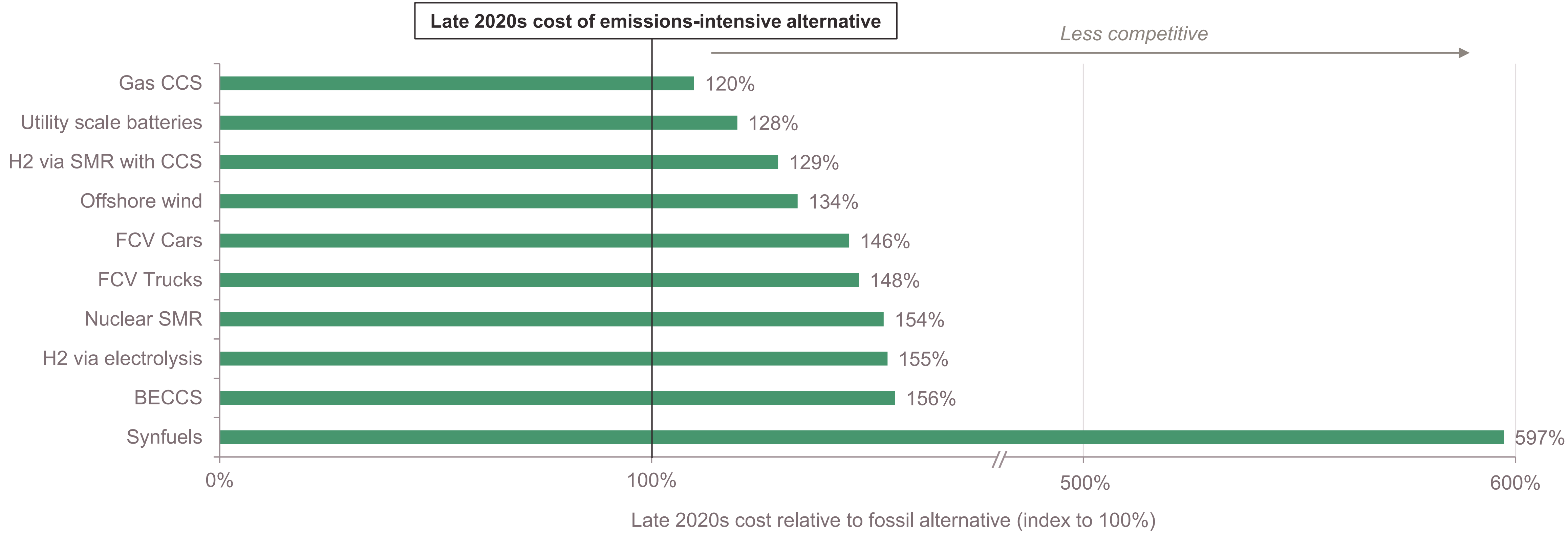
Middle East and North Africa

Solar and system flexibility innovations provide low-cost electricity and disproportionate system benefits

Part 2: The policy and spending needs to unlock the benefits of innovation

Key technologies remain uncompetitive under low innovation

Although many low carbon options are already available, some are not on track to become cost competitive by 2030 if innovation remains low, even under an escalating carbon price on emission-intensive alternatives,[1] and all technologies face a playing field tilted by fossil fuels subsidies

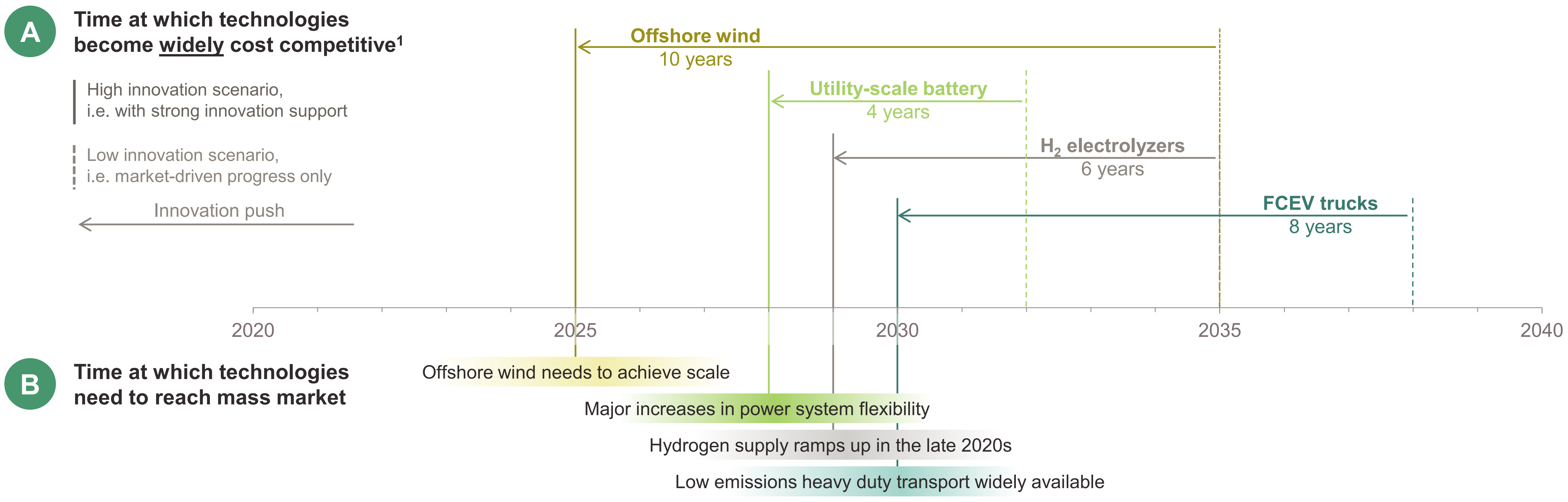


(1) Based on global technology costs under a low innovation scenario, assuming effective carbon prices of around $30/tCO_2$ imposed on the fossil fuel-based alternative, such as unabated gas-fired power and diesel trucks. This is in line with IEA projections for major economies under stated policies, including China ($17/tCO_2$). In comparison, the IMF estimates that today's global carbon price is around $3/tCO_2$.

Note: Further detail for technologies and innovation areas, including their potential role in a net zero system as well as a discussion of alternatives, is provided in focussed reports on each innovation area

Net zero innovation means supporting low carbon options to move rapidly through to mass market deployment

Historically, it takes 2-4 decades to fully commercialize a technology after demonstration.
A rapid transition to net zero would require supporting low carbon innovations to achieve market scale much earlier.



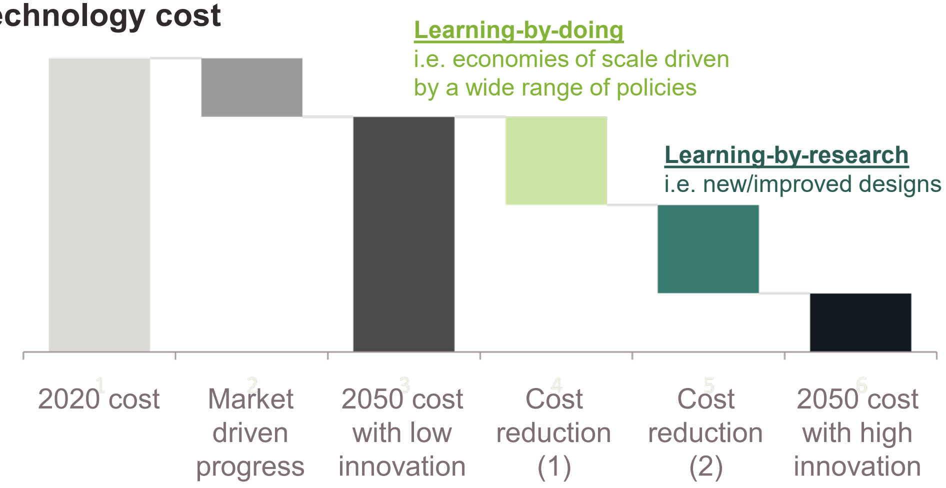
(1) Based on technology costs for the global level. Cost competitiveness defined as levelized costs falling within 10-15% difference of the emissions-intensive alternative, subject to a carbon price.
Note: Further detail for technologies and innovation areas, including their potential role in a net zero system as well as a discussion of alternatives, is provided in focussed reports on each innovation area

To achieve this, both RD&D and commercialization are necessary

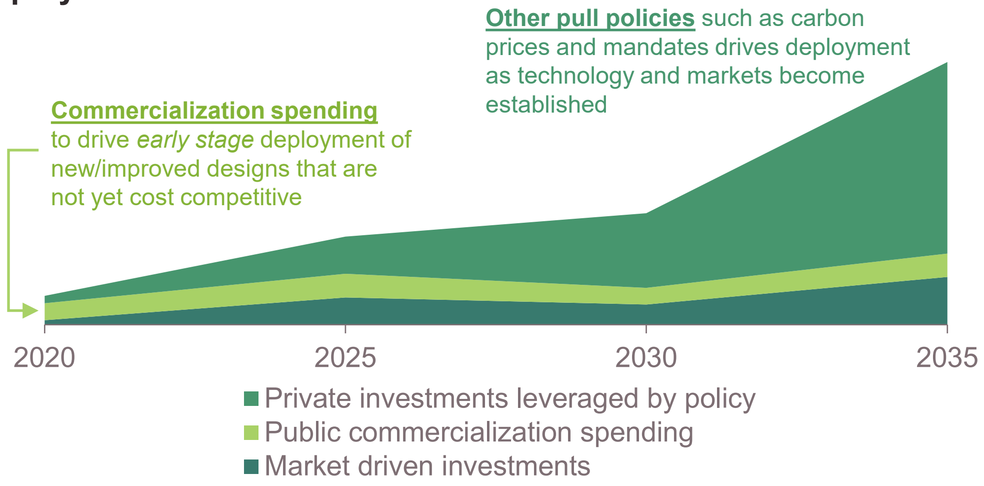
	Public RD&D spending	Public commercialization spending
Definition	Spending for the first steps of the technology development cycle, eventually demonstrating a technology in field conditions	Spending to bring a technology/product from demonstration to market and profitably deploy, reaching volume manufacturing
Economic rationale for public support	The private sector is unable to fully capture the societal benefits of knowledge spillovers and hence underinvests in RD&D	Given risks, and still developing pull policies, the private sector is cautious in taking the commercial risks for early-stage deployment and underinvests
What is estimated by the GINAs	Spending needed to drive costs down through RD&D, based on the historic trends relationship between RD&D and cost reduction for each technology	Spending needed to bridge the gap between technology cost and market prices to raise deployment to a 'high innovation' pathway

Effect of policies to support innovation

Technology cost

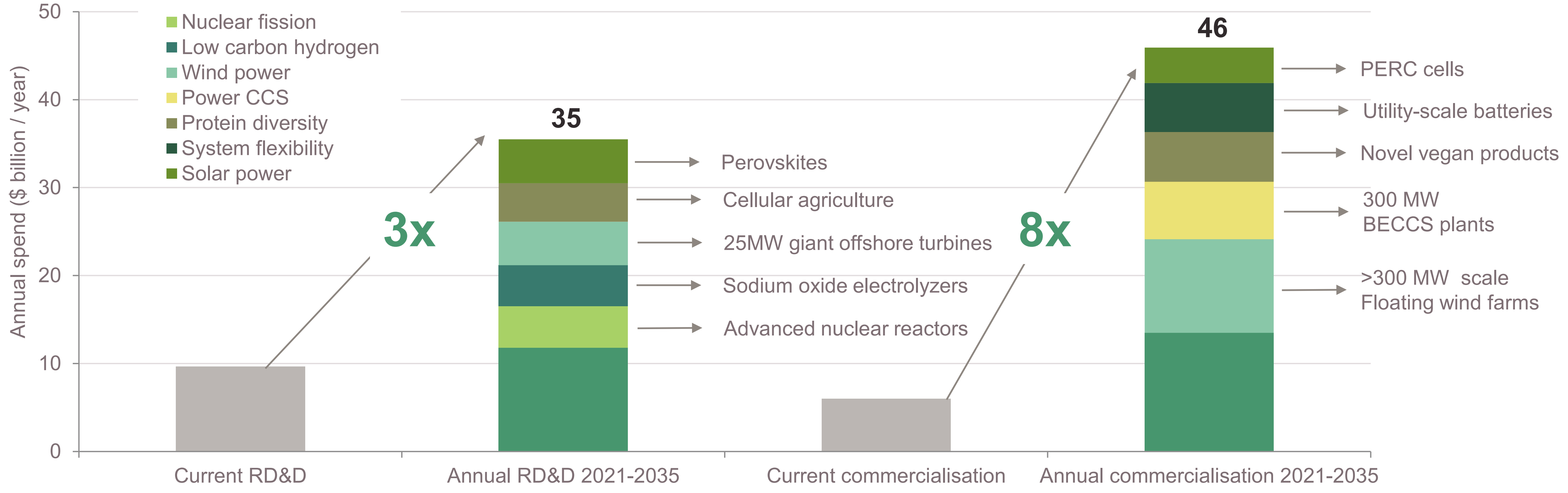


Deployment investment



A 3x increase in RD&D and 8x increase in commercialization spending is required to maximize cost reductions and benefits,

While RD&D spend increases 3x, the larger change required for net zero innovation is large scale funding for commercial scale deployment of key technologies

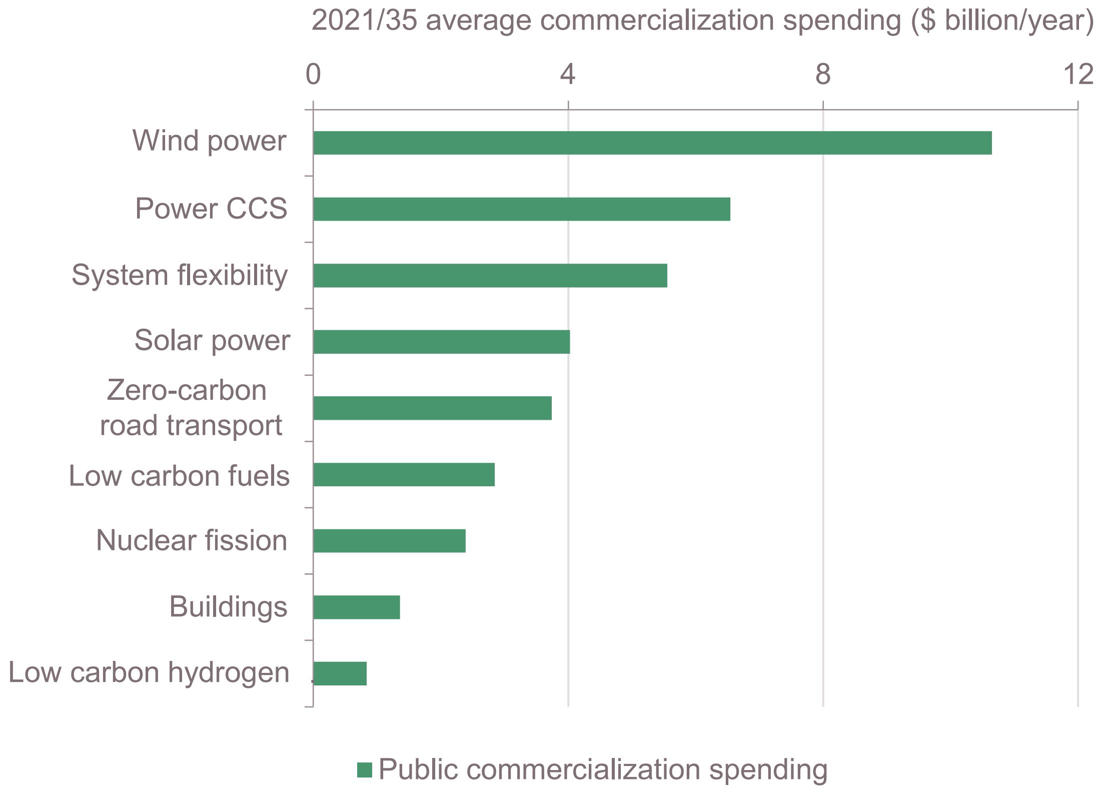


Note: Current RD&D spending for energy innovations is based on a subset of technologies in the IEA RD&D database that lies within the scope of the GINAs. Current commercialization spending is not tracked consistently globally and is estimated by Vivid Economics using available public spending data for wind, solar, CCS and hydrogen. Additional information on the method is reported in the annex.

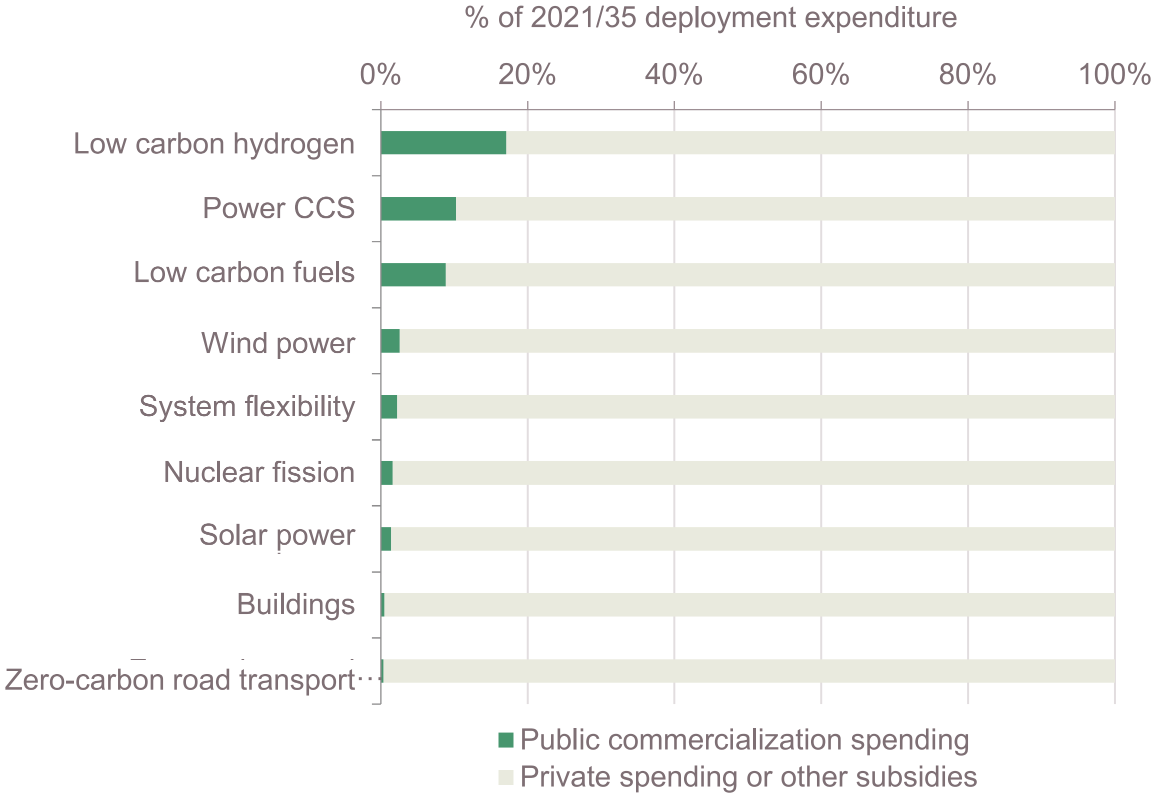
Note: Further detail for technologies and innovation areas, including their potential role in a net zero system as well as a discussion of alternatives, is provided in focussed reports on each innovation area

Public commercialization needs to increase 8x across technologies, starting from a low base

In absolute terms, commercialization spending is larger for technologies to be deployed at scale in the medium term



Commercialization spending is the most important for technologies furthest away from competitiveness



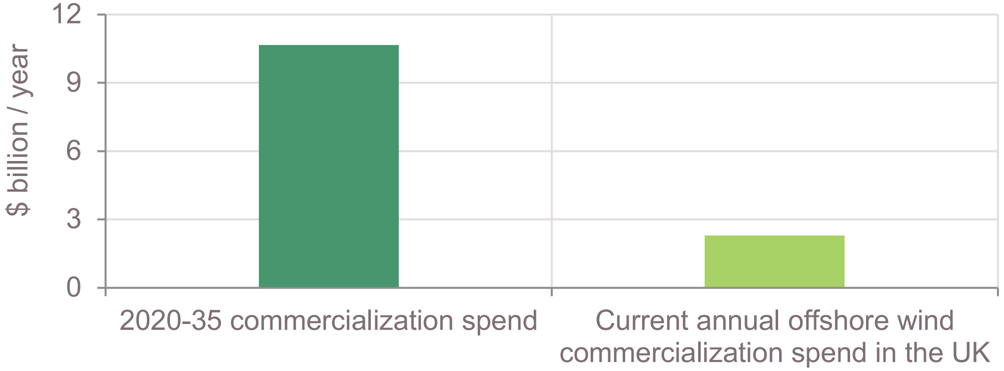
Note: Further detail for technologies and innovation areas, including their potential role in a net zero system as well as a discussion of alternatives, is provided in focussed reports on each innovation area

Commercialization spending complements existing and developing pull policies – ensuring commercial readiness of supply chains when rapid deployment ramp ups are required

For mature technologies, commercialization spending is directed to deploying 2nd generation technologies

Wind power

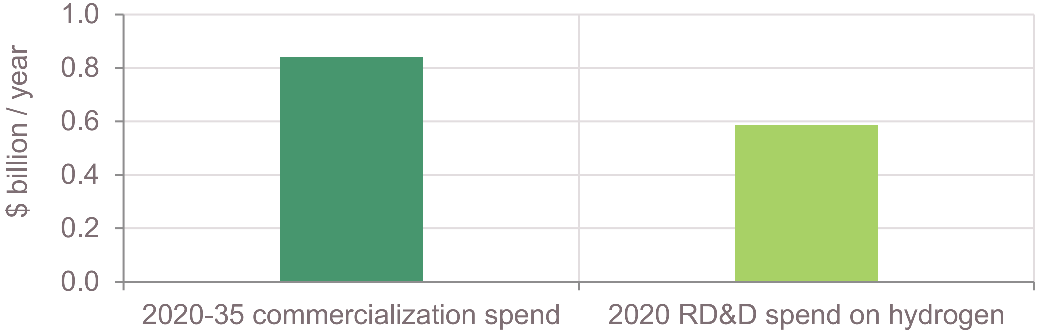
- Globally, the proposed scale of wind commercialization spending would be equivalent to public support for around 5-10 new commercial scale floating offshore wind parks per year, depending on how much private funding can be leveraged.
- For comparison, the scale of funding globally is approximately 5x the (primarily commercialization) funding UK Government alone has provided annually to help commercialize fixed offshore wind turbines.
- This funding would **complement** public subsidies for wind power in electricity markets to address the carbon externality in lieu of a carbon price



For immature technologies, commercialization spending supports 1st generation deployment at scale for the first time

Low carbon hydrogen

- Globally, the proposed scale of hydrogen commercialization spend is similar to current global RD&D spending in hydrogen.
- It is equivalent to annually deploying ~2GW of electrolyzers, depending on the private funding that can be leveraged, enough to meet the demand of several industrial clusters.
- While comprehensive pull policy frameworks for hydrogen are still being developed, this commercialization funding kick-starts hydrogen markets, creating (local) liquid markets for hydrogen and laying the framework for large scale private investment in the late 2020s.



Sources: Low Carbon Contracts Company (2021) Annual report and accounts 2020-21 and IEA (2021) RD&D Database

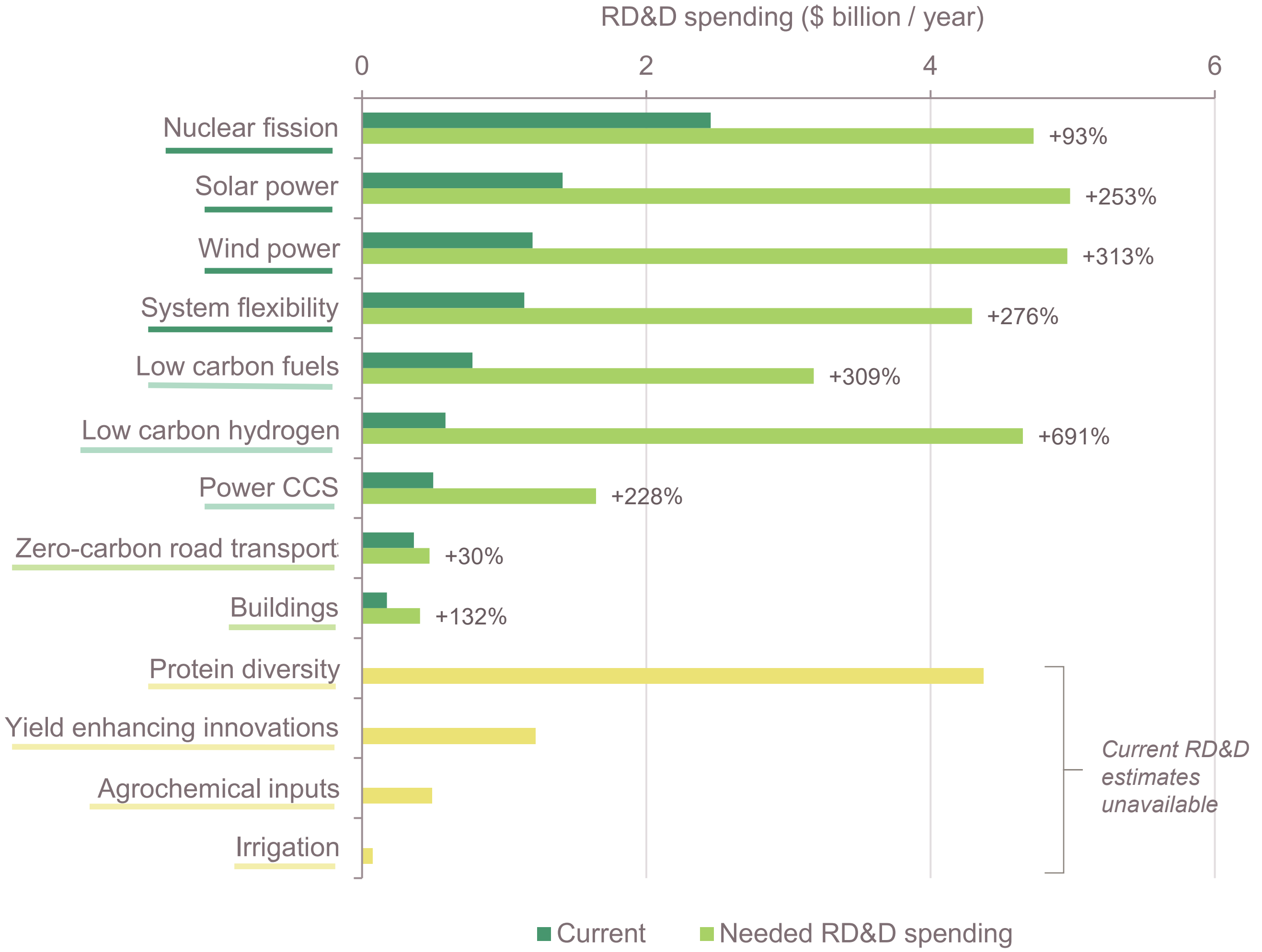
While lower than commercialization spending needs, RD&D spending needs to triple this decade

Mature energy technologies, such as solar power, already achieved large cost reductions in the past. Further innovation can still deliver large system benefits, but unlocking it requires high levels of RD&D spend.

Immature energy technologies, such as low carbon fuels, still have large room to increase their cost competitiveness. Here, further RD&D is a key driver for cost reductions.

Within **zero-carbon road transport and buildings**, public sector involvement in RD&D spend is much lower than in other sectors, largely due to the high maturity and relatively low capital intensity of these sectors.

The development of **agriculture and land-use** technologies for net zero merit RD&D spending on a similar scale to that of energy technologies.



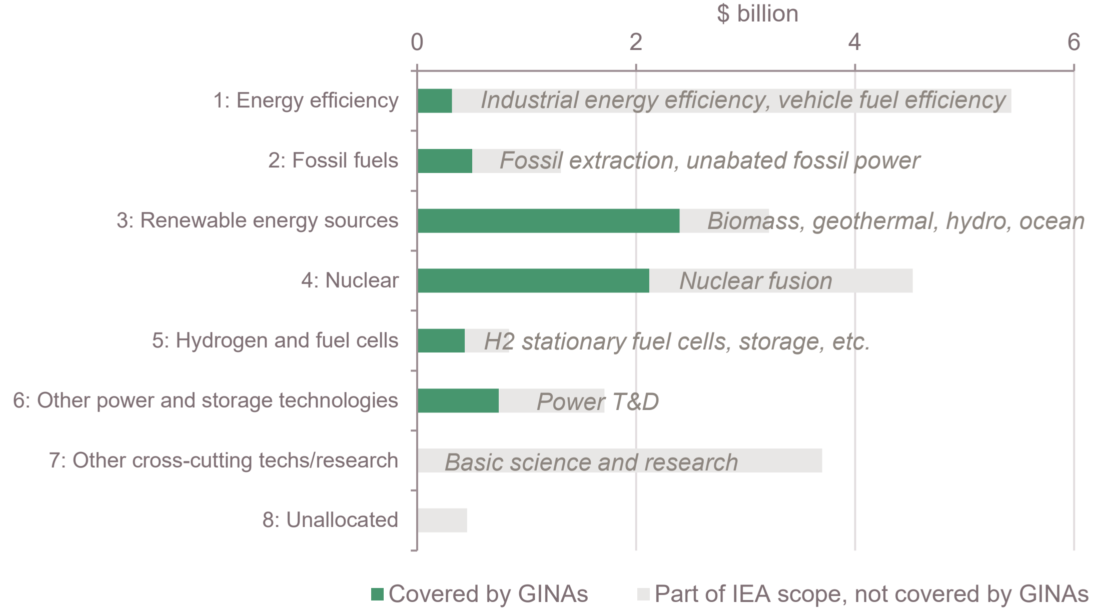
Note: Further detail for technologies and innovation areas, including their potential role in a net zero system as well as a discussion of alternatives, is provided in focussed reports on each innovation area

GINAs energy RD&D spending estimates are comparable with other estimates from the IEA and U.S. research centers

Current global RD&D spending on energy innovations covered by the GINAs is $9 billion/year, which is a third of the $26 billion/year public RD&D spending on clean energy reported by the IEA

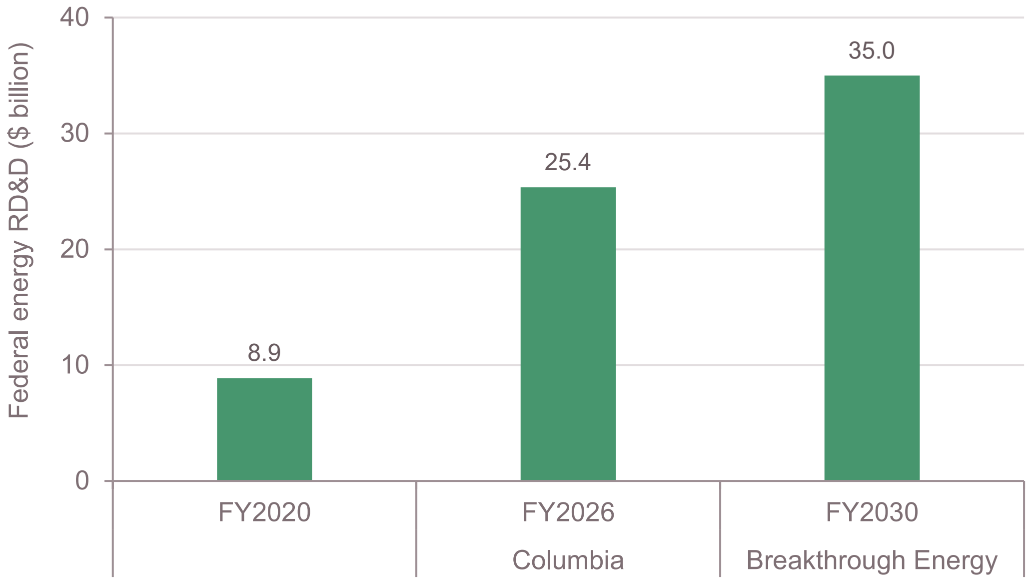
GINAs scope in terms of 2019 RD&D spending by IEA member countries[1]

Key omissions from the GINAs



Future RD&D spending estimated by the GINAs for the global level (2021/2030 average as 3x of 2020) is comparable to the increase suggested recently by Columbia University and Breakthrough Energy

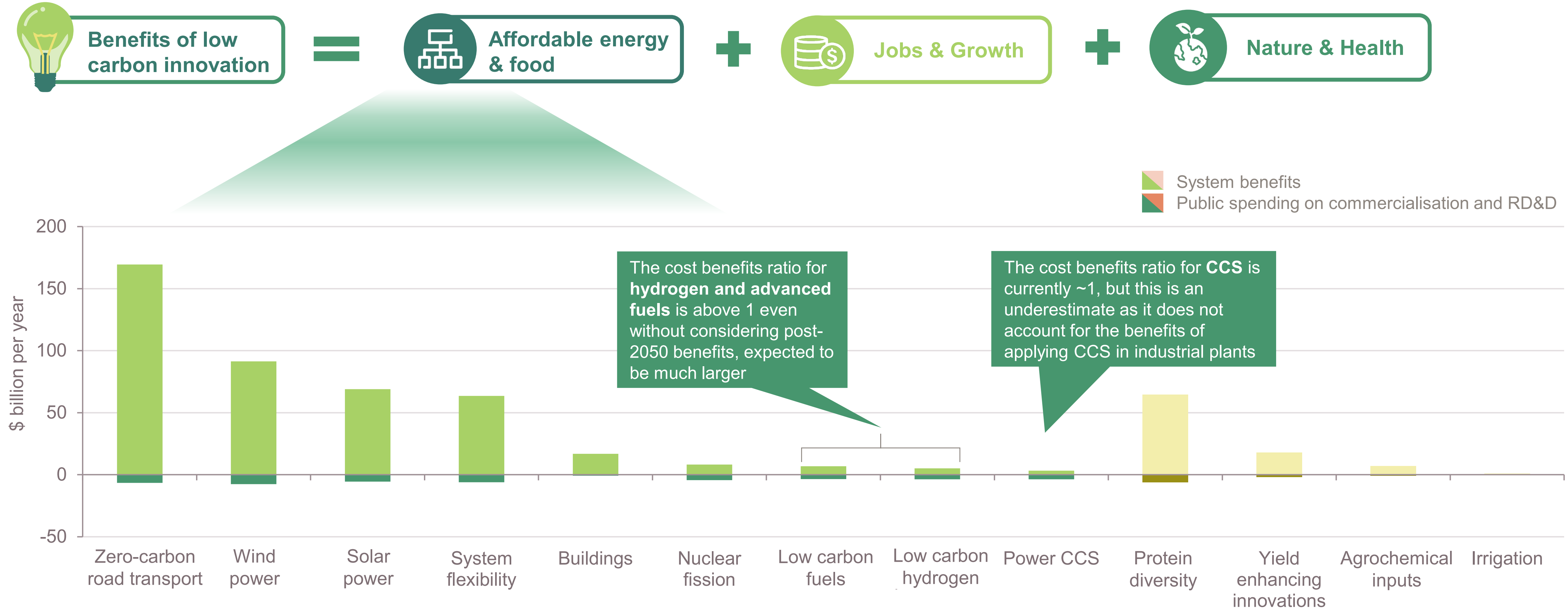
US Federal RD&D in energy in FY2020 compared against proposals[2]



(1) The IEA's RD&D database contains granular RD&D data only for IEA member states, which the GINAs rely on for estimating global RD&D in selected technologies. Other countries such as China and Chile are added back into the dataset based data shown in Mission Innovation publications and IEA's own estimates: global public RD&D spending on energy is estimated at $31 billion for 2019, of which $26 billion is on clean energy. IEA member states accounted for about $21 billion.

(2) See report by Columbia University SIPA Center on Global Energy Policy and report by Breakthrough Energy respectively.

RD&D and commercialization investment could bring 10x larger benefits through affordable energy & food alone



Note: Figures shown represent 2021/2035 annual averages for estimated public spending in the high innovation scenario, and the discounted annual average benefits for 2021/2050 for each technology family. Spending need is explicitly quantified for energy technologies using learning rates and cost estimates. Spending need for land use innovations are proxy values based on observed ratios in system benefits and innovation spending. Yield-enhancing innovations consist of 2 GINAs technology families: advanced agricultural technologies and genetically modified food.

Note: Further detail for technologies and innovation areas, including their potential role in a net zero system as well as a discussion of alternatives, is provided in focussed reports on each innovation area