Capturing the Invisible Resource

Analysis of Waste Heat and Other Energy Efficiency Potentials in Chinese Industries

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Technologies and Policies to Decarbonize the Industry Sector

Aspen Global Change Institute

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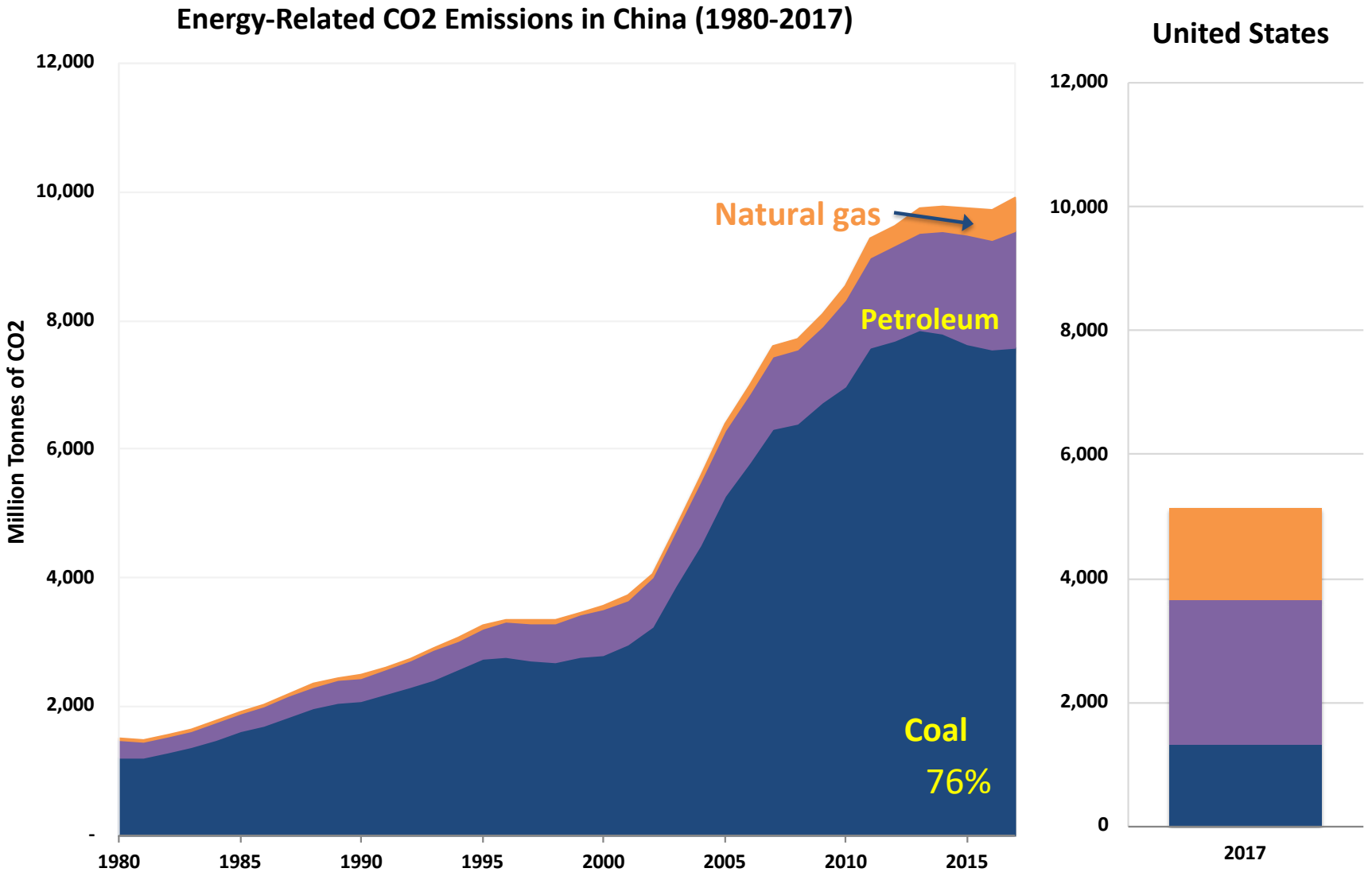
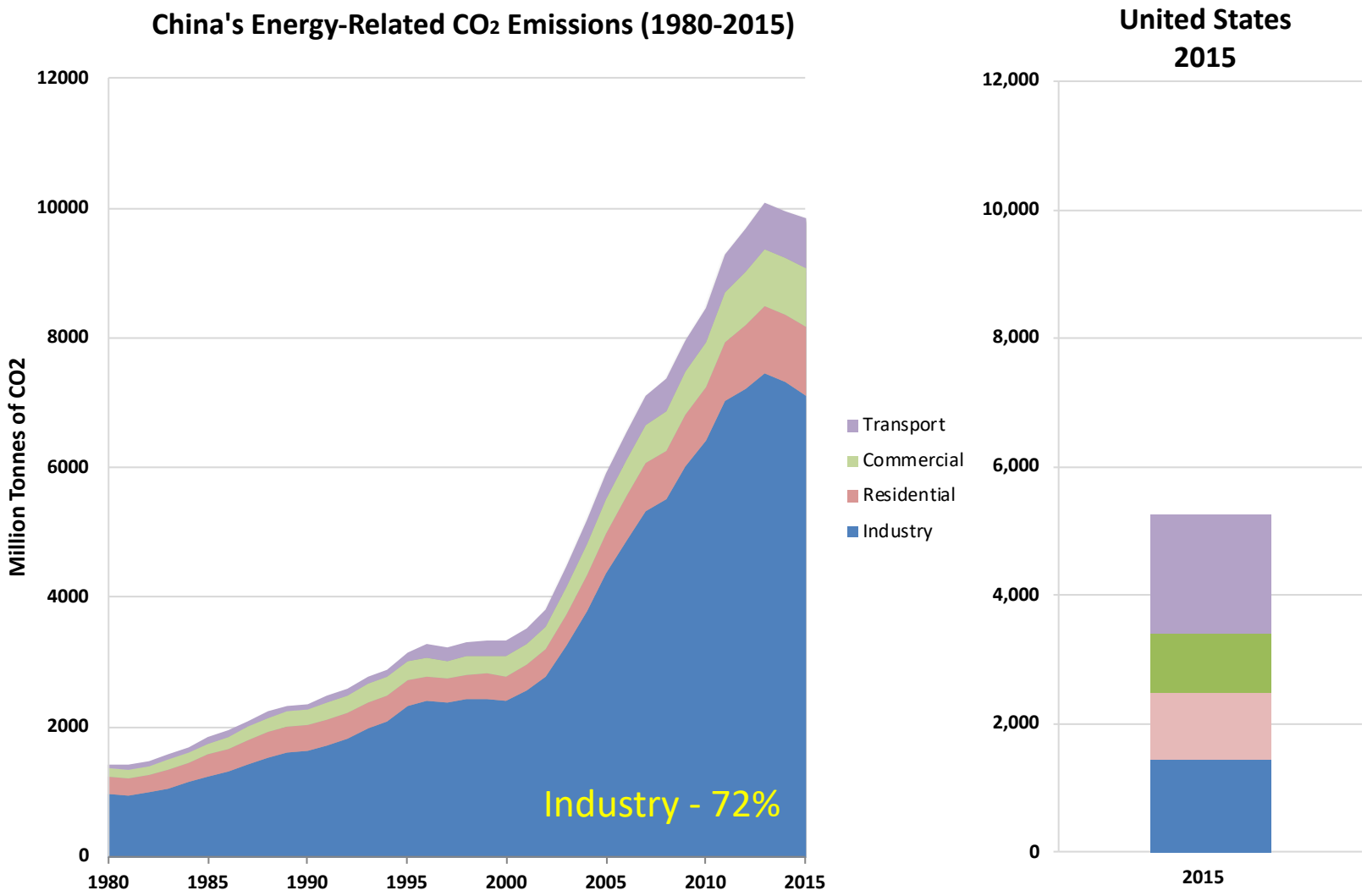
Coal - largest source of China's energy-related CO_2 emissions



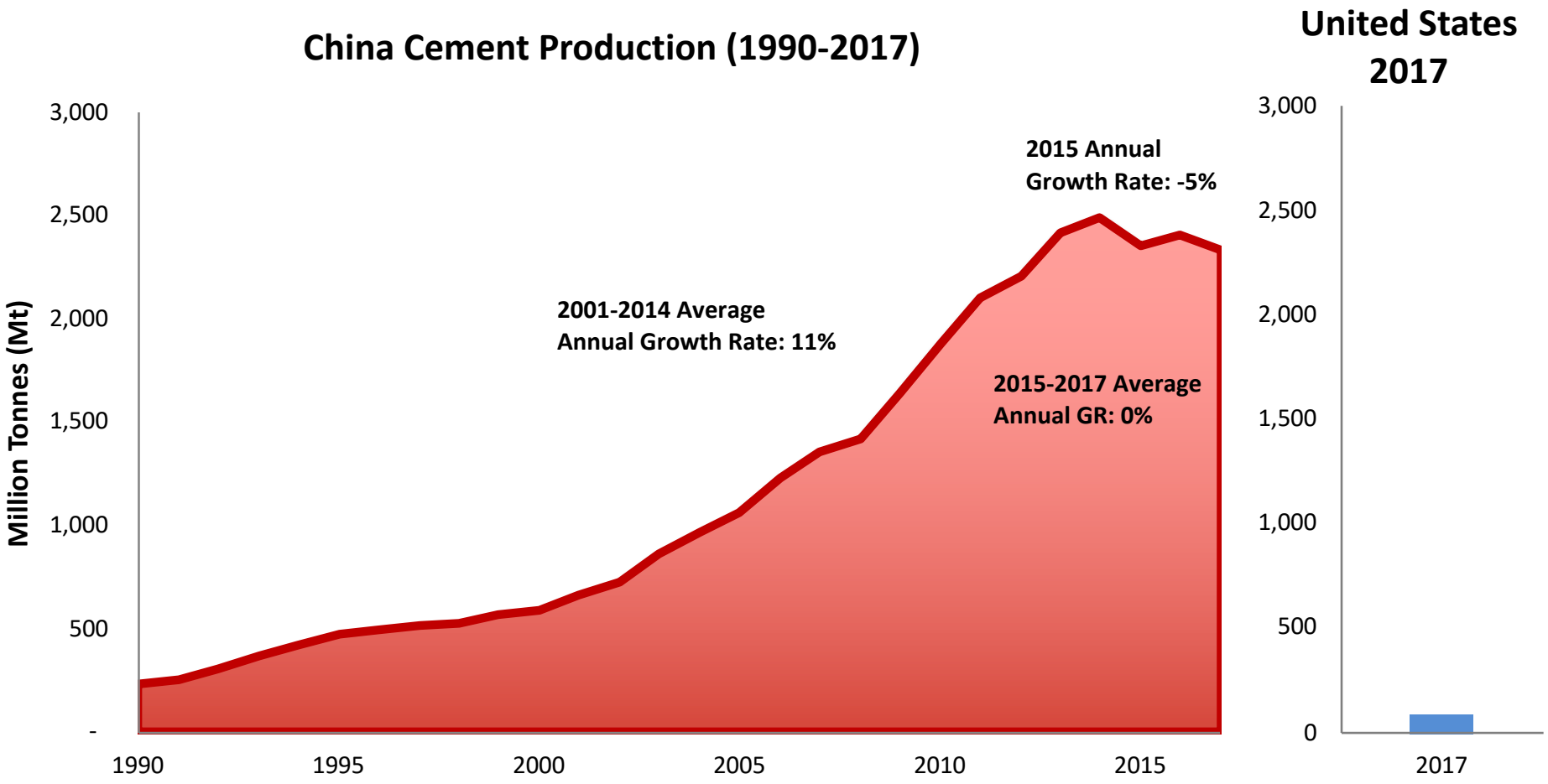
Sources: NBS, China Energy Statistical Yearbooks; IPCC emission factors; US EIA, 2016.

Industry is the largest end-use sector in China



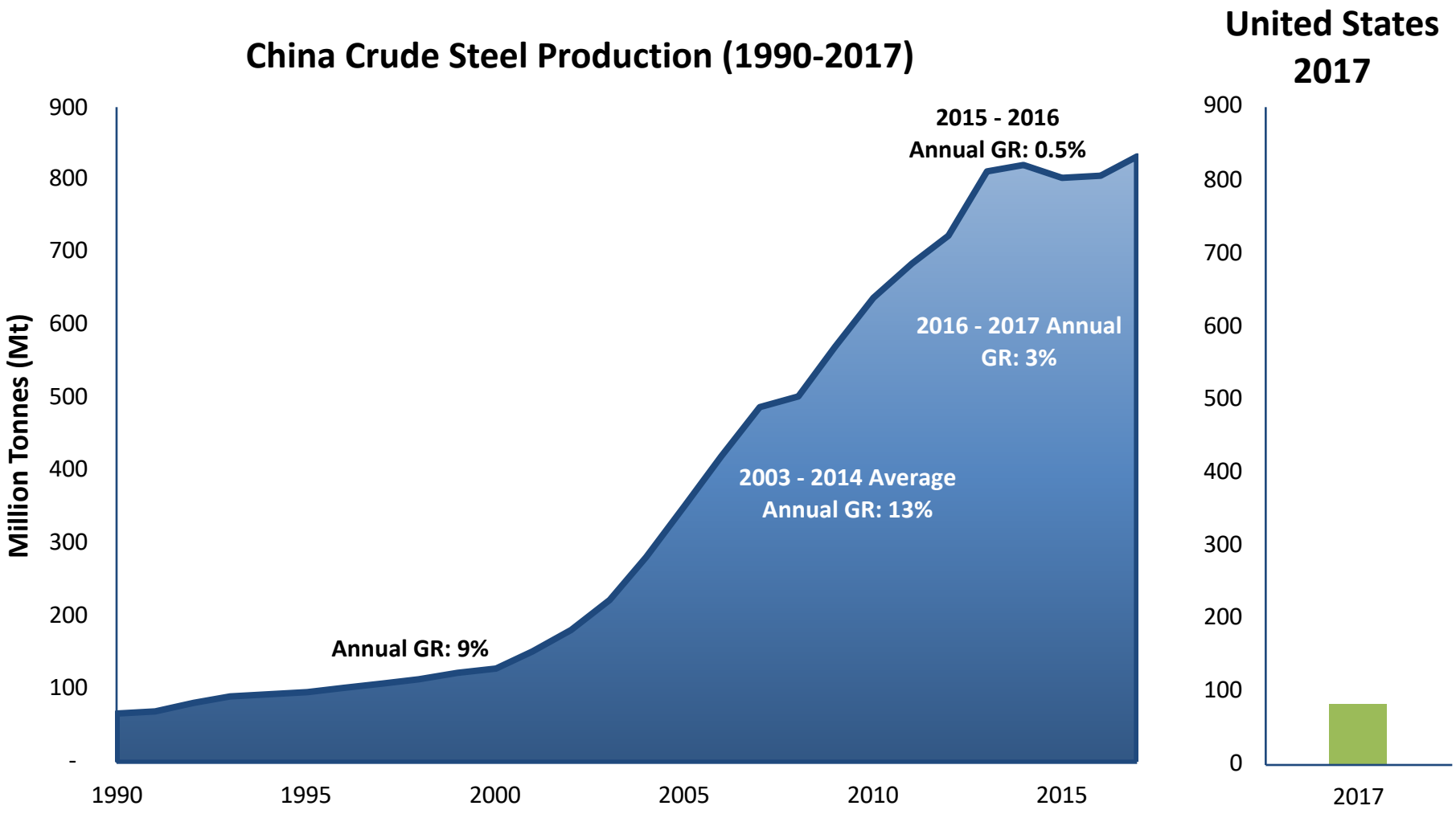
Sources: NBS, China Energy Statistical Yearbooks; US EIA, 2016.

Cement production in China



Sources: China Cement Association, China Cement Almanac. National Bureau of Statistics, 2005-2018. China Statistical Yearbook; USGS Cement Mineral Yearbook.

Steel production in China



Sources: NBS, various year; USGS, 2018.

Recent data tell us…

- Cement, steel, and thermal power generation contributed to the decrease in China's CO_2 emissions in 2015.
- However, recent data show that China's coal use, steel production, and end-use electricity has been growing.
- These industries play a significant role in shaping China's CO_2 trajectory.

How much waste heat potential do we have in key Chinese industries?

What is the quality of the waste heat in key Chinese industries?

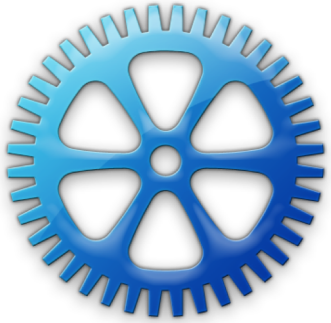
Lu, H., L. Price, and Q. Zhang. 2016. "Capturing the invisible resource: Analysis of waste heat potential in Chinese industry", *Applied Energy*, 161, pp. 497-511. http://dx.doi.org/10.1016/j.apenergy.2015.10.060

Lu, H. 2015. *Capturing the Invisible Resource: Analysis of Waste Heat Potential in Chinese Industries and Policy Options for Waste Heat to Power Generation.* Lawrence Berkeley National Laboratory (LBNL-179618). Berkeley, CA. May.

Method: thermal analysis

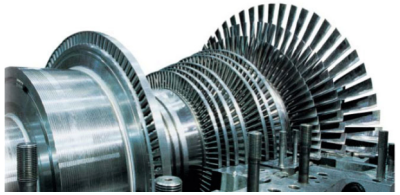
$$E_{waste\ heat} = \left(m_{exhaust\ gas}\right) \times \sum_i \left(x_i \times h_i(t)\right)$$

Fuel input



Combustion controls

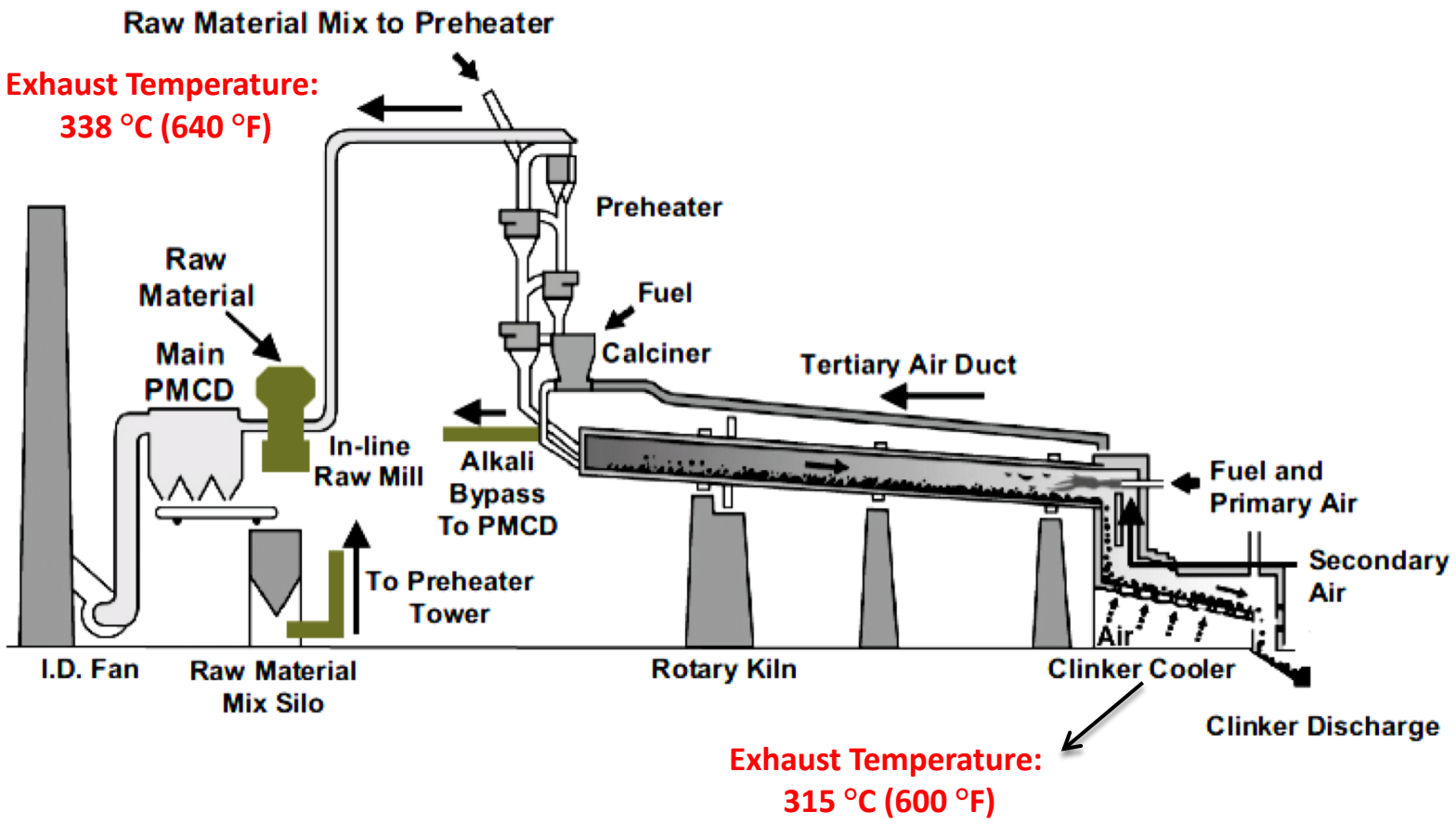
Exhaust and reference temperatures



Type of technology

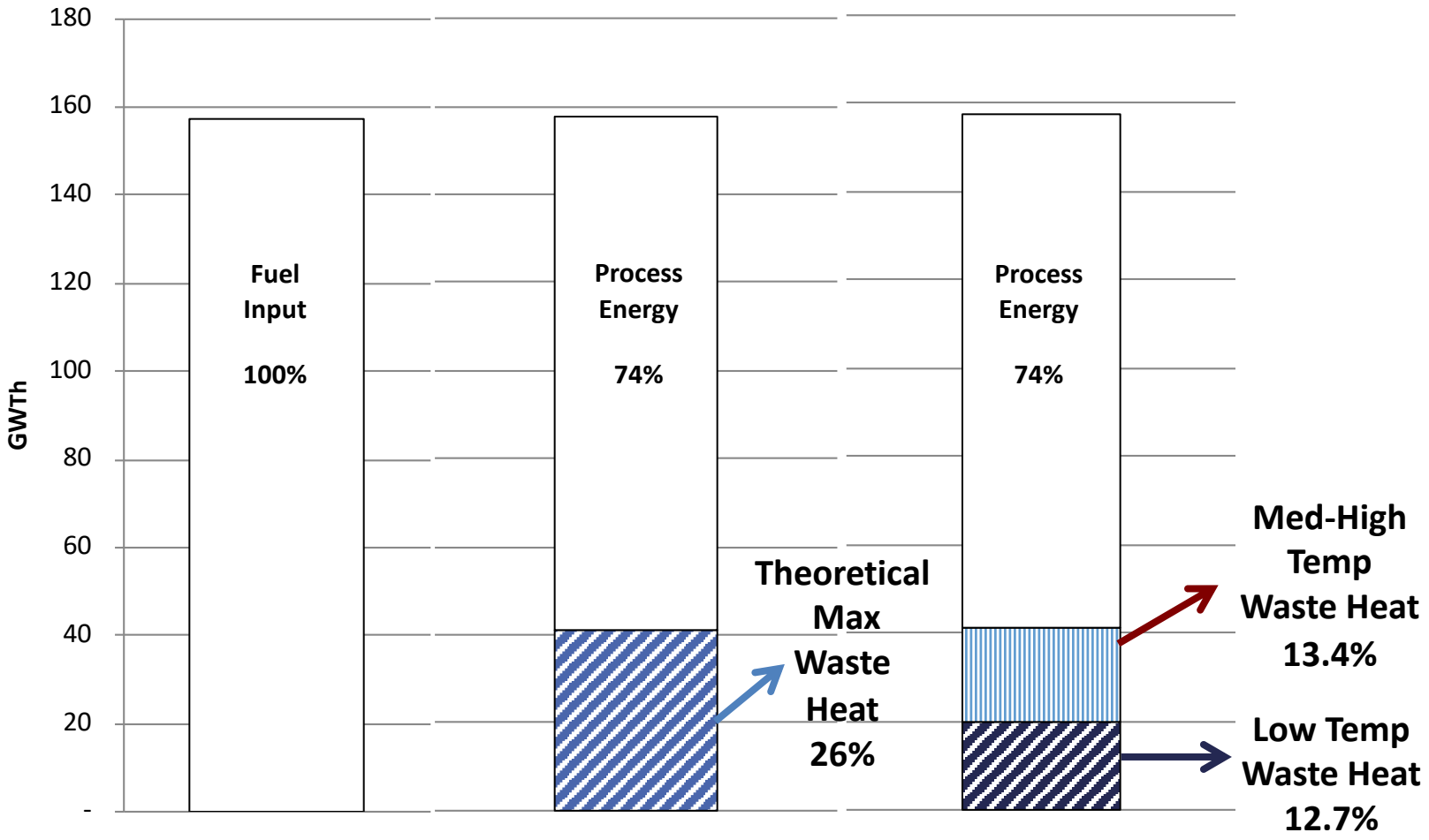
Sources: Lu et al., (2016) and Lu (2015).

Cement Rotary Kiln with Preheaters/Precalciner



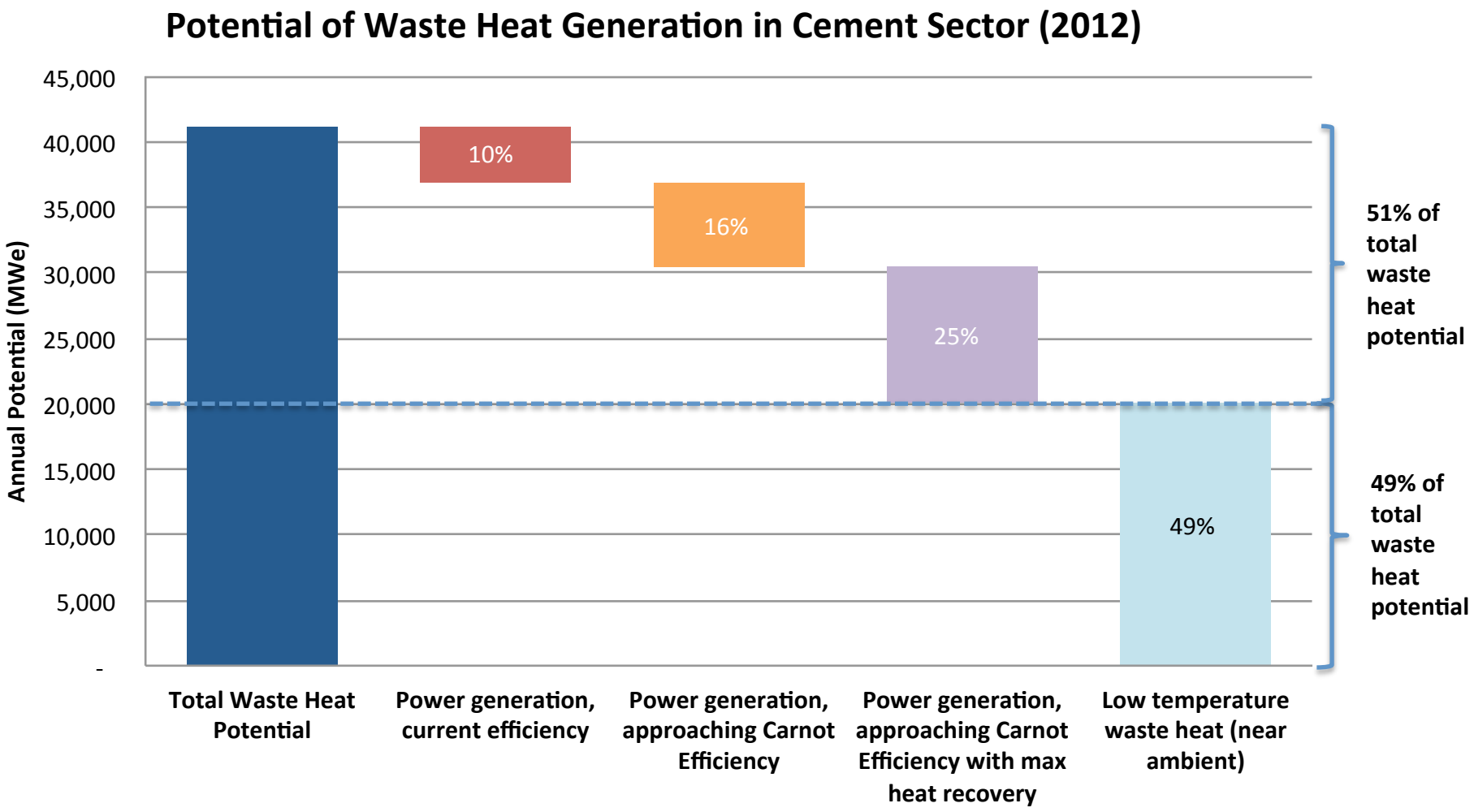
Source: E3M, Inc.

Cement sector waste heat potential



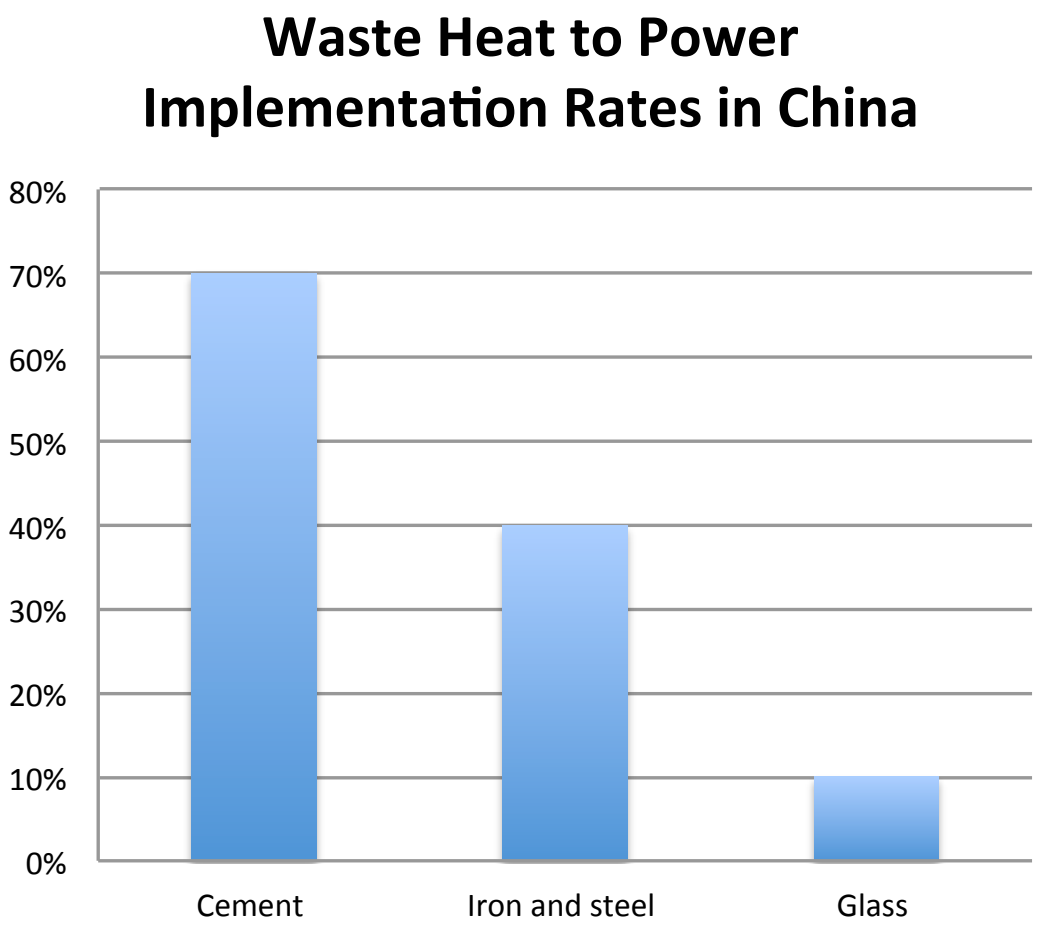
Sources: Lu et al., (2016) and Lu (2015).

Cement sector waste heat to power potential



Sources: Lu et al., (2016) and Lu (2015).

Waste Heat to Power



Why the adoption of waste heat generation is limited in energy-intensive industries in China, other than the cement sector?

Sources: Lu et al., (2016) and Lu (2015).

Key Findings

To deploy easily-adopted and cross-sector waste heat to power technologies, a sector needs to meet at least the following criteria:

- Product: a homogenous product
- Process: relatively simple
- Exhaust temperature: medium-high
- Contaminants: fewer contaminants
- System components: easy to manage
- Penetration of waste heat generation: low

Waste Heat Management

Reduce

- Minimize waste heat
  - e.g., combustion optimization, process controls, insulation improvement

Recycle

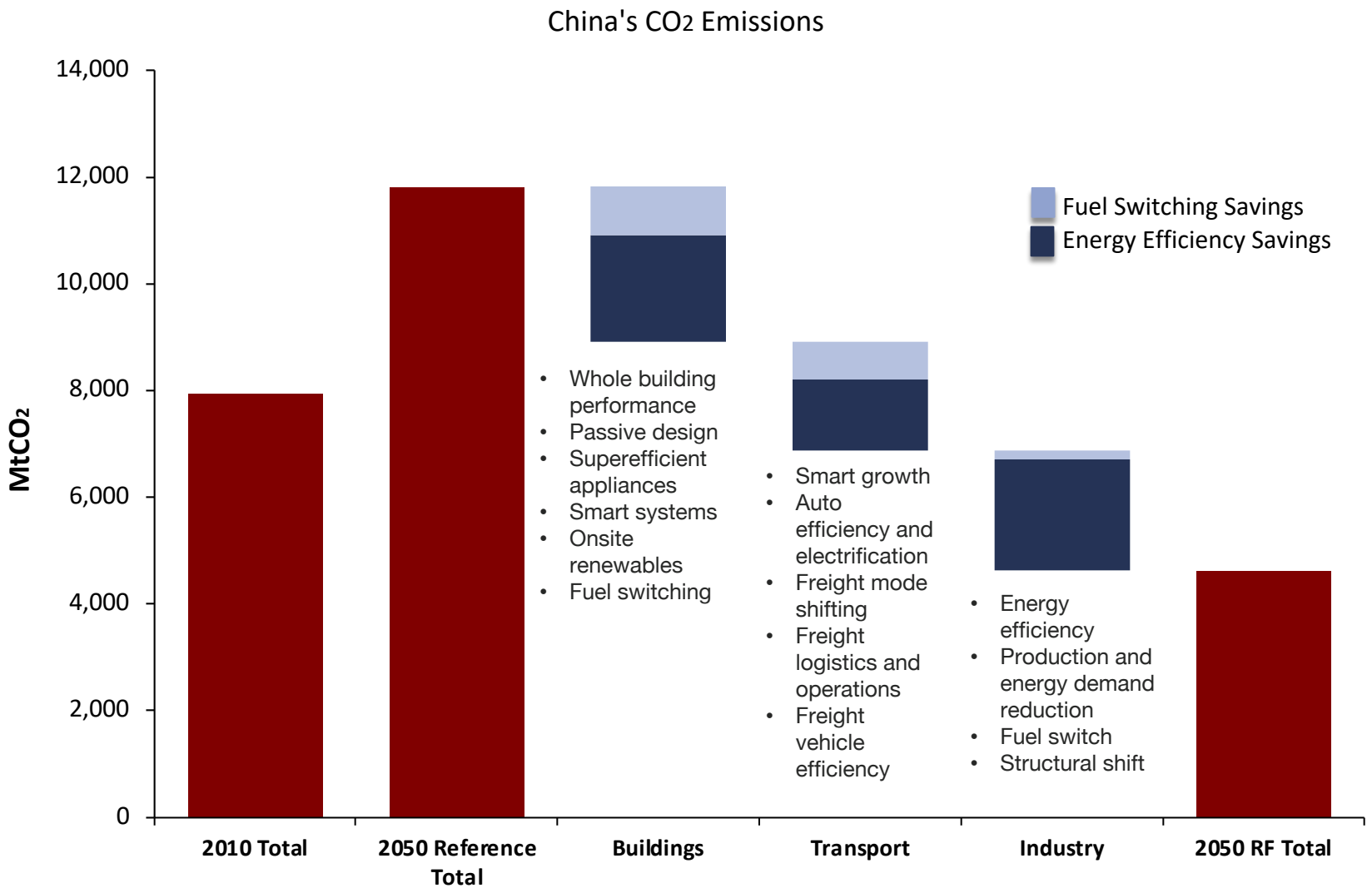
- Recycle waste heat within the process
  - e.g., preheating combustion air, make-up air, fuel, and charging materials

Recover

- Recover waste heat to produce steam
- Recover energy through waste heat to power generation

The key role of energy efficiency!!

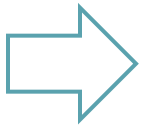
Reinventing Fire: China CO_2 Emissions Reductions



Source: *Reinventing Fire: A Roadmap for China's Revolution of the Consumption and Production of Energy to 2050.*

Promoting industrial energy efficiency in China

- LBNL's China Energy Group has been working on industrial energy efficiency in China since 1990s
- In collaboration with Chinese research institutes, universities, think-tanks, other national labs, and international NGOs
- Funding by the U.S. government (DOE, EPA, State) and foundations (esp. Energy Foundation China)
- Focused on:
  - Technology assessments
  - Tool development
  - Training workshops
  - Policy analysis



Two examples:

- International Industrial Energy Efficiency Training and Deployment (IIEETD)
- Comprehensive Program to Improve Energy Efficiency, Increase the Use of Alternative Fuels and Raw Materials, and Reduce Emissions in the Cement Sector in China (APP Cement Project)

International Industrial Energy Efficiency Training and Deployment (IIEETD)

Sponsors: **U.S. Department of Energy, Energy Foundation China**

U.S. Collaborators	Chinese Collaborators	
• Lawrence Berkeley National Laboratory, China Energy Group • Institute for Sustainable Communities • Oak Ridge National Laboratory	• National Energy Conservation Center • University Alliance for Industrial Energy Efficiency • Zhengzhou University • University of Science and Technology – Beijing • EHS Academy Jiangsu	• EHS Academy Guangzhou • Suzhou Energy Conservation Center • Shandong Energy Conservation Office • Shandong University • Sun Yat-sen University

- Developed and Deployed Trainings in Energy Assessment and Management
  - Industry-Focused System-Specific Assessments: Four 5-day training workshops conducted by world-leading experts for 40-50 trainees
    - Process heating system assessment workshop held in Zhengzhou, Henan Province in October 2011: on-site visit to an alumina plant
    - Process heating system assessment workshops in for Guangzhou and Jinan in May 2012
    - Steam system assessment workshops in Suzhou and Beijing in January 2013
  - Implementation of Energy Management Solutions and ISO 50001

International Industrial Energy Efficiency Training and Deployment (IIEETD)

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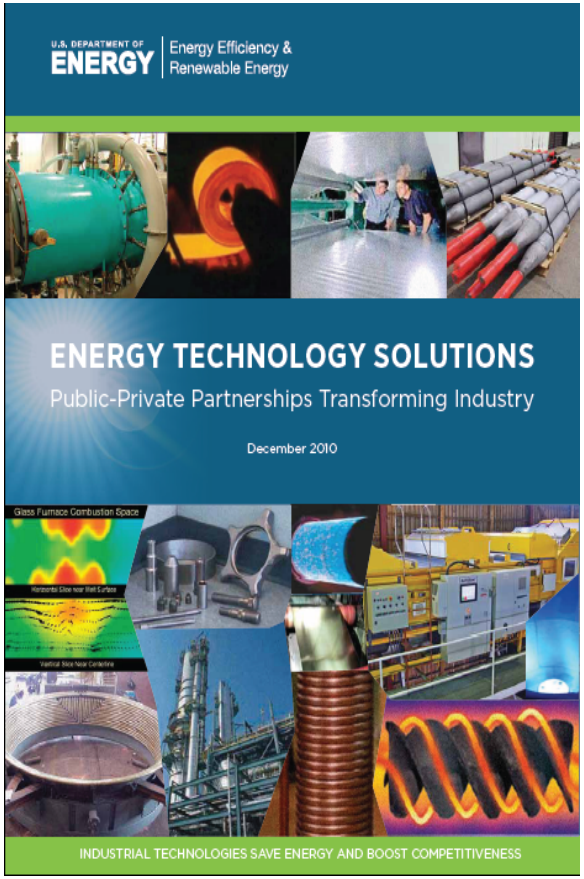
- Accelerated the Growth of China's Industrial Energy Efficiency Market
  - Candidates for Qualified Process Specialists
  - Webinars and Self-Assessment Tools
- Developed Chinese version of the Process Heating Assessment and Survey Tool (PHAST), and localized the Steam System Assessment Tool and the Steam System Scoping Tool
- Joined by U.S. companies, including Dow Chemical, GE, 3M, Alcoa, Honeywell, Bloom, Eclipse, Maxon, Arc Pacific, and ICF.
- Project report: "Energy Assessments under the Top 10,000 Program: A Case Study for a Steel Mill in China" presented at the European Council for an Energy-Efficient Economy's 2014 Industrial Summer Study

Information dissemination and long-term impact

- Information dissemination:
  - Disseminated energy-efficiency technologies and solutions from U.S.
  - Invited 12 representatives from U.S. companies to present their energy-efficiency solutions to the Chinese local officials, energy service companies, consulting agencies, and research institutions
- Long-term evaluations of completed workshops:
  - Participants passed on knowledge/tools to hundreds of others already
  - Many factories used the tools to identify EE opportunities; achieved savings
  - Universities incorporating materials into training programs
  - Policymakers recognize importance of assessment to Top-10,000 program targets

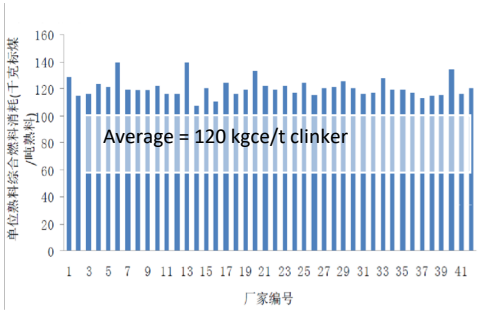


Asia Pacific Partnership Cement Project

Sponsors: **U.S. Department of State**

Collaborators: **China Building Materials Academy, Cement Industry Energy Efficiency and Environmental Protection Evaluation and Test Center of China Building Material Industry, China Cement Association, E3M, Inc., World Resources Institute**

- Enhanced the capacity of 42 key representative cement companies
  - Conducted on-site energy and GHG emissions assessments
  - Identified energy-saving measures and potentials
- Demonstrated the substantial environmental and economic benefits for co-processing of alternative fuels and raw materials
  - Six demonstration plants
  - Four technical guidelines
  - One sewage sludge techno-economic tool
- Document and disseminate the results of the project throughout China to build up the capacity of entire cement sector
  - Public online database
  - Containing summary reports and assessment results



Fuel Consumption Per Unit of Clinker (kgce/t of Clinker)

APP Cement Project Database - Interface

Benchmarking and potential assessment

- BEST-Cement development:
  - Benchmarking and Energy Saving Tool for Cement
  - Process-based assessment
  - Benchmark cement facilities to a hypothetical cement plant that uses international and domestic “best practices”
  - Provide >150 energy-efficiency measures

- Localization:
  - Adapted to Chinese industry standards:
    - Clinker intensity comparison (GB16780-2007)
    - Grades of cement products
  - Energy conversion factors
  - English and Chinese, SI and Chinese units
  - *http://china.lbl.gov/research/industry/benchmarking/best-cement/best-cement-china*

Train the Trainers

- Multiple training workshops held in Hebei, Shanxi, Shandong, and Beijing:
  - Trained ~300 cement plant engineers and researchers using the BEST-Cement Tool
- Train the trainers
  - Trained Chinese experts to continued to train Chinese cement plant staff using BEST-Cement and PHAST-Cement for benchmarking and potential assessment
- Use of the tools
  - First three on-site visits – demonstrate how to conduct energy and CO_2 emissions assessments
  - Chinese experts continued to visit the other 39 cement plants
  - Used the tools to assess the energy-saving potential in 42 cement plants in China, representing 5% of China's total cement production

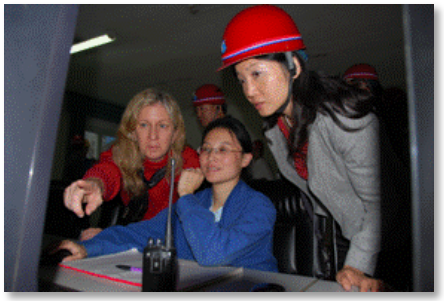
Project results

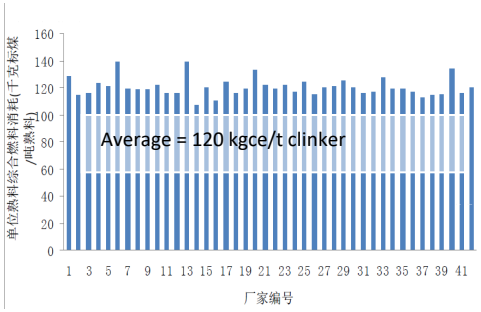
- Results

Cement production intensity	42 Plants Average	China Minimum Performance standards	World Best Practice
Fuel intensity (kgce/t clinker)	120	128	97
Electricity intensity (kWh/t clinker)	76	73	45

  - Energy-saving measures were selected by 42 plants using the BEST-Cement Tool
    - Indicating their energy saving and emission reduction potentials
  - If the average saving potentials are applied to all 42 cement plants
    - Potential electricity savings: 2,730 GWh/year
    - Potential fuel savings: 1,806 tce/year
    - Potential emission reductions: 7.35 $MtCO_2$/year CO_2 , which represent 15% of total energy-related CO_2 emissions/year

- Information dissemination
  - A database was built based on the APP project
  - Documents outcome of initial energy assessments
  - Provides key performance indicators of the assessments
  - Can be used to track the performance improvement





Fuel Consumption Per Unit of Clinker (kgce/t of Clinker)

APP Cement Project Database - Interface

Conclusions

- There is still significant energy efficiency potential to be captured in China's industries.
- Energy efficiency plays an essential role in cost-effectively reducing industry's GHG emissions.
- Decarbonization of heavy industry is a critical issue that requires an "all-of-the above" strategy.
- Some elements of this strategy are medium-term (e.g. fuel switching) or longer-term (e.g. CCUS), but energy efficiency is available now!

Thank you for your time and attention!

Questions?

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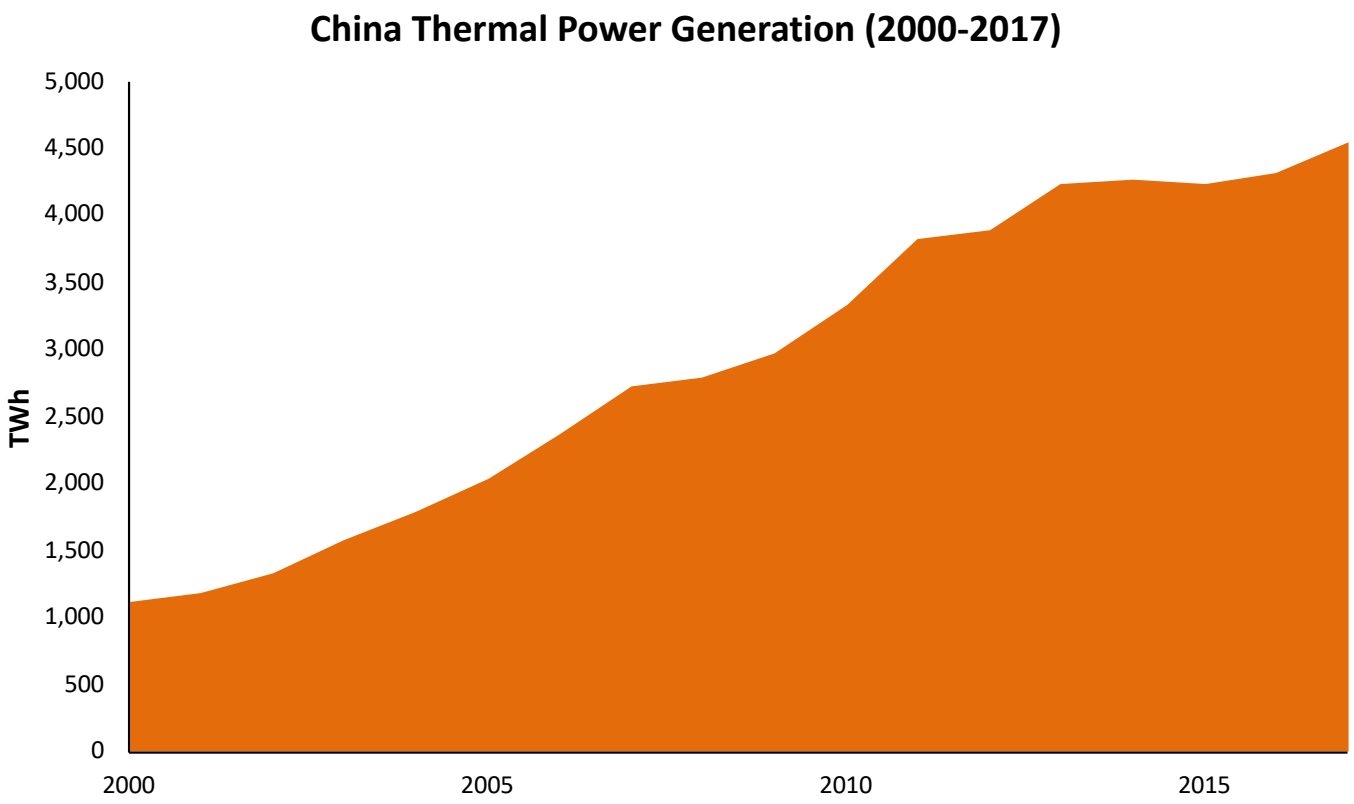
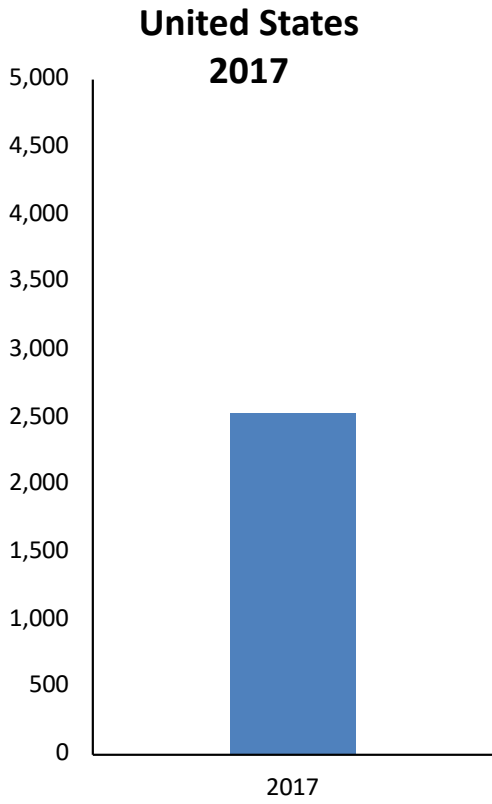
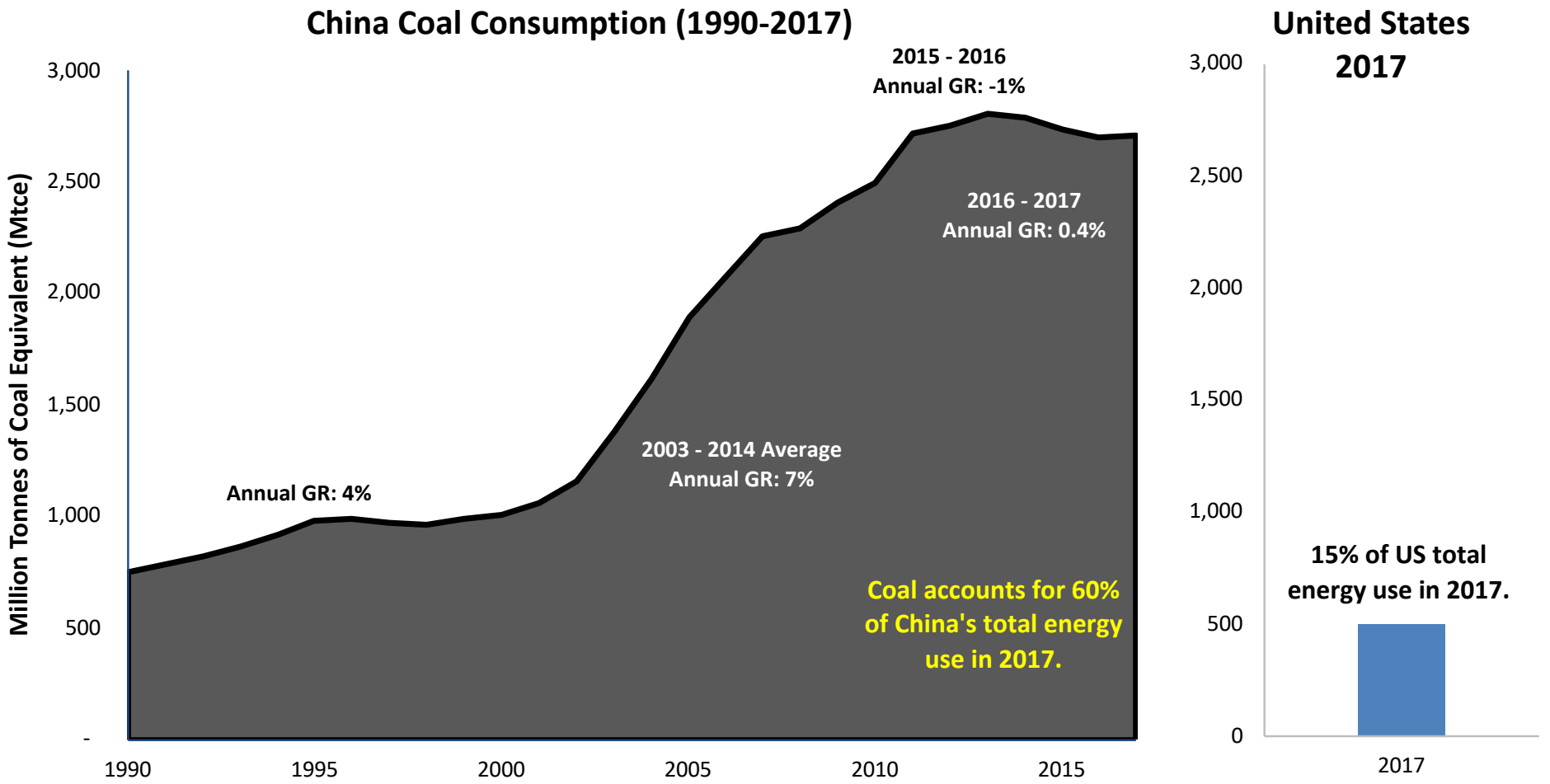
Backup slides

Thermal power generation

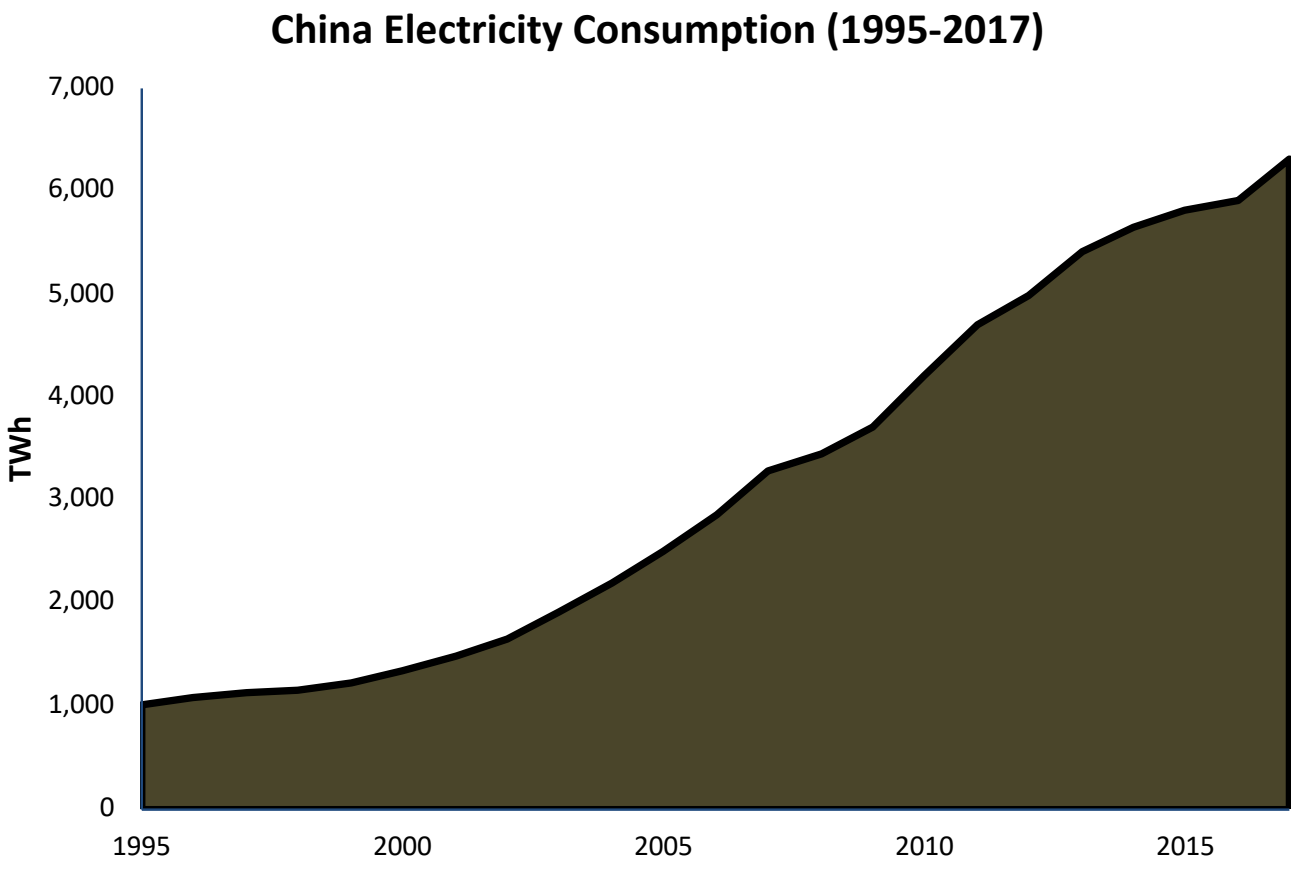


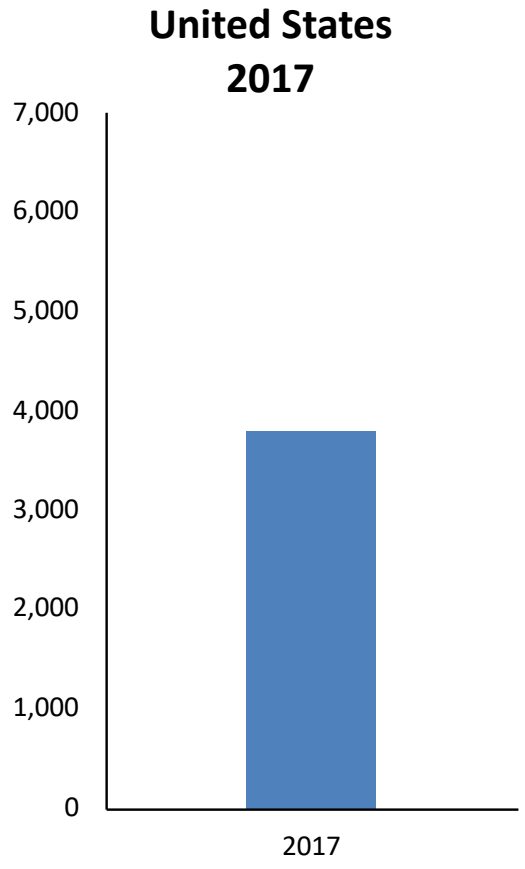


Coal consumption



Electricity consumption in China

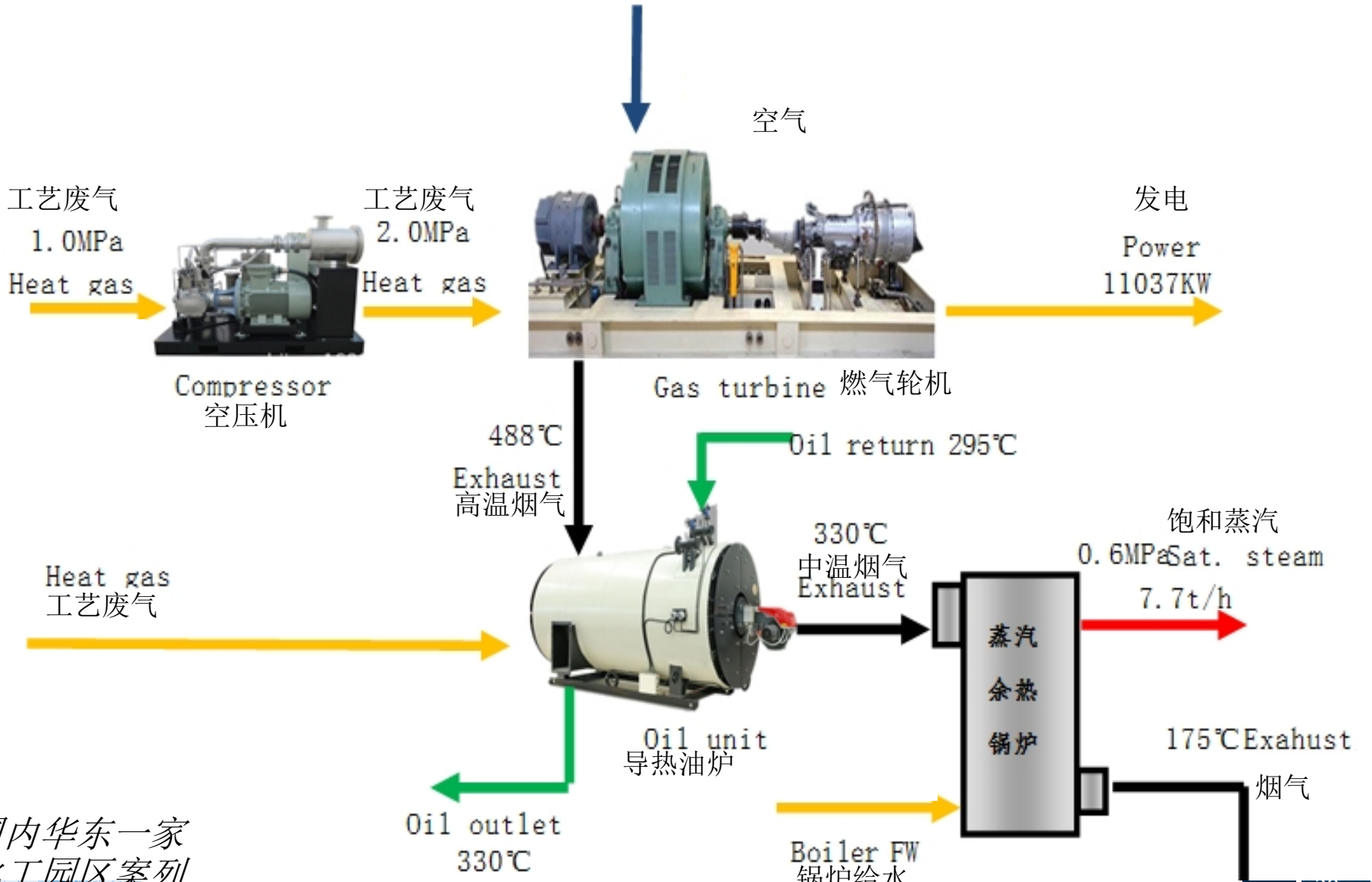




Support to Promote Waste Heat Utilization

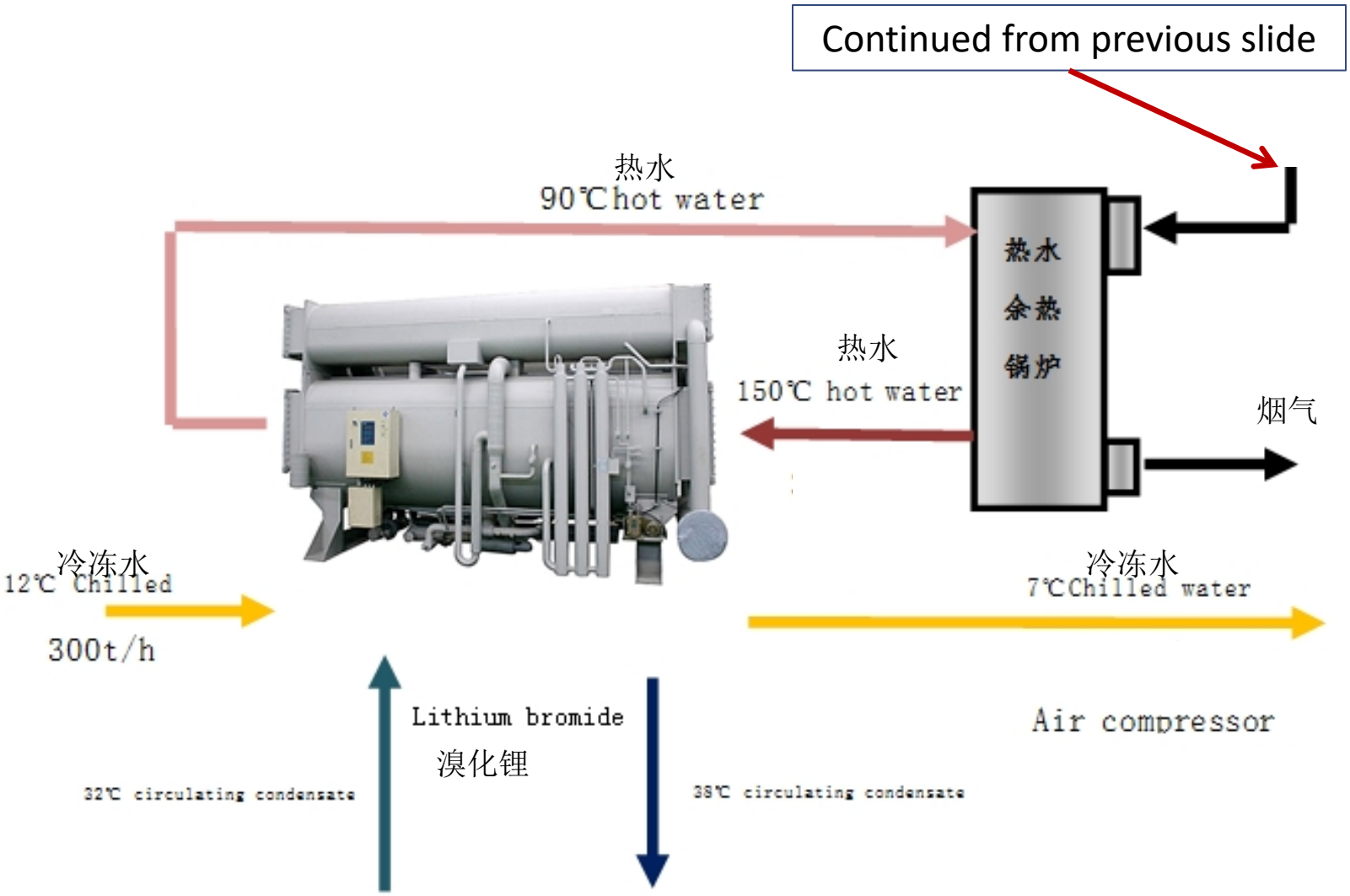
- Legislative recognition
  - *Energy Conservation Law of China*
  - China's *Circular Economy Promotion Law*
- Incentives
  - Top Ten Projects
  - Technical Retrofit Incentives
- Mandates
  - Top 10,000 Program goals
  - Minimum Energy Performance Standards (MEPS)
  - Differential electricity tariffs

Cogeneration System (part 1)

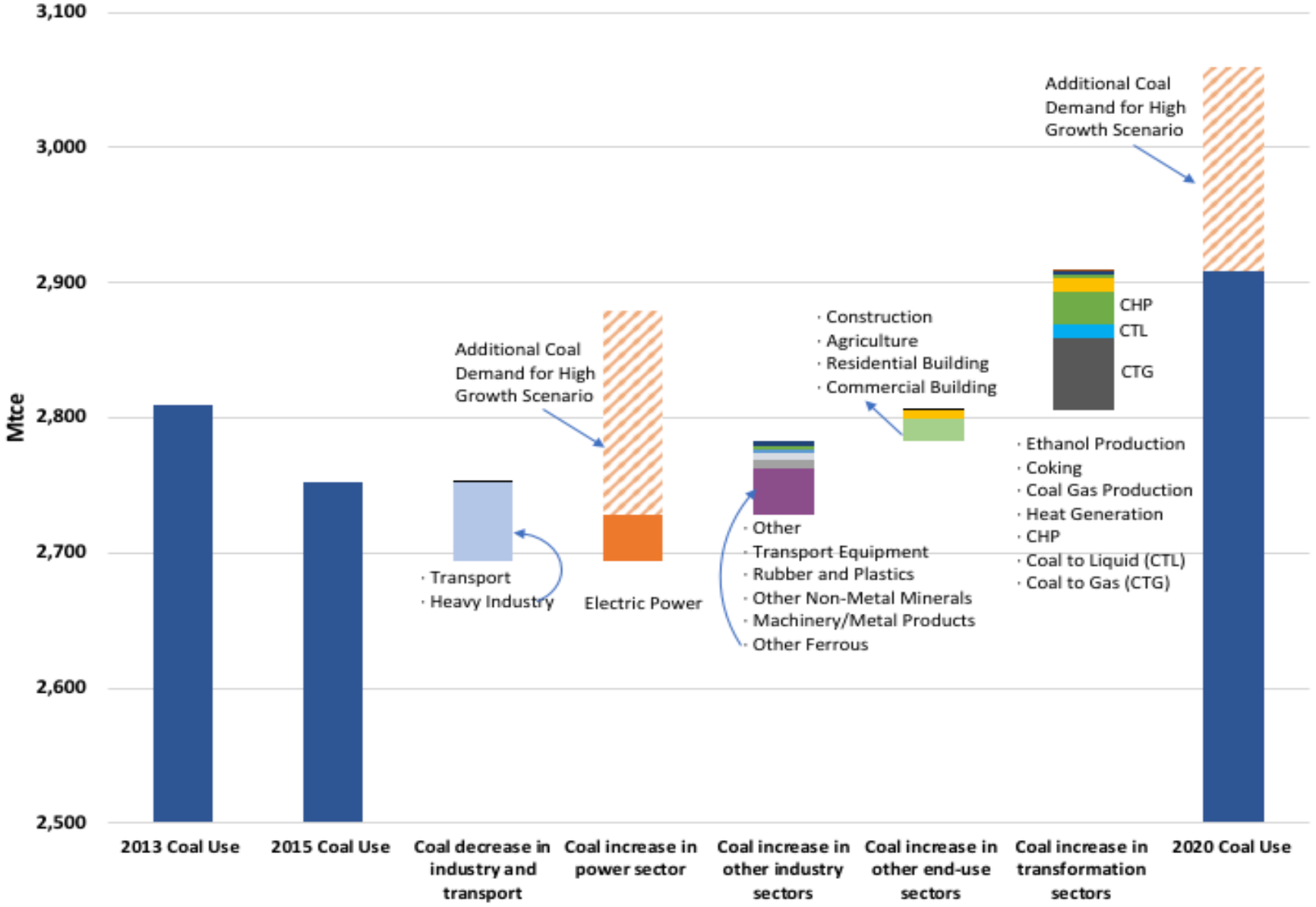


国内华东一家化工园区案列

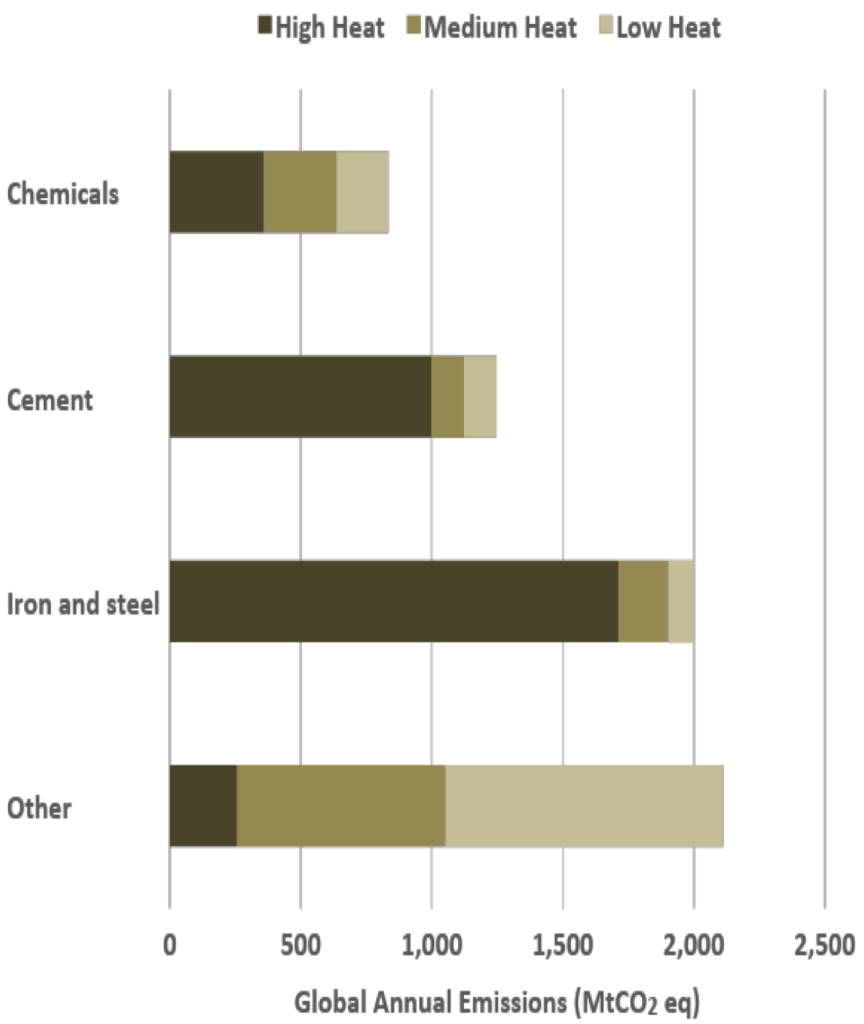
Cogeneration system (part 2)



China Coal Use in 2020

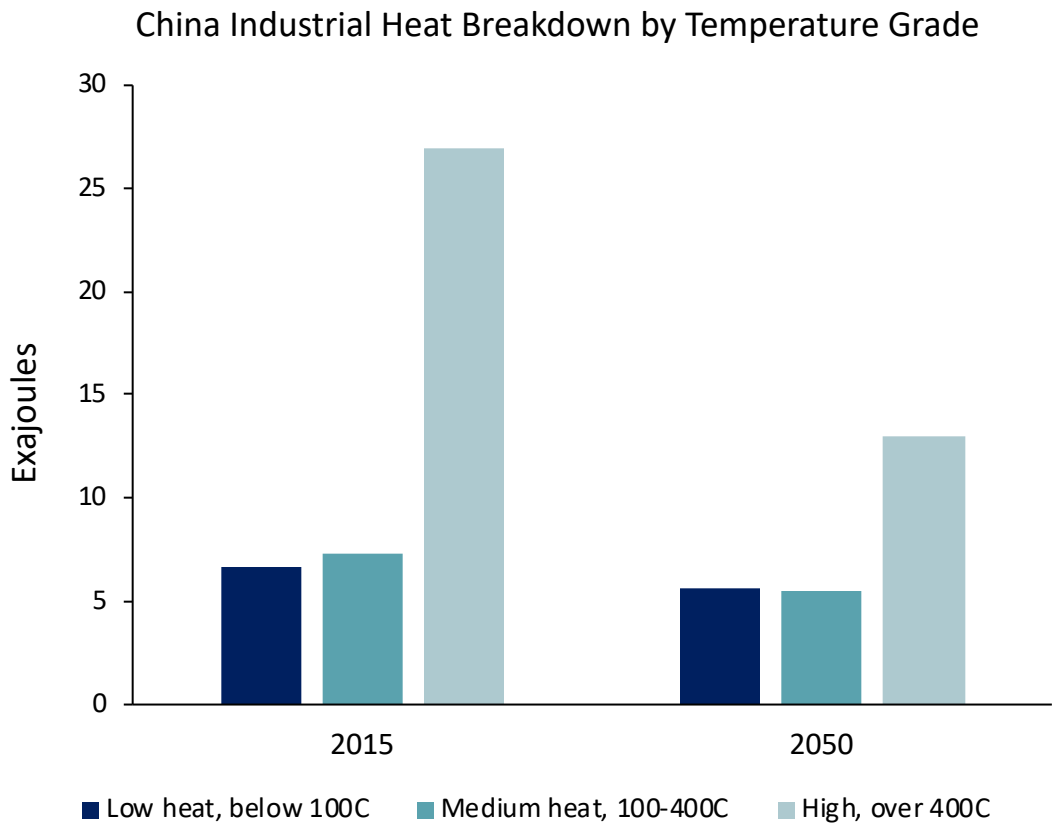


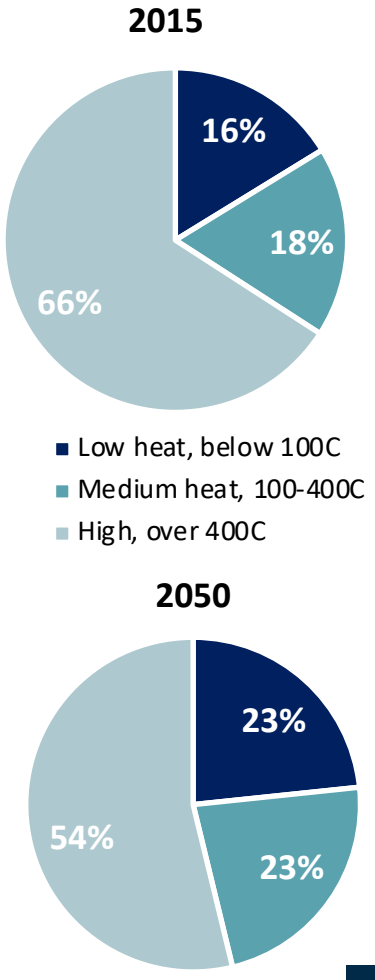
Electrifying Industrial Heat Processes



Low to Medium Temperature Heat *up to 400°C* Main uses: drying and distillation	
Commercial Heat pumps Electric boilers Induction heating Radio frequency heating Renewable (pre-)heating	**Emerging** Microwave heating UV heating Electric infrared heating
High Temperature Heat *Above 400°C* Main uses: process heating and melting	
Commercial Electric arc furnace	**Emerging** Plasma melting Electrolytic reduction Electric induction melting Hydrogen

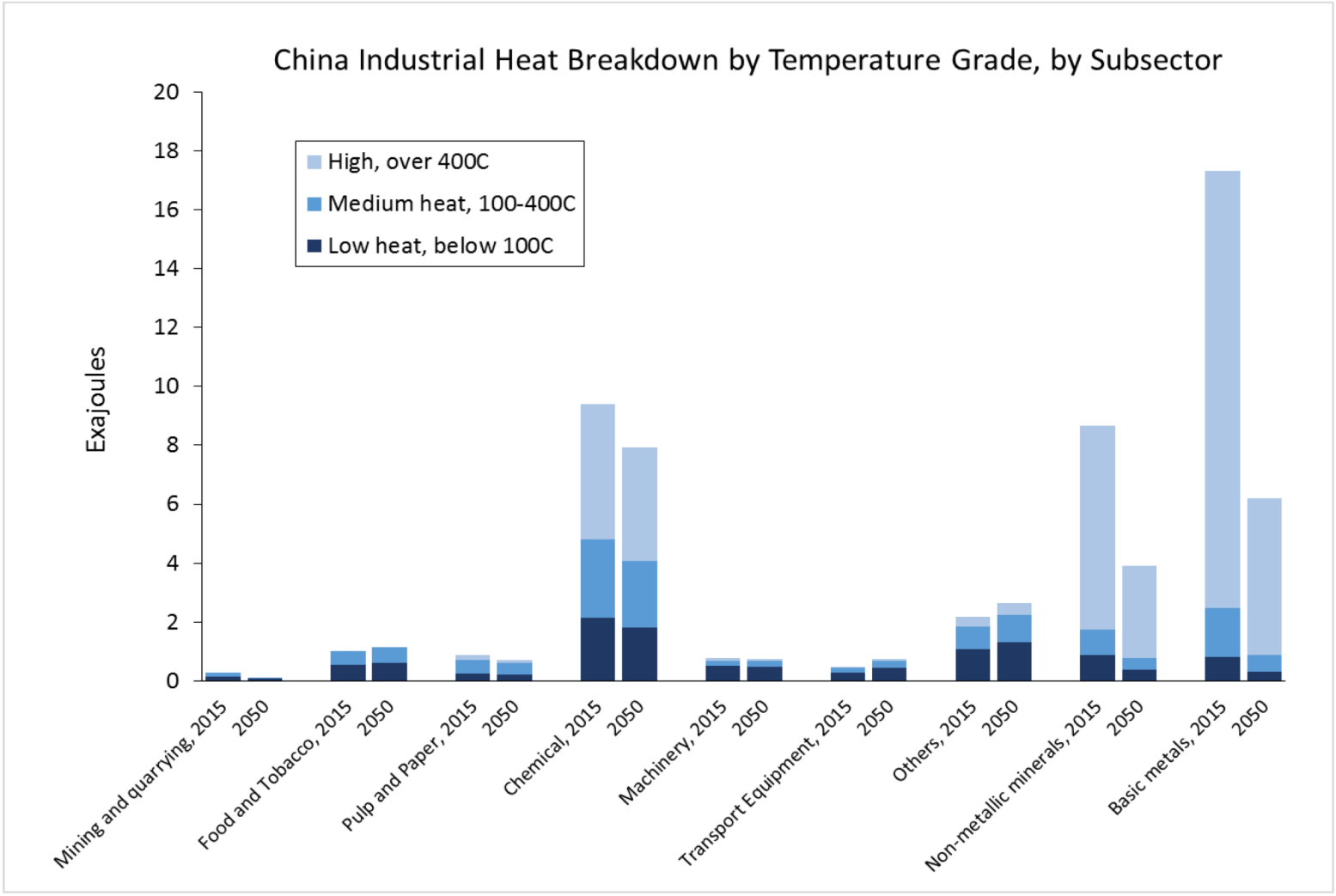
High-temperature heat accounts for the largest share of industrial heat in China, with its share expected to decline over time as industry shift towards high value-added manufacturing





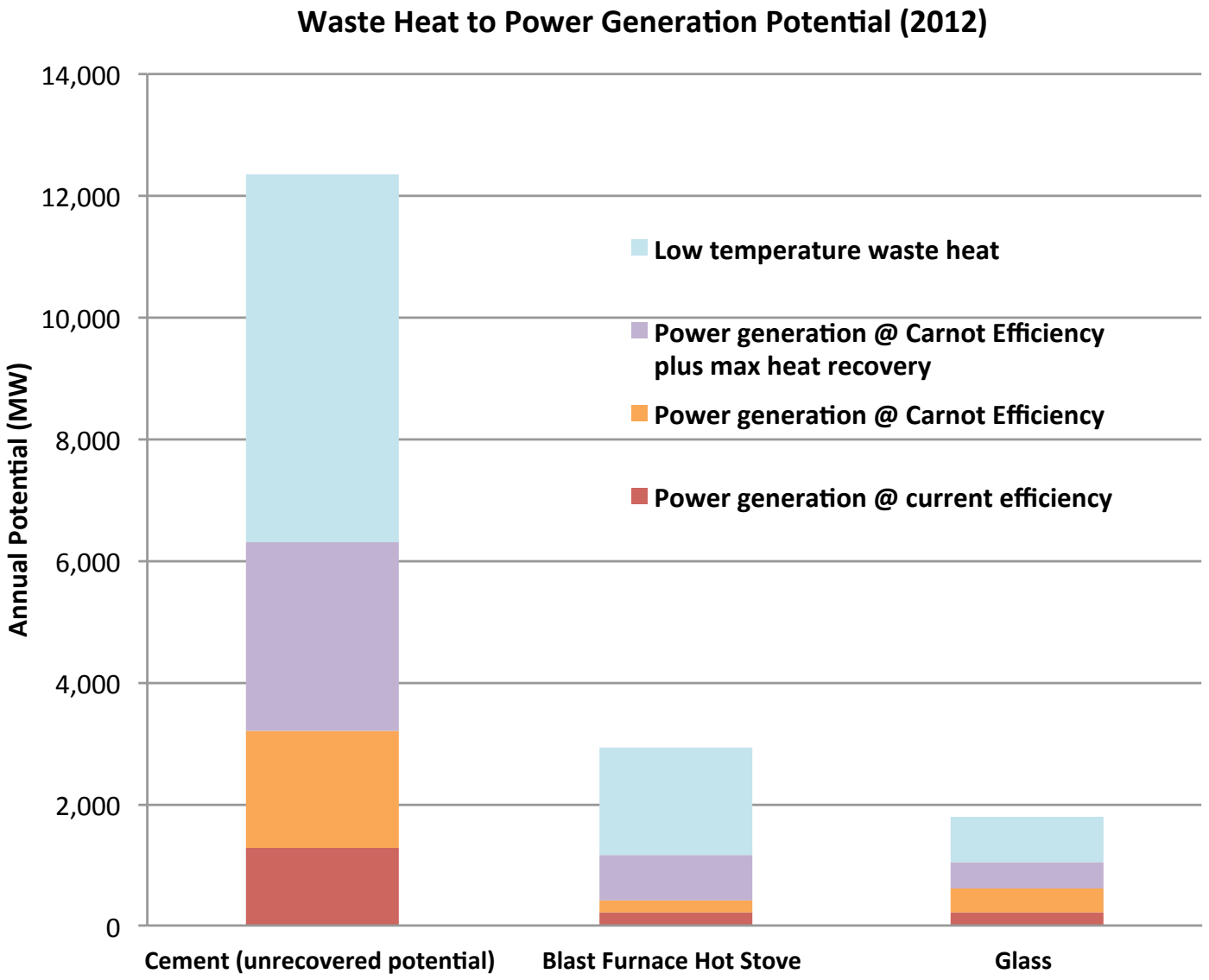
Source: China 2050 DREAM model results, calculated using EU shares for heat temperature breakdown for specific industrial subsectors

Within industry, heavy industries such as basic metals, chemicals and non-metal minerals use the most high-temperature heat



Source: China 2050 LBNL DREAM model results, calculated using EU shares for heat temperature breakdown for specific industrial subsectors

Waste Heat to Power Generation Potential

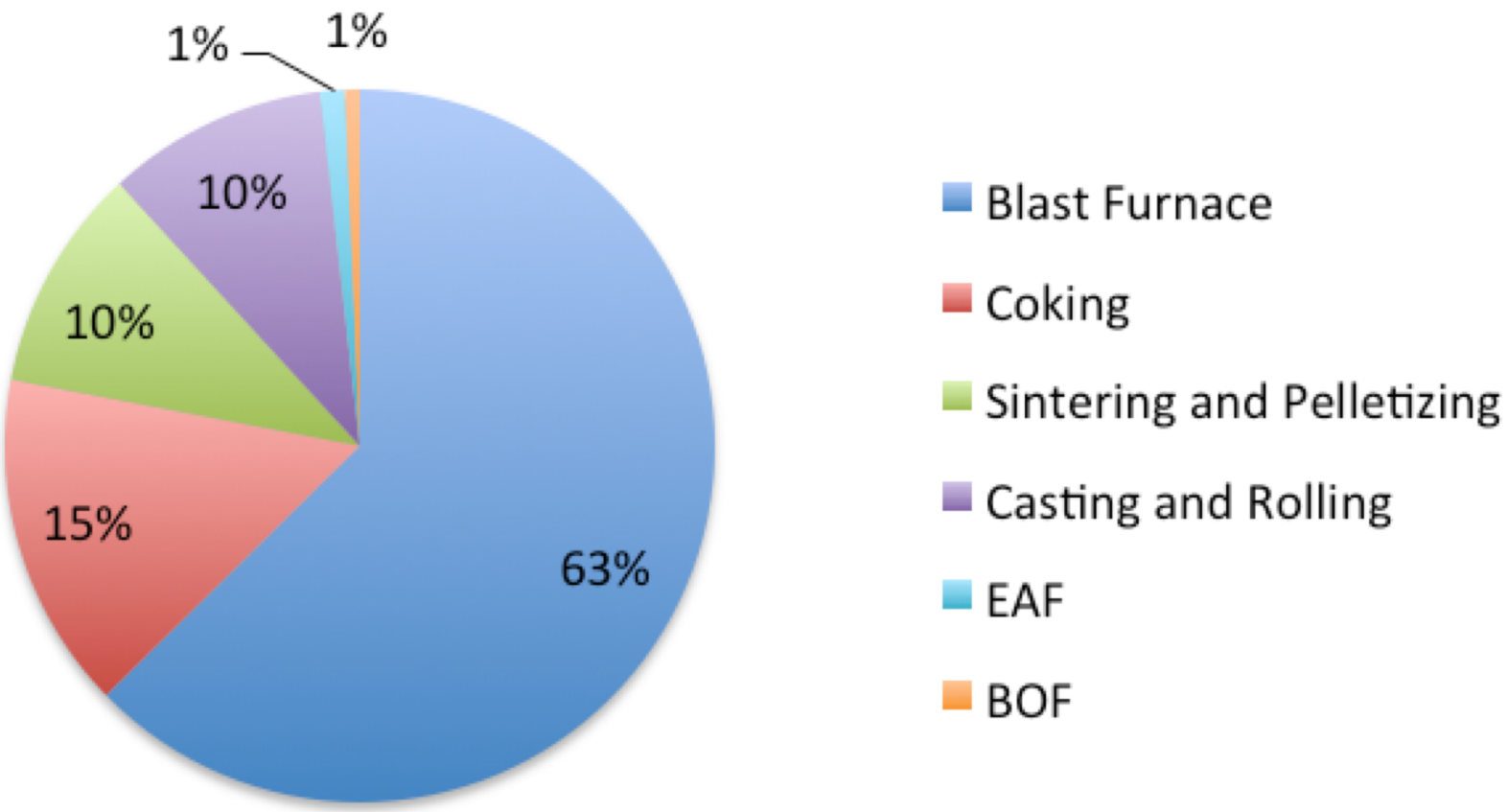


Recent Trends

- China's iron & steel, cement production
- China's coal consumption
- China's electricity demand

Iron and Steel Sector

Energy Use by Process of China's Iron and Steel Sector (2012)



Glass Sector