THE OXFORD INSTITUTE FOR ENERGY STUDIES

China clean energy innovation and the global clean energy transition

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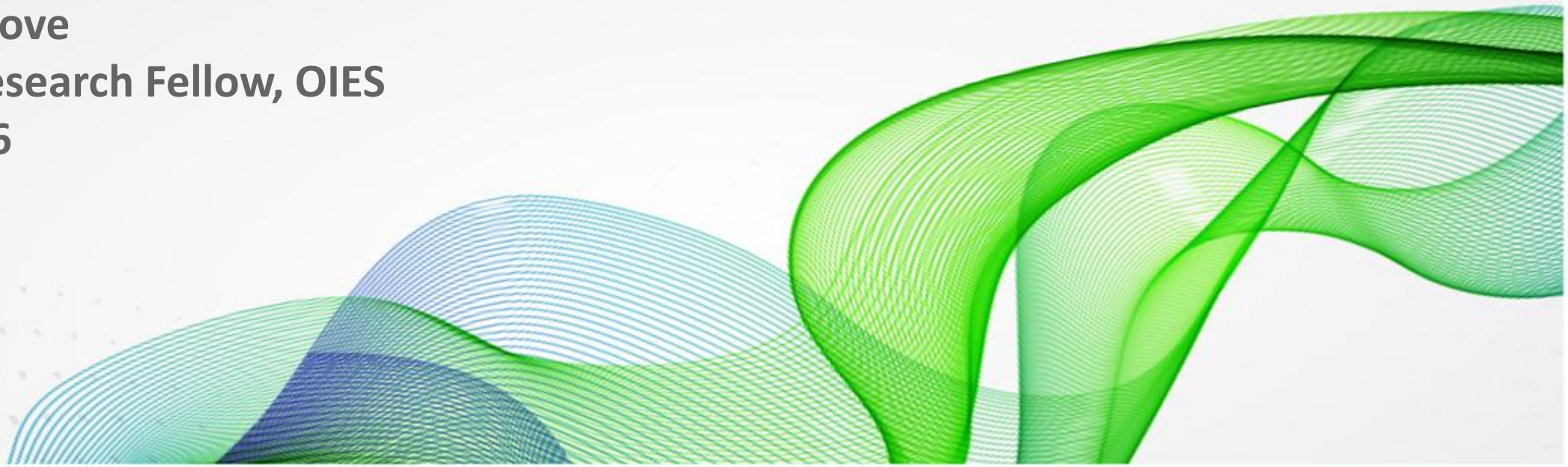


Presentation outline: key factors in China’s clean energy revolution

- ‘Socialist market economy’ with a weak central state
- Policy: industrial policy, including subsidies, targets, and resources for favoured industry
- Human capital: workforce, scientists, and links to international expertise
- Entrepreneurship, including in partnership with the state
- Match between technology characteristics and China’s (manufacturing-led) economic structure, built around domestic geographic supply chain clusters

Contrast between Washington Consensus and China model

Washington Consensus or Western Model

- Technology neutral (don't pick winners); focus on 'level playing field' and consumer benefit
- Price externalities; enable the market to decide – both ST (consumers, power sector dispatch) and LT (investment)
- Fund R&D to ensure technology leadership (the 'Entrepreneurial State'), scale up and commercialize via the private sector (capital markets)
- Free trade that benefits consumers and industry, enabling dominance of 'high-value' sectors and offshoring 'commodity manufacturing'

Contrast between Washington Consensus and China model

China model

- State identifies strategic emerging industries, and channels capital and resources to firms and entrepreneurs in those fields
- Market mechanisms (carbon pricing, power markets) exist to guide ST firm behaviour based on best practices, not intended to price externalities or guide investment
- Local governments actively intervene to promote economic specialization, supply-chain integration / scale up, local hyper-competition
- Trade is managed to encourage or require localization and ‘mastery’ of whole supply chain

How China stacks up as a clean technology innovation system (TIS)

Critical enabling factors for technology innovation systems (Hekkert 2007; Bergek 2008)

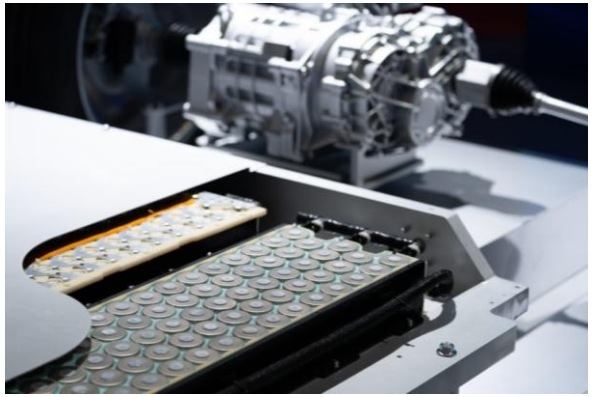
1. Entrepreneurial activities	High in disruptive techs, powerful incumbents
2. Knowledge development	R&D spending, patenting, workforce
3. Knowledge networks	Access to global knowledge, supply chain linkages
4. Guidance of search	FYP, SEI designation, targets, R&D catalogs
5. Market formation	Capital investment bias, market barriers
6. Resource mobilization	High: SOE soft budget constraint, POE low CoC
7. Legitimacy	Success in strategic emerging industries, confidence in policy stability, carbon policy since 2020

China’s Clean Energy Take-off: Role of Policy

Wind power

- Long-term policies: renewable law, renewable obligation, CDM local content requirement
- Subsidies: FIT
- Targets: FYPs, NDC, technology catalogues

PV



Batteries

- Long-term policies: local content requirements for EV subsidies
- Subsidies: low-cost loans

EVs

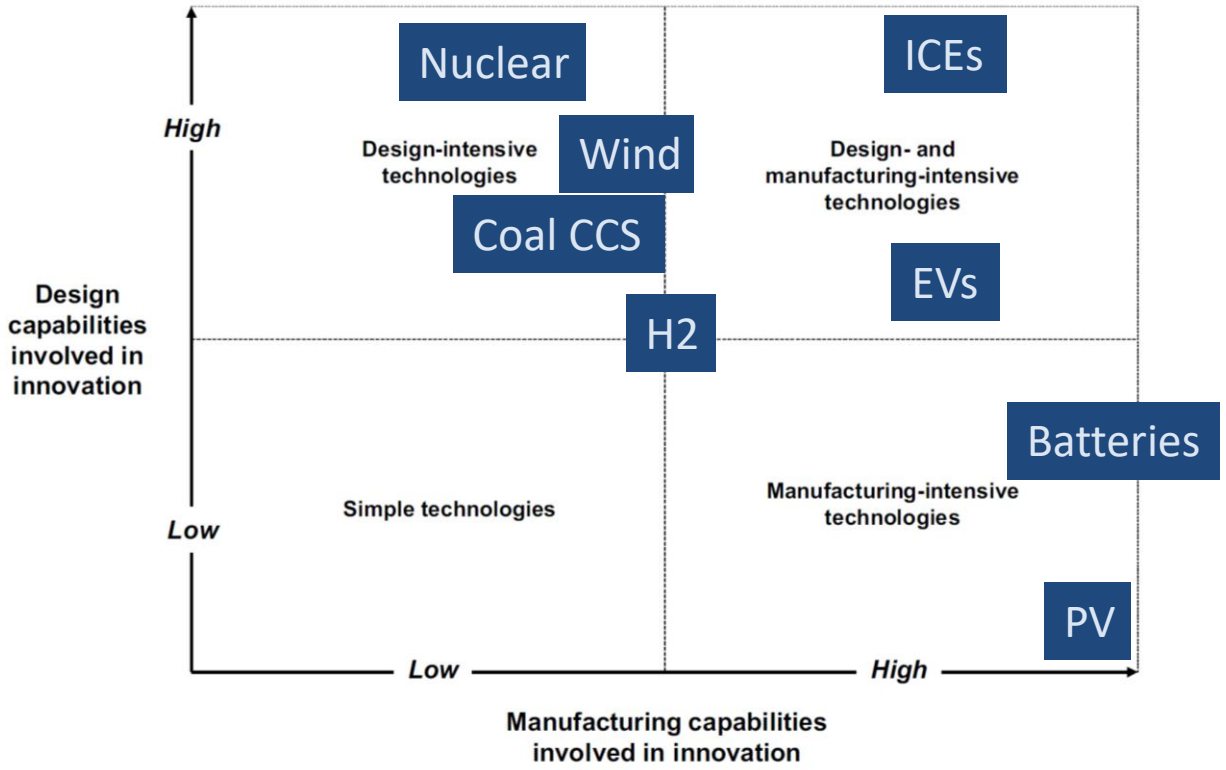
- Long-term policies: NEV mandate, local policies, SEI
- Subsidies: tax, purchase subsidy
- Targets: 2025, 2027, and 2030

How did technology transfer happen so fast?

- Wind: Clean Development Mechanism, local content requirements, JVs and partnerships
- PV: Turnkey production lines, acquisition of defunct solar startups
- Batteries: Turnkey production lines, local content requirements, licensing and patent acquisitions
- EVs: JV requirements, FDI (BYD, Tesla)

Technology characteristics and the nature of tech diffusion

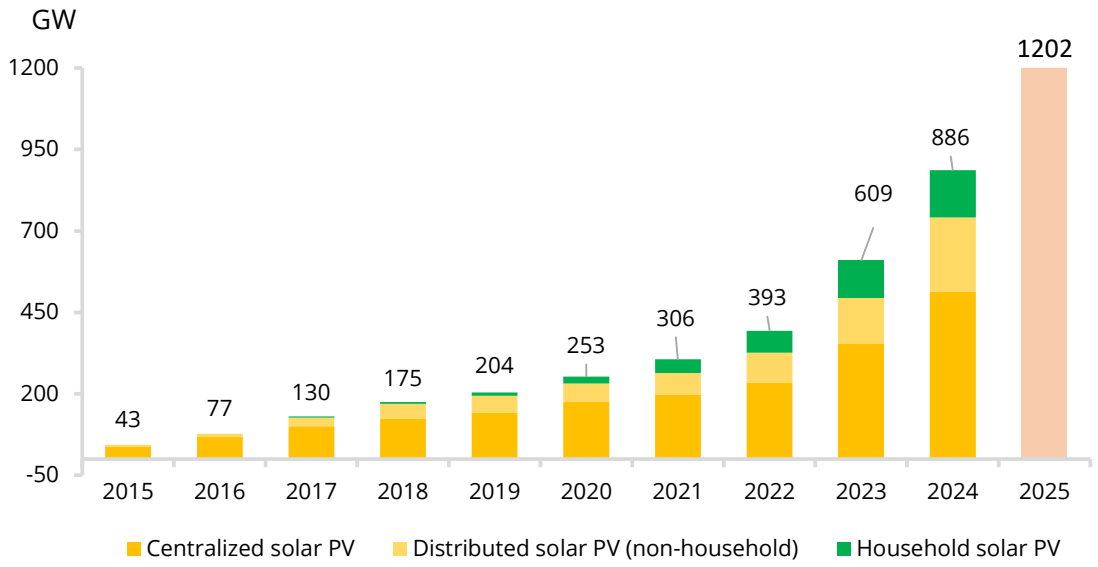
- Clean energy technologies are relatively manufacturing intensive
- Speed of scale-up depends on manufacturing knowhow, size of market
- Turnkey production lines result in lower barriers to entry
- Global knowledge base assists tech transfer
- Vertical integration accelerates learning-by-doing, by enabling interactions among suppliers



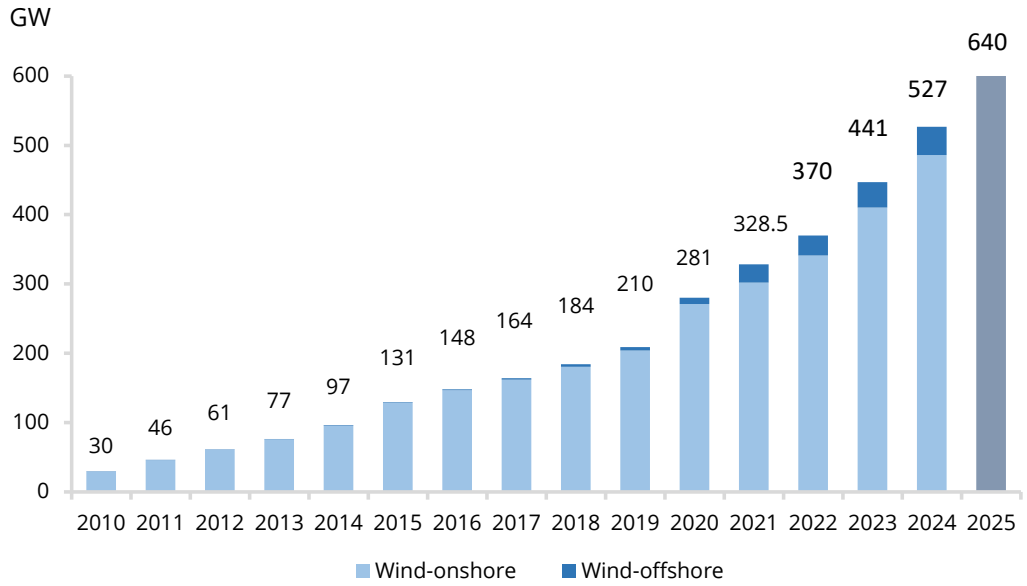
SCHMIDT & HUENTELER (2016)

Domestic demand is key to China's scale-up (1)

China PV capacity, 2015 to 2025, in GW



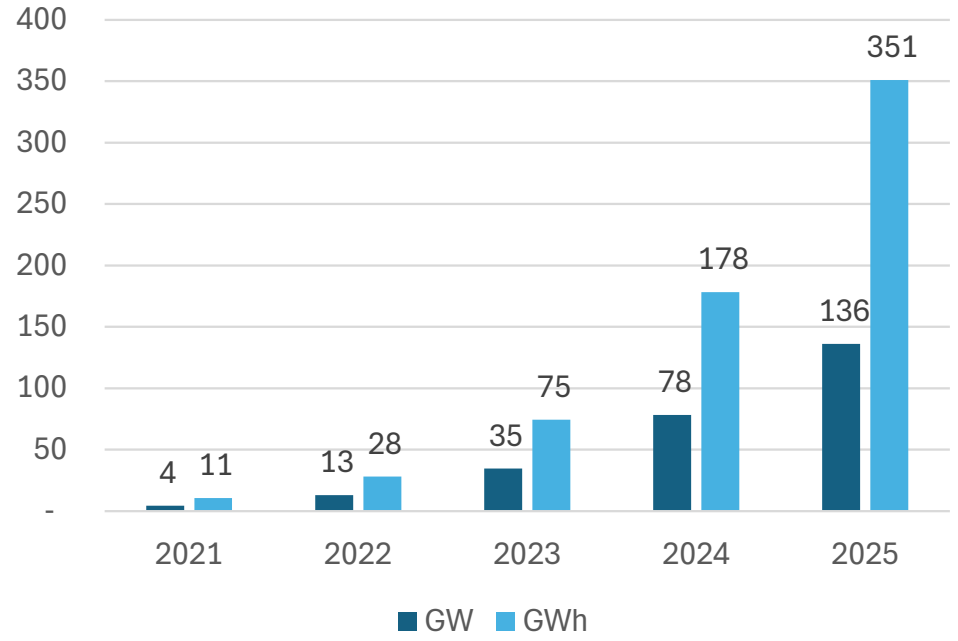
China wind capacity, 2015 to 2025, in GW



Source: OIES, based on NEA data

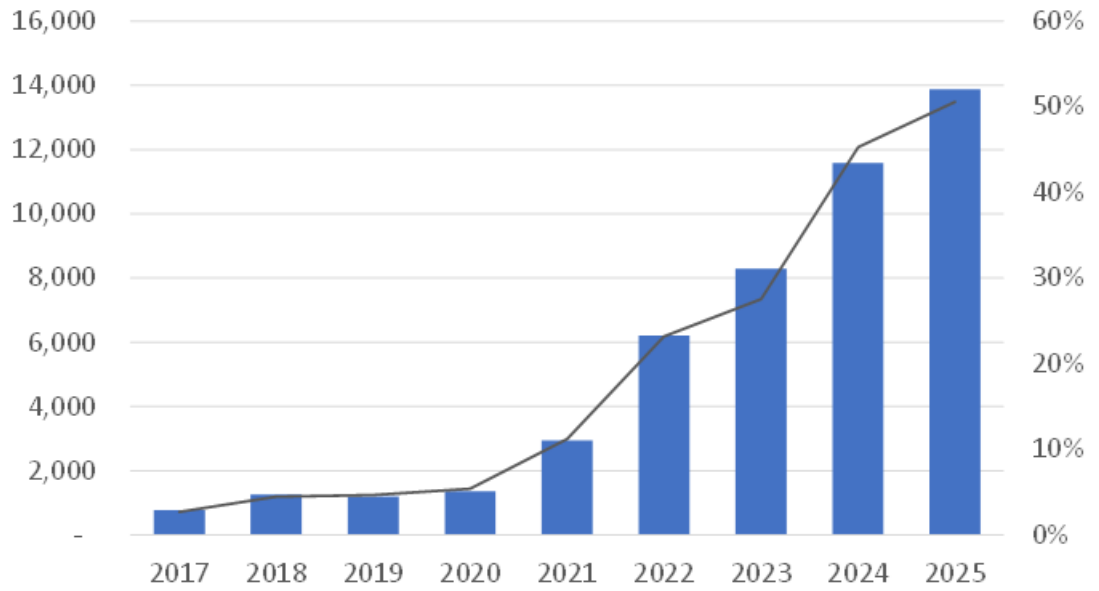
Domestic demand is key to China's scale-up (2)

China grid-scale battery capacity, 2021 to 2025



Source: OIES, based on CNESA data

China Domestic NEV sales, NEV % market share



Source: OIES, based on CAAM data

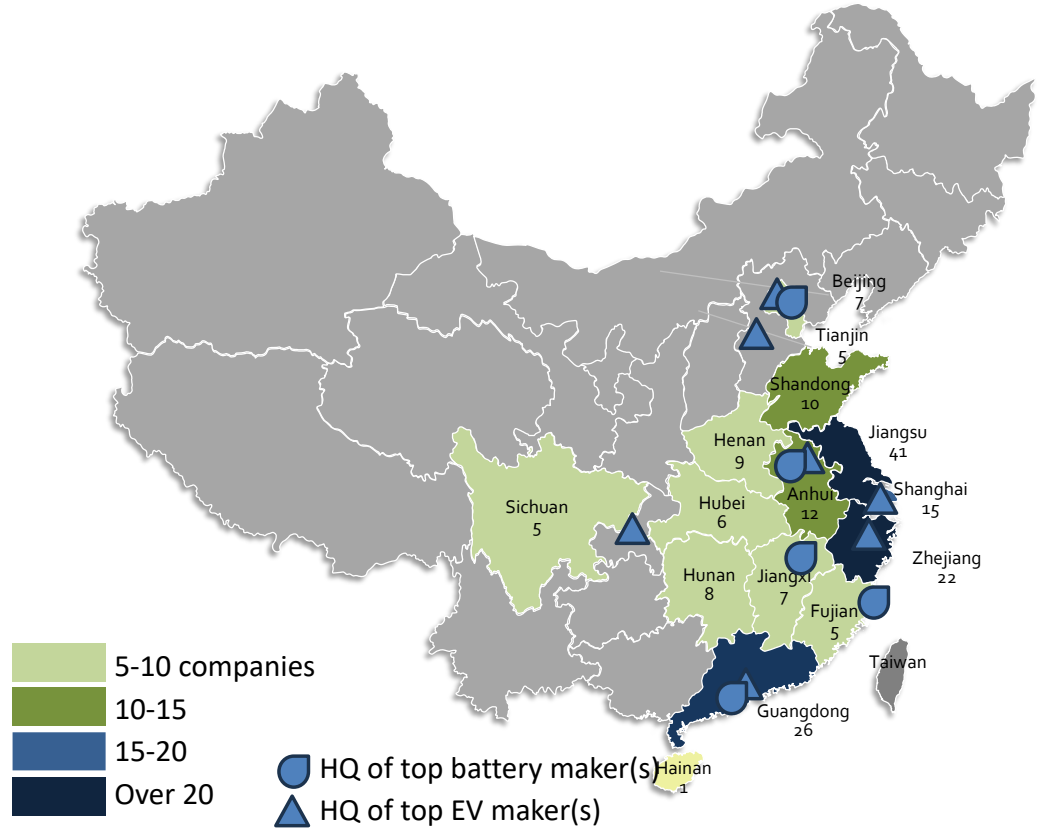
How do pilot programmes actually work in China?

- Pilots are often cited as a hallmark of China's economic development strategy
- Advantages:
  - Experimentation
  - Motivation for local officials
  - Target resources
- Disadvantages
  - Duplication
  - Overcapacity / value-destructive bankruptcies
- EV case shows pilot strategy at its best
  - NEV pilot provinces selected by political-economic criteria: (1) car manufacturing, (2) existing EV policies, (3) infrastructure
  - Subsidies targeted to best provinces, and withheld if province didn't meet own targets (EV adoption, infrastructure)
  - Synergy with content requirement and FDI
- Shenzhen, Beijing, and Shanghai show that many paths were available to high EV penetration

Big role for vertical integration and industrial clusters

- Encouraged by local government
- Intense competition within each cluster, especially among suppliers
- Co-evolution of technology
- Entrepreneurs see benefits of vertical integration and clustering
  - Trina
  - CATL
  - BYD
- Critical to speed and scale-up

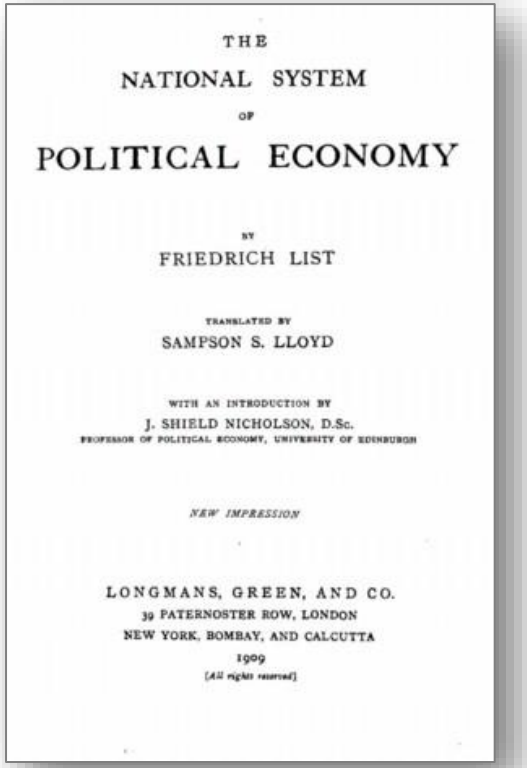
Battery and EV manufacturing clusters, 2021

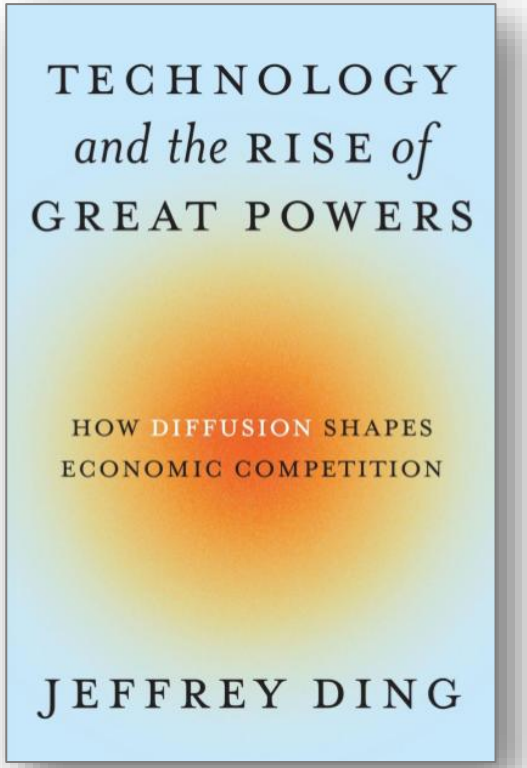


Source: Boy Lüthje et al., 'China's New Energy Vehicle Battery Industry', 2021

Intellectual capital, workforce composition critical enablers

- Science and technology focus encouraged since Reform and Opening
- Support for top universities, emphasis on technical fields
- Recruitment of returning scholars, entrepreneurs
  - Encouragement of study abroad
- Massive increase in R&D spending – now 2.8% GDP
- Incentives for patent filings, scientific publications



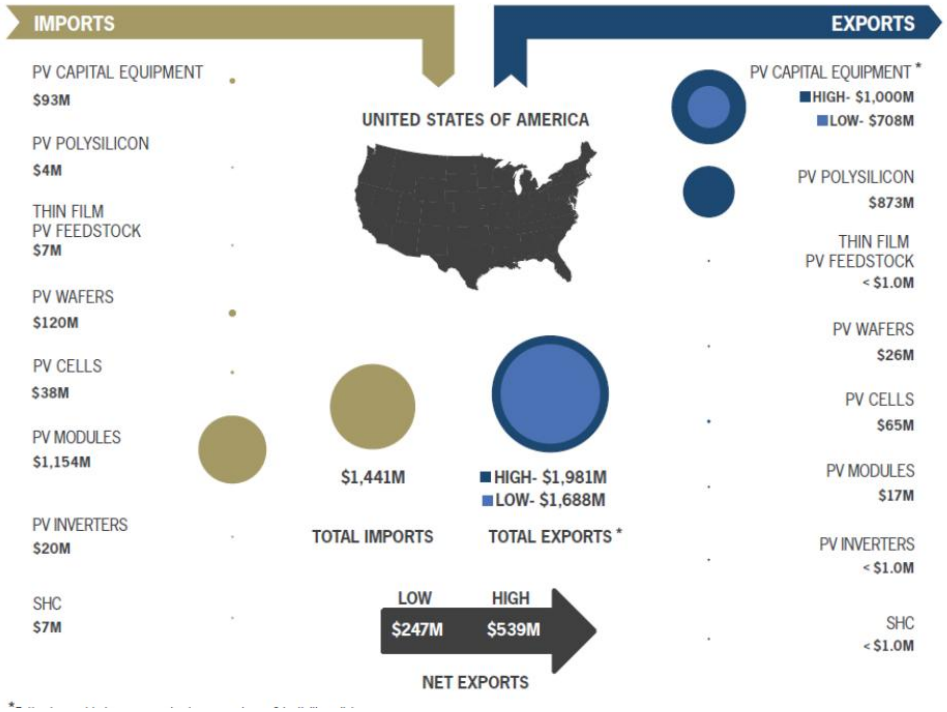


Shift in manufacturing and demand → shift in high value too

Example of solar industry

- 2011 Alan Goodrich (NREL) paper: U.S. benefits from solar PV trade with China, maintains lead in highest-value tools
- March 2017 Jefrey Ball New Solar System report: China now producing high-end tools, albeit with lower quality
- 2022 IEA report (Special Report on Solar PV Global Supply Chains): China now dominates global manufacturing of high-end solar manufacturing tools

US-China solar trade balance, 2011



Source: Alan Goodrich et al., National Renewable Energy Laboratory, 2011

Startups and entrepreneurships central to China new energy industry

Trina

- Founder: Jifan Gao
- Founded 1997, Changzhou, Jiangsu
- Founder background: Detergent, energy-efficient building materials

Yingli

- Founder: Liansheng Miao
- Founded 1998, Baoding, Hebei
- Founder background: Cosmetics, water purification

Jinko

- Founder: Xiande Li
- Founded 2006, Shangrao, Jiangxi
- Founder background: Firefighting equipment

LDK

- Founder: Xiaofeng Peng
- Founded 2004, Nanjing, Jiangsu
- Founder background: Chemical protective clothing

Startup leaders focused on manufacturing

BYD

- Wang Chuanfu
- Company origins in contract manufacturing for Nokia, Eriksson
- Focused on mastering all aspects of electronics

Geely

- Li Shufu
- Founded Geely in 1990s
- Ambition to beat European companies on quality – ended up acquiring Volvo

CATL

- Robin Zeng
- Initially founded ATL in 1999, sold to LDK for $100m in 2005
- CATL initially focused on electronics

Scale-up strategy depends on securing resources & innovation

- 2000s: US solar industry focused on thin films, Europe on high-efficiency c-Si; China on conventional C-Si
- Early 2010s: US & Japanese EV exploration focused on Li-NMC battery, Li-NCA; China licenses LFP technology
- By 2022, LFP accounted for 65% of China NEV market, up from 30% in 2019
- Process repeating for Na-ion (Chang-an / CATL winter testing shown at right)

Chinese firms following familiar pattern abroad

- Localizing human resources and supply chains viewed as a positive for efficiency and scale-up
- CATL has battery plants in Germany and Hungary
- In Dec 2024, Stellantis and CATL announced will invest Euro 4.1 billion in new LFP battery plant in Spain
- Mid-2024 CATL launched Euro 1.5 billion fund for building out European supply chains

CATL prepares 1.5 billion fund to secure battery supply chain

CATL has initiated discussions with various sovereign funds and automobile manufacturers, such as Mercedes-Benz, to invite them to participate in this new financial tool, aimed at increasing its presence in Europe and other international markets.

Policy makers clearly concerned at ease of technology diffusion

New battery technology export restrictions announced October 2025:

Lithium-ion battery manufacturing:

- Winding machines, stacking machines, electrolyte-injection machines, hot presses, formation and grading systems, capacity sorting cabinets

Cathode materials and manufacturing:

- Roller kilns, high-speed mixers, sand mills, air flow mills

Graphite anode materials and manufacturing:

- Granulation process, continuous graphitization technology liquid-phase coating technology

South China Morning Post

China unleashes battery export controls as it makes strides in solid-state science

Analysts say the measures are meant to consolidate China's advantage in the lithium battery industry and slow the progress of competitors

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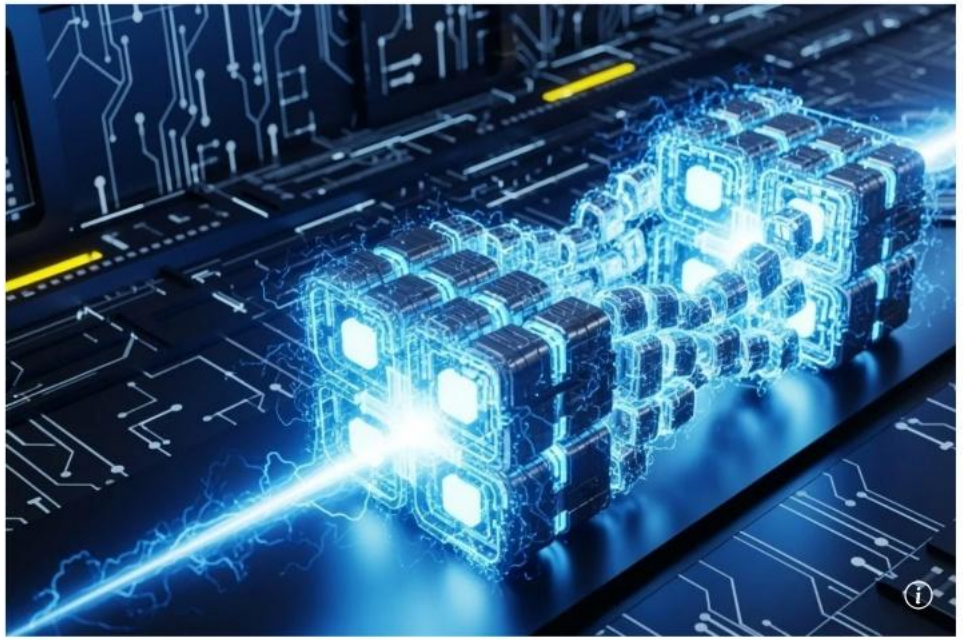

Will these strategies help the *world's* green energy transition?

Optimistic:

- Manufacturing intensive fields have lower barriers to entry
- Tacit knowledge sharing and learning-by-doing are difficult, but easier than new IP
- Chinese companies establishing technology clusters outside of China
- Many of the same policy tools employed by China are available, but effectiveness in doubt

Pessimistic:

- Advanced economies suffer from greater technology lock-in, especially when incumbent energy and manufacturing companies take the lead in managing the transition
- Developing world countries may lack skilled workforce, technology base in related industries, necessary to catch up

Industrial policy literature: old and recent findings

Old knowledge

- While comparative advantage benefits consumers in the ST, leads to a passive approach by governments, little interest in guiding development
- National Innovation Networks and Intellectual Capital position countries for future
- Protective tariffs lead to higher costs for consumers but stifle future industries – they lock in older technologies and infrastructure

Newer thinking

- U.S. and other countries recognize that R&D expertise does not translate to manufacturing knowhow, and shift of manufacturing leads to higher-value industries shifting as well
- Demand-pull policies serve as ‘guidance of search’ for industry and knowledge networks
- General purpose technologies and manufacturing technologies may require more engineering and management knowledge than top scientific talent – makes catch-up easier and means industrial transition longer, giving government ability to prepare

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