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 CO₂ emissions


- **Coal**: 76%
- **Natural gas**
- **Petroleum**

Sources: NBS, China Energy Statistical Yearbooks; IPCC emission factors; US EIA, 2016.
Industry is the largest end-use sector in China

Cement production in China

China Cement Production (1990-2017)

2001-2014 Average Annual Growth Rate: 11%
2015 Annual Growth Rate: -5%
2015-2017 Average Annual GR: 0%

Steel production in China

China Crude Steel Production (1990-2017)

- Annual GR: 9%
- 2003 - 2014 Average Annual GR: 13%
- 2015 - 2016 Annual GR: 0.5%
- 2016 - 2017 Annual GR: 3%

Sources: NBS, various year; USGS, 2018.
Recent data tell us...

- Cement, steel, and thermal power generation contributed to the decrease in China’s CO₂ 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 CO₂ 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?


Method: thermal analysis

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

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

Exhaust Temperature: 338 °C (640 °F)

Exhaust Temperature: 315 °C (600 °F)

Source: E3M, Inc.
Cement sector waste heat potential

Sources: Lu et al., (2016) and Lu (2015).
Cement sector waste heat to power potential


- Total Waste Heat Potential
- Power generation, current efficiency
- Power generation, approaching Carnot Efficiency
- Power generation, approaching Carnot Efficiency with max heat recovery
- Low temperature waste heat (near ambient)

51% of total waste heat potential
49% of total waste heat potential

Annual Potential (MWe)

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 CO₂ Emissions Reductions

China's CO₂ Emissions

- 2010 Total
- 2050 Reference Total
- Buildings
- Transport
- Industry
- 2050 RF Total

### Fuel Switching Savings
- Whole building performance
- Passive design
- Superefficient appliances
- Smart systems
- Onsite renewables
- Fuel switching

### Energy Efficiency Savings
- Smart growth
- Auto efficiency and electrification
- Freight mode shifting
- Freight logistics and operations
- Freight vehicle efficiency
- Energy efficiency
- Production and energy demand reduction
- Fuel switch
- Structural shift

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

<table>
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- 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
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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

Average = 120 kgce/t clinker

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
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 continue training 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 CO₂ 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**

<table>
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<tr>
<th>Cement production intensity</th>
<th>42 Plants Average</th>
<th>China Minimum Performance standards</th>
<th>World Best Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel intensity (kgce/t clinker)</td>
<td>120</td>
<td>128</td>
<td>97</td>
</tr>
<tr>
<td>Electricity intensity (kWh/t clinker)</td>
<td>76</td>
<td>73</td>
<td>45</td>
</tr>
</tbody>
</table>

- 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 MtCO₂/year CO₂, which represent 15% of total energy-related CO₂ 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
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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Thermal power generation


United States 2017

TWh
Coal consumption

China Coal Consumption (1990-2017)

- 1990-2002 Average Annual GR: 4%
- 2003-2014 Average Annual GR: 7%
- 2015-2016 Annual GR: -1%
- 2016-2017 Annual GR: 0.4%

Coal accounts for 60% of China’s total energy use in 2017.

United States 2017

15% of US total energy use in 2017.

Coal consumption

China Coal Consumption (1990-2017)

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United States 2017

15% of US total energy use in 2017.
Electricity consumption in China


United States 2017
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)

- **Compressor (空压机)**
  - 1.0 MPa
  - Heat gas

- **Gas turbine (燃气轮机)**
  - Exhaust: 488°C
  - Oil return: 295°C

- **Oil unit (导热油炉)**
  - Oil outlet: 330°C

- **Boiler FW (锅炉给水)**
  - Oil outlet: 330°C

- **Power**
  - 11037 kW

- **Other Outputs**
  - 0.6 MPa Sat. steam
  - 7.7 t/h
  - 175°C Exhaust
  - 196 Nm³
  - 39 Nm³

- **Additional Data**
  - Internal combustion engine (IC engine)
  - Efficiency: 45.2%
Cogeneration system (part 2)

Continued from previous slide

- 90°C hot water
- 150°C hot water
- 12°C chilled water
- 300 t/h
- Lithium bromide
- 32°C circulating condensate
- 39°C circulating condensate

Air compressor
China Coal Use in 2020

Additional Coal Demand for High Growth Scenario

- Construction
- Agriculture
- Residential Building
- Commercial Building
- Ethanol Production
- Coking
- Coal Gas Production
- Heat Generation
- CHP
- Coal to Liquid (CTL)
- Coal to Gas (CTG)

2013 Coal Use
2015 Coal Use
Coal decrease in industry and transport
Coal increase in power sector
Coal increase in other industry sectors
Coal increase in other end-use sectors
Coal increase in transformation sectors
2020 Coal Use

- Transport
- Heavy Industry
- Electric Power
- Other
- Transport Equipment
- Rubber and Plastics
- Other Non-Metal Minerals
- Machinery/Metal Products
- Other Ferrous
Electrifying Industrial Heat Processes

Low to Medium Temperature Heat

*up to 400°C*

Main uses: drying and distillation

<table>
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<tr>
<th>Commercial</th>
<th>Emerging</th>
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<tbody>
<tr>
<td>Heat pumps</td>
<td>Microwave heating</td>
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<tr>
<td>Electric boilers</td>
<td>UV heating</td>
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<tr>
<td>Induction heating</td>
<td>Electric infrared heating</td>
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<tr>
<td>Radio frequency heating</td>
<td></td>
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<tr>
<td>Renewable (pre-)heating</td>
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High Temperature Heat

*Above 400°C*

Main uses: process heating and melting

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<tr>
<td>Electric arc furnace</td>
<td>Plasma melting</td>
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<td>Electrolytic reduction</td>
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<tr>
<td></td>
<td>Electric induction melting</td>
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<td>Hydrogen</td>
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</tbody>
</table>
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


- Low temperature waste heat
- Power generation @ Carnot Efficiency plus max heat recovery
- Power generation @ current efficiency

Annual Potential (MW)

Cement (unrecovered potential)  Blast Furnace Hot Stove  Glass
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)

- 63% EAF
- 15% BOF
- 10% Coking
- 10% Sintering and Pelletizing
- 1% Casting and Rolling
- 1% Blast Furnace
Glass Sector