

Marking ten years of *Nature Energy*

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This issue marks ten years of *Nature Energy*, offering a moment to reflect on a decade of energy research and to look ahead at what comes next.

Nature Energy was launched in January 2016, at a time when the United Nations Climate Change Conference (COP21) underscored the urgent need for a global energy transition. In the decade since, rapid advances in clean-energy technologies and integrated power-system transformation have reshaped how energy is produced, managed, and used. These developments have brought deep decarbonization closer, while also exposing new technical and socio-political challenges. In this issue, we bring together 13 leading experts, each contributing a World View article, to assess progress and identify the obstacles in key areas that will define the next phase of the transition.

Wind and solar photovoltaics are now key drivers of the global energy transition, reducing emissions and enhancing the resilience of power systems. Their growth in electricity generation has outpaced other sources.

Martin Green attributes the rapid rise of solar photovoltaics to falling costs driven by economies of scale and improvements in energy-conversion efficiency. Further expansion will depend on advances in high-efficiency photovoltaic technologies and appropriate grid adaptation.

Julie Lundquist identifies knowledge gaps for advancing wind power. These include understanding variability in wind speed and direction to better predict performance, mitigating turbulence to reduce structural loads, and improving extreme-event forecasting to design more resilient systems.

Alongside variable renewables, nuclear energy has recently regained attention as a low-carbon complement to intermittent generation. However, M. V. Ramana argues that high costs and long construction times remain barriers to wider deployment, highlighting the economic and practical challenges of scaling nuclear power.

As renewables penetration increases, system integration becomes ever more

important. Mark O’Malley reflects on how grids have adapted to variable renewables and evolving demands. These changes highlight the need to manage costs and reliability, expand infrastructure, address seasonal and technology-driven fluctuations, and foster cross-disciplinary collaboration to ensure a resilient integration.

Batteries and other storage technologies provide critical flexibility to balance supply and demand across daily and seasonal cycles, supporting grid operation. Peter Bruce discusses advances in lithium-ion technology, noting that continued electrification will require both further improvements to existing lithium-ion systems and progress in next-generation battery chemistries.

The growth in renewable power has also spurred greater interest in the electrification of chemical processes, such as hydrogen production via water electrolysis. However, as Sunita Satyapal discusses, despite technological developments in fuel cells and electrolyzers, investment volatility and policy changes mean that the future of the hydrogen industry is uncertain.

Continuing with electrifying chemical production, the field of CO₂ electrocatalysis – where CO₂ can be converted into a range of fuels and chemicals – has seen improved understanding of factors controlling catalytic activity and selectivity, alongside advances in reactor design and scale-up. Yet, many fundamental issues remain. Beatriz Roldan Cuenya argues that the next step is to further our understanding of catalyst deactivation processes and consider the structural dynamics of catalysts as a central part of their functionality.

Beyond advances in technology, the energy transition also depends on how energy is used in key applications, which will be critical for achieving deep decarbonization and meeting climate goals. Vapour compression cooling dominates air conditioning, but its liquid and vapour refrigerants are a significant source of greenhouse gas emissions. Ichiro Takeuchi highlights two solutions: adopting low-emission refrigerants, which requires better understanding of atmospheric interactions, and developing solid-state technologies, which must overcome cost and scaling challenges to become viable.

Another frontier in managing energy use is the urban environment, which requires coordinated planning, operation, and management of energy production, distribution, and consumption across transport, buildings, and other urban systems. Jinyue Yan describes persistence challenges, including coordinating energy in real time while maintaining system reliability, managing large volumes of energy data safely, creating fair ways to trade energy, and adapting solutions to the needs of different urban contexts. The growing role of artificial intelligence is highlighted as a key enabler for more effective coordination.

Road transport electrification has progressed rapidly, supported by significant improvements in battery storage, charging availability, and speeds. As highlighted by Patrick Plötz, continued growth will depend on how we tackle a range of behavioural, policy, grid infrastructure and sustainability challenges, such as an underdeveloped second-hand electric vehicle market, supply chain constraints, affordability, and grid-connection delays.

Energy justice is set to remain central to defining the success of the energy transition. As Destenie Nock outlines, incorporating equity metrics into established methods for assessing energy access, as well as pursuing inclusive decision-making processes and policy design, are critical measures to ensure a fair distribution of transition costs and benefits.

While technological innovation and strong commitment to energy justice are necessary for large-scale electrification, effective financing and supportive policy frameworks are essential to turn this potential into widespread adoption. However, Florian Egli explains that financial support for clean electricity is unevenly distributed, and there is a clear need for future research to focus on derisking financing, particularly in low- and middle-income countries.

In addition to reducing emissions through renewables and electrification, carbon capture technologies are emerging as a valuable tool for achieving climate goals. Advances – particularly in direct air capture of CO₂ – have moved the field from lab-scale material development towards full-system engineering. However, Jennifer Wilcox notes that political polarization and misunderstandings have

hampered progress. For carbon capture technologies to take a foothold, more strategic collaboration across academia, industry and government is needed.

Taken together, these experts' views show substantial progress across multiple fronts, as reflected in this Focus, though not exhaustively, and reveal recurring challenges in integrating technologies with systems and

society. As *Nature Energy* celebrates ten years of publishing, these accumulated insights highlight both how far the field has come and the work that remains to translate technical advances into real-world impact. The next phase of the energy transition will depend on continued technological progress as well as effective coordination across infrastructure, policy, and markets. Success will also

be defined by our ability to simultaneously address equity, financing, and political constraints. How effectively these challenges are tackled will determine whether the momentum of the last decade leads to lasting global decarbonization.

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