China Energy Investment Group

Corporate profile

神华集团 SHENHUAA GROUP **+** 中国国电 CHINA GUODIAN

CHN ENERGY 国家能源集团

- Formed in 2017 by merger of Shenhua and Guodian
- Over 1.8 Trillion RMB in assets + 330K employees

World's largest ...

500 MM MT/yr	190 GW	33 GW	15 MM MT/yr
Coal production	Coal-fired power capacity	Wind power capacity	Coal-chemicals production

Corporate R&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 ... ~500 researchers
- Sites ... Beijing, China; Mountain View, CA; Schwabisch Hall, Germany

Mission-driven Research Platforms

Adv Tech

- Catalysis
- Clean coal
- Coal-based materials

- Distributed Energy
- Hydrogen Energy
- Water Treatment

- Advanced technologies
  - ... Emissions/carbon management
  - ... Innovation pipeline

Policy landscape:

13th Five Year Plan (2016-2020)

Energy landscape

Energy targets for 2020

Total Use	Non-fossil	O&G	CO_2
141 EJ 4.8 BB sce	**15%** share (20% by 2030)	**15-30** BB m^3 Shale gas	**18%** reduction vs 2015

Generation mix by 2020 (capacity, GW)

	Coal	Hydro	Wind	Nuclear	Solar-PV
2016 EOY est	960	330	149	34	77
2020 target	1100	380	210	58	110

300 g sce/kWh ~ 40.9% LHV efficiency

Coal

Coal mining

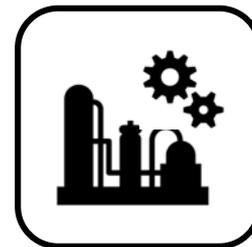| Cap total output.	Improve efficiency.	Consolidate industry.
3.3 ➡ 3.9 BB MT/yr (2016) (2020)	800 ➡ 500 MM MT/yr (inefficient) (adv)	6000 mines with 80% >1.2 MM MT/yr

Coal usage

Power Generation

- Efficiency
    ... 300 g sce/kWh (new)
    ... 310 g sce/kWh (old)
- CHP integration
- ULE upgrades

Coal-to-Chemicals

- Modernize industry
- Indigenous capabilities
    ... classification
    ... gasification
    ... syngas cleanup
    ... wastewater treatment

Emissions

- State Council Action Plan (2013)

  ... Reduce urban $PM_{2.5}$ by 10% vs 2012 levels

  ... Reduce $PM_{2.5}$ in Jing-Jin-Ji by 25%, Pearl
  River Delta by 20% and Yangtze River
  Delta by 15%

  ... Reduce annual PM in Beijng to <60 ug/m^3

- CO_2 trading markets

  ... Seven regional markets now; national in 2020

  ... Power industry target... 550 g/kWh (2020)

- Ministry of Ecological Environment

  ... announced March 2018

  ... assumes responsibility from MEP and NDRC

Ultra-low emissions power plant
Guohua Zhoushan No. 4 (2014)

Source	Particulate Matter, mg/Nm³	SO₂, mg/Nm³	NOₓ, mg/Nm³
Guohua Zhoushan No. 4 Unit	2.46	2.76	19.8
Gas power unit emission standards	5	35	50
Coal-fired emission standards (key areas)	20	50	100

Ref: Ling, Cornerstone 2015, 3, 12-14.

R&D focus areas

Clean coal utilization

- Automation for mining & Deep mine safety

- Unconventional oil and gas development

- Low- and medium-temperature pyrolysis for upgrading of low-rank coal

- Advanced ultrasupercritical (700°C) coal-fired power generation

- Design and manufacturing of high energy-efficient boilers and electric motors

Ultra-low emissions (ULE) technology deployment and impacts

Acknowledgments: X Liu, X Gao, X Wu, J Lin

ULE targets

Primary emissions limits (mg/m³)

	Existing units	New builds	Special areas	ULE limits	NGCC emissions
NO_x	100	100	100	50	50
SO_2	200	100	50	35	35
$PM_{2.5}$	30	30	20	10	5

Installation ... all power plants by 2020

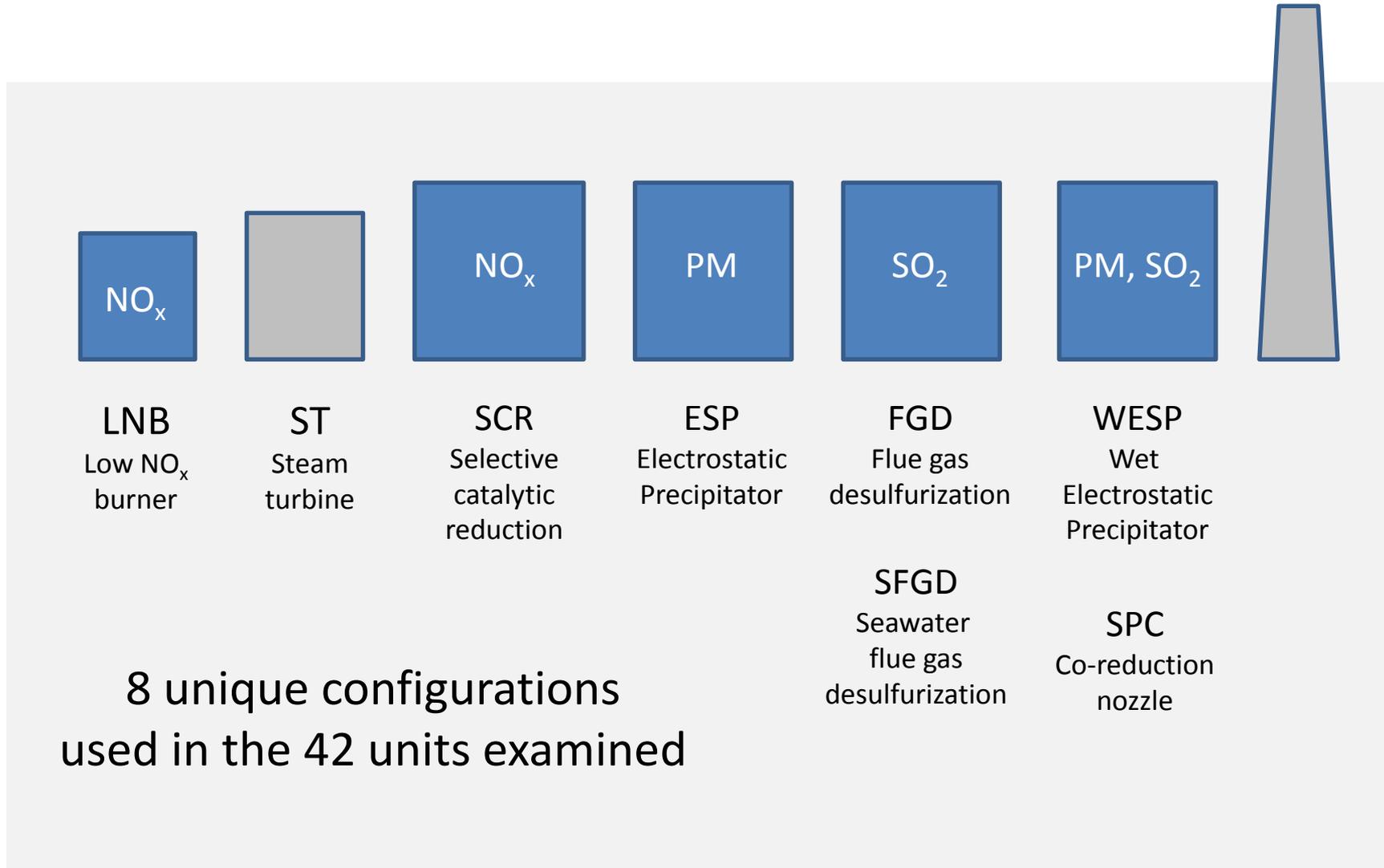| Company	Huaneng	Datang	Huadian	Guodian	Zhongdiantou	Shenhua
Installation ratio （end of 2016）	59%	68%	51%	53%	52%	63%

Case study

Objective

Estimate benefits of ULE retrofitting on NO_x, SO_2 and PM emissions factors and air quality in urban areas

Data set
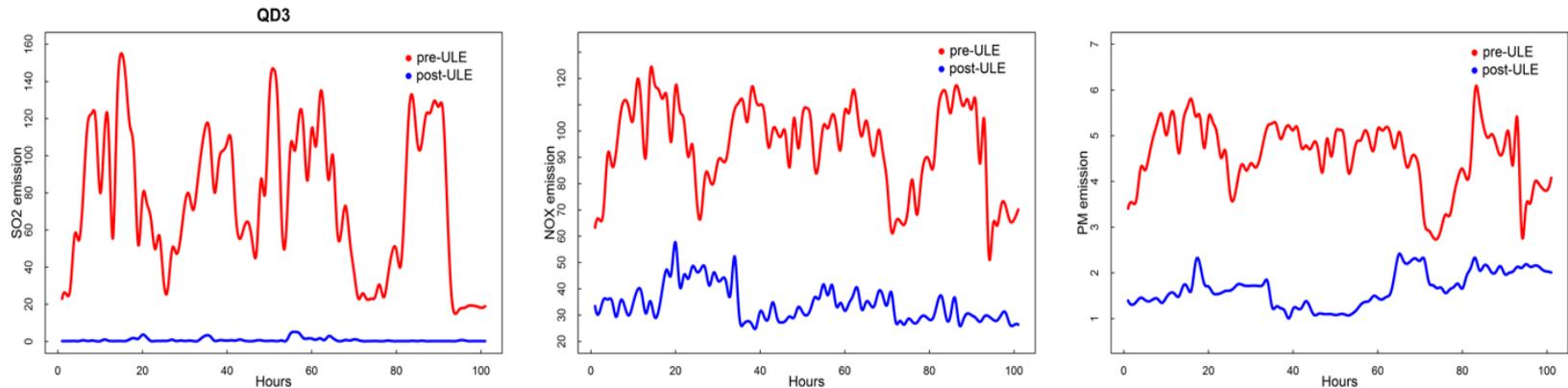
- 42 units at 18 power plants
  ... 215 to 1050 MW capacity
  ... 6 geographic regions

  ... 22 units – electricity only
  ... 20 units – cogeneration

- Data from Jan 2015 to Oct 2017
  ... pre-and post ULE retrofit

Ref: Liu, 2018

Technology

NO$_x$		NO$_x$	PM	SO$_2$	PM, SO$_2$
LNB Low NO$_x$ burner	**ST** Steam turbine	**SCR** Selective catalytic reduction	**ESP** Electrostatic Precipitator	**FGD** Flue gas desulfurization	**WESP** Wet Electrostatic Precipitator
				SFGD Seawater flue gas desulfurization	**SPC** Co-reduction nozzle

8 unique configurations
used in the 42 units examined

Individual power plant data
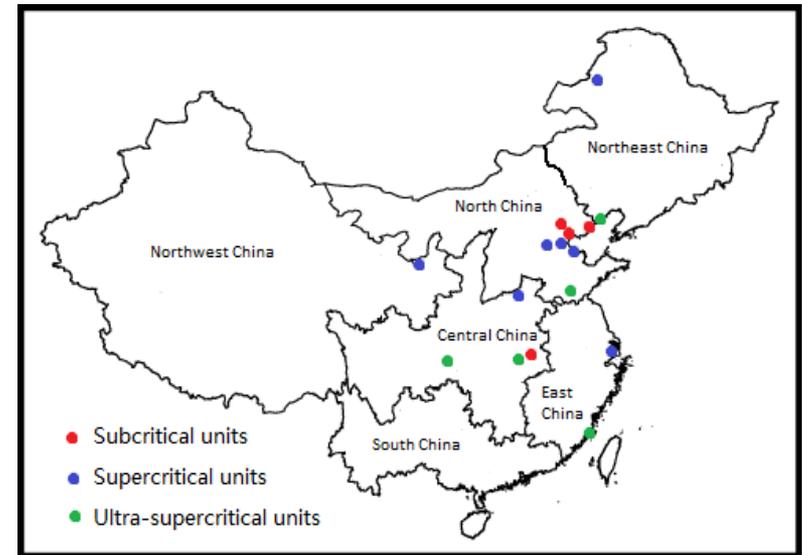
Raw data … hourly emissions profiles from a single plant

Emissions factors … corrected for power plant load

Ref: Liu, 2018

Fleet level performance
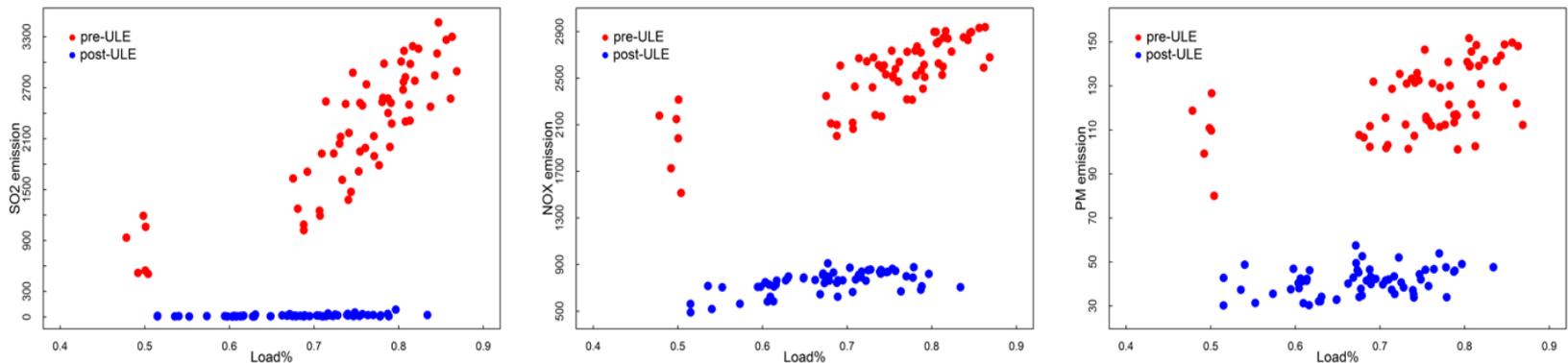
ULE performance across the sampled fleet

PM (pre-ULE retrofit)   PM (post-ULE retrofit)

Ref: Liu, 2018

Updated emissions factors
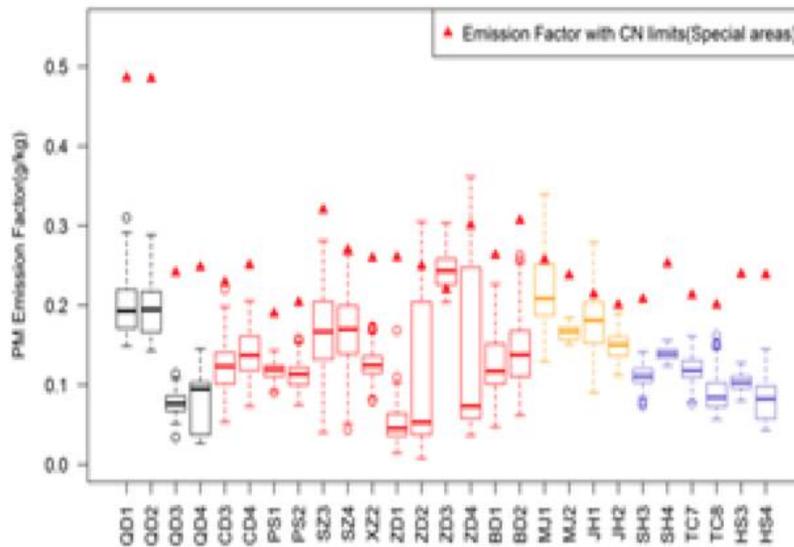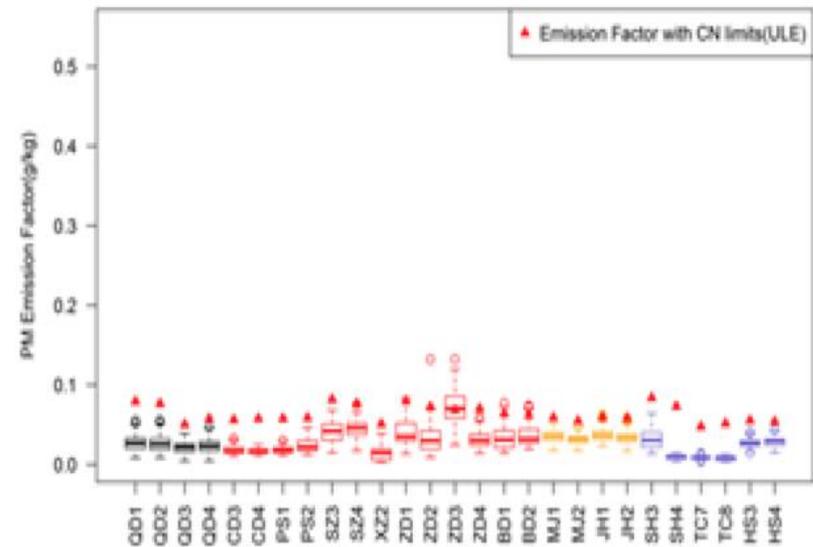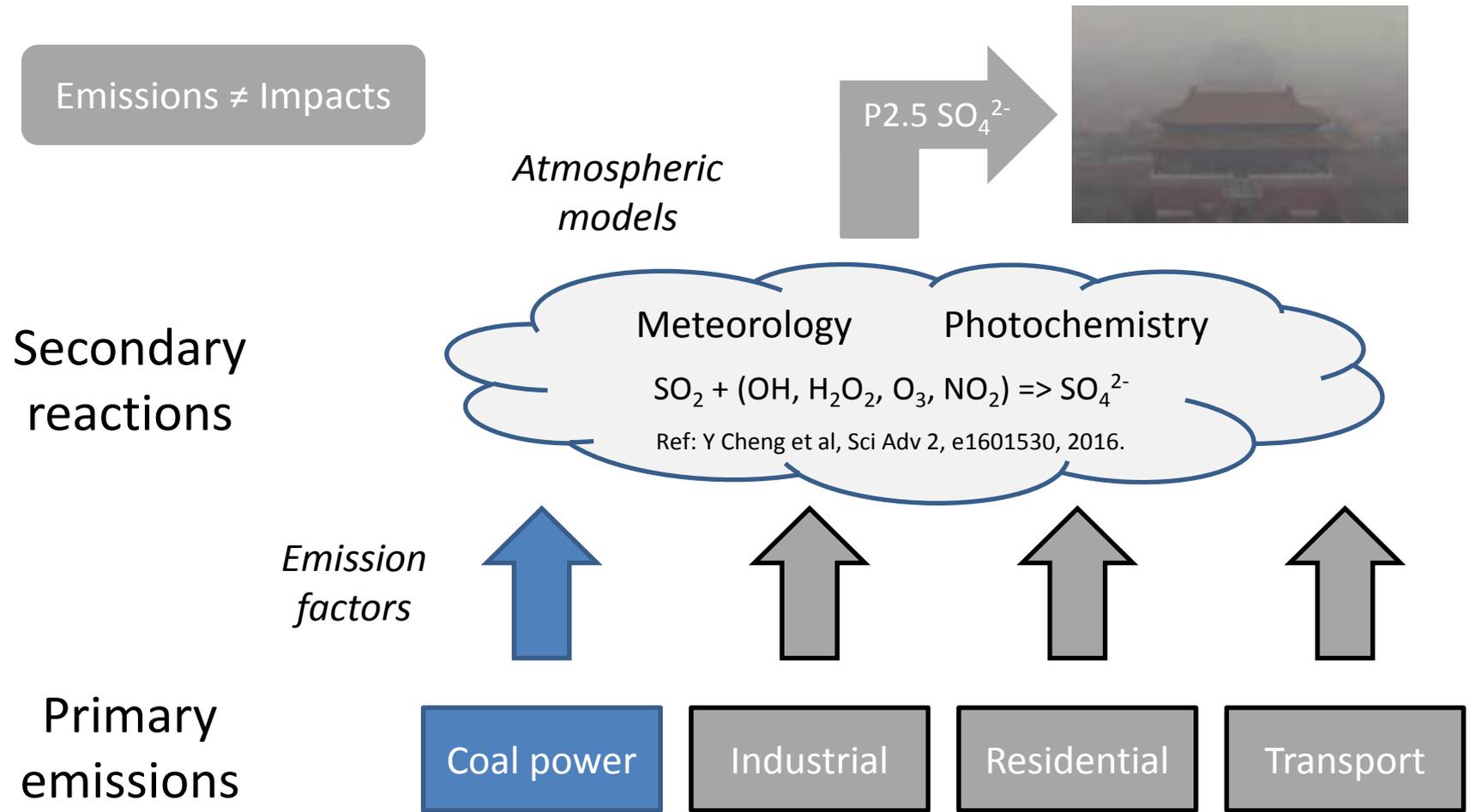
Comparison of EF from different inventories

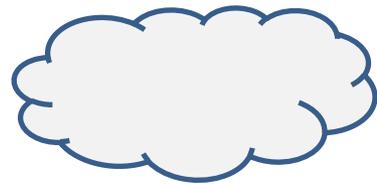NO$_x$ SO$_2$ PM
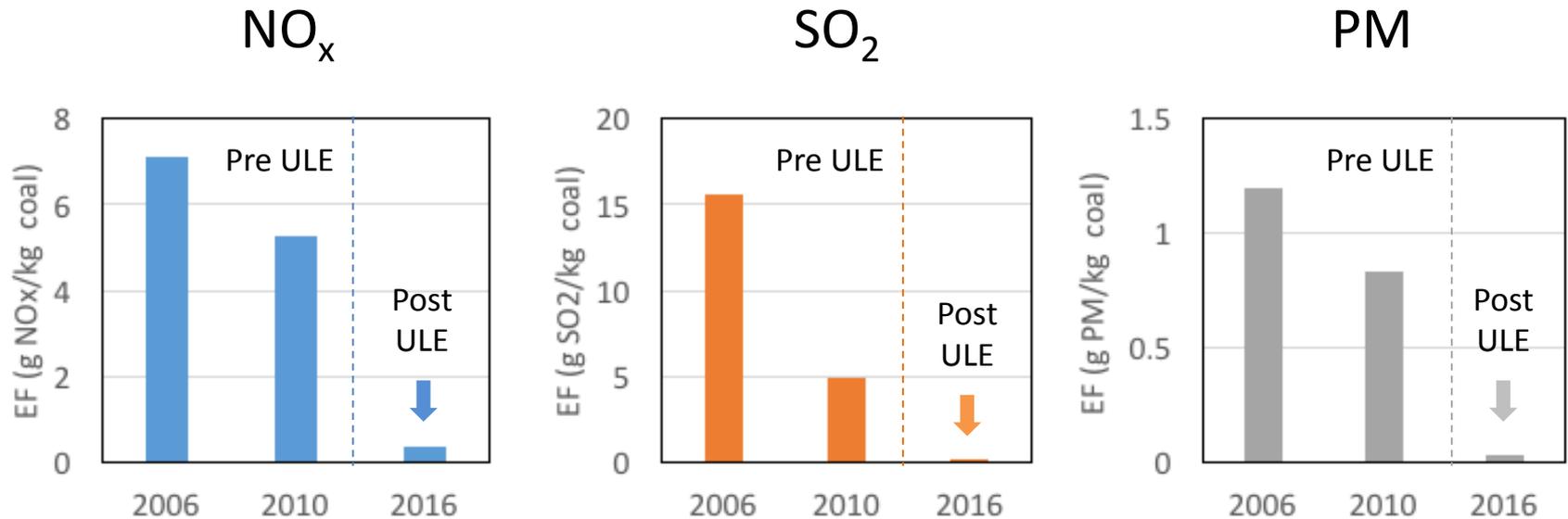
Refs: Zhang, 2009; Liu, 2011; Liu, 2018

Fleet-average EF's for ULE retrofitted plants are up to order of magnitude lower than from inventories before ULE retrofitting.

Power industry contributions to haze

Haze formation mechanism

Emissions ≠ Impacts

P2.5 SO_4^{2-}

Atmospheric models

Secondary reactions

Meteorology   Photochemistry

$SO_2 + (OH, H_2O_2, O_3, NO_2) => SO_4^{2-}$

Ref: Y Cheng et al, Sci Adv 2, e1601530, 2016.

Emission factors

Primary emissions

| Coal power | Industrial | Residential | Transport |

Modeling the effectiveness of different mitigation options
(work in progress)
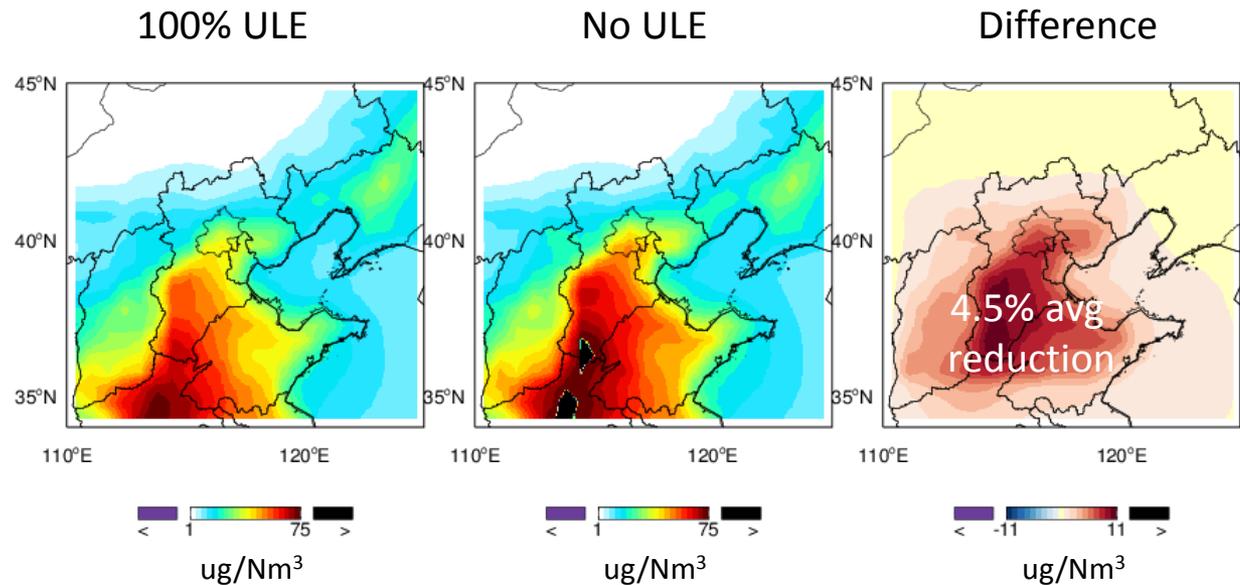
ULE

Coal power

Atmospheric modeling of $PM_{2.5}$ haze in Jing-Jin-Ji region
(MEIC inventory data, Time averaged 2012)

100% ULE

No ULE

Difference

4.5% avg reduction

ug/Nm³

ug/Nm³

ug/Nm³

Ref: Liu, 2017

Coal conversion

Coal conversion

Coal chemical conversion

Gas fuel	Liquid fuel	Chemicals	Others
SNG	Direct liquefaction oil · Thermal dissolution oil · FT synthesis oil · Carbonization oil · MTG · Low carbon alcohol	Methanol · MTO · MTP · Acetic acid/anhydride · MTD · MTA · Ethylene glycol	Hydrogen · Calcium carbide · Coke · Semi coke · Synthesis ammonia

Gasification · Liquefaction · Pyrolysis
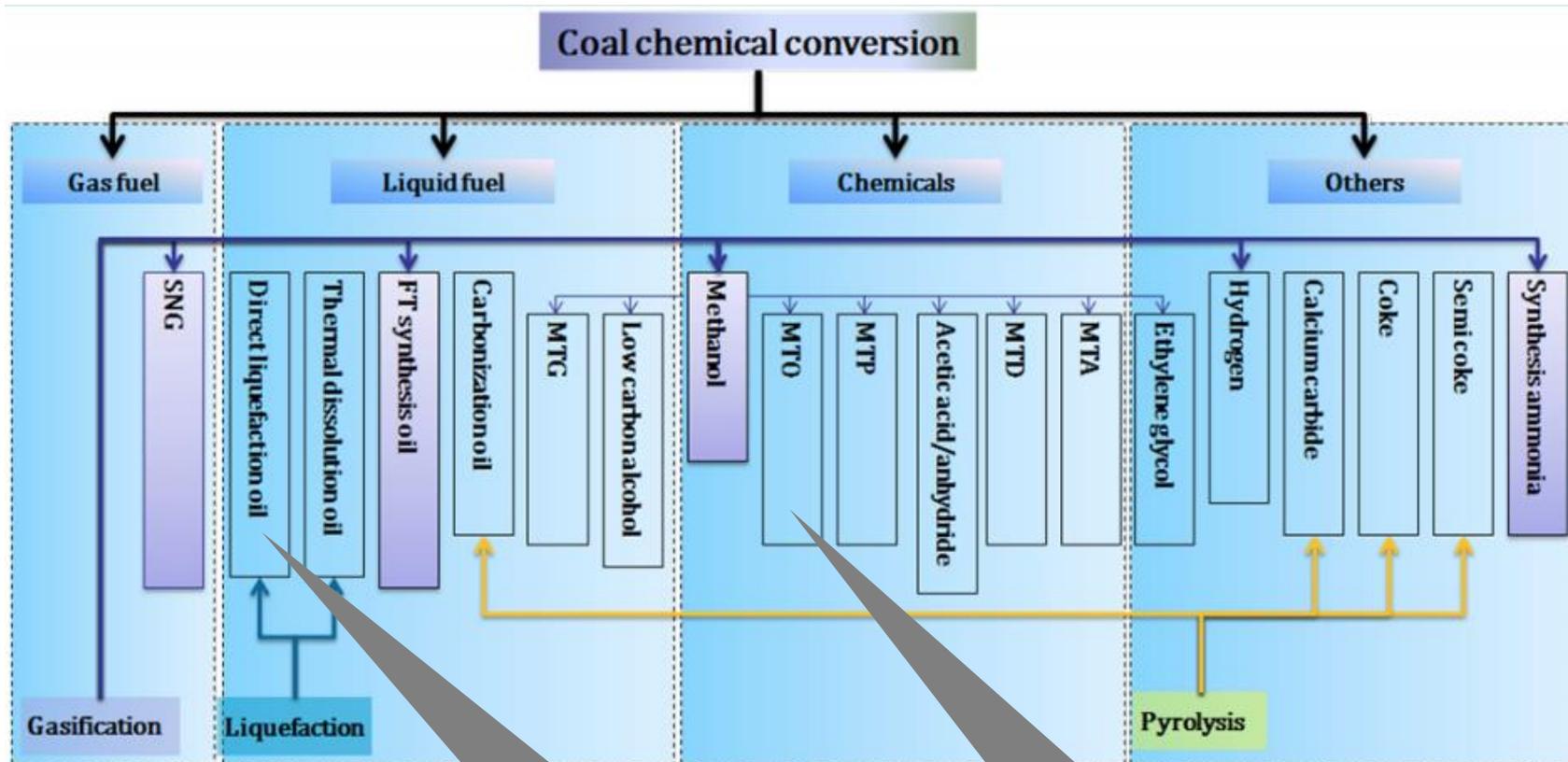
Large scale projects

Ordos (DCL)
6000 tpd coal
1 MM tpa liquids
   (naphtha, diesel, etc)

Baotou (MTO)
4.4 MM tpa coal
1.8 MM tpa MeOH
600 k tpa olefins (PE, PP)

Ref:
T Yajun, 2012

Ordos DCL plant

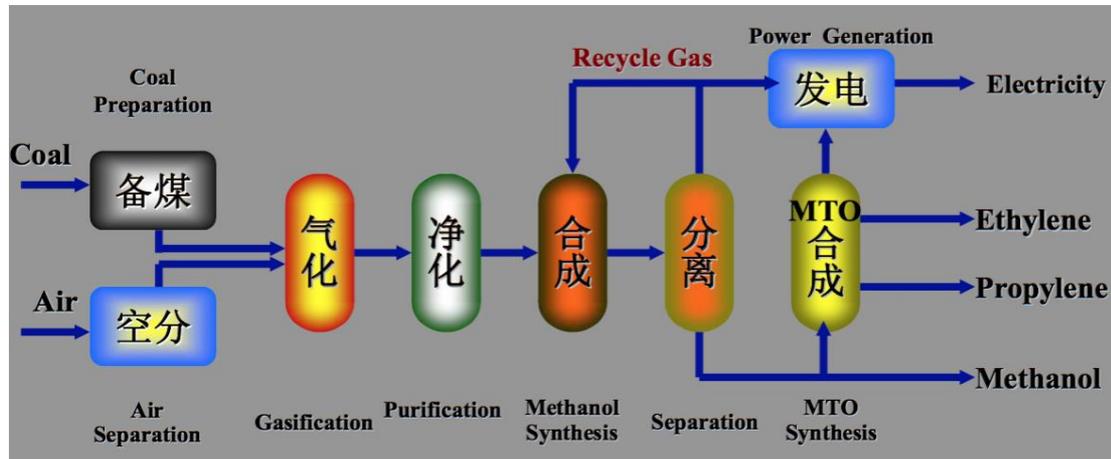| Proposal approved	Pilot testing complete	Phase 1 commissioning	Continuing commercial operation (1MM tpy)
2001	2004	2008	2018
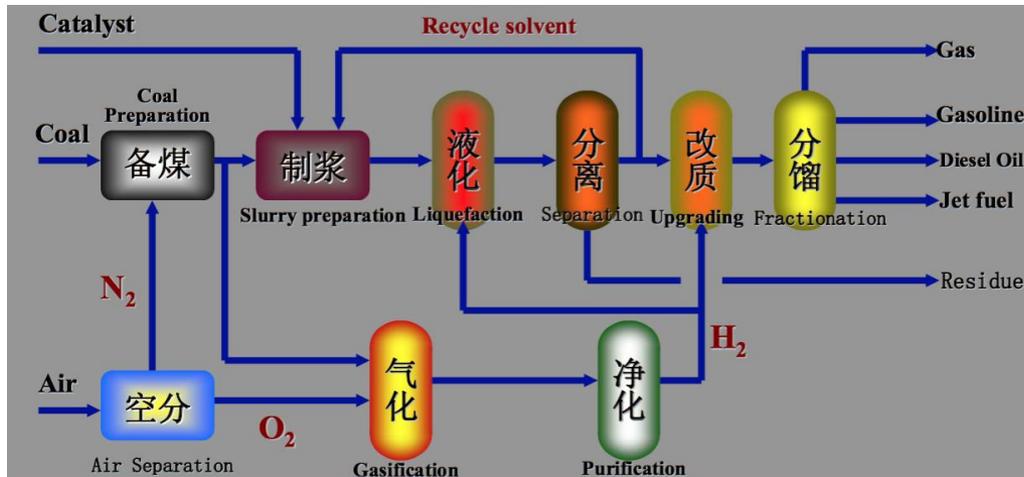
Key technology features:

1. Mild operating conditions (18MPa, 445-455C)

2. New and high-efficiency coal liquefaction catalyst

3. Robust engineering design

Ref: Y Zhang, 2010

Baotou MTO plant

Ref: Zhang and Lu, 2011

Coal-to-methanol
Methanol-to-olefins

Commercial operation
since 2010

Production in 2017
350k tpy PE
400k tpy PP

Outlook

- Coal will continue to be an important part of China's energy mix.

- ULE technology is rapidly being deployed across the power sector.

- Large scale coal-to-chemicals operations are approaching their second decade of operation and remain an area of strategic interest.

- Sustained R&D will continue to clarify impacts of policies to date and move capabilities forward.