The State of Energy and Power Generation/Consumption in China

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Energy $\approx$ Quality of Life
Some Energy Related Facts of China

- World’s most populated country with a rapid economic growth since 1980’s.
- World’s largest energy consumer (~18%); but energy/capita is low (1/6 of US); inefficient system
- World’s largest oil importer (will past US Oct. 2013, 6.3M Barrel/day), was an oil exporter in 1970 and 1980’s
- World’s largest producer and consumer of coal, #3 in reserve; but still import coal
- World’s largest greenhouse gas emitter
- World’s largest producers of rare earth materials
- Heavy energy user - coastal area producer - inland

special economic zone
Coal – North
Oil & Gas – West
Hydro - no 3-gorge
Thermal - north
Nuke - not at all
U.S. Energy Consumption

BY SOURCE

- Renewable: 8%
- Nuclear: 7%
- Coal: 23%
- Natural Gas: 23%
- Oil: 39%

BY SECTOR

- Transportation: 28%
- Residential: 22%
- Commercial: 19%
- Industrial: 31%

Energy Consumption in U.S.

US 2011 Data

Source

Percent of Sources

Percent of Sectors

Petroleum\(^1\)
35.3 (36%)

Transportation
27.0 (26%)

Natural Gas\(^2\)
24.8 (26%)

Industrial\(^3\)
20.3 (21%)

Coal\(^3\)
19.7 (20%)

Residential & Commercial\(^3\)
10.7 (11%)

Renewable Energy\(^4\)
9.1 (9%)

Electric Power\(^7\)
39.3 (40%)

Nuclear Electric Power
8.3 (8%)

\(^1\) Includes 2/3 of crude oil imported

\(^2\) Includes 100% of natural gas

\(^3\) Includes 30% of coal

\(^4\) Includes 39% of renewable energy

\(^7\) Includes 100% of electric power

US Electric Power Generation by Fuel Types

The image shows a graph of US Electric Power Generation by fuel types from 1995 to 2020. The y-axis represents Kilowatt-hours of Generation, ranging from 0 x 10^9 kWh to 2,500 x 10^9 kWh. The x-axis represents the years from 1995 to 2020.

- **Coal** is represented by a black line, increasing steadily with time.
- **Natural Gas** is represented by a blue line, which also shows an increase over time.
- **Nuclear Power** is represented by a red line, showing a slight decrease after 2005.
- **Conventional Hydropower** is represented by an orange line, remaining relatively constant over the years.
- **Petroleum** is represented by a yellow line, which remains relatively flat.
- **Other Renewables** is represented by a green line, showing a steady increase over time.

Information is U.S. kWh generation by fuel type. Source: AEO 2001, Table A.8 for renewable and hydro, Table A.17.
Energy Demand Today

101 QBtu / Year
85% Fossil Energy

Energy Demand 2030

131 QBtu / Year
86% Fossil Energy

Fossil Fuels Continue to Provide Primary Supply

U.S. data from EIA, Annual Energy Outlook 2007, years 2006 and 2030; world data from IEA, World Energy Outlook 2006, years 2004 and 2030
The world will need about 10~20 tetra (10^{12}) watt-hours electricity per year in the next 20 yrs.

Fossil energy, i.e. oil, coal, natural gas, ..., dominates, which emits CO_2.

CO_2 free power generation:
- Nuclear (~20% projected)
- Renewable (~10% projected): wind, hydro, solar, ...

Unrealistic and virtually impossible to rely solely on nuclear and renewable energy.
What is coal???

- Carbon
- Ash (rock)
- Sulfur
- Nitrogen
- Hydrogen
- Mercury
- Water

Clean-up technologies for Mercury, Sulfur Oxides, SOx Nitrogen Oxides, Nox are well established.

The “dirtiest” and “cheapest” fossil fuel of vast reserves

Control of carbon dioxide, CO2, as a greenhouse gas is problematic & challenging.
Conventional Coal Plant

\[ C + O_2 = CO_2 \]

Energy Flow:
- Coal Supply
- Conveyor Belt
- Boiler
- Steam Generator
- Turbine
- Generator
- Switchyard
- Condenser
- Cooling Water

100 MW in → 45 MW out → 14 MW out → 86 MW out → 41 MW out

Efficiency: 41%
Gas Turbine

For electric power generation, “Fuel” is Natural Gas, mainly Methane, $\text{CH}_4$

Exhaust:

$\text{CH}_4 + 2\text{O}_2 = 2\text{H}_2\text{O} + \text{CO}_2$

Air contains Oxygen, $\text{O}_2$
Gas Turbine “Simple” Cycle

100 MW

62 MW

38 MW

38% Efficiency
Gas Turbine “Combined” Cycle

19 MW + 38 MW = 57 MW, 57% Efficiency! “Combined Cycle” means gas-turbine combined with steam turbine for higher efficiency!
Coal Combustion & Gasification

Gasification produces mainly $H_2$ and CO, both are good fuels

General burning coal results in $CO_2$ and $H_2O$
Integrated (Coal) Gasification Combined Cycle (IGCC)

Net Coal to Power: $30 + 21 - 9 = 42\%$

Same as Conventional Coal Plant; but expensive to build
Clean Coal Technology

- **Clean & Efficient** Coal Based Power Systems that **Capture CO₂**

- Most advanced technological solution is the **Integrated Gasification Combined Cycle (IGCC)** based electrical power generation plants with CO₂ capture and sequestration (CCS)
IGCC: Integrated Gasification Combined Cycle

- Also known as “Hydrogen Turbine” Power System
- If CO₂ is completely capture and sequestrated before combustion in turbine, emission will only be steam – pollution free!

For a conventional coal plant retrofitted for CO₂ sequestration, the Carbon capture occurs after combustion

Coal gas burned here

“Combined” with steam turbine for higher efficiency
Coal vs. Natural Gas

- Worldwide electricity generation, ~40% from coal, 21% from natural gas
- Natural gas is much “cleaner” than coal. Natural gas emits virtually no mercury and sulfur oxides (SO$_x$), 1/3 of nitrogen oxides (NO$_x$), and 1/2 of carbon dioxides (CO$_2$) than coal. Natural gas today is also cheap, hence many developed countries move coal to natural gas for power generation.
- Top coal producers are: China, United States, and India. Top natural gas producers are: United States, Russia, Canada and Iran
- World reserve has 950 billion tons of coal and 850 trillion cubic meters of natural gas – huge!
- 35% of US natural gas is recovered by hydraulic fracturing (fracking)
Natural Gas in China

- Systematic recovery started from late 1990’s, Liquefied LNG, Compressed CNG
- Has world’s largest shale gas reserve, similar to the level of the U.S.
- Gas reserve is deeper, 200-1000m; region lacks water resources; recovery is challenging
- Most reserve is in the west, transportation & pipeline - 西气东输，川气东送
Energy Consumption U.S. vs. China

China’s Energy Profile:
- Coal dominant
- Natural Gas very low
- Nuclear is insignificant

Fossil Power Generation Carbon Emission

Global Carbon Emissions (million metric tons carbon) vs. CO₂ Concentration (ppm-vol)
## CO₂ Production Source

<table>
<thead>
<tr>
<th>Process</th>
<th>Emissions (MtCO2/yr)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fossil Fuel</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Generation</td>
<td>8,236</td>
<td>34.7%</td>
</tr>
<tr>
<td>Autoproducers</td>
<td>963</td>
<td>4.1%</td>
</tr>
<tr>
<td>Other Energy Sources</td>
<td>1,228</td>
<td>5.2%</td>
</tr>
<tr>
<td><strong>Manufacturing and Construction</strong></td>
<td>4,294</td>
<td>18.1%</td>
</tr>
<tr>
<td>Transportation</td>
<td>5,623</td>
<td>23.7%</td>
</tr>
<tr>
<td>Road</td>
<td>4,208</td>
<td>17.7%</td>
</tr>
<tr>
<td>Other Sources</td>
<td>3,307</td>
<td>13.9%</td>
</tr>
<tr>
<td>Residential</td>
<td>1,902</td>
<td>8.0%</td>
</tr>
<tr>
<td><strong>Bioethanol and Bioenergy</strong></td>
<td>91</td>
<td>0.4%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>23,742</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
Timescales of Greenhouse Gases

CO₂ Effects can be long lasting!
World CO₂, Annual Emissions 2007-2030

**CO₂ Emissions 2007**

- **United States**: 21.0%
- **China**: 19.4%
- **Middle East Africa**: 12.5%
- **Central/South America**: 10.2%
- **India + non-OECD Asia**: 12.4%
- **OECD (minus U.S.) + non-OECD Europe and Eurasia**: 36.9%

**CO₂ Emissions 2030**

- **United States**: 18.5%
- **China**: 26.2%
- **Middle East Africa**: 13.6%
- **Central/South America**: 6.8%
- **India + non-OECD Asia**: 12.4%
- **OECD (minus U.S.) + non-OECD Europe and Eurasia**: 29.3%

**28.9 billion metric tons/year**

**42.9 billion metric tons/year**

*Developing Countries Have Significant Share of Emissions Growth*

* - IEA estimates China has surpassed the U.S. in 2007
What Does This Mean?

- 1 million metric tons of CO\(_2\)
  - Every year would fill a volume of 32 million cubic feet
  - *Close to the volume of the Empire State Building*

- U.S. & China each emits roughly 6 billion tons (gigatons) of CO\(_2\) per year
  - *Enough to fill Lake Erie with liquid CO\(_2\) almost twice*
  - Under an EIA reference case scenario, cumulative CO\(_2\) emissions 2004 – 2100 are expected to be 1 trillion tons
CO₂ Geological Sequestration

Overview of Geological Storage Options
1. Depleted oil and gas reservoirs
2. Use of CO₂ in enhanced oil and gas recovery
3. Deep saline formations — (a) offshore (b) onshore
4. Use of CO₂ in enhanced coal bed methane recovery
CO$_2$ Ocean Sequestration
Estimated North American CO$_2$ Storage Potential (billion tons)

<table>
<thead>
<tr>
<th>Sink Type</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil and Gas Fields</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Saline Formations</td>
<td>3,300</td>
<td>12,600</td>
</tr>
<tr>
<td>Unmineable Coal Seams</td>
<td>160</td>
<td>180</td>
</tr>
</tbody>
</table>

Carbon Capture and Storage (CSS) in China

Key Activities & Issues

- Location and adequacy of CO2 storage sites (see map)
- Technology and IP rights framework for CCS
- Retrofit low-efficient coal plants for CCS compatibility; plant size/age, land/space, water/cooling
- Development of a regulatory framework for CCS in China
- International collaboration, mainly with EU and US
CCS’s “Double-Edged Sword”

• Current Carbon Capture and Sequestration (CCS) technology is costly, e.g. CO2 compression to high pressure, piping to transport, leakage monitoring,…etc.

• Compared to a conventional (pulverized) coal plant
  - $/KW plant construction costs, +30%
  - $/KW electricity production costs, +40%
  - Plant net power output, -15%
  - Plant thermal efficiency, -10% to -20%, depends on capture method

• In general, a 600 MW IGCC plant, adding CCS will lose ~100MW. To make up the “lost” power and efficiency could mean more fuel consumption and accordingly more CO2 emission

• CSS for natural gas plants is even more difficult and costly, because the concentration of CO2 in flue gas is low
China Near-term Energy Targets (2013-2020)

1. Fossil - Retrofit old coal plants, Build/Order higher efficient supercritical plants, Natural gas fired plants, Clean coal technology, IGCC - Integrated Gas Combined Cycle + CO2 sequestration

2. Nuclear - Gen 3 (AP 1000) or Gen 4 technology developments, from 17 to 47 nuke plants, 3X

3. Renewable - hydro 40% up, wind 3X, solar 7X
Potential Role of Energy Efficiency + Renewables in Reducing China's Emissions from Coal

Even with strong policy incentives for energy efficiency, renewables and other low carbon technologies, coal will remain a major part of China's energy mix until at least 2030:

China 2002
Total: 1089 Mtoe
- Coal 64.7%
- NG 3.02%
- Renewables 7.19%
- Oil 24.6%

Renewables in China are mainly hydropower

China 2025
Total: 2752 Mtoe
- Coal 58.2%
- NG 6.96%
- Renewables 6.14%
- Oil 26.7%

Mtoe = million tons oil equivalent = 4.2 GJ

Source: IEA World Energy Outlook 2007
China’s Current Efforts to Reduced Coal Usage

• Focus is on improving energy efficiency and promoting renewables and other alternative technologies
• Key targets and requirements determined by Chinese Government:
  – target to reduce coal in overall energy mix below 60%
  – requirement that all new large power plants use high efficiency super-critical coal-fired technology
  – expected improvement in coal power generation efficiency - from 32% in 2000 to 39% in 2030
  – target of 70 GW of nuclear power by 2020 (up from 14 GW in 2013)
  – requirement that 10% of total energy should come from renewables by 2020
## Coal based Power Generation Technology in China

<table>
<thead>
<tr>
<th>Technology</th>
<th>Efficiency</th>
<th>Cost ($ per kW)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcritical</td>
<td>30-36%</td>
<td>500-600</td>
<td>Main base of China's current generating fleet</td>
</tr>
<tr>
<td>Supercritical</td>
<td>41%</td>
<td>600-900</td>
<td>About half of current new orders</td>
</tr>
<tr>
<td>Ultra-supercritical</td>
<td>43%</td>
<td>600-900</td>
<td>Two 1000 MW plants in operation</td>
</tr>
<tr>
<td>IGCC (pre-combustion)</td>
<td>45-55%</td>
<td>1100-1400</td>
<td>Twelve units waiting for approval by NRDC</td>
</tr>
</tbody>
</table>

Supercritical and ultra supercritical plants operated steam (heated by coal) of very high temperature and pressure. Higher efficiency meaning use less coal, and less emission. In average, China builds one new power plant every other week.

Current power Generation is based on the least efficient, cheapest technology.
China’s IGCC Plan
**Nuclear Power Plants in China 2011**

**2013 Data:**
17 plants in operation, 
~14GW

**2020 Projection:**
30 plants under construction, all coastal;
35 more plants planned on coastal provinces, total ~68GW
24 plants planned inland total ~25GW, mostly delayed
**Total 89 plants planned construction, ~93GW**

Jinshan PWR ~600MW
Renewable Energy

- Solar
- Wind
- Hydropower
- Biomass, Biofuels

Except hydropower, other renewables are very nominal now, <1%
Summary

• China’s energy demand will continue to increase substantially and its dependence on coal and oil remains strong. Usage of natural gas for power generation will still be far below world’s average.

• China faces great technical and political challenges to be more energy efficient and clean, while sustaining economic growth.

• China’s carbon management needs a comprehensive retrofit strategy for aging, low efficient coal based power plants.

• Nuclear energy and renewable energy (excluding hydro) are subject to heavy investment and grow rapidly; but their combined weightage in China’s overall energy portfolio remains insignificant.

• Huge commercial and technical opportunities exist in these transformational challenges.
http://www.iea.org/country/map_indicators/index.html

http://rhg.com/notes/chinas-2012-energy-report-card


China’s Energy Policy 2012
Thank You !
In your view, what would be the best way for China to approach its development of power generation technology in order to meet the increased energy demand while keeping the greenhouse gas emission in control?

The energy sources for consideration are: (1) fossil fuels, e.g. coal, natural gas, and oil, (2) nuclear energy, and (3) renewable energy, e.g. solar, wind, hydro, geothermal, and biomass.