ECECP Investment and Technologies for Net-zero Carbon Infrastructure

ECECP净零碳基础设施投资和关键技术研究

CCUS and PtX in China

中国的碳捕集、封存与利用和PtX技术

State Grid Energy Research Institute

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(1) Importance of CCUS 碳捕集、利用与封存技术的定位

国家电网有限公司
STATE GRID
CORPORATION OF CHINA

CCUS is the only technological option to realize low-carbon utilization of fossil energy.

CCUS 是目前实现化石能源低碳化利用的唯一技术选择。

- It is estimated that by 2050, fossil energy will account for 10%-15% of China's energy consumption.
- 到2050 年，化石能源仍将扮演重要角色，占中国能源消费比例的10%~15%。

CCUS can maintain the flexibility of power system to realize carbon neutrality.

CCUS 是碳中和目标下保持电力系统灵活性的主要技术手段。

- By avoid an early phasing out of coal-fired power stations, the necessary support for system inertia and frequency control is then guaranteed when facing the great volatility of renewable energy and potential seasonal power shortages.
- 火电加装CCUS是具有竞争力的重要技术手段，可实现近零碳排放，提供稳定清洁低碳电力，平衡可再生能源发电的波动性，并在避免季节性或长期性的电力短缺方面发挥惯性支撑和频率控制等重要作用。

(1) Importance of CCUS 碳捕集、利用与封存技术的定位

国家电网有限公司
STATE GRID
CORPORATION OF CHINA

CCUS is a feasible technology option for hard-to-abate sectors, like steel and cement.

CCUS 是钢铁水泥等难以减排行业低碳转型的可行技术选择。

- After implementing measures like efficiency improvement, raw material substitution, and etc, it is estimated that 34% of carbon emissions in the steel industry and 48% of carbon emissions in the cement industry are hard to abate.
- 预计到2050年，钢铁行业通过采取工艺改进、效率提升、能源和原料替代等常规减排方案后，仍将剩余34%的碳排放量，即使氢直接还原铁(DRI)技术取得重大突破，剩余碳排放量也超过8%。水泥行业通过采取其他常规减排方案后，仍将剩余48%的碳排放量。

CCUS coupled with renewable energy could realize negative emissions.

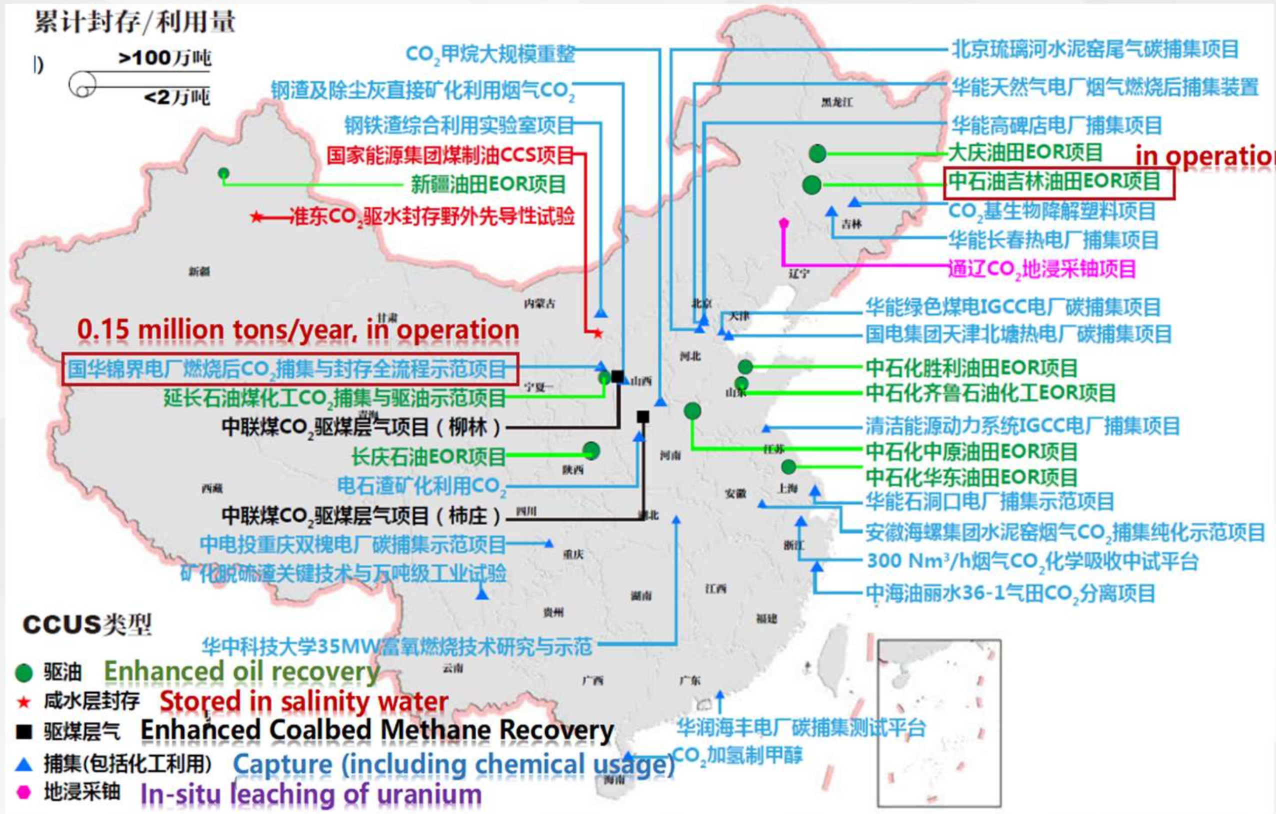
CCUS 与新能源耦合的负排放技术是实现碳中和目标的重要技术保障。

- CCUS coupling with bio-energy, usually referred to as BECCS, could realize negative emssions. Negative emission technologies can neutralize greenhouse gas emissions and provide important support for achieving the goal of carbon neutrality.
- BECCS及其他负排放技术可中和该部分温室气体排放，推动温室气体净零排放，为实现碳中和目标提供重要支撑。

(2) CCUS projects in China 碳捕集、利用与封存项目开展情况

CCUS Projects in China

- There are about 40 CCUS projects that are in operation or under construction in China. The capture capacity is around 3 million tons/year and the cumulative storage capacity is 2 million tons.
- **中国已投运或建设中的CCUS示范项目约为40个，捕集能力300万吨/年，累计封存200万吨CO_2。**



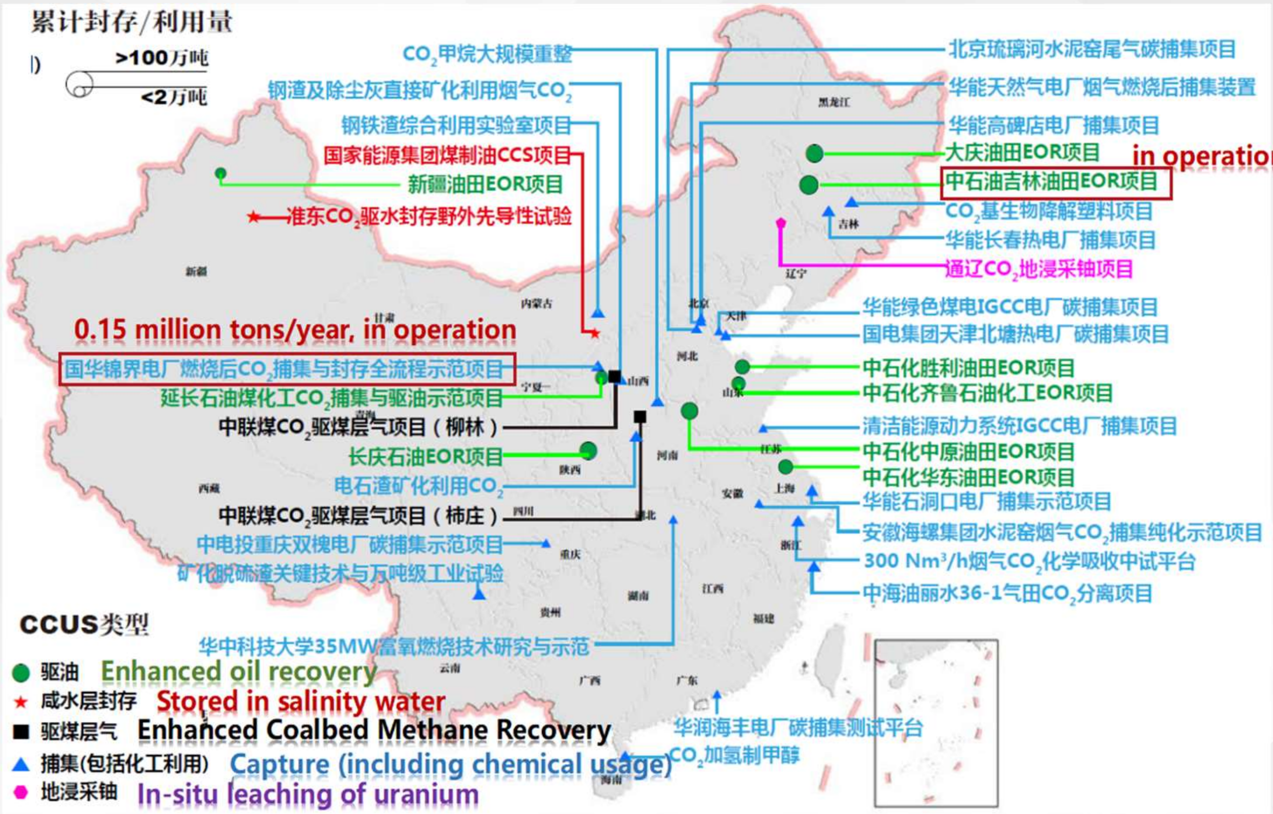
CCUS projects in China

Source: China CCUS Annual Report 2021.

(2) CCUS projects in China 碳捕集、利用与封存项目开展情况

CCUS Projects in China

- The existing CCUS pilot demonstration projects focus on demonstrating carbon capture technology and EOR technology. Large-scale, full-chain projects are rare.
- **现有的CCUS试点示范项目主要关注展示碳捕集技术和EOR技术。大规模、完整链条的项目相对较少。**
- China has the design capability of a large-scale, full-process system and is actively preparing for the full-chain CCUS industrial clusters.
- **中国具备大规模、全过程系统的设计能力，并积极准备建设完整链条的CCUS工业集群。**



CCUS projects in China

Source: China CCUS Annual Report 2021.

(3) CCUS technology costs in China 技术成本情况

国家电网有限公司 STATE GRID CORPORATION OF CHINA

China's CCUS demonstration projects are small in scale and expensive. The cost of CCUS mainly includes economic costs and environmental costs. 中国的CCUS示范项目规模较小且成本较高。CCUS的成本主要包括经济成本和环境成本。

Economic costs include fixed costs and operating costs. 经济成本包括固定成本和运营成本。

Environmental costs include environmental risks and energy consumption. 环境成本包括环境风险和能源消耗。

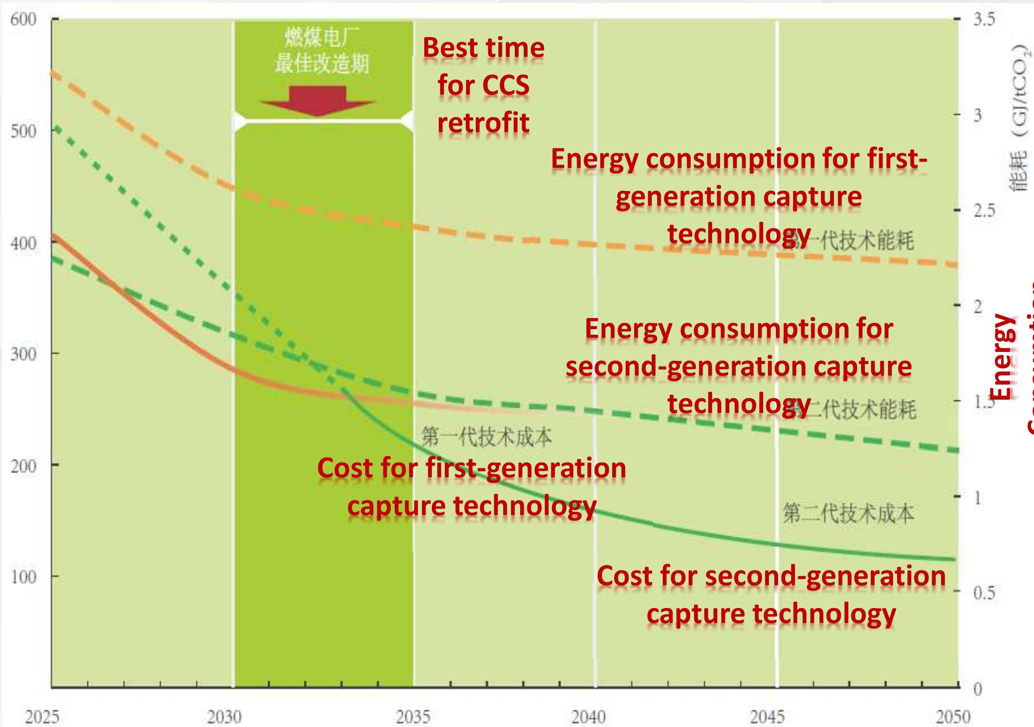
2025-2060年CCUS技术的成本 Cost for CCUS Technologies in 2025-2060

Year		2025	2030	2035	2040	2050	2060
捕集技术 Capture	燃烧前捕集 Pre-combustion	100-180	90-130	70-80	50-70	30-50	20-40
	燃烧后捕集 Post-combustion	230-310	190-280	160-220	100-180	80-150	70-120
	富氧燃烧 Oxy-fuel combustion	300-480	160-390	130-320	110-230	90-150	80-130
运输Transport (RMB/t·km)	罐车 Truck	0.9-1.4	0.8-1.3	0.7-1.2	0.6-1.1	0.5-1.1	0.5-1
	管道 Pipeline	0.8	0.7	0.6	0.5	0.45	0.4
封存 Storage		50-60	40-50	35-40	30-35	25-30	20-25

Source: China CCUS Annual Report 2021.

(3) Carbon capture technology in China 碳捕集技术现状

- China's thermal power industry will reach a peak for unit renewal from 2035 to 2045. Considering the development of carbon capture technology, before 2035, the first-generation capture technology should be the mainstream while after 2035, the-second generation technology should be the mainstream.
- **2035年前后将是捕集技术实现代际升级的关键时期。**我国火电行业在2035-2045年间将迎来机组更新高峰。综合考虑火电行业的发展规律与捕集技术的发展趋势，2035年前应以采用第一代捕集技术的存量火电机组改造为主，2035年后应以采用二代捕集技术的新建火电机组为主。



Levelised additional electricity costs for coal-fired power units suitable for retrofitting 适合改装的燃煤发电机组的电力水平化附加成本

Notes: the first-generation capture technology are ready to be used on a large scale. The second-generation capture technology's energy consumption and cost will decrease to more than 30% compared to the first-generation.

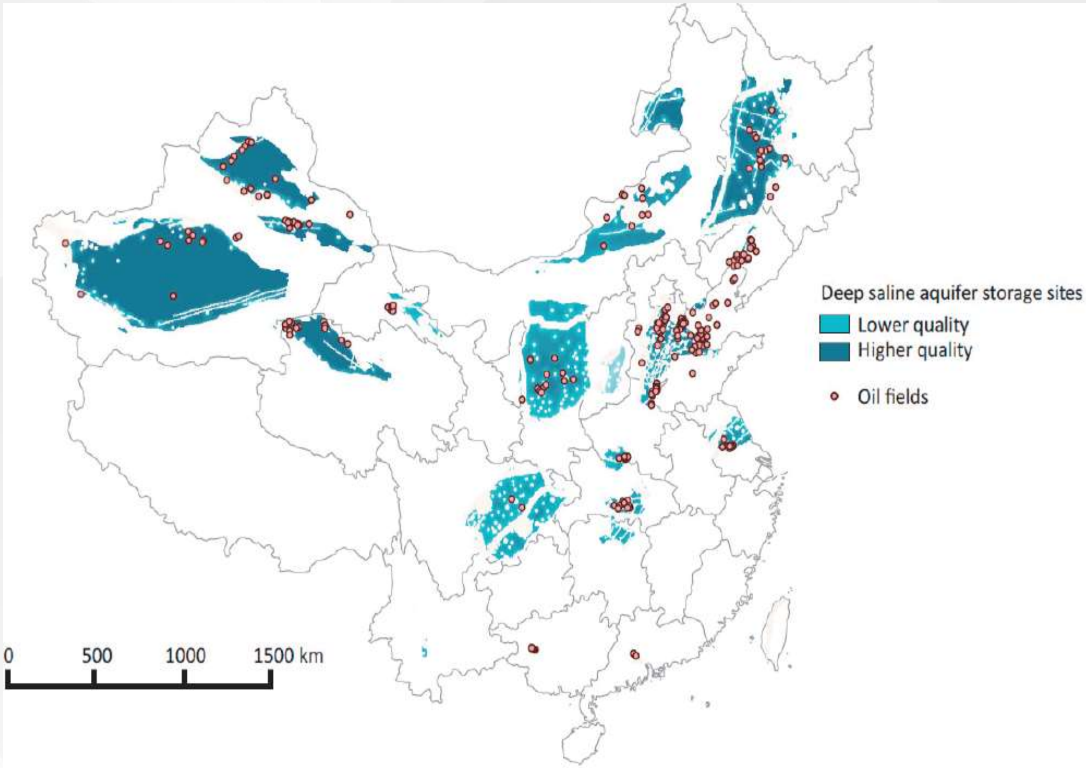
注：**第一代捕集技术**指现阶段已能进行大规模示范的技术，如胺基吸收剂、常压富氧燃烧；**第二代捕集技术**指技术成熟后能耗和成本可比成熟后的第一代技术降低30%以上的新技术，如新型膜分离技术、新型吸收技术等。

(4) Carbon storage in China 碳封存技术现状

The potential for CO_2 storage in China is about 1.21-4.13 trillion tons. **中国地质封存潜力约为1.21~4.13 万亿吨。**

The potential for CO_2 storage

- **Oil fields:** Songliao Basin, Bohai Bay Basin, Ordos Basin and Junggar Basin. **CO_2-EOR,** 5.1 billion tons.
- **石油区域：松辽盆地、渤海湾盆地、鄂尔多斯盆地、准噶尔盆地。CO2-EOR，51亿吨。**
- **Gas fields:** Ordos Basin, Sichuan Basin, Bohai Bay Basin and Tarim Basin. **Depleted gas fields:** 15.3 billion tons; **CO_2-EGR:** 9 billion tons.
- **天然气区域：鄂尔多斯盆地、四川盆地、渤海湾盆地和塔里木盆地。已枯竭的天然气田：153亿吨； CO2-EOR， 90亿吨。**



The potential for CO_2 storage in China

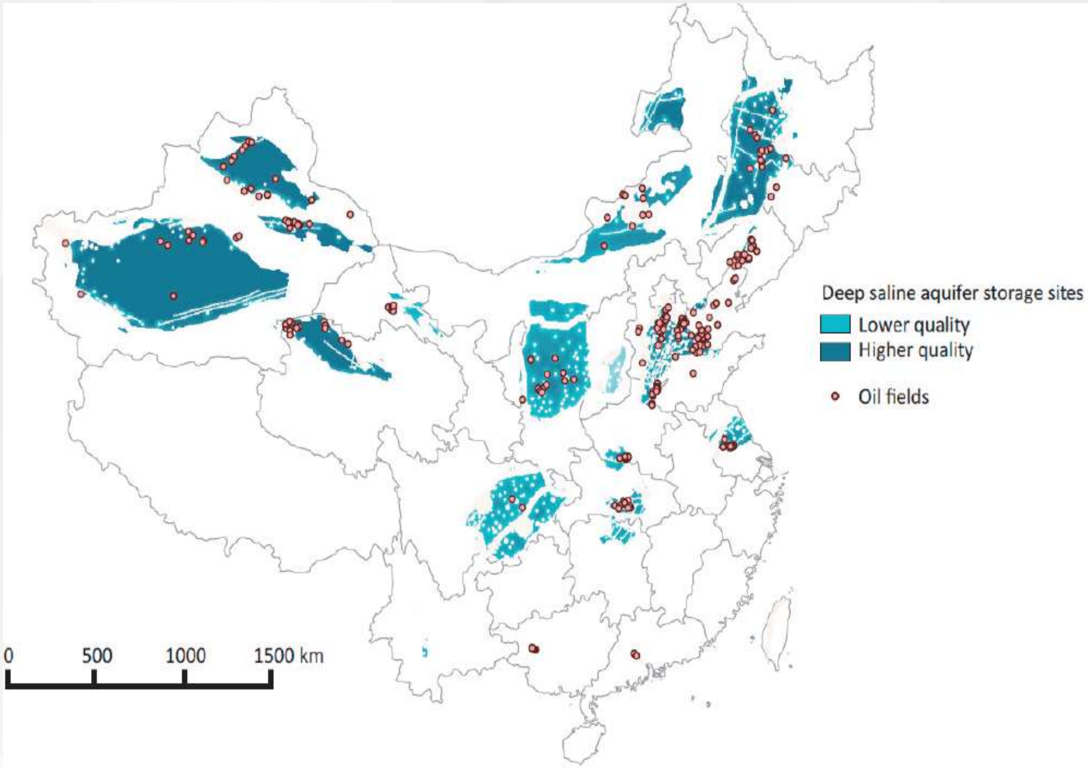
Ref: Roadmap for Carbon Capture and Storage Demonstration and Deployment.

(4) Carbon storage in China 碳封存技术现状

The potential for CO_2 storage in China is about 1.21-4.13 trillion tons. **中国地质封存潜力约为1.21~4.13 万亿吨。**

The potential for CO_2 storage

- **Deep saline aquifer:** 2420 billion tons.
  Songliao Basin: 694.5 billion tons;
  Tarim Basin: 552.8 billion tons;
  Bohai Bay Basin: 490.6 billion tons;
  Subei Basin: 435.7 billion tons;
  Ordos Basin: 335.6 billion tons.
- **深层咸水含气层：24200亿吨。**
  松辽盆地：6945亿吨；
  塔里木盆地：5528亿吨；
  渤海湾盆地：4906亿吨；
  苏北盆地：4357亿吨；
  鄂尔多斯盆地：3356亿吨。



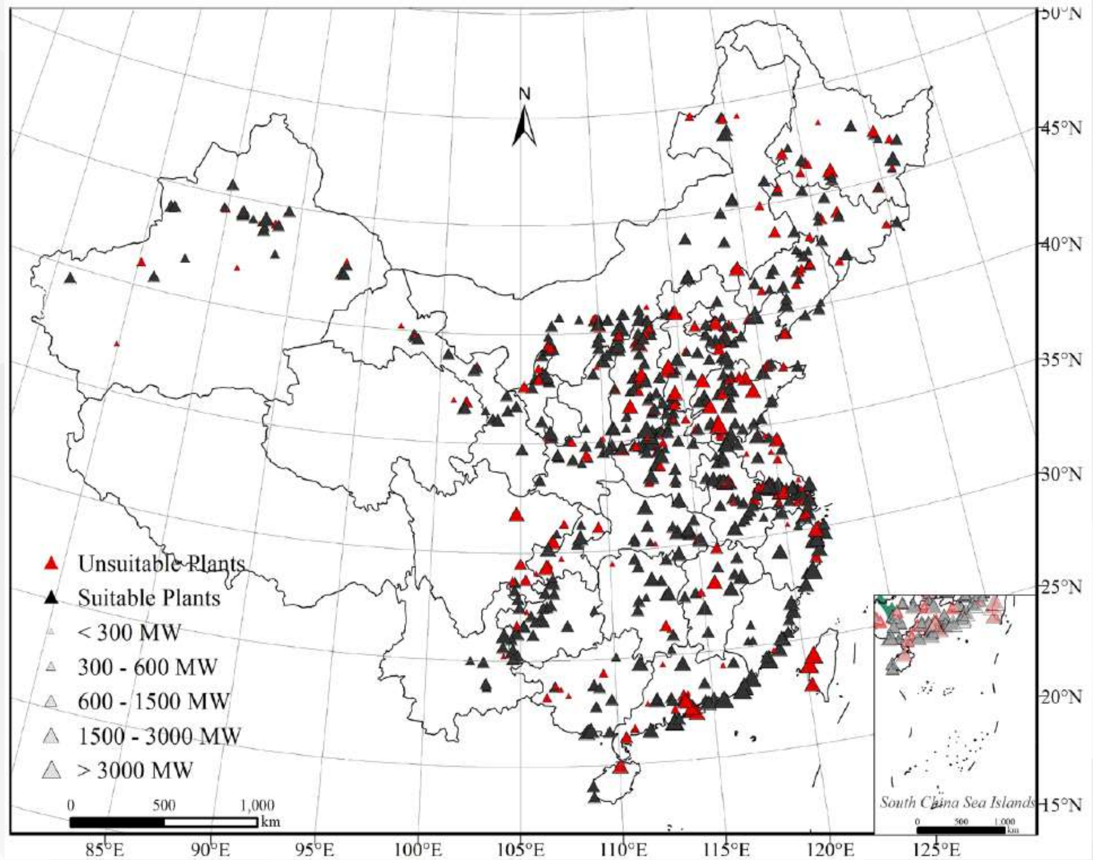
The potential for CO_2 storage in China

Ref: Roadmap for Carbon Capture and Storage Demonstration and Deployment.

(5) Retrofitting coal-fired power stations with CCUS 煤电机组的CCUS改造

Suitability Criteria for Power Plants
发电厂适用性标准

- Proximity to CO_2 storage site ≤ 800km;
- **距离二氧化碳储存地点 ≤ 800公里**
- Unit age ≤ 40 years;
- **使用年限 ≤ 40年**
- Unit size ≥ 600 MW, or the total amount of capturable CO_2 ≥ 10 Mt/year and annual operating hours ≥ 4000.
- **单元容量 ≥ 600兆瓦，或可捕获二氧化碳总量 ≥ 10百万吨/年且年运行小时数 ≥ 4000。**

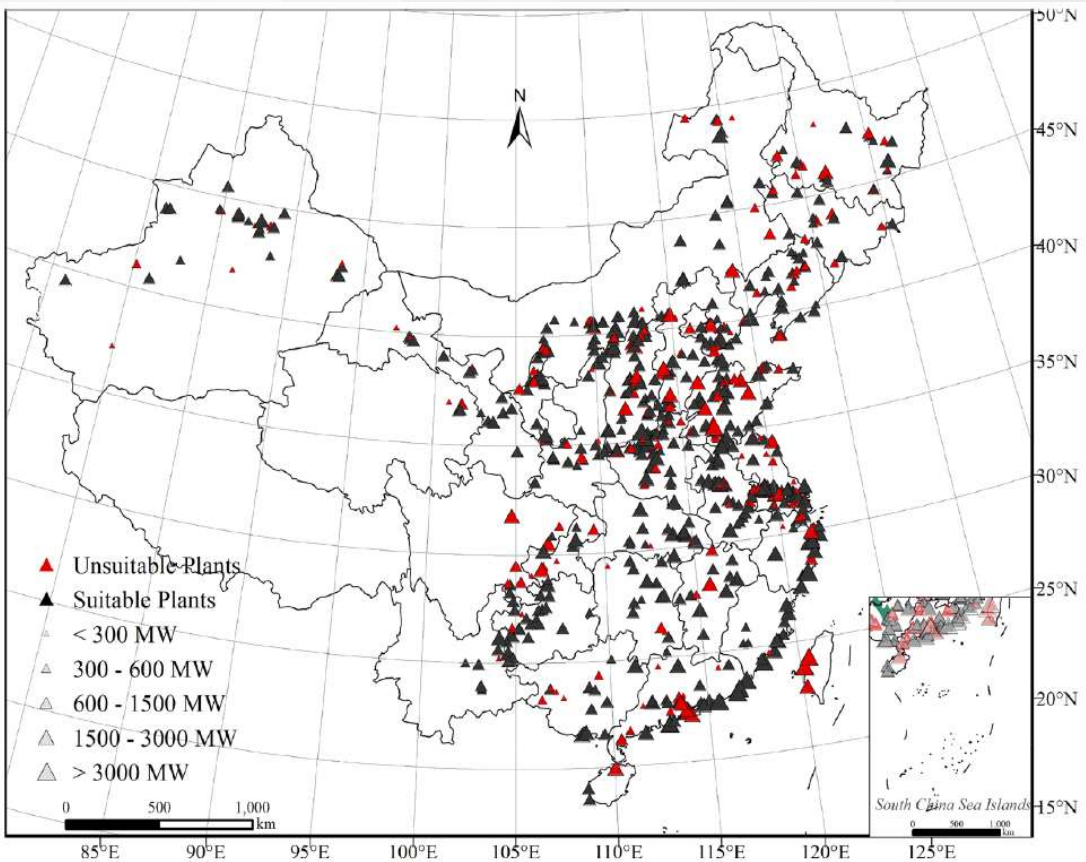


Distribution of coal power plants with suitability results

Source: Decarbonizing the Coal-Fired Power Sector in China via Carbon Capture, Geological Utilization, and Storage Technology

(5) Retrofitting coal-fired power stations with CCUS 煤电机组的CCUS改造

- At least **613 GW or 508 plants (73% of total installed capacity or 63% of total coal plants)** appear suitable for CCUS retrofits. The total CO_2 emission is about 2.2 Gt/year.
- **至少有613千兆瓦或508座电厂（占总装机容量的73%或总煤电厂的63%）适合进行碳捕获利用与储存（CCUS）的改造。总二氧化碳排放约为每年22亿吨。**
- Almost all selected coal power plants with one or more generating units of more than 600 MW capacity were built between 2005 and 2015. **These plants still have many decades of expected operational life.**
- **几乎所有含有一个或多个容量超过600兆瓦发电单元的燃煤电厂都建于2005年至2015年之间，这些电厂仍有数十年的预期运营寿命。**



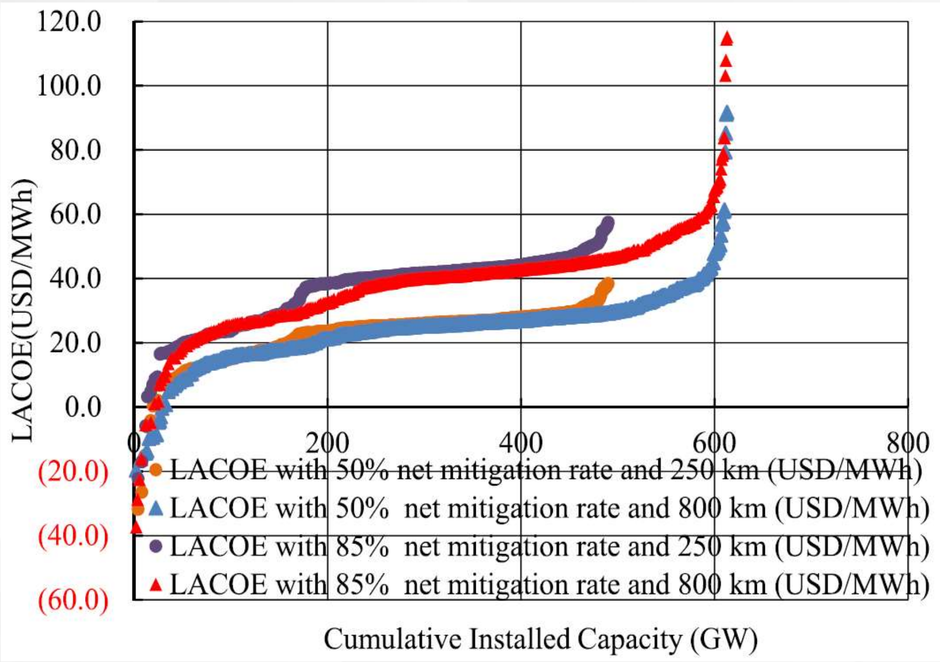
Distribution of coal power plants with suitability results

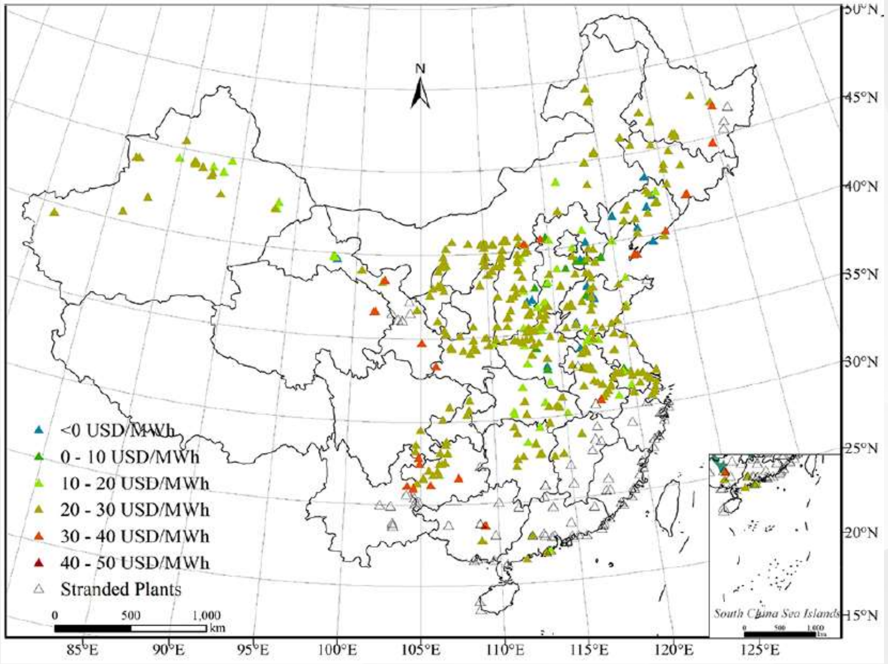
Source: Decarbonizing the Coal-Fired Power Sector in China via Carbon Capture, Geological Utilization, and Storage Technology

(5) Retrofitting coal-fired power stations with CCUS 煤电机组的CCUS改造

- Retrofitting CCUS to the existing coal fleet would increase the LCOEs by an average of 24.1-37.2 USD/MWh for the entire fleet with between 50% and 85% net mitigation rates.

将碳捕获利用与储存（CCUS）改装到现有的燃煤电厂将使整个电厂的电力生产成本（LCOEs）增加，净减排率在50%至85%之间的电厂平均增加24.1-37.2美元/兆瓦时。





Source: Decarbonizing the Coal-Fired Power Sector in China via Carbon Capture, Geological Utilization, and Storage Technology

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(1) Technologies included in PtX PtX中的技术

Most of the PtX technologies are based on power-to-hydrogen, except for power-to-cool and power-to-heat. **除了电转冷、电转热以外，大部分PtX技术都是基于电转氢。**

Main technologies of PtX

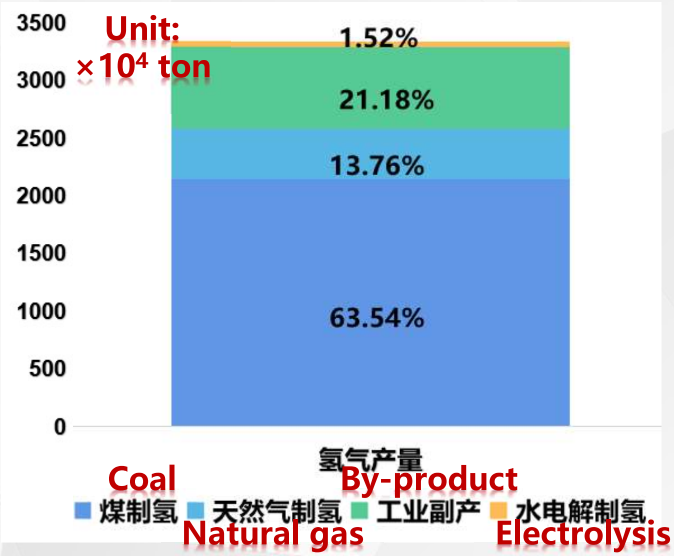
Name	Advantages	Limitation	Technologies	Stage
Power to Cool (P2C) 电转冷	clean, convenient 清洁、便利	-	air conditioners 空调	commecial application 商业应用
Power to Heat (P2H) 电转热	clean, safe, convenient 清洁、安全、便利	low energy efficiency in a complete cycle, high cost 在一次完整循环中，能效较低、成本较高	heat pumps, electric boiler, electric heater 热泵、电锅炉、电暖器	initial stage of commecial application 商业应用初始阶段
Power to Gas (P2G) 电转气	clean, flexible 清洁、灵活	low energy efficiency in a complete cycle, high cost 在一次完整循环中，能效较低、成本较高	electrolysers 电解槽	demonstration & initial stage of commercial application 示范&商业应用初始阶段
Power to Liquid (P2L) or Power to Fuels (P2F) 电转液或电转燃料	clean 清洁	high cost 成本高	electrolysers, synthesis 电解，合成	demonstration 示范
Power to Chemicals (P2C) or Power to Products (P2P) 电转化学或电转产品	clean 清洁	high cost 成本高	electrolysers, synthesis 电解，合成	demonstration 示范
Power to Power (P2P) 电转电	long storage time 长周期存储	high cost, low efficiency 成本高，能效低	fuel cells 燃料	demonstration 示范

Source: Research on P2X Technology Progress and its Participation in Power System Operation Optimization Simulation

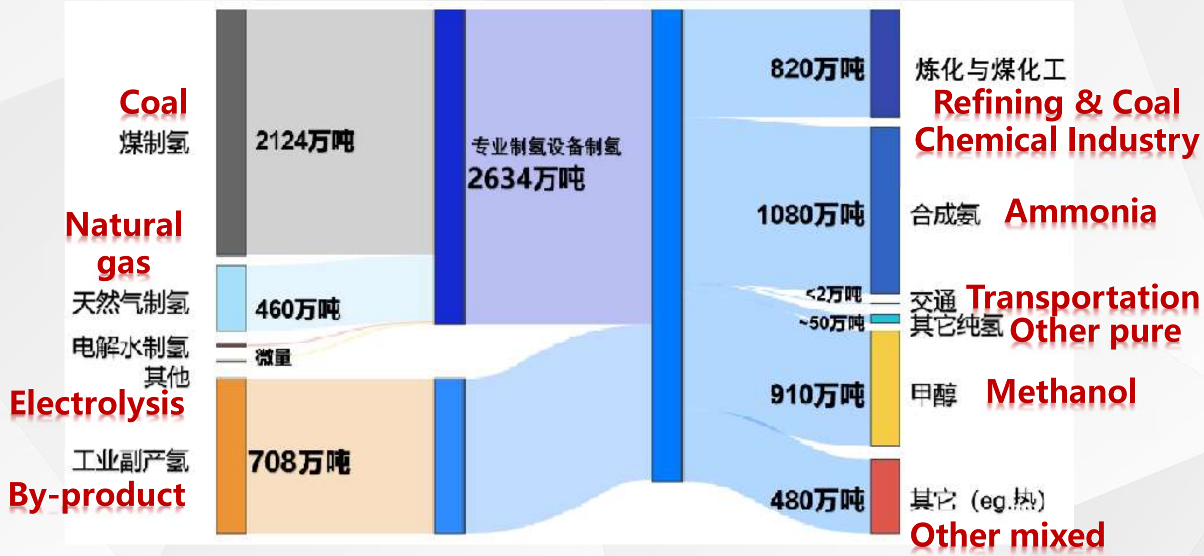
(2) Hydrogen production and consumption in China 中国氢能的产消

The current hydrogen production is fossil-fuel based (coal, natural gas and industrial by-product). The largest share of hydrogen demand is from the chemicals sector for the production of ammonia (10.8 million tons/year, 32.3%) and methanol (9.1 million tons/year, 27.2%).

目前的氢气生产主要依赖化石燃料（煤炭、天然气和工业副产品）。氢气需求的最大份额来自化工行业，用于氨的生产（每年1080万吨，占32.3%）和甲醇的生产（每年910万吨，占27.2%）。



The supply structure of hydrogen in China



The hydrogen flow diagram in China

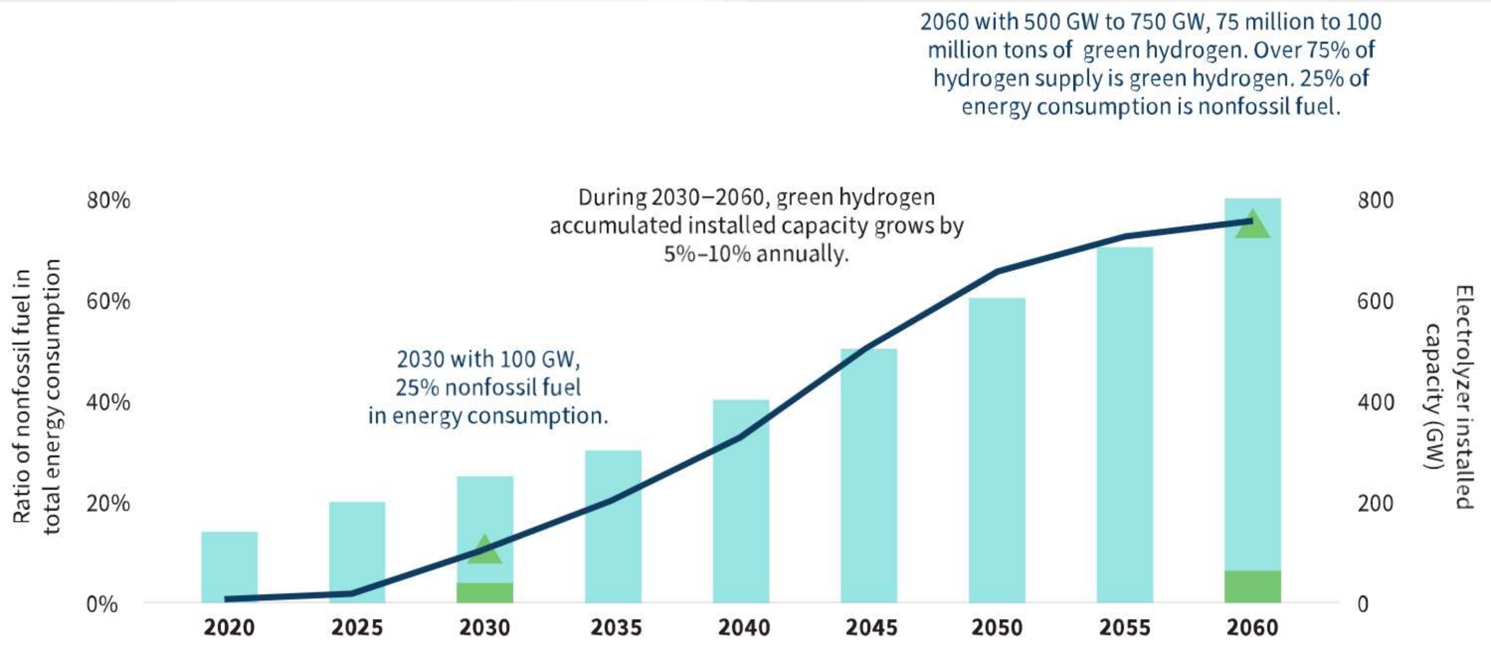
Ref: China hydrogen energy and fuel cell industry development report 2020.

(3) Scale of power-to-hydrogen in China 中国电制氢的规模

The production of hydrogen in 2019 is 33.42 million tons, around 1/3 of the world's total (115 million tons). **2019年，中国的氢气产量为3342万吨，约占全球总产量（1.15亿吨）的三分之一。**

Green Hydrogen

- **Now**: 161 projects are planned, 12 are in operation, 22 under construction, **23100 tons per year. 计划161个项目，12个在运营，22个在建，每年23100吨。**
- **2030: 7.7 million tons per year， 100GW electrolysers. 770万吨/年，100GW电解槽。**
- **2060: 75-100 million tons per year.每年0.75-1亿吨。**



Development of renewable hydrogen capacity under 100 GW scenarios

Source: Opening China's Green Hydrogen New Era: A 2030 Renewable Hydrogen 100 GW Roadmap

(4) Technical iusses and cost of power-to-hydrogen in China 中国电制氢的技术问题及成本

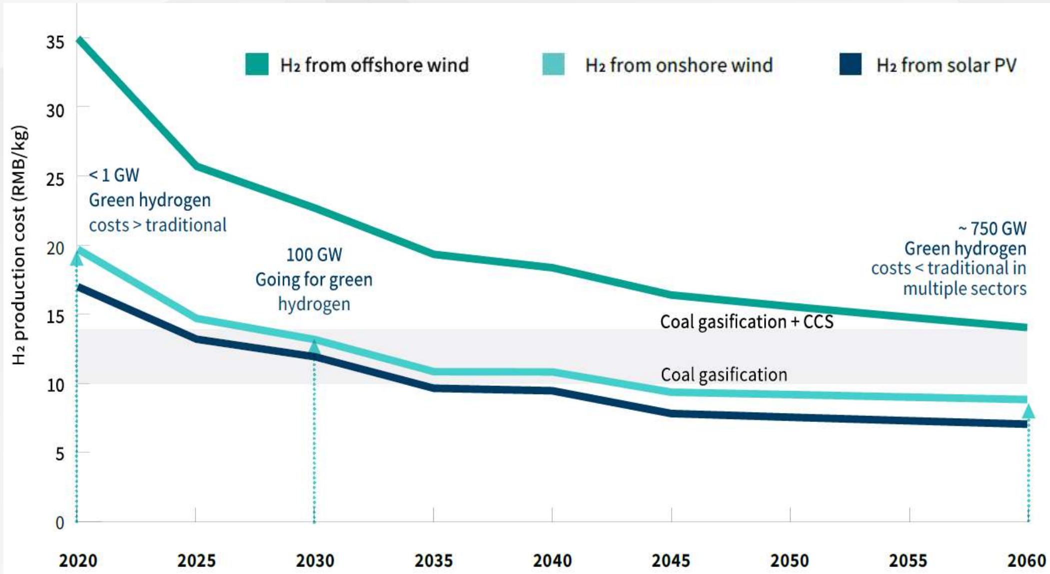
	ALK	PEM	SOEC	AEM
Efficiency (kWh/Nm$_3$) 能效	4.2	5	3.0-4.0	4.5-5.5
Single electrolyser (Nm^3/h) 单个电解槽	1400	200	-	-
Stage 应用阶段	Commercial Application	Initial Stage of Commercialization	Demonstration	R&D

Green Hydrogen Production

■ The proton exchange membrane and catalyst (platinum, iridium) are highly dependent on import. **质子交换膜和催化剂（铂、铱）高度依赖进口。**

■ As the scale of electrolyzers expands to 100 GW, the investment cost of ALK electrolyzers in China will decrease from 2000 RMB/kW in 2020 to 1500 RMB/kW in 2030. **随着电解槽规模扩大到100 GW，中国的ALK电解槽投资成本将从2020年的每千瓦2000元降低到2030年的每千瓦1500元。**

■ The average total cost of green hydrogen will drop to 13 RMB/kg. **绿色氢气的平均总成本将下降到每千克13元。**



Production cost of green hydrogen

Source: Opening China's Green Hydrogen New Era: A 2030 Renewable Hydrogen 100 GW Roadmap

(5) Industrial application of power-to-hydrogen in China 中国电制氢技术的工业应用

Green hydrogen projects are beccoming more and more common. However, hydrogen producers are reluctant to interact with the power grid. **绿氢项目越来越常见，然而产氢端与电网互动较少。**

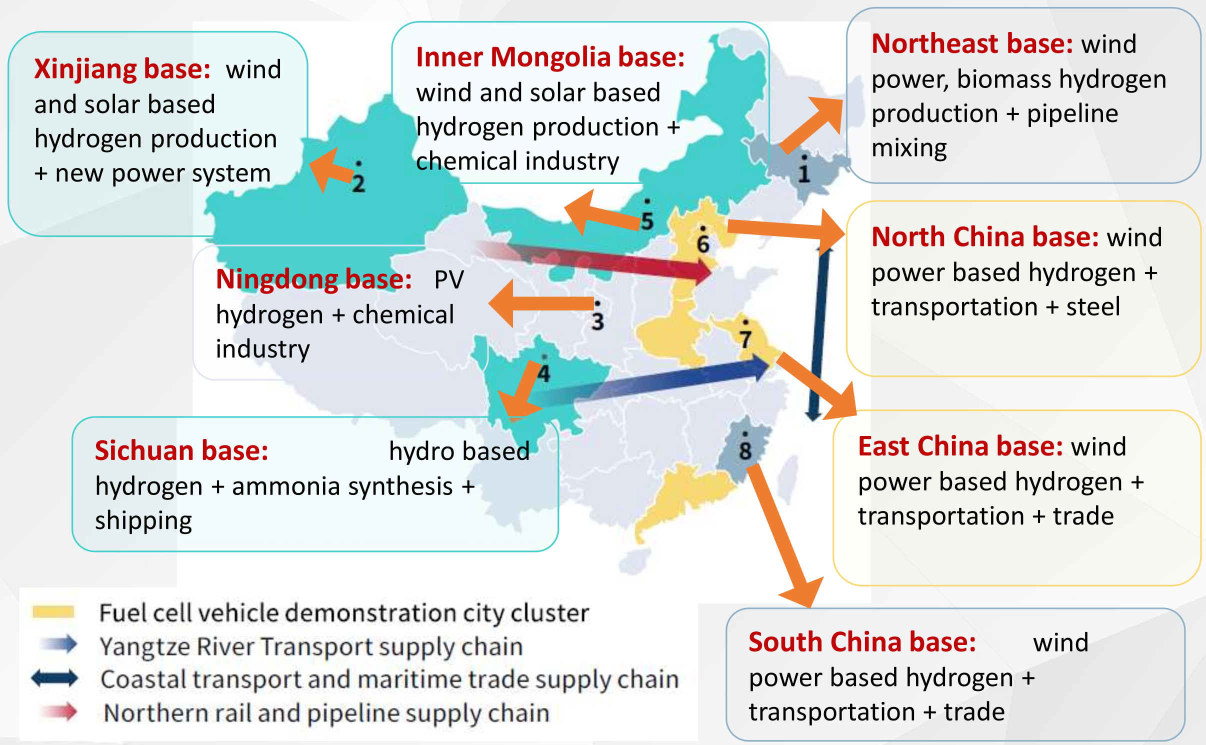
Representative Projects

■ **Ningxia:** National demonstration project for H_2 produced through elecytrolysis powered by solar energy, **largest in the world**, 200 MW PV + 30000 Nm^3/h eletrolysers, H_2 used for chemical synthesis.

■ **宁夏：通过太阳能电解制氢的国家示范项目，是世界上最大的项目，包括200 MW光伏发电和30000 Nm³/h的电解槽，生产的氢气用于化学合成。**

■ **Xinjiang: Kucha project,** will build 300 MW PV station (618 GWh of electricity) and 52000 Nm^3/h of electrolysers, H_2 used for refining.

■ **新疆：库车项目，将建设300 MW光伏电站（发电量为618 GWh）和52000 Nm³/h的电解槽，用于炼油过程中的氢气生产。**



Source: Opening China's Green Hydrogen New Era: A 2030 Renewable Hydrogen 100 GW Roadmap

(6) Hydrogen and the power grid 氢能和电网的关系

- **Reducing VRE curtailment 降低弃风弃光率**
- **Long-term energy storage 长周期储能**

Hydrogen storage, hydrogen-fueled gas turbines and fuel cells can realize long-term energy storage.

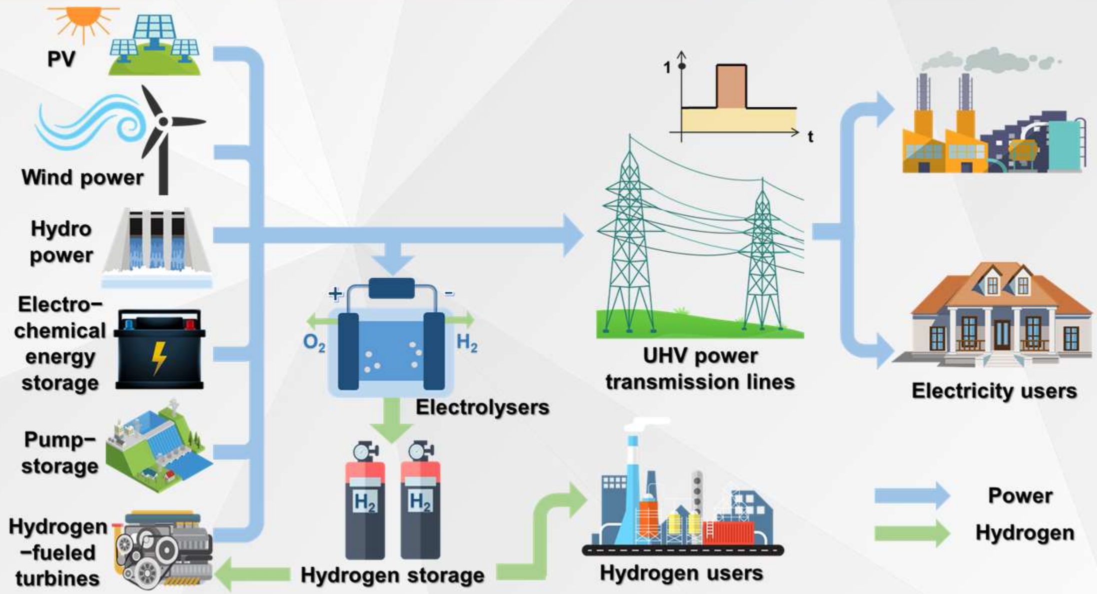
储氢结合燃氢机组或燃料电池，保障新能源为主体下的全时段电力电量平衡。

- **Providing grid-balancing services via electrolysers 为电网提供调峰、调频等辅助服务**
- **Transporting renewable power over long distances as H_2 将可再生能源转化为氢能实现大范围优化配置**

Little investment is needed to adapt natural gas infrastructure to transport hydrogen.

利用新能源尖峰出力制氢，利用天然气管道或氢气管道进行输送，缓解电网外送新能源的压力。

Ref: Comparison of Different Coupling Modes between the Power System and the Hydrogen System Based on a Power–Hydrogen Coordinated Planning Optimization Model



Different Power-hydrogen Coupling Modes

- **power–hydrogen coupling at the load side 受端电氢耦合**
- **power–hydrogen coupling at the source side 源端电氢耦合**
  - for power transmission **输电**
  - for hydrogen transport **输氢**
  - for local usage **就地利用**

Thank you!