R&D Needs for MD/HD Filling in China

Jimmy Li

NICE (National Institute of Clean-and-low-carbon Energy), a part of China Energy Investment Corporation

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China Energy Investment Corporation

国家能源集团 CHN ENERGY

- China's largest power company, accounting for 15% of electricity production
- Assets: 1.8 TT RMB ($286 BB)
- Employees: 350,000
- Formed in 2017 through the merger of Shenhua Group and China Guodian Group

Coal production and use

480 MM tons mined/yr

15 MM tons chemicals/yr

Electricity generation

226 GW total installed capacity

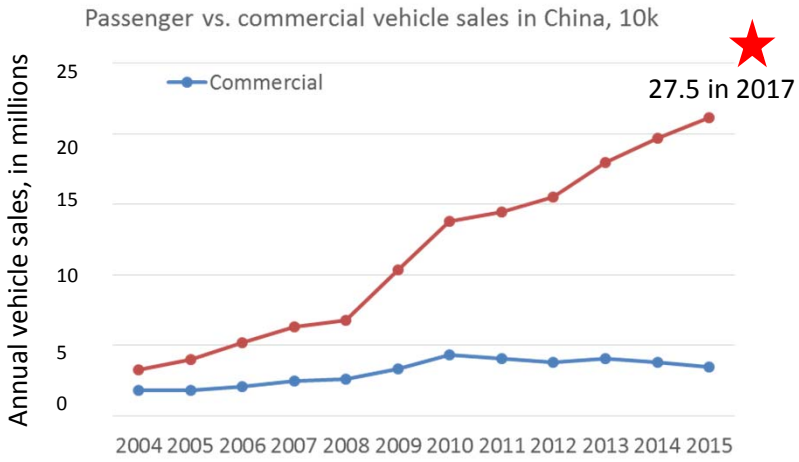
30 GW installed wind

Transportation

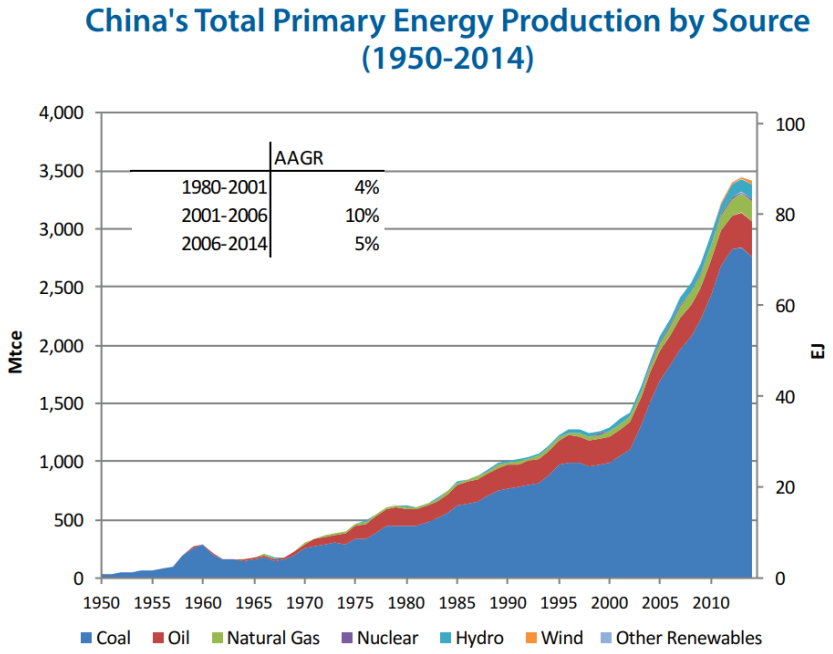
2155 km rail network

270 MM tons port capacity

What's unique about the energy landscape in China?



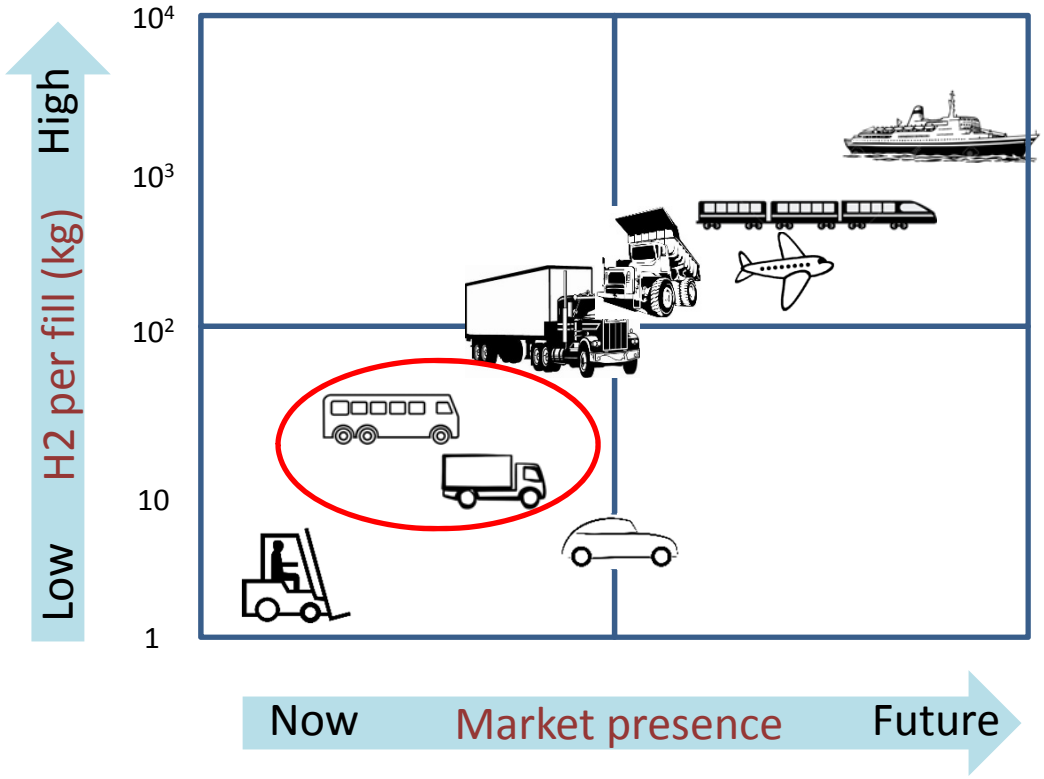
Buses and delivery trucks are a big deal in China



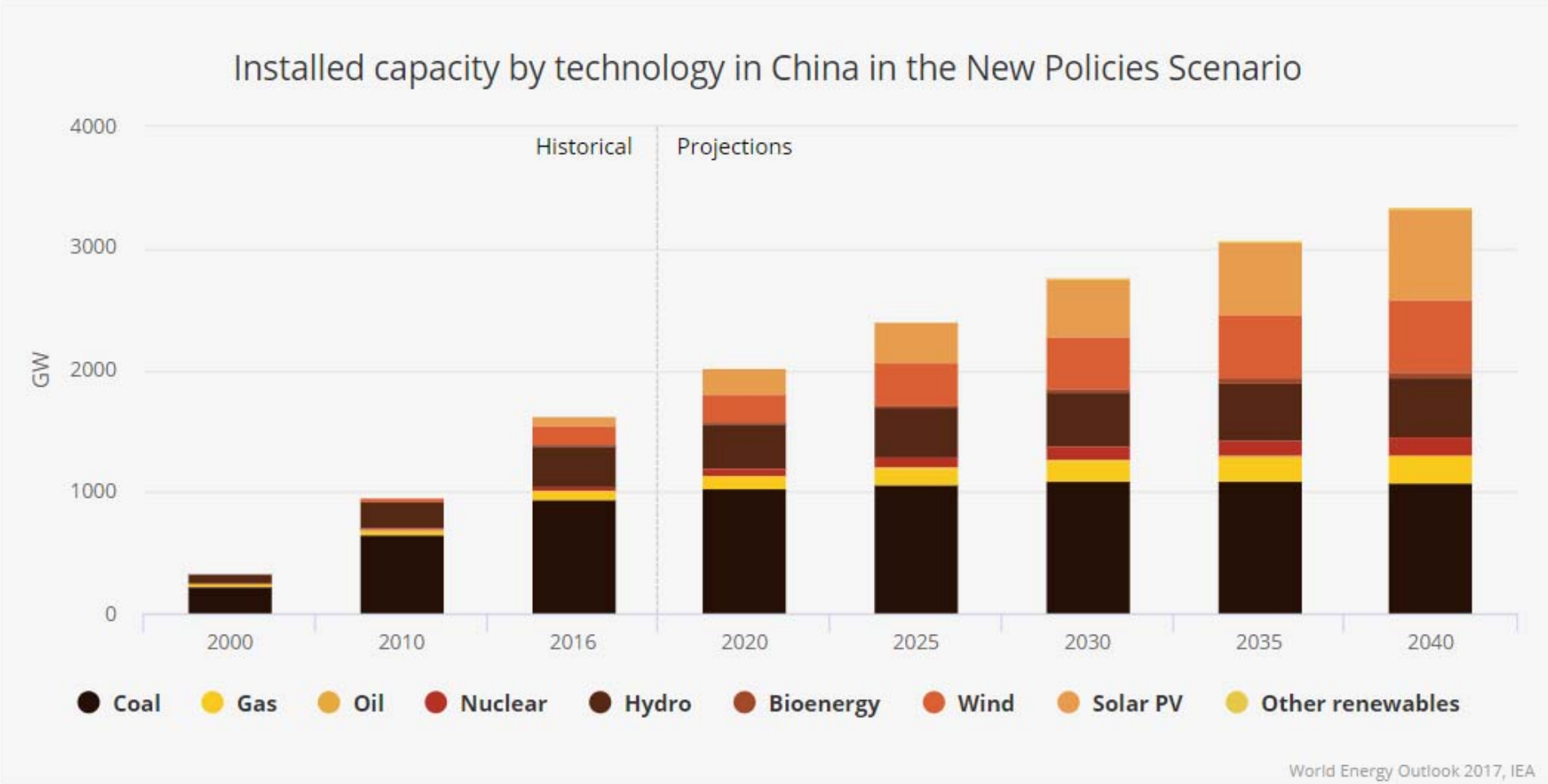
Coal is king: 96% of fossil energy reserve, 60.4% primary energy use in 2017, still >50% by 2030

- Key China Energy Statistics 2016, Berkeley Lab. https://china.lbl.gov/sites/default/files/misc/ced-9-2017-final.pdf
- Car sales statistics, http://usa.chinadaily.com.cn/a/201801/04/WS5a4de2cba31008cf16da51af.html

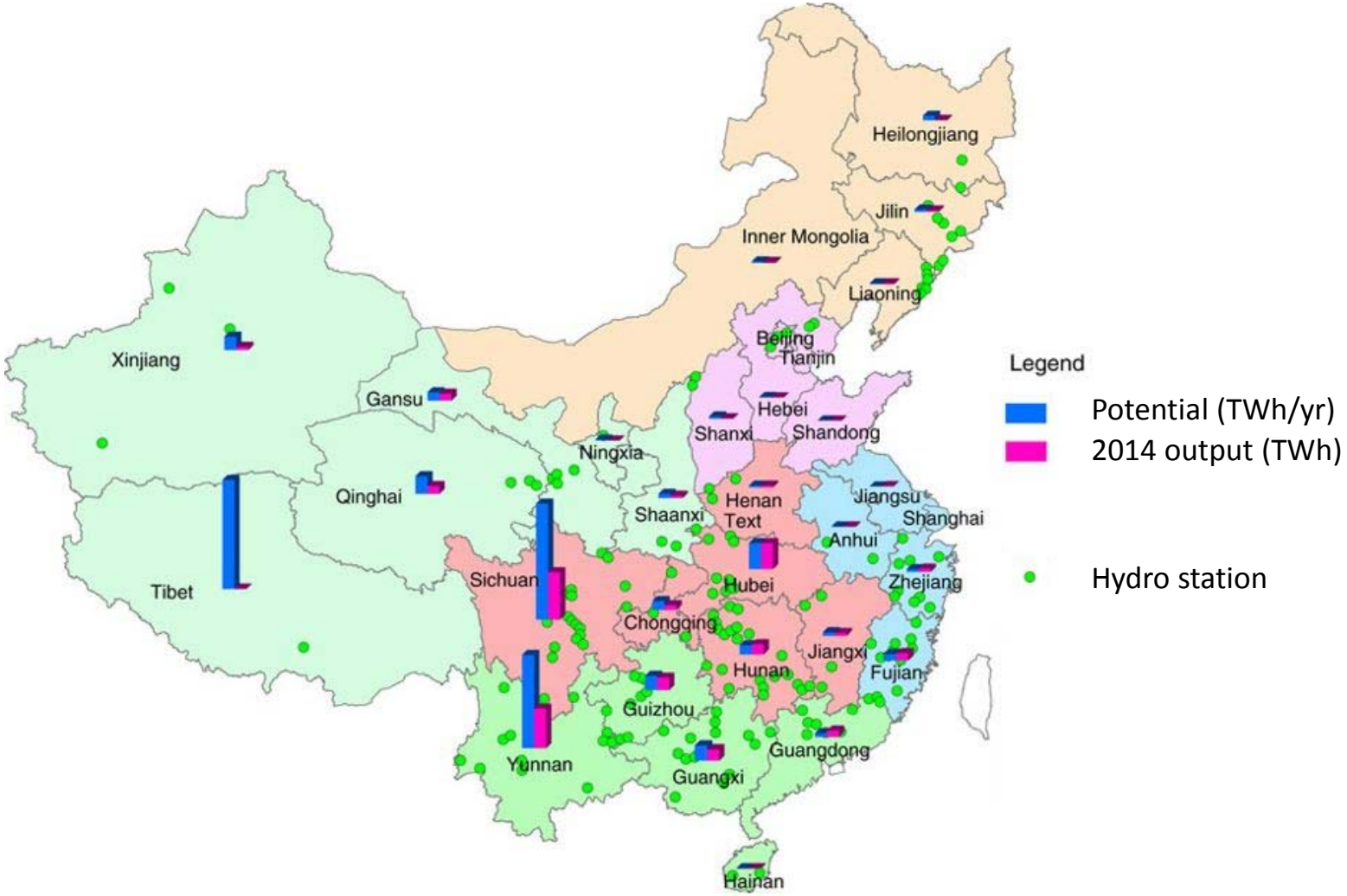
Fleets with fixed routes and high H2 per fill are good for building up H2 demand in a cluster



But the energy structure in China is evolving … renewables are in



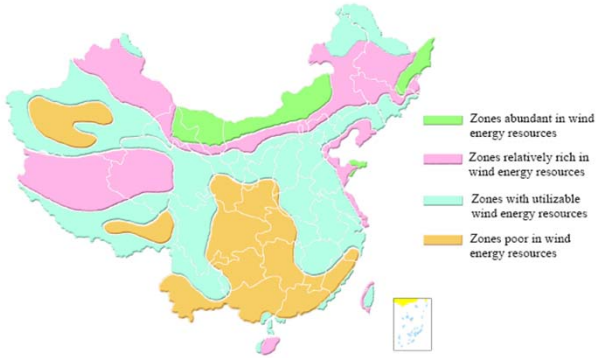
Hydro is huge



The Three Gorges Dam alone is 22.5 GW

https://www.britannica.com/topic/Three-Gorges-Dam

Wind is massive (China Energy has 30 GW)



Solar covers the mountain range …

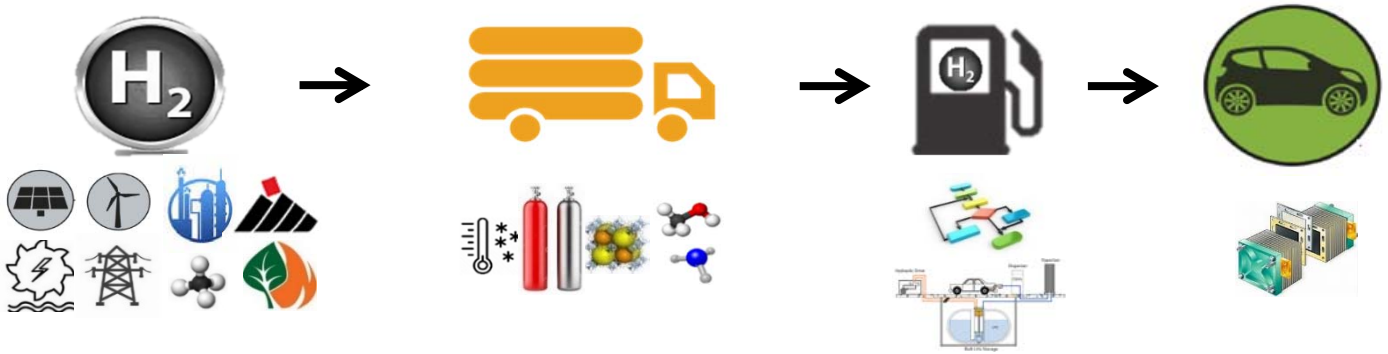
… and beyond

Unique requirements for MD/HD filling
(also future compatible with LD filling)

- Large capacity
  - 20-50 kg/fill for buses and delivery trucks
  - 150-300 kg/fill for trucks
  - HRS storage needs to be large as well
- Time limit, ~10 minutes
  - Currently diesel trucks also need to fill up Diesel Exhaust Fluid (urea solution)

Hydrogen Energy: Clean Mobility for the Masses

Convenient and Compelling ➔ $4.5/kg for market enablement



Production: $3/kg | Transport: $0.5/kg | Refueling: $1/kg | FC devices

Safe, reliable, convenient, and economically compelling

Production: $3/kg. Distributed production for availability & coverage, near-zero carbon H2 the end game

Gen.	Relevance	Technology	Pain points / R&D needs
1	By-product or vent stream purification	PSA, Compressor, High capacity gas trailer, liquefier, liquid trailer	Cost, safety, LH2 infrastructure, kWh/kg
2	Wind, solar, hydro … Curtailed & baseload	Alkaline / PEM electrolysis	kWh/kg, reliability, dynamic response
3	Clean Coal LH2	CCS, Liquefier	$ for CCS Regs for LH2

Transport: $0.5/kg

Eliminate stranded assets

Route	Limits	Technology	Pain points / R&D needs
CGH	~300 km	Composite vessels, banks	Kg per truck load
LH2	~ 1600 km	Liquid trailer	Boil-off loss, safety, codes and standards
Pipeline	Unlimited	Materials, compression and safety equipment	High capital, safety and reliability
Metals	Niche	Lt wt metal hydrides	Low system wt%, high release energy, slow kinetics
Carriers (single or multi use)	Various	NH3, methanol, LOHC	High T for NH3 cracking, LOHC opex, methanol CO2

Refueling station: $1/kg

Easy and safe for the customer, profitable for the station owner

HRS type	Technology	Pain points / R&D needs
CGH2	Gas H2, multiple compressors, cascade tubes, pre-cool via refrigeration for fast fill	Large footprint, reliability, logistics for scale
LH2	LH2 supply, underground storage, direct fill, cryo-compressed onboard storage	LH2 safety, boil-off loss
Multi energy	LD filling, EV charging, Gasoline / diesel	Safety, footprint, logistics, interconversion

Thank you. Questions?