

SEMINARIO
“LA COOPERACION ESTRATEGIA EN LA INNOVACIÓN
ENERGETICA”

16 de Noviembre de 2006,
Santiago, Chile

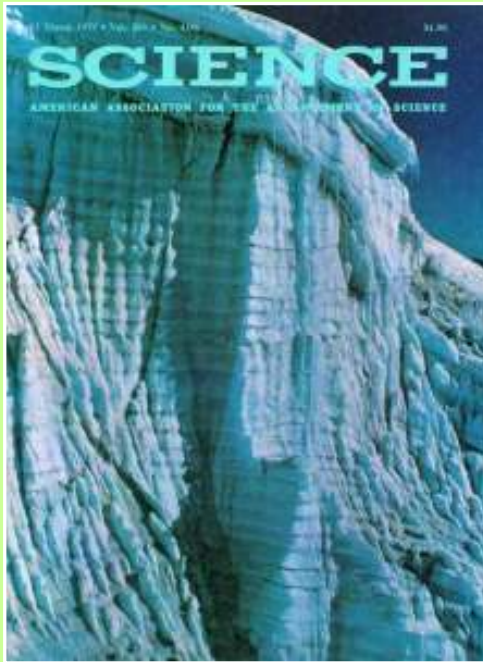
“Futuro de las tecnologías energéticas”
Zero-Emission, Domestic Energy - from
Hydrocarbons and Renewable Resources



Dag Nummedal
Colorado Energy Research Institute
Colorado School of Mines
Golden, CO 80401, U.S.A.



- **The problems**
 - Global warming and the costs of action or inaction
 - Fossil energy resource conflicts
 - The energy growth challenge
- **The solutions: Emissions free, accessible, and affordable energy systems**
 - Unconventional hydrocarbons w/carbon capture
 - Coal to gas and liquids w/carbon capture
 - Solar
- **Value of Chile – U.S. energy R&D collaboration**



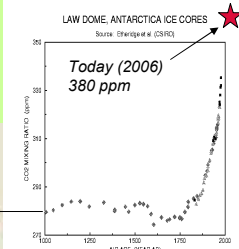
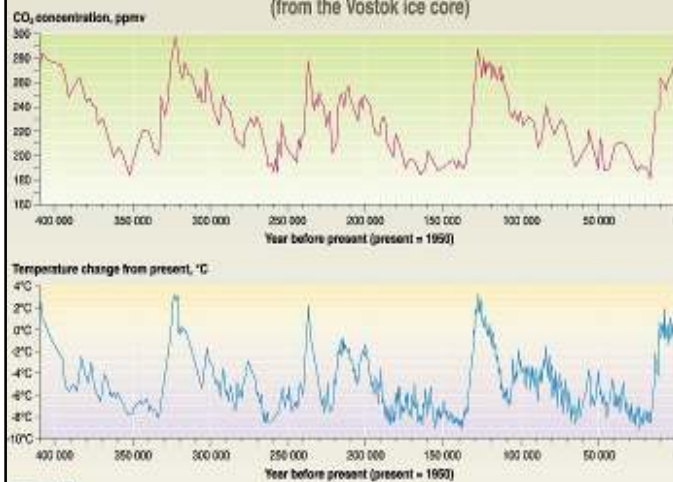
Best Documentation of Past Climates Comes from Ice Cores

Annual bands in ice can be used to reconstruct past climatic conditions...

Quelccaya Ice Cap, Peru
(Lonnie Thompson)

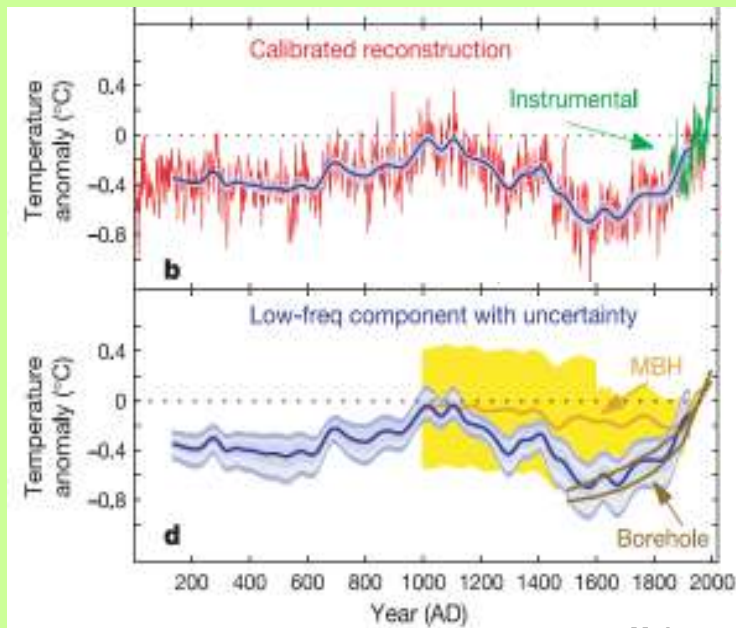
CO₂ History from 400,000 ka to the Present

Temperature and CO₂ concentration in the atmosphere over the past 400 000 years (from the Vostok ice core)



Source: J.P. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 400 000 years from the Vostok ice core in Antarctica. Nature 399 (34), pp.429-436, 1999.

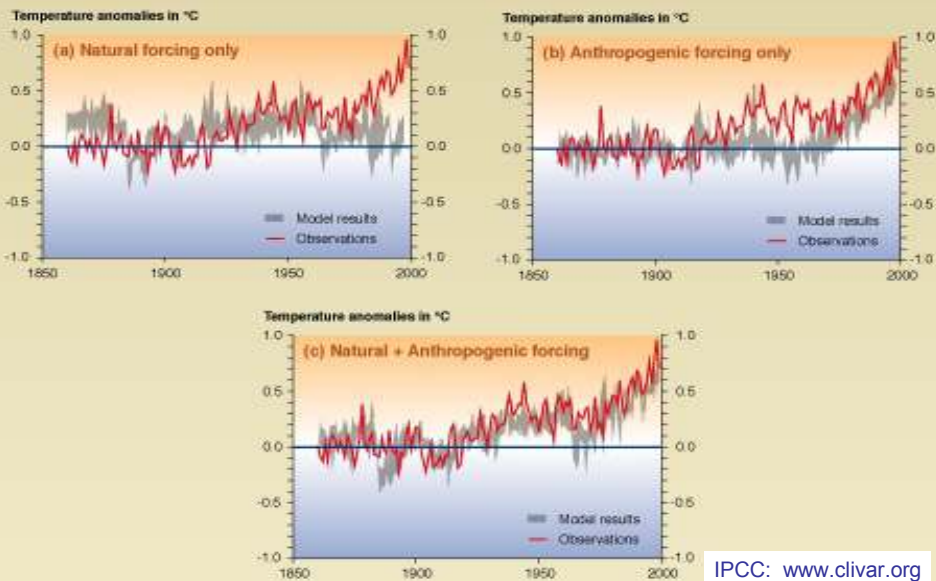
N. Hemisphere Surface Temperature Reconstruction



Moberg et al. (2005)

Natural and Man-made Climate Change

Comparison between model and observations of the temperature rise since 1860

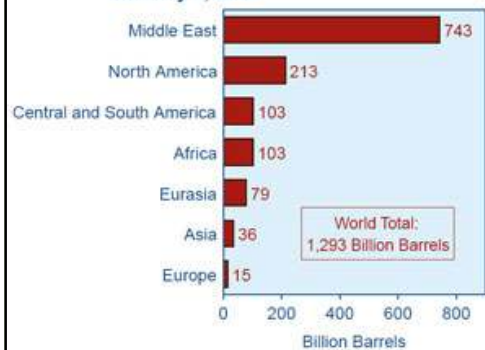


Oil in the History of the Middle East

1913: First oil discovery in the Middle East
1917: World War I: British War Cabinet:
 “Control of these resources becomes a first class war aim”
1920s: US – Britain conflict over Iraq
1942: Battle for Stalingrad (⇒ Baku)
 Battle of El Alamein (⇒ Arabia)
1953: Mossadegh’s government fall. Result of Anglo-Iranian conflict
1956: Nasser; the Suez Canal conflict
1973-74: Arab oil embargo. The price of oil rose from \$3 to \$11.60 in 3 months
1979: Fall of the Shah of Iran
1979 – 1989 Soviet war in Afghanistan
1991: The Gulf War
2003 - ?: Iraq war



Figure 29. World Proved Oil Reserves by Geographic Region as of January 1, 2006

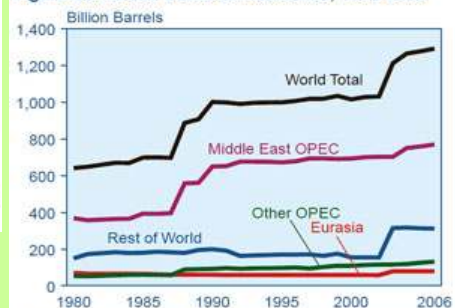


Source: “Worldwide Look at Reserves and Production,” *Oil & Gas Journal*, Vol. 103, No. 47 (December 19, 2005), pp. 24-25.

Energy Information Agency, DOE
Annual Energy Outlook, 2006

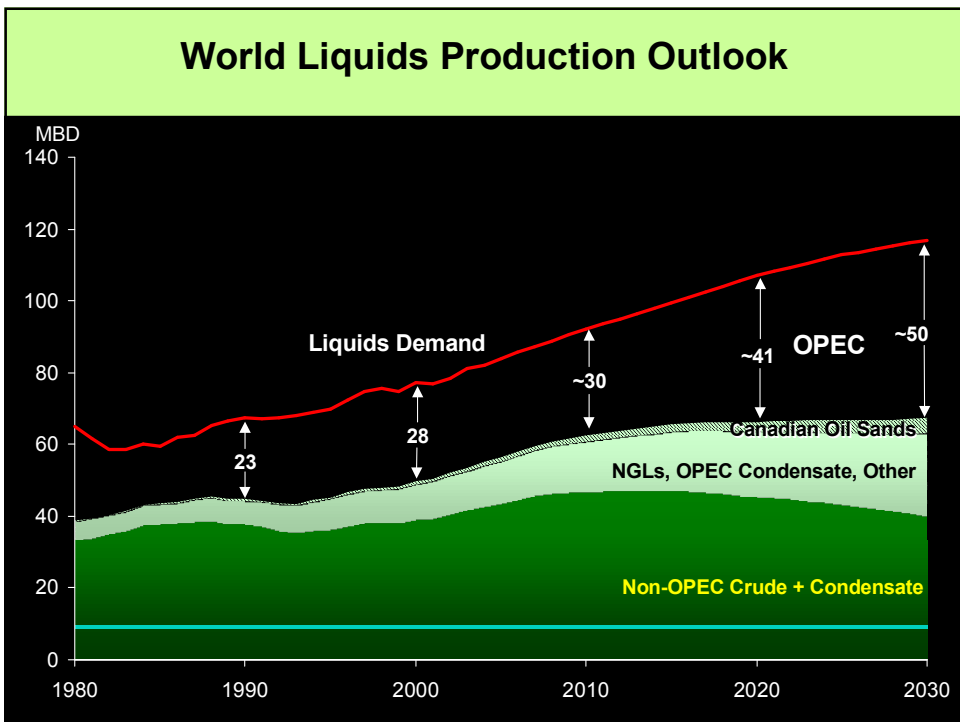
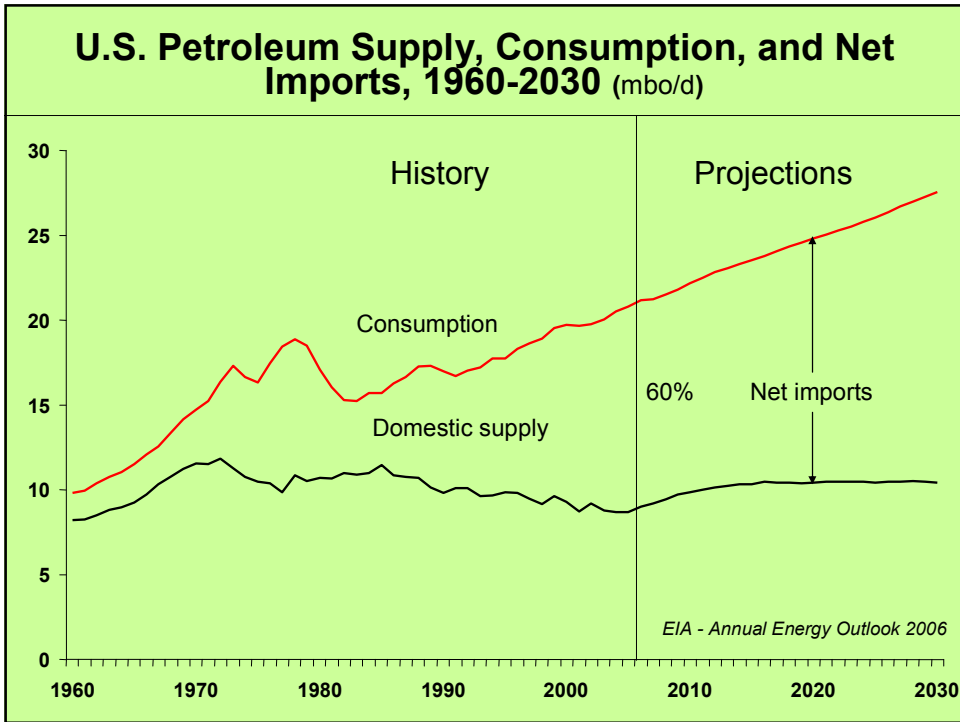
Distribution of Oil Reserves

Figure 28. World Crude Oil Reserves, 1980-2006



Note: Reserves include crude oil (including lease condensates) and natural gas plant liquids.

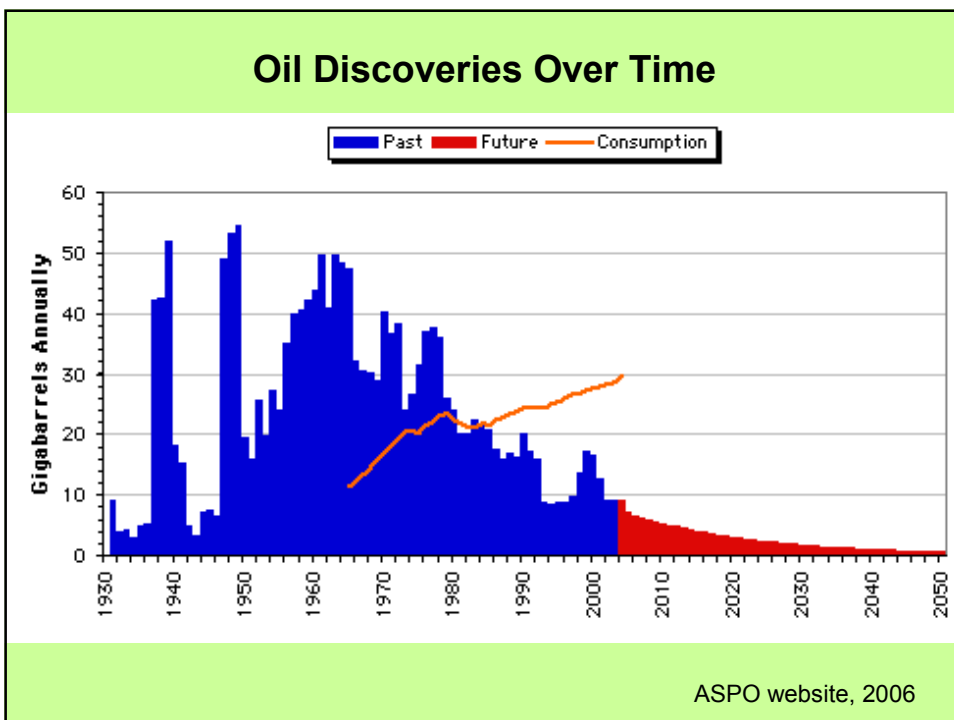
Sources: 1980-1993: “Worldwide Oil and Gas at a Glance,” *International Petroleum Encyclopedia* (Tulsa, OK: PennWell Publishing, various issues). 1994-2006: *Oil & Gas Journal* (various issues).

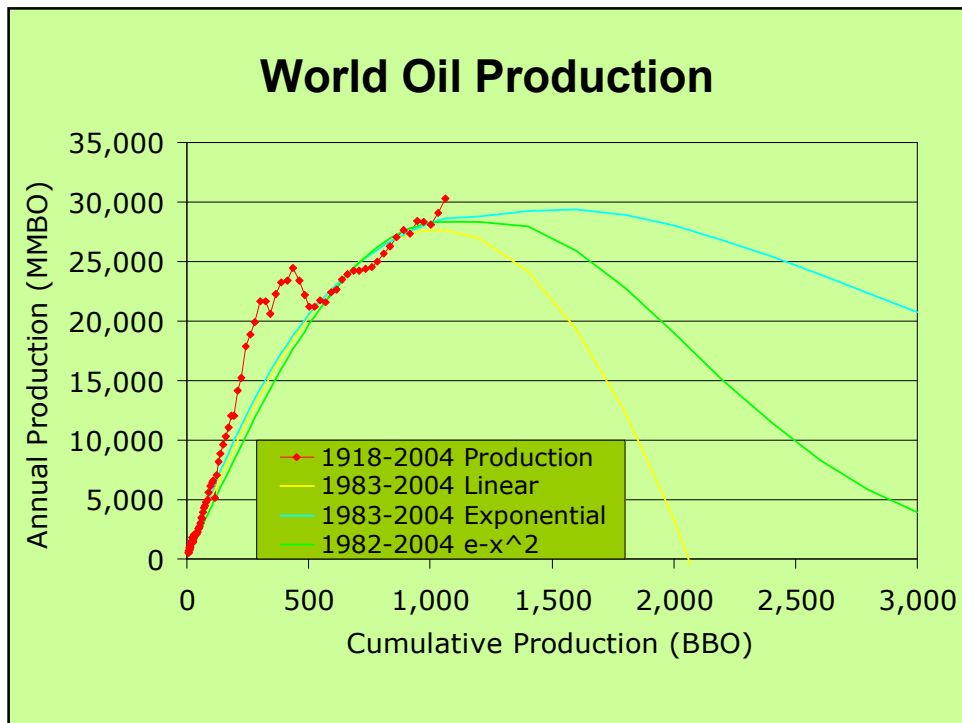


Demand is Growing Because Global Demand is Being Equalized



Oil Discoveries Over Time



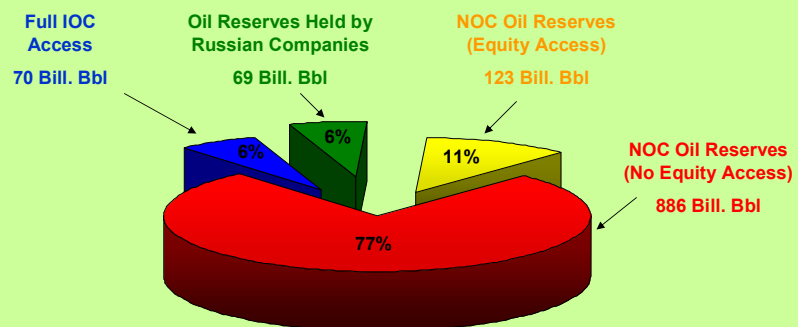


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Stern Review (10/30/2006) The Economics of Climate Change

- Using the results from formal economic models, the Review estimates that if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more.
- In contrast, the costs of action – reducing greenhouse gas emissions to avoid the worst impacts of climate change – can be limited to around 1% of global GDP each year,
- Ultimately, stabilisation – at whatever level – requires that annual emissions be brought down to more than 80% below current levels.

National Oil Companies on the Rise - They Control the Resources



**WW Proven Oil Reserves: 1,148
Bill. Bbl**

Source: PFC Energy

Unconventional Fossil Energy

Oil from US/Canada in 2025

- Alberta heavy oil: 2.5 mmbod
- Colorado shale oil: 3.0 mmbod
- CO₂-EOR: 4.0 mmbod
- US/Canada total today: 7.5 mmbod

Resources

- Heavy oil (Can): 2.0 Tbbbls
- Oil shale (CO): 1.2 Tbbbls
- Tight gas sands (48 states): 1100 Tcf resource – 2% current recovery
- Gas hydrates: 100,000s Tcf in-place - recoverability not established
- Shale gas (48 states): 200 Tcf resource



Piceance Basin, CO

★ Shell Test Site

Mahogany Ledge

Roan Cliffs near Rifle, CO

Global Oil Shale Resources (10⁶ barrels)

US, Green River Fm.	1,499,000	Sweden	6,114
US, other	619,222	Egypt	5,700
Russia	447,331	Israel	4,000
Brazil	80,000	Kazakhstan	2,837
Morocco	53,381	Turkey	1,985
Jordan	34,172	Luxembourg	675
Australia	32,729	Armenia	305
Estonia	16,286*	Mongolia	294
China	16,000	Hungary	56
Canada	15,241		
Thailand	6,401	Grand Total	2,840,735

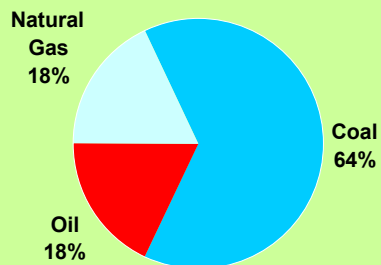
Jack Dyni, 2003

* Perhaps 1,500x10⁶ bbls recoverable (Purga, 2006)

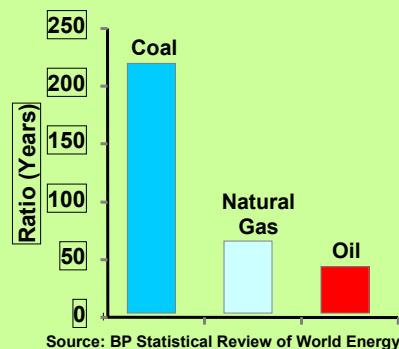
The U.S. National Energy Policy Act of 2005 directs the USGS to perform a **new** national oil shale assessment

Fundamentals Reinforce Coal's Global Role

Share of Worldwide Proven Reserves (2001)



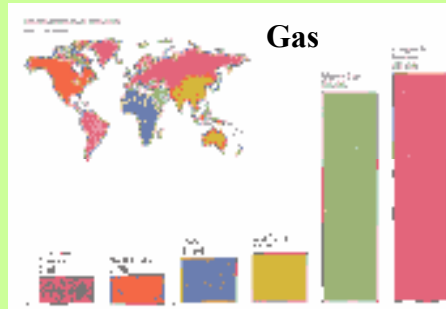
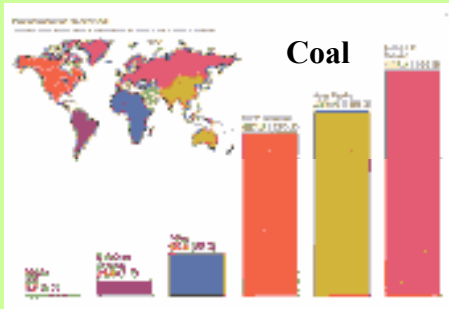
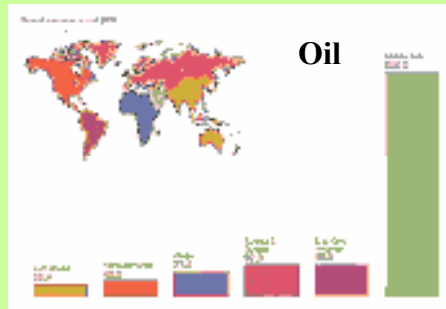
Reserves:Production Ratio



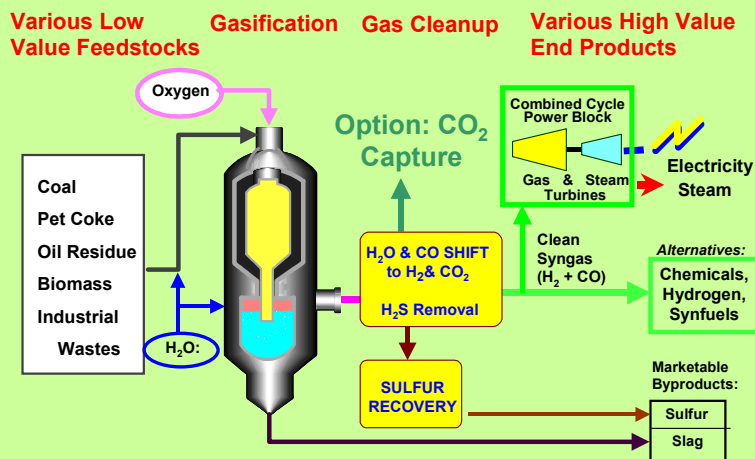
- Moreover, coal is 'equitably' distributed across the globe

Fossil Energy Resources Distribution

BP statistical review of world energy (2004)



Major Promise for the Rocky Mountain Region is Coal Gasification



...and "Polygeneration" with potential for negative carbon emissions through CO₂-EOR Williams, 2005

Clean Power Plants w/Carbon Capture

British Consortium to Generate Clean Electricity from Hydrogen

BP press release, June 30, 2005. Petershead, Scotland

BP, ConocoPhillips, Shell and Scottish and Southern Energy (SSE), have announced that they are to commence engineering design of the world's first industrial scale project to generate 'carbon-free' electricity from hydrogen.

Raw material: natural gas.

Main product: H₂ as fuel for turbine for electricity.

CO₂: Pipeline to Miller oil field, 240 km offshore.

Pet Coke for H₂ and CO₂-EOR

BP press release, February 14 2006. Carson, CA

BP and Edison Mission Group (EMG), a subsidiary of Edison International, plan on building a new \$1 billion, 500 MW hydrogen-fueled power plant in California, which, while not using renewable energy, will generate clean electricity and sequester its carbon dioxide (CO₂) emissions.

Raw material: petroleum coke.

Main product: H₂ to fuel gas turbine for electricity.

CO₂: Capture 90% of emissions; pipeline to an oil field for CO₂-EOR.

Solar Energy Potential

Current total global energy generation: 13 TW

Projected increase by 2050: 30 TW

Average nuclear power plant: 1 GW

The Jim Bridger coal-burning power plant in WY is 2.4 GW

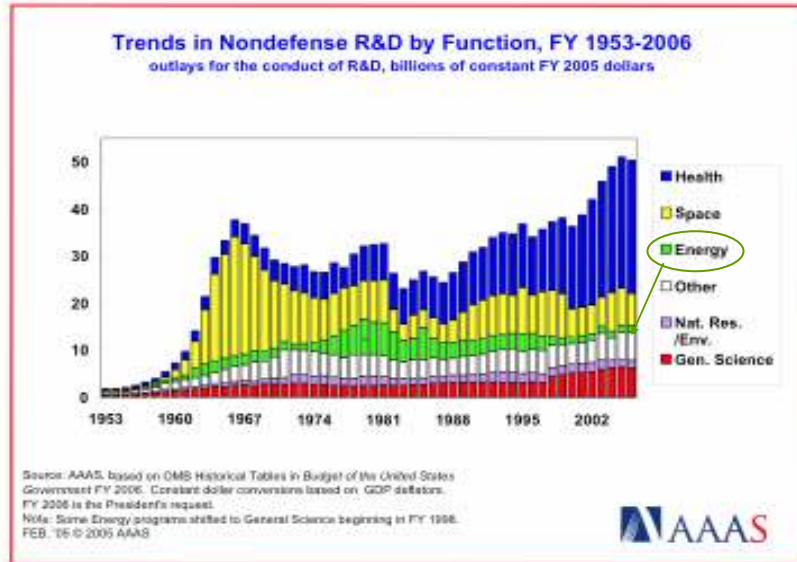
30 TW new energy requires construction of TWO 1-GW power plants per day!

Theoretical: 1.2×10^5 TW solar energy potential

Practical: $\approx 600 - 1500$ TW solar energy potential
(depending on land fraction etc.)

Modified from Nathan Lewis (2003)

Energy Science Funding has Collapsed since 1980



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Value of U.S.- Chile Collaboration in Clean Energy R&D

- Greater international co-operation to accelerate technological innovation and diffusion will reduce the costs of mitigation
- A technology portfolio that emerges from individual national R&D priorities and deployment may not be sufficiently diverse to serve global needs
- Forms of collaboration may be embodied in multilateral agreements that allow countries to pool the risks and rewards for major investments in R&D, including demonstration projects and dedicated international programs to accelerate key technologies
- International co-ordination of regulations and product standards can be a powerful way to encourage greater energy efficiency

Conclusions

- Global warming is accelerating. The cost to mitigate the change is much less than the cost of inaction
- Shift in energy technologies from conventional oil to unconventional hydrocarbons (oil shale, coal gas), with carbon capture, will improve domestic energy security for most countries and reduce the rate of climate change
- Investment in energy R&D has been dreadful in the past 25 years; signs of change are now starting to appear
- International collaboration in R&D will produce a richer and more diverse set of technology options than what we will get by working in isolation