Prospects for Reducing Climate Forcing in the Global Power Generation Sector: Overview, Alternatives, Issues

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Conference on Air Pollution as Climate Forcing: Alternative Scenarios – Their Benefits and Costs

Honolulu, Hawaii

4-6 April 2005

Key questions

- Which power sector emissions matter to climate?
- Where are those emissions headed?
- How is the global power system expected to grow between now and 2050?
- What are the emissions characteristics, costs of current technologies available to meet future demand?
- What could we accomplish through “strong action” favoring low pollution technologies (using US, China and India as examples)?
- What are the major scale and uncertainty issues?
- What are the policy implications of the above?

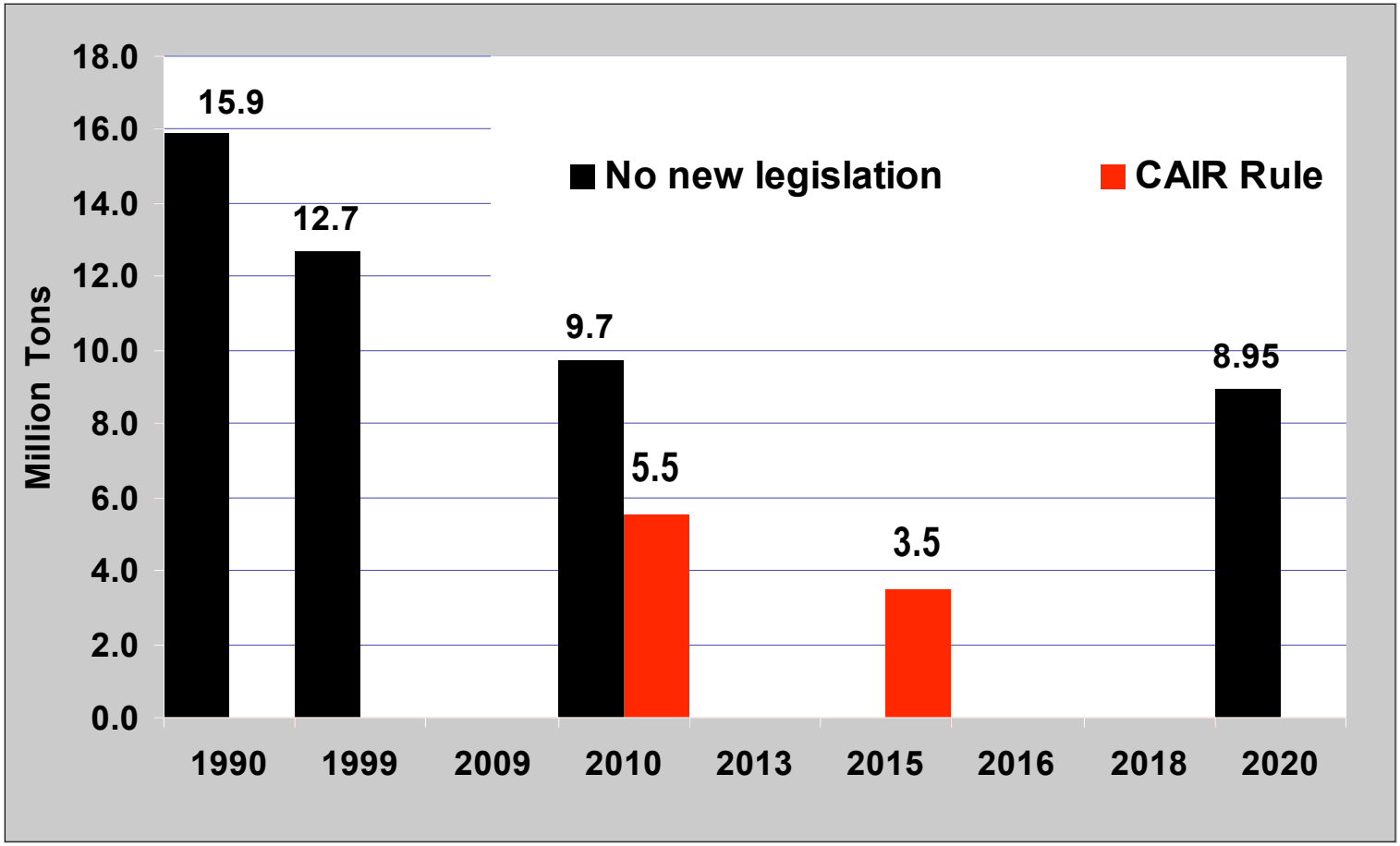
Which power sector emissions matter to climate?

- CO2 (+) [40% of global]
  - Positive forcing
- SO2 (-) [55+% of global]
  - Negative forcing
- NOx (+/-) [20% of global]
  - Neutral to slightly negative forcing, depending on coupling with other emissions and time scale?
- BC (+)
  - Not associated with power sector, except few remaining smaller stoker boilers?
- N2O (+)
  - Possibly associated with new CFB coal plants.

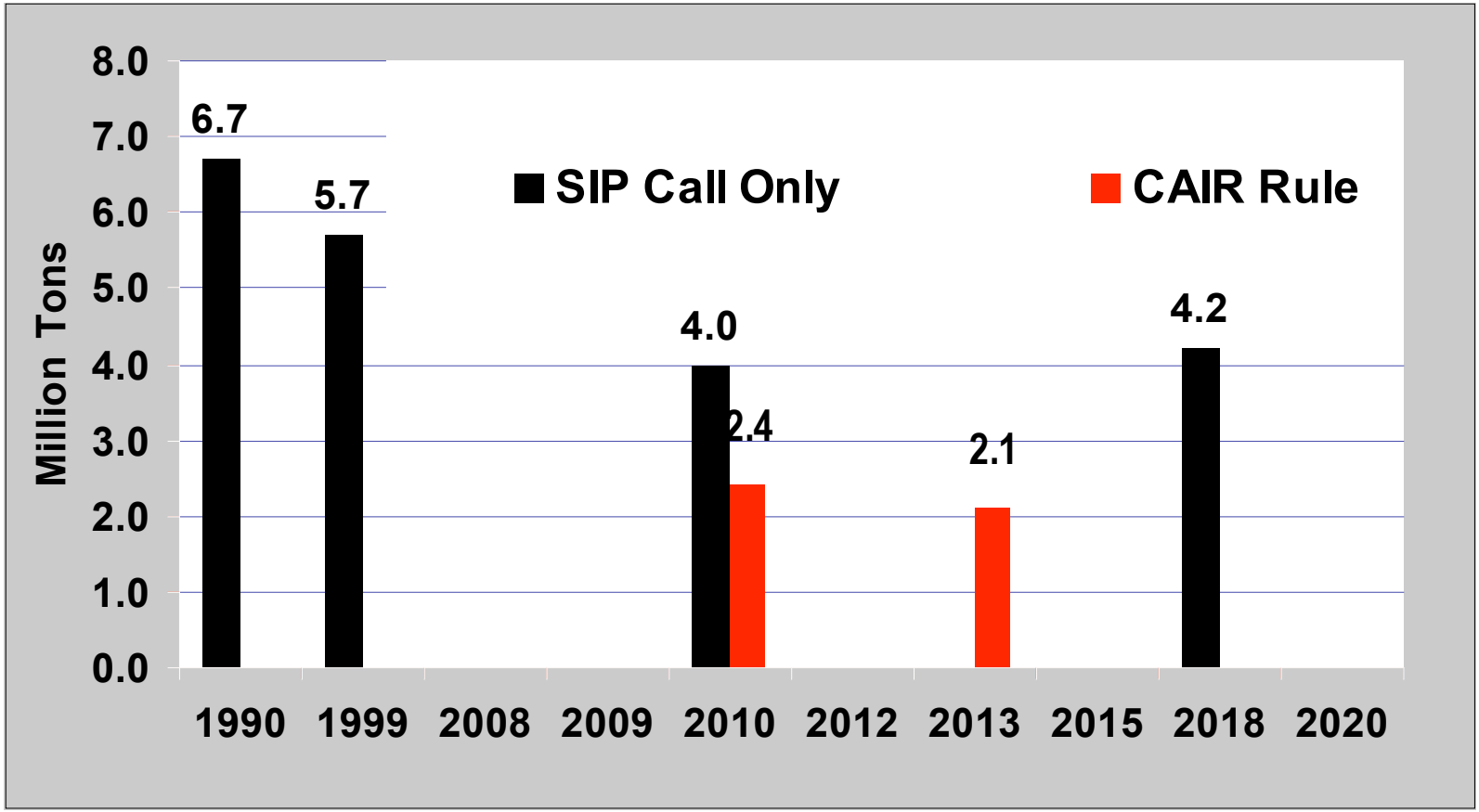
Where are those emissions headed under BAU?

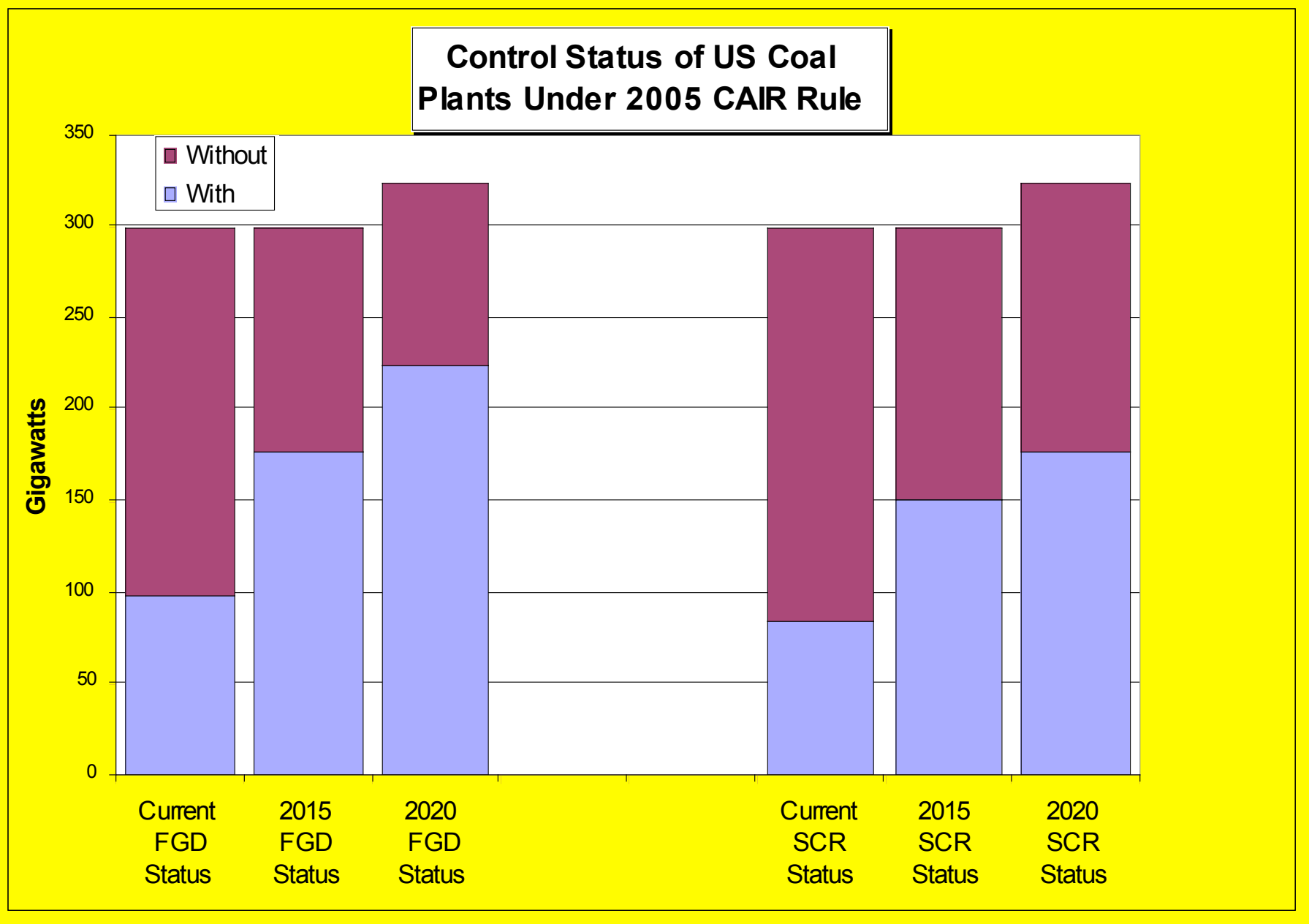
- In EU and US (together, roughly 50% of global demand), SO2 and NOx both headed downward due to national and EU policy.
  - This will involve widespread installation of Flue Gas Desulphurization (FGD) to control sulfur and Selective Catalytic Reduction (SCR) to control NOx.
  - See US Clean Air Interstate Rule (CAIR) trajectories on next slides.
- In China, SO2 headed downward on both existing and new plants; NOx may be headed downward after 2010.
- In India, no national policy yet to control power sector NOx or SO2.
- It is reasonable to assume that, over a 25 year period, power sector SO2 and NOx will be widely controlled for public health reasons.
- CO2 headed upwards dramatically.

US CAIR Rule: SO2



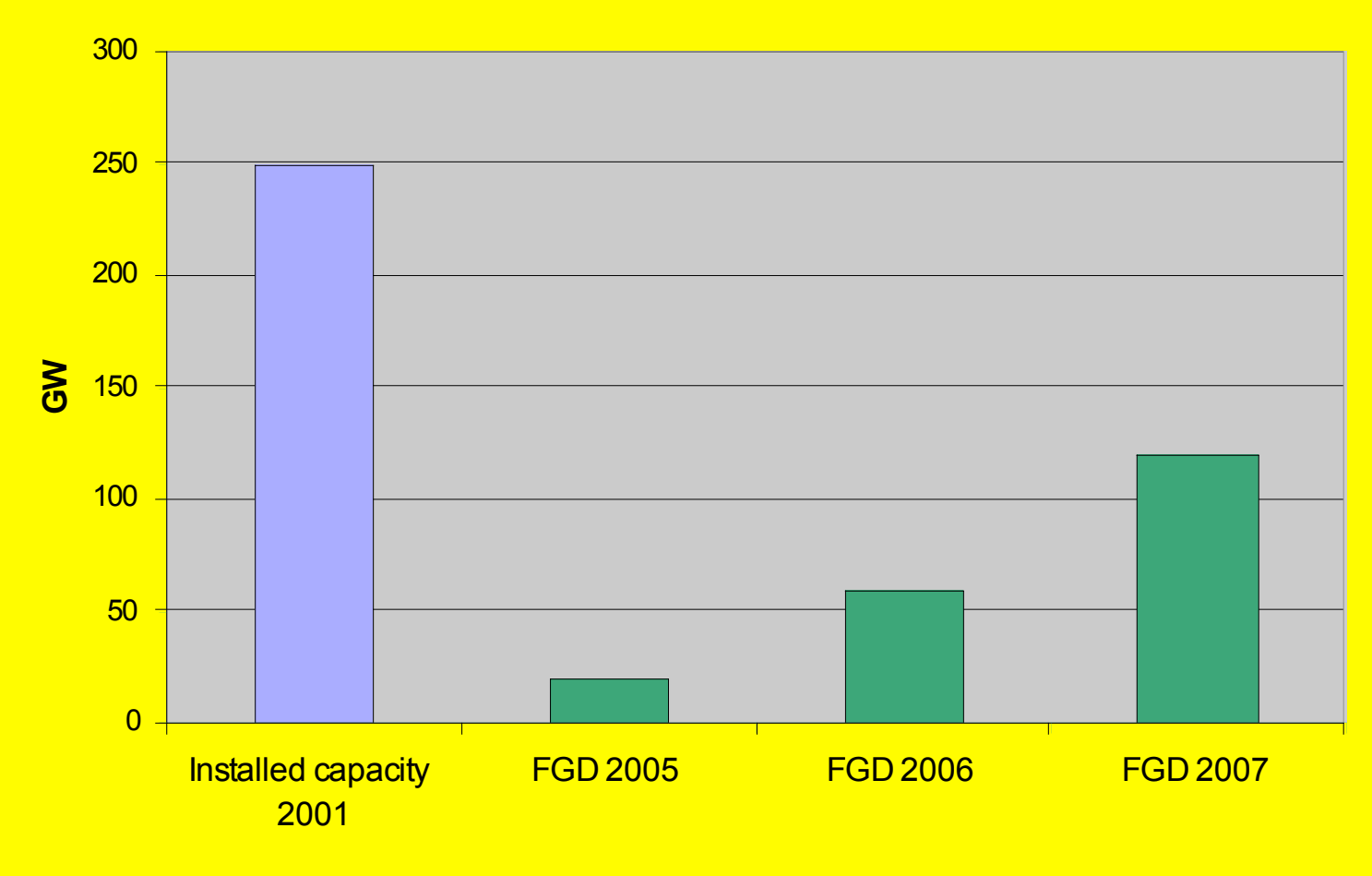
US CAIR Rule: NOx





Source: Data for this chart comes from the IPM runs prepared by EPA as part of its CAIR support package and made available on the EPA web site at www.epa.gov/airmarkets/epa-ipm/iaqr.html#cair.

China: installed coal capacity vs. FGD in place or on order



Source: McIlvaine and Co.

How is the global power system expected to grow?

- IEA estimates 4800 GW of new capacity by 2030 (current OECD installed capacity is 2000 GW)
- Roughly $10 Trillion in new power sector investment by 2030.

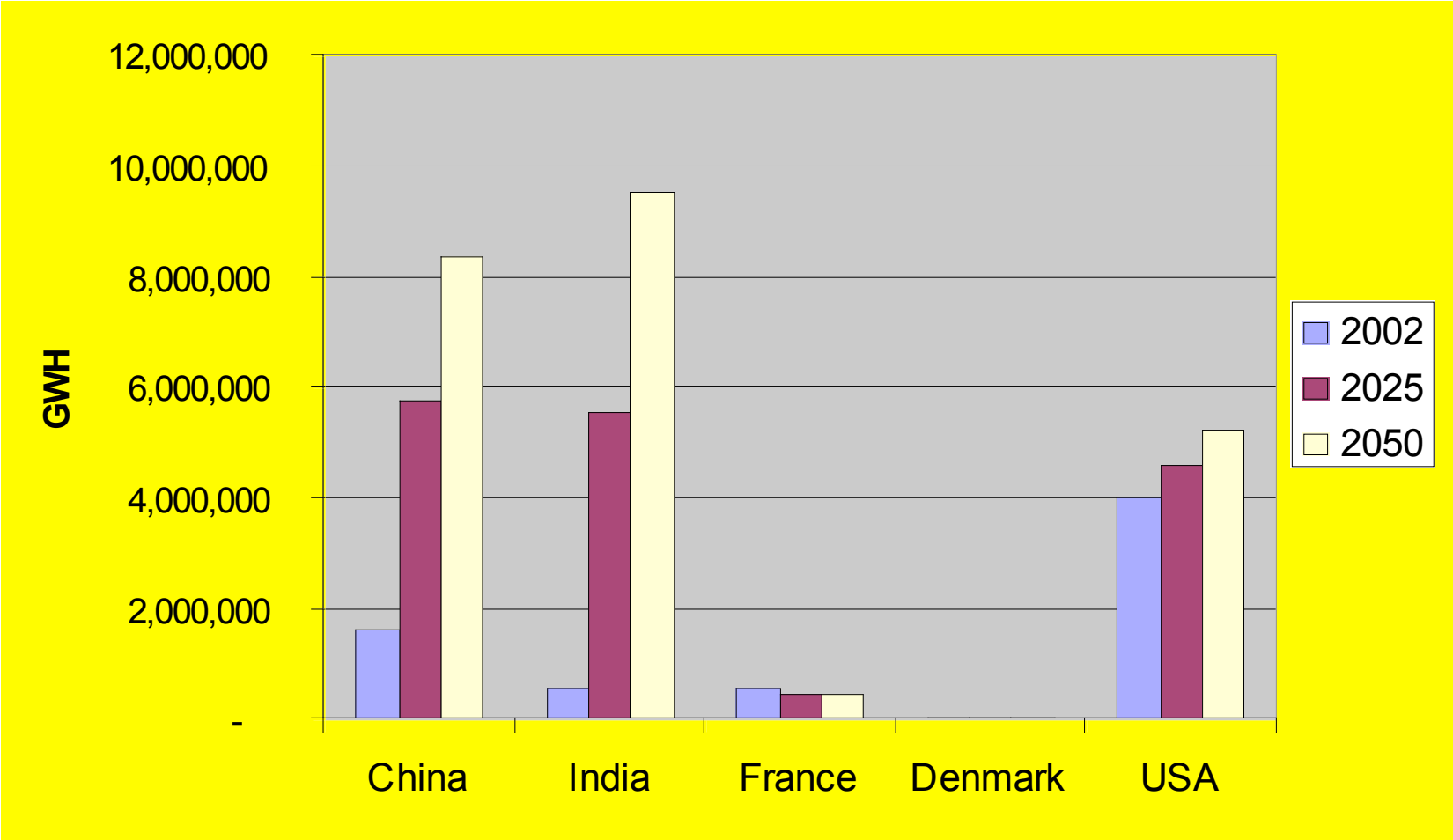
Our Approach

- Simple spreadsheet scenario analysis to identify major patterns, themes, and focus more analysis -- ***not*** energy modeling.
- Looked at generic “zero carbon” placeholders rather than specifying nuclear vs. renewable sources of various kinds.

Scope and assumptions

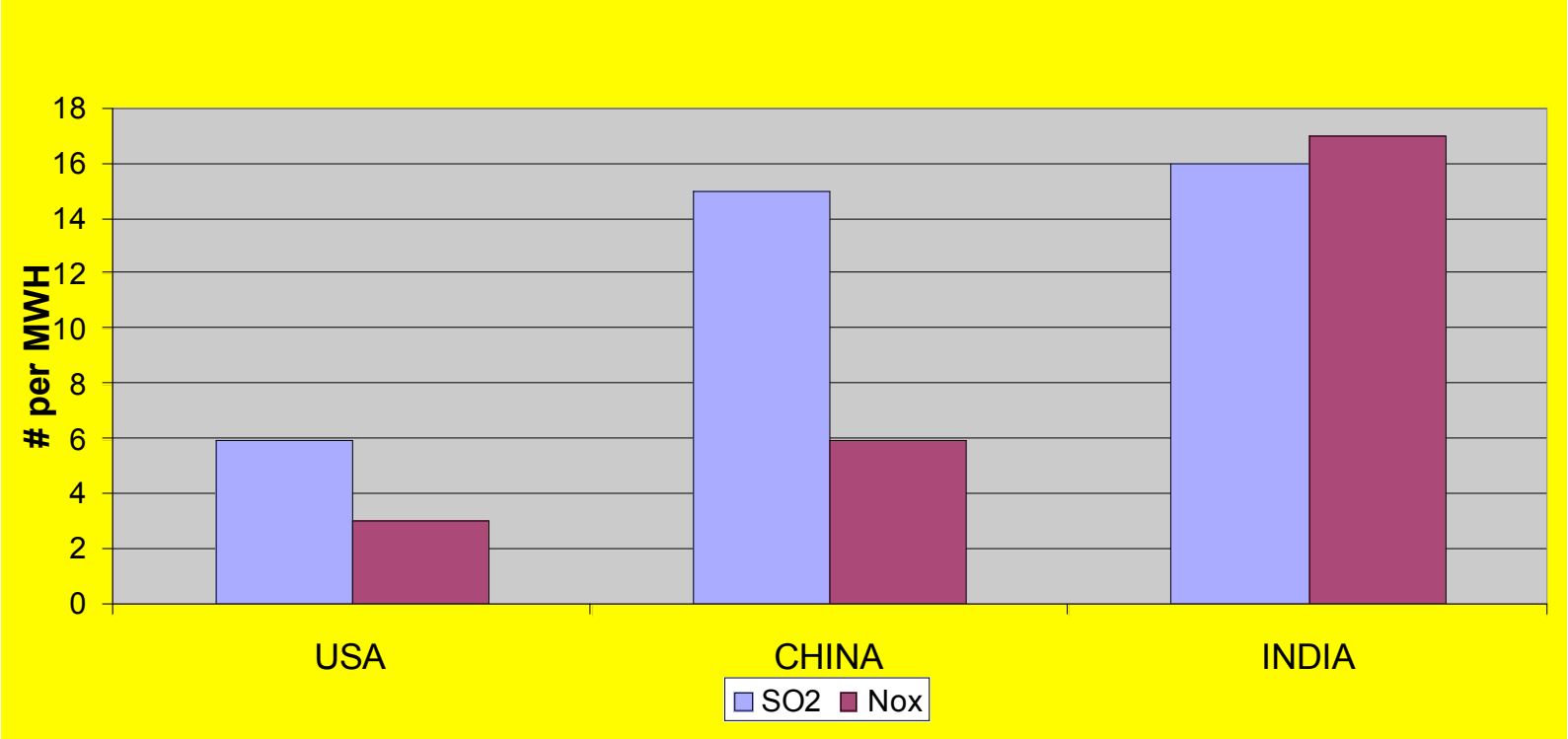
- Focus on US, China and India, which represent 40% of world power generation, 44% of world CO2, and 40% of world NOx, and are proxies for OECD and developing world.
- Middle range UN population growth estimates
- Future per capita electric consumption taken from MIT nuclear study (2004) – assumes 4,000 kwh per capita consumption in China and India by 2050 – roughly levels of Greece and Bulgaria today.
- Note: Totals differ somewhat from IEA: higher for India and China, lower than for US.
- Did ***not*** count demand or environmental benefits from electric displacement of current non-electric fuels (e.g. domestic coal displacement, or use of coal gasification to produce low-carbon transportation fuels).
- Scant and inconsistent data on current China and India coal plant emissions; triangulated from numerous sources.

Forecasted electric consumption

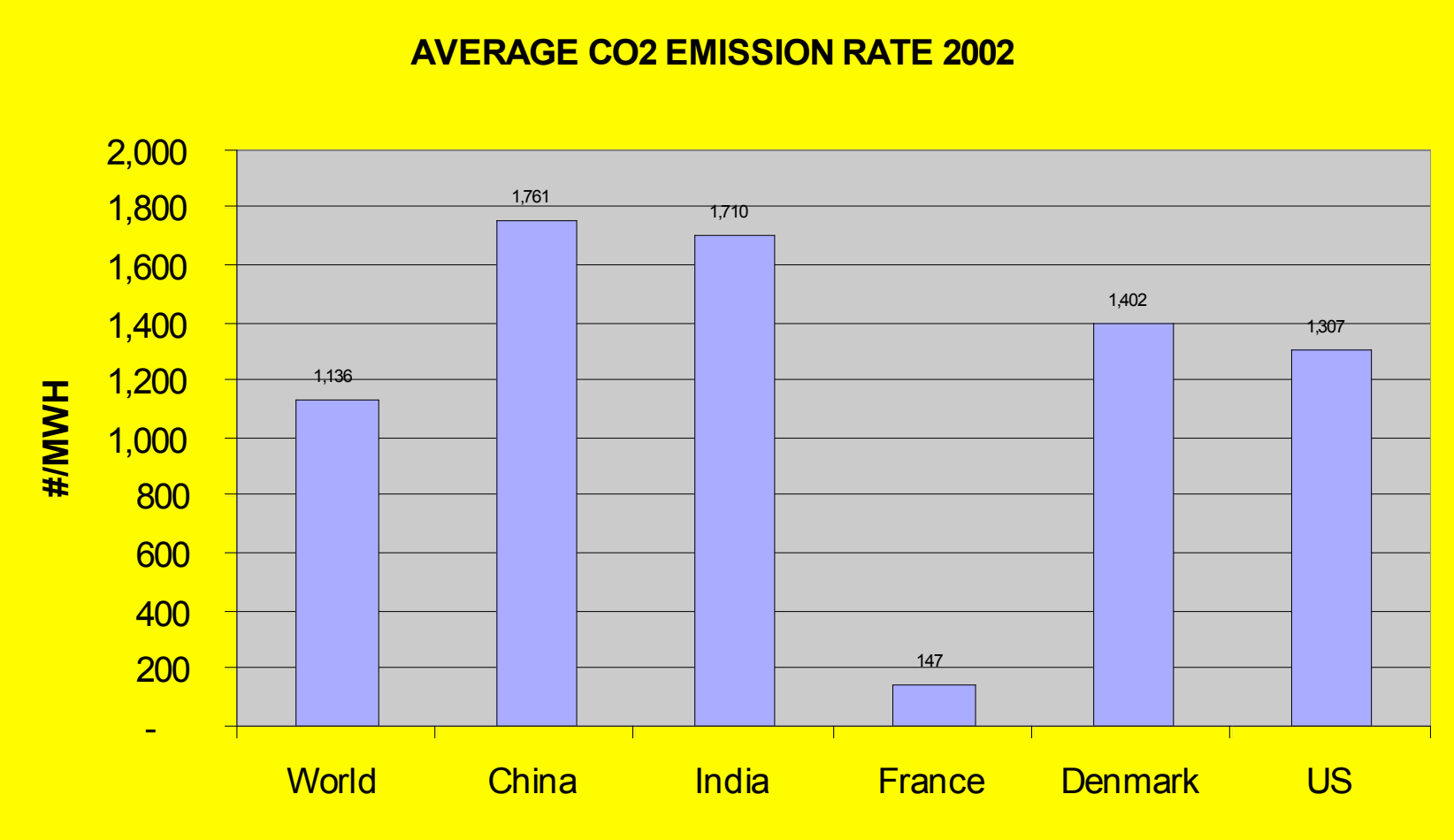


Source: ECW and CATF using data from UNEP and MIT

Current fleet emission rates: SO2 and NOx



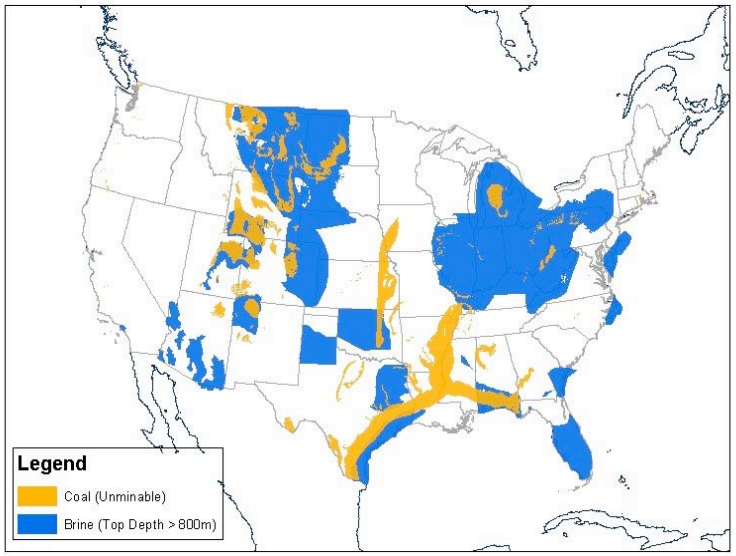
Current fleet emission rates: CO2

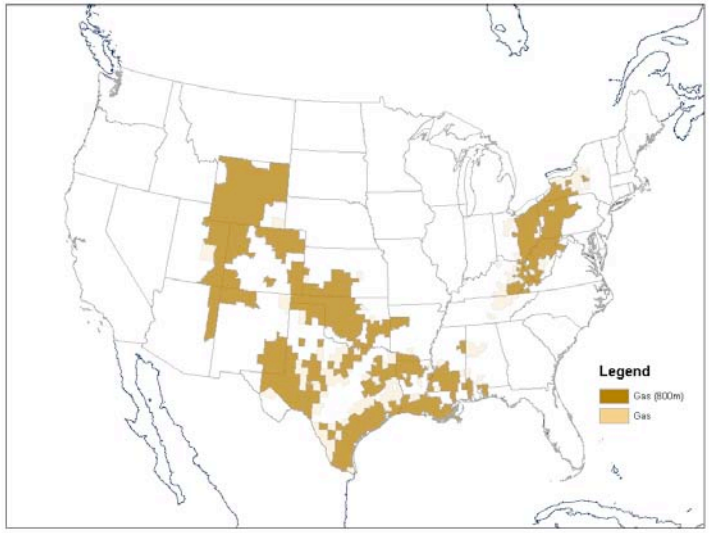


Current Technology: New Sources

- New coal IGCC plants provide the practical opportunity to add carbon capture as a retrofit technology at some future point in time. This practical opportunity does not yet exist for conventional PC coal plants.
- New coal IGCC and natural gas NGCC plants can be built today with carbon capture (for sequestration).
- IGCC plants also significantly reduce solid waste and mercury management problems.
- Geologic carbon sequestration is in commercial practice (for acid gas injection) at sub-coal plant scales.
- Several “no carbon” new power generation technologies exist or are emerging:
  - Advanced nuclear
  - Wind
  - PV
  - IGCC with carbon capture and sequestration

Potential US geologic storage sites





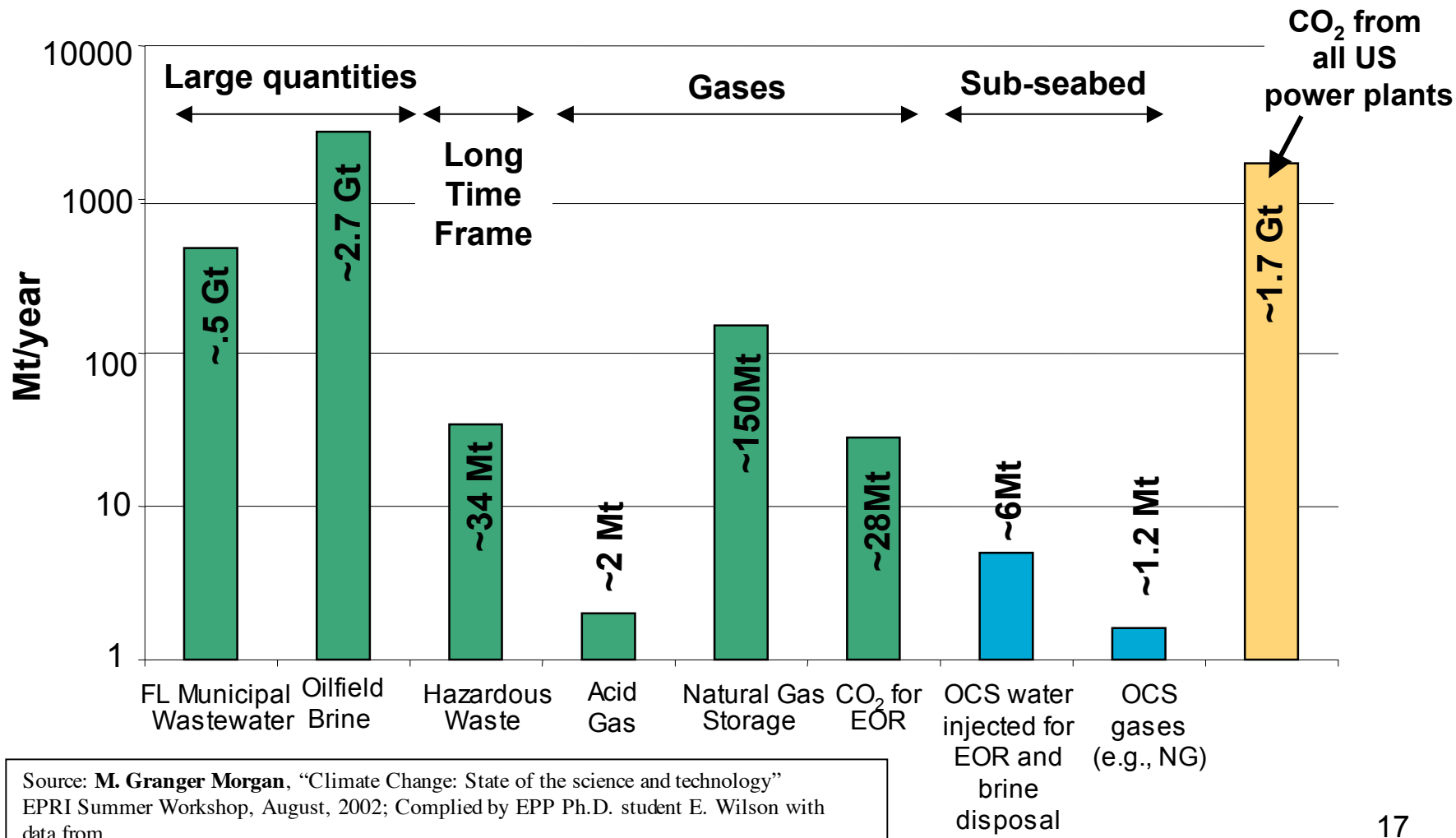
Unmineable Coal Seams

Deep Brine Formations

Gas Reservoirs

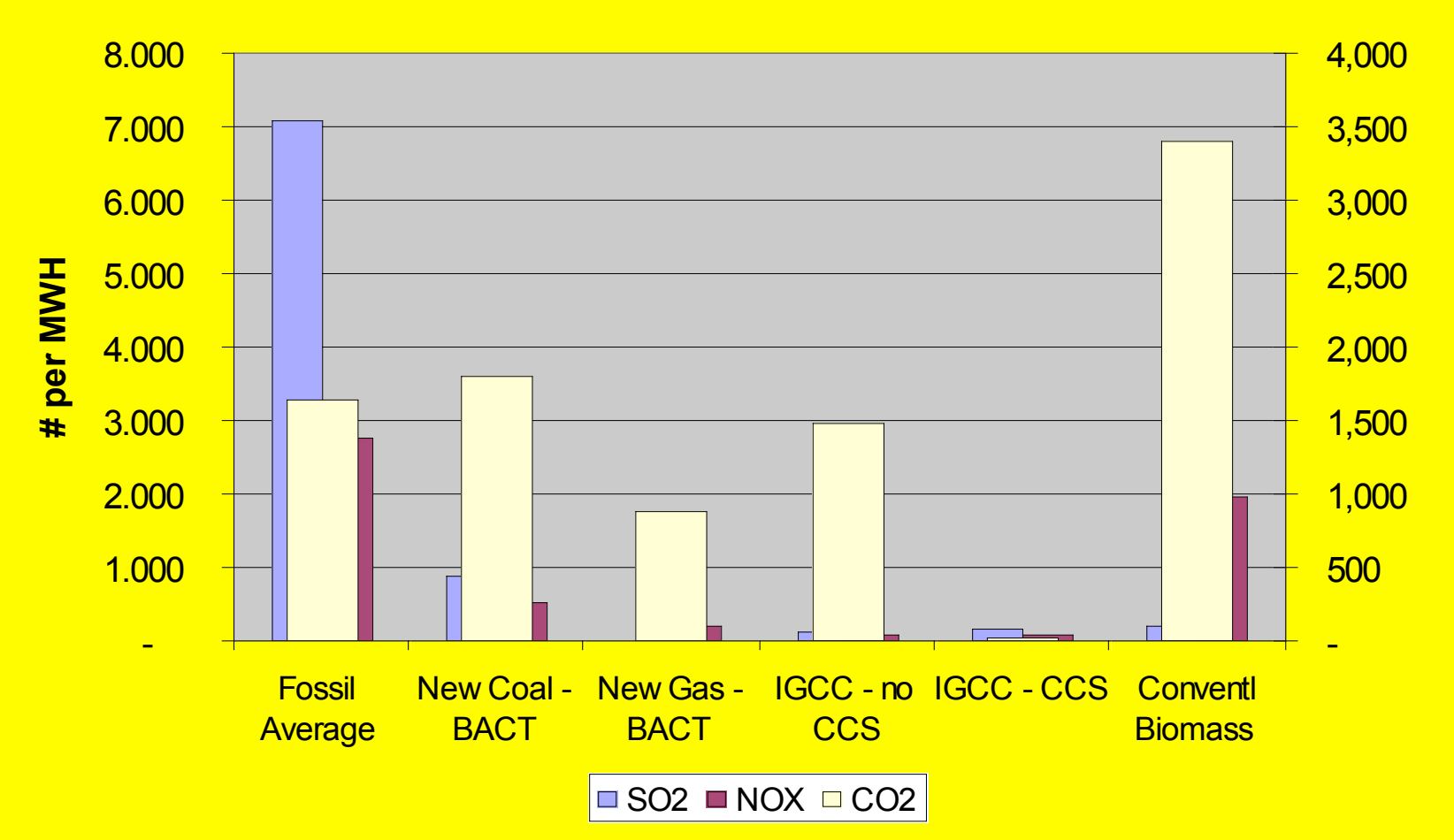
Note: Additional opportunities not in these databases may exist. Subsurface geology is best understood in areas where fossil fuels have been extracted

Current underground injection practices & power sector CO2



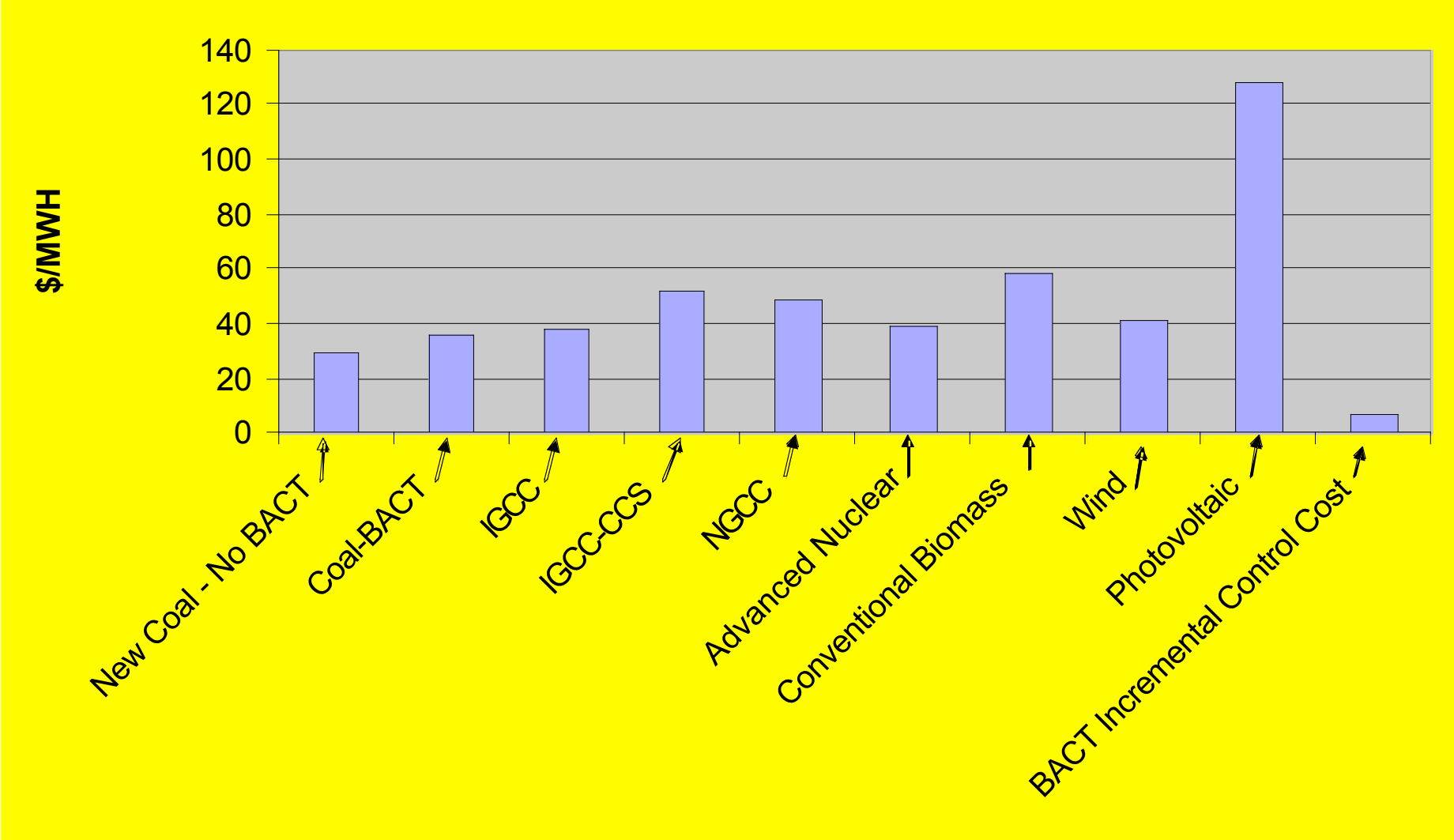
Source: **M. Granger Morgan**, "Climate Change: State of the science and technology" EPRI Summer Workshop, August, 2002; Complied by EPP Ph.D. student E. Wilson with data from
EPA, 2001; Deurling, 2001; Keith, 2001; DOE, 2001; DOE, 2001.

Technology emission rates



Sources: CATF, based on recent permits and EPA emissions data base

Technology levelized costs



Sources: US EIA Annual Energy Outlook (2004); ECW (new coal/no BACT)

Scenarios: 2025 and 2050

- Business as usual (BAU):
  - For US, current expected NOx/SO2 emissions caps for power sector.
  - For China and India: No retirement of existing units and apply 2002 average fleet emission rates to fit 2025 and 2050 demand.
- Best Available Control Technology (BACT): BAU with 100% installation FGD and SCR, resulting in 95% and 85% reductions in SO2 and NOx, respectively.
- IGCC/CCS (Integrated Coal Gasification Combined Cycle power plants with Carbon Capture and Storage): All energy produced by IGCC with carbon capture and sequestration.
- IGCC/Zero: Half of energy produced by IGCC/CCS, half with generic “zero emissions” technology.

Scenarios: 2025 and 2050 (2)

- Also looked at “vintaged” scenarios in which current technology stock is held in place and all new supply is met by new technologies.
- Purpose was to see how much slow stock turnover retards emissions improvements.

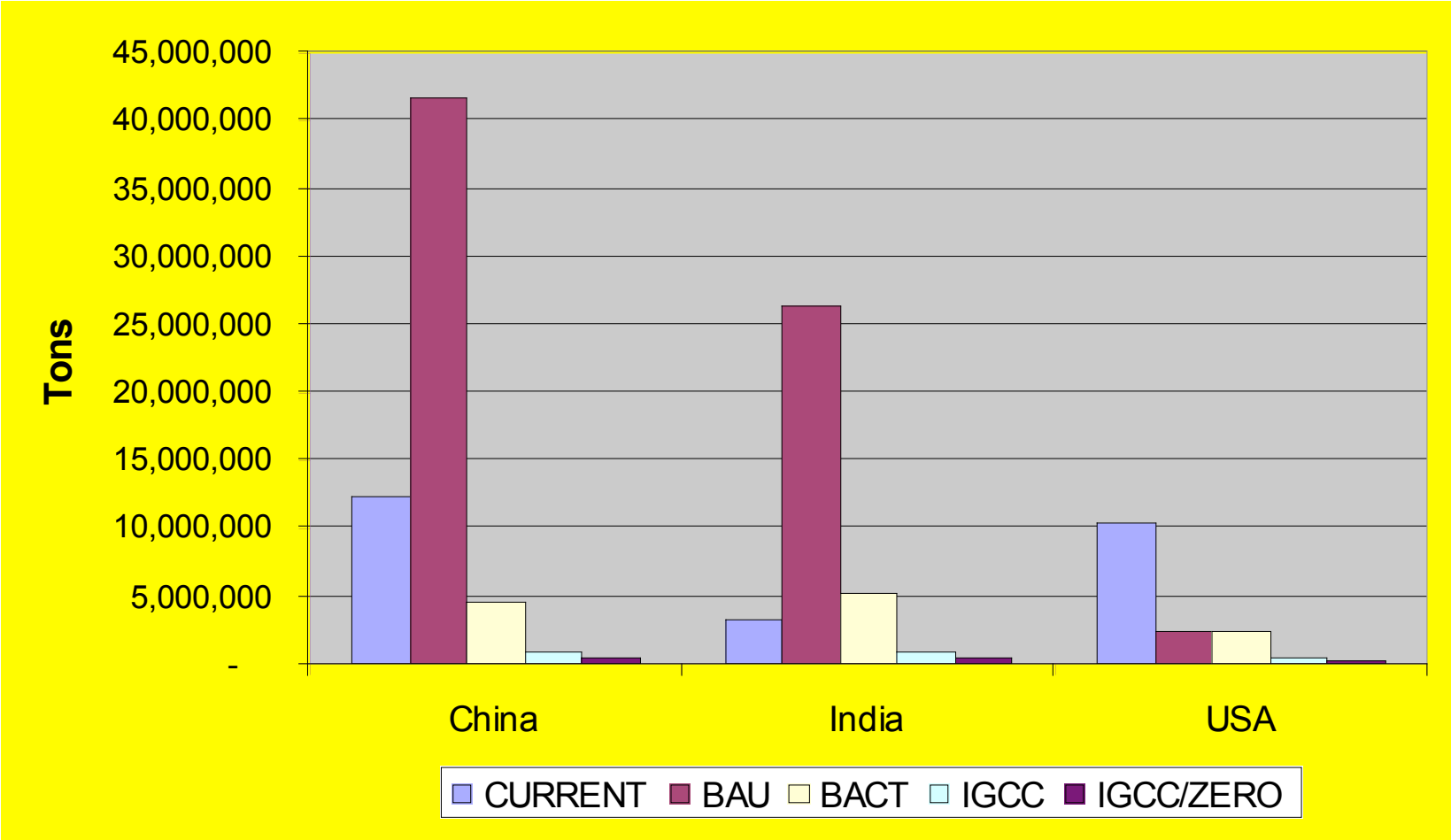
General conclusions from scenarios

- Coal plant BACT on new or old plants is powerful enough that US, China and India can achieve significant reductions from current NOx and Sox levels even with substantial growth by 2050 through BACT retrofits *or* replacement of existing stock with new stock of any kind (including conventional PC).
- Further health gains are available with either IGCC *or* zero emissions sources but returns are diminishing as compared with BACT
- Major value of IGCC/CCS or zero emissions resources, then, is in avoiding carbon emissions (as well as solid wastes and mercury emissions).
- Retiring existing stock matters for 2025 CO2 stabilization targets in the US, not as much for China and India.

Conclusions: SOx

- BACT alone reduces SOx substantially from either 2002 or 2050 BAU levels .
- Further improvements from replacing BACT with IGCC are smaller but could be considered non-trivial in some locations 3.75 MT/year in China, 2 MT/year in US).
- Further reductions from “half zero” scenario are smaller: total 1.2 MT for China, India and US.

SO2: 2050

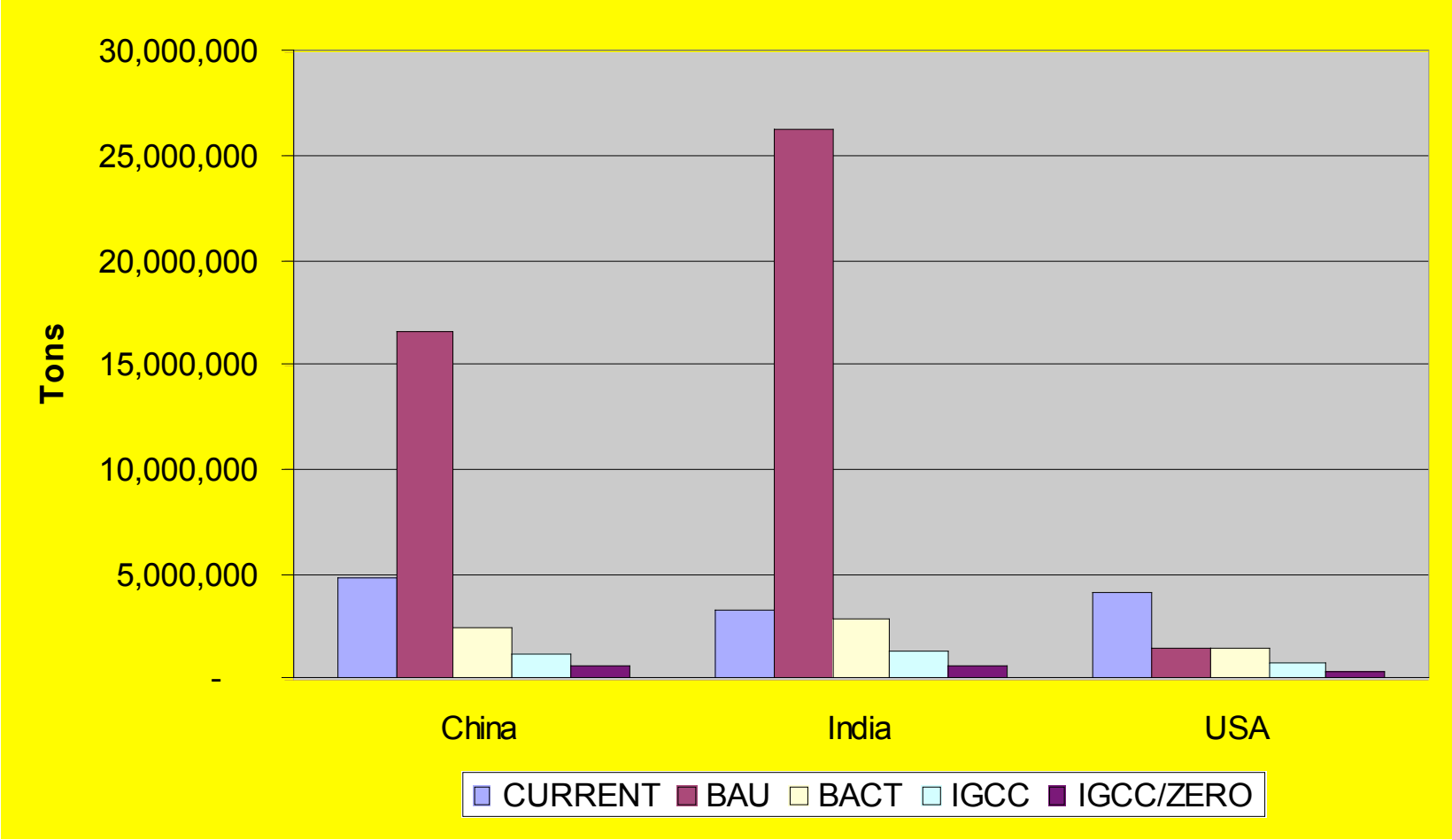


Note: USA BAU and BACT assumes continuation of capped emissions ultimately at BACT levels.

Conclusions: NOx

- BACT alone reduces NOx substantially from either 2002 or 2050 BAU levels .
- Further improvements from replacing BACT with IGCC are small -- but could be considered non-trivial in some locations (1.3 MT/year in China, .7 MT in US).
- Further reductions from IGCC to “half zero emissions resources” gets an additional 1.7 MT in China/India/US.

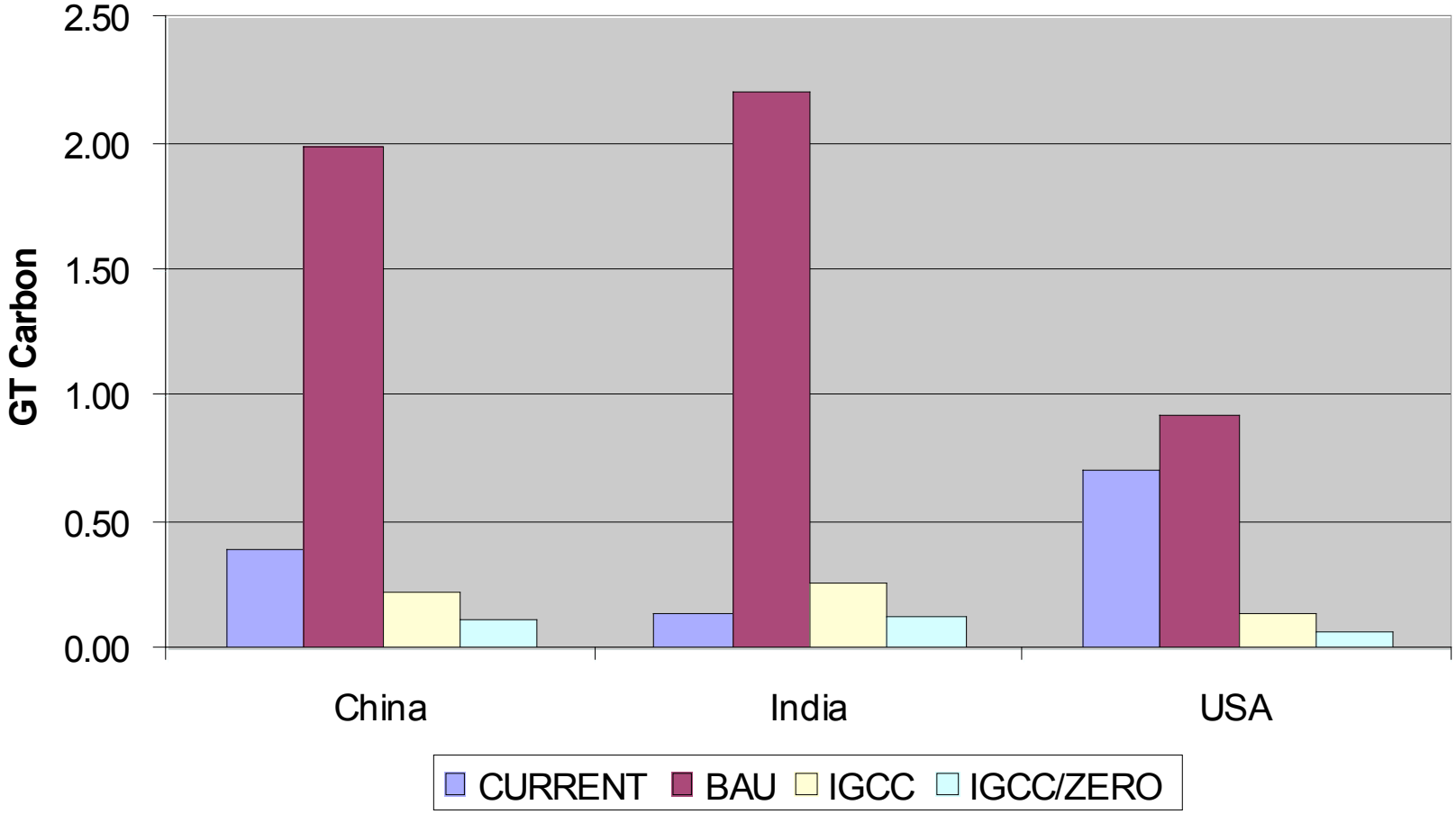
NOx 2050


30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
Tons
China
India
USA
CURRENT
BAU
BACT
IGCC
IGCC/ZERO

Conclusions: Carbon

- IGCC/CCS drops CO2 by 2050 by approx. 4 GTC as compared with BAU in 2050.
- Adding “half zero emissions” drops CO2 by another .25 GTC in 2050.

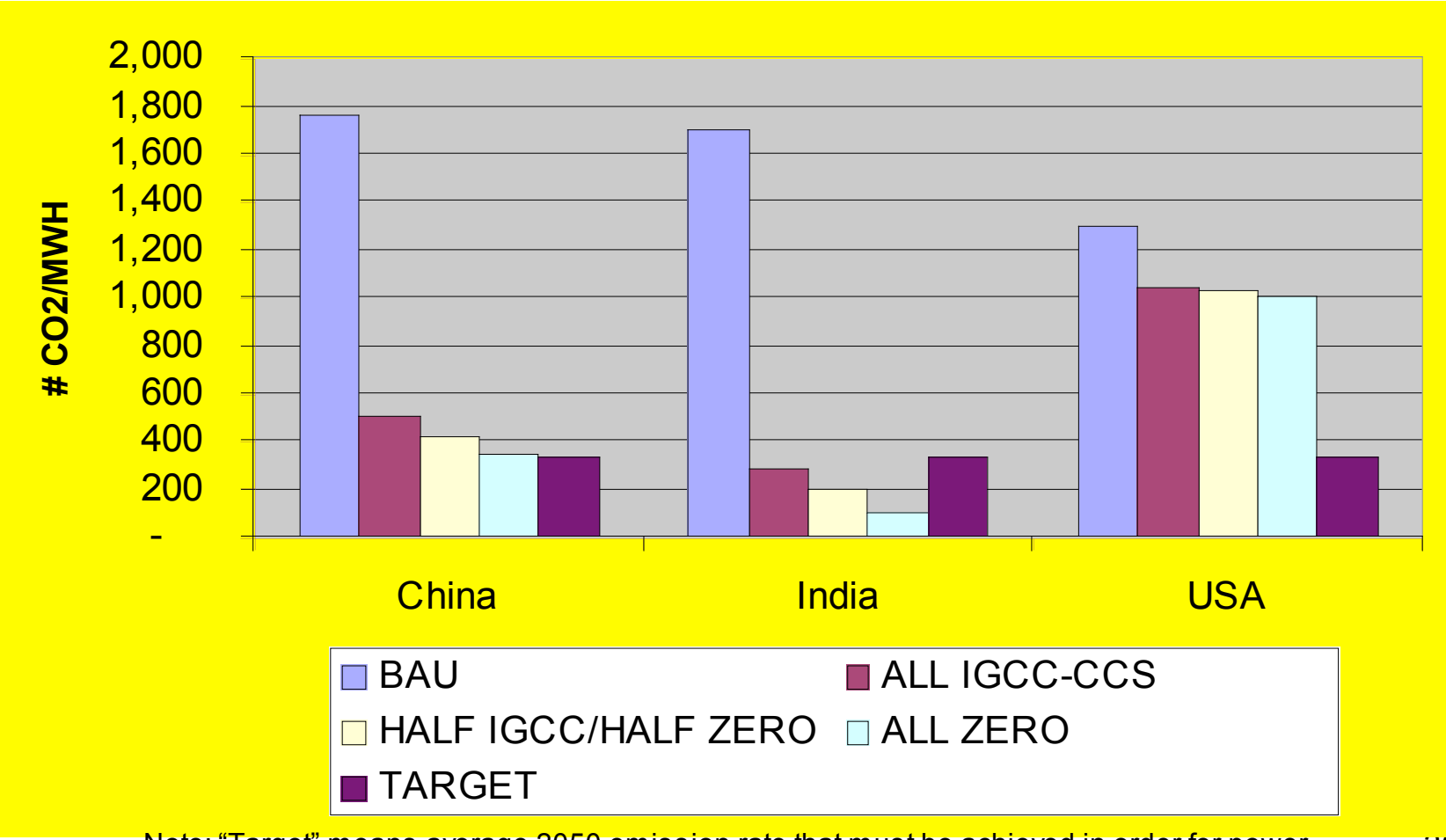
CO2 2050


2.50
2.00
1.50
1.00
0.50
0.00
GT Carbon
China
India
USA
CURRENT
BAU
IGCC
IGCC/ZERO

Effects of “vintaged stock” in retarding CO2 emission improvements

- Much more pronounced in the US than in India or China since US supply growth is so much slower and embedded stock emissions so much higher.
- A target CO2 emissions rate of 337 lbs/MWH will hold 2050 emissions at 2002 levels. Accordingly,
  - US violates this target by 300% even if all new plants are zero emissions.
  - India can comply with this target if all post-2000 stock is IGCC/CCS.
  - China can come close to this target if all post-2000 stock is IGCC.

2050 CO2 emissions rates if all current stock continues to operate



Note: "Target" means average 2050 emission rate that must be achieved in order for power sector CO2 emissions on China, India and US to remain at 2002 levels in 2050.

General observations and policy implications

- For SOx and NOx, most reductions can be accomplished through fossil BACT.
- Justification to move from BACT to IGCC/CCS or to zero carbon emission technology will depend on:
  - Value placed on carbon emissions reduction; and
  - Value of reducing the residual sulfur and nitrogen emissions left after BACT
  - Vs. the incremental cost of IGCC/CCS or zero emissions resources vs. BACT, which in some cases can be large.
  - [Rubin et al estimate $26/ton CO2 valuation would be necessary to justify CCS add on to IGCC].

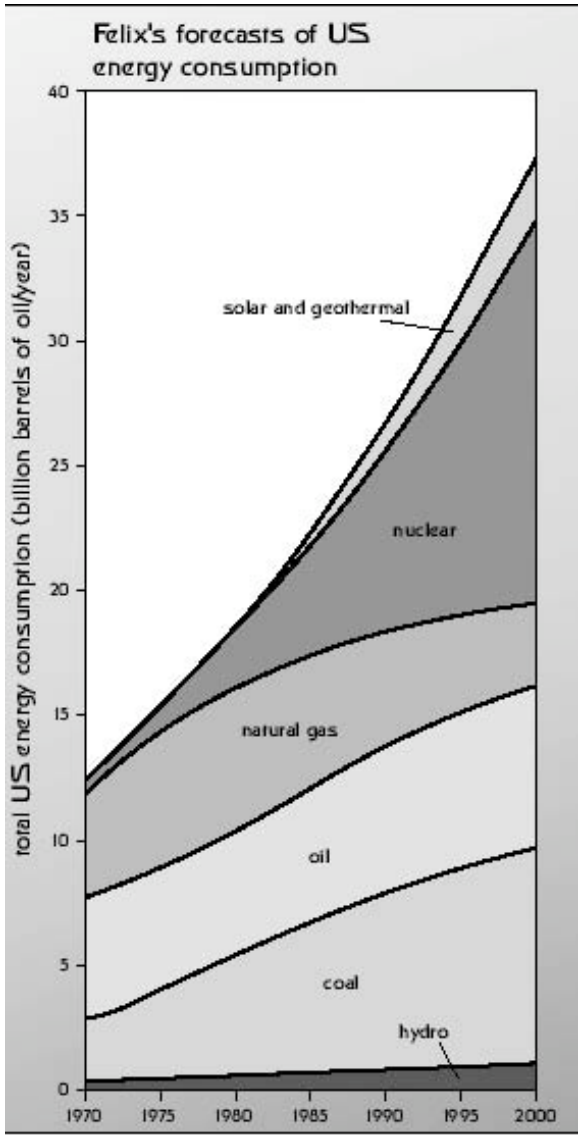
General observations and policy implications

- In China and India, the choice of new generation is the most important driver of future emissions; in the United States, future emissions driven more by retrofit and retirement (which should be complete in any event by 2050).
- For US, China and India, two imperatives are likely to be essential for controlling CO2:
  - Preventing siting of new conventional (non-IGCC) coal, which is not amendable to carbon capture and will lead to further slow-to-reverse CO2 build-up;
  - Narrowing the cost delta between new conventional coal plants and low emission (like IGCC) and zero emission technologies;
  - Early demonstration of IGCC and CCS on a commercial basis.

Wild cards

- 50 years is a long time!
- Consider what the world's technology and environmental vision was in 1955:
  - Civilian nuclear power was on the drawing boards but not yet commercially deployed.
  - No environmental movement; "Silent Spring" still 7 years away.
  - The personal computer is 25 years away.

Things change!



1970 forecast of 2000 US energy consumption (Felix,1970) updated by Smil (2004)

Wild cards (2)

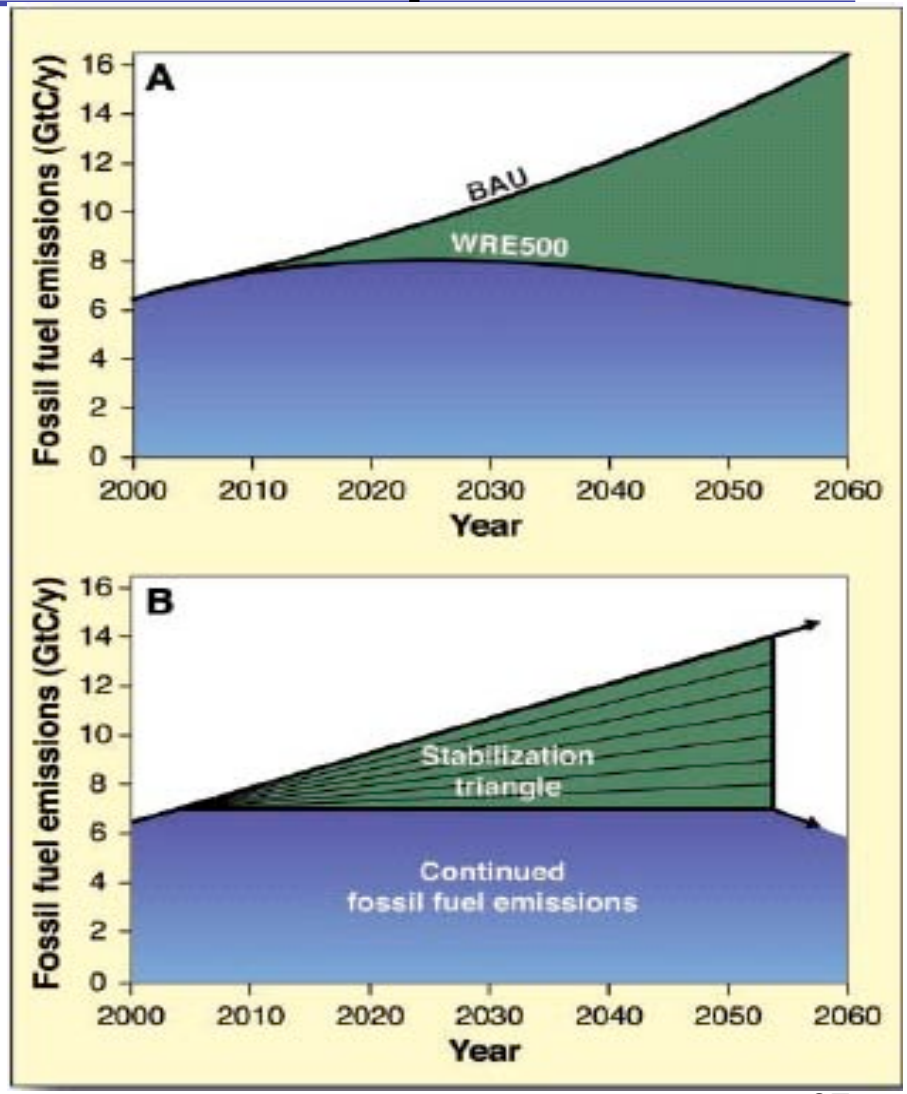
- Possible significant developments in:
  - Relative costs: learning curves vs. brick walls.
  - Nuclear plant safety, economics and public acceptance
  - Bio-tech applications to energy production
  - Recovery of unconventional natural gas reserves (e.g. coalbed methane, tight sands)
  - Advanced fossil power technologies (advanced gasification; much higher efficiency power conversion, much less expensive carbon capture, etc.)
  - Economic and practical conversion of fuel carbon to solids suitable for commercial products or simple sequestration (for example, landfill disposal) ?
- Nurturing RD & D may be the single most important thing we can do.

One wild card we know about: transportation/power sector interactions

- This analysis draws a box around the power sector, BUT
- As Denise Mauzerall's work shows for China, use of coal gasification for displacement of dirtier transportation and heating fuel could create even larger health (and climate) benefits.

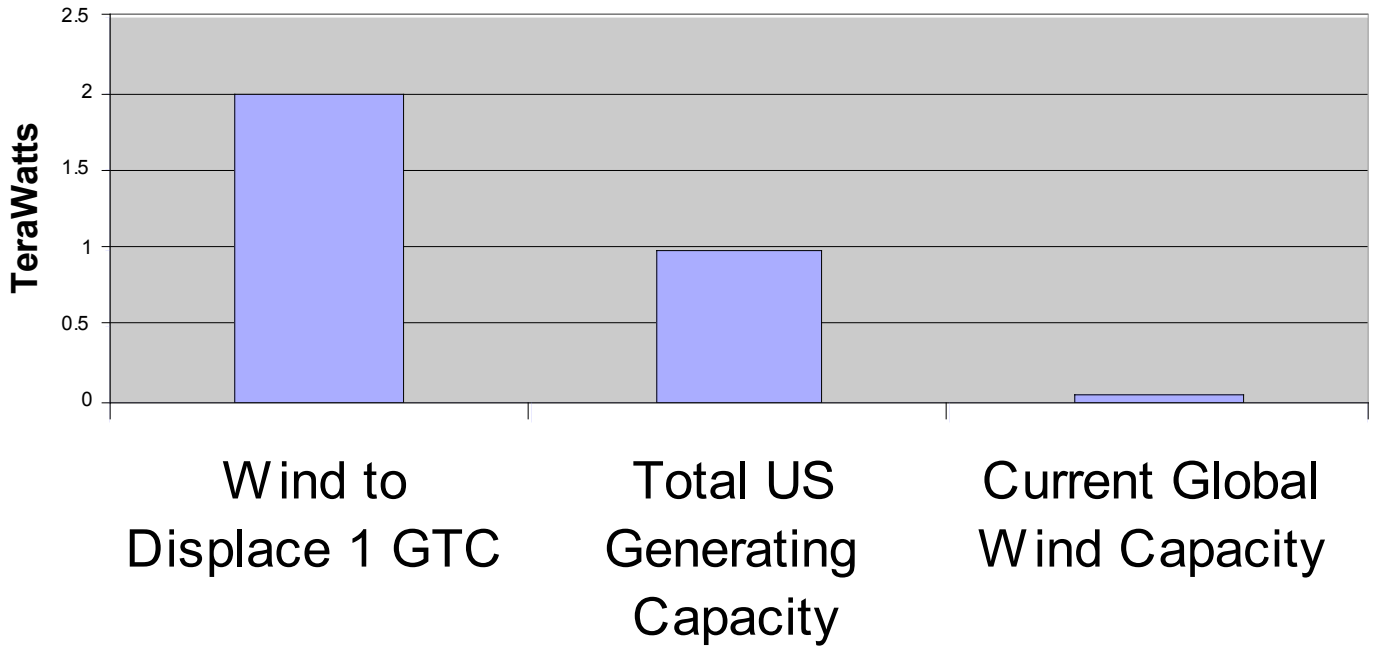
A thought on scale and priorities

- The CO2 “lift” is so large that, if we are serious about climate, very low or zero CO2 resources may not be competing against each other – we may need every possible option available at large scale.



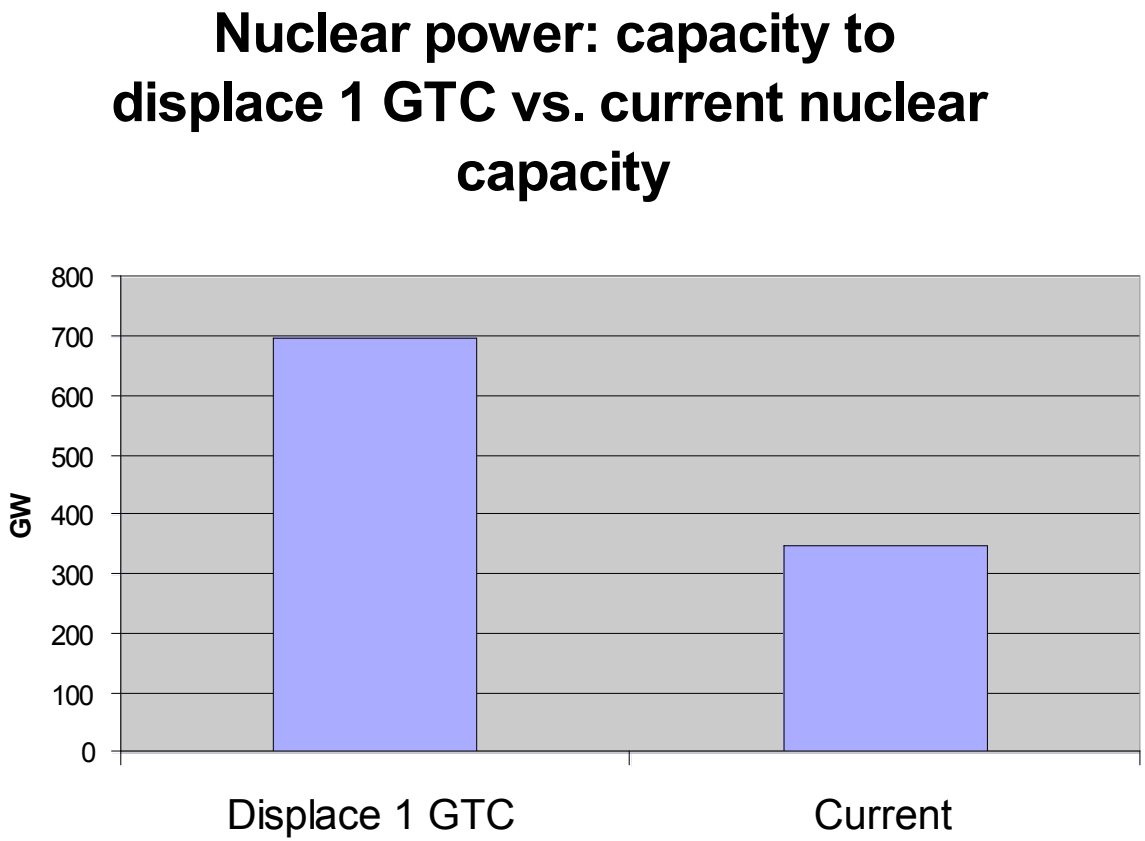
Pacala and Socolow: (*Science*, August 13, 2004)

Wind energy: 1 GTC avoidance (7 GTC required)



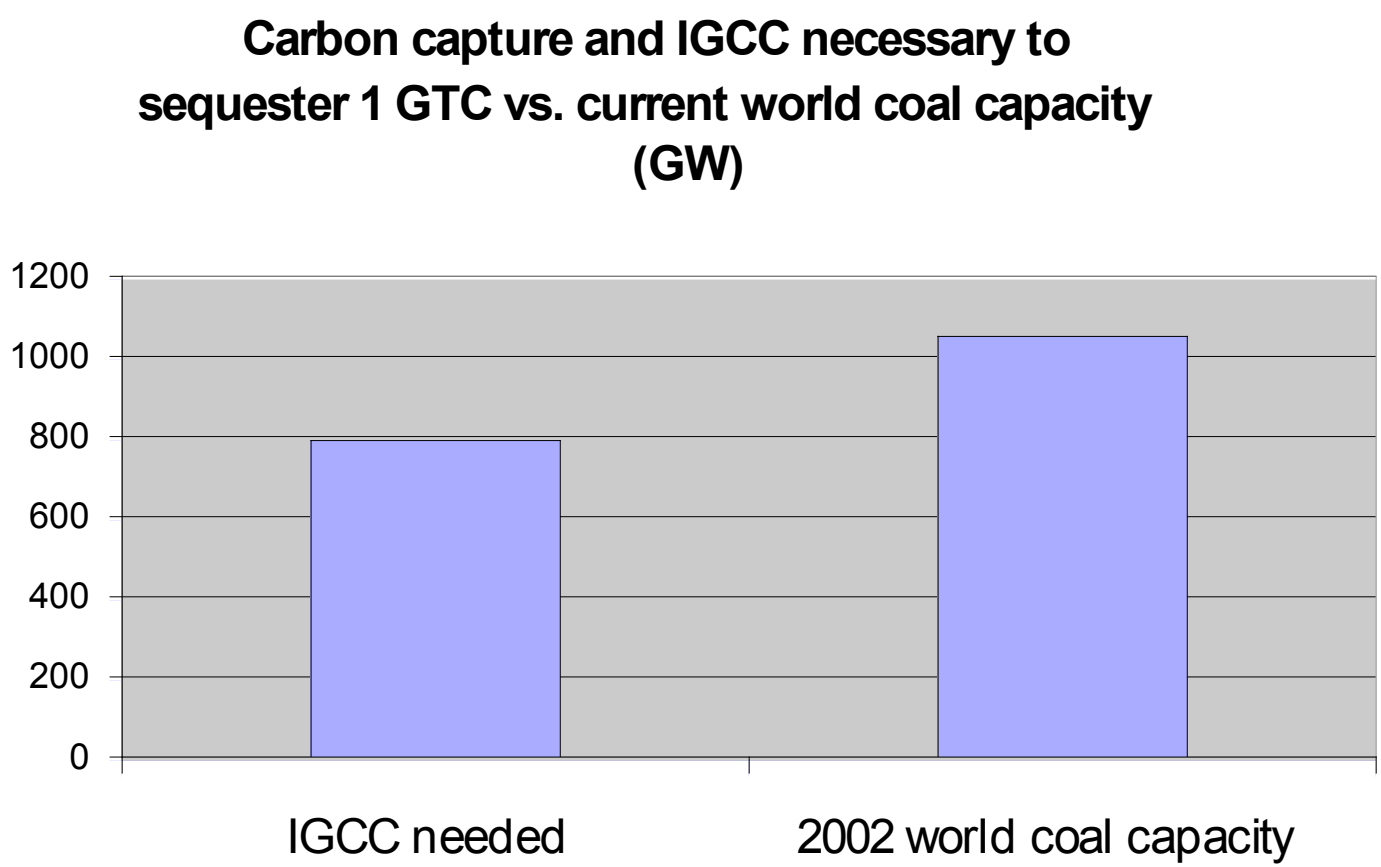
Source: Pacala and Socolow (2004)

1 GTC Displacement Through Nuclear



Source: Pacala and Socolow (2004)

1 GTC Displacement Through CCS



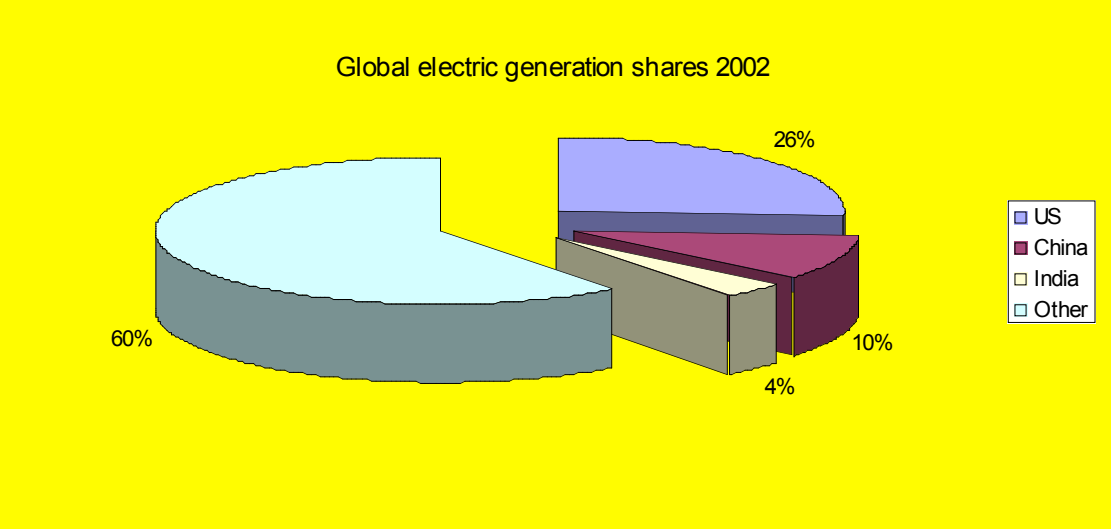
Source: Pacala and Socolow (2004)

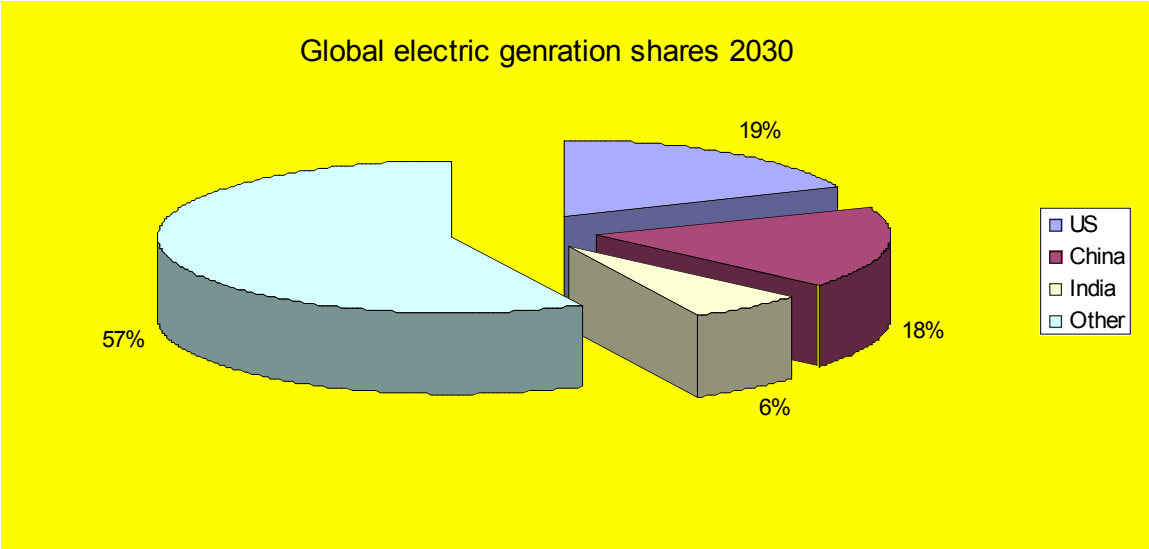
Conclusions

- BAU/BACT is likely to control NOx, SOx (and possibly toxics) significantly
  - This will likely create more positive climate forcing.
- Therefore, “intermediate” or “strong action” to move to IGCC/CCS or zero emissions resources is likely to be driven primarily by CO2 concerns, not concerns over health.
- For CO2, new capacity is what matters, and closing the cost gaps is critical.
- The most important “no regret” options for CO2:
  - don’t site new conventional coal.
  - Get very serious about RD&D – none of the current options look like easy lifts!

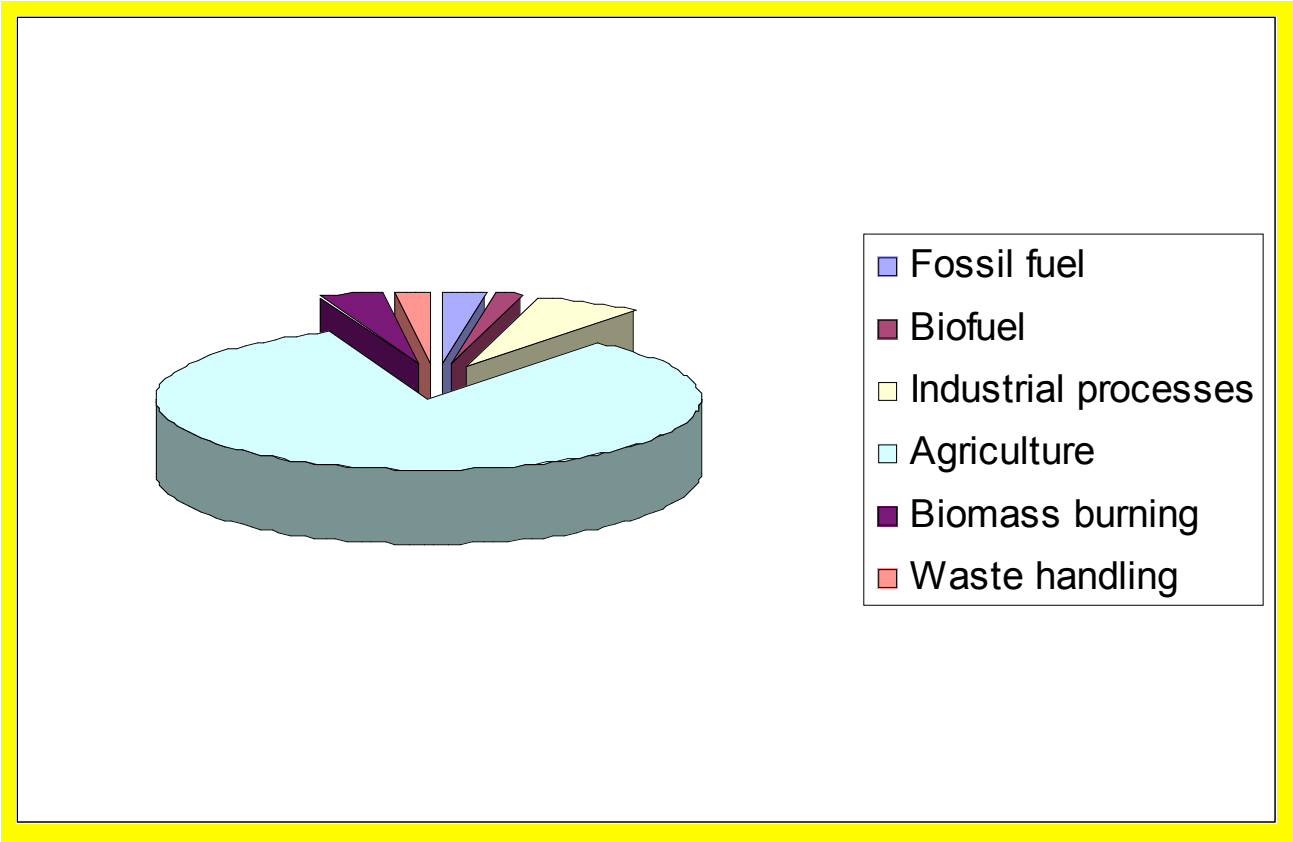
Supplementary Material

Global electric generation shares 2002 and 2030 (IEA)





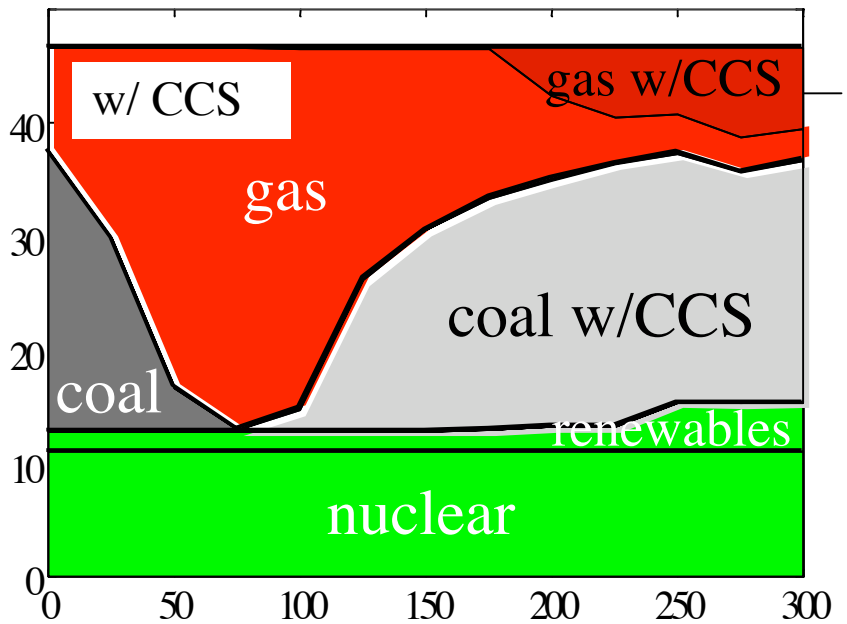
Global sources of N20



Source: EDGAR database
http://arch.rivm.nl/env/int/coredata/edgar/

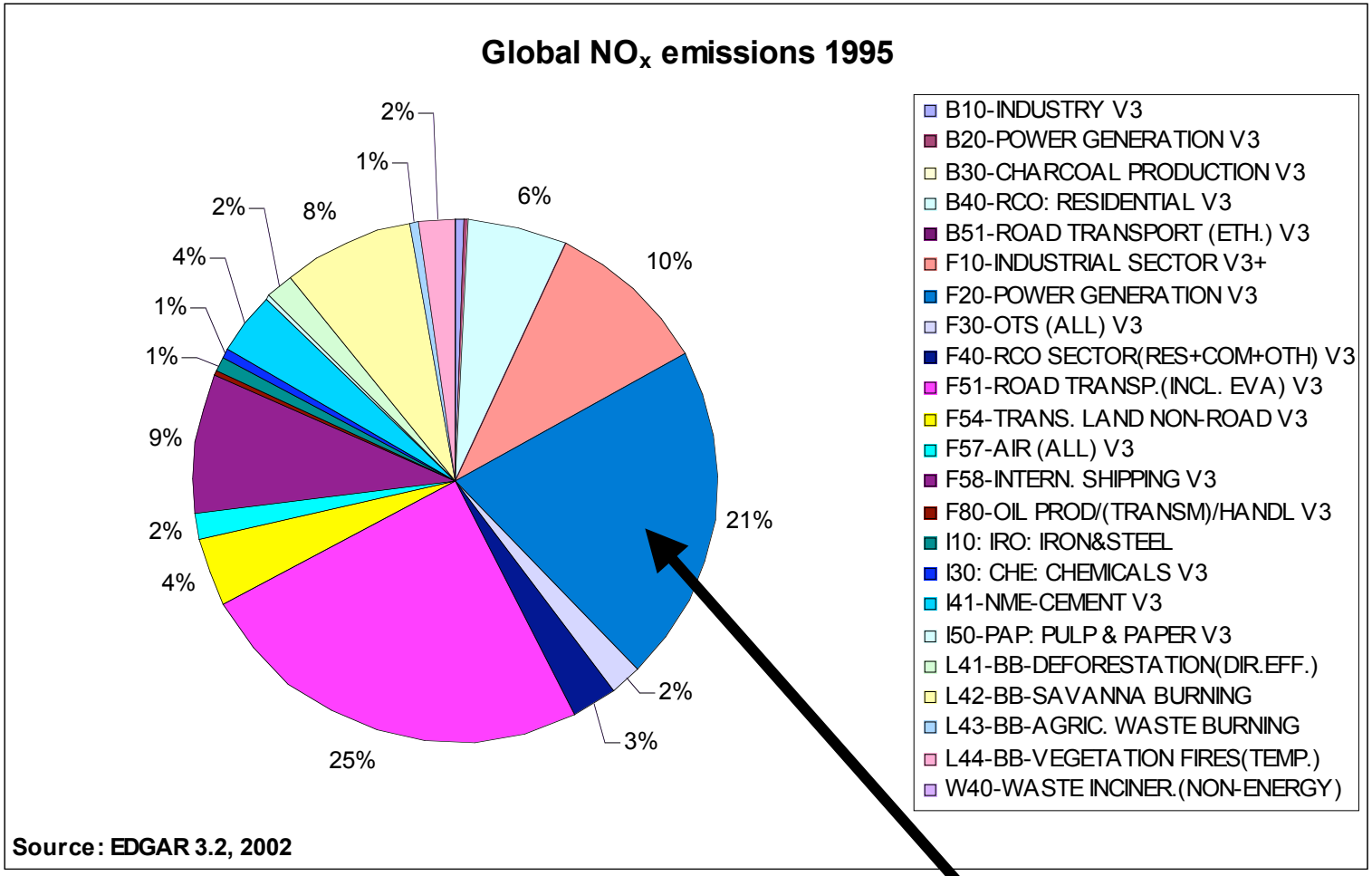
The strategic economic issue for IGCC and CCS: “The Valley of Death” between no and intensive climate policy

Average annual generation in PJM (GW) as estimated by Carnegie Mellon from dispatch modeling



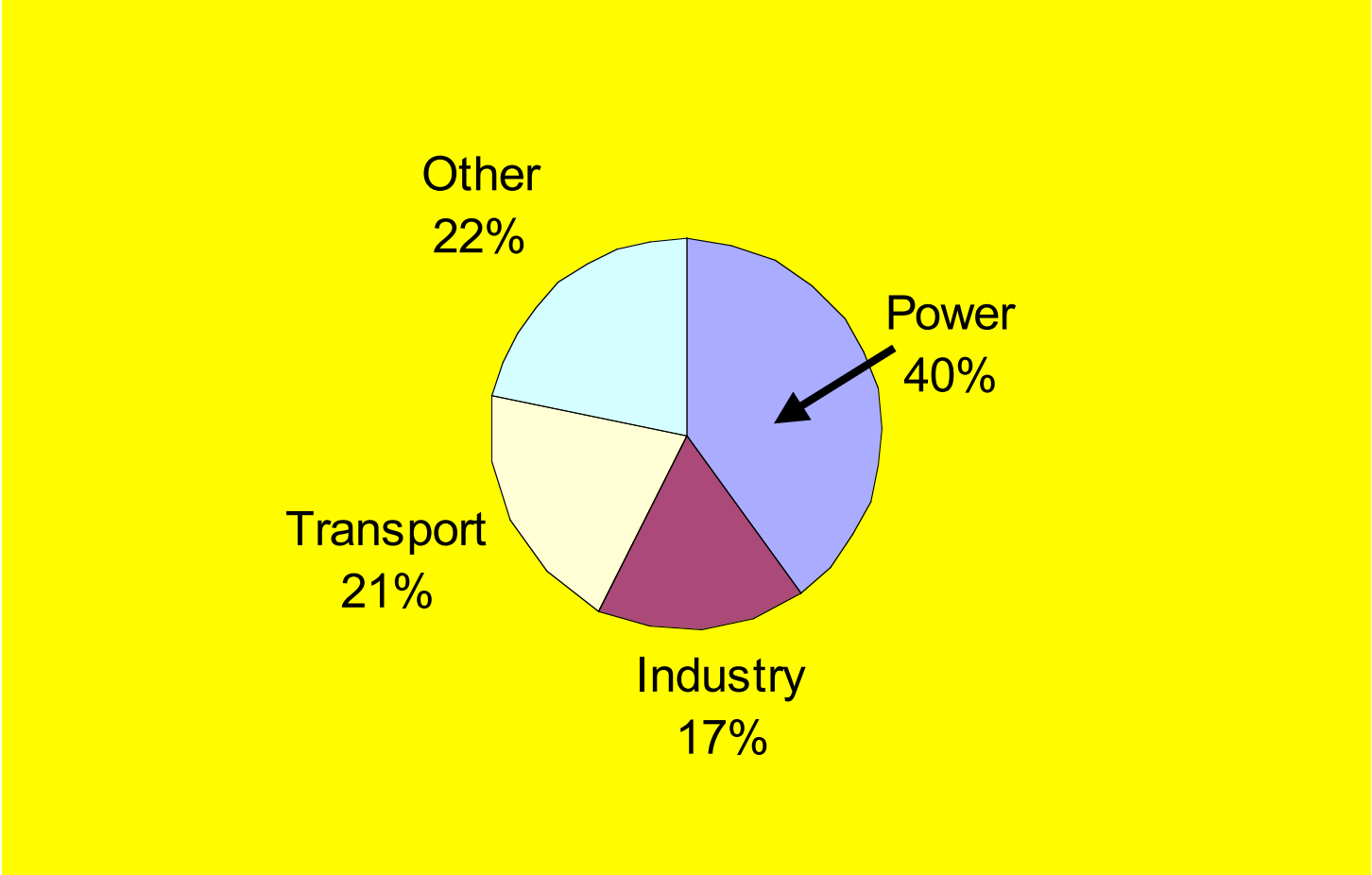
Carbon allowance price $/TON

Sector shares of Global NOx



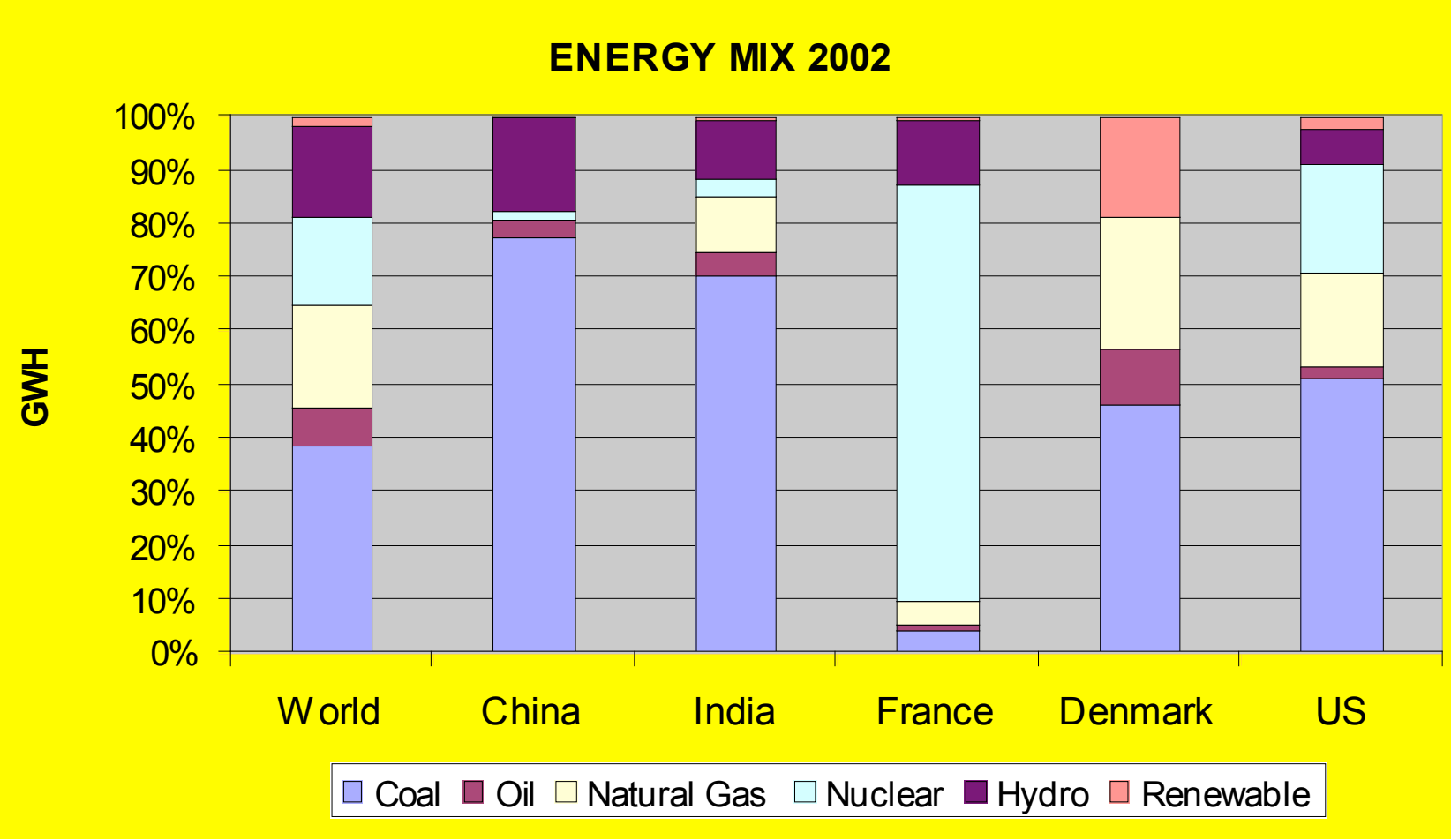
Electric power

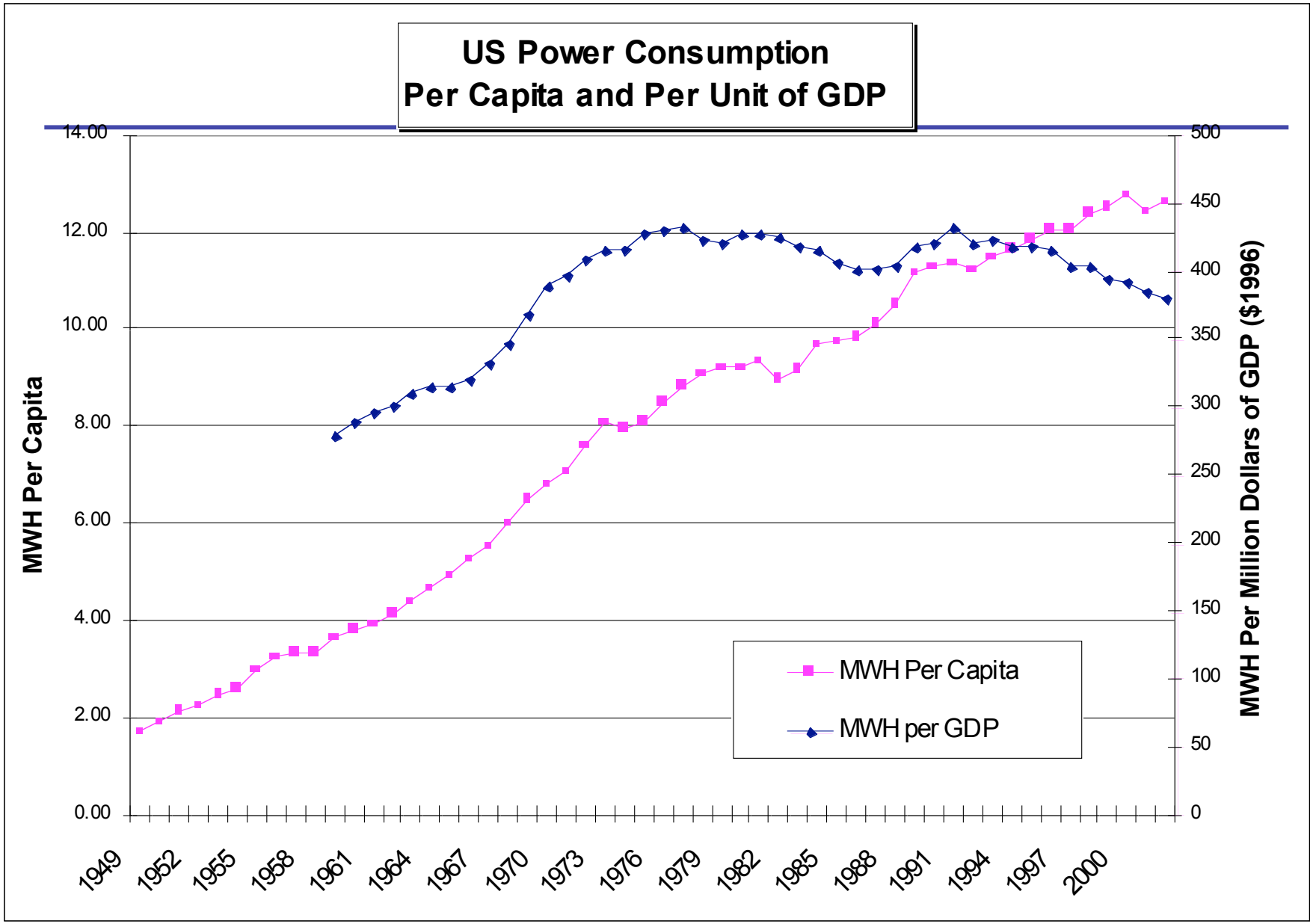
Sector shares of global CO2



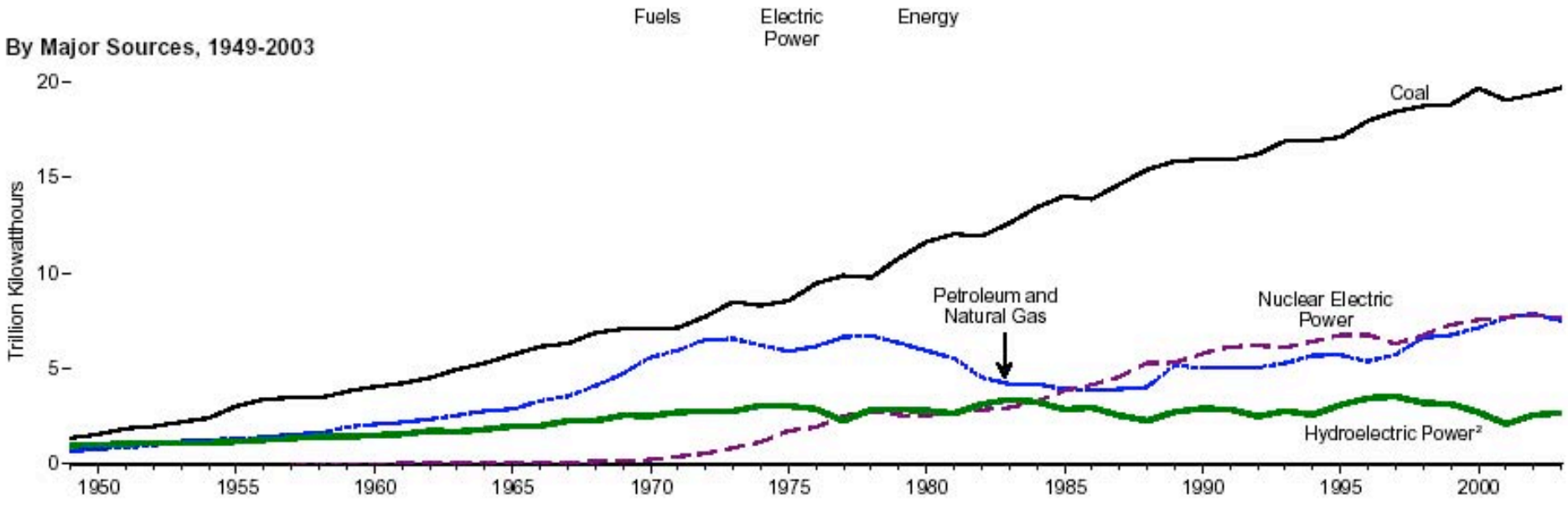
Source: IEA (2004)

Current and BAU electricity shares




US Power Consumption
Per Capita and Per Unit of GDP
MWH Per Capita
MWH Per Million Dollars of GDP ($1996)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
500
450
400
350
300
250
200
150
100
50
0
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
MWH Per Capita
MWH per GDP

US electric power production in last 50 years, by source



[1] Petroleum, wood, waste, geothermal, other gases, wind, solar, and other.
[2] Conventional hydroelectric power and pumped storage.

Note: Because vertical scales differ, graphs should not be compared.
Sources: Tables 8.2a, 8.2b, and 8.2d.