



Flexible CO₂ capture in China

Pingjiao Hao, Anthony Ku, Surinder Singh, Chang Wei, Jihong Cheng,
Jeffrey Allen, Xiao Liu, Bin Xu, Xinglei Zhao, Qian Cui, Baodeng Wang

June 5, 2019

NICE AMERICA RESEARCH, INC.

Corporate profile

- Delivers 15% of China's electricity
- Fortune 100
- Assets: 1.8TT RMB (\$286B)
- 350K employees



World's largest ...

500 MM
MT/yr
Coal
production

180 GW
Coal-fired
power capacity

38 GW
wind
19 GW
hydro

15 MM
MT/yr
Coal-chemicals
production

Corporate RD&D lab

- *Mission ... To become a world-class R&D institute supporting China Energy's transition to a clean and low carbon energy supplier*
- Founded in 2009 ... ~700 researchers
- Sites ... Beijing, China; Mountain View, CA; Schwabisch Hall, Germany

Mission-driven research platforms



- Catalysis
- Clean coal
- Coal-based materials
- Advanced technologies
- Distributed Energy
- Hydrogen Energy
- Water Treatment

Corporate RD&D lab

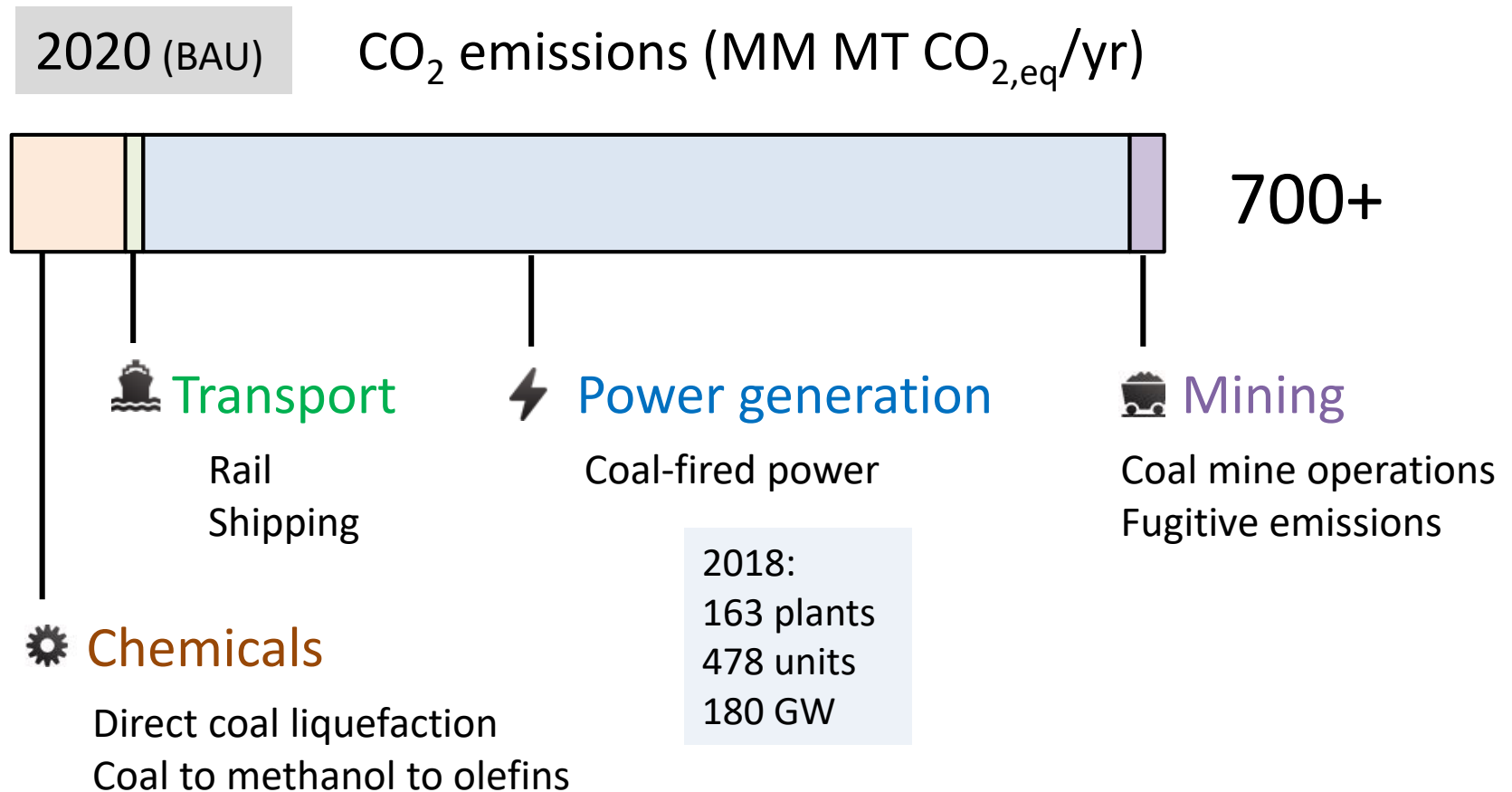
- *Mission ... To become a world-class R&D institute supporting China Energy's transition to a clean and low carbon energy supplier*
- Founded in 2009 ... ~700 researchers
- Sites ... Beijing, China; Mountain View, CA; Schwabisch Hall, Germany

Mission-driven research platforms



- Catalysis
 - Clean coal
 - Coal-based materials
 - Advanced technologies
 - Distributed Energy
 - Hydrogen Energy
 - Water Treatment
- ... Emissions/carbon management

Estimated CO₂ footprint for China Energy



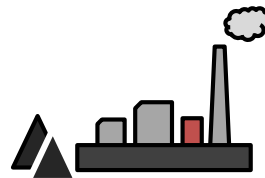
Enable CE to affordably reduce CO₂ emissions by 100+ MM tons per year by 2030.



Fleet modeling

system trade-offs and data

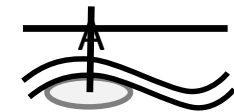
- Identify “lowest cost” paths for system-wide CO₂ reduction
- clarify and quantify “highest impact” RD&D opportunities



CO₂ capture

power retrofits

- Validate technology under “China-specific” conditions
- Accelerate maturation of practical capture for China



CO₂ offtake

supply chain/enablers

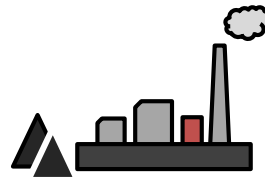
- Create a close-out process for saline aquifer storage in China
- Prove value proposition for near-term utilization options

Enable CE to affordably reduce CO₂ emissions by 100+ MM tons per year by 2030.



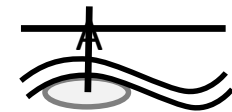
Fleet modeling *system trade-offs and data*

- Identify “lowest cost” paths for system-wide CO₂ reduction
- clarify and quantify “highest impact” RD&D opportunities



CO₂ capture *power retrofits*

- Validate technology under “China-specific” conditions
- Accelerate maturation of practical capture for China



CO₂ offtake *supply chain/enablers*

- Create a close-out process for saline aquifer storage in China
- Prove value proposition for near-term utilization options

Hardware

- Retrofits ... Over 50% of generation capacity < 15 yrs old
- Water stress ... Significant generation located in arid regions
- ULE pollution controls ... SCR, FGD, ESP by 2020

Operations

- Low capacity factor ... 4300h or 50% (national average, 2017)
- Load-following ... changing CO₂ concentration in flue gas

Market

- ETS market definitions ... 2020 target = 550 g/kWh for power plants
- Electricity market operation ... Regulated dispatch and power tariffs

Dynamic operation of the CO₂ capture system to **maximize operating profit** of a power plant in response to **variable electricity prices**.

Strategy	Principle	Benefit	Disadvantage
Reduced load / flue gas bypass	Reduce capture rate + pay CO ₂ “tax” during high electricity price periods	Capture value from high electricity price	Pay CO ₂ “tax” during low capture/bypass periods to offset lower capture rate
Solvent storage	Store solvent during high electricity prices; regenerate when electricity price is low	Capex savings from undersized regenerator	Pay for solvent storage tanks and extra solvent
Time-varying solvent regeneration	Vary lean loading with electricity price	Avoid costs for solvent storage tank	Process control could be more challenging; Pay CO ₂ “tax” during low capture periods

Drivers	Western	China	Implication for flexibility in China
Market structure	Dispatch pricing	Regulated power tariffs	Much weaker electricity price signal
Capture rate target	90%	50-60% 550 g/kWh (Nat'l ETS)	Reduced economic penalty at lower rates of CO ₂ capture
Power plant load profile	Dispatch priority	Scheduled dispatch profiles	Variability in power plant loads driven by regulation (details vary by provinces)
ETS	Mass-Based	Rate-based	Possible enhanced benefit from carbon credit trading

A weaker electricity *price signal* and *CO₂ emissions penalty* will favor flexible CCS strategies that minimize cost of capture...

... but how will the strategies differ?

Hypotheses:

1. Cost of capture will be, on average, lower relative to other parts of the world.
2. **Cost drivers** for flexible operation in China will be comparable to trends observed elsewhere, but **market drivers** will differ.

Approach:

1. Estimate costs for selected post-combustion CO₂ capture scenarios for retrofitted coal-fired power plants.
2. Compare magnitudes of cost drivers and market signals.
3. Infer general principles for flexible capture strategy in China.

	No load following	load following (50%,70%)
On/off capture (0, 90%)	<p>Baseline & Case 1:</p> <p>BL1 CF 57%, Load 100%, Cap 0% BL2 CF 85%, Load 100%, Cap 0% 1.1 CF 57%; Load 100%, Cap 90% 1.2 CF 85%, Load 100%, Cap 90%</p>	<p>Case 3:</p> <p>3.1 CF 57%, Load 50%, Cap 0% 3.2 CF 57%, Load 70%, Cap 0% 3.3 CF 57%, Load 50%, Cap 90% 3.4 CF 57%, Load 70%, Cap 90%</p>
Partial capture (30, 50, 70%)	<p>Case 2:</p> <p>2.1 CF 57%; Load 100%, Cap 30% 2.2 CF 57%, Load 100%, Cap 50% 2.3 CF 57%, Load 100%, Cap 70%</p>	<p>Case 4:</p> <p>4.1 CF 57%, Load 50%, Cap 30% 4.2 CF 57%, Load 50%, Cap 50% 4.3 CF 57%, Load 50%, Cap 70%</p>

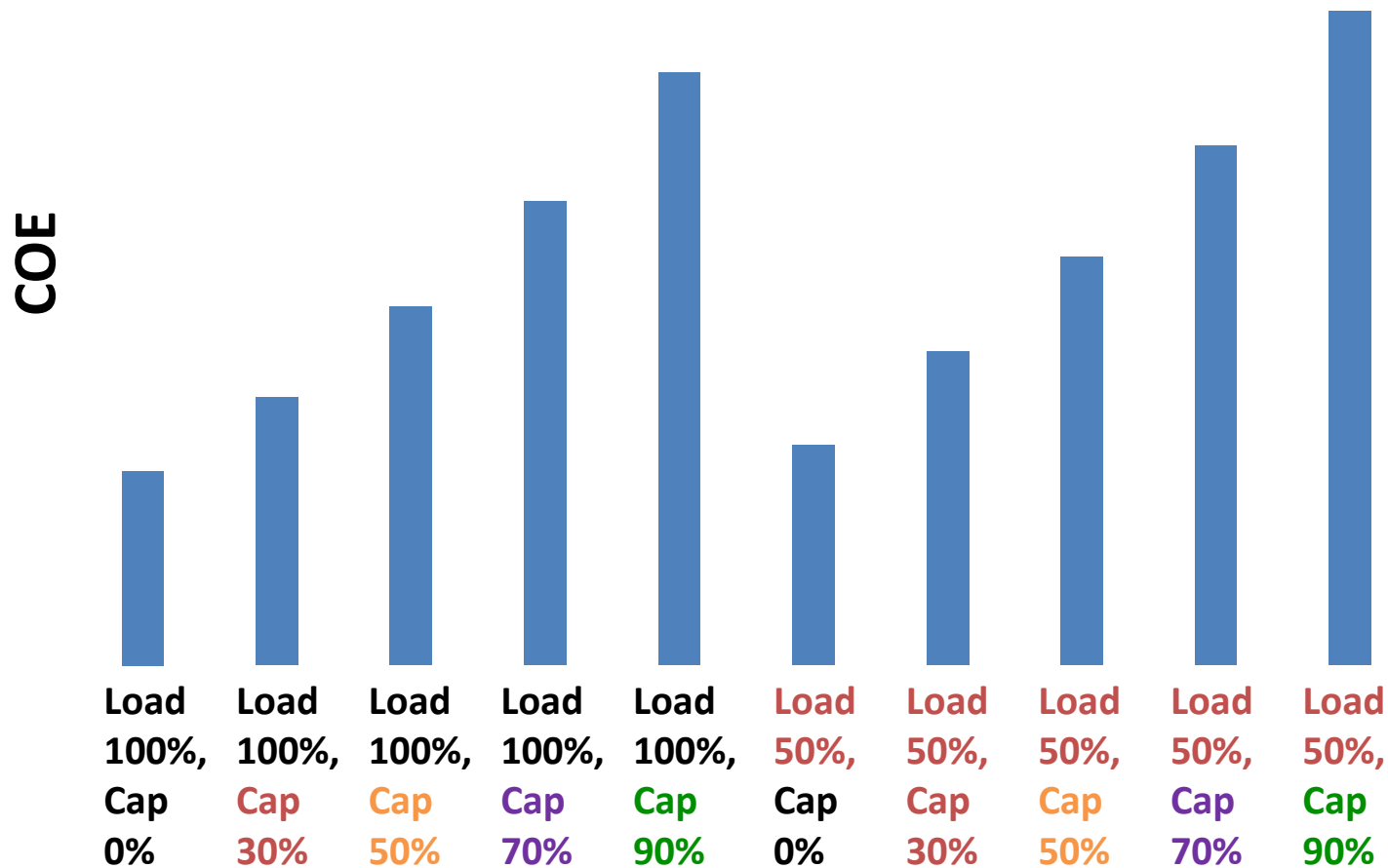
Post combustion capture, Retrofit, MEA solvent capture system
 China costing assumptions: S. Singh, IJGGC, 78 (2018): 429-436.

Description of costing methodology

1. Cost basis ... IJGGC reference
2. Turndown ... efficiency correction; scaling by plant output
3. Partial capture ... reduced capture trains
4. Turndown and partial capture ... superposition of effects from (2) and (3)

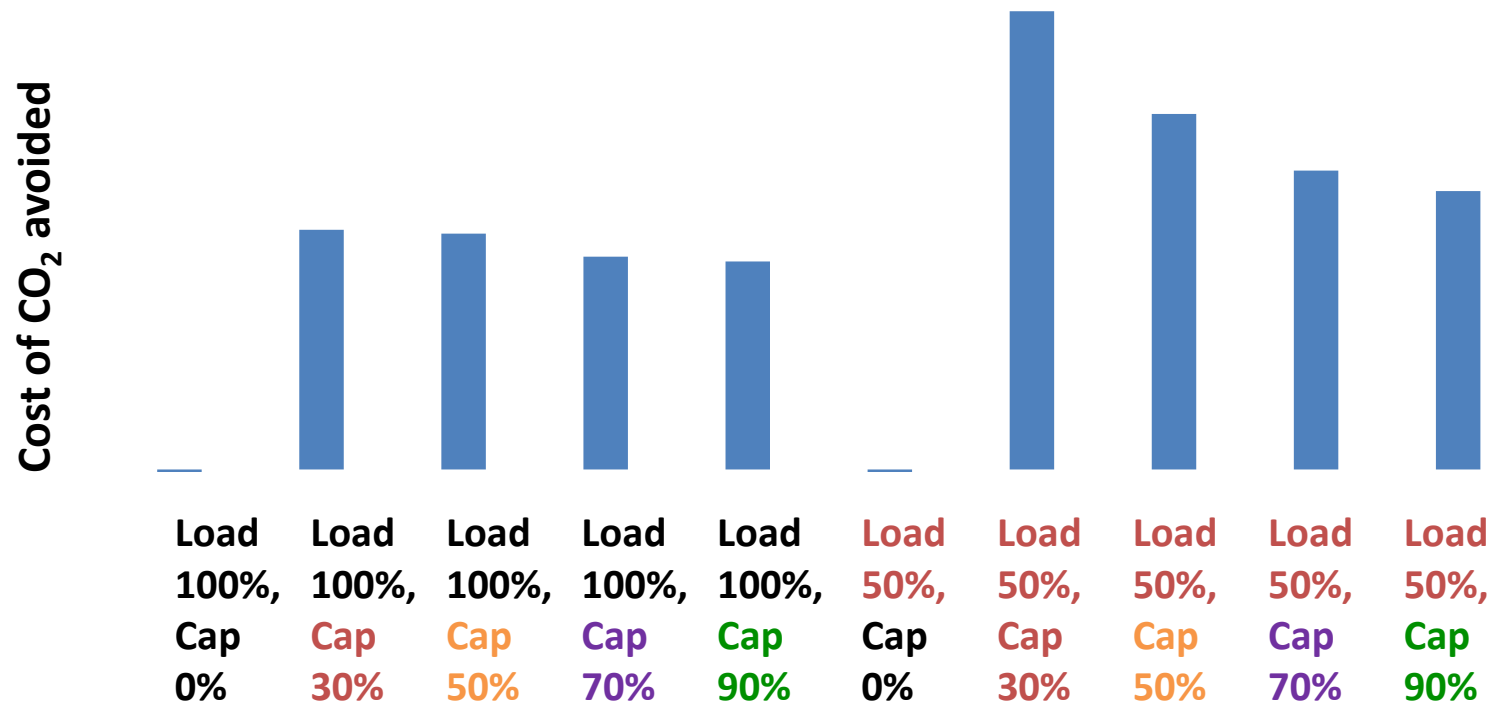
Notes:

- error bars of $\pm 20\%$
- interaction terms ignored for first estimate of (4)



COE increases with load following and capture rate

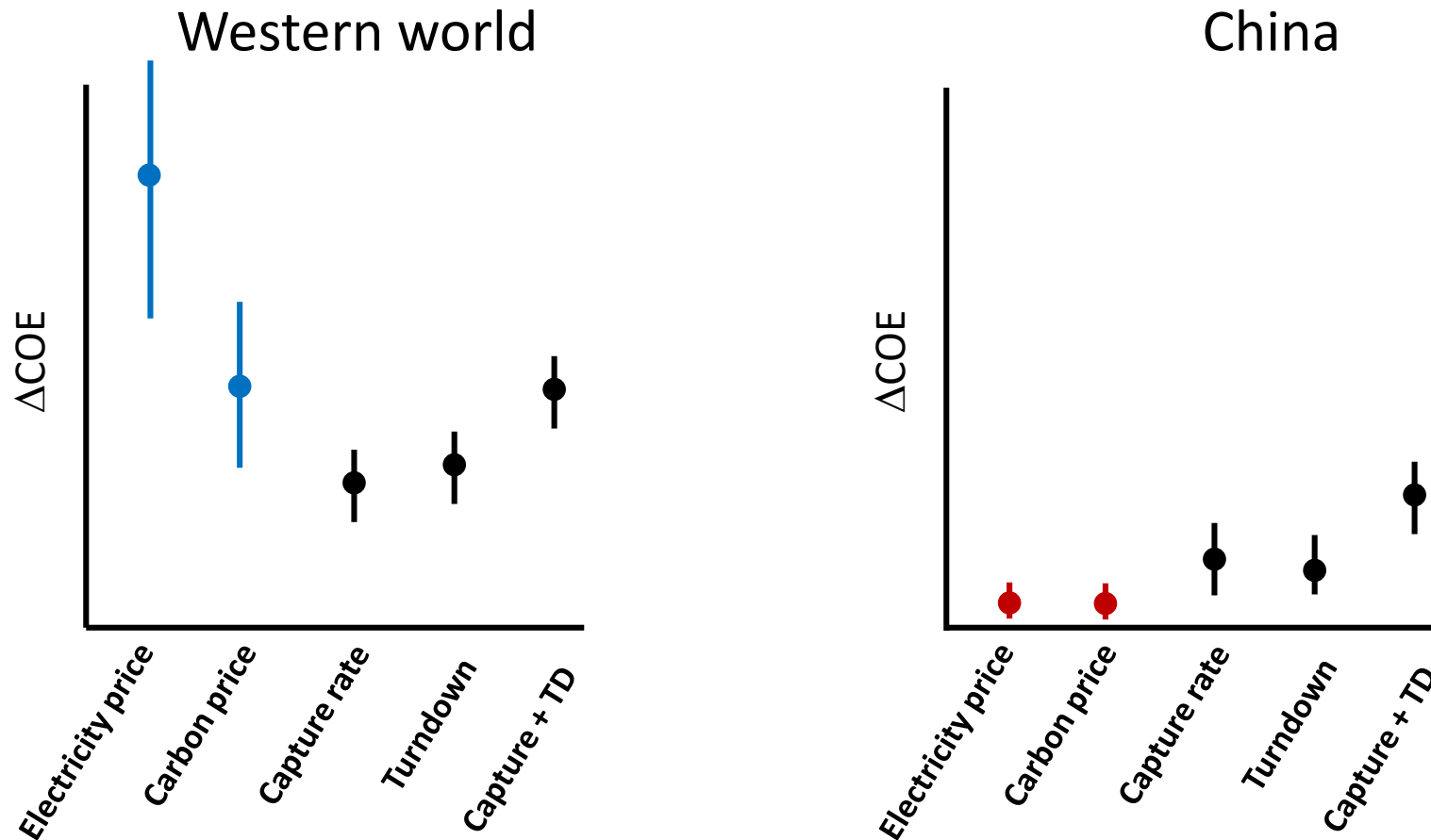
Hao, IJGGC, In preparation



**Cost of CO₂ avoided increases with load following;
decreases with capture rate**

Hao, IJGGC, In preparation

Magnitude of cost drivers vs market signal



Cost of capture drives flexible capture in China.

Hao, IJGGC, In preparation

© 2019 National Institute of Clean and low carbon Energy

Flexible capture can be different *in China*.

- **Lower impact of market drivers has not been recognized.**
- Optimal strategies for flexible capture in China will favor operating plants at high capture rates and high capacity factors.

Future work includes:

- Detailed modeling to understand province level variability in optimal strategies
- Effects of 2nd generation capture technology
- Fleet-level optimization through ETS trading
- How will electricity market reform impact the optimal strategy?