Advanced Energy Solutions Industry Vision

Supported by L.E.K. Consulting

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Advanced energy solutions refer to five key technologies: Energy storage, Clean Hydrogen, Carbon Management, Sustainable Aviation Fuel and Advanced Nuclear

Advanced Energy Solutions definition and focus

	Energy storage	Clean hydrogen	Carbon management	Sustainable aviation fuel	Advanced nuclear
Definition and technologies	Includes most energy storage solutions such as lithium ion, thermal storage, metal to air (with the exception of pumped hydro)	Hydrogen delivered through low carbon means, i.e. through electrolysis (green), or through combined carbon capture (blue)	Includes both carbon capture and carbon removal technology like direct air capture and bio energy	Bio-fuel derived from renewable means i.e. rapeseed, sugarcane, waste cooking oil. E-fuels like HEFA, FT, ATJ, and Power to X	Small modular reactors, microreactors and fusion technologies. Excludes large scale non modularised nuclear power plants
The need for this solution	• Enables renewable energy integration • Solves the intermittency challenge • Short-duration storage deals with daily peaks and troughs • Long-duration to manage the seasonal variations of energy production	• Essential to decarbonize hard to abate sectors that represent 30% of the world's emissions, such as transport, agriculture and steel	• Provides a way to minimize emissions and remove CO2 to balance unavoidable emissions	• Only short-term way for decarbonizing the aviation sector that accounts for 2% of global emissions • Battery storage and hydrogen solutions currently unproven for long haul flights	• Critical emissions free source capable of providing clean and dispatchable energy to the grid at industrial loads, offering base load power and stability

Source: L.E.K. research and analysis

Scale

Market outlook, capacity and investment needs

Advanced solutions need to scale annual investment to $500 billion by 2030, making10% of the total spend on energy transition

The scale of deployment and investment for net-zero

Technology Area	Current Capacity	Capacity Required in 2030	Annual Investment required in 2030	Growth rate required by 2030 (CAGR)
Battery Storage	28GW	970GW	150 Bn US$	66%
Clean Hydrogen	1 Mt	69 Mt	130 Bn US$	83%
Carbon Capture Storage	50 Mt	1024 Mt	100 Bn US$	54%
Sustainable Aviation Fuel	0.24 Mt	45 Mt	80 Bn US$	111%
Advanced Nuclear	~0 GW*	~0 GW	75 Bn US$**	n/a

Source: IEA World Energy Outlook 2023, BNEF, Global Data, Hydrogen Council.

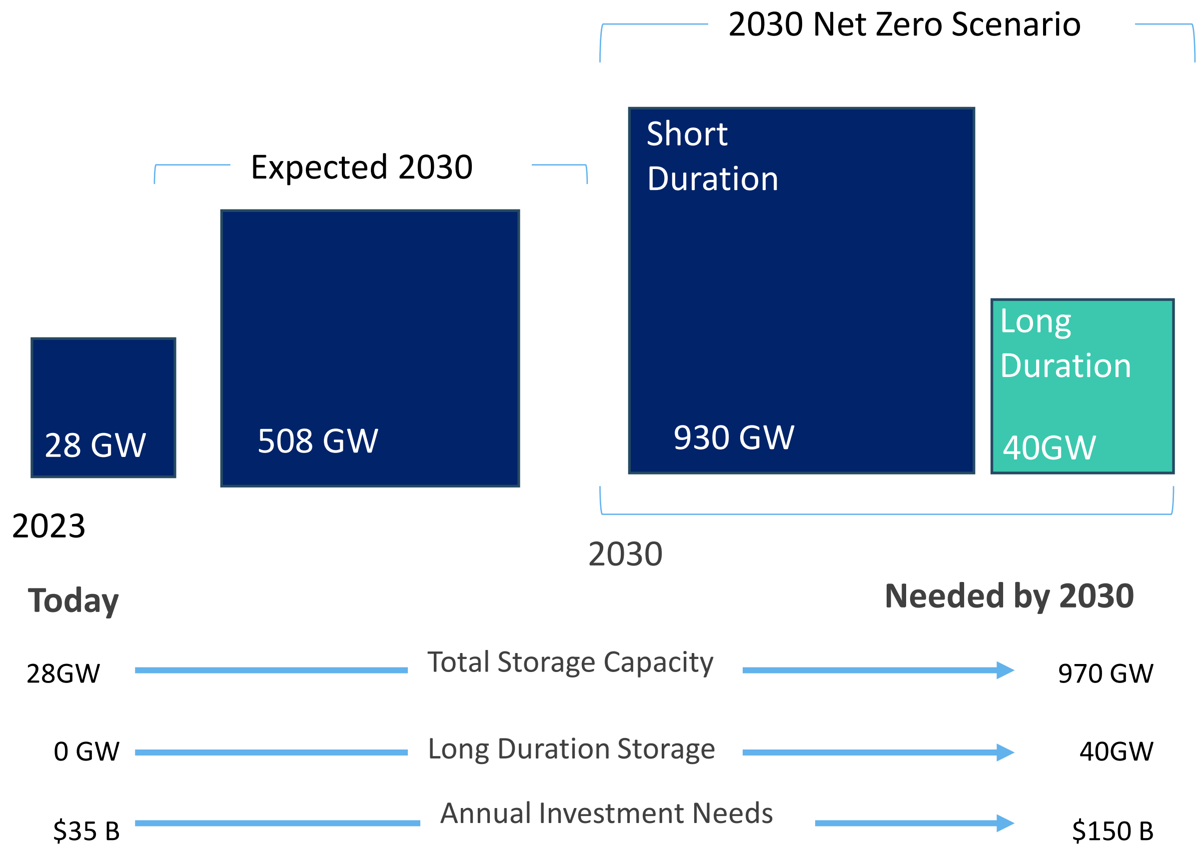
* Russia’s Akademik Lomonosov floating plant uses two 35 MW SMRs . China operates 200 MW HTR-PM . Both are demonstration only.

** Investment comes before capacity. Based on achieving 25% SMR capacity by 2043. ~$4.5 billion is allocated for fusion development. Figure based on LEK Research and Analysis

Grid scale battery storage must scale to 940GW to serve an increasingly renewable grid by 2030. This equates to around $150 billion of annual investment in 2030.

- Global investment in battery energy storage exceeded $35 billion in 2023
- IEA estimates that 170GW of storage will need to be added in 2030 alone to meet net zero targets, which equates to approx. $150 billion in that year
- $70 billion of $150 billion will be in long duration storage.

Energy Storage capacity and investment growth to 2030 for net zero path

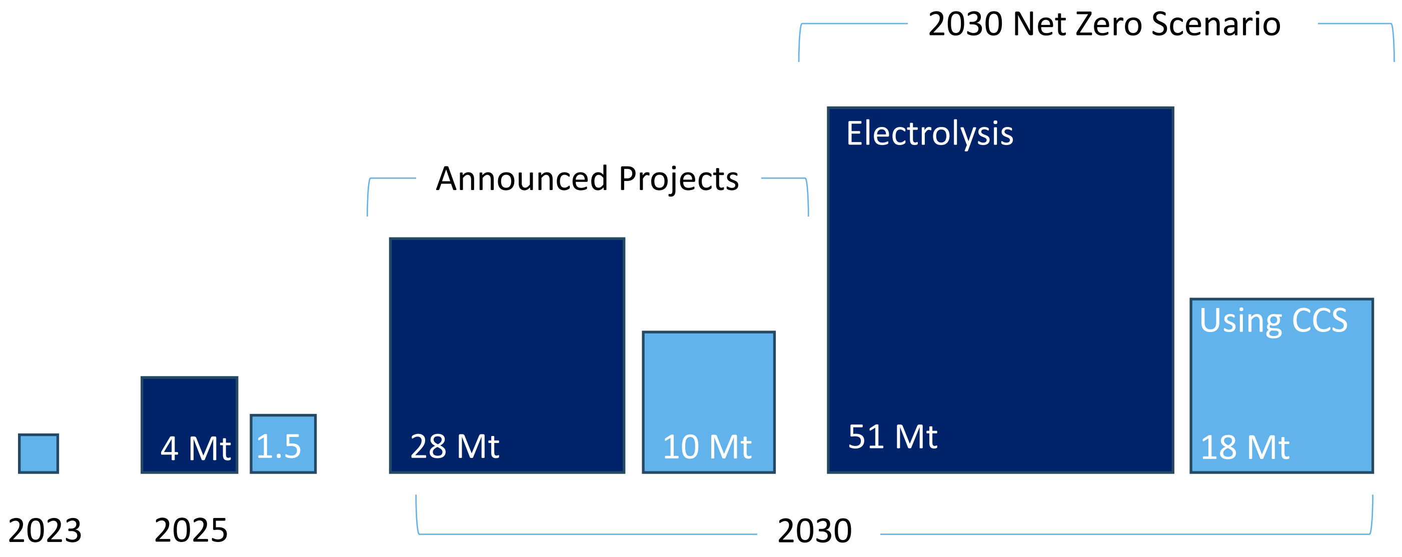


Source: LDES Council, Mckinsey, IEA

Capacity of low emission hydrogen is expected to reach 69Mt. Achieving this level of capacity will involve scaling investment to $130 billion p.a. by 2030

- Up to $130 billion in investment is needed to scale clean hydrogen to the level required for the path to net zero
- For green hydrogen, this equates to an electrolyser capacity of 590 GW to provide 51 Mt of clean hydrogen.
- For blue hydrogen, to generate the 18 Mt around 215 Mt of CO2 would need to be captured

Clean Hydrogen capacity and investment growth to 2030 for net zero path



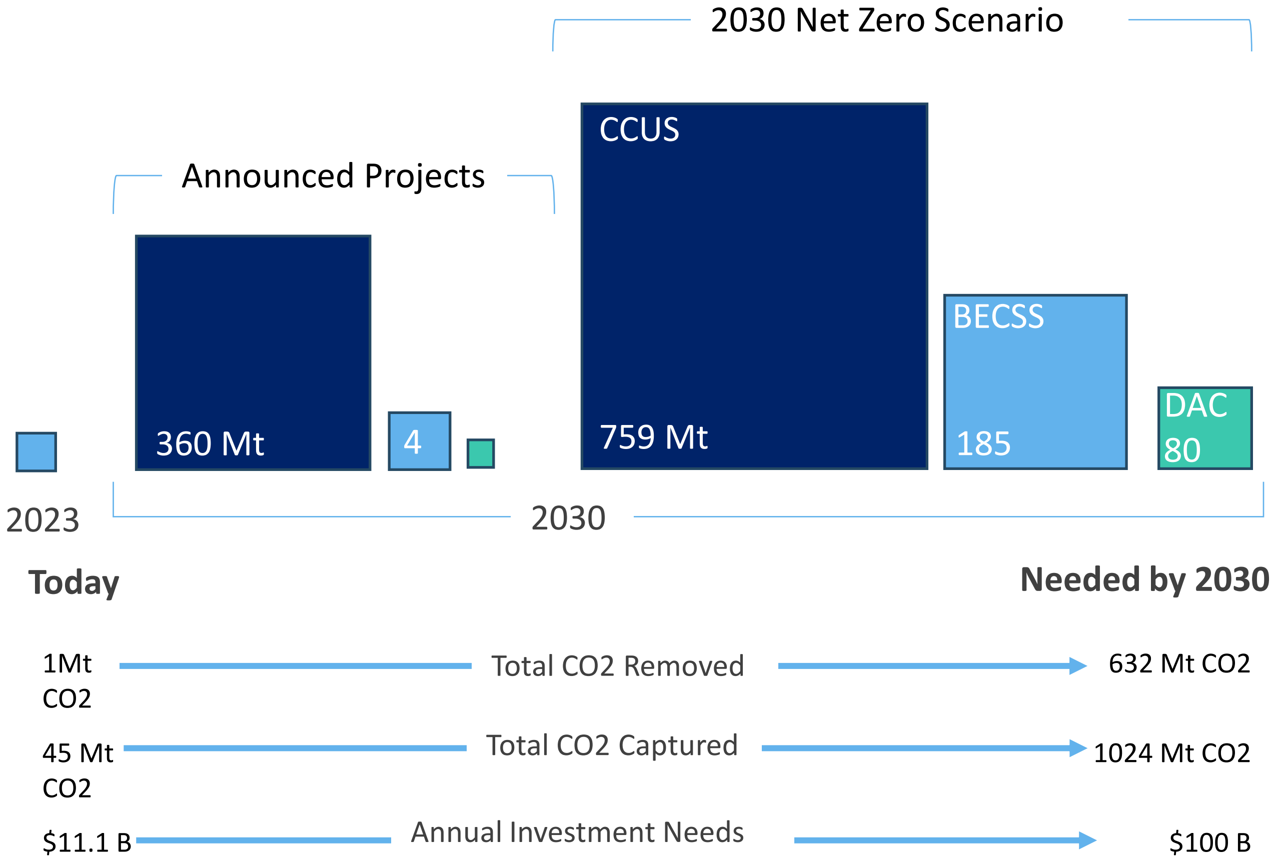
Today		Needed by 2030
1GW	Electrolysis Capacity	590 GW
5000 km	Hydrogen Pipelines	1900 km
11 Mt	CO2 Storage for Hydrogen	215 Mt
$10 B	Annual Investment Needs	$130 B

Source: IEA World Energy Outlook

Capacity to manage carbon emissions is expected to reach 1024Mt in 2030 (CCUS, BECSS, and DAC). Annual investment needs to grow to $100 billion by 2030.

- To get on the path for net zero in 2030, IEA estimates that 1024 Mt of CO2 must be captured, and approximately 632 Mt removed from atmosphere
- CCUS solutions are the primary investment area up to 2045, when investment in Direct Air Cabon capture becomes key.
- Total investment in 2030 across key technologies is estimated at $100 billion, with $20 billion in DAC

Carbon Management capacity and investment growth to 2030 for net zero path

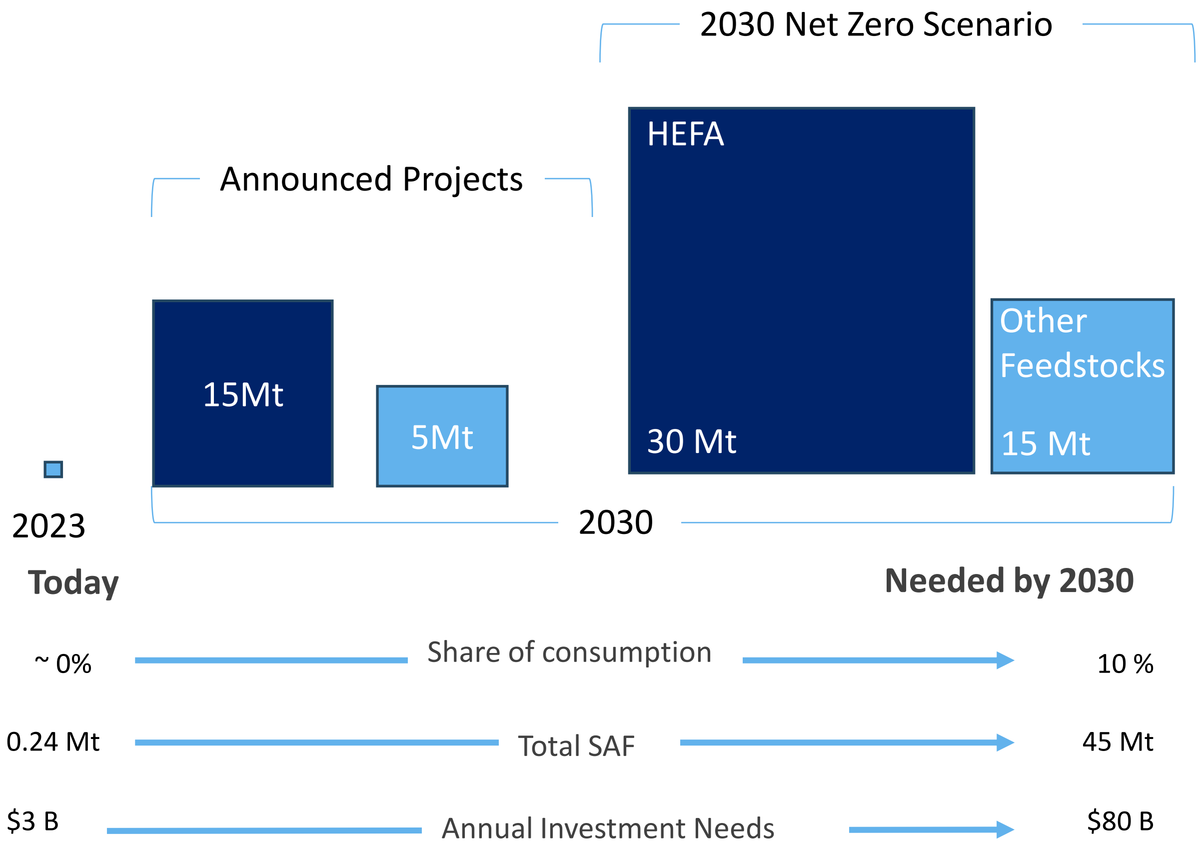


Source: LEK Research and Analysis, IEA

Sustainable aviation fuels are expected to scale to 45Mt in 2030 to meet SAF mix of 10% globally. It will equate to an annual investment growth up to $80 billion by 2030.

- To get on track for net-zero the globe needs to be at 10% SAF blend by 2030 which equates to 45 Mt (almost double of the 6% EU mandate)
- In the long term, aviation industry is targeting 65% SAF penetration by 2050. This will require >400MT p.a. of SAF capacity

SAF capacity and investment growth to 2030 for net zero path

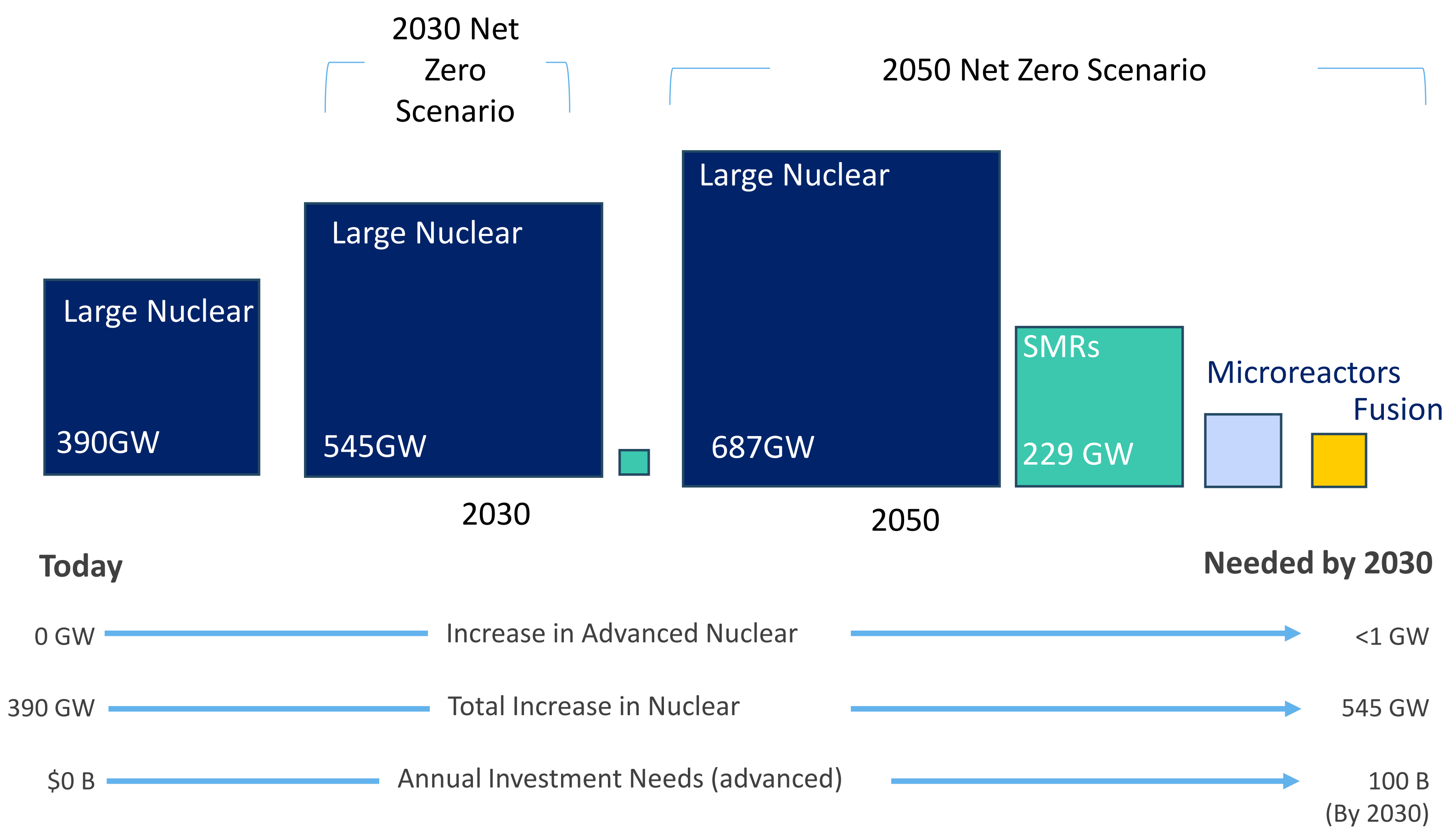


Source: Sustainability Together, ICAO

Advanced Nuclear capacity is expected to be commercialised by 2030, and thus will see a significant amount of investment and build out from then

- It is estimated that approximately 25% of new builds from 2030 will be small modular reactors
- Investment will scale in 2030 once reactors become purchasable
- Nuclear will need approximately 229GW of small modular reactors by 2050
- Fusion still has uncertainty with timelines, needing more evidence of commercial feasibility, with predictions ranging from 2030 all the way to 2050

Nuclear capacity and investment growth to 2030 for net zero path



Source: IEA, IDTechEx,

Technology Readiness

Timeline of deployment and existing facilities

Scaled deployments exist across energy storage, clean hydrogen, SAF and CCS - despite this there is a misconception that the technology readiness is the main issue

- There is an increasing number of plants that exist and are being commissioned in energy storage, clean hydrogen, SAF and CCS that demonstrate that technology exists
- Examples include Baofeng Project on clean hydrogen in China or Shutes Creek on Carbon Capture in US. Industrial scale storage facilities are being built almost routinely now, for examples Moss Landing in US
- Advanced nuclear solutions are often seen as less mature, even though technologies behind small modular reactors, for instance, have been around for decades

Facilities already in operation

Caption: Existing advanced energy plants in operation: (Clockwise from top left: DAC facility, Orca; Battery Storage, Moss Landing; Carbon Capture, Shutes Creek; Clean Hydrogen, Baofeng Project)

Source: Exxon, Baofeng, Climeworks, Vistra

Large scale battery storage projects are already in operation, with many more in the pipeline. Long duration storage however needs to mature to commercialisation

Moss Landing battery storage project is at the retired power plant site

California solar-plus-storage project with world's largest BESS fully online in Jan 24

Moss Landing
3,000 MWh, previously the largest in the world

Significant improvements in short duration
Commercialization of advanced battery technology such as solid state

2024 | 2030 | 2040 | 2050

Deploy with existing technology - - - - - - - Deploy Innovation

Edwards & Sanborn Solar Project
3,287 MWh becomes largest plant in the world

Deployment at scale
170 GW of grid scale storage is added to be on the path for net zero

Deployment of Long Duration Storage
Technologies such as metal to air and other longer duration storage systems come online

Seasonal Storage
Seasonal storage delivered through hydrogen or other. California alone could need 45-55 GW of long-duration energy storage

Source: LEK Research and Analysis

Large scale hydrogen facilities are already in operation, demonstrating that the technology exists.

Ningxia Baofeng Energy Group is powered by a 200MW solar array with 150 MW Alkaline electrolyser capacity

Air Liquide, 20MW plant in Canada produces about 3000 tonnes of green hydrogen a year

Source: LEK Research and Analysis

Deploy with existing technology - - - - - - - Deploy Innovation

2024 — 2030 — 2040 — 2050

Ningxia Baofeng Group

Worlds largest clean hydrogen facility, capable of producing 27,000 tonnes per annum

Air Liquide

200 MW plant in Canada is online, producing 2000 tonnes per annum

SOEC Technology cost competitive

Solid Oxide Electrolyser Cell will be commercialized

Commercialization of Advanced Electrolysis Technology

Other more advanced technology in the electrolyser space such as AEM

Commercialization of pyrolysis and other

Disruptive technologies such as pyrolysis come to market, also supporting creation of carbon black

Full centralized hydrogen distribution system

The world starts to move away from industrial clusters to a centralized system

A number of large-scale CCUS plants exists in tandem with oil production. Most of new projects focuses in power generation, hydrogen production and a variety of new industries

Orca, biggest CO2 Direct Air Capture plant in the world starts operations in Iceland in 2021

Shute Creek – world's largest carbon capture facility sells CO2 for oil production, but vents unsold

Deploy with existing technology - - - - - - - Deploy Innovation

2024 | 2030 | 2040 | 2050

Orca

Direct air capture facility capable to remove 4,000 tons of CO_2 from the air each year

Large scale DAC facilities open

Oxy Blackrock JV due to come online in 2025

Schute Creek

Around 95% of Shute Creek's captured CO2 (≈ 114 MT) has been sold to oil companies for enhanced oil recovery (EOR)

Demand for CO2 increases

There becomes a clearer market for none EOR carbon, such as power to X.

CO2 infrastructure and pipelines build out

Transporting as much CO2 as possible to demand to reduce the amount that needs to be stored through a centralized system

Source: LEK Research and Analysis

Singapore refinery demonstrates SAF technology is ready, with large scale facilities planned to open in the near future. Longer term innovation needs to solve for cost and feedstock

Singapore home to world's largest production facility for jet fuel made from waste materials

World Energy teams with Air Products in new $2 billion SAF production project in California

Source: LEK Research and Analysis

Deploy with existing technology - - - - - - - Deploy Innovation

2024 – Singapore Refinery opens
1 Mt capacity plant based on the HEFA process

SAF Production plant opens in California
World Energy teams SAF production plant comes online

Largest FT plant online 2028
A 0.6 Mt capacity plant opens based on the Fischer Tropsch process

2030 – 10% SAF Blend Worldwide
Feedstocks are assured and production facilities are scaled across the globe

2040 – E-fuels commercialized
Advanced solutions such as Power to X become available

2050 – 65 % blend achieved
>400Mt p.a. in 2050 (compared to <0.1Mt p.a. in

Reactors based on small modular reactor technology exist, although full commercial deployment is not expected until 2030

Huaneng Group`s Small Modular Nuclear Reactor in Shidao Bay

The Akademik Lomonosov floating nuclear power plant commenced operations at the start of 2020

Source: LEK Research and Analysis

2024 | 2030 | 2040 | 2050

Deploy with existing technology - - - - - - - Deploy Innovation

China Huaneng Group
200 MW modular reactor in Shidao Bay feeds power into the grid

Microreactors Deployed
Very small reactors can be used to serve remote communities, mines

The Akademik Lomonosov
Worlds first operational reactor based on SMR technology is launched in 2020

SMR companies expect to deploy
Reactors have passed regulation and FOAK reactors are connected to the grid in nuclear nations

Next Wave of Deployment
Nuclear starts to be widely adopted amongst nontraditional nuclear organizations, such as data centers

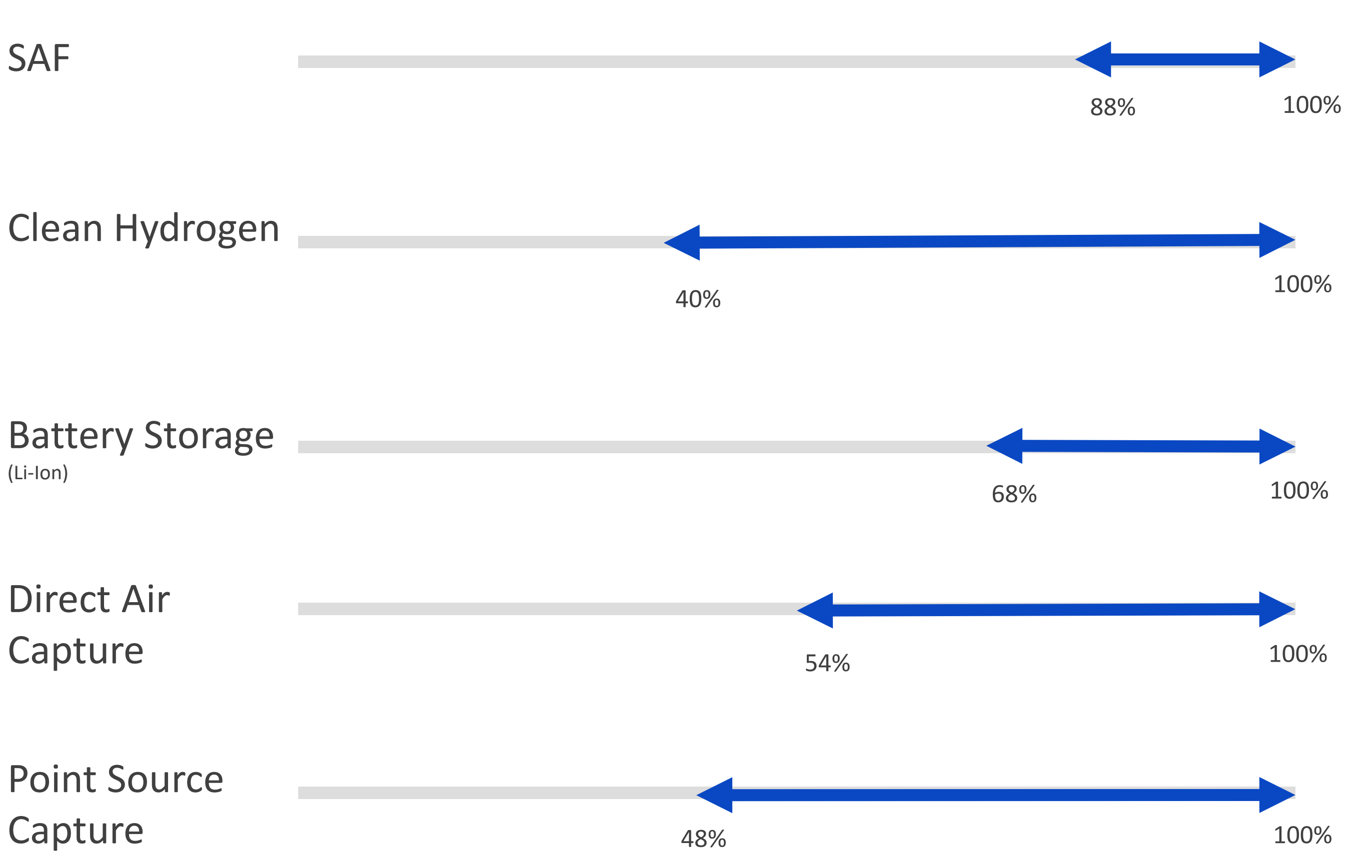
Commercial Fusion
Whilst demonstrator reactors could occur much earlier, commercial fusion expected to be 20 years away

Potential cost reduction

Cost analysis

Innovation combined with increasing scale and industrialization is expected to substantially lower costs by 2030, as has happened with wind and solar power.

Potential cost reductions by 2030 across key technology areas



Advanced energy solutions are going through intense innovation to drive down costs. Substantial improvements are expected

Clean electricity cost will remain a key variable that drives the competitiveness of advanced energy solutions. Clean hydrogen, SAF and carbon management technologies require large amounts of power, making their cost very sensitive to clean electricity prices

Similarly, the price of carbon is an important factor. It directly drives economic calculations for carbon management technologies like CCS and DAC. At the same time, the price of carbon improves advanced energy solutions cost competitiveness in comparison with high greenhouse gas emitting technologies

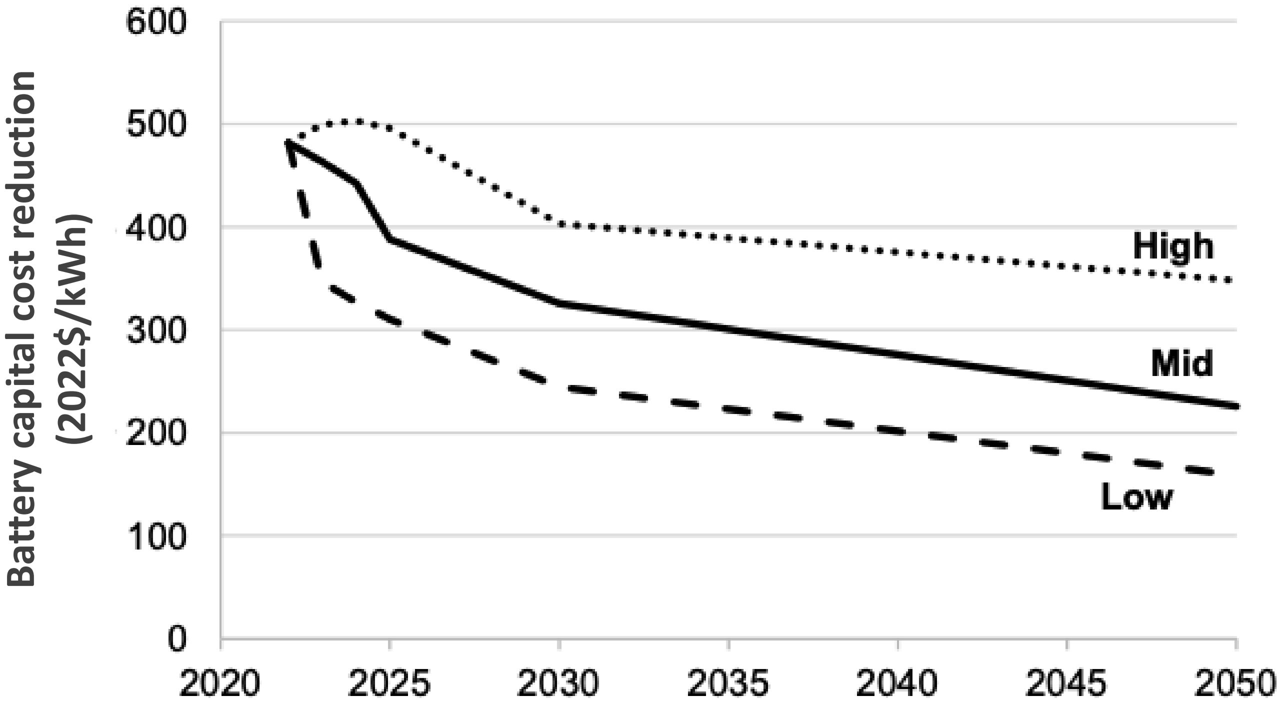
Source: IEA, Hydrogen Council, LEK Research and Analysis

Utility-scale battery storage costs are expected to decline up to 49% by 2030 in the most optimistic scenario for Li-ion by 2030

Projections show a wide range of storage costs, both in terms of current costs as well as future costs. Overall, the results show 16-49% capital cost reductions by 2030 and 28-67% cost reductions by 2050

In 2022, rising raw material and component prices led to the first increase in energy storage system costs since BNEF started its ESS cost survey in 2017. Costs are expected to remain high in 2023 before dropping in 2024

Reduction in battery capital cost for a 4 hour system, based on lithium-ion technology expected to 2050



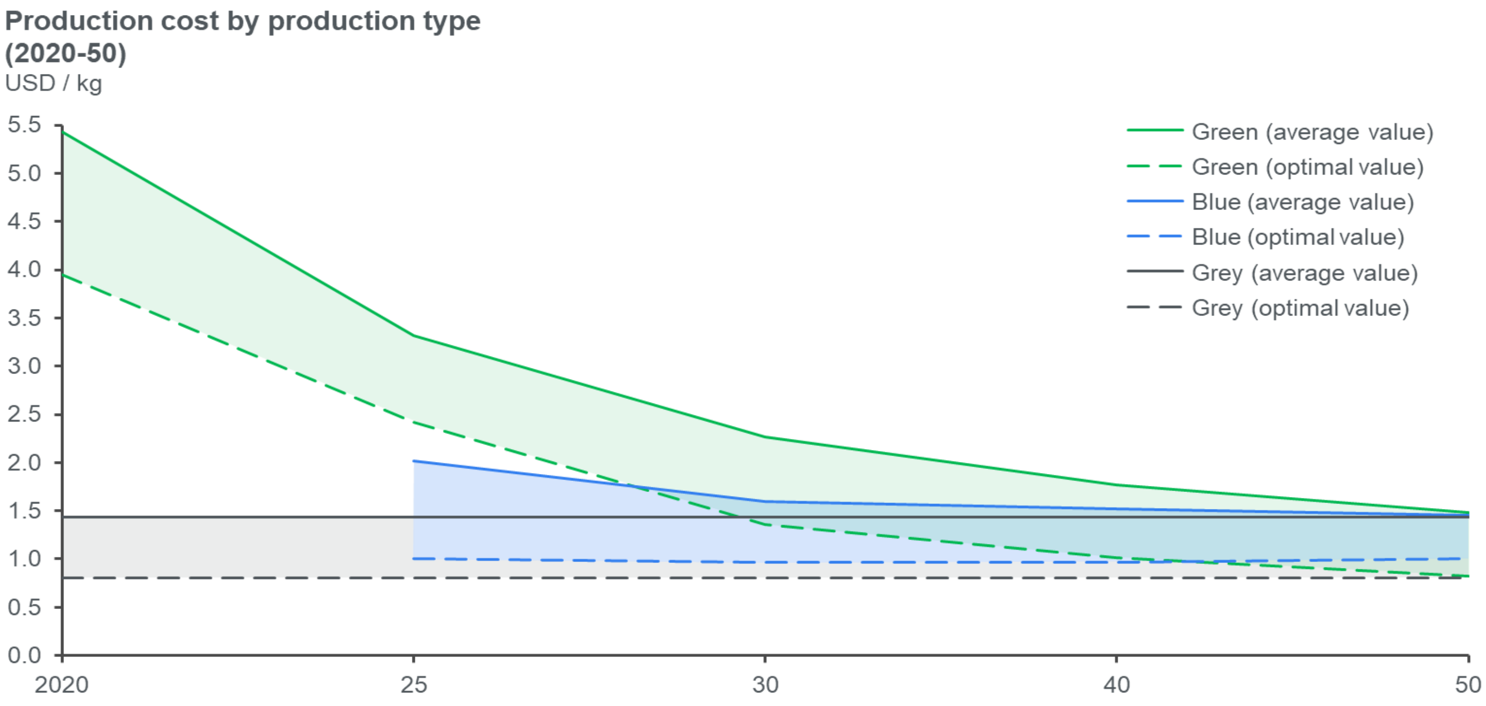
Source: US National Renewable Energy Laboratory (NREL), 2023

Clean hydrogen is forecasted to drop up to 60% from 2023 values, dependent heavily on the price of renewables.

Green hydrogen is expected to reduce by as much as 60% dependent on the scenario by 2030, with the cost of blue hydrogen expecting more modest drops

Green hydrogen is very heavily reliant on price of electricity, making up to 55% of the cost of production. Blue H2 cost expected to decline to be almost the levels of grey by 2030

Range of reduction in various types of hydrogen production cost expected to 2050



Notes: Assumptions: gas price of 2.6-6.8 USD / Mmbtu; LOCE USD / MWh 25-73 (2020), 13-37 (2030), and 7-25 (2050); Green hydrogen: dedicated renewable / electrolyser system, fully flexible production, scale up of renewable hydrogen production, and additional costs to reach end supply price; Blue hydrogen: development of carbon dioxide pipelines and at-scale sites, scale-up of low-carbon hydrogen production, and scale-up of CCS outside of hydrogen production

Source: Hydrogen Council (Hydrogen Insights Report, 2021)

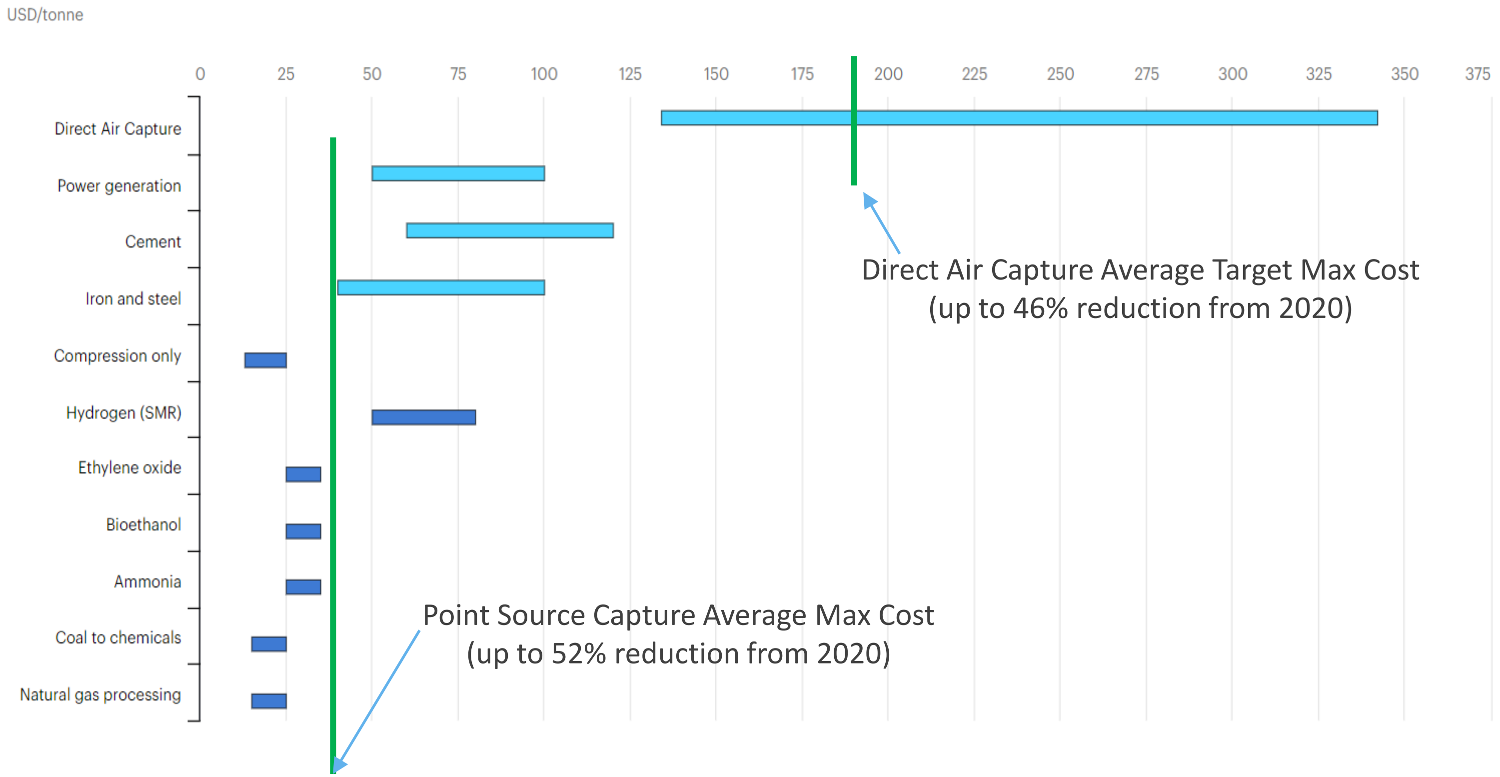
Carbon management technologies vary substantially on cost, related to the concentration of carbon dioxide being removed. Both DAC and CCUS have good opportunity for cost reduction

Point source capture is expected to drop 52% with Direct Air Capture dropping 46% dependent on concentration of CO2

The persistent high costs of CCS are attributed to high design complexity and the need for customization that limits the deployment of CCS. Many of these solutions are also energy intensive

In general, carbon capture costs less per tonne when concentration of CO2 at source is higher

Cost ranges for carbon capture technology related to different processes in USD/tonne for different carbon capture markets



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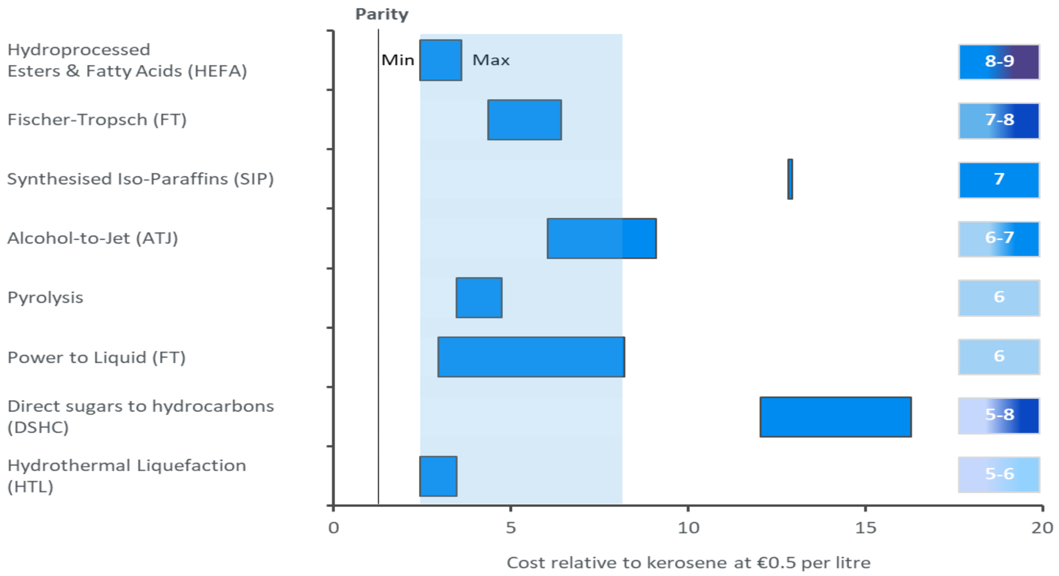
Source: Hydrogen Council (Hydrogen Insights Report, 2021)

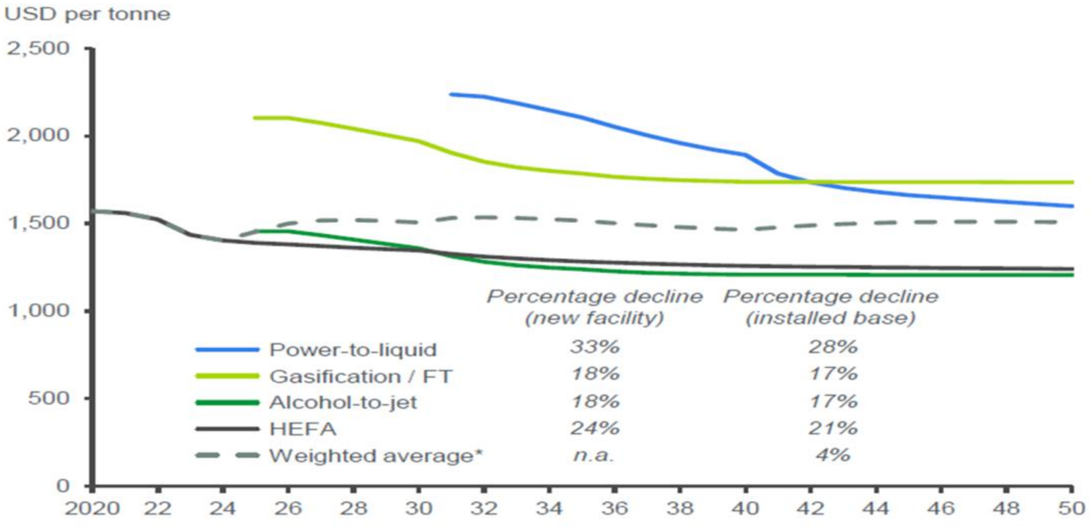
The cost of each individual SAF technology is expected to decline materially in the future, on average to about 22% by 2030; however, average weighted cost will remain high

Eu mandates require SAF blend of 2% in 2025, 6% in 2030, 65% in 2050. It helps drive scale now. However, as demand increases, and capacity scales to meet that demand, the mix of technology pathways deployed will gradually shift to higher cost technologies such as Gasification FT and ultimately PtL.

Current Estimated cost and TRL of SAF production method



Average levelised SAF production cost by method up to 2050

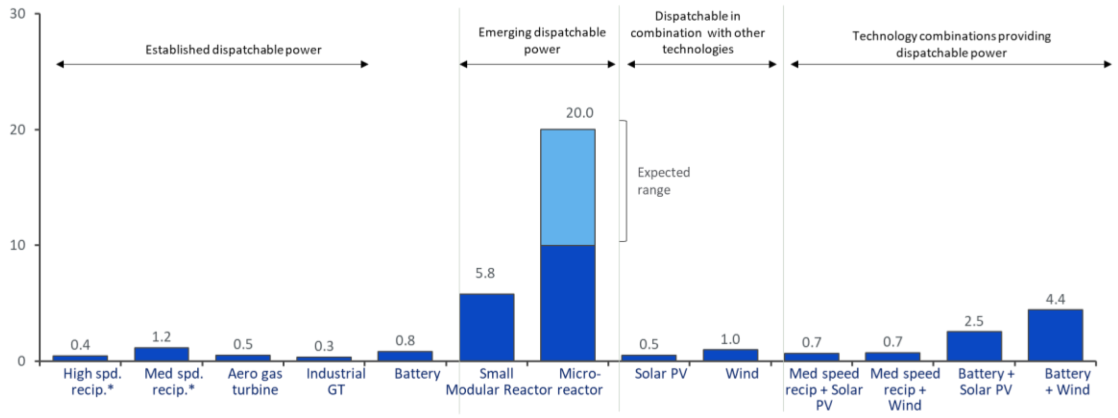


Source: LEK Research and Analysis

The cost of SMRs by 2030 averages to around $60 MWh with a comparatively high capex. Small modular reactors are expected to cost ~$2billion USD for a 300-400 MW reactor

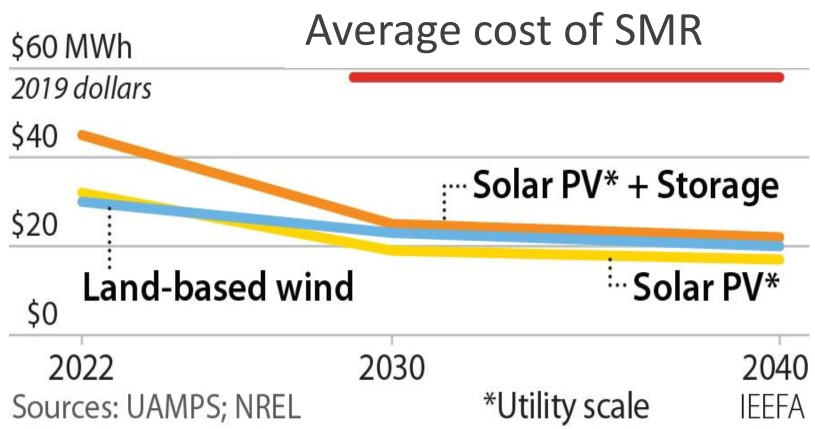
The average cost of Small Modular Reactors is expected to average out at around $60 MWh once it has been deployed in 2030s. There is expected to be minimal cost reduction improvements over the next decade.

Initial Unit Capacity Cost per MW (Millions GBP)



Graph shows the initial unit cost of nuclear to be significantly higher at 5.8 Million per MW and up to 20 million per MW for smaller micro reactors

Total Average Price of nuclear vs. Renewables



Average price of nuclear at around $60 MWh up to 2040, higher than renewables that are expected to see declines towards $20 MWh

Source: LEK Analysis, UAMPS, NREL, IEEFA

Business case

Making the business case work

Despite cost improvements, additional cost of advanced solutions will persist over the next decade when comparing various options solely on cost basis

Additional cost for business and end consumer

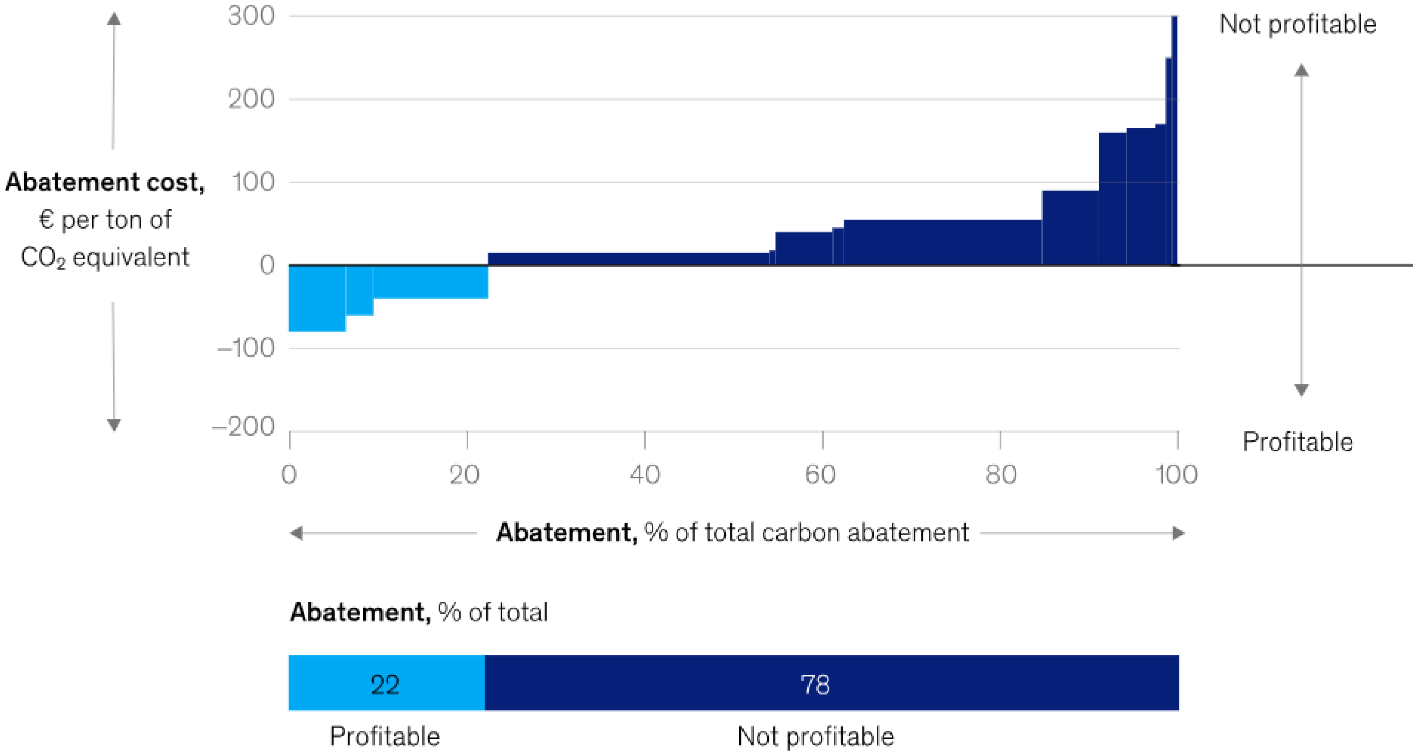
Industry	Advanced Energy Solution	Business Cost	Consumer Cost	
Aviation	SAF	+300% per tonne of fuel	+18% per passenger ticket	SAF is likely to remain 2-3 times more costly than kerosene by 2030. Covering this cost would increase the passenger price by 18% to reduce approximately 50% of flight emissions.
Steel	Clean Hydrogen	+350% per tonne of steel	+15% per house	Clean hydrogen would triple price of steel, which would be increase construction of housing by 15%
Cement	Carbon Capture	+50-85% per tonne of cement	+1-3% per house	The housing construction market would also be impacted by carbon capture that would be used to decarbonize the cement sector, resulting in an increase of up to 3% in cost
Electricity Grid	95% Decarbonised grid	+14 EUR Average household bill in Europe	+18USD Average household bill in USA	Decarbonizing Europe's power grid by 90 to 95 percent would cause electricity bills to go up roughly €14 per month for a typical household in the European Union. In the United States, it would cost an extra $18 per month for the average home

Source: World Economic Forum, Net Zero Tracker, EurElectric, LEK Research and analysis

Persisting additional cost needs to be addressed to create successful, commercially viable business cases.

- It needs to be established how the additional cost of green solutions will be met and distributed
- Profit margins usually would not be enough to cover this cost. For example, in the airline industry, profit margins are low on average with leading airlines rarely consistently hitting 10% margin. Much of this is tied into the price of the kerosene. When switching to SAF, airlines quickly become unprofitable
- Options primarily include government subsidies and consumers paying more. Philanthropic capital also plays a role to help minimize capital cost

Illustrative example of the how carbon abatement solutions erode profit margins



Source: McKinsey, Decarbonize and create value: How incumbents can tackle the steep challenge

Benefits like emissions reduction, public health, energy security, competitiveness and jobs must be valued and priced in

- Understanding the value of emissions and pollution reduction, better public health, improved industrial competitiveness and energy security will be instrumental to strengthening business cases

- One such practical approach can be observed in California in the United States. The state has launched a plan for carbon neutrality by 2045, including $48.3 billion from state funds additional to the Inflation Reduction Act.4

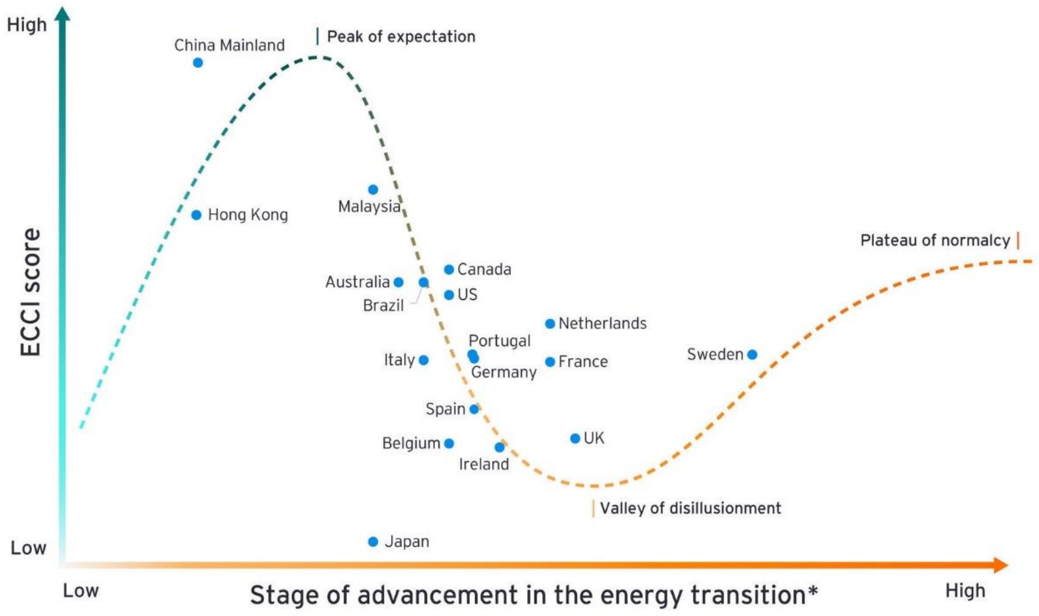
- The cost has been justified by redefining the value of clean solutions. In addition to neutralizing carbon, the plan factors in 71% reduction in air pollution, 4 million new jobs and $200 billion of savings in health costs

Source: California Air Board

Despite optimistic growth forecasts actual demand confidence remains low and long-term purchase agreements remain essential to the market

- Market studies and forecasts project exponential growth of advanced energy solutions
- Despite such robust market outlook, confidence in actual demand from industries and individuals remains low
- Purchase agreements and offtake contracts are often key levers for providing demand confidence
- Suppliers greatly need these demand signals to invest in production facilities, infrastructure, feedstock and materials. At the same time, purchasers are often unwilling to sign purchase agreements with "take or pay" obligations at current prices when prices are likely to fall in future

Energy transition Confidence curve



*WEF Energy Transition Index score.

The confidence curve illustrates how the more advanced nations in the energy transition, are currently in a plateau of disillusionment, which means there is a lack of confidence in the market. This lack of confidence transcends across the ecosystem, including purchasers, investors, public, and even policy makers

Source: WEF Energy Transition Index Score

Conclusions

It is not a technology readiness challenge by 2030. The challenge is primarily related to low level of confidence in the technology, the demand, the business case and by the public.

Many stakeholders recognize the need and opportunity but are not confident enough to move at the speed and scale that is required

Technological Confidence

- The increasing number of projects and plants that exist and are being commissioned in energy storage, clean hydrogen, SAF and CCS demonstrate that technology is up to the task
- Misconceptions over the technological readiness of many of these solutions continue to linger

Business Case Confidence

- To scale, every solution needs a viable business case. For advanced energy solutions, any business case must include clear mechanisms to cover additional costs
- It needs to be established how additional cost will be met and distributed through a range of options from government subsidies, consumers paying more to philanthropic capital

Demand Confidence

- Despite such robust market outlook, confidence in actual demand from industries and individuals remains low
- Demand confidence is necessary to justify investments in supply. Purchase agreements and offtake contracts are often key levers for providing demand confidence

Public Confidence

- For people to proactively embrace advanced technologies, the necessity, urgency and safety of advanced energy solutions need to be made clear, and misconceptions clarified
- Public support can help rapid scale-up. Much of the confidence in the public stems from gaining a better understanding of the value these solutions bring