碳排放约束及多重危机叠加时代的清洁能源技术创新
Clean energy innovation in an increasingly carbon-constrained world disrupted by poly-crises

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博众智合能源转型论坛 | Agora Energy Transition China

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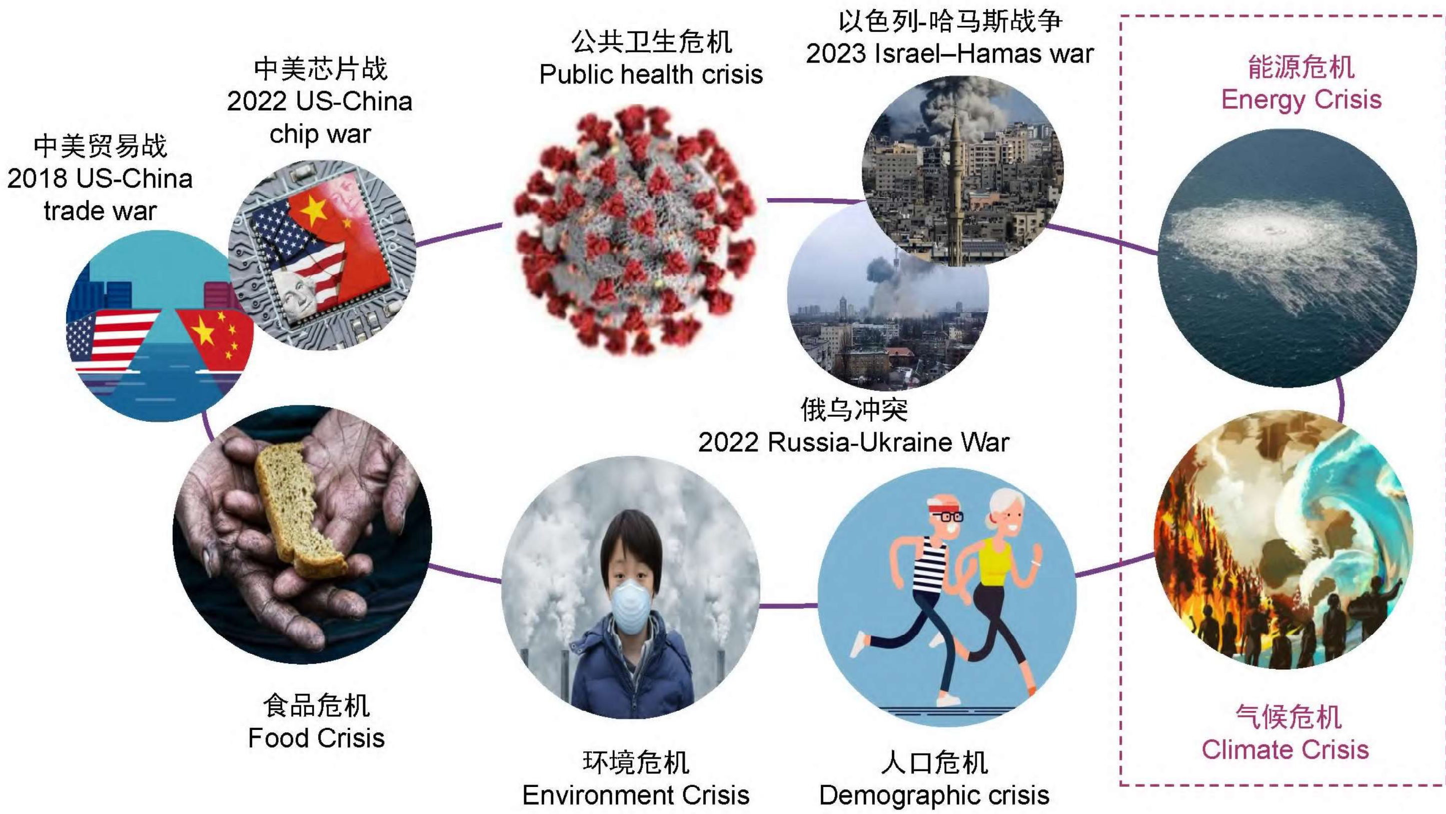
讲座大纲 Outline

人类社会正面临诸多危机与冲突的挑战 A world disrupted by multiple crises



Records derived from ice core measurements show that average global CO2 concentration in the atmosphere for 1750 to 1800 was around 278 ppm, the new record in 2023: 419.3 ppm.

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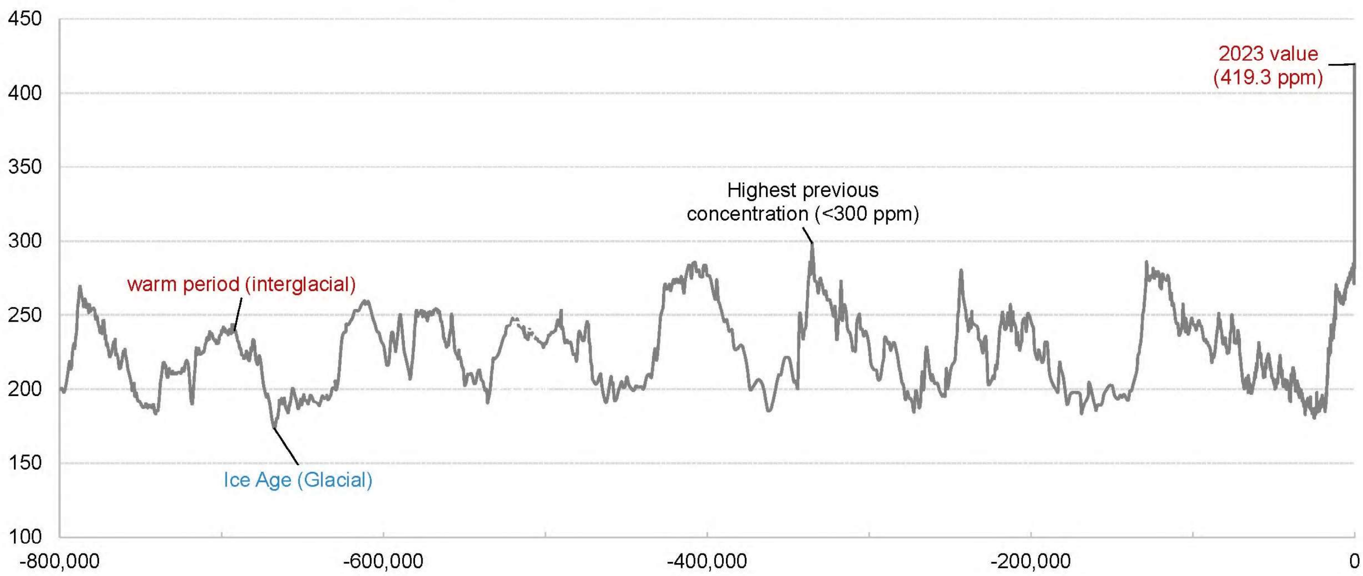
Carbon dioxide concentrations in the atmosphere



Source: NOAA, Our World in Data.

Climate crisis: global average temperature anomalies in 2023 are 1.19 ℃ higher than the 20th century average, reaching record level since 1880

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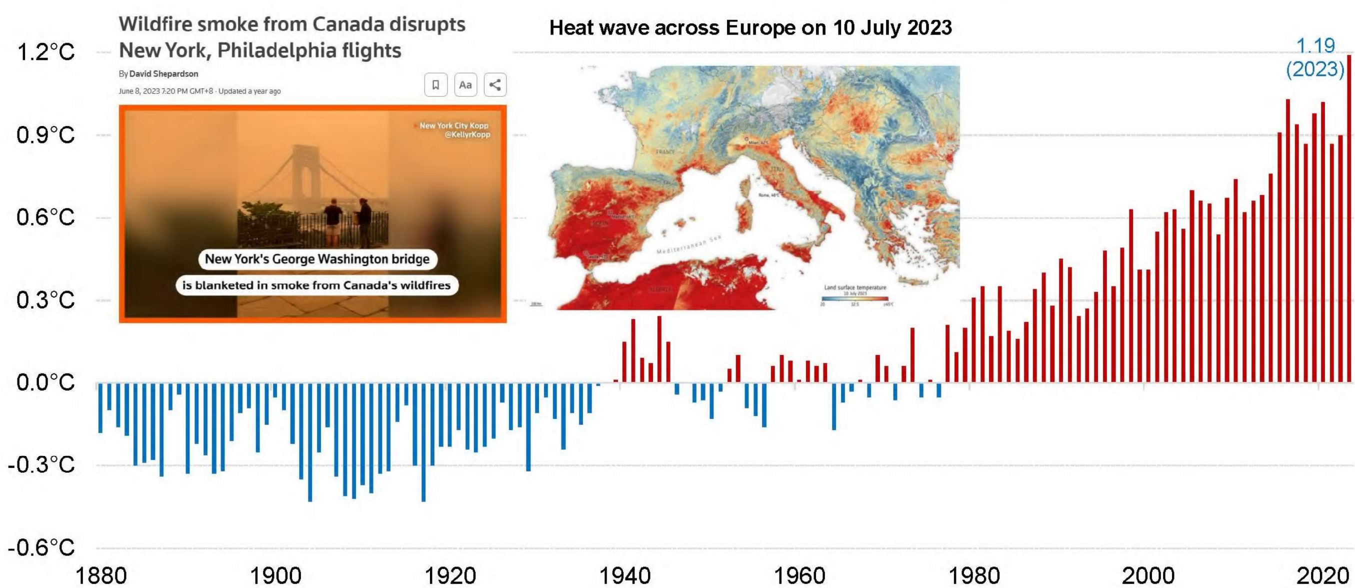
Global land and ocean Jan-Dec average temperature anomalies



Source: NOAA; Reuters, 8 June 2023; European Space Agency, 13 July 2023.

Potential impacts of global warming

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Overview of global temperature rise

Temp. rise	
1°C	Coral reefs already in serious danger. The increase in extreme weather events such as flooding, hurricane etc.
2°	Melting of north pole, Polar bears would probably become rapidly extinct.
3°C	Drought will be permanent in the sub-tropics and Central America. Many plant species will become extinct.
4°C	rise sea level changes would be irreversible, would see a collapse of civilization, leading to conflicts worldwide.
5°C	Habitable areas will shrink towards the poles: No ice sheets remain, no rain forests left......
6°C	Sea levels could be 20 m higher. The human species may survive but it is by no means certain.

Source: Six degree: our future on a hotter planet.

能源转型的历史规律 The laws governing historical energy transitions

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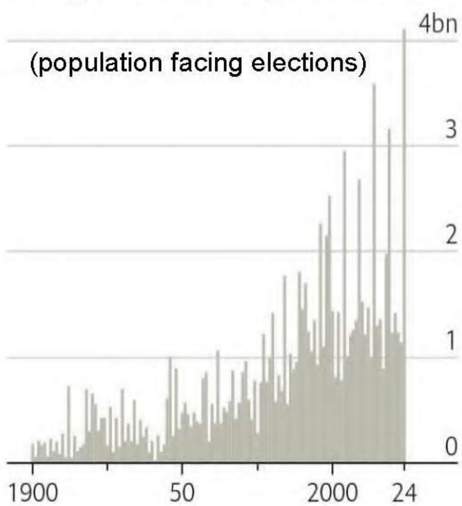
充满不确定性的2024年 Keyword in 2024: volatility

2024年是全球超级大选年
A super election year in 2024



Source: The Economist, 3 Nov 2023

川普如果再次当选的深远影响
Implications of a second Trump presidency

Source: The Times, 30 Dec 2023.

全球能源气候合作需要克服地缘政治的干扰。Prospects of international collaboration on energy transition and climate change become increasingly uncertain amid rising geopolitcal tensions.

The politics of energy security: as US policy towards China shifts from tariffs to tech & investment restrictions, China's political priority shifts from maintaining economic growth to ensuring security especially national energy security

- Tariffs on China imposed during the Trump Administration are likely here to stay

Source: US Census Bureau, BLS, Goldman Sachs GIR.

US revokes licences for supply of chips to China's Huawei

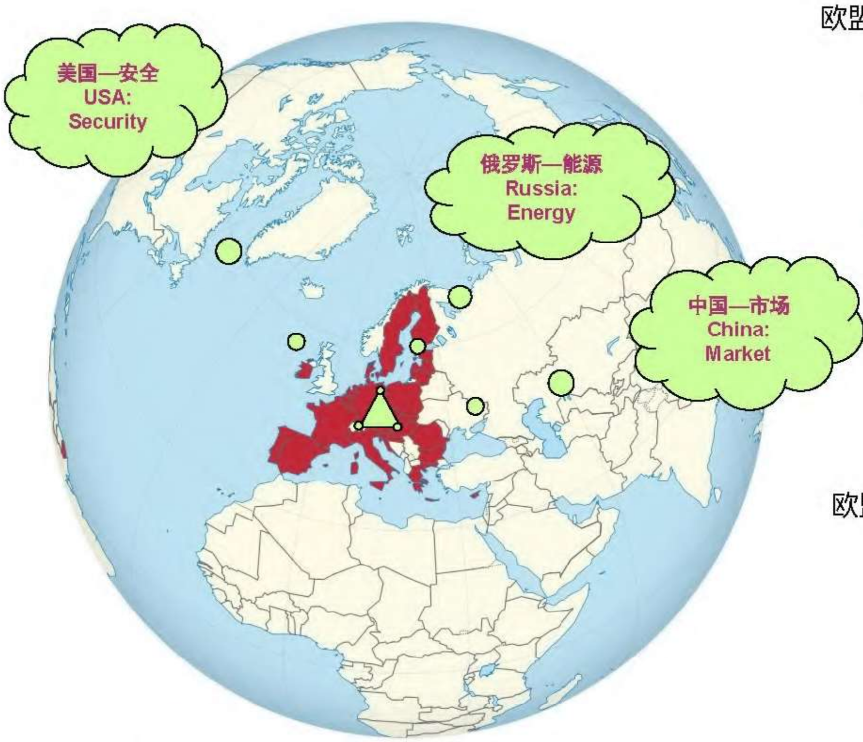
Move marks Biden administration's latest effort to target Chinese tech sector

A Huawei store in Shanghai © Qilai Shen/Bloomberg

Demetri Sevastopulo in Washington

Source: Financial Times, 8 May 2024.

欧盟正处于十字路口 The European Union at a Crossroads



Source: EU Foreign Affairs and Security Policy, 10 October 2022.

欧盟繁荣的三大支柱 The three pillars of EU prosperity

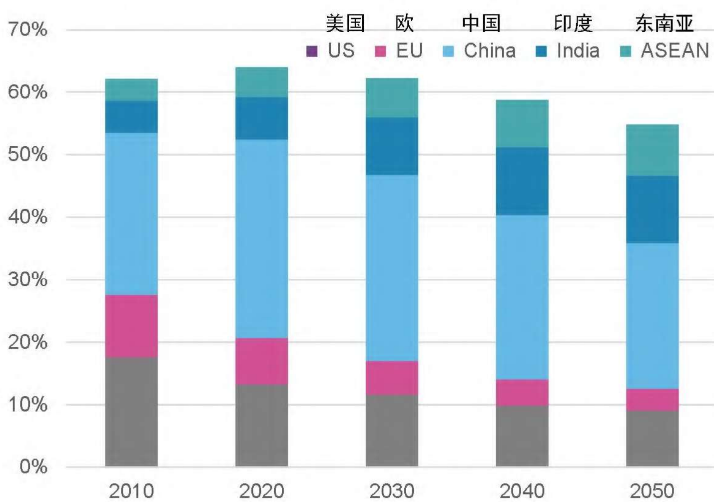
- 俄罗斯的能源 The urgent need to diversify energy supply away from Russia due to Russia-Ukraine War
- 中国的市场 The access to China is becoming more and more difficult
- 美国的安全保护 What would have happened if, instead of [Joe] Biden, it would have been [Donald] Trump or someone like him in the White House?

欧盟的中国政策 EU's China policy since March 2019

- 合作或谈判伙伴 Cooperation or negotiating partner
- 经济竞争者 Economic competitor
- 制度性对手 Systemic rival

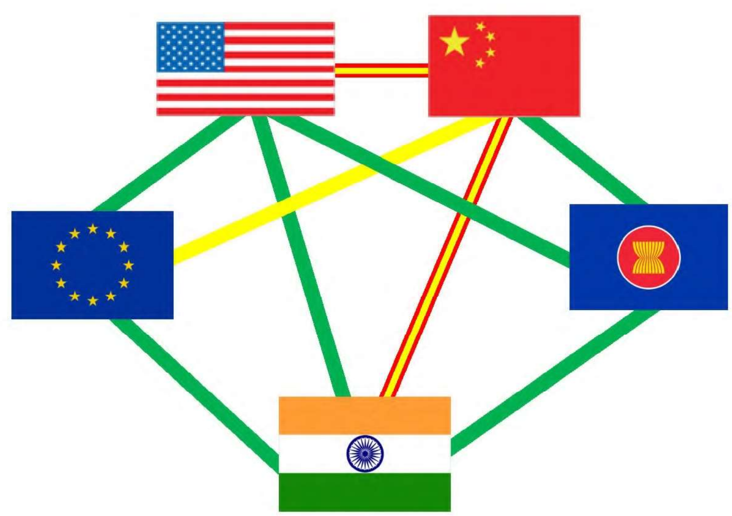
在多重危机的大背景下，中、欧、东南亚有必要进一步深化三方在能源转型和气候变化等领域的合作 In the era of poly-crises, the EU, China and ASEAN economies should explore trilateral engagement in areas of energy transition, climate change and beyond

前五大排放经济体的全球碳排放占比
Share of global emissions by C5 economy

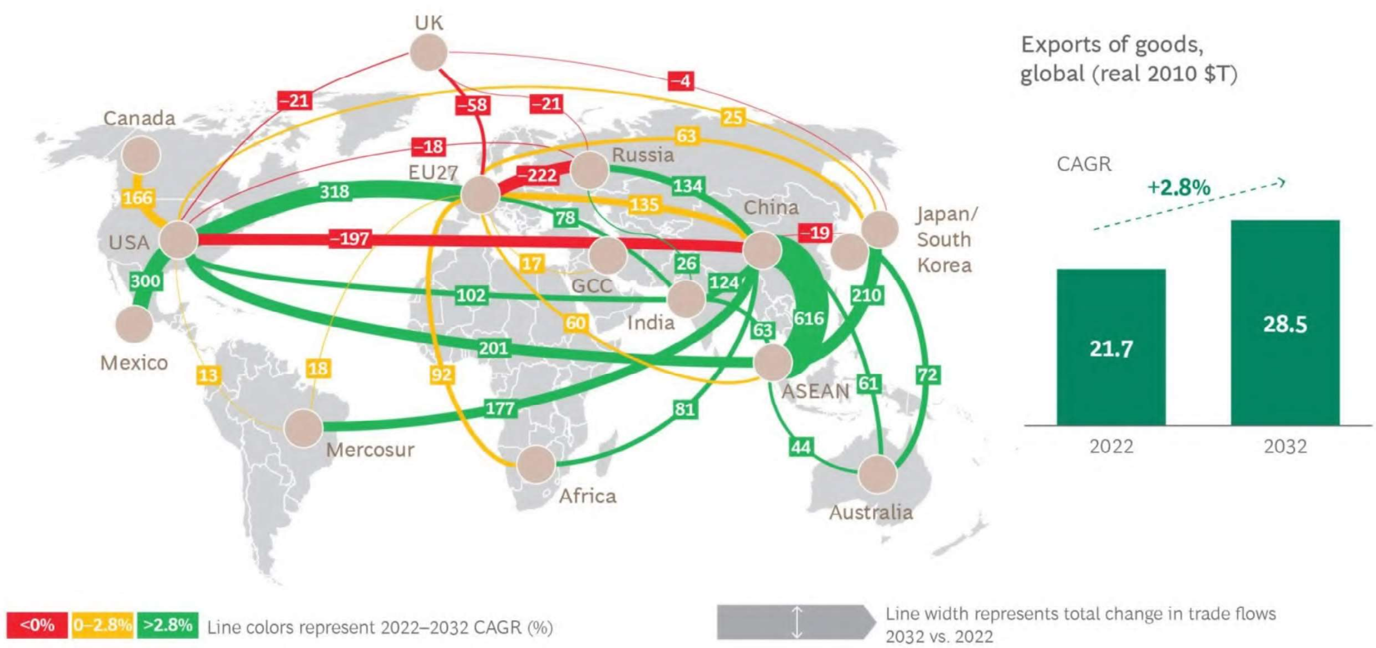


Source: World Energy Outlook 2021.

C5经济体双边关系图
Relations among C5 economies



Reshape of global trade flow by 2032 as a result of de-risking of supply chain: China-West differences cause trade barriers to persist and divert trade flow to other corridors especially ASEAN, and fellow BRICs.

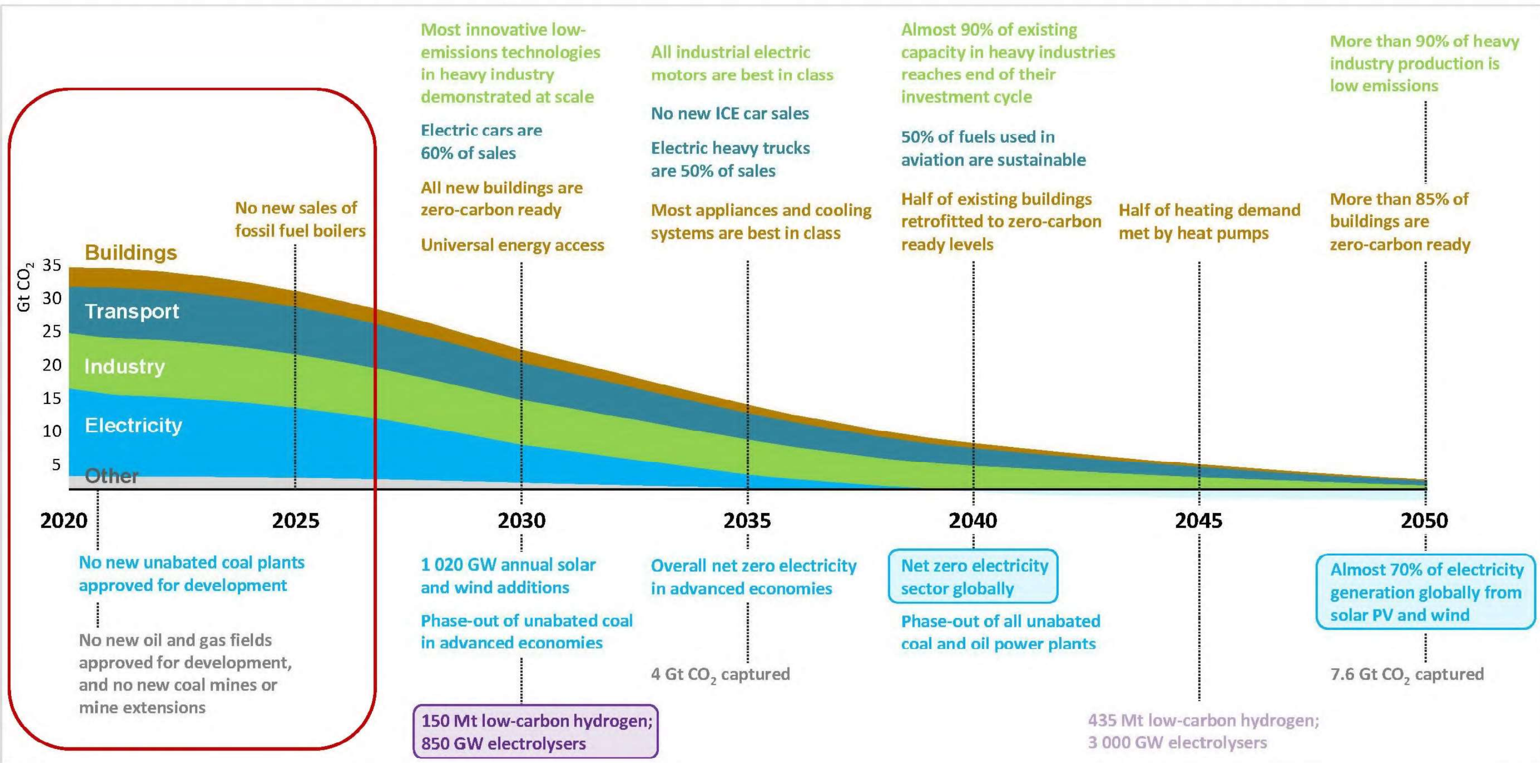


Sources: UN Comtrade, Oxford Economics, IHS, WTO, BCG Global Trade Model 2023, BCG analysis.

[1]Map corridors represent ~45% of global trade in 2022. Map does not include trade of services.

Part II: Clean energy innovation in a net-zero world

The world is apparently not on track to reach net-zero by 2050



Innovations: prerequisite of a net-zero world by 2050

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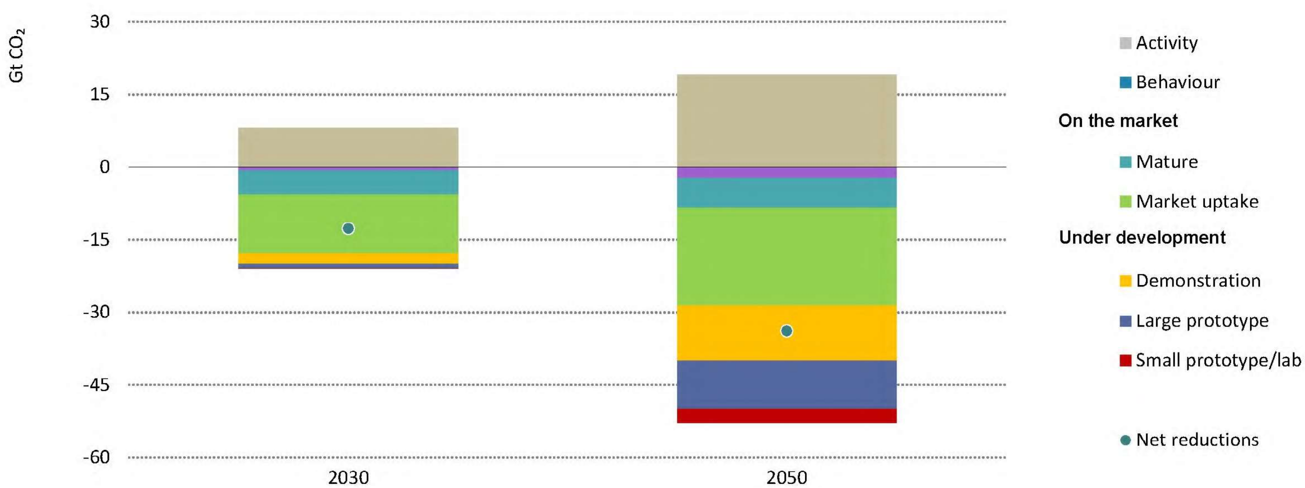
Global CO2 emissions changes by technology maturity category in the NZE

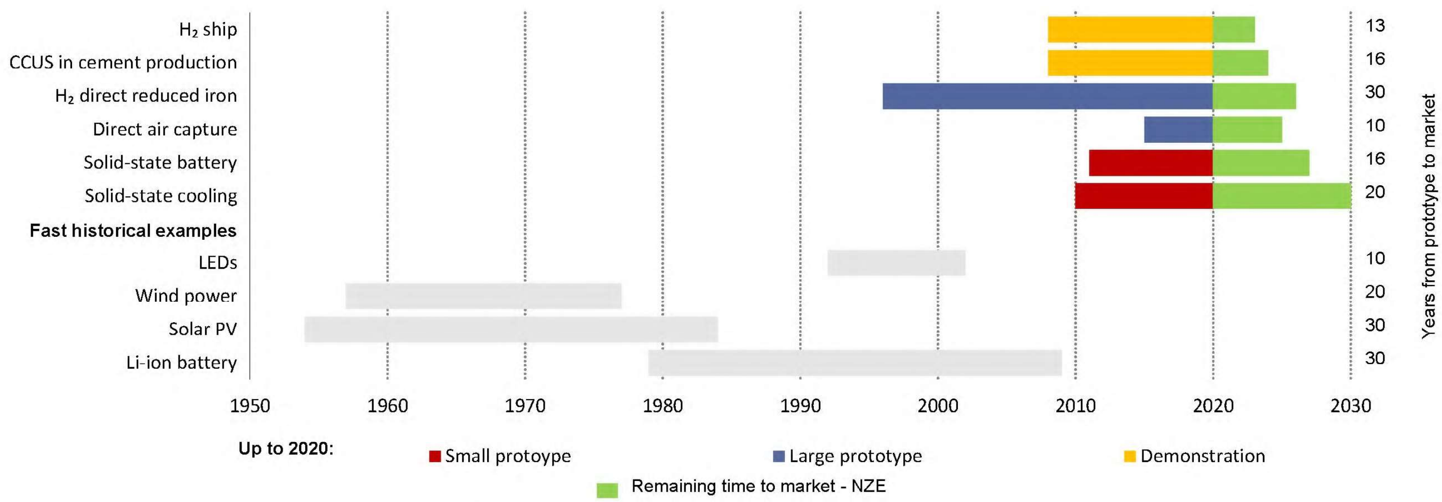


Source: International Energy Agency (2021), Net Zero by 2050, IEA, Paris.

In 2050, almost 50% of CO2 emissions reductions in the NZE come from technologies currently at demonstration or prototype stage.

Key innovations in support of net-zero transition

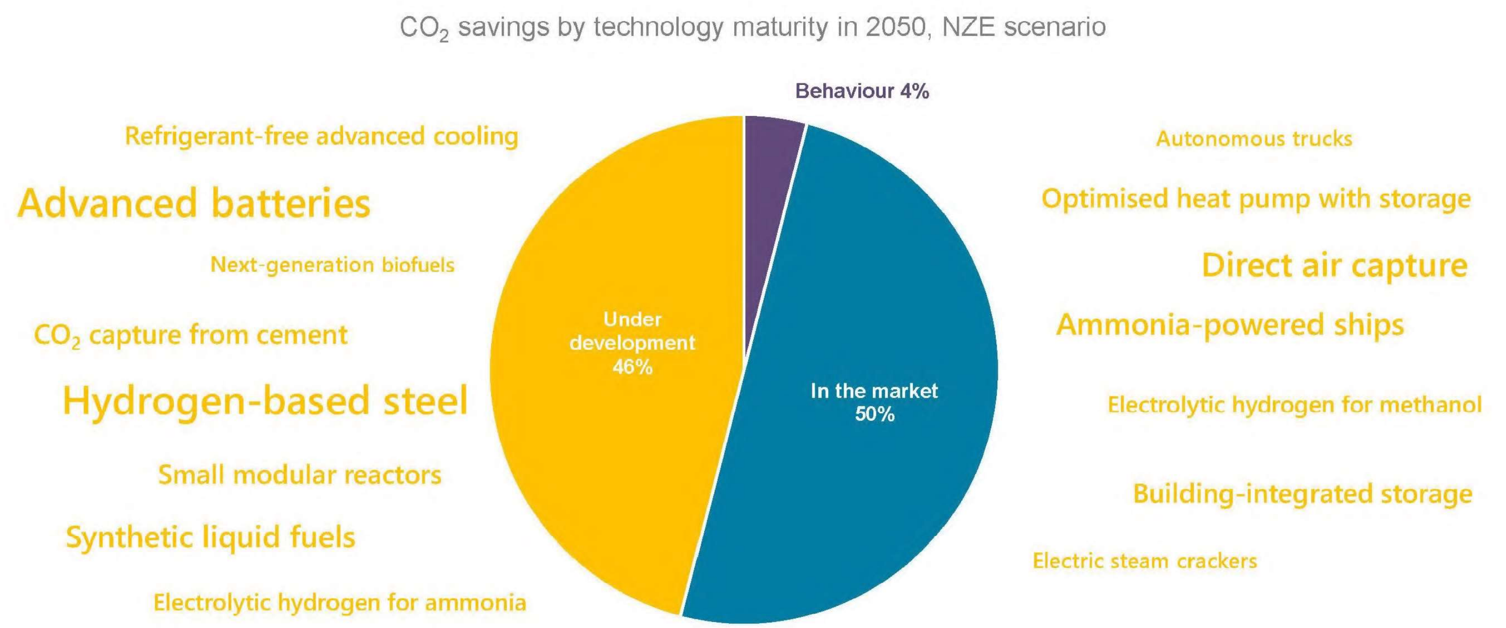
Time from first prototype to market introduction for selected technologies in the NZE and historical examples



Source: International Energy Agency (2021), Net Zero by 2050, IEA, Paris.

To deliver net-zero emissions goal by 2050, most clean energy technologies that have not been demonstrated at scale today need to reach markets by 2030 at the latest.

Prepare for the next phase of the transition by boosting innovation



Unlocking the next generation of low-carbon technologies requires more clean energy R&D and $90 billion in demonstrations by 2030; without greater international co-operation, global CO_2 will not fall to net-zero by 2050.

The importance & necessity of hydrogen

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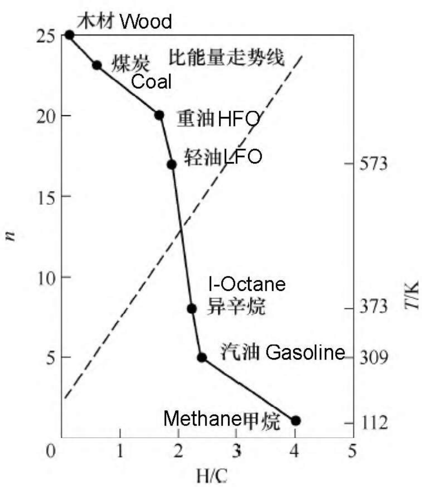
Evolvement of dominant energy carriers



Source: Hydrogen energy and economy.

Decomposing carbon emissions with Kaya Identity

$$CO_2 = \text{population} \times \frac{\text{GDP}}{\text{capita}} \times \frac{\text{energy}}{\text{GDP}} \times \frac{CO_2}{\text{energy}}$$

population:
- Development status
- Family planning
- Extreme events
- Armed conflicts

GDP/capita:
- Economic growth rate
- Birth/death rate ratio

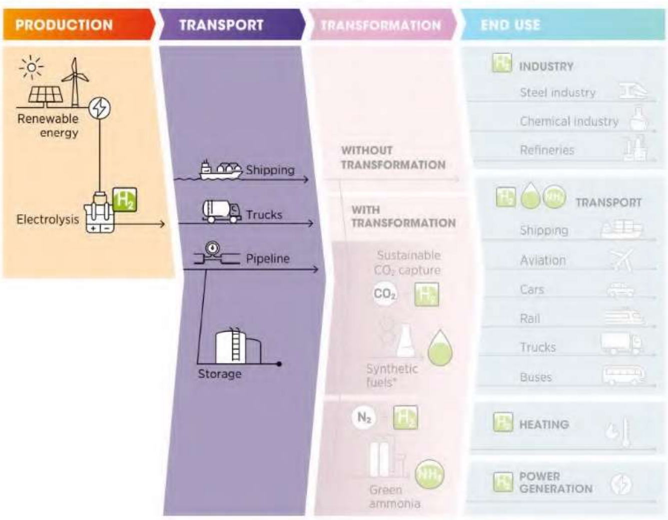
energy/GDP:
- Energy efficiency
- Structure change

CO_2/energy:
- Electrification
- Hydrogen economy
- CCUS
- Negative emissions

Hydrogen is a versatile energy vector with characteristics of fuel + chemical feedstock + energy storage.

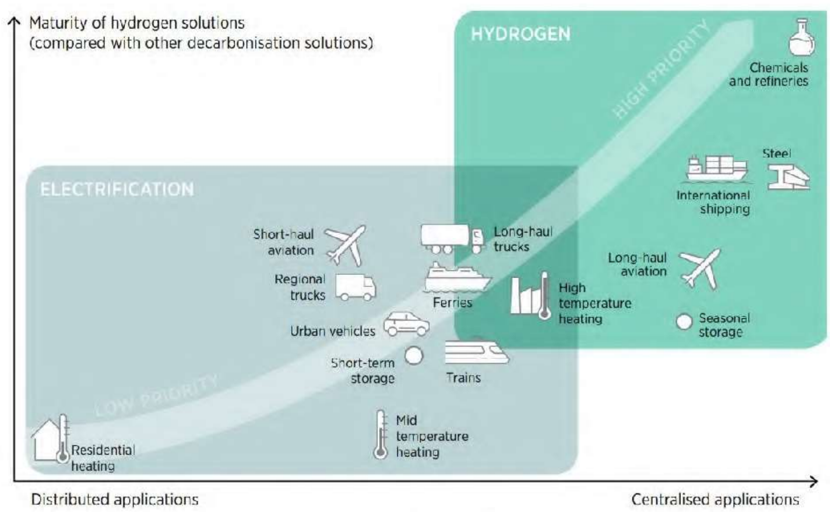
R&D opportunities exist throughout hydrogen value chain

Green hydrogen supply chain



Source: IRENA (2021) Green Hydrogen Supply.

Priority settings for hydrogen applications across the energy system



Source: IRENA (2022) Global Hydrogen Trade Outlook for 2050.

In a net-zero world, global hydrogen production is expected to expand by almost five times, to 614 MtH2/year, to satisfy 12% of the final energy demand by 2050 in a 1.5° C scenario.

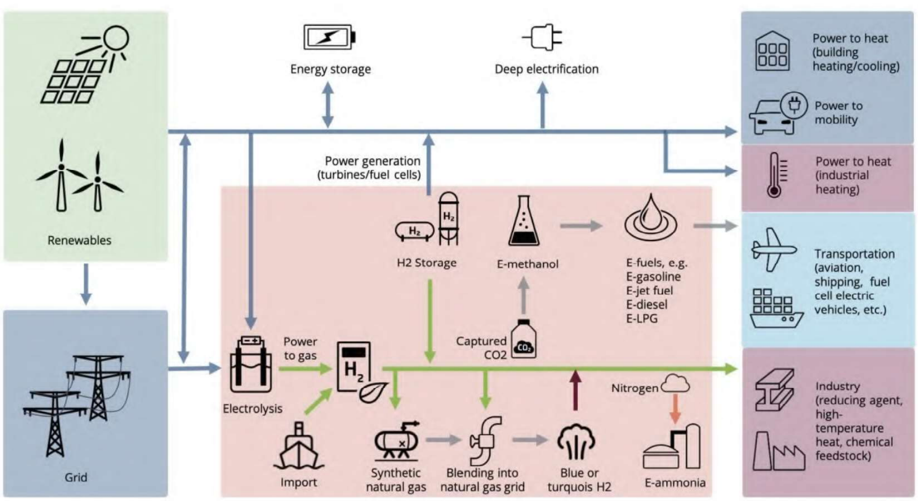
Priority should be given to green hydrogen in hard-to-abate sectors such as iron & steel manufacturing and shipping

绿氢应用领域 Green hydrogen application sectors	无悔 No-regret	有争议 Controversial	不明智 Bad idea
工业 Industry	▪ 反应剂（直接还原铁）Reaction agents (DRI steel) ▪ 原料（制氨、化工品）Feedstock (ammonia, chemicals)	▪ 高温用热 High-temperature heat	▪ 低温用热 Low-temperature heat
交通 Transport	▪ 长途航空 Long-haul aviation ▪ 海运 Maritime shipping ▪ 长途重卡运输 Long-haul heavy-duty trucking	▪ 港口、工业园区商用车 Commercial vehicles with ports and industry clusters ▪ 短途航空和船运 Short-haul aviation and shipping ▪ 火车(取决于运距、频率和能源供应) Trains (depending on distance, frequency and energy supply options)	▪ 乘用车 Passenger cars ▪ 轻型车辆 Light-duty vehicles
电力 Power	▪ 根据风光占比和季节需求作为可再生能源备用能源 Renewable energy back-up (seasonal demand)	▪ 考虑到其他灵活方案和储能选项后的固定用电需求 Absolute size of need given other flexibility and storage options	
建筑 Buildings	▪ 居民供暖提供灵活性的部分 Residual heating after renewable power and biomass, etc		▪ 独栋建筑供暖 Building level heating

Source: Kevin Tu & Isa Wang (2022) Prospects of Renewable Hydrogen in China and its Role in Industrial Decarbonization.

Similarity and difference of Power-to-X vs. CCU

→ Sector coupling via renewable hydrogen

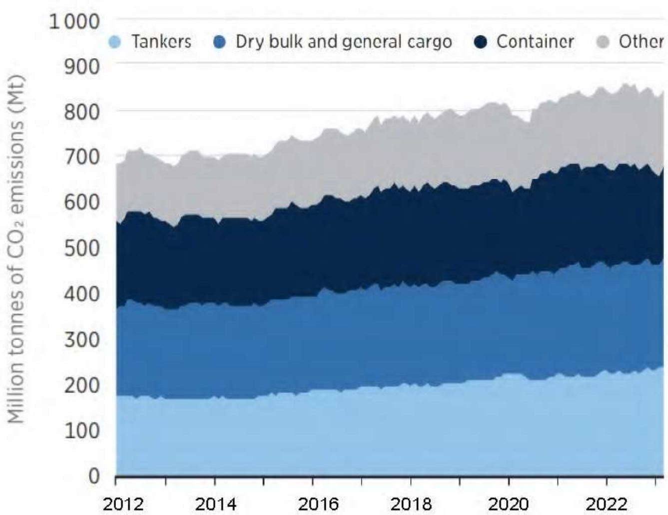


Source: Kevin Tu & Isa Wang (2022).

- Sector coupling is defined as the connection of at least two different sectors via substitution of non-renewable activities with renewable alternatives to establish fully renewable energy systems.
- PTX refers to a range of technologies that convert electricity, particularly from renewable sources, into other forms of energy or products.
- Renewable hydrogen is well positioned in sector coupling via gas blending, power generation, e-fuels and etc.

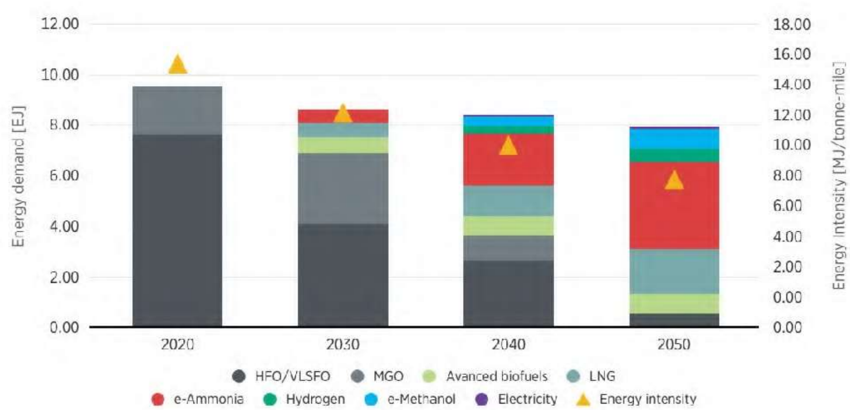
Hydrogen and its derivatives are key to decarbonize the shipping industry

Global shipping emissions 2012-2023



Source: IRENA (2023).

1.5° C Scenario energy pathway for shipping 2018-2050



Source: IRENA (2021)

Maritime transport accounts for 2-3% of global CO2 emissions, 10% of global transport emissions. Fossil LNG vs. renewables, renewable ammonia vs. methanol.

The HYBRIT pilot plant in Luleå, Sweden has completed test production of sponge iron in June 2021, with around 90% carbon emissions captured. In Dec 2023, the Swedish Energy Agency grants a total of SEK 3.1 billion in support to LKAB and Hybrit Development AB to build a 1.35 Mt/annum DRI plant in Gällivare.

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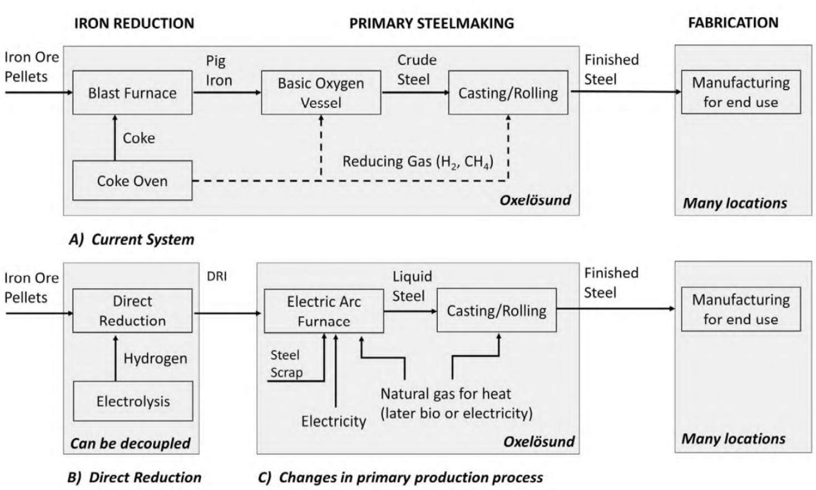
→ Steel manufacturing: blast furnace process vs. DRI



→ Technology option for steel decarbonization

	Routes	Mitigation potential	TRL	Resource capacity	Economics	Easiness of implementation
Incremental technology	Energy efficiency	15%-20%	●	●	●	●
	Oxygen blast furnace (OBF)	30%	◔	◔	◔	◑
	Hydrogen blending in BF	10%-20%	◕	◕	◕	◕
	Biomass	30% (95% with CCS)	◔	◔	◔	◕
	CCS	60%	◕	◑	◔	◑
	Smelt reduction (HIsarna, HIsmelt, COREX, FINEX, etc.)	20% (80% with CCS)	◑	◑	◔	◑
Fully decarbonized primary steel	Hydrogen DRI	95%	◕	◑	◔	◔
	Hydrogen plasma smelting reduction (HPSR)	95%	◔	◑	◔	◔
	Direct electrolysis	95%	◔	◔	◔	◔

Source: Kushnir & et al. (2020) .

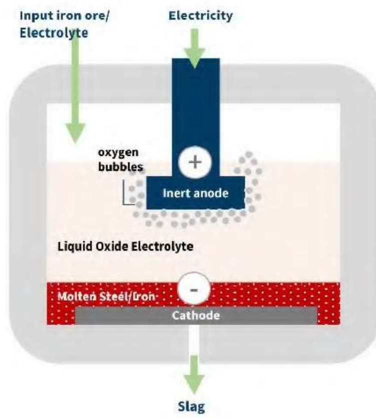
Source: RMI China (2021).

Iron Ore Electrolysis: Promising Technology for Zero-Carbon Steel

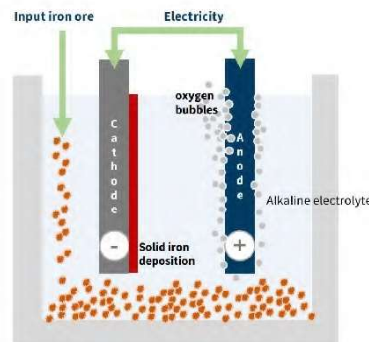
Major stages from iron ore to molten steel in different steelmaking processes

	Pretreatment		Ironmaking	Steelmaking
	Ore selection	Agglomeration	Iron reduction	Molten iron with impurities
Carbon emission share of each step in BF-BOF based long-process steelmaking (Sum total is less than 100% as refining and reducing agent processing excluded)	<10%	~25%	~40%	<10%
 BF-BOF	Crushing, screening	Sintering, pelleting	BF reduction	BOF ironmaking
 Gas-based shaft furnace — EAF (Natural gas/H2)	Crushing, screening	Pelleting	Shaft furnace reduction	EAF ironmaking
 Waste steel recovery	Crushing, smelting			EAF ironmaking
 MOE				MOE
 Electrowinning	Crushing, screening		Electrowinning	EAF ironmaking

Schematic diagram of a molten oxide electrolysis (MOE) electrolyzer



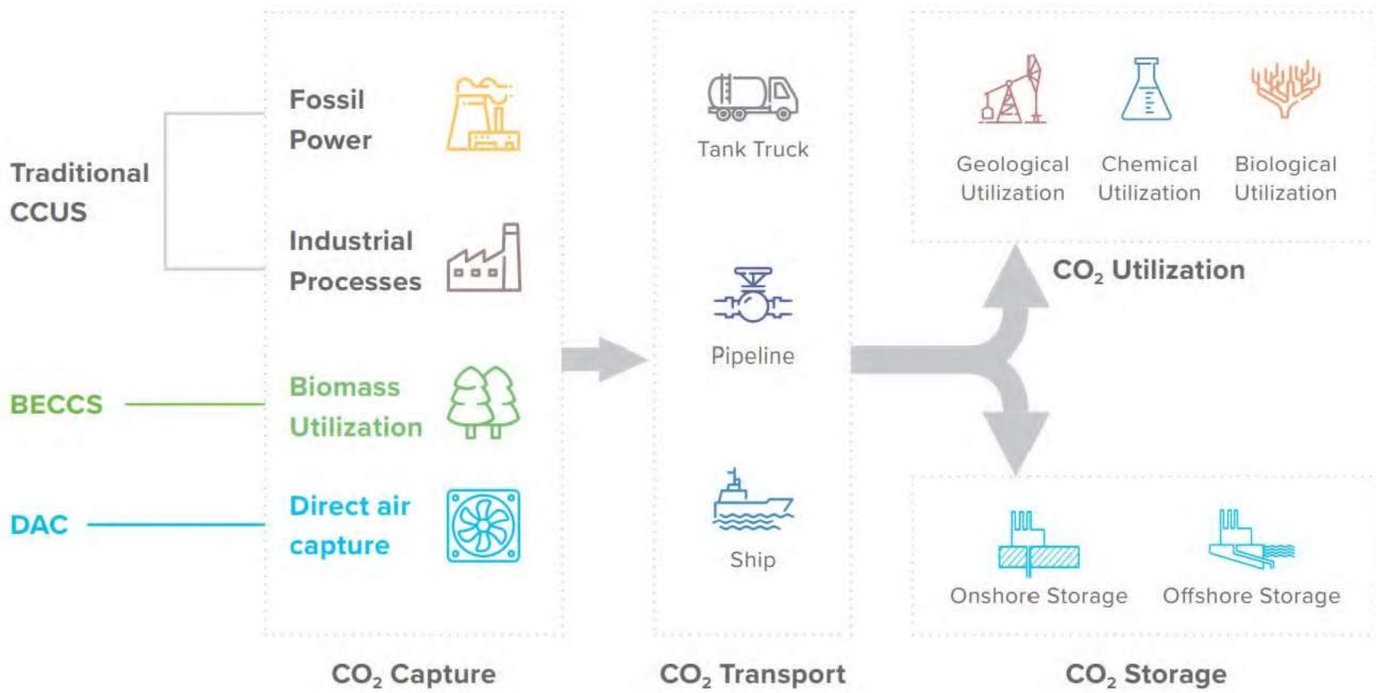
Schematic diagram of a low-temperature electrowinning electrolyzer



Source: RMI China (2023).

Low-temperature electrowinning is estimated to achieve carbon reduction by 50%–80% by 2050, while MOE may achieve an emissions reduction of up to 95% in a zero-carbon grid.

Categorization of CCUS in support of net-zero goals

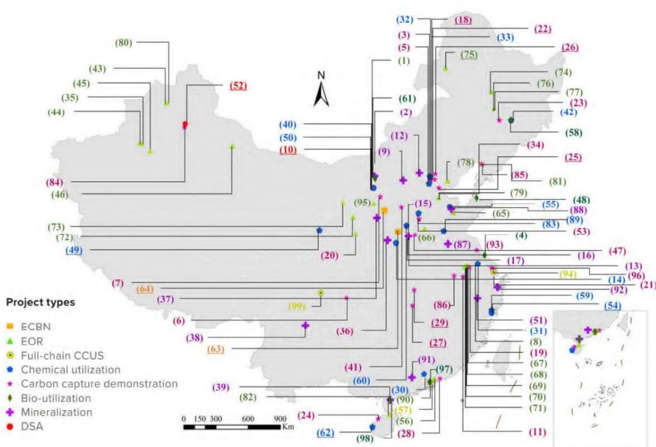


Source: CCUS Progress in China 2023.

CCUS is key for the future of coal in China

Roles of CCU and CCS in China's energy transition should be appropriately differentiated.

→ CCUS pilot projects in China: >4 Mt/annum capture capacity, >2Mt/annum injection capacity by the end of 2022



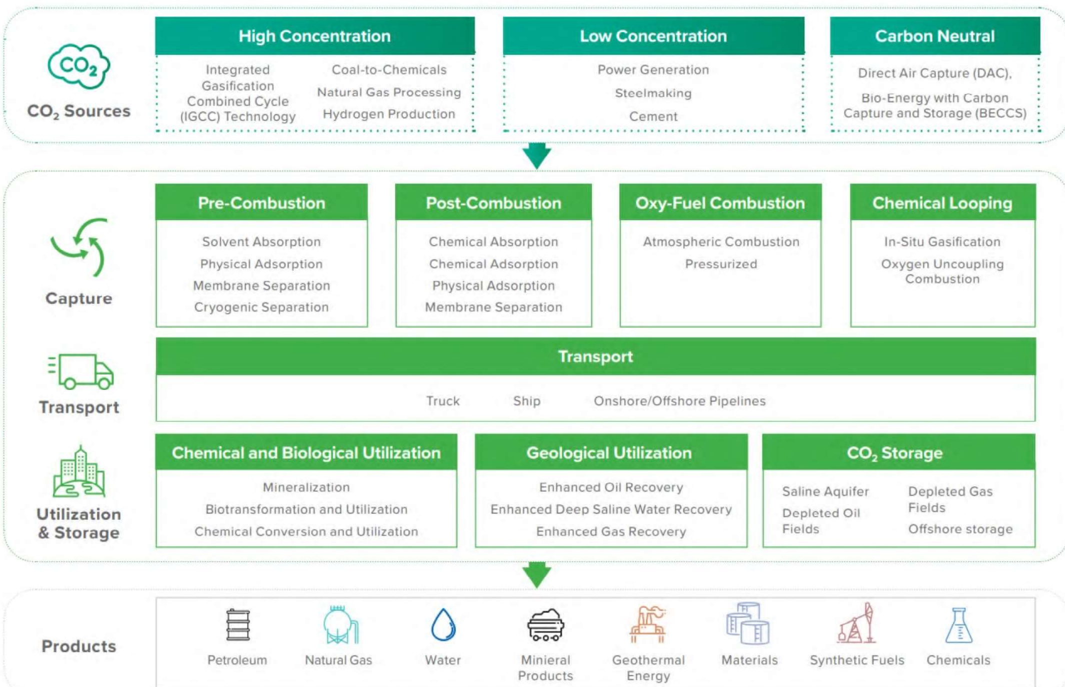
Source: CCUS Progress in China 2023.

→ Prospects of CCUS in China

- Given the dual carbon goals, China's CCUS strategy should also be formulated in a phased approach.
- The nature of CCU and CCS projects should be differentiated.
- To continuously learn CCUS-related experience and lessons from regions with high carbon prices especially EU countries through enhanced international cooperation.
- Large-scale geological storage of captured CO_2 is expected to serve as China's "last resort" backup option to achieve carbon neutrality.

Source: Kevin Tu & Sally Qiu (2021) Status and Prospects of CCUS Development in China.

The role of CCUS in a net-zero world: Convergence of CCU & PTX



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- CCUS is not only an option to decarbonize fossil energy, but also a feasible solution for deep decarbonization in hard-to-abate industries such as cement.
- CO2 utilization technologies are gradually transitioning from geological utilization for enhanced energy resource recovery to CO2 chemical and biological utilization, which yield value-added chemical and biological products.

Source: CCUS Progress in China 2023.

Negative emissions technologies: 1)BECCUS involves the direct capture, utilization and storage of CO2 via biomass combustion for power and heat; 2) the purpose of DAC technologies is to capture CO2 from the air and produce a more concentrated stream of CO2, with end goal of scalable CO2 storage..

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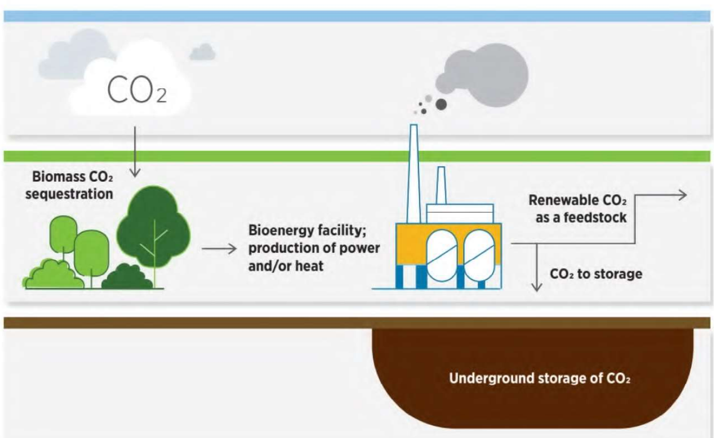
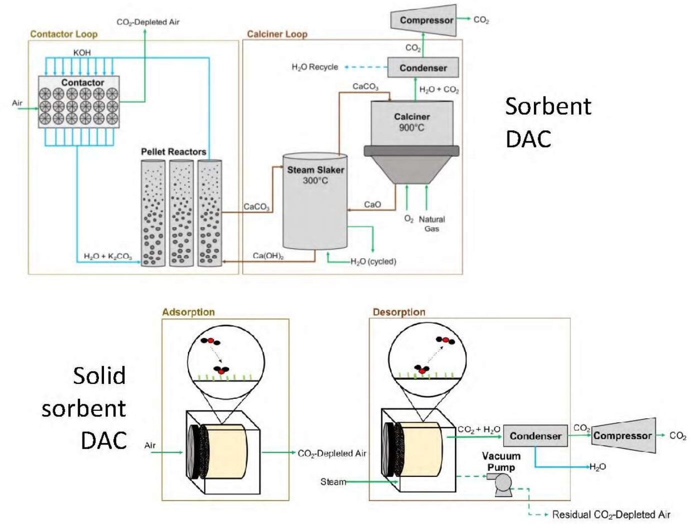
→ Flow diagram of bioenergy with CCUS (BECCUS)

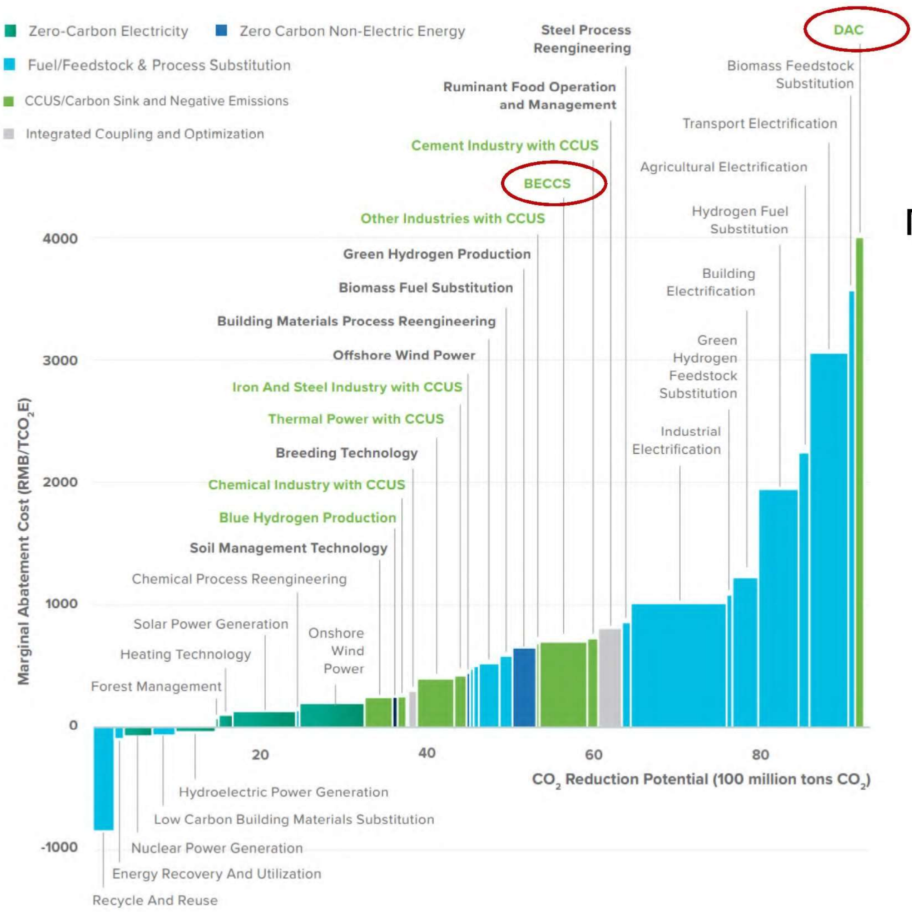


→ Flow diagram of representative direct air capture (DAC)



Source: IRENA (2021) A pathway to decarbonize the shipping sector.

Source: Noah McQueen & et al. (2021).

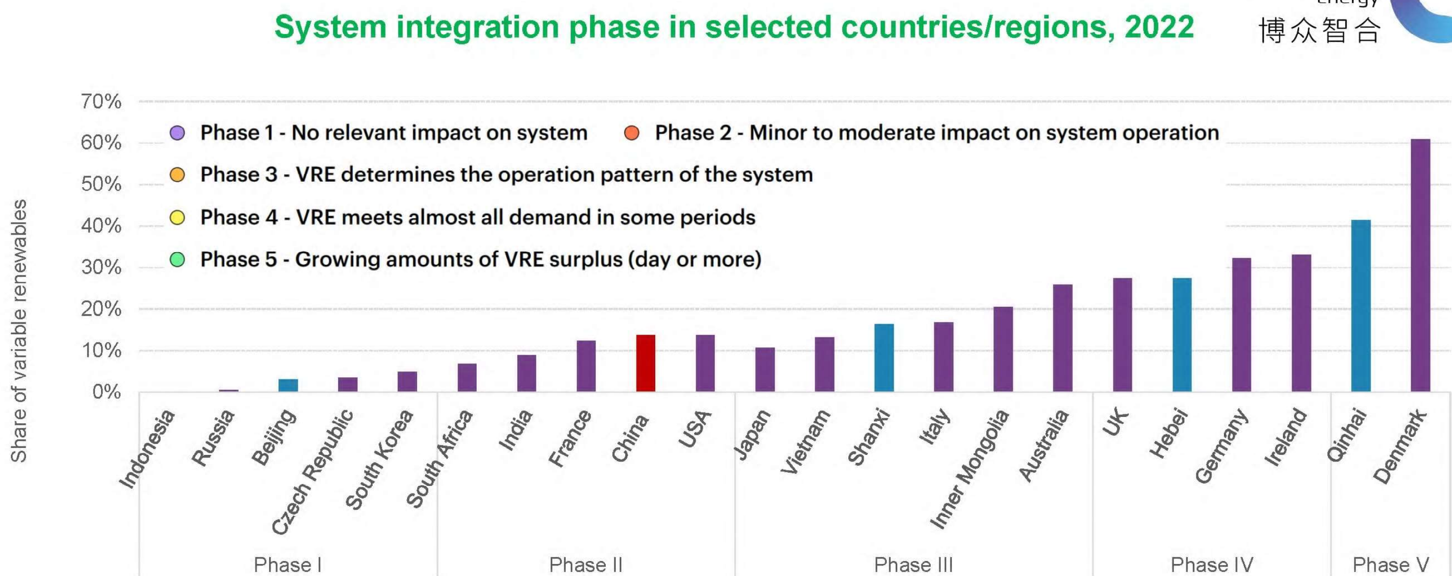


Marginal abatement cost curve in China

- The cost of the CCUS demonstration project is much higher than carbon pricing signal in China's national carbon market.
- The overall cost of China's CCUS demonstration projects is at a medium to low level compared with the rest of the world.
- How to achieve economies of scale via R&D as well as international collaboration?

Source: CCUS Progress in China 2023.

Grid integration of variable renewables



Source: ETP 2020 special report.

Starting from 2023, China has entered phase 3 of GIVAR.

China's energy storage capacity in 2023: 83.7 GW with pumped storage, new energy storage and molten salt thermal storage accounting for 60.5% (50.6 GW), 38.4% (32.2 GW) and 1.1%.

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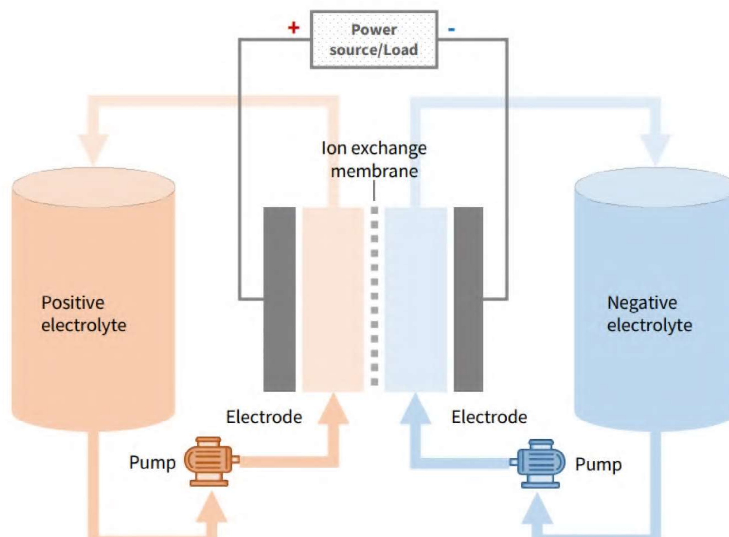
→ Comparison of major new energy storage technologies

New Energy Storage (non-exhaustive)		Market share*	Advantage	Disadvantage
Electroch-emical	Li-ion battery	94.9%	High energy intensity, high output power and fast startup	Major fire risk, high system cost and recovery cost
	Lead battery	1.1%	Low cost and stable output power	Low energy density, short service life and highly polluting
	Flow battery	0.9%	High safety, long service life and can be easily expanded	Low energy density, high system cost
	Super capacit or		Long service life, high charging/ discharging power and fast startup	Low energy density, high system cost and high self-discharge rate
Compressed air		0.6%	Long service life, long duration and high system efficiency	Strict requirement on geographical condition and long lead time
Flywheel		0.5%	High power density, long service life and strong environment adaptability	Low energy density and high self-discharge rate

→ Schematic diagram of flow battery operation



Source: RMI (2023) and CIES 2024.

Part III: Successful stories in China and policy implications

China's importance in key energy & climate indicators

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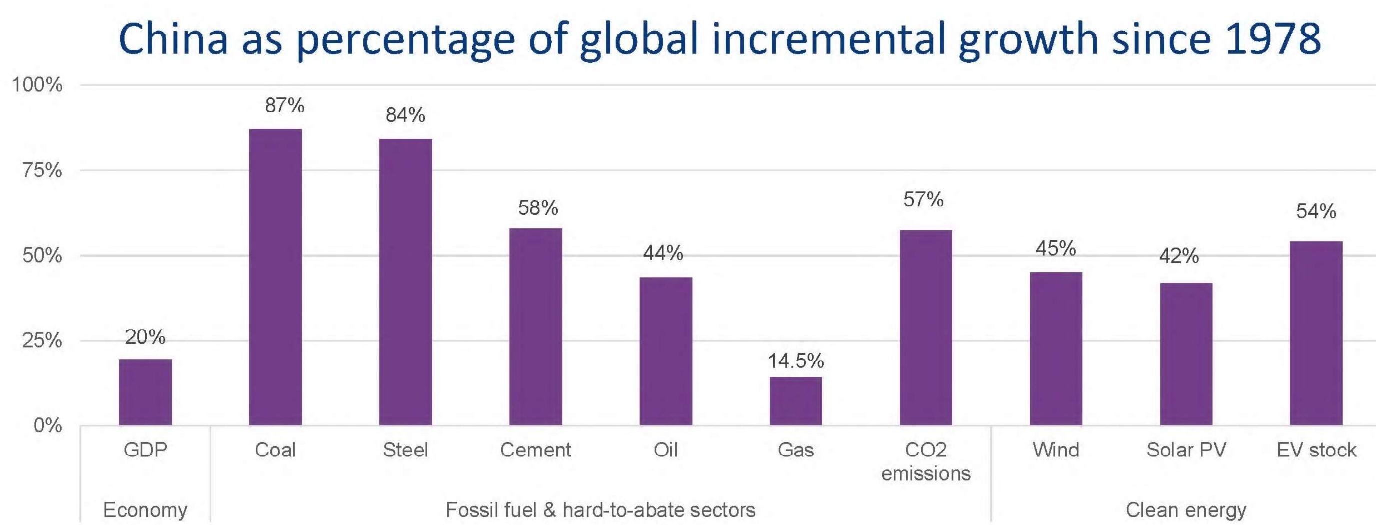

The Chinese energy economy is full of contradictions:
It's the most dominant CO_2 emitter yet the largest clean energy market.

Source: World Bank data portal, IEA, World Steel Association, Statista and BP

China's hybrid superpower status could well explain its dual carbon goals of peaking national carbon emissions before 2030 and achieving carbon neutrality before 2060

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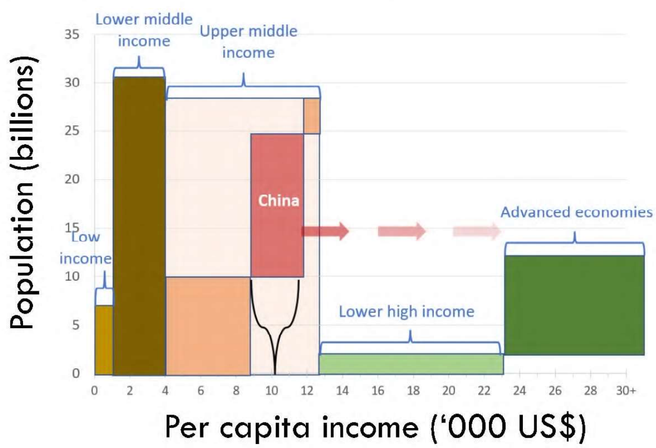
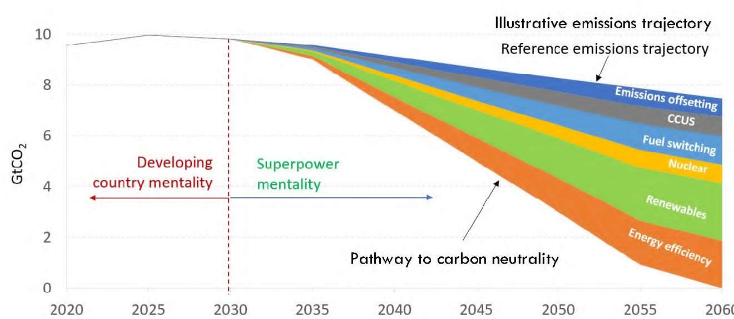
China is the first-ever hybrid superpower in the modern era



Illustrative wedge analysis of China's carbon-neutral pathway



Source: Benoit, Philippe, and Kevin Tu. "Is China Still a Developing Country? And Why It Matters for Energy and Climate." CGEP at Columbia University: New York (2020).

https://www.energypolicy.columbia.edu/publications/china-still-developing-country-and-why-it-matters-energy-and-climate/

First mover advantages vs. disadvantages: how to deal with free rider effects? i.e., the imitation of adoption by later adopters at lower costs, technology uncertainty of the “dominant design”, and market shifting

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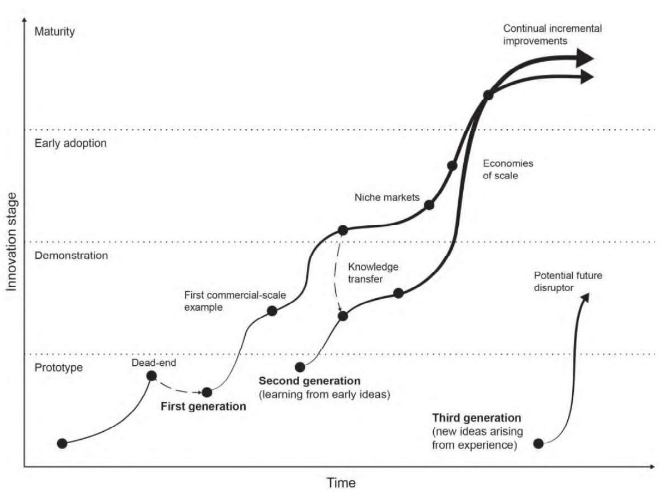
→ Four stages of technology innovation



Technology iteration

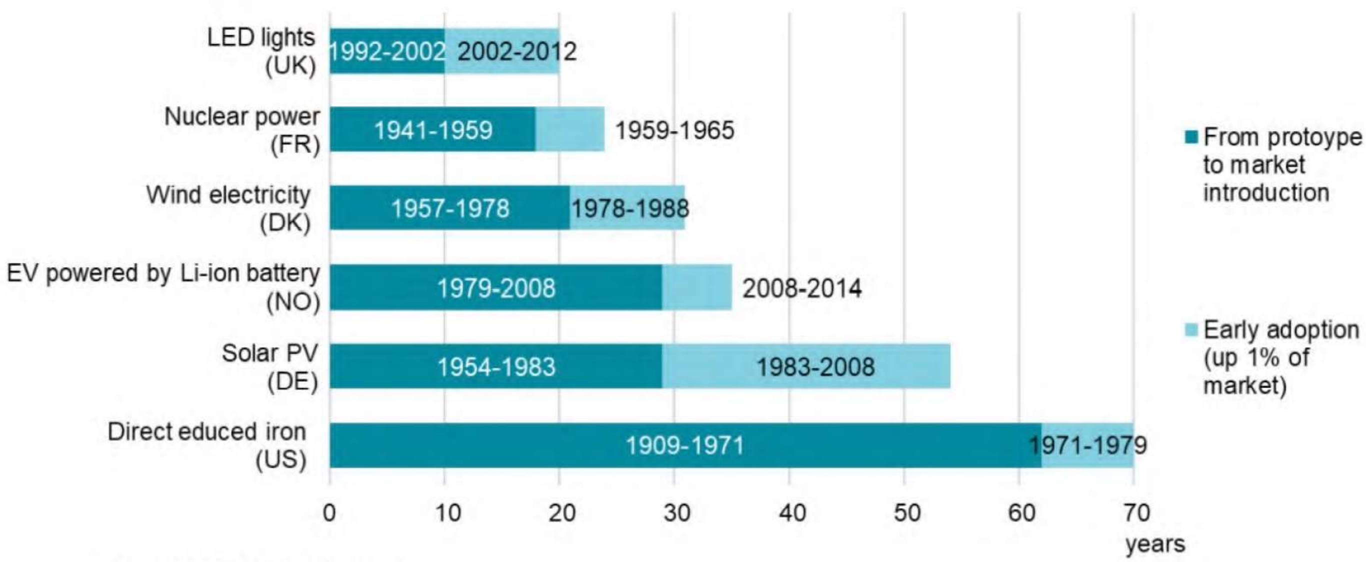
→ Technology readiness level scale applied by the IEA

CONCEPT	1	**Initial idea** Basic principles have been defined	Beyond the SDS
	2	**Application formulated** Concept and application of solution have been formulated	
	3	**Concept needs validation** Solution needs to be prototyped and applied	
SMALL PROTOTYPE	4	**Early prototype** Prototype proven in test conditions	
LARGE PROTOTYPE	5	**Large prototype** Components proven in conditions to be deployed	Scope of the SDS
	6	**Full prototype at scale** Prototype proven at scale in conditions to be deployed	
DEMONSTRATION	7	**Pre-commercial demonstration** Solution working in expected conditions	
	8	**First of a kind commercial** Commercial demonstration, full scale deployment in final form	
EARLY ADOPTION	9	**Commercial operation in relevant environment** Solution is commercially available, needs evolutionary improvement to stay competitive	
	10	**Integration needed at scale** Solution is commercial and competitive but needs further integration efforts	
MATURE	11	**Proof of stability reached** Predictable growth	

Source: ETP 2020 special report.

First mover advantages vs. second mover advantages

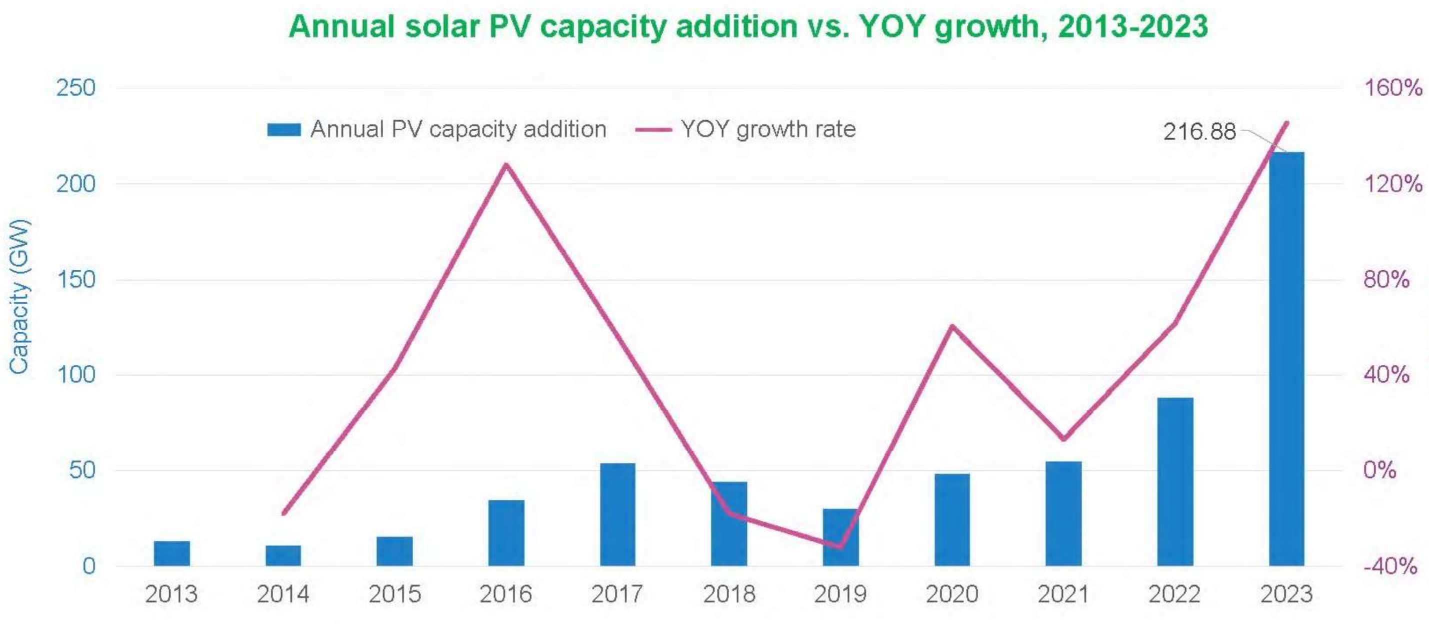
Prototype to market introduction and early adoption periods for selected energy technologies



Source: ETP 2020 special report.

History shows that it can take between 20 and almost 70 years for new energy technologies to go from first prototype to materiality (that is, to reach 1% of a national market).

China adds more solar power in 2023 than US has ever built (175.2 GW)

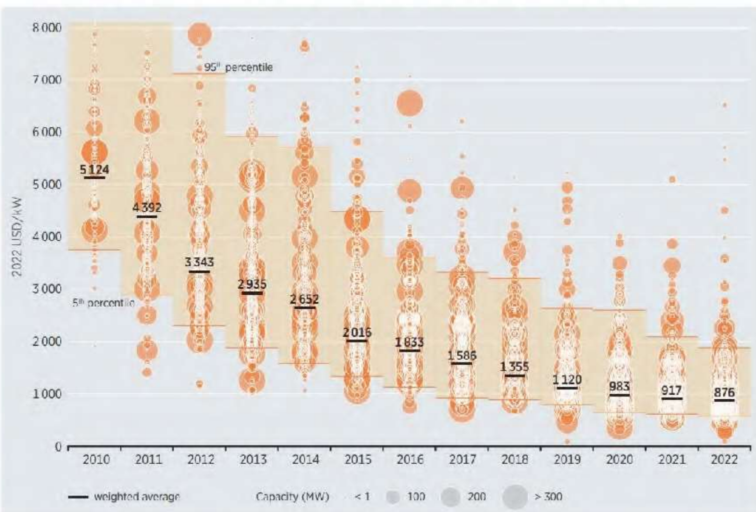


Source: China Photovoltaic Industry Association.

China's solar PV capacity addition in 2023 accounts for 58% of global total, and 14% of the world's cumulative solar PV capacity to date.

Economies of scale achieved by Chinese solar panel manufacturers

Total installed PV system cost for utility-scale projects declined by 83% in 2010-2022



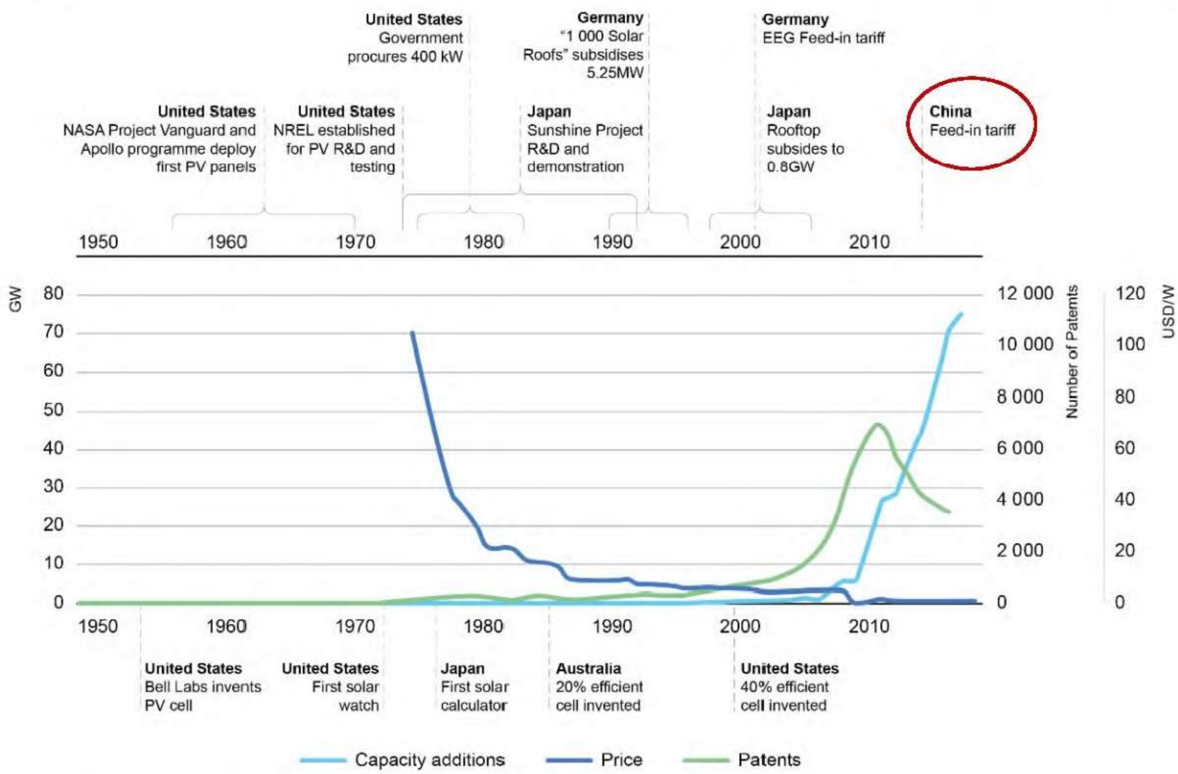
Source: Renewable Power Generation Costs in 2022.

Unit cost of PV system & solar modules in China declined by 94% and 96% in 2007-2023

Source: China Photovoltaic Industry Association.

In 2023 alone, unit cost of solar modules declined by about one third in China.

Key government programmes (top) and milestones (bottom) in PV development

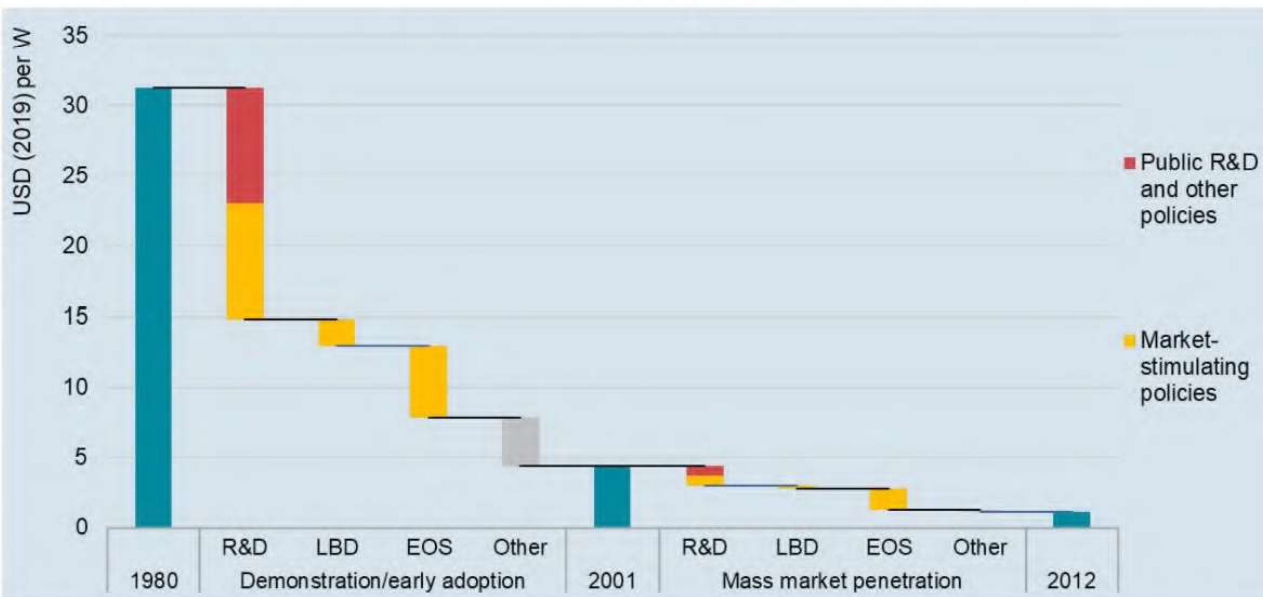


Source: ETP 2020 special report.

- What should be the appropriate role of the government?
- Even though the development of solar PV took for decades, progress would almost certainly have been slower if these countries – and others not mentioned here – had not shared the responsibility for these innovation stages.

The dividend of globalization and international collaboration

Contributions to solar PV cost declines by high-level mechanism and driver



Source: ETP 2020 special report.

R&D = learning-by-researching; LBD = learning-by-doing; EOS = economies of scale. Other includes externally driven input prices and costs.

What type of companies are more innovative?

Top 10 solar module companies in 2023

Rank	Module Supplier	Shipment(GW)
1	JinKO Solar	75+
2	Trinasolar	70
3	LONGi	65-67
4	JA SOLAR	60-65
5	CanadianSolar	30.2-30.7
6	TW SOLAR	28-30
6	ASTRONERGY	28-30
8	risen	25.5
9	DASOLAR	18-20
10	协鑫 GCL 协鑫集成	≈11.8
10	YINGLI SOLAR	11.5-12

Source: SOLARBRE.

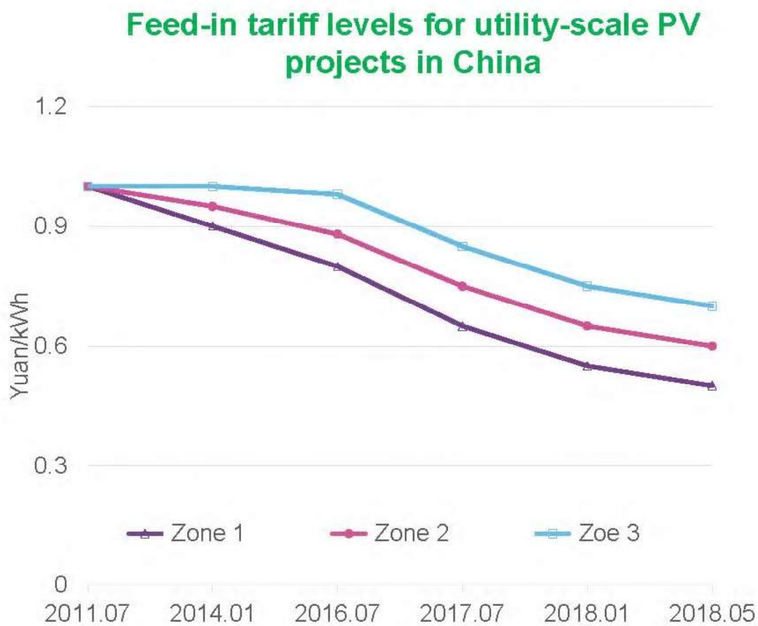
Top 10 EV battery manufacturers in 2023

Company	Country	2023 Production (megawatt-hour)
CATL	China	242,700
BYD	China	115,917
LG Energy Solution	Korea	108,487
Panasonic	Japan	56,560
SK On	Korea	40,711
Samsung SDI	Korea	35,703
CALB	China	23,493
Farasis Energy	China	16,527
Envision AESC	China	8,342
Sunwoda	China	6,979
Other	-	56,040

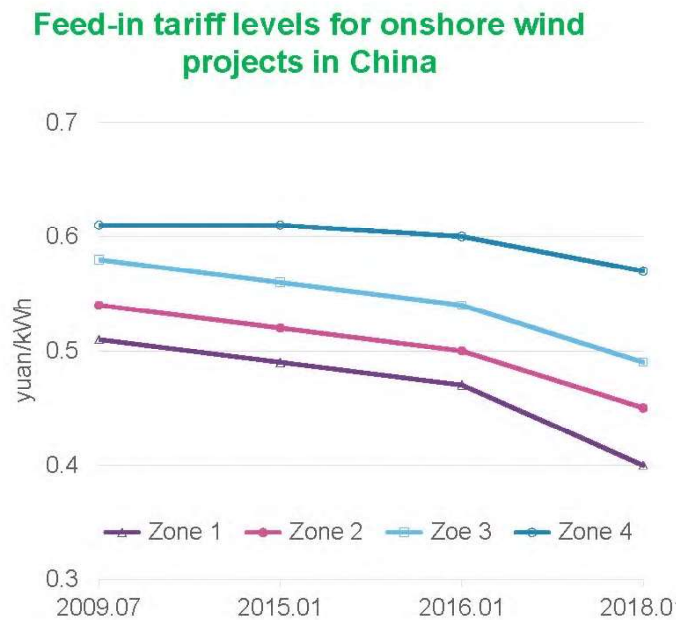
Source: EV Volume.

Though state-owned enterprises dominate most segments of the Chinese energy economy, they are outperformed by their private counterparts on clean tech innovation.

The art of subsidies: not too low to start, not too long to end

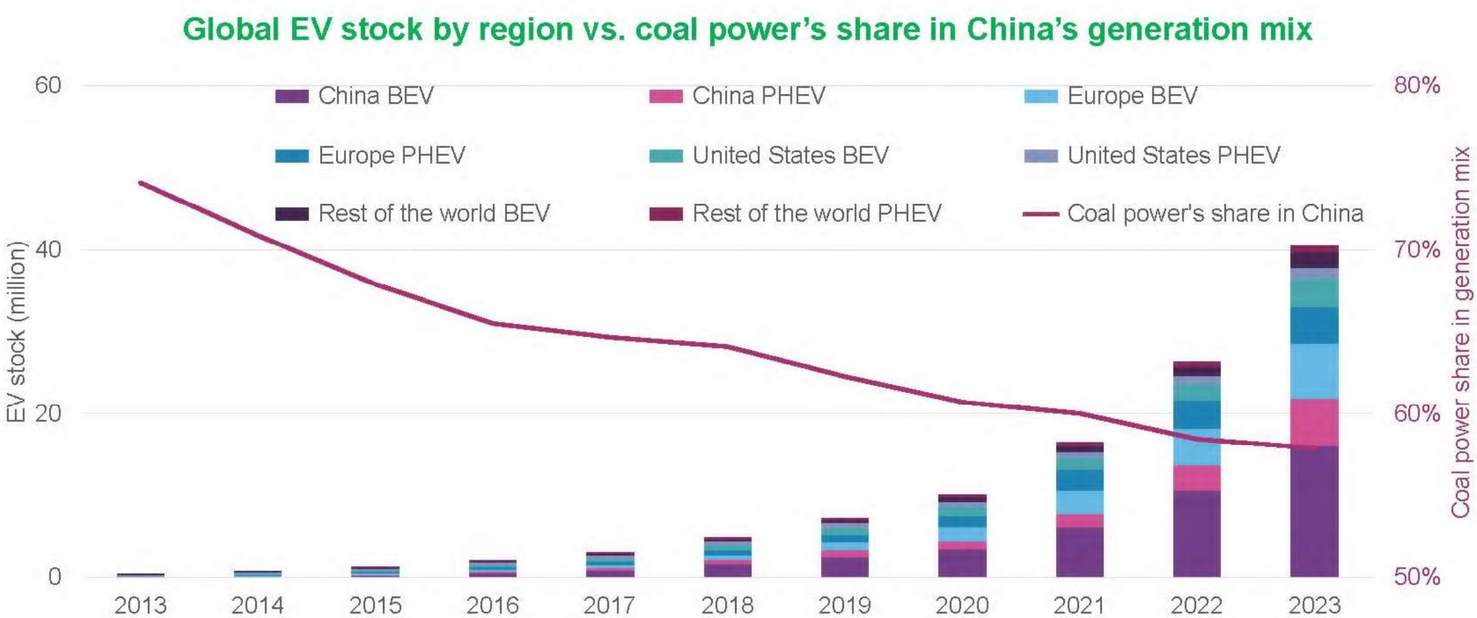


Source: NDRC.



In Jan 2019, NDRC & NEA promoted grid parity of solar PV projects. In August 2021, China stopped subsidizing utility-scale PV projects, industrial and commercial distributed renewables & onshore wind.

The success of China's EV programme

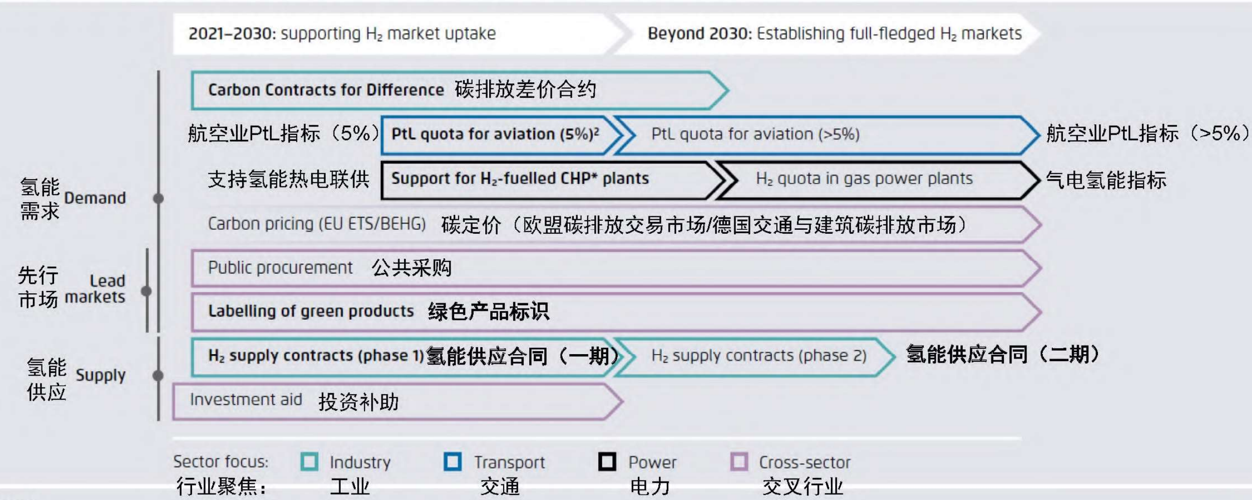


Source: Global EV Outlook 2024.

In China, the number of new electric car registrations reached 8.1 million in 2023, just under 60% of global total. China EV stock accounts for 54% of global total.

How to incentivize technology innovation

不同政策工具所需时间不尽相同 Different policy instruments require different timelines

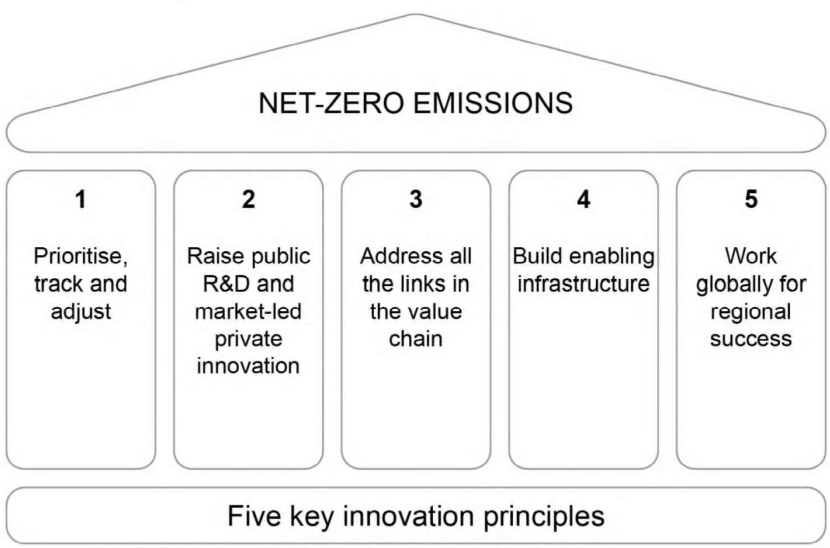


Guidehouse (2021)

Concluding remarks

Agora Energy 博众智合

Key principles to accelerate clean energy technology innovation



Source: ETP 2020 special report.

- → In the era of poly-crises, tech innovation needs to play an even more important role to bridge the widening gap between pledges and actions, though institutional reform remains key.
- → How to nurture an innovation-friendly environment will test wisdom of key stakeholders, especially government.
- → International collaboration and tech transfer are both major barriers and promising opportunities to move innovation agenda forward.

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Thank you for your attention.

如果您有任何问题，欢迎与我联系。
If you have any questions, please feel free to email me.

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