McKinsey & Company

# McKinsey Technology Trends Outlook 2022

## Future of clean energy

August 2022

# What is this trend about?

The clean-energy future is a trend toward **energy solutions that help achieve net-zero emissions** across the energy value chain, from **power generation** or production to **storage** to **distribution**

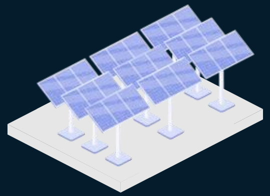
*Power generation*

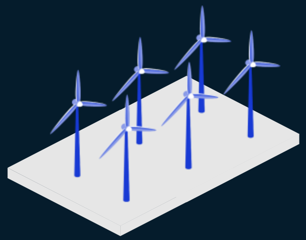
## Renewable energy

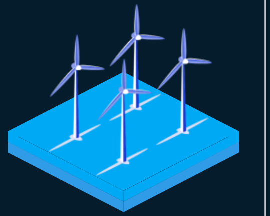
*Solar photovoltaics (PV) and thermo-solar, wind, geothermal, nuclear*

**About 84% of global power demand,** which is estimated to grow 3× by 2050, **can be met using renewable energy**

**Solar photovoltaics** are expected to cover **~60%, onshore wind** power generation to cover **~20%,** and **offshore wind** power generation to cover **~4%**







## Sustainable fuels

*Including biofuels*

Sustainable fuels could **decarbonize high-energy-density requirements** of aviation, maritime shipping, and heavy freight

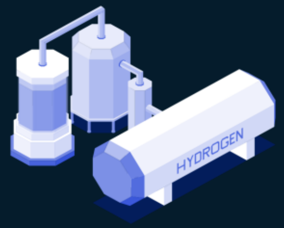
**Demand growth rate is expected to outpace that of fossil fuels**

**Limited capital is required to transition;** these “drop-in” fuels do not require upgrading existing engines

## Hydrogen ($H_2$)-based fuels

*Production of hydrogen as an energy source*

**Producing decarbonized hydrogen** (blue, using carbon capture; green, using renewable electricity) is projected to **cost less than producing conventional hydrogen** (gray, from natural gas) by 2030




Electrolyzers’ **critical role** in **unlocking demand for green hydrogen** is that they reduce the cost of production


Source: McKinsey analysis

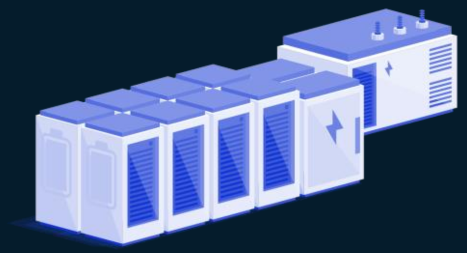
# What is this trend about? (continued)

*Power storage*

**Energy storage**
*Battery technologies, battery recycling/second use, long-term storage, gravity-based storage, etc*

## Stationary storage system

**Long-duration energy storage technologies** are expected to drive **~20% of renewables adoption,** enabling ~2.4 gigatons (Gt) of renewables abatement; **short- to mid-duration storage** is expected to **expand renewables penetration from 30–80%,** indirectly enabling up to ~6 Gt of abatement



*Power distribution*

**Energy optimization and distribution**

## Smart grid

**Advanced, intelligent electric grid system** could provide real-time insights and control for the distribution grid

**Increasing AI applications across smart grids** could leverage big data's potential (eg, improving accuracy of demand predictions)

## EV[1] charging infrastructure (EVCI)

**EVCIs compete primarily on charging time and cost,** with wide ranges in both: charge times range from ~8 hours to just 10 minutes, and prices range from €7,500 to €110,000

[1]Electric vehicle.

Source: McKinsey analysis

# Why should leaders pay attention?

## Overall trend

### Significant near-term value at stake

**~$2.4 trillion**

**Annual capital spending required in 2031–35** for the net-zero transition: $1.2 trillion in power generation, $1 trillion in the power grid, and $200 billion in energy storage in the NGFS[1] Net Zero 2050 scenario

### Bolder environmental regulation

**~20%**

**Increase of climate-related laws** and policies since 2020 in China, EU, and US[2]

### Increasing power demand

**~3.3×**

**Increase in global electric power demand in a 1.5°C scenario by 2050**

### Increasing corporate commitment

**>1,000**

**Number of companies** that in 2021 **set science-based targets** toward 1.5–2.0°C goals, growing by ~3× from 2020 and representing a market cap of ~$23 trillion

[1]Network for Greening the Financial System.
[2]Current number of policies is 11 in China, 17 in US, and 48 in EU.

Source: *Major risk or rosy opportunity: Are companies ready for climate change?,* CDP Worldwide, 2019; “Nuclear fusion market could achieve a $40 trillion valuation,” Bloomberg, Dec 28, 2021; *The net-zero transition: What it would cost, what it could bring*, McKinsey, Jan 2022; *Global energy perspective 2022*, McKinsey, Apr 2022; McKinsey analysis

# Why should leaders pay attention? (continued)

## Energy tech

### Renewable energy

**>80%**

Share of 2050 **global power demand** that could be generated by renewable energy, with solar PV generating ~43%, onshore windmills generating ~26%, and offshore windmills generating less than ~7%

### Sustainable fuels

**3.3×**

**Growth in sustainable fuels until 2035,** driven primarily by road transport, reaching 290 Mt in the Further Acceleration scenario, while aviation plays an increasingly important role thereafter

### Nuclear fusion

**>$4 billion**

**Investment across 35 nuclear fusion projects,** focused on tackling engineering challenges

### Energy storage

**~30% CAGR**

**Growth in battery demand by 2030,** driven mainly by electrification of mobility applications, which account for >90% of 2030 demand

### Energy storage

**30–60%**

**Decrease in battery prices expected by 2030;** however, offering bespoke battery solutions to fulfill segment-specific requirements presents profitable opportunity

Source: *Global energy perspective 2022*, McKinsey, Apr 2022; "Unlocking growth in battery cell manufacturing for electric vehicles," McKinsey, Oct 2021; *Major risk or rosy opportunity,* CDP Worldwide, 2019; *Science-based net-zero: Scaling urgent corporate climate action worldwide*, Science Based Targets initiative, June 2022; McKinsey analysis

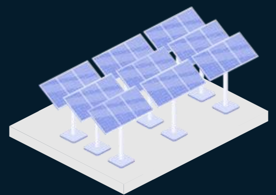
# What are the most noteworthy technologies?

## Renewable energy
*Solar PV and thermo-solar, wind, geothermal, nuclear*

### Solar photovoltaics (PV)

Maturity in tech has **driven down costs below costs of traditional fossil fuels** (ie, vs coal)

**Advancements** in 3rd-generation solar PVs are primarily **manipulating semiconducting materials** (organics[1] and perovskites[2]) at nano-scale to achieve higher efficiencies



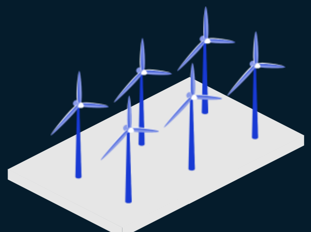
### On- and offshore wind generation

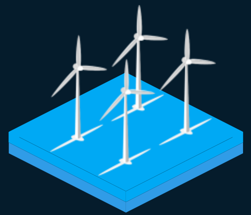
Wind power plants with larger rotors, blades, and height are better suited to **harvest lower wind speeds at higher altitudes**

Offshore plants (expected by 2025) face engineering challenges (eg, marine infra-structure); onshore turbines face nontechnical limits[3]

Wind turbines **mounted on floating structures** allow **power generation in water depths where bottom-mounted structures are not feasible**

Current global shift from single-turbine pilots to multiturbine projects is expected by 2025 or later

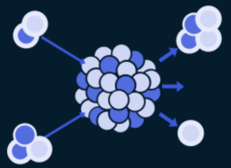




### Nuclear fusion

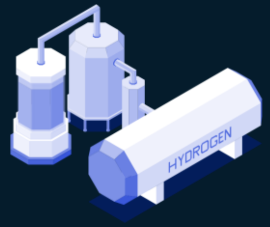
Fusion is the **process of combining atoms** under high temperatures and pressure **to release clean energy**

**Fusion power research is could yield commercially-viable plant within a decade**, driven by advancements in materials research and AI, with commercial launch of a nuclear fusion plant expected in the next decade[3]



## $H_2$-based fuels
*Production of hydrogen as an energy source*

**Primary methods for hydrogen production** are gray/brown (unsustainable, being replaced), blue (affordable, lower-carbon alternative), and green (zero carbon emissions) hydrogen[4]




### Electrolyzers

**Electrochemical energy conversion technologies convert water into green hydrogen** (sustainable energy source), with the only byproduct of the process being oxygen (ie, zero carbon emissions)


[1]Use of organic electronics for light absorption and charge transport. [2]Hybrid (organic-metallic) semiconductor material composition tweaked to absorb broader light spectrum. [3]Including transportation and infrastructure choke points, land use, view, birds, shadows, etc. [4]More mature technologies include water electrolysis and steam reforming of biomethane/biogas with or without carbon capture and utilization/storage. Others include biomass gasification/pyrolysis, thermochemical water splitting, etc.

Source: Andy Ridgway, "Why the promise of nuclear fusion is no longer a pipe dream," *BBC Science Focus*, Dec 3, 2021; Philip Ball, "The chase for fusion energy," *Nature*, Nov 17, 2021; *The global fusion industry in 2021*, Fusion Industry Association and UK Atomic Energy Authority, Oct 2021; McKinsey analysis

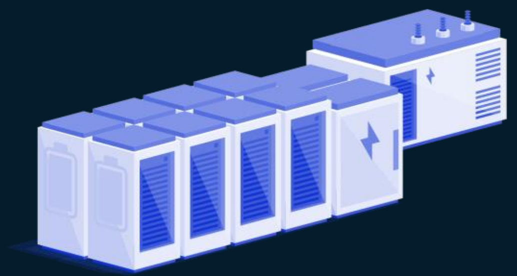
# What are the most noteworthy technologies? (continued)

## Energy storage
*Battery tech, recycling, second use, long-term storage, gravity-based energy storage, etc.*

### Battery storage system

**Lithium-ion batteries' price declined >90% in past decade**, and they can only shift energy for **<8 hours** without becoming very expensive and incurring issues with their high self-discharge rate

**Other solutions** (ie, long-duration energy storage, gravity-based energy storage) are **required for weeks or months of storage**



## Energy distribution

### EV-charging infrastructure (EVCI)

**Extensive networks of stations boost the accessibility** and **speed of recharging EV batteries**

**EVCI hardware** includes grid and site electrical upgrades, on-site energy storage, and charger unit

**EVCI software and services** include energy management, electrical installation, operations and maintenance, and customer apps

### Smart grid

**A smart grid is an advanced, intelligent electric-grid system** that can provide real-time insights and control for the distribution grid

Source: McKinsey analysis

# What disruptions could renewable energy enable in the electric power, natural gas, and utilities industry?

| Technology | Capabilities required |
|---|---|
| **Solar PV** | Cost-efficient manufacturability with improved stability/reliability would **accelerate scaling of solar panels** globally |
| **On- and offshore wind generation** | Ability to generate power efficiently **in low-wind scenarios** could unlock new sites for wind energy |
| **Long-duration energy storage** | **More efficient energy storage capabilities are required,** given increased solar and wind power generation; often, power demand and supply don’t match simultaneously, especially in “off seasons” when solar or wind farms produce little energy |
| **Smart grid** | **Changes to grid operation and infrastructure** to **optimize supply-side responses to demand in real time;** eg, augmented integration of distributed renewable energy resources and reduced reliance on fossil fuels |

Source: *Global energy perspective 2022*, McKinsey, Apr 2022; McKinsey analysis

## Key disruptions enabled

**Net-zero power**
Targets set by developed economies for 2040 and by emerging economies for 2050

**80–90%**
Share of 2050 global energy mix to be sourced from renewable generation

**8×**
Growth in annual solar PV capacity installations (gigawatts per year) from 2020 to 2030 in a 1.5ºC pathway

**5×**
Growth in power generated via onshore wind energy from 2016 to 2030

**Access deep-water regions**
Ability to access new sites (where water depth is ≥60 meters) for development of offshore wind parks by not requiring solid foundation

# What disruptions could hydrogen enable in the electric power, natural gas, and utilities industry?

| Technology | Capabilities required |
|---|---|
| **Hydrogen-based fuels** | **Drastic reductions in production costs, coupled with infrastructure development** (to enable adoption), are required to scale hydrogen production across a wider set of applications |
| | **Lower production costs of electrolyzers must be paired with higher efficiency** to improve hydrogen density, purity, lifetime, etc |
| | **Dispatchable electrolyzers** will allow for the **integration of more intermittent renewable energy** sources in the system |

**Additional enablers** include greater regulatory clarity, government decarbonization commitments,[1] and deployment of transport and storage infrastructure

[1]About 40 countries already have dedicated hydrogen strategies in place (eg, French government's target of 10% green hydrogen use in industry for 2022 and 20–40% for 2027).

Source: *Global energy perspective 2022*, McKinsey, Apr 2022

## Key disruptions enabled

**~28%**

**Share of final energy consumption** could be met by green hydrogen by **2050**

**5×**

Growth in hydrogen demand by 2050, driven primarily by road transport, maritime, and aviation

**~0.5 Gt**

Carbon abatement by 2030, reaching 2.5 Gt by 2050, which is particularly critical for some hard-to-abate sectors (eg, iron and steel production, chemical and refining, long-haul trucks, cargo ships)

**~65%**

Share of hydrogen supply mix coming from green hydrogen by 2035—and up to ~80% by 2050

# What other industries are most affected by the trend?

Other industries are experiencing **implications** of clean-energy tech, primarily focused on **supporting the clean-energy transition**, meeting **changes in resource demand**, and **shifting value pools**

| Industry affected | Implications of technology trend |
|---|---|
| **Metals and mining** | **Growing demand for specific raw materials** (eg, copper for electrification, lithium and cobalt for batteries) |
| **Oil and gas** | **Decarbonizing upstream operations** and **exploring alternative low-carbon technologies and shifting value pools** (eg, hydrogen) by leveraging strengths in access to capital and operational expertise |
| **Construction and building materials** | **Constructing additional transmission and distribution infrastructure** to enable the delivery of electricity generated by renewable sources to where it is demanded |
| **Chemicals** | **Increasing demand for chemicals needed for the production of renewables** (eg, silicon for the development of photovoltaic cells) |
| **Public and social sectors** | **Prioritizing clean energy on governments' agendas** by providing greater **regulatory clarity**, government **decarbonization commitments, investment incentives**, among other actions |

The construction industry is involved in **decommissioning fossil-fuel assets** (eg, coal mines, fossil-fuel power plants) and **environmental remediation of industrial sites** and infrastructure for the energy and utilities, oil and gas, and mining sectors

Source: McKinsey analysis

# Who has successfully created impact with clean-energy technologies?

| Industry | | Case example |
|---|---|---|
|  | **Electric power, natural gas, and utilities** | **Ørsted, a Danish energy company,** committed to **reducing greenhouse-gas emissions from energy production by 96%** from 2006 to 2023 through building >**1,000 offshore wind turbines**, **reducing** offshore wind **technology costs by >60%** since 2012, and **reducing coal consumption by 82%** in power stations since 2006 by switching to sustainable biomass, among other actions. Ørsted also divested its oil and gas business to focus on expanding its international renewable energy operations |
| | | **Iberdrola, one of the world's largest utilities** (by market cap), aims to **reduce all emissions 43% by 2030** (from 2017) and **achieve carbon neutrality** in Europe by 2030 and globally by 2050; key actions include **drastically increasing renewable capacity** and increasing investments in **smart grids** and **green hydrogen** for industrial use |

Source: Company websites; Science Based Targets initiative

# What uncertainties must be resolved for the trend to achieve scale?

Not exhaustive

## Renewables

**Cost-efficient manufacturability** is required to accelerate scaling of solar-power and wind generation tech

**Higher capacity, stability, and reliability** are needed in solar PVs and on- and offshore wind generation plants

**Supply chain risks** persist amid global economic uncertainties

## Hydrogen production

**Significant cost reductions** in green hydrogen production (eg, electrolyzers) are needed to scale

**Higher production efficiency in electrolyzers** is crucial to improve hydrogen density, purity, and lifetime

**Hydrogen use is currently confined to a few sectors,** pending wider applications

The **slow pace of infrastructure development** inhibits adoption

## Electrification

**High production costs** (eg, EV battery pack currently is 30–40% of total EV cost) are expected to drop as consumer demand accelerates by 2030, unlocking economies of scale

**Current limited distribution of EV-charging infrastructure** needs scaling to accelerate EV adoption

## Energy storage/smart grids

**Long-duration energy storage technologies remain under R&D**, requiring major leaps in the short run and continuous innovation in the long run to optimize costs and storage duration

**Smart grids face integration, costly installation, and deployment challenges** that require further research investments

**Overarching uncertainties** include supply chain risks amid global economic uncertainties, as well as insufficient regulatory clarity on decarbonization commitments, renewable-energy requirements, and uncertain carbon pricing

Source: McKinsey analysis

# What are some topics of debate related to the trend?

**Not exhaustive**

| | 1. Will traditional renewables be outpaced by newer technologies? | 2. Is it feasible to switch to 100% renewable energy? | 3. Will business opportunities in clean tech continue to grow? |
|---|---|---|---|
| **Supportive view** | • Solar and wind renewables are **"battle tested,"** with **clear business case and cost advantage**<br>• Solar and wind **capacity is expanding**<br>• Solar and wind **costs are decreasing** every year | • The long-term **cost** of renewable energy is **competitive or lower** than today's energy sources<br>• Solar, wind, and geothermal **capacity is expanding** every year<br>• Fossil fuels have both **environmental costs and national security** risks in some countries | • **The global consensus** is for clean energy, with initiatives beyond investing (eg, emission penalties, mine shutdowns)<br>• **B2C market is growing** as consumers increasingly favor sustainable products<br>• **B2B market is growing** as businesses are anticipating sustainability regulations and seeking energy and cost savings |
| **Opposing view** | • **Hydrogen** is attracting significant investments and already has commercialized use cases<br>• **Nuclear** power could become more attractive, thanks to new yet untested designs that would reduce environmental and national-security risks<br>• **Fusion** power may or may not become scalable in the foreseeable future | • Most renewable energy sources are intermittent; therefore, **storage systems remain a bottleneck**<br>• In some **countries,** 100% renewable energy is **more difficult to achieve,** since it depends on one's resources<br>• **Political forces** and incumbent players **may stifle** the transition | • Many tech projects remain **costly in terms of capital expenditures** and bear high execution risks<br>• Some technologies will prove to be more effective than others; **not all clean tech will remain** viable<br>• In **2006–11**, a **clean-energy bubble burst** |

Source: McKinsey analysis

# Additional resources

## Knowledge centers

Insights on the net-zero transition

Innovate to net zero

## Related reading

Global energy perspective 2022

The net-zero transition: What it would cost, what it could bring

An AI power play: Fueling the next wave of innovation in the energy sector

Decarbonizing the world's industries: A net-zero guide for nine key sectors

Failure is not an option: Increasing the chances of achieving net zero