The Dominant Piece of the Energy System: Fossil Fuels

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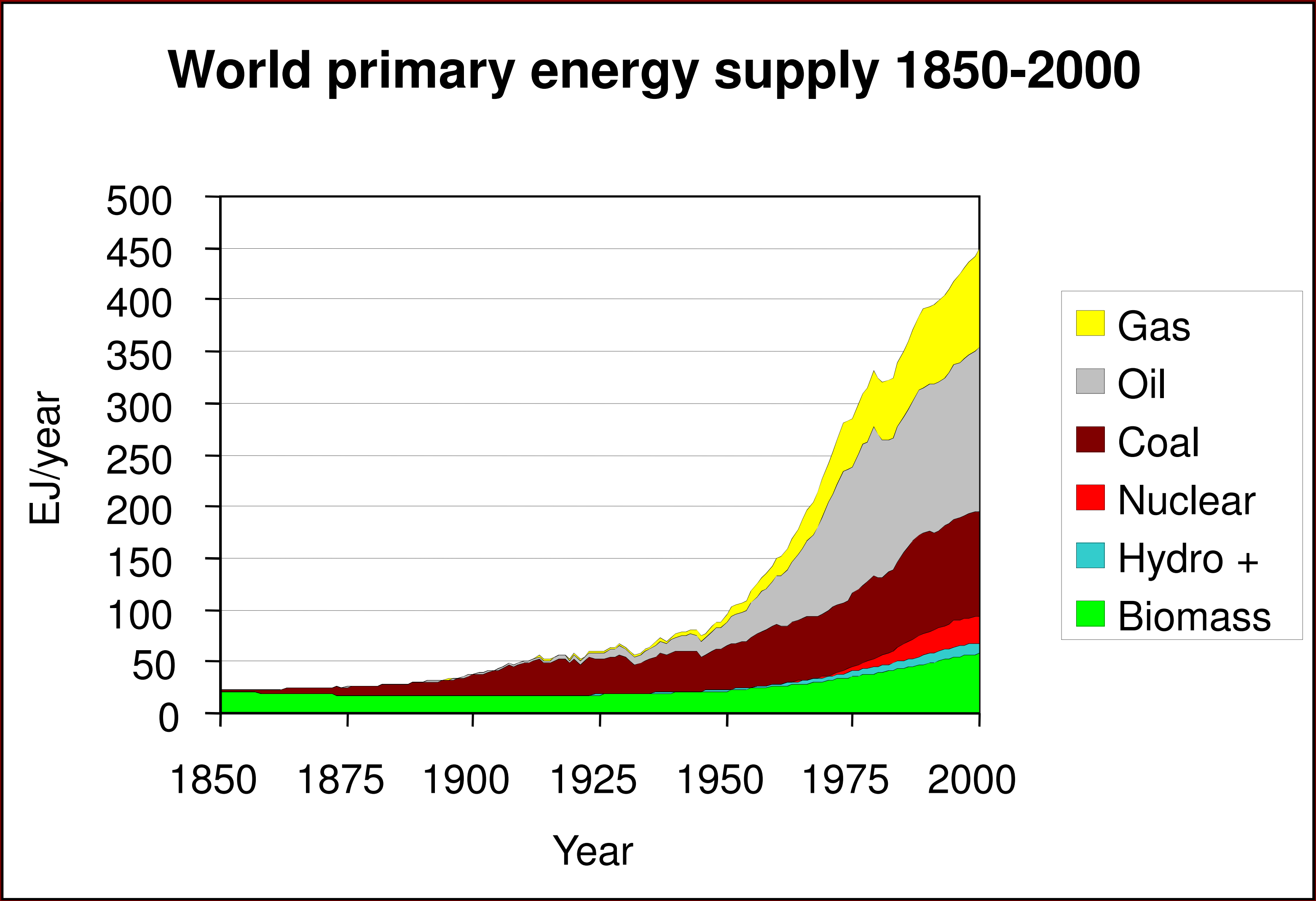
Sustainable Energy class, Fall 2010

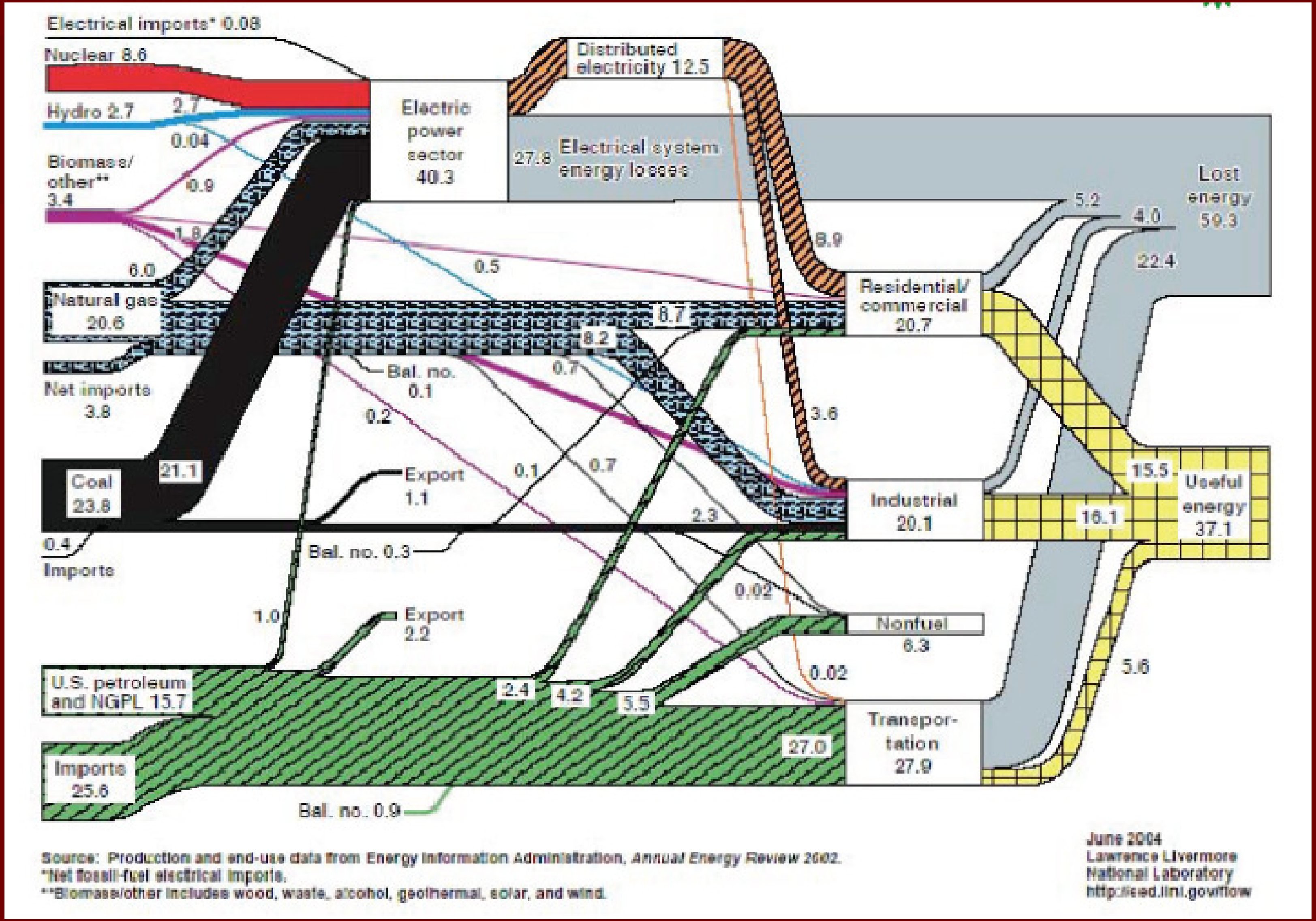
Fossil Fuels DOMINANT for last 100 years



We live in a fossil-fuel dominated world (80+% of supply in 2000)

E.M Drake

US Energy System 2002: consume 10^{20}J/yr, ~85% fossil



U.S. consumption per capita ~60% higher than most developed countries

Fossil Fuels Basics

- Dig carbon out of the ground, burn it to make heat + CO2.
  - Some heat used directly to heat buildings, reactors.
  - Most heat used in engines, to make electricity or transportation
- Electricity, transport from burning fuel in heat engines.
- A simple overall chemical reaction:
  - $CH_{2x} + (1+x/2)\ O_2 \rightarrow CO_2 + x\ H_2O$ + heat
  - x~2 for natural gas, x~1 for oil, x~0.5 for coal
  - Almost always (4+2x) N_2 molecules come in with the O_2 , go out with the CO_2
  - 70 to 150 kg of CO_2 emitted per GJ of heat.
- Fossil fuels, created over 10^8 years by conversion of plant material in sediments, will probably be mostly consumed in $<10^3$ years.

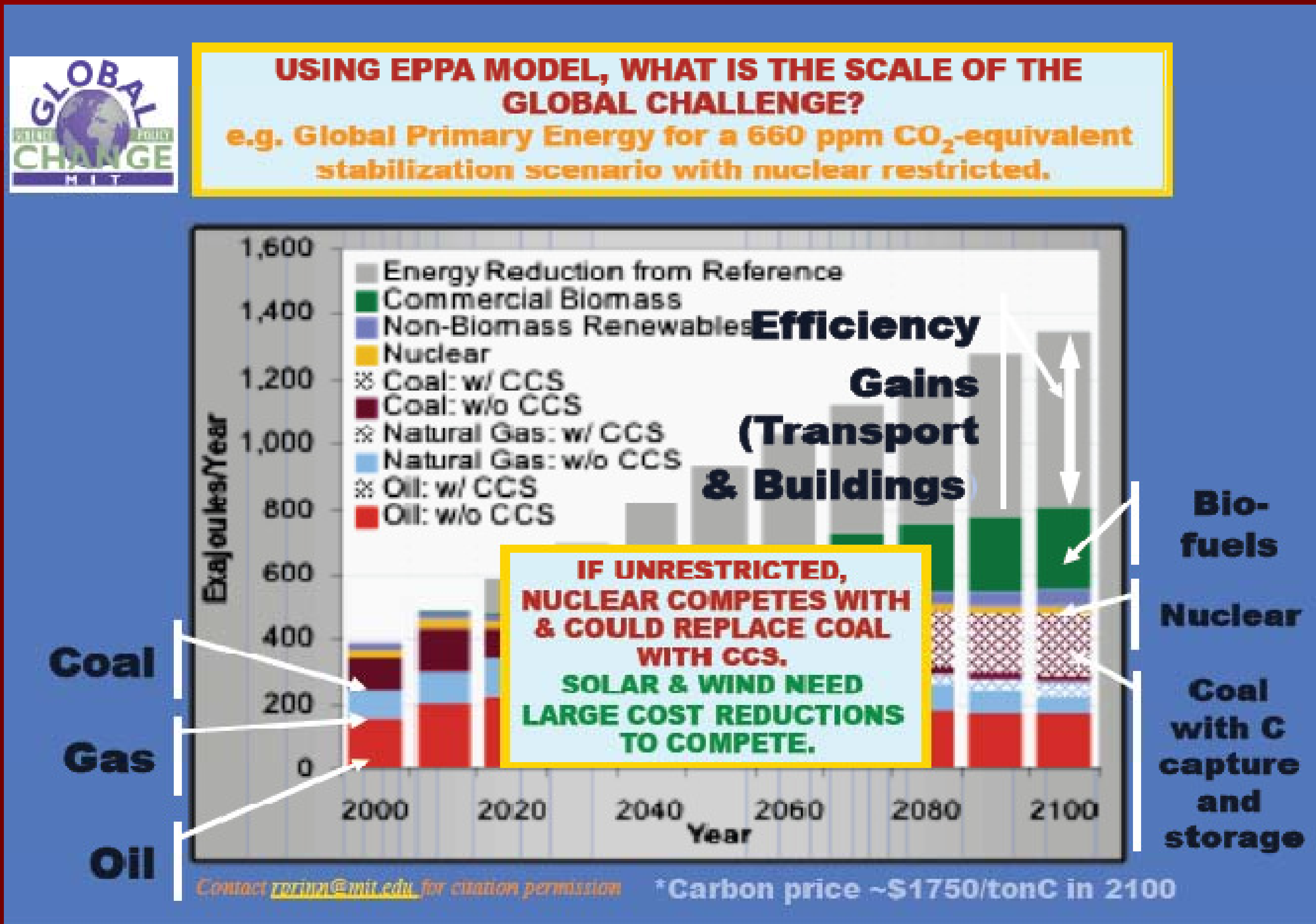
Energy Problem has many Aspects

- **Sufficient Supply?**
  - Will we exhaust conventional petroleum & gas this century?
  - Energy supply system robust to natural disasters?
- **Price / Affordability**
  - At current prices, energy is unaffordable to many people.
  - If prices double, world economy crashes!
  - Most options significantly increase cost of energy.
- **Security**
  - Most energy resources remote from population centers.
  - Blockades, embargos, upheavals do disrupt supply.
  - Diversion of nuclear material to nuclear weapons?
- **Environmental & Health Problems**
  - Local pollution from energy a major health issue.
  - Significant Water use and Land use issues
  - **Global Climate Change from CO_2**

Why & Why Not use Fossil Fuels?

- **Finite but Very Large Amount of Fossil Fuel**
  - **We are definitely going to run out of fossil fuel energy… in a century or two: *Long Term issue***
  - **Fossil fuels are available now in huge scale (unlike most other energy sources)**
- **Greenhouse Effect on Climate Change is the *Medium-Term issue***
  - **We'll "run out of atmosphere" to hold the CO_2 before we run out of fossil fuel.**
  - **Might even run out of capacity to store CO_2 underground or in ocean…**

One Proposal to stabilize CO2: Efficiency+Biofuel+CO2 CCS



Short-term Politico-Economic Issues

- Fossil Fuels are Cheaper than Alternatives
  - Why ~85% of world's energy from fossil fuels
  - How to incorporate social cost into price?
- A few countries hold almost all the world's oil and gas reserves
  - Security? Balance-of-Trade? Development?
- Prices fluctuate wildly (inflexible market)
  - Adds to risks for new energy supply ventures
- Energy is lifeblood of economy
  - Governments very heavily involved…

Pressing Issues, Now to 2025

- **~50% increase in total global energy demand!!**
  - Huge long-term energy infrastructure investments
  - Do these investments work for the planet, long term?
- **Engineering & policies for large-scale conservation**
  - Electricity: more efficient production, devices, system?
  - Capex vs. Opex: Doesn’t always favor energy efficiency.
- **Can Oil production keep up with demand?**
  - Probably OK until 2020 if Iraq recovers. Doubtful after that…
  - Better recovery from existing fields? Exploit Arctic Ocean?
  - Unconventional Oil? Other Sources of Liquid Fuels?
- **~100% (!) increase in global electricity use**.
  - Natural Gas? Price? How to transport it? Security?
  - Coal? Greenhouse Gases! Feasible to sequester CO_2?
  - Nuclear? Reduce chance of Weapons proliferation?

Facts to Bear in Mind

- Energy production and use is capital-intensive (both renewables and fossil)
  - Capex for power plant, oil platform, automobile, or HVAC system more than single-year energy cost.
  - Reluctance to replace equipment until it is worn out.
  - Multi-year lag times in building big energy projects.
- Energy conversions and separations cost energy
  - Often lose a factor of 2 or more in each conversion
    - Fuel to electricity
    - Gas or Coal to liquid fuels
  - Separating CO_2 or O_2 from N_2 costs energy
    - Required for CO_2 sequestration.

Energy Resource Basics

- **Liquid Fuels are much more valuable than gases, solids:**
  - **Liquid Fuel (oil): ~$20.00/MBtu**
    - **High energy density, easy handling, *ideal for transportation***
  - **Natural Gas: ~ $6.00/MBtu**
    - **Hard to transport: ~100x the volume per carbon.**
      location dependent price (free at some remote locations)
    - ***Very convenient for electricity, buildings***
  - **Coal: $1.50/MBtu**
    - **Difficult to handle or burn cleanly: ash, slag**
    - ***Most burned to make electricity***
- **Most Hydrocarbon Resources are Solids**
  - **Coal: 1000 Gton carbon (~100 years)**
  - **Oil Shale: 500 Gton carbon (~50 years)**
  - **Tar Sands: 400 Gton carbon (~30 years)**
  - **Biomass: 60 Gton carbon/yr**
  - **Oil: 300 Gton carbon (~30 years)**
  - **Natural Gas: >100 Gton carbon (~30 years)**

Making Fossil Fuels *Less* Unsustainable

- Fossil Fuels are THE REALITY until 2050
  - Biofuels can substitute for some fossil fuel (but not enough biomass on earth to replace even 50% of current fossil fuel usage).
- How to Improve Fossil Fuel Sustainability?
  - **Improve Efficiency!!**
    - Fuels last longer, prices lower, reduce security concerns
    - Reduce Health/Environment/Climate Impacts
  - Sequester CO2
- Improving Fossil Fuel Production/Supply
  (but this usually *increases* CO2 emissions!)
  - Make Liquid Fuels from Solids, Gas
  - Transport Natural Gas
  - Use Difficult Hydrocarbon Resources
  - Less Destructive/Dangerous Mining Methods

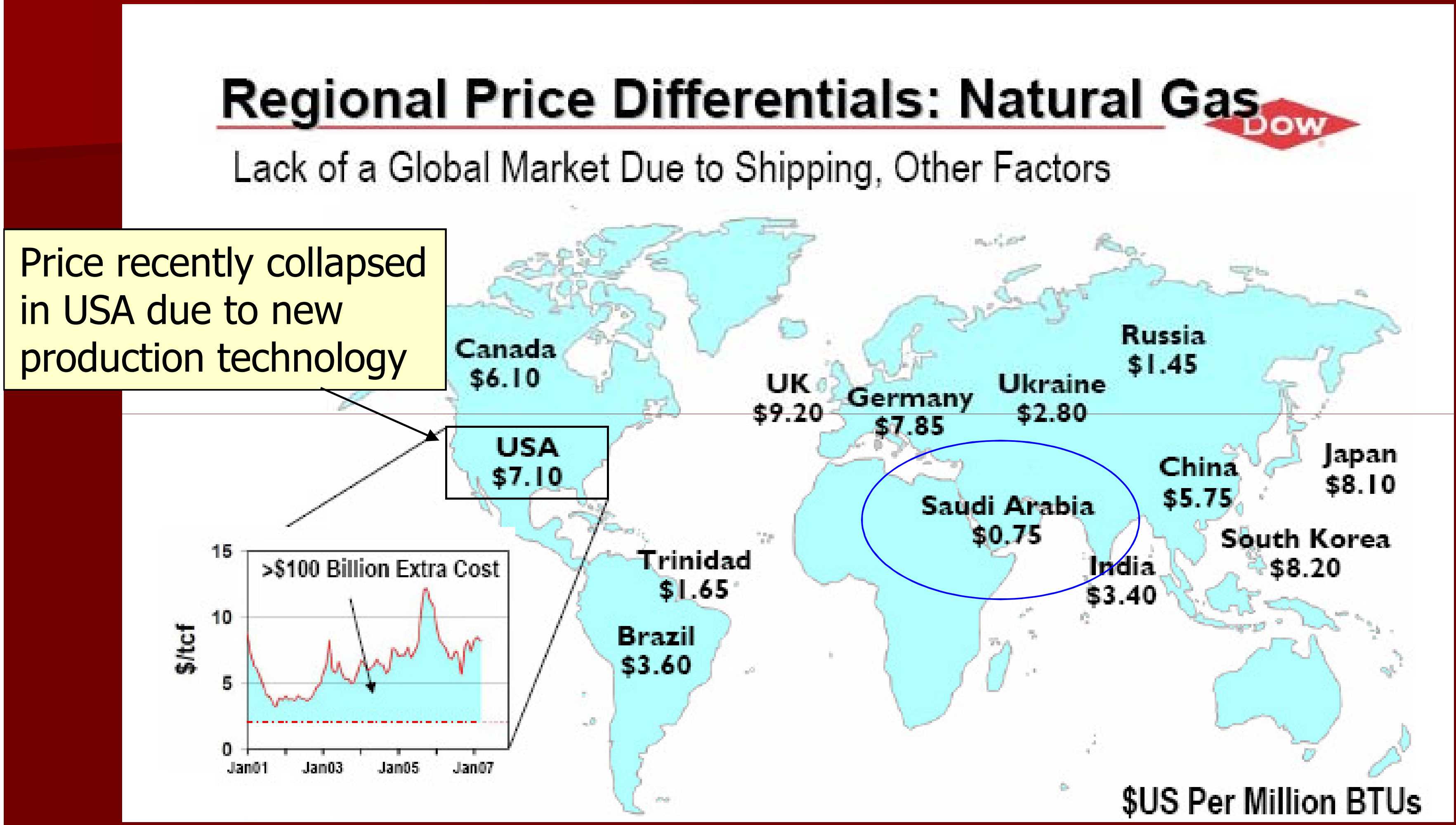
Presentation Order

- Rest of this lecture:
  - Fossil Fuels other than Oil
  - CO2 capture (for sequestration) overview
- Later in the Course:
  - More on Oil, Liquid Fuels for Transportation
  - Biomass to Liquid Fuels

Energy security, environment, economics often in conflict

Please see slide 5 in McRae, Gregory. "Cost Modeling and Comparative Performance of Coal Conversion Systems." MIT Energy Short Course, June 14, 2006.

Natural Gas is a *great* fuel… but most is located far from consumers



W.F. Banholzer, DOE workshop Aug 2007

No one has yet invented a cost - effective way to make gas into a shippable liquid transportation fuel.

Technical Challenge: Converting Natural Gas to Liquids

- Refrigerate to liquified natural gas (LNG)
  - Works, but huge capital investment, requires very large gas reserve. Costs a lot of energy, CO_2 emissions.
- Gasification then Fischer-Tropsch to diesel:
  - $CH_4 + 1/2\ O_2 = CO + 2\ H_2$
  - $n\ CO + 2n\ H_2 = (CH_2)_n + n\ H_2O$
  - A lot of chemical energy being converted to heat in remote location, often wasted. Big CO_2 emissions.
- Other CH_4 reactions??
  - Several concepts / patents, none successful so far
  - General problem: CH_4 is less reactive than products

Local Environmental Impacts

- Burning fossil fuels makes local pollution
  - Air pollution (other than CO2) can de dramatically reduced by emission-control devices
    - Requires more capital
    - Requires ongoing government oversight
    - Often reduces energy efficiency
  - Solid waste from impurities in coal
- State-of-the-art oil/gas production minimizes environmental impacts, yet…
  - Significant CO2 emissions in production.
  - Potential for large accidental leaks.
  - Work in Arctic and off-shore is dangerous.
- Coal and tar production is *very messy*
  - Often big environmental impacts at the mine.
  - Tar mining consumes lots of water, energy.
  - Mining is dangerous.

Tar Sands

- Locations: **Canada**, Venezuela, Siberia.
- ~85% sand, ~15% hydrocarbon
- Highly porous: bitumen will flow out if T>80 C.   H:C ~ 1.5
- **Commercial**: ~2 mbd in Canada.
  - Surface mining and hot-water washing
  - In-situ underground production (inject steam).
  - Coke/Hydrotreat to make liquid, remove S.

Canadian Tar Sands:
World's largest earthmoving operation

Photo by Alex Abboud on Flickr.

Truck is bigger than a house, costs $5M.

~5 tons of sand and peat moved and **~1 barrel of wastewater produced per barrel of oil**.

At 2 mbd, that is a lot of polluted water!

In-situ production from tar sands

Diagram of steam-assisted gravity drainage removed due to copyright restrictions.

Oil Shale

- Locations: USA, Brazil. Colorado's Green River formation is most valuable.
- 15-20% *solid* kerogen in impervious mineral matrix. Does not flow...
- Pyrolysis of crushed shale T~500 C converts 2/3 of kerogen to heavy oil.
- Upgrade to remove N,S, reduce viscosity.
- H:C ~ 1.6 similar to diesel.

Mining Oil Shale in the Colorado Rockies

Photo by SkyTruth on Flickr.

~8 tons of rock mined
and ~3 tons of water consumed per ton of oil produced.

Maybe new *in situ* method will avoid mining, reduce water use?

Issues with Tar Sands & Shale

- Expensive processes
  - Large Capital Costs
  - Need lots of Labor in remote areas: new cities.
  - Consume huge amount of gas, water.
    - ~2 barrels water evaporated per barrel of oil made
    - ~100% of Mackenzie Delta gas will soon be used for tar sands production.
- Environmental impacts
  - **CO_2 emissions** (~30% energy consumed to produce)
  - Waste water (comparable volume to oil made)
  - Waste solids (comparable volume to oil made, unless produced in situ)

Greenhouse Gas Considerations

- **Fossil solids emit more CO_2 than oil**
  - **Biomass routes emit less CO_2 than oil**
- **Fossil Solids-to-Liquids conversion doubles CO_2 emissions**
- **China is committing heavily to Coal**
  - **Coal-to-Electricity is the biggest single source of CO_2.**
  - **Technology to reduce CO_2 emissions…at a price consumers in China, India, US will accept?**
- **Some sort of political response to Climate Change is coming (probably, eventually)….**
  - **Carbon caps or taxes?**
  - **Tighter efficiency regulations?**
  - **Largescale CO_2 capture and sequestration??**

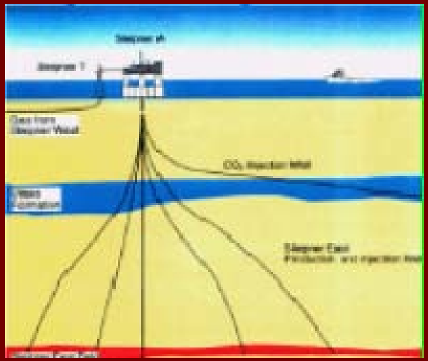
CO2 capture and underground sequestration is possible, but significantly increases both capital & operating costs

Please see slide 22 in McRae, Gregory. "Cost Modeling and Comparative Performance of Coal Conversion Systems." MIT Energy Short Course, June 14, 2006.

Public acceptance and unresolved policy issues even more problematic

CO_2 Sequestration Projects

Sleipner, Statoil, Norway



Courtesy of Statoil. Used with permission.

In Salah/Krechba, BP, Algeria

Courtesy of BP. Used with permission.

Technical Challenge: CO_2 capture

- Option #1: CO_2 capture from smokestack
- $2\ CH + 2.5\ O_2 + 10\ N_2 = 2\ CO_2 + H_2O + 10\ N_2$
  - low P CO_2 dilute in lots of N_2, hard to capture
- Option #2: gasify at high pressure (IGCC)

  $$4\ CH + O_2 + 6\ H_2O = 4\ CO_2 + 12\ H_2$$

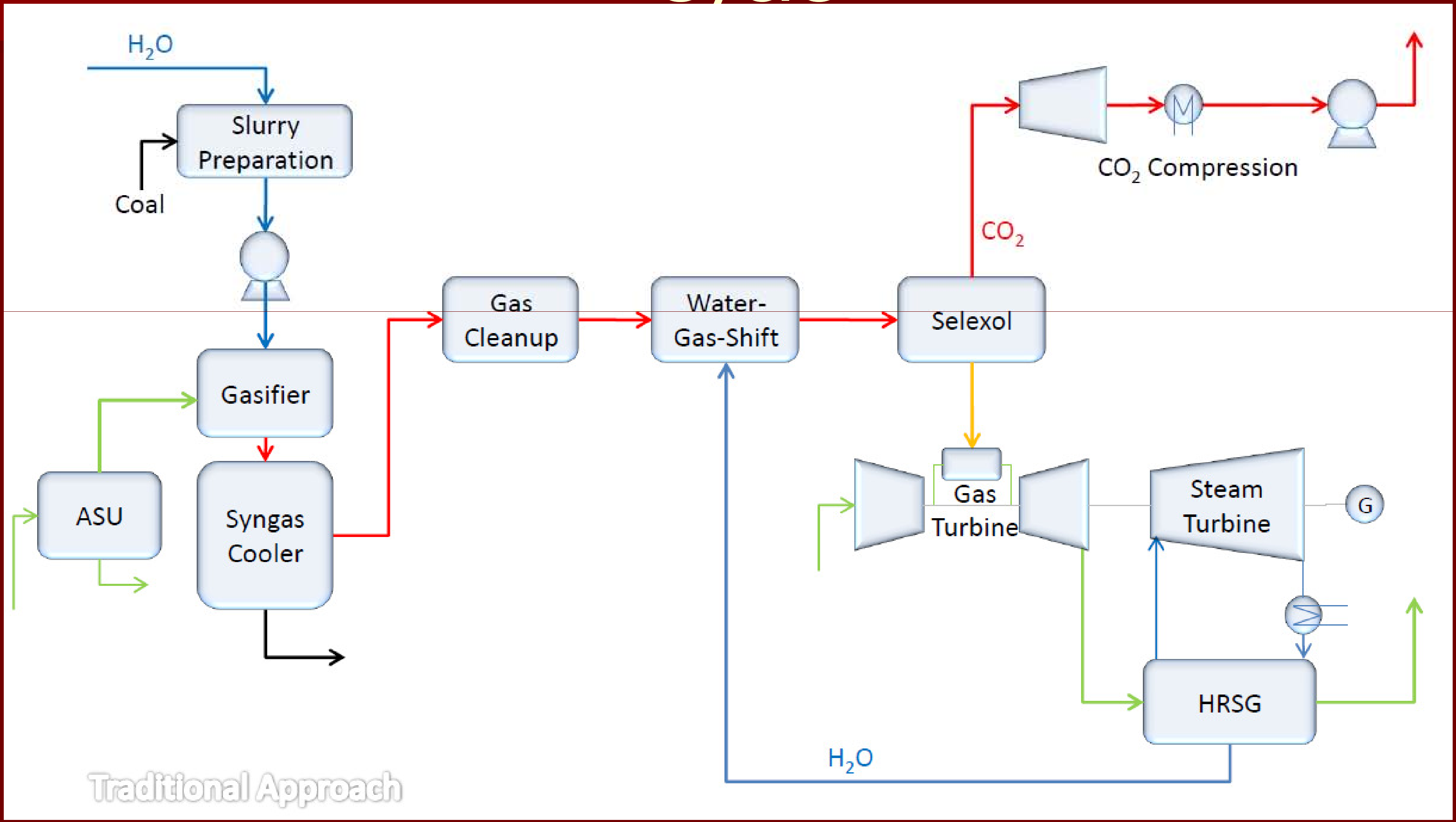
  - Separate O_2 from N_2, and CO_2 from H_2
- Option #3: oxycombustion

  $$2\ CH + 2.5\ O_2 = 2CO_2 + H_2O$$

  - Separate a LOT of O_2 from N_2 (~5 N_2 per C burned)

Please see slide 21 in McRae, Gregory. "Cost Modeling and Comparative Performance of Coal Conversion Systems." MIT Energy Short Course, June 14, 2006.

Integrated Gasification Combined Cycle



Source: Botero, MIT

Please see slide 30 in McRae, Gregory. "Cost Modeling and Comparative Performance of Coal Conversion Systems." MIT Energy Short Course, June 14, 2006.