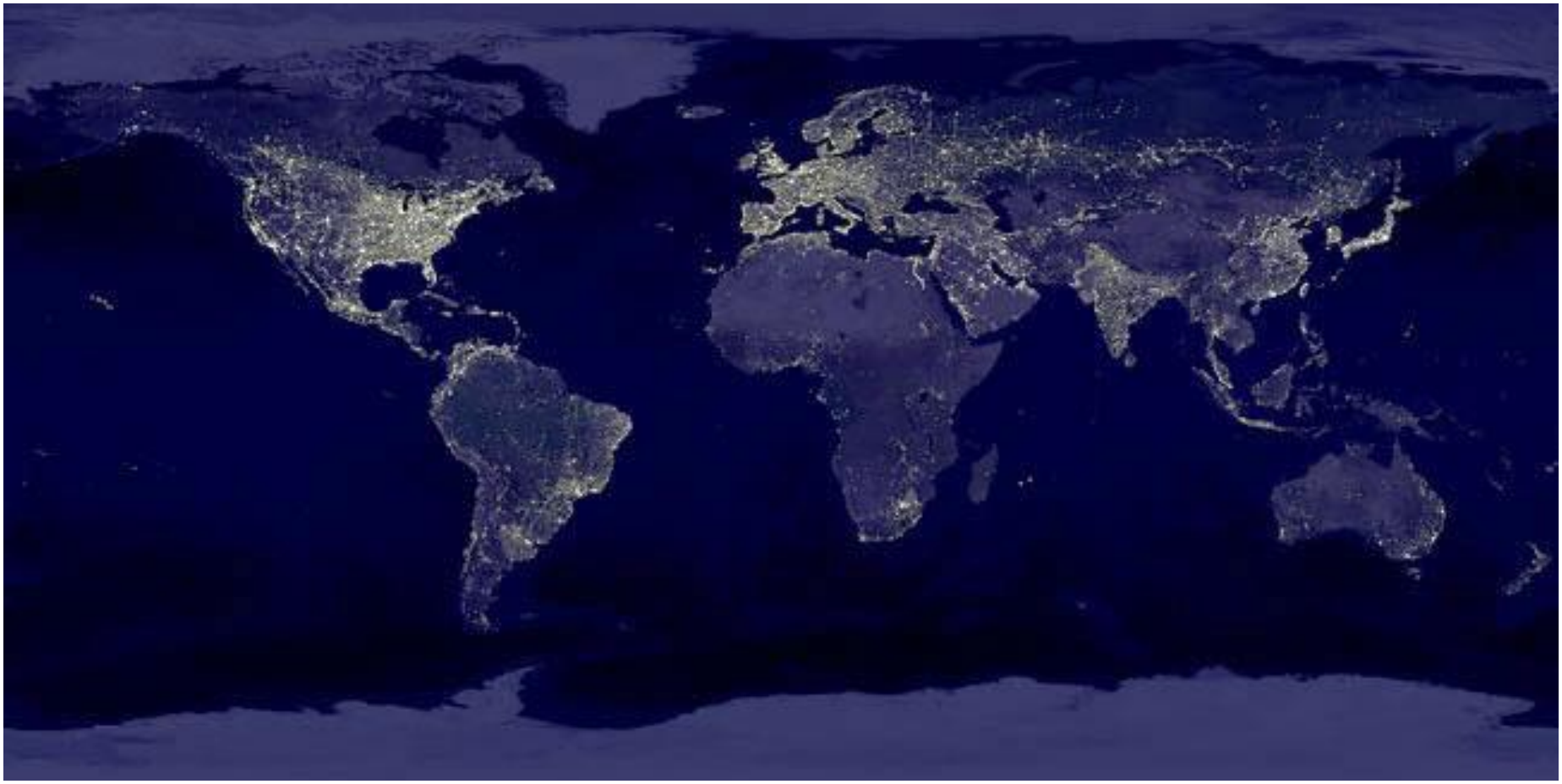
UNIVERSITY OF PITTSBURGH

The State of Energy and Power Generation/ Consumption in China

Minking K. Chyu
Leighton and Mary Orr Chair Professor and Chairman
Department of Mechanical Engineering and Materials Science
University of Pittsburgh

Energy ≈ Quality of Life



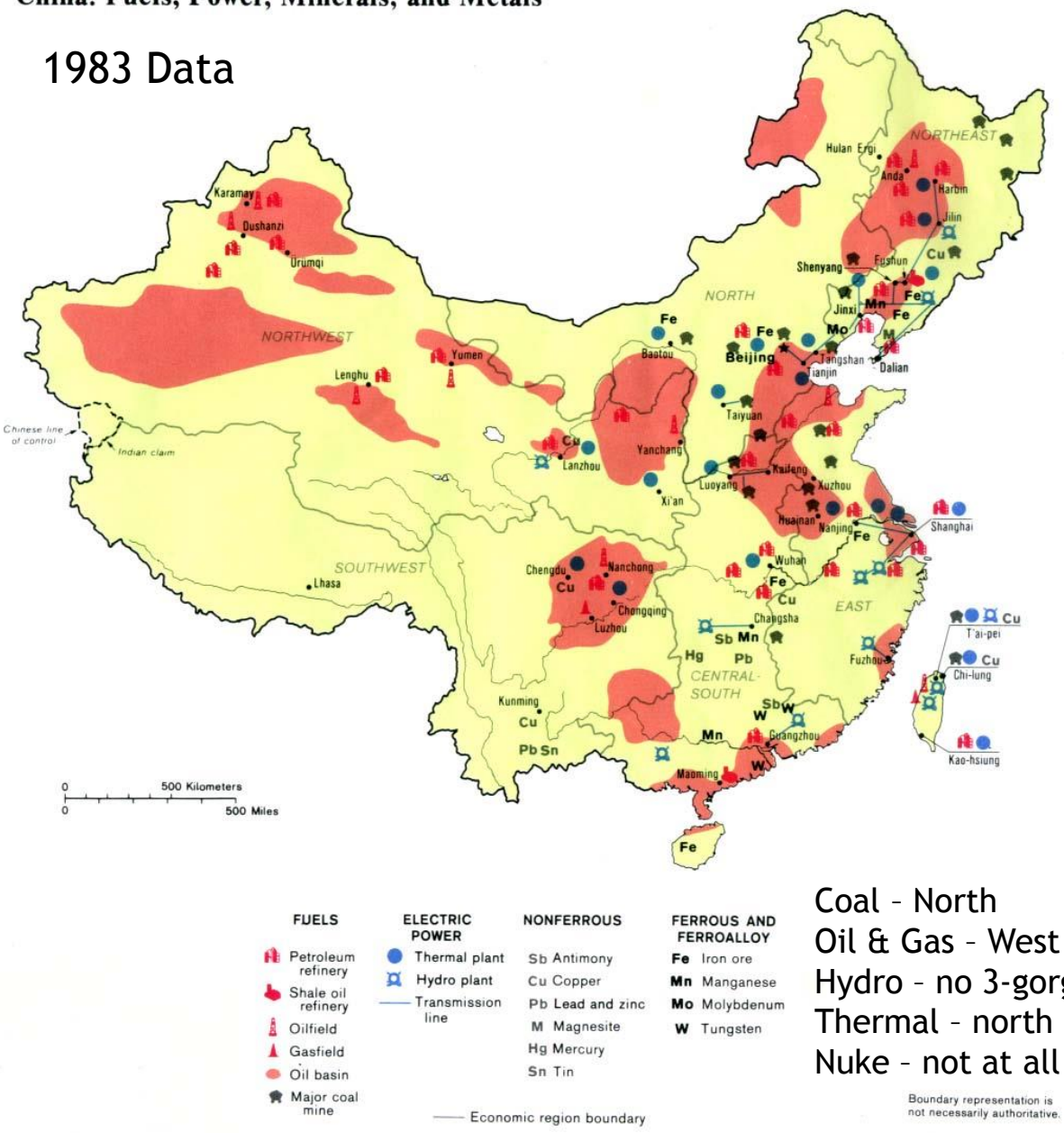
Some Energy Related Facts of China

- 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, 6.3MBarrel/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 – costal area producer - inland

special economic zone

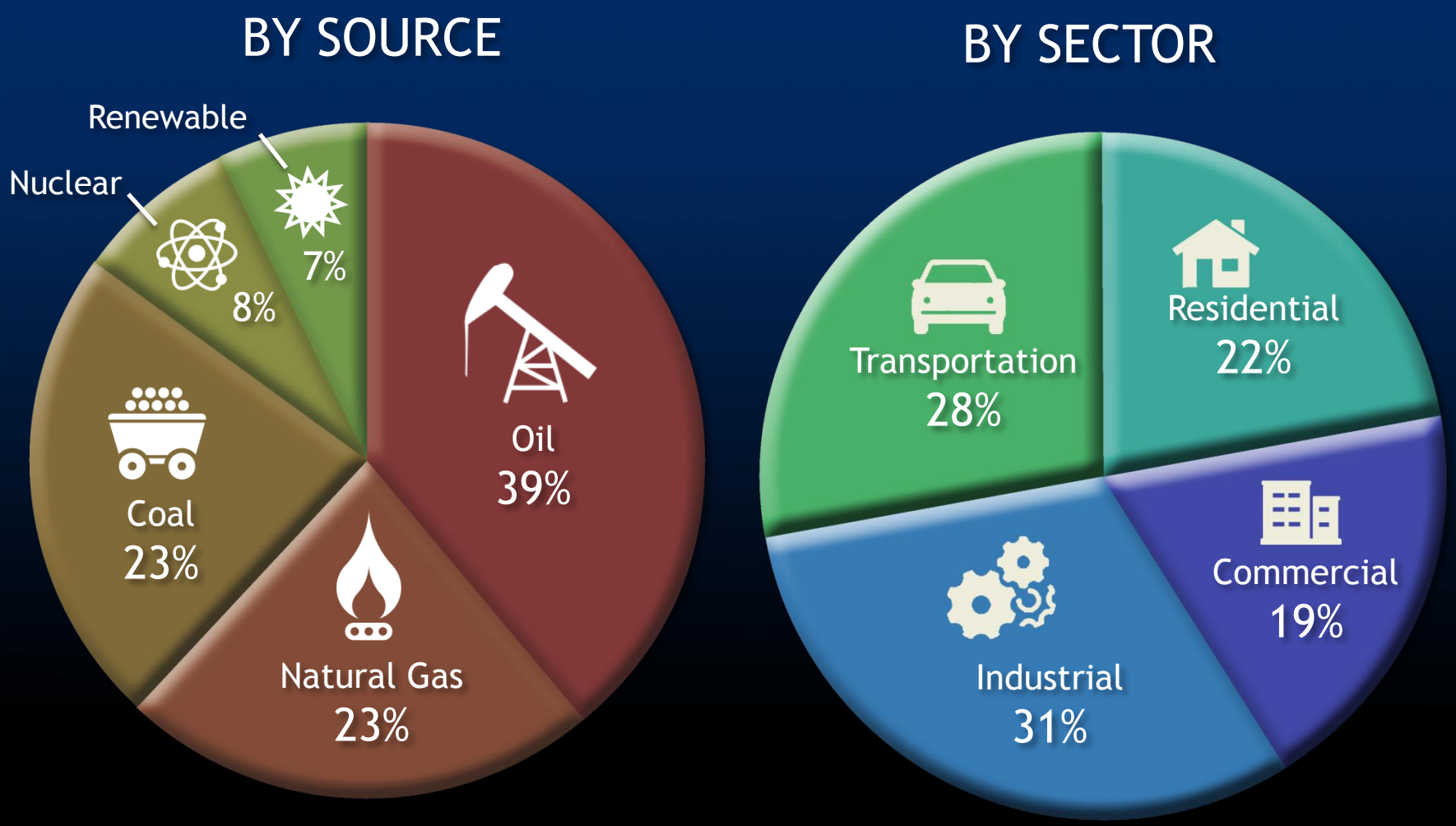
China: Fuels, Power, Minerals, and Metals

1983 Data



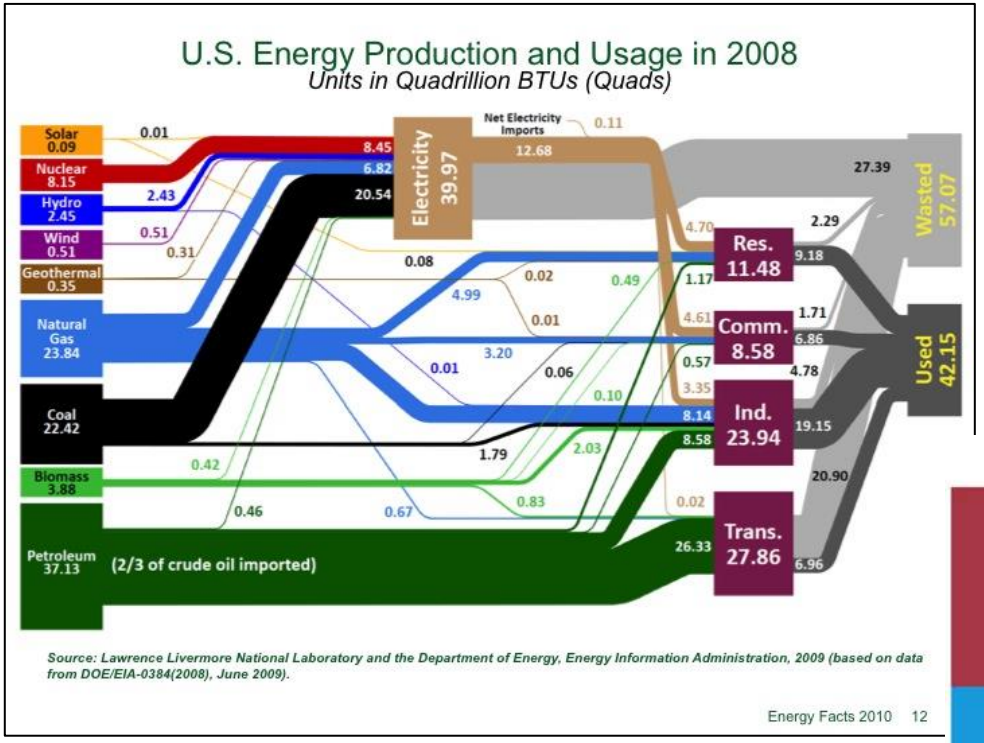
Coal – North
Oil & Gas – West
Hydro – no 3-gorge
Thermal – north
Nuke – not at all

U.S. Energy Consumption

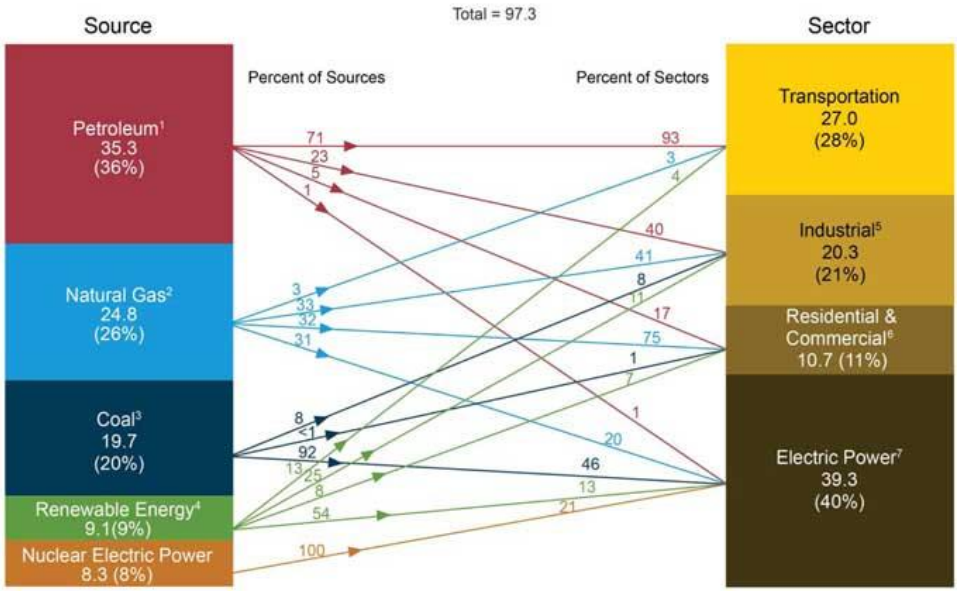


Sources: U.S. Energy Information Administration (EIA) 2007; EIA Annual Energy Review 2008

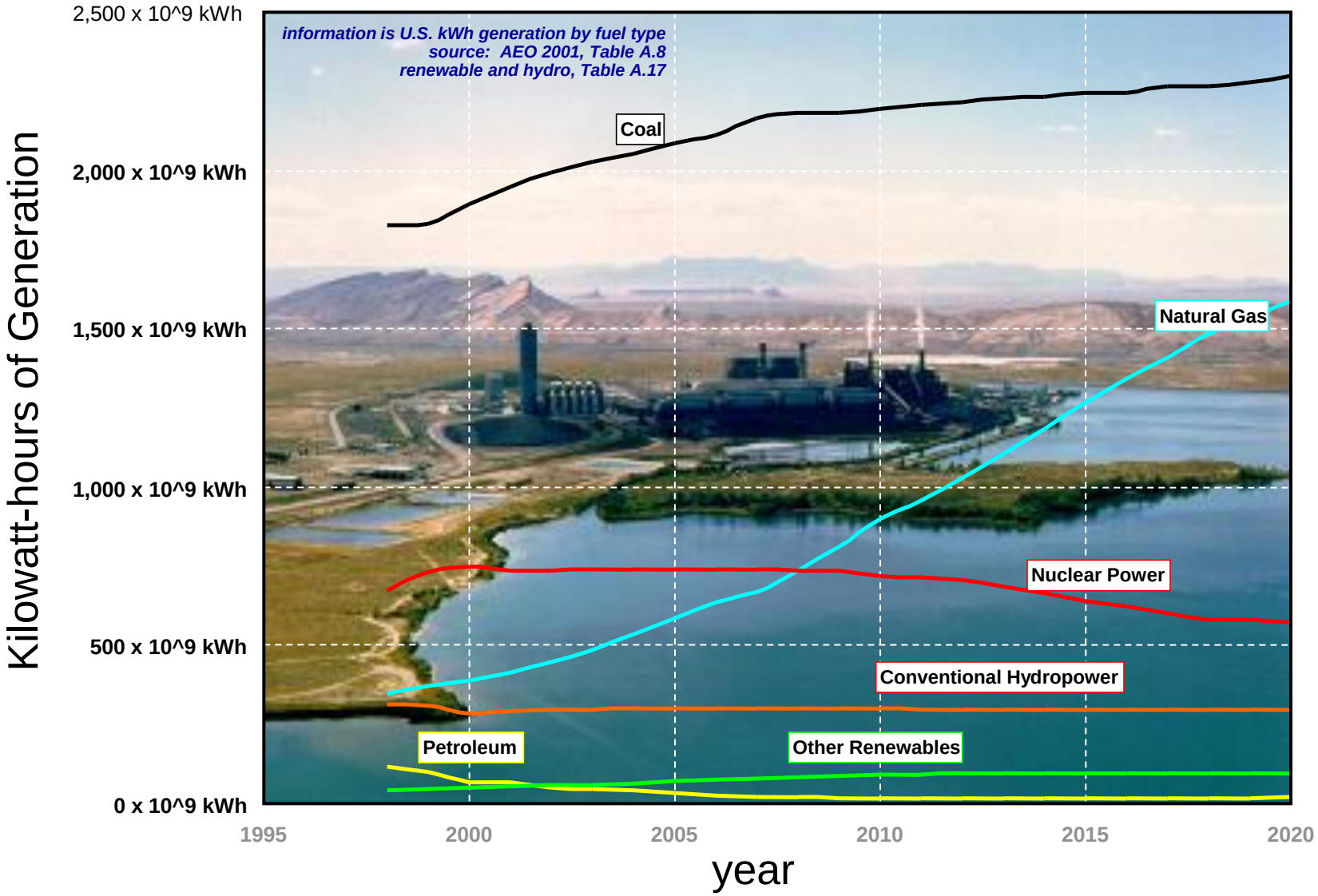
Energy Consumption in U.S.



US 2011 Data



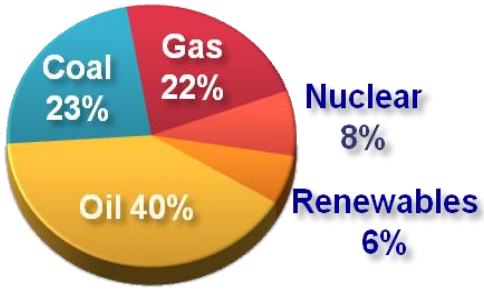
US Electric Power Generation by Fuel Types



Energy Demand Today

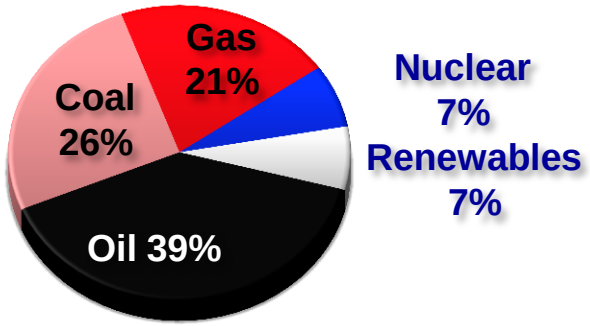
Energy Demand 2030

101 QBtu / Year
85% Fossil Energy

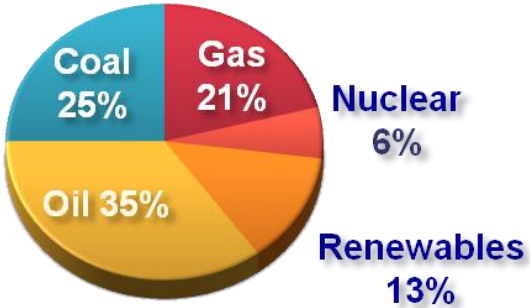


United States

131 QBtu / Year
86% Fossil Energy

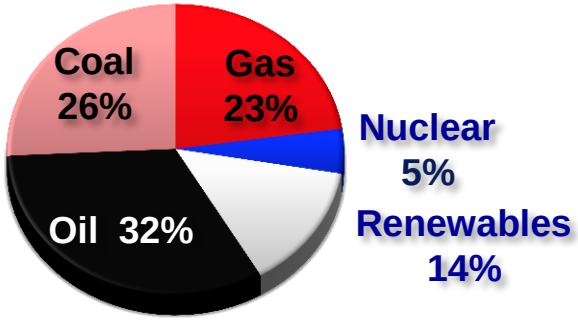


475 QBtu / Year
80% Fossil Energy



World

725 QBtu / Year
81% 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

"Total Energy" Perspectives

- 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???

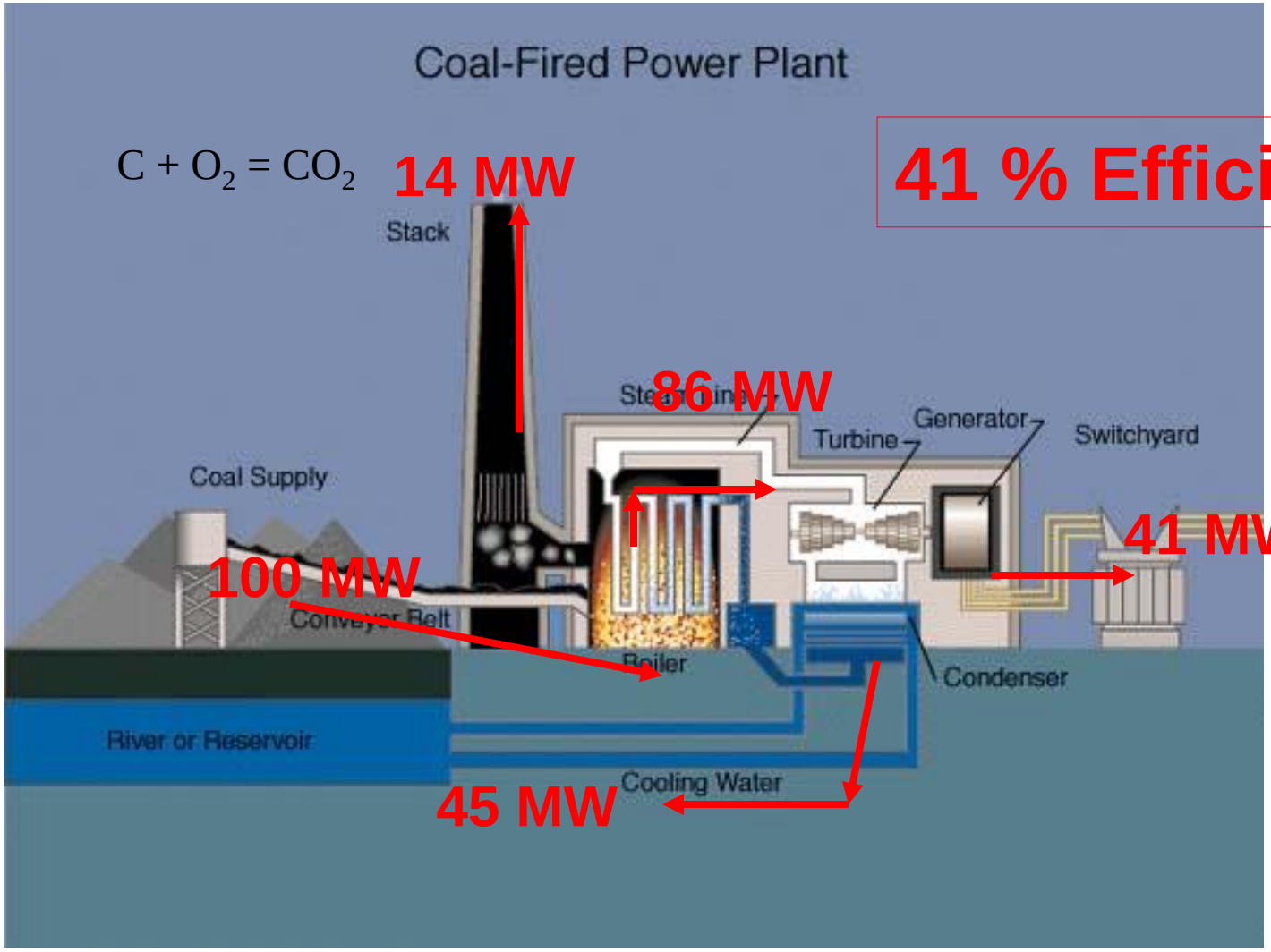
- Carbon
- Ash (rock)
- Sulfur
- Nitrogen
- Hydrogen
- Mercury
- Water

The "dirtiest" and "cheapest" fossil fuel of vast reserves

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

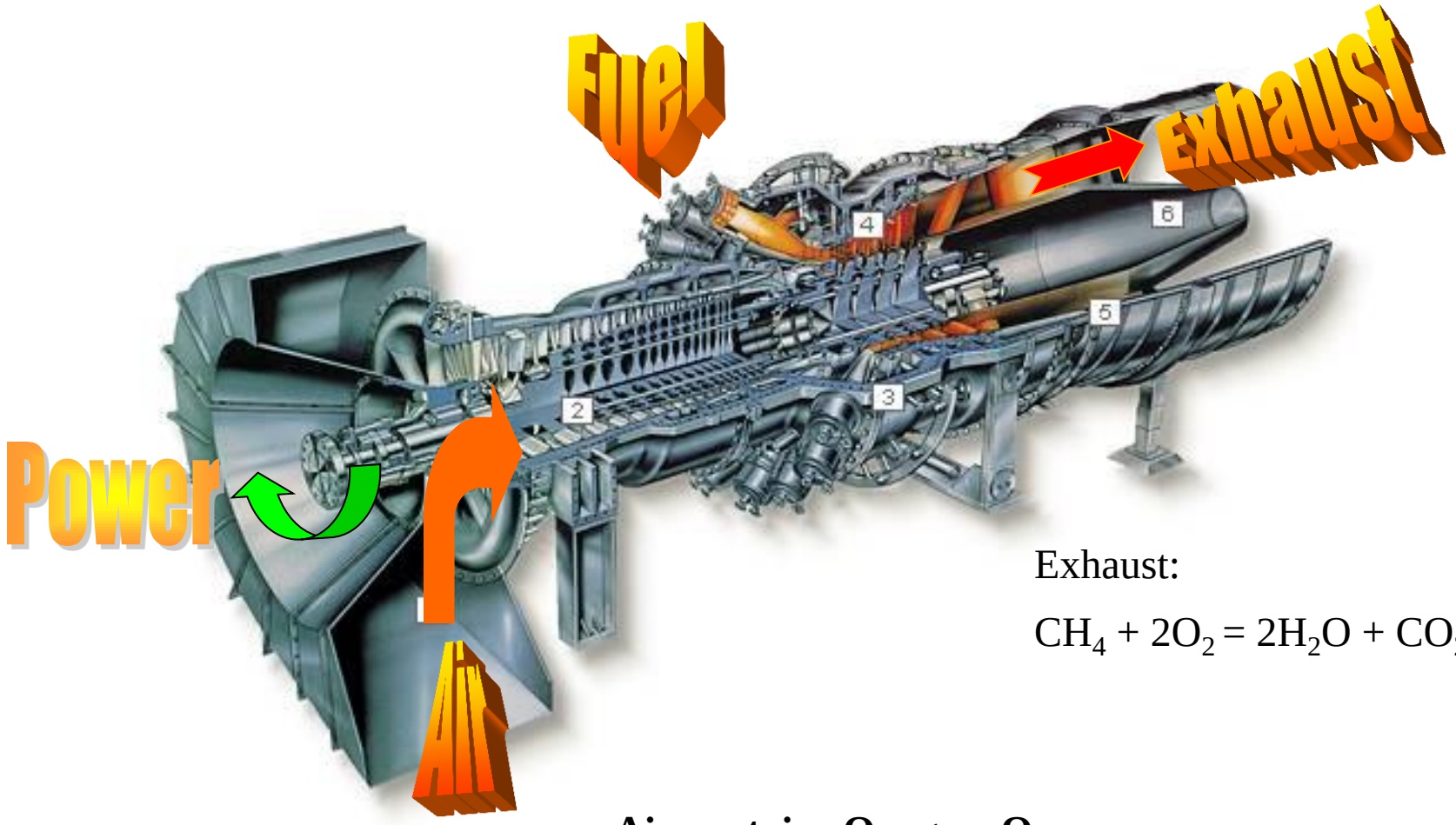
Control of carbon dixoides, CO2, as a greenhouse gas is problematic & challenging

Conventional Coal Plant



Gas Turbine

For electric power generation, "Fuel" is Natural Gas, mainly Methane, CH_4

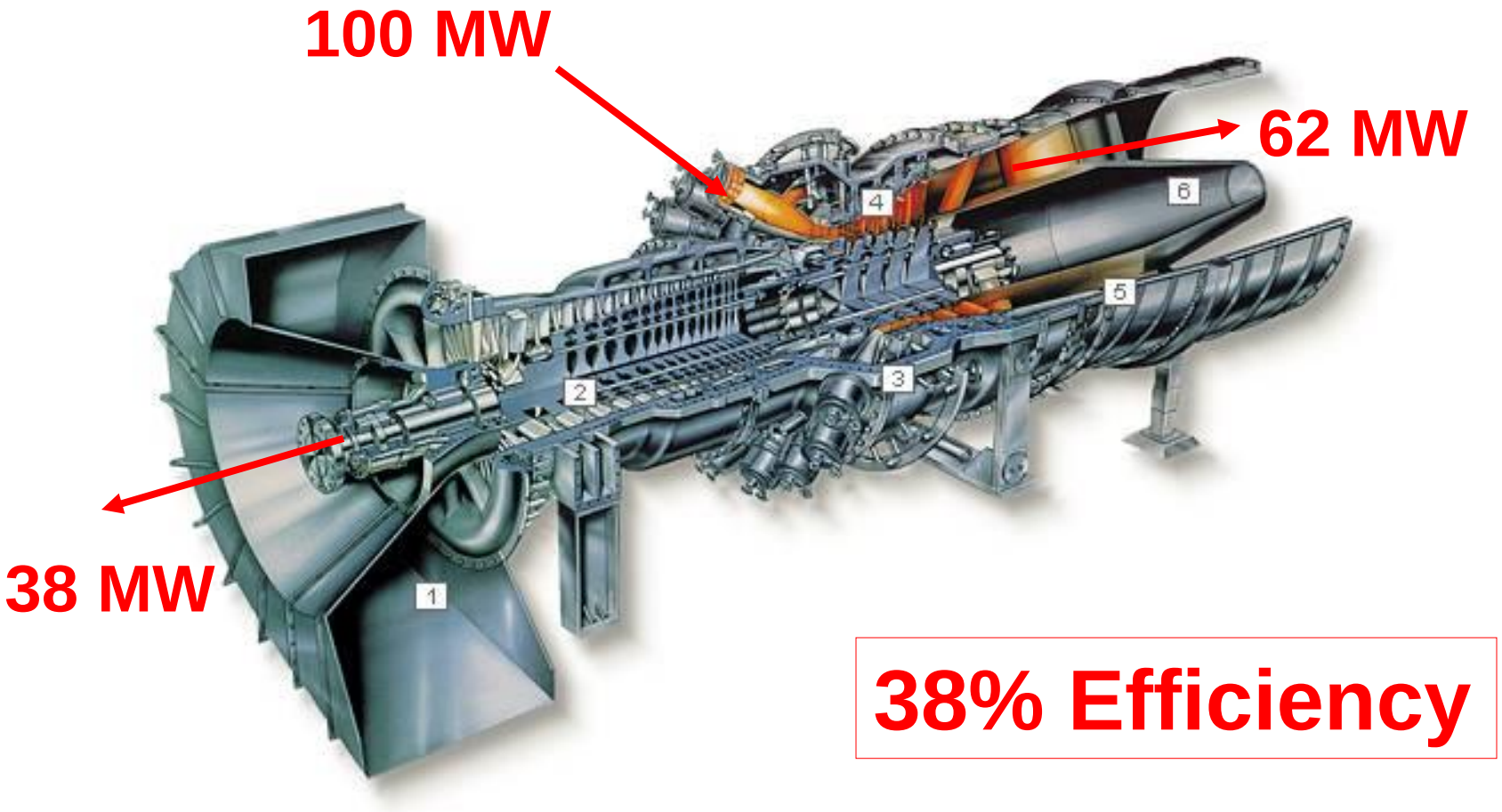


Exhaust:

$CH_4 + 2O_2 = 2H_2O + CO_2$

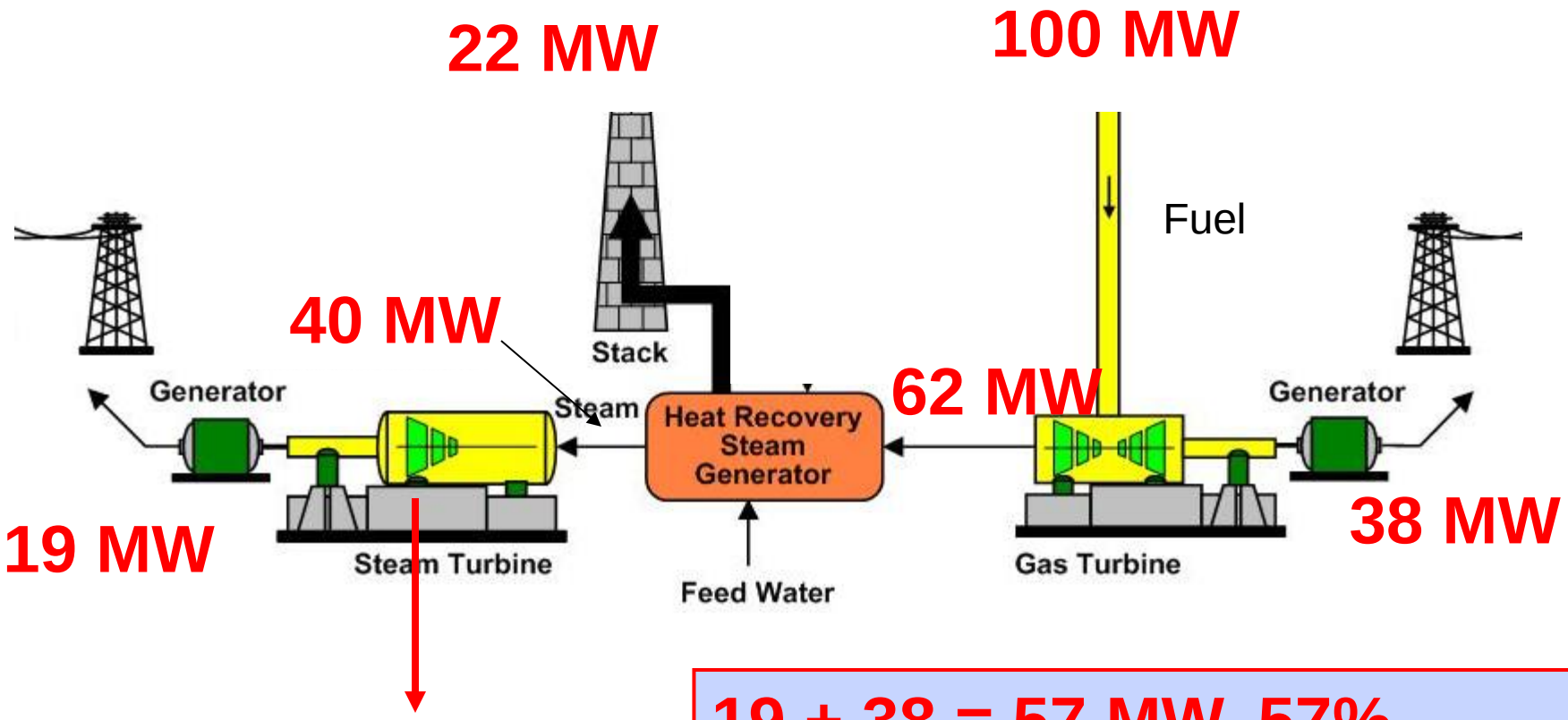
Air contains Oxygen, O_2

Gas Turbine "Simple" Cycle



38% Efficiency

Gas Turbine "Combined" Cycle

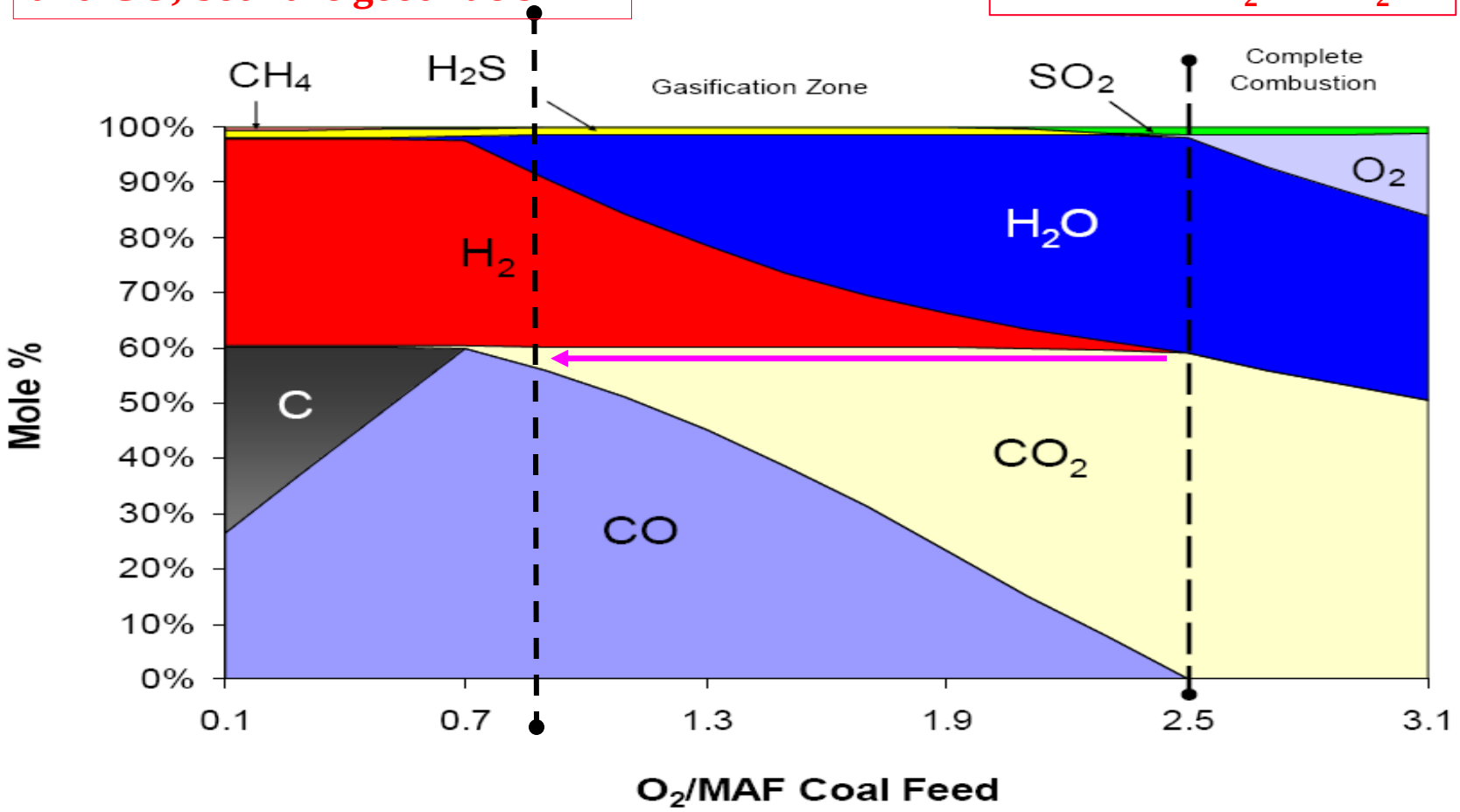


19 + 38 = 57 MW, 57% Efficiency! "Combined Cycle" means gas-turbine combined with steam turbine for higher efficiency!

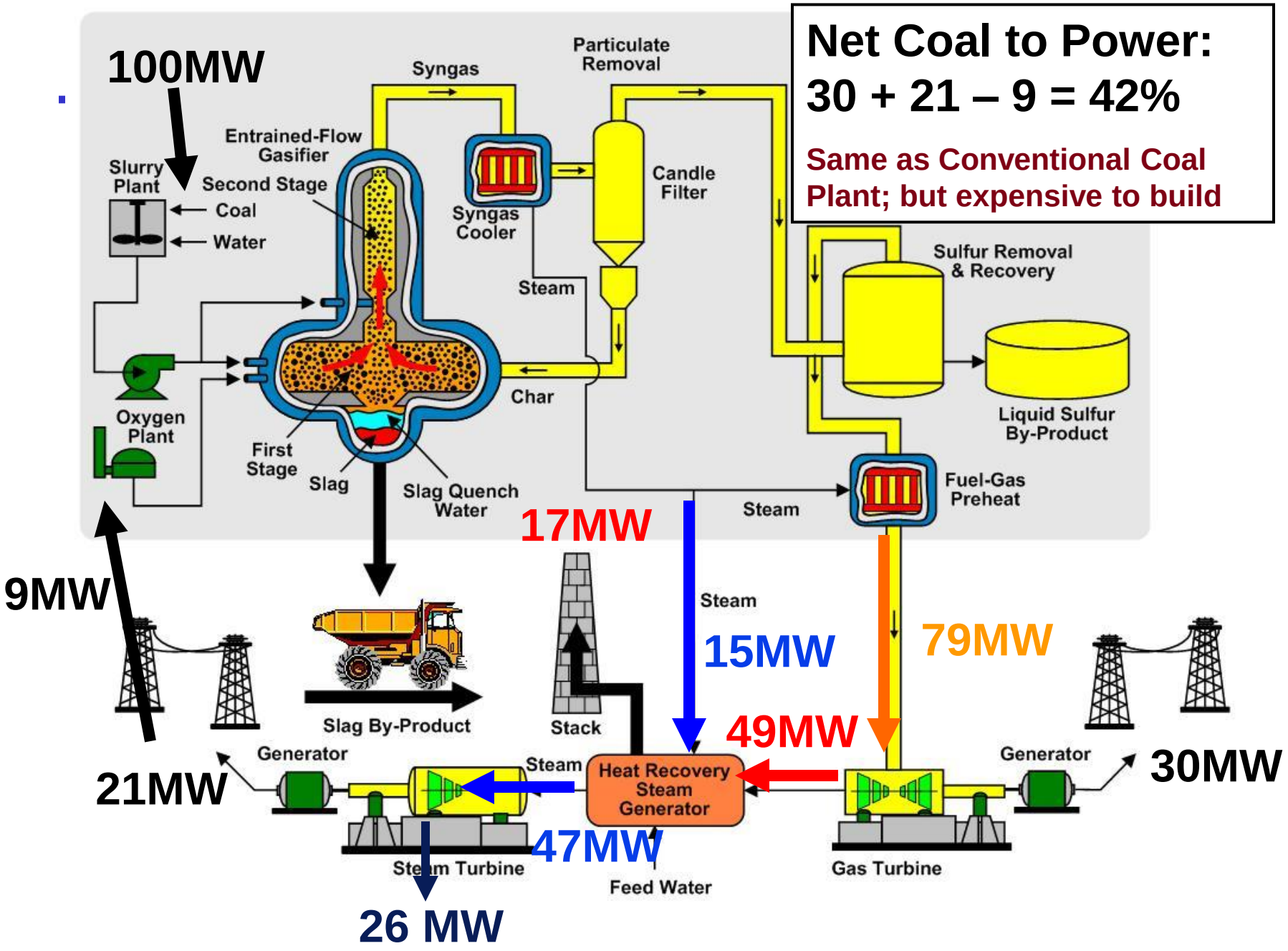
Coal Combustion & Gasification

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%

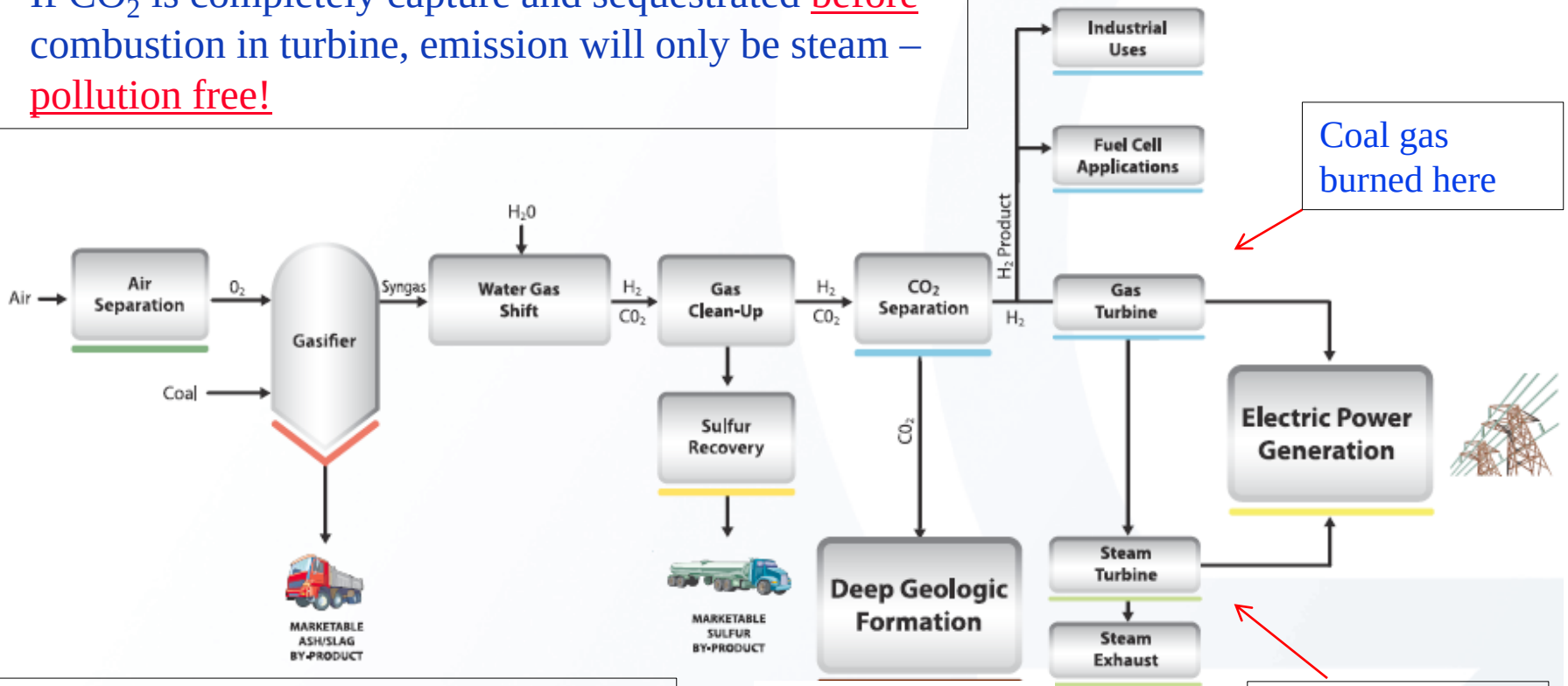
Same as Conventional Coal Plant; but expensive to build

Clean Coal Technology

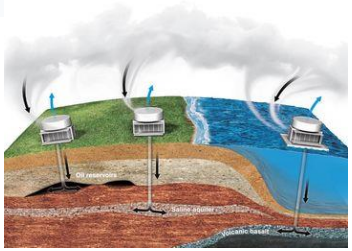
- Clean & Efficient Coal Based Power Systems that Capture CO_2
- Most advanced technological solution is the Integrated Gasification Combined Cycle (IGCC) based electrical power generation plants with CO_2 capture and sequestration (CCS)

IGCC: Integrated Gasification Combined Cycle

- Also known as "Hydrogen Turbine" Power System
- If CO_2 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

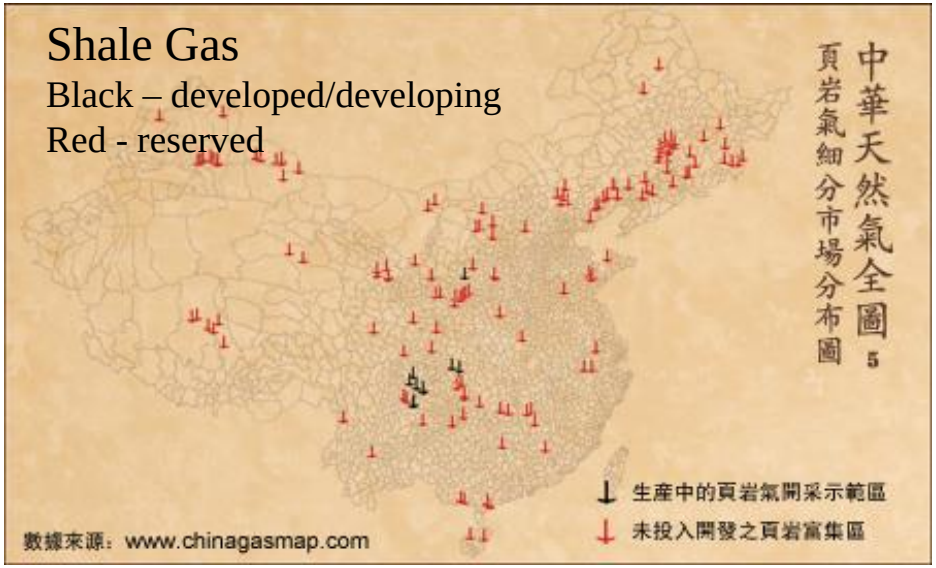


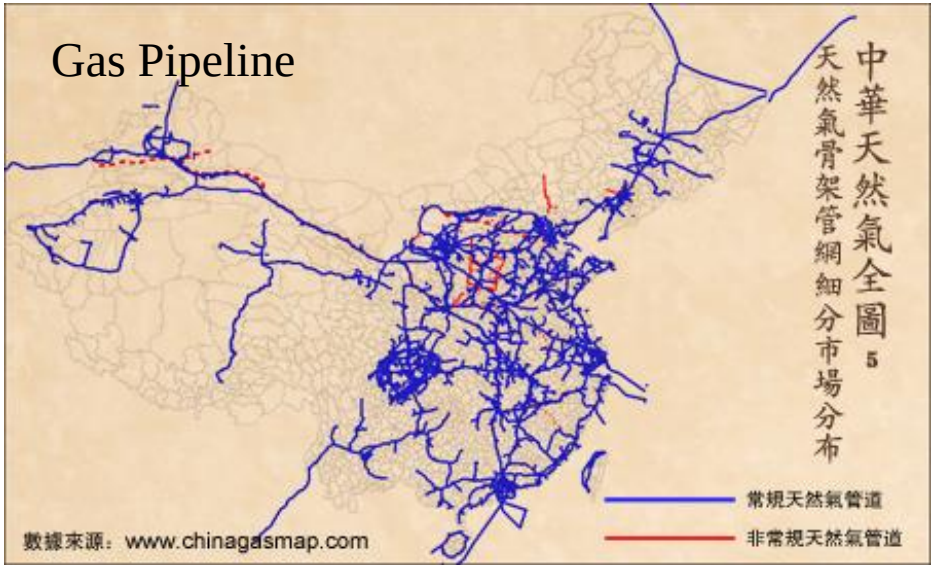
"Combined" with steam turbine for higher efficiency

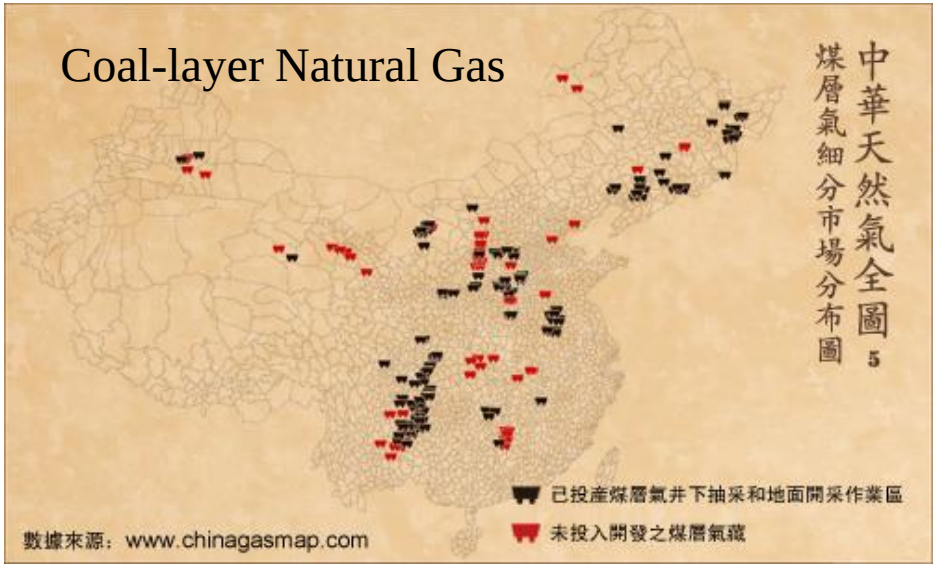
Coal vs. Natural Gas

- 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

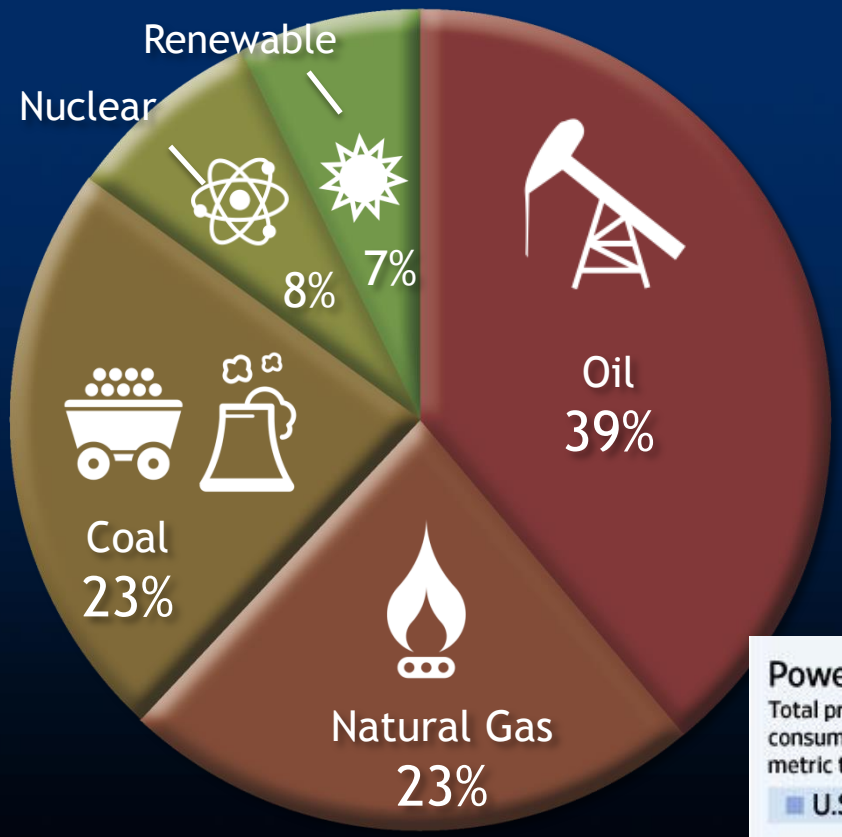


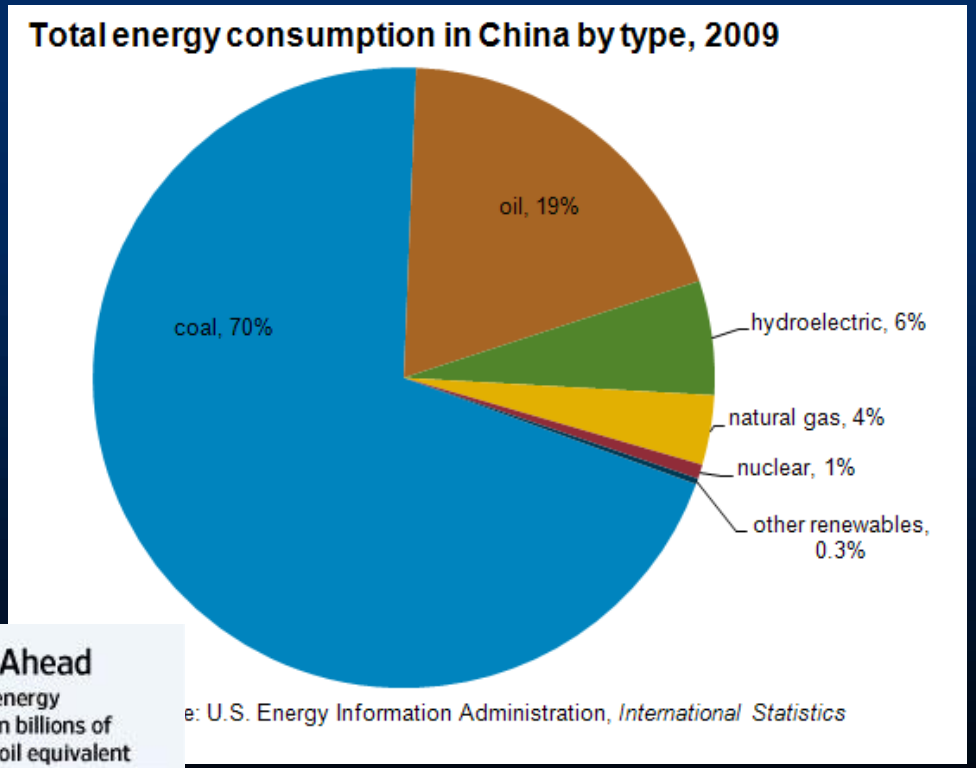


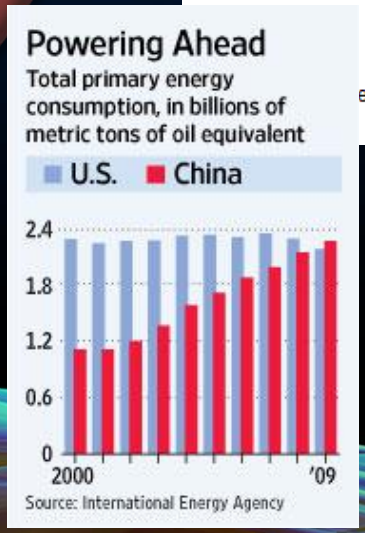


- Systematic recovery started from late 1990's, Liquefied LNG, Compressed CNG
- Has world's largest shale gas reserve, similar to the level of the U.S.
- Gas reserve is deeper, 200-1000m; region lacks water resources; recovery is challenging
- Most reserve is in the west, transportation & pipeline -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

Energy Consumption U.S. vs. China



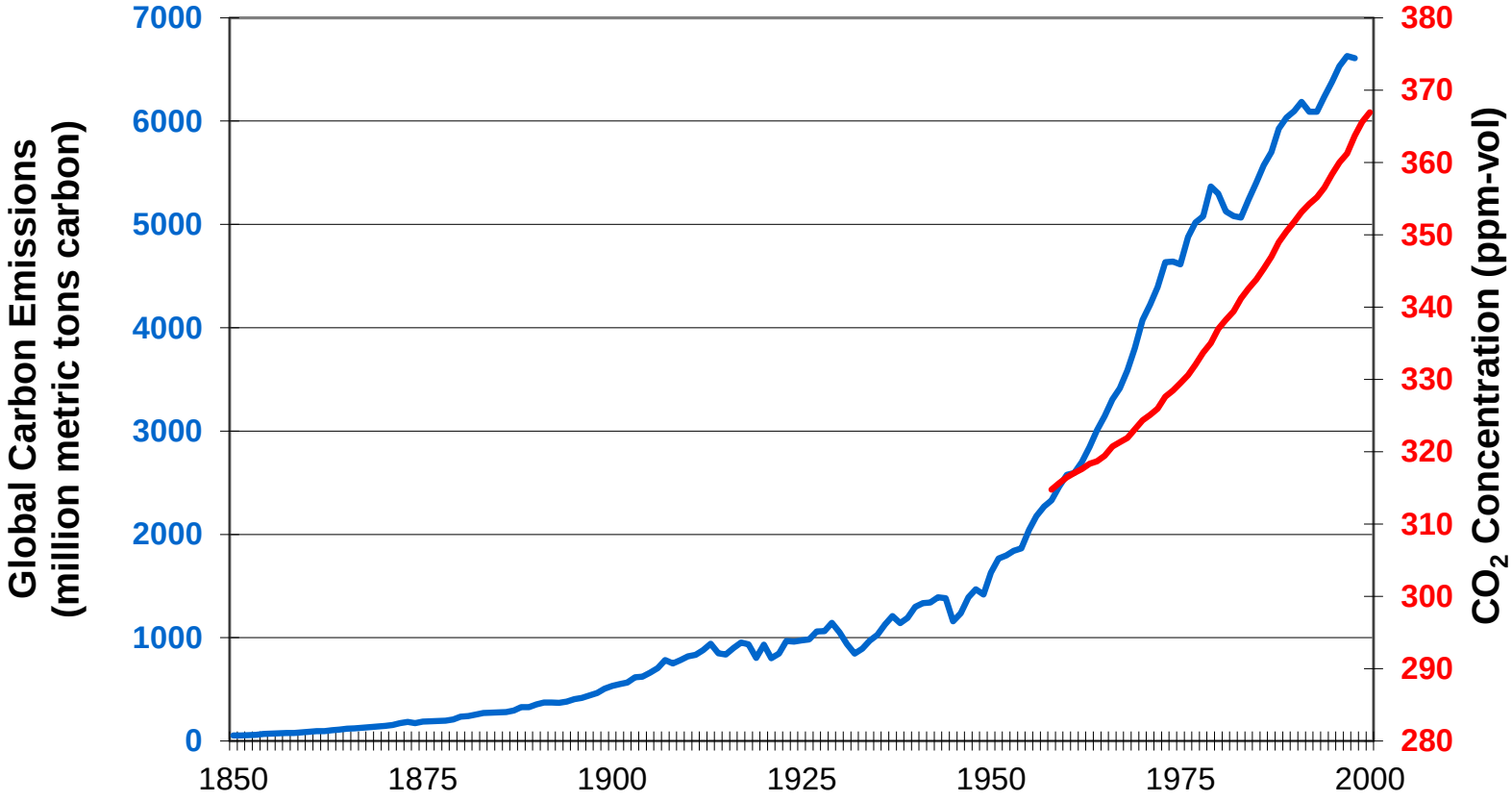




China's Energy Profolio:
Coal dominant
Natural Gas very low
Nuclear is insignificant

Sources: U.S. Energy Information Administration (EIA) 2007; EIA Annual Energy Review 2008

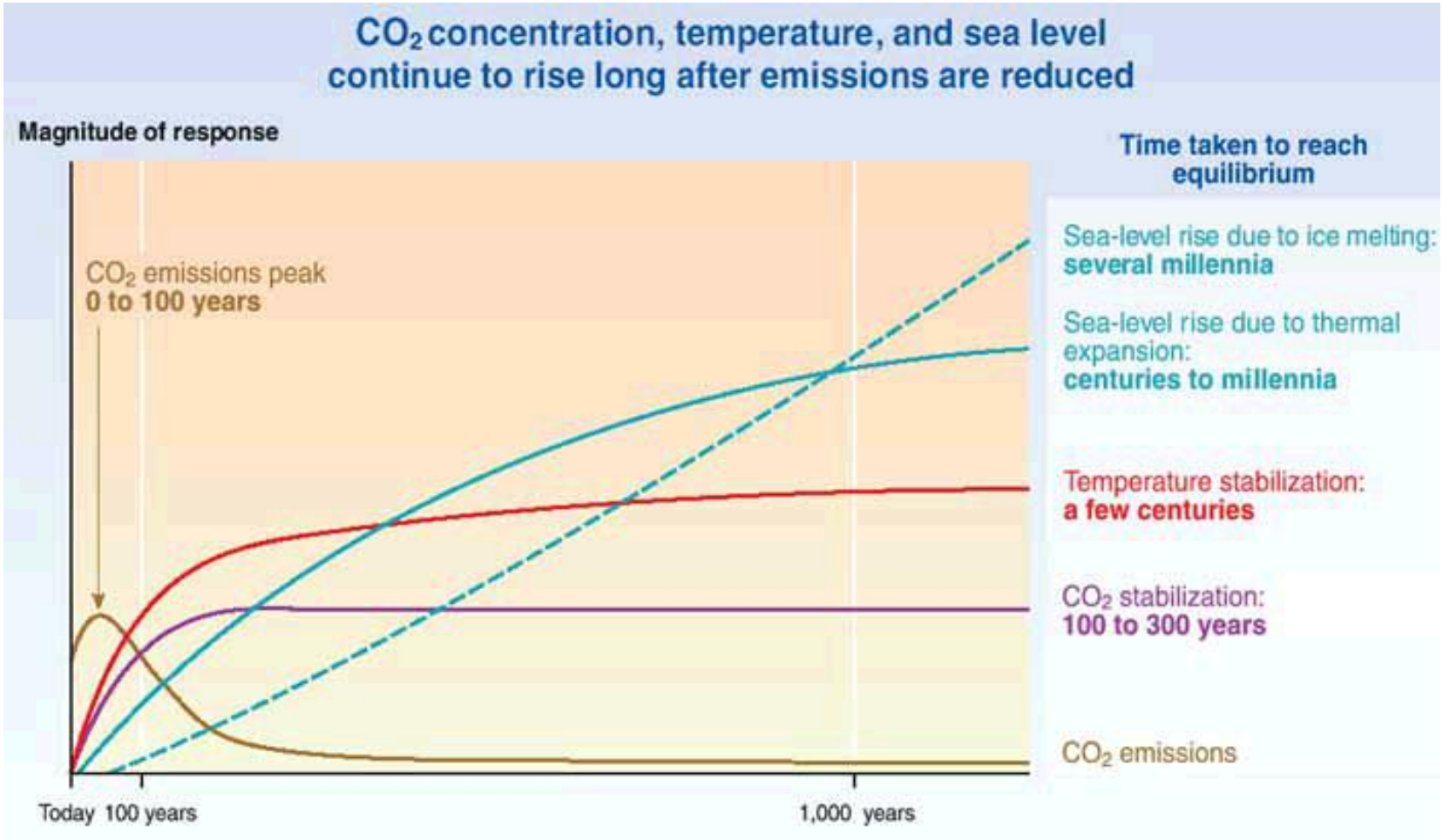
Fossil Power Generation Carbon Emission



CO_2 Production Source

	Process	Emissions (MtCO2/yr)		Percentage
Fossil Fuel	Power Generation	8,236		34.7%
	Autoproducers	963		4.1%
	Other Energy Sources	1,228		5.2%
	Manufacturing and Construction	4,294		18.1%
	Transportation	5,623		23.7%
	Road		4,208	17.7%
	Other Sources	3,307		13.9%
	Residential		1,902	8.0%
Biomass	Bioethanol and Bioenergy	91		0.4%
Total		23,742		100.0%

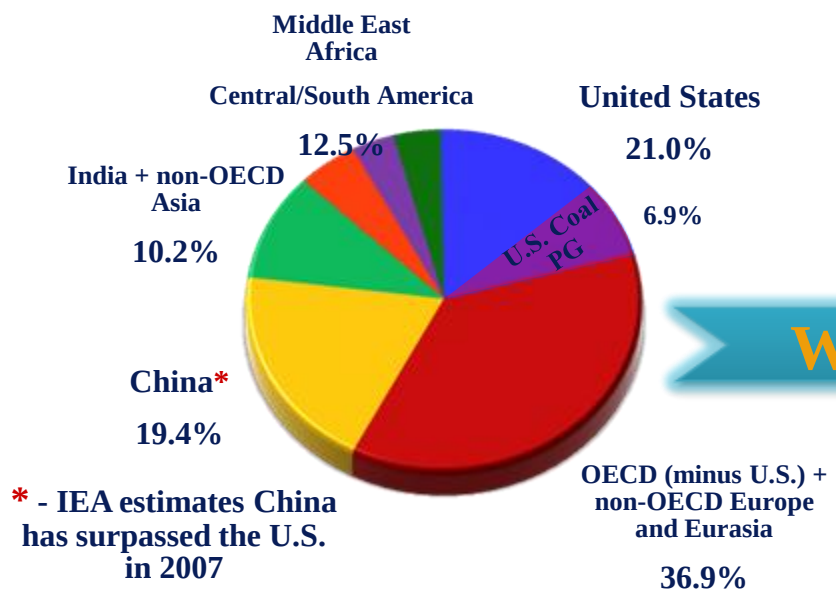
Timescales of Greenhouse Gases



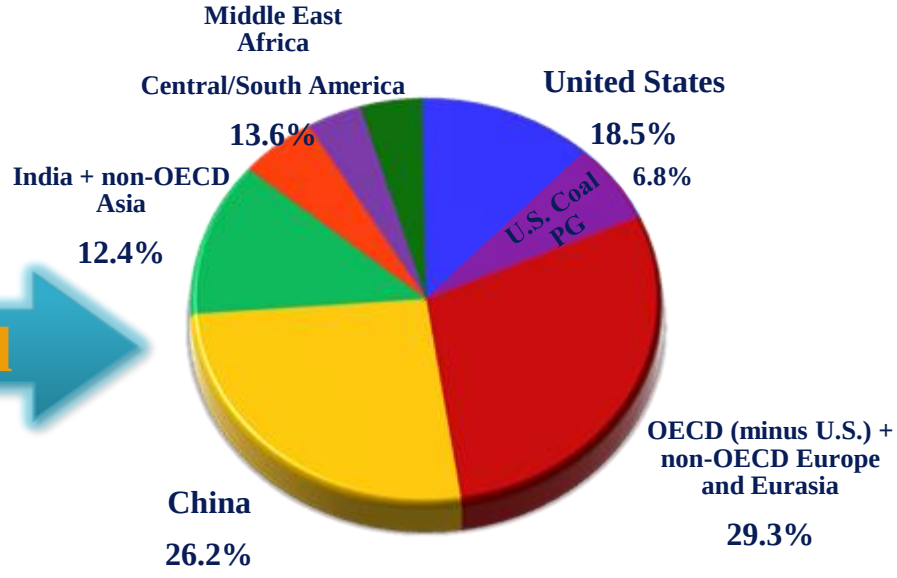
CO_2 Effects can be long lasting!

World CO_2 Annual Emissions 2007-2030

CO_2 Emissions 2007



CO_2 Emissions 2030



World

28.9 billion metric tons/year

42.9 billion metric tons/year

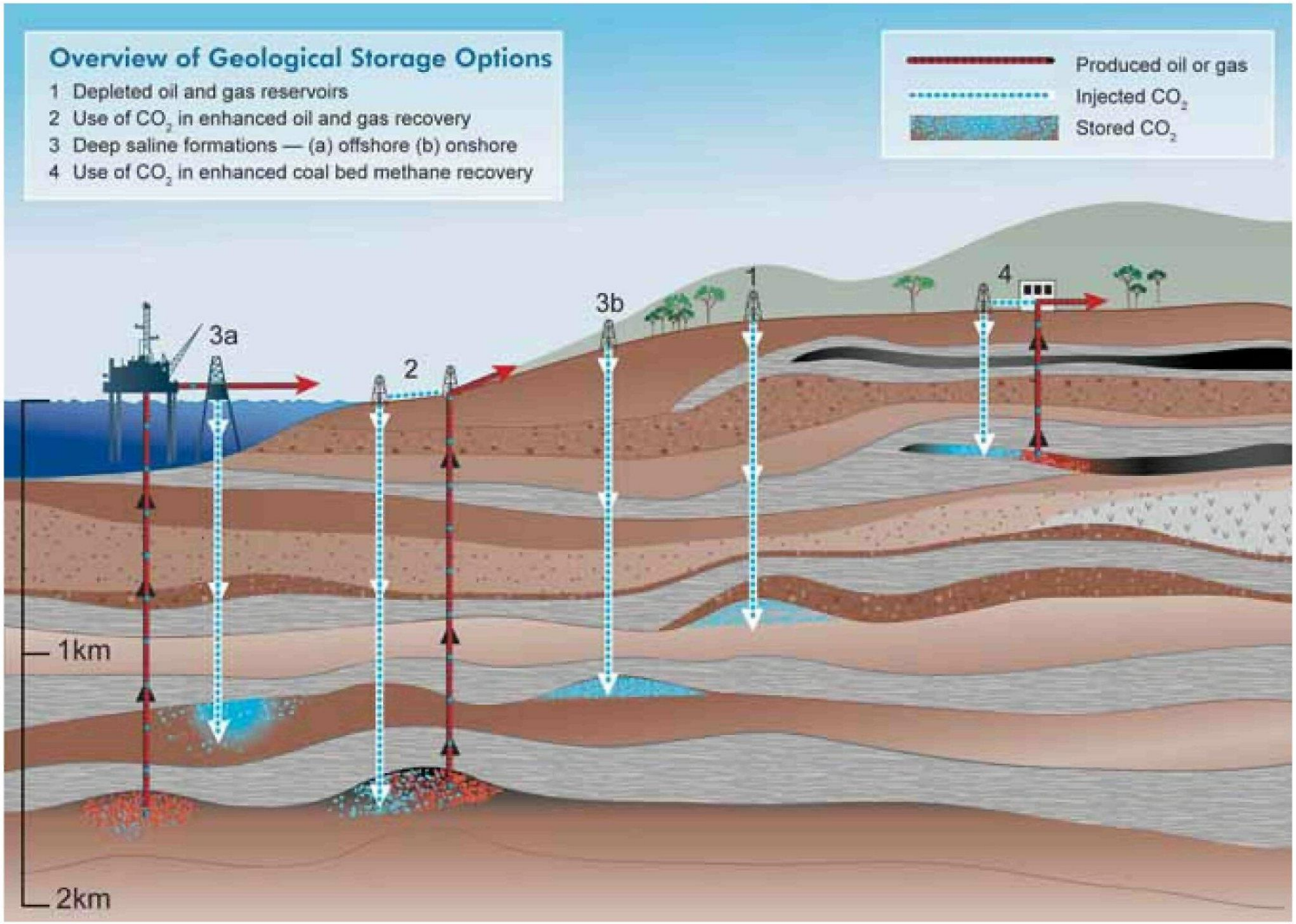
Developing Countries Have Significant Share of Emissions Growth

EIA, International Energy Outlook 2007

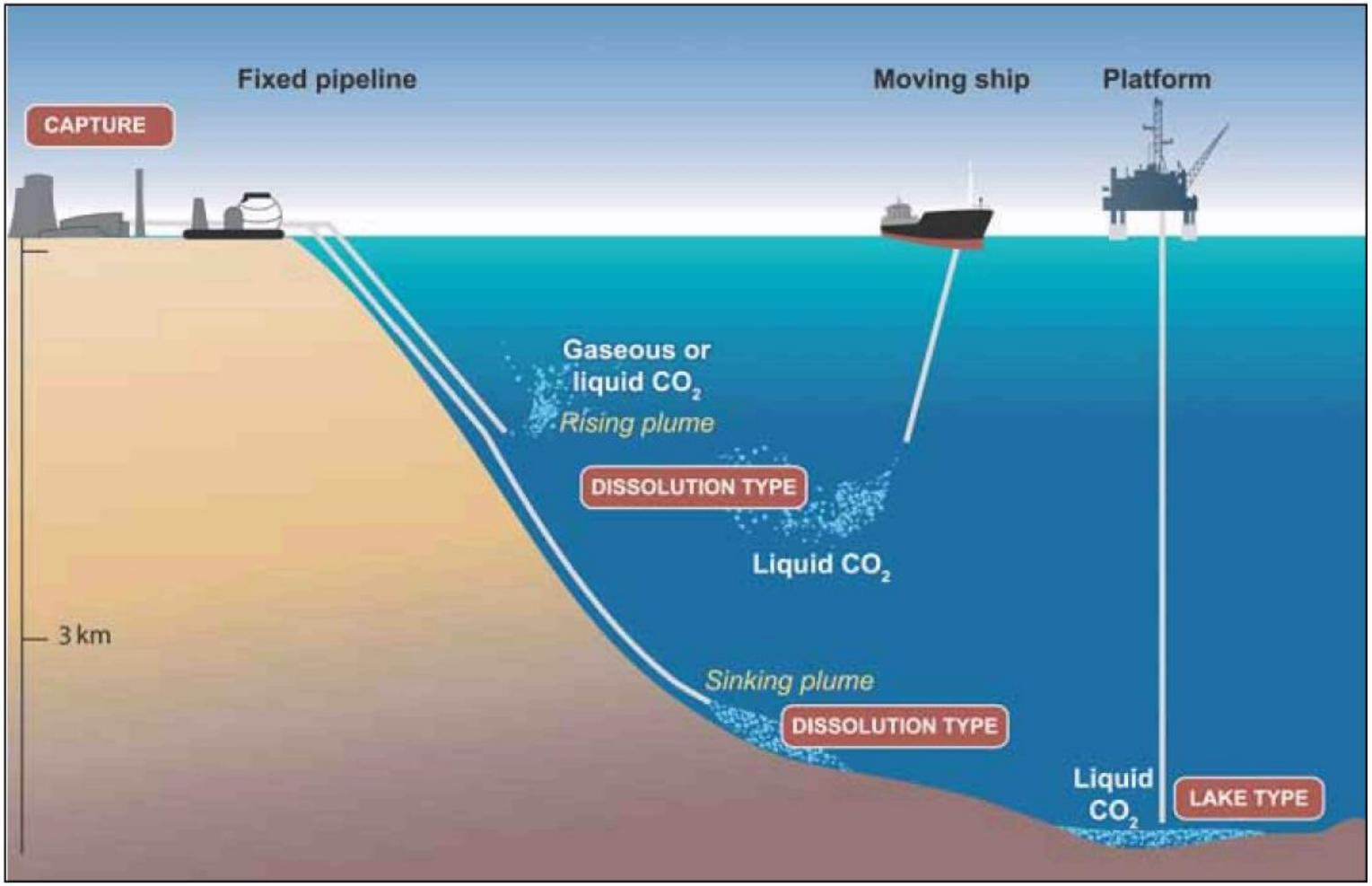
What Does This Mean?

- 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

CO_2 Geological Sequestration



CO_2 Ocean Sequestration



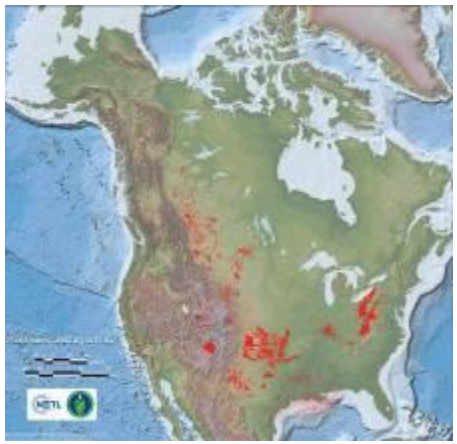
ICCP, 2003

Geologic Sink Capacity Estimates

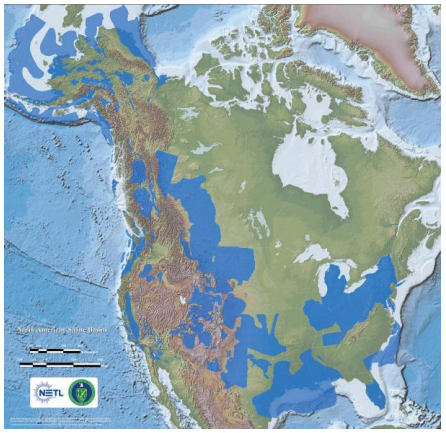
Adequate Storage Projected

U.S. emissions ~ 6 Gt CO_2 / yr, all sources

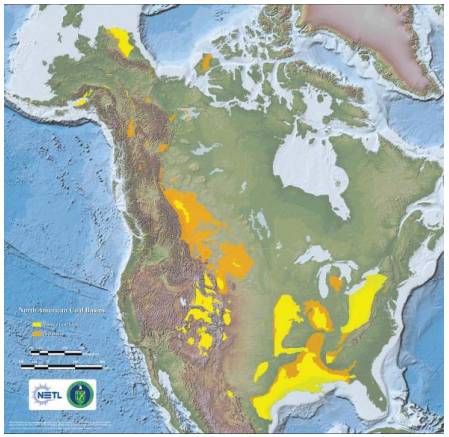
4,674 stationary sources identified



Oil and Gas Fields



Saline Formations



Unmineable Coal Seams

Estimated North American CO_2 Storage Potential (billion tons)

Sink Type	Low	High
Oil and Gas Fields	140	140
Saline Formations	3,300	12,600
Unmineable Coal Seams	160	180

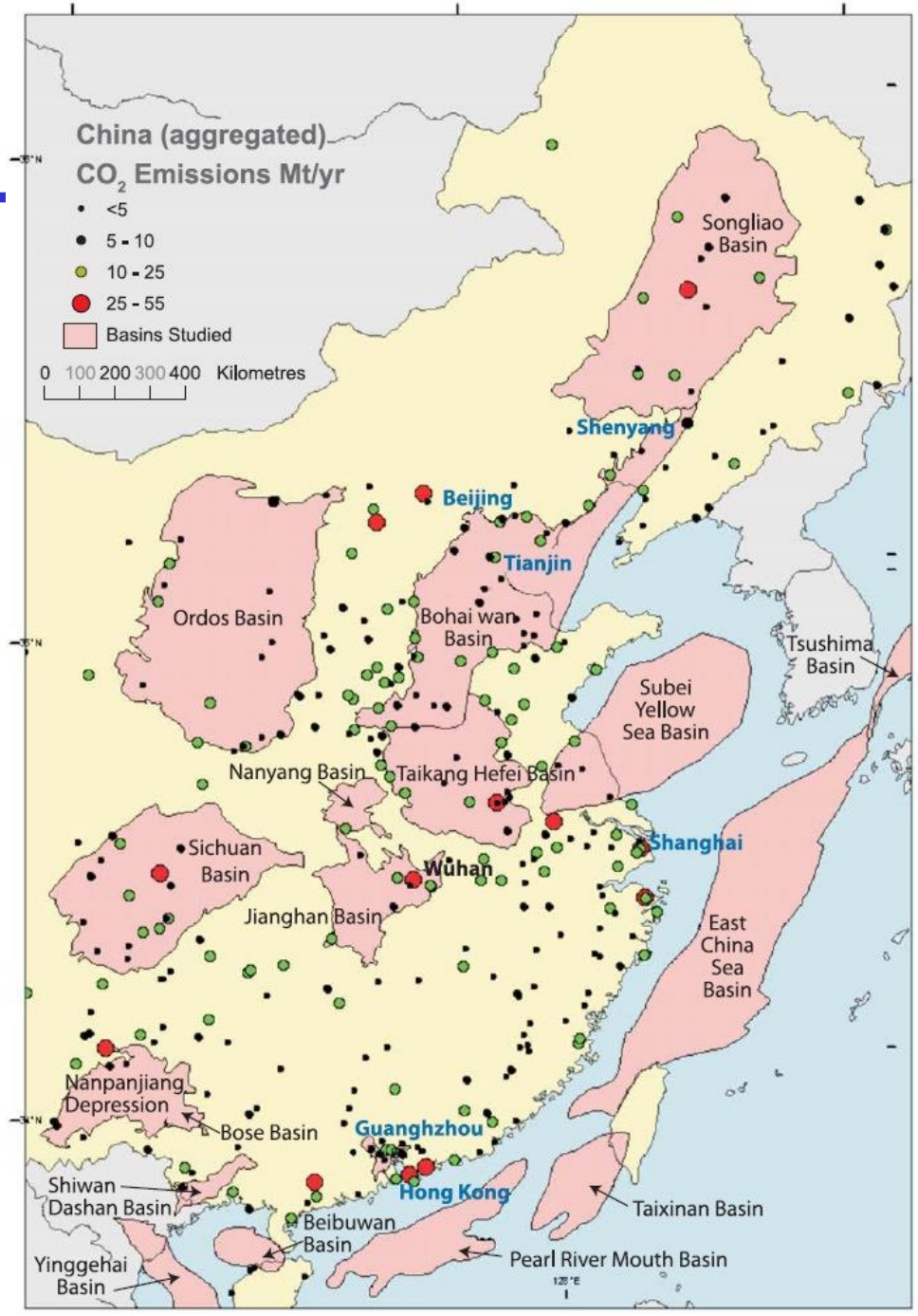
Hundreds of years storage potential!

DOE/Fossil Energy/NETL, Carbon Sequestration Atlas of the United States and Canada, November 2008

Carbon Capture and Storage (CSS) in China

Key Acitivities & Issues

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



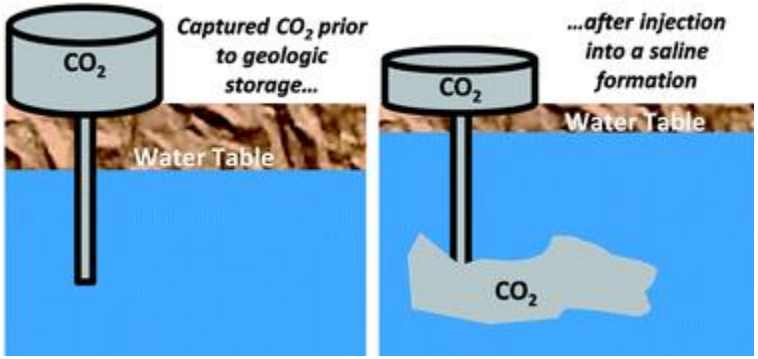
CCS's "Double-Edged Sword"

- 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



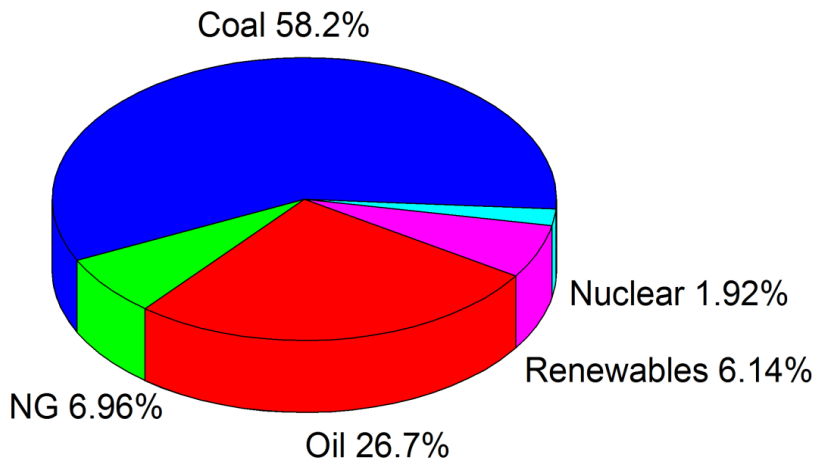
China Near-term Energy Targets (2013-2020)

1. Fossil – Retrofit old coal plants, Build/Order higher efficient supercritical plants, Natural gas fired plants, Clean coal technology, IGCC – Integrated Gas Combined Cycle + C02 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

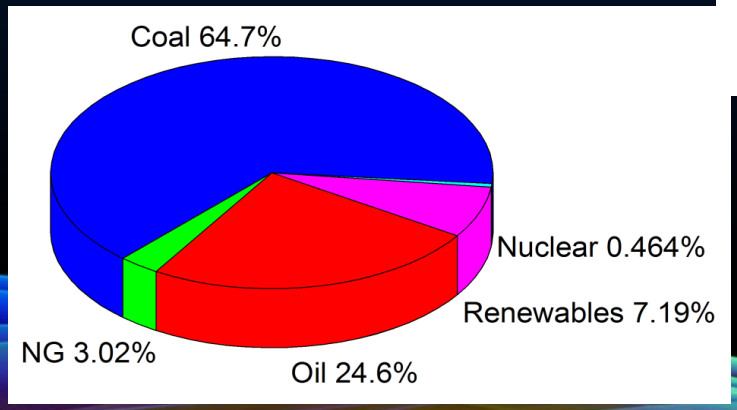
Potential Role of Energy Efficiency + Rnewables in Reducing China's Emissions from Coal

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 2025
Total: 2752 Mtoe



China 2002
Total: 1089 Mtoe

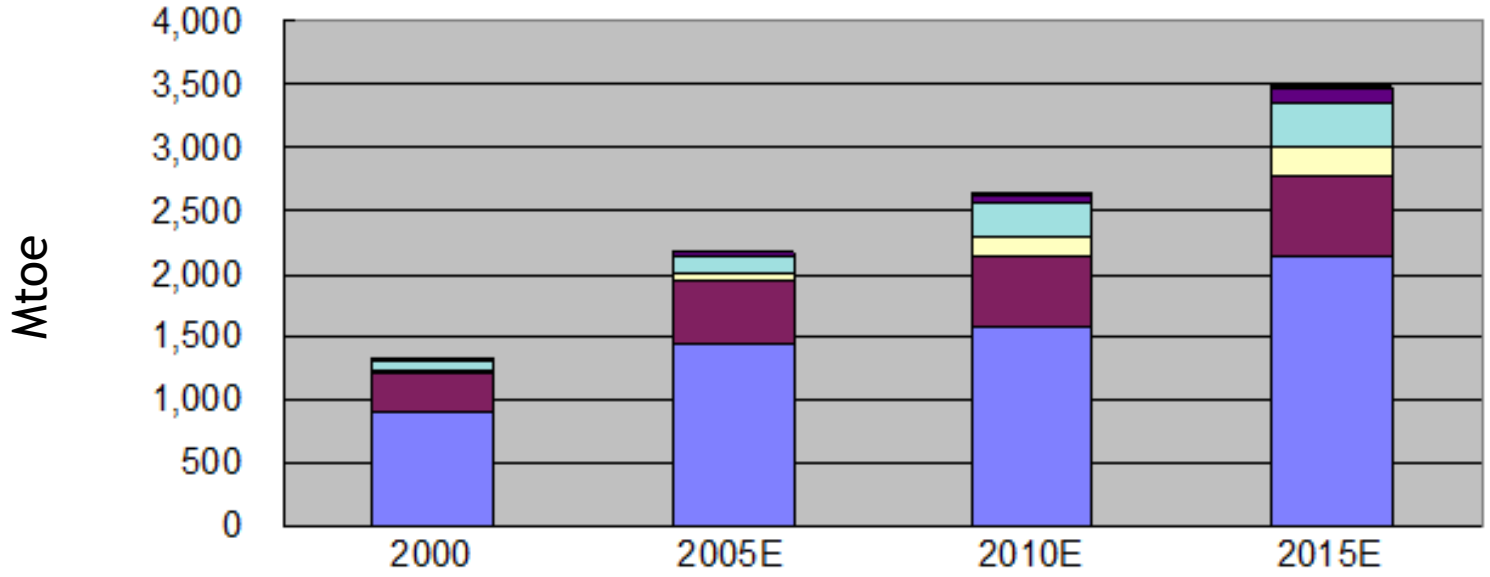


Renewables in China are mainly hydropower

Mtoe = million tons oil equivalent = 4.2 GJ

Source: IEA World Energy Outlook 2007

China Energy Mix Distribution



	2000	2005E	2010E	2015E
Renewable	0	1	10	30
Nuclear Power	6	26	62	101
Hydro	88	128	263	342
Natural Gas	33	80	159	226
Crude Oil	303	500	571	643
Coal	890	1,429	1,571	2,143

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

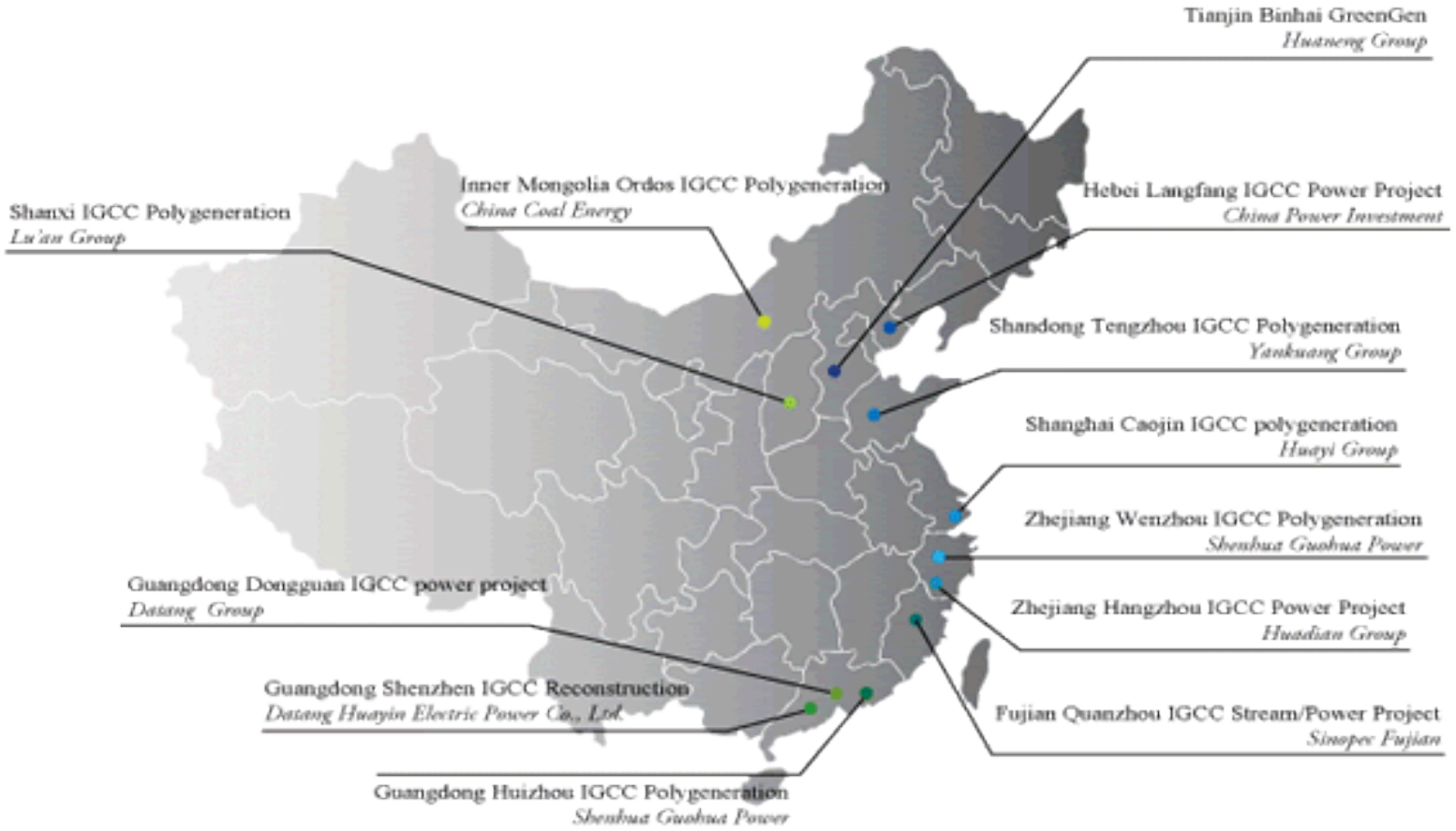
Coal based Power Generation Technology in China

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

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.

References

http://www.iea.org/country/map_indicators/index.html

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

CCS Retrofit Analysis of the Globally Installed Coal-Fired Power Plant Fleet, M. Finkernrath J. Smith, and D. Volk, International Energy Agency, 2012

China's Energy Policy 2012
http://www.ambpechino.esteri.it/NR/rdonlyres/54879255-E4DB-4BF3-A1B2-2C8C0D47C8CF/21586/Librobiancoenergia2012Cina.pdf

Thank You !

Prompt

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.