A Global Perspective of Coal & Natural Gas

Energy Options for the Future

Rita A. Bajura, Director

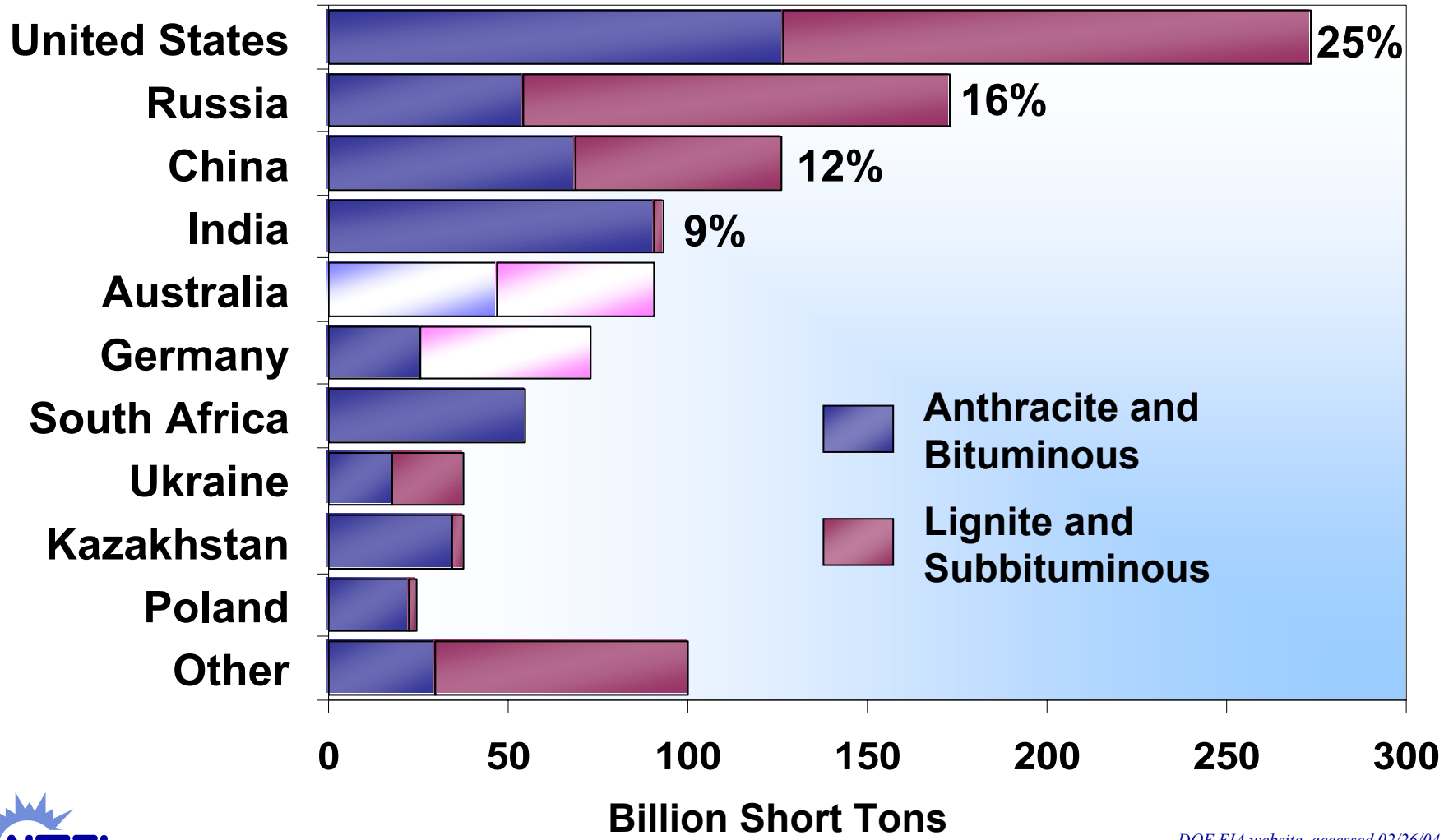
March 11, 2004

National Energy Technology Laboratory

Office of Fossil Energy

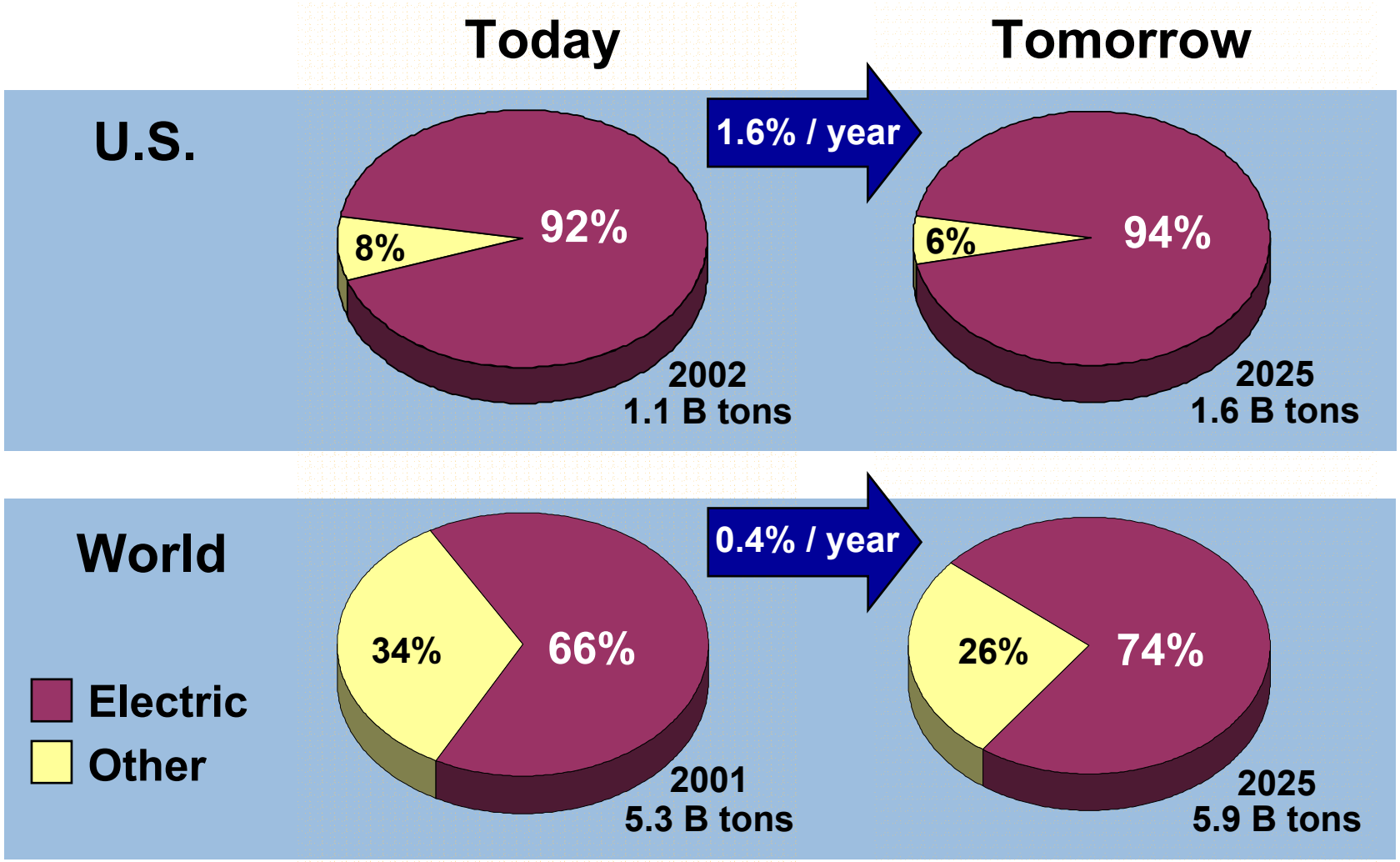
World Recoverable Coal Reserves

1,083 Billion Tons — 210-Year Supply at Current Use



DOE EIA website, accessed 02/26/04

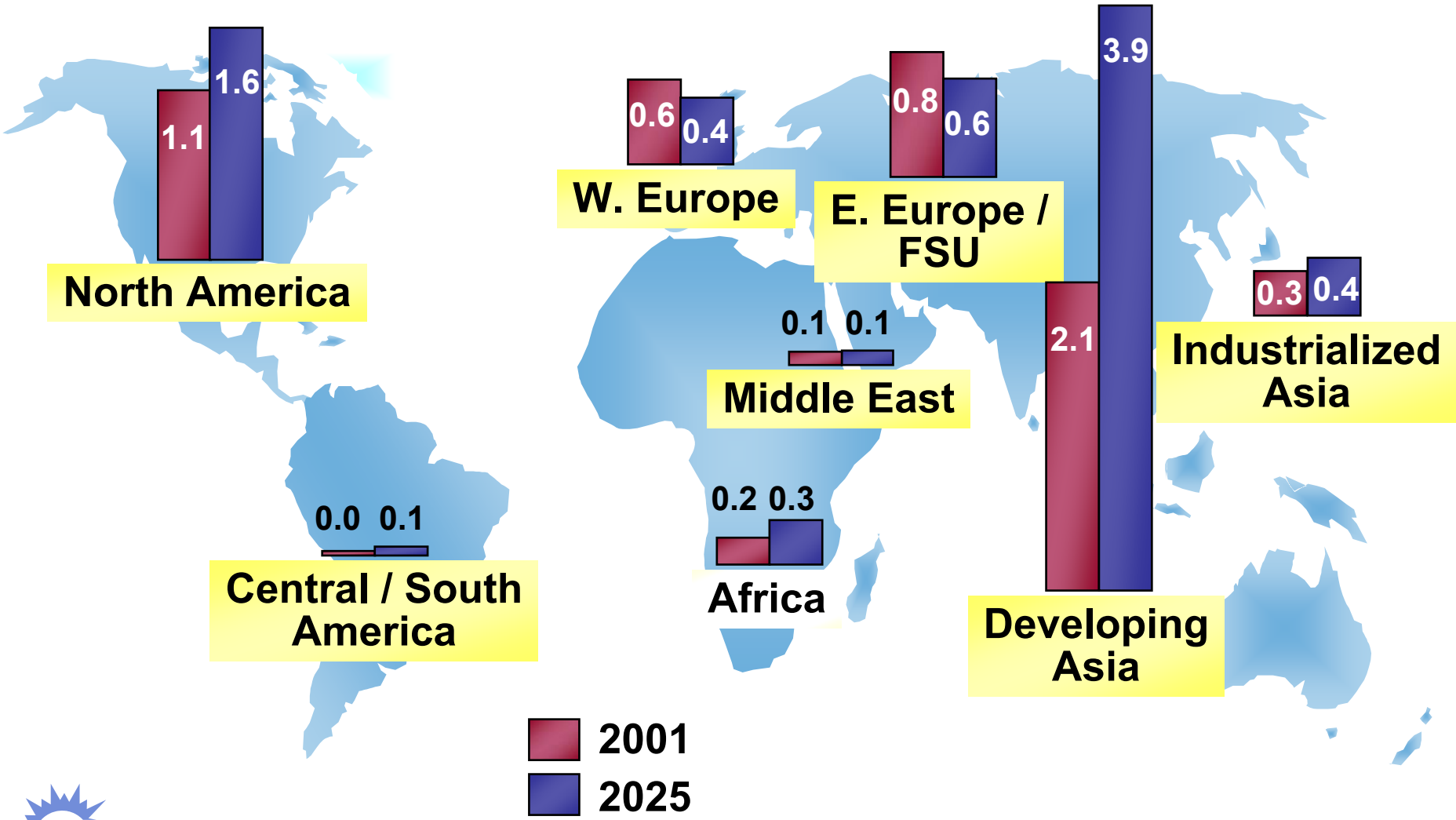
Increasingly, Coal Used for Electricity Generation



EIA, AEO 2004 and EIA International Energy Outlook (except for world: "electricity/other" split estimated from IEA, World Energy Outlook 2002)

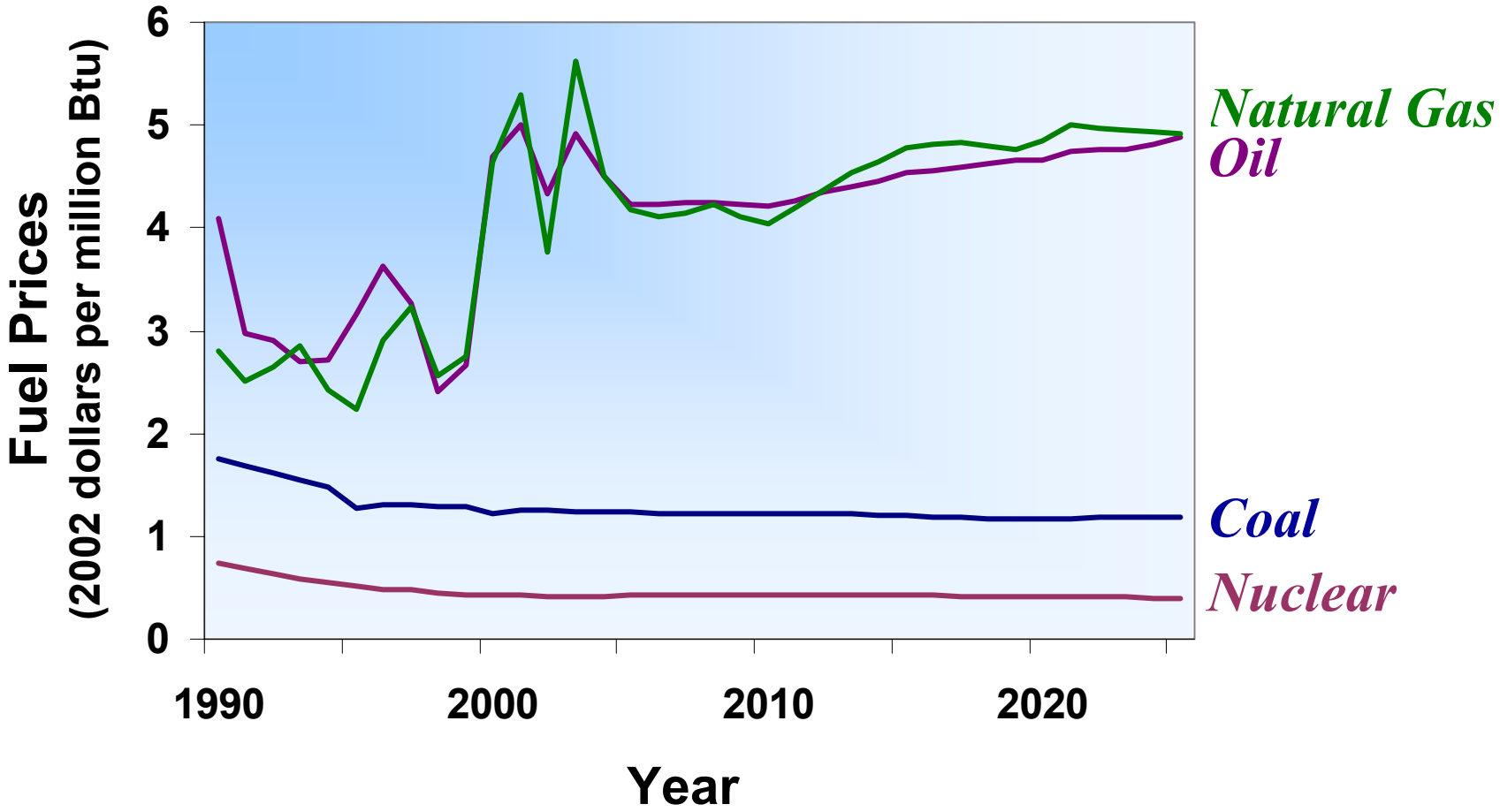
Coal Consumption by Region

Billion Short Tons / Year



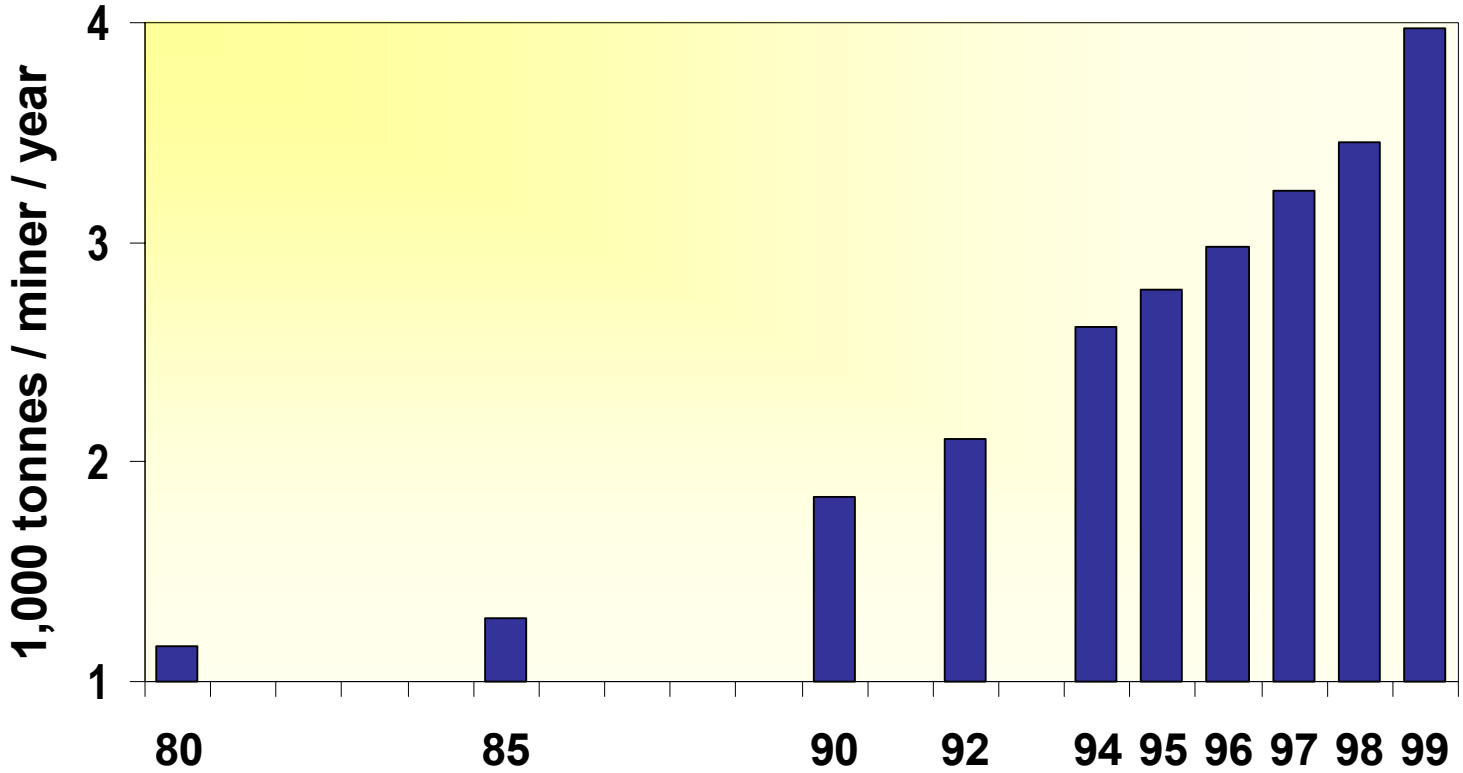
DOE EIA, International Energy Outlook 2003, Table A6

U.S. Fuel Prices to Electricity Generators



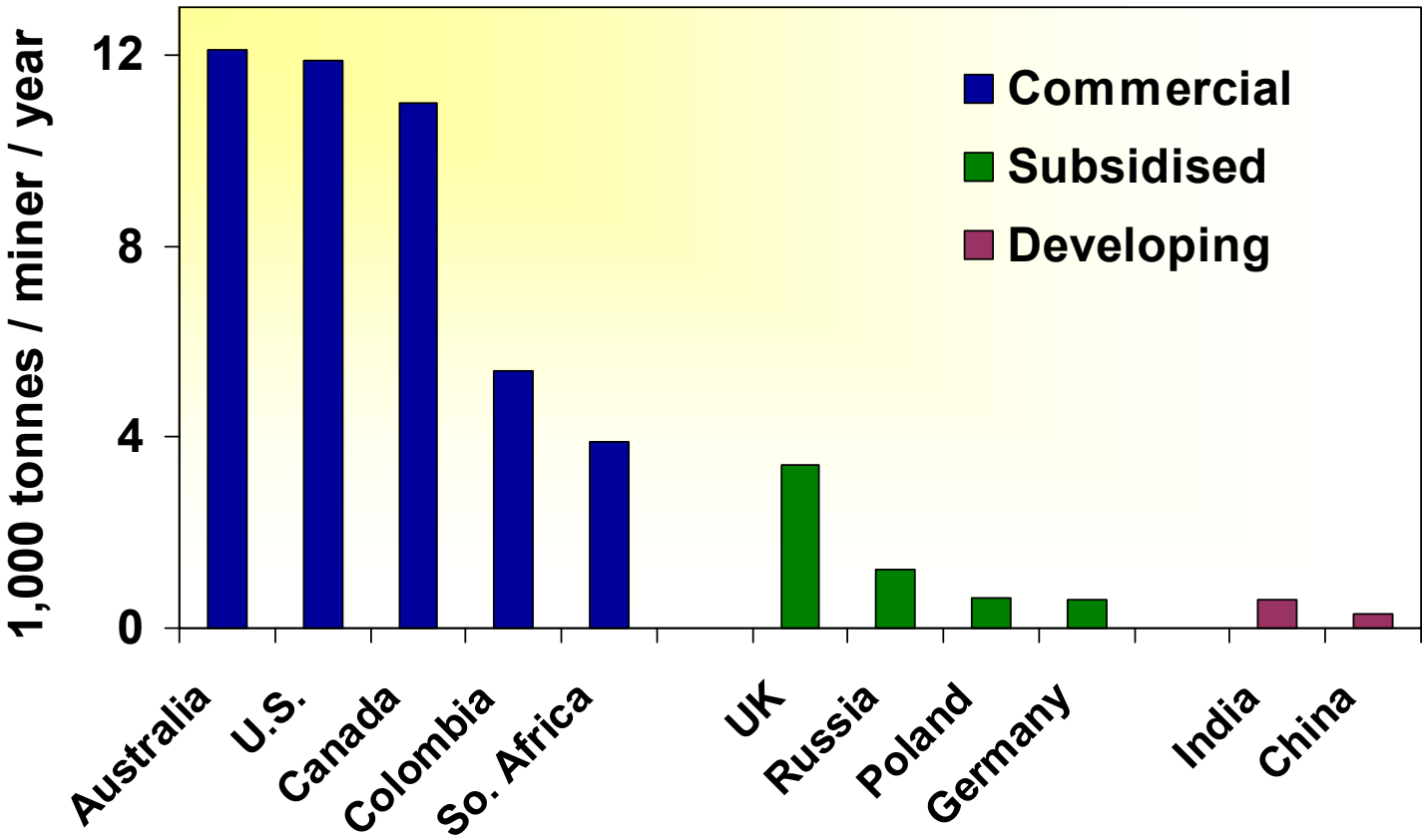
DOE EIA, Annual Energy Outlook 2004, Figure 73

Improved Global Coal Productivity



- Advanced technology
- Economies of scale

Coal Productivity by Nation



Productivity in developing countries lags that in developed countries

Coal Mining Safety

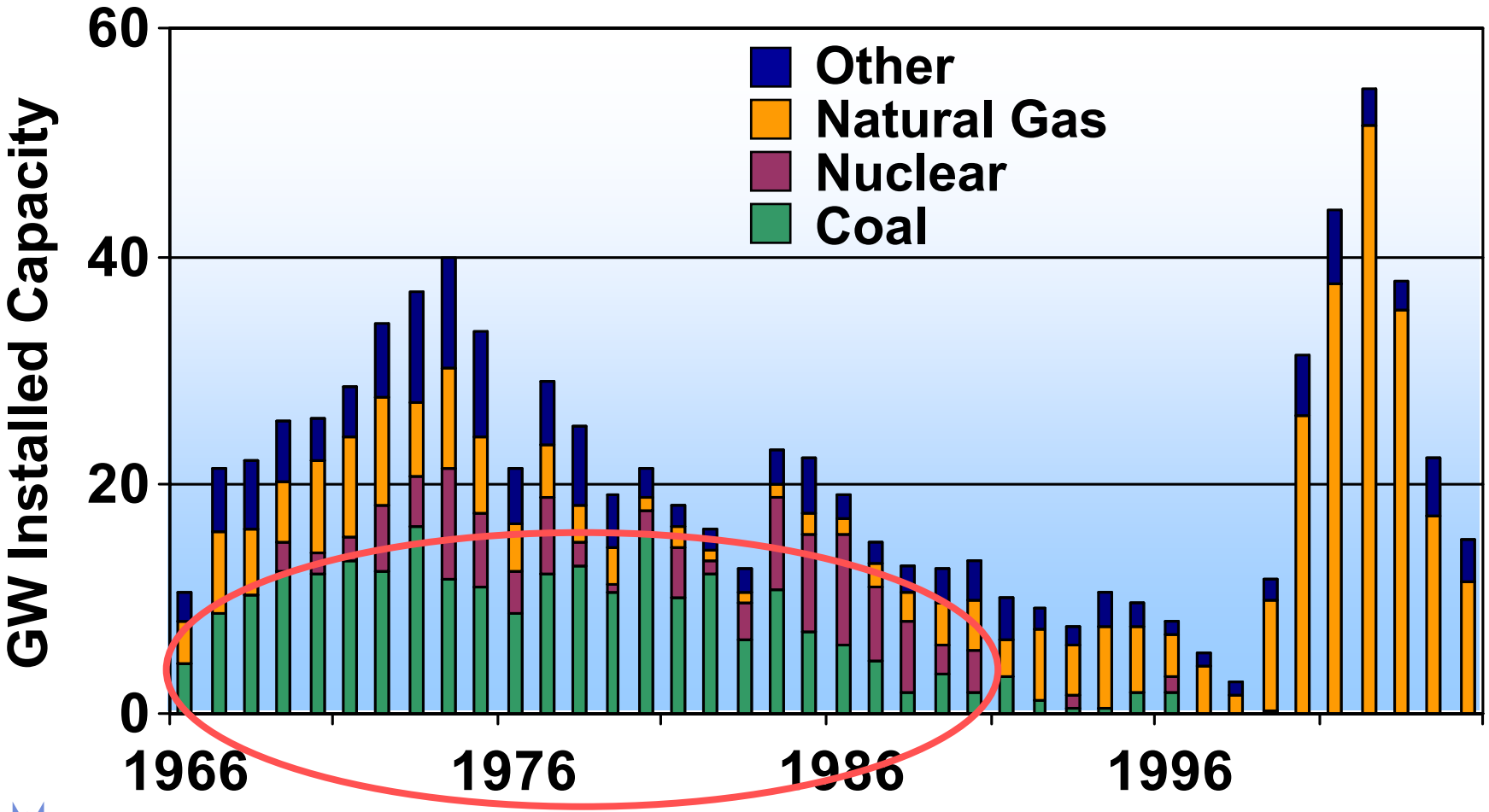
- **U.S. solved many safety issues**
  - 3,200 mine deaths in 1907
  - 30 deaths in 2003

- **Still an issue in developing countries**
  - 7,000 – 10,000 deaths / year in Chinese coal mines

Longwall photo: NREL
U.S data: U.S. Dept. of Labor, Mine Safety & Health
Chinese data: China Labor Bulletin

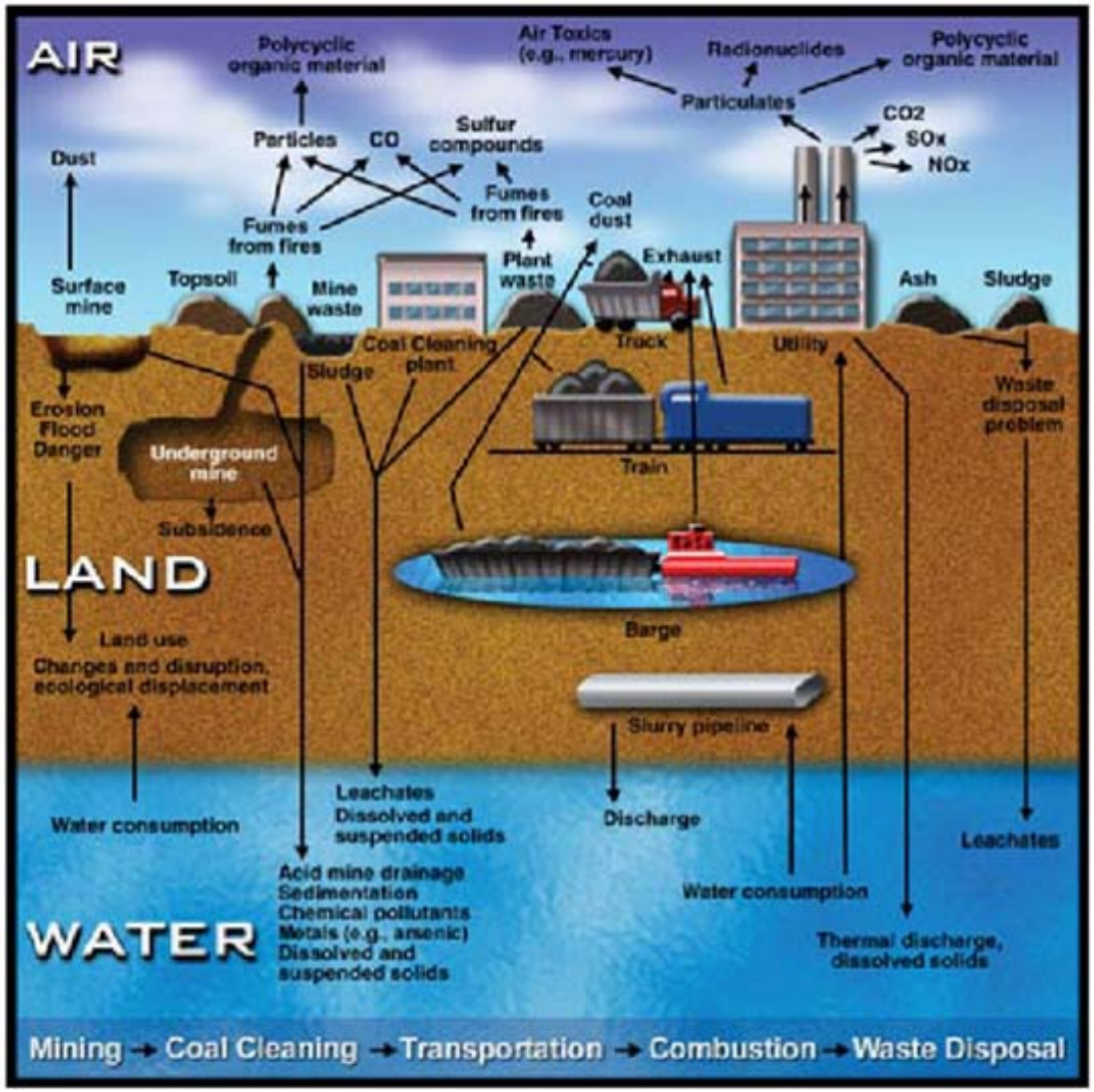
330 GW of Coal-Fired Capacity

U.S. Generation Capacity Additions



NPC Study 2003 based on EIA, Platt's , AEP

Broad Environmental Concerns About Coal



Cradle to Grave: The Environmental Impacts from Coal, Clean Air Task Force, Boston, MA,June 2001

Environmental Impacts of Mining

- Land disturbance
- Habitat loss
- Dust and noise pollution
- Atmospheric emissions
- Solid wastes
- Surface and groundwater
- Infrastructure development and transport movements

Regulators and Industry Working to Reduce Environmental Impacts of Coal Mining

Improved

- Permitting
- Reclamation
- Groundwater management
- Utilization of coal mine methane

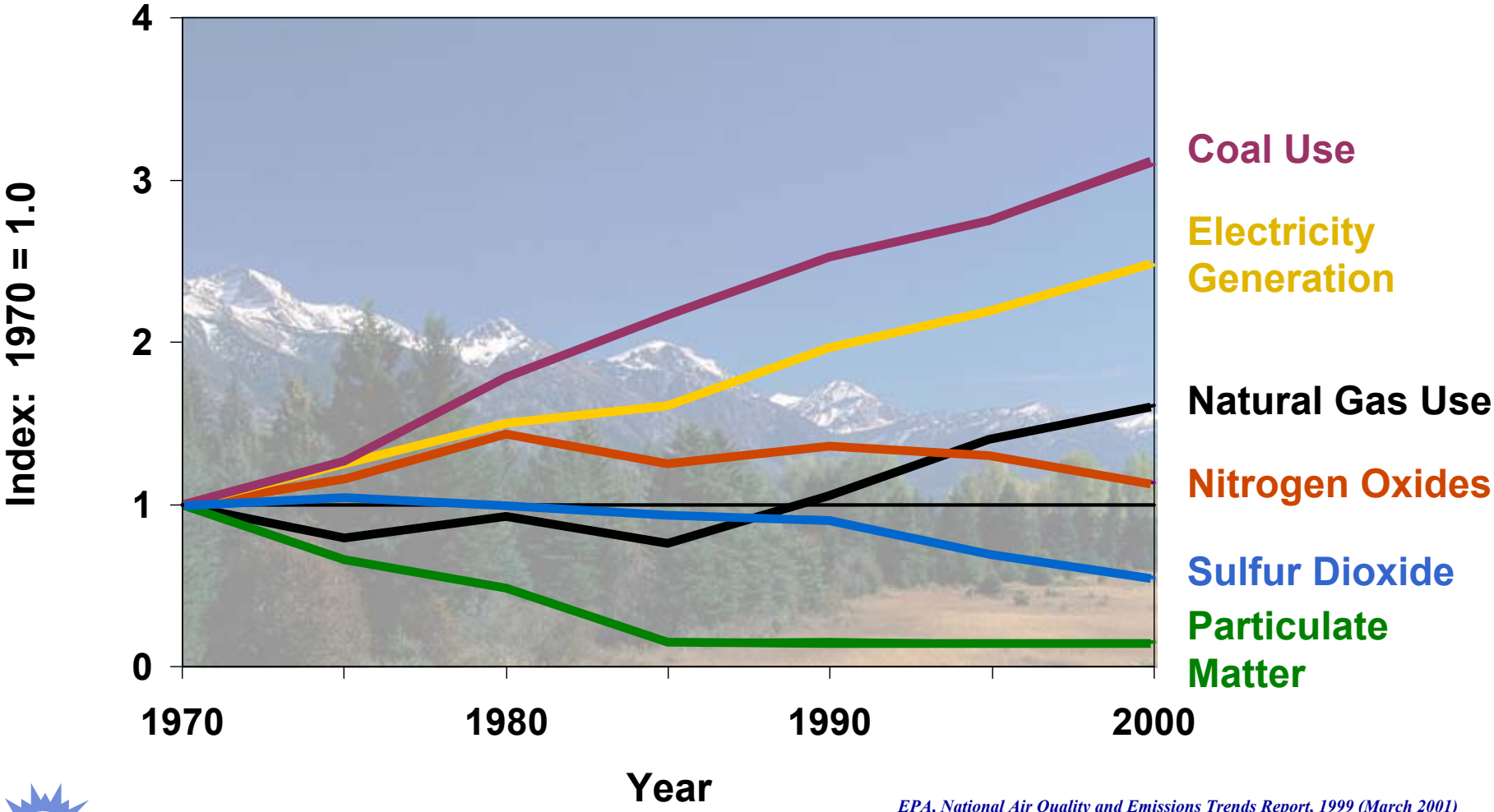
Reclaimed surface mine in western PA

St. Louis in 1939

Air Pollution Control Systems "Dust In The Wind,"
Omer Roberts, Environmental Engineer

Contaminant Emissions Down Sharply

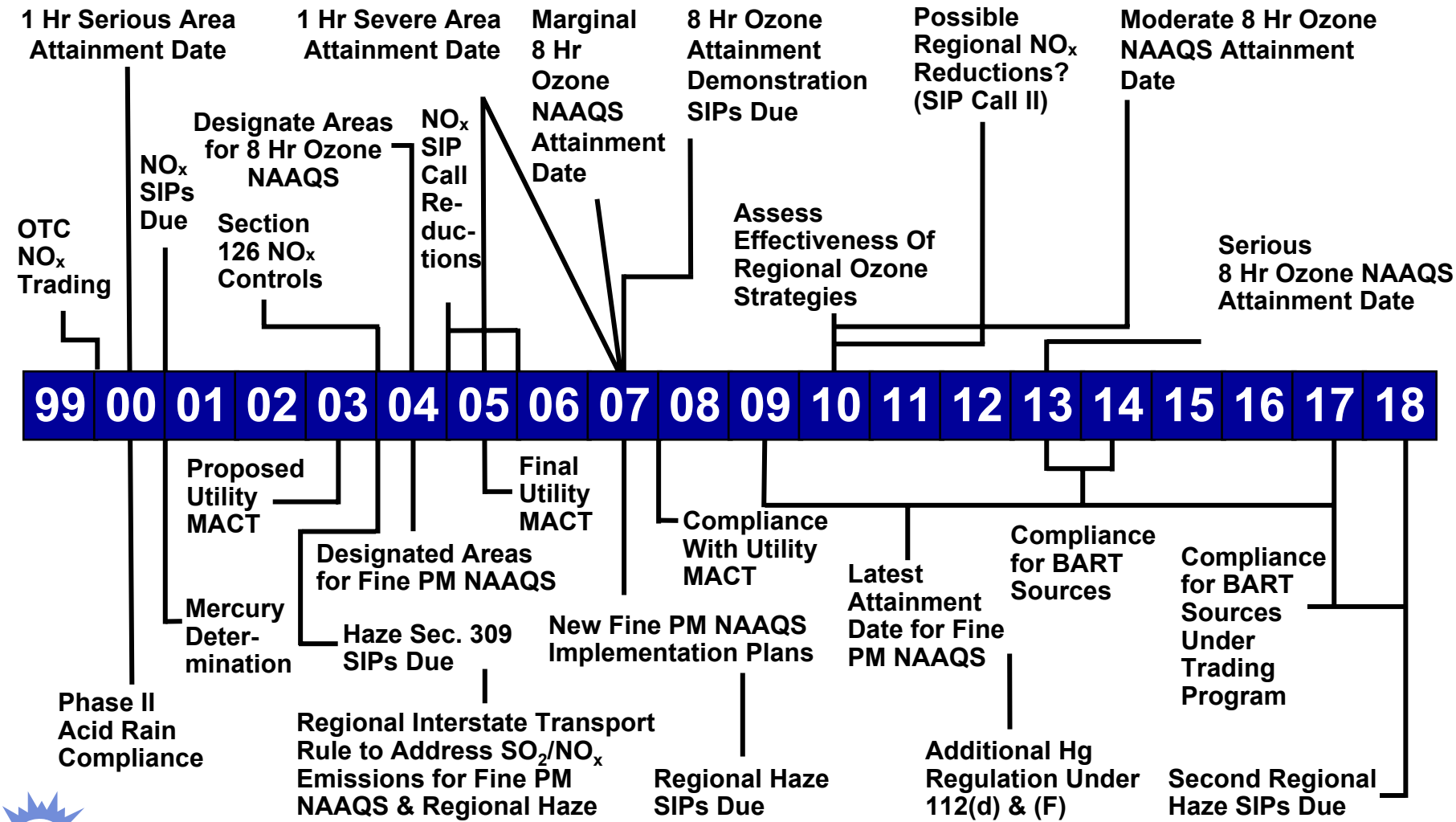
U.S. Power Plants



EPA, National Air Quality and Emissions Trends Report, 1999 (March 2001)
DOE, EIA Annual Energy Review

Regulatory Complexity for Coal Plants

Current Environmental Regulations



Environmental Control Technologies

Percent Removal and Cost

Technology	*Particulates*	*SO_x*	*NO_x*	*Cost / kW*
Electrostatic Precipitation	99.9%	–	–	$40 – 50[*1]
Combustion Modification	–	–	20 – 60%	$5 – 20[*1]
Flue Gas Desulfurization	–	80 – 99%	–	$145 – 200[*2]
Selective Catalytic Reduction	–	–	80%	$80[*2]

**1 World Bank, Table, Technologies for Reducing Emissions in Coal-Fired Power Plants*

**2 CERA Into the Black: Advanced Technologies Clean Up Coal*

Global Mercury Cycle

Metric Tons

Natural Emissions 1,000 Mt / yr

Atmospheric Pool 5,200 Mt

Net Ocean Flux 1,200 Mt / yr

Land Deposition 2,200 Mt / yr

U.S. Coal Largest U.S. Emitter

Mixed Layer Ocean Pool 10,800 Mt

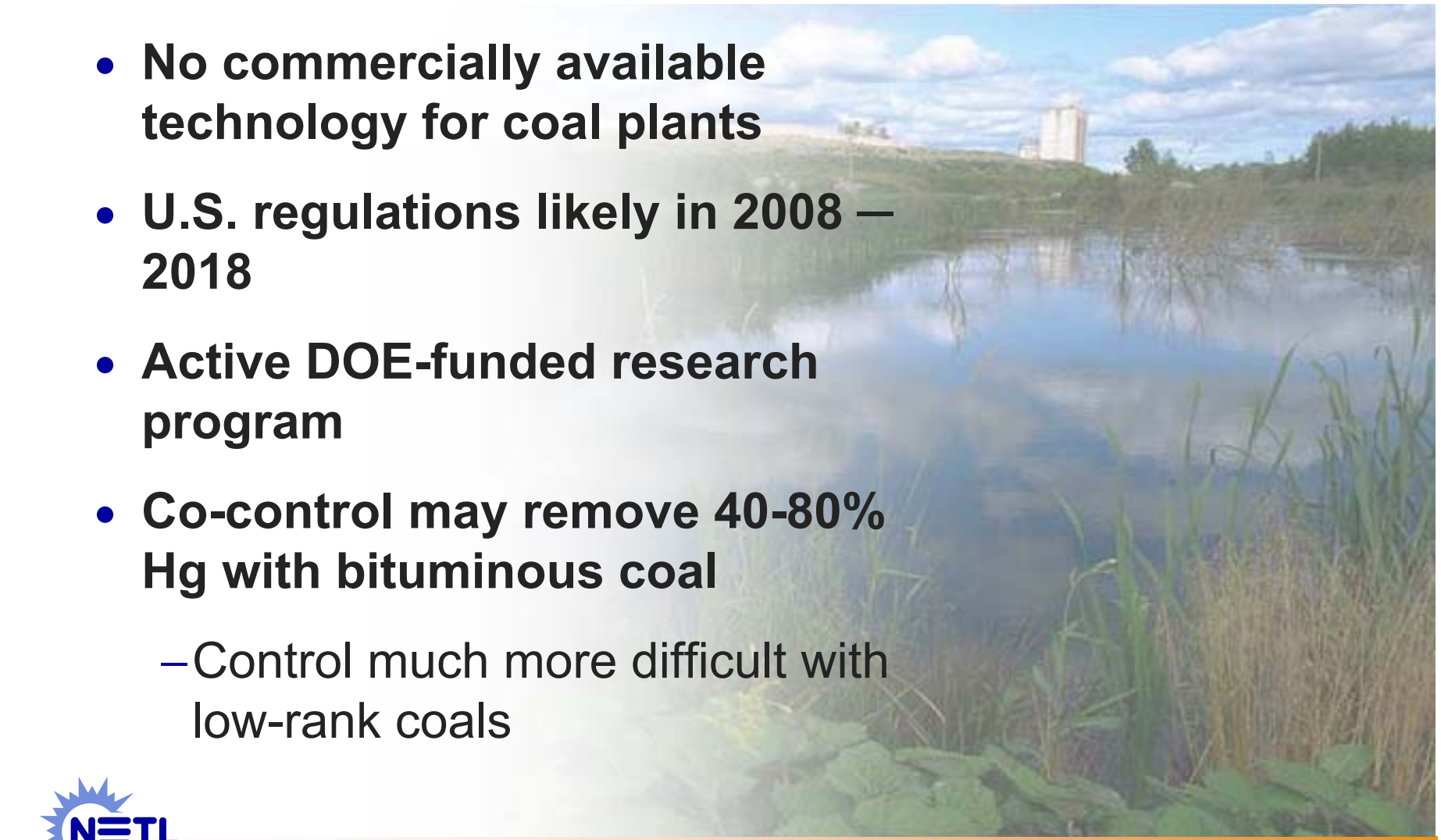
Anthropogenic Emissions 2,600 Mt / yr

U.S. Coal Contributes 2%

Deep Ocean Pool 216,000 Mt

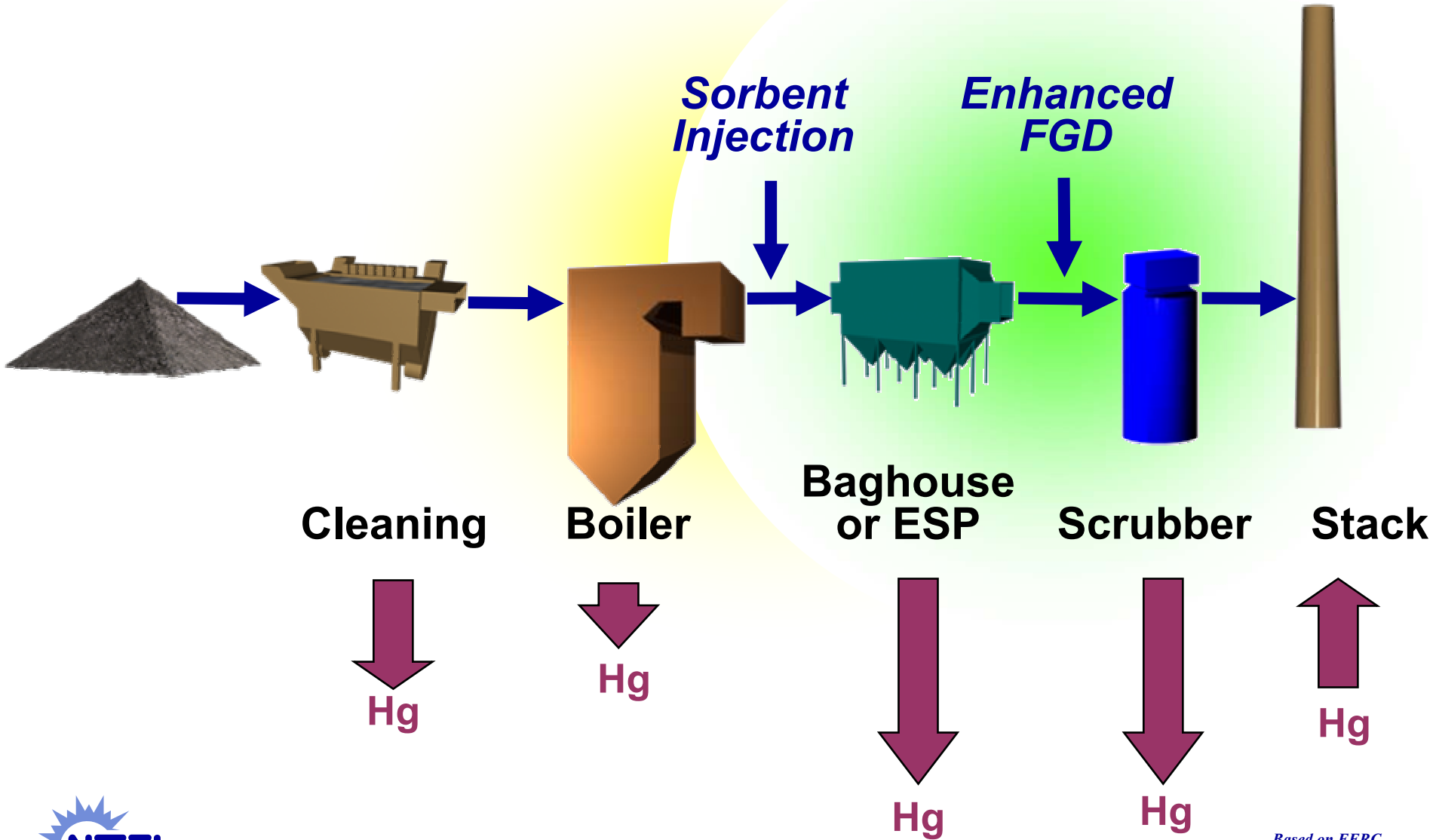
n United Nation Environmental Program's Global Mercury Assessment, December 2002, which is based on Lamborg et al. (2002)

Status of Technologies to Control Mercury



- **No commercially available technology for coal plants**
- **U.S. regulations likely in 2008 — 2018**
- **Active DOE-funded research program**
- **Co-control may remove 40-80% Hg with bituminous coal**
  - Control much more difficult with low-rank coals

Options for Mercury Control



Based on EERC

Field Sites for Mercury Control Testing

ADA-ES Sorbent Injection

Alabama Power
Gaston

PG&E
Brayton Point

PG&E
Salem Harbor

We Energies
Pleasant Prairie

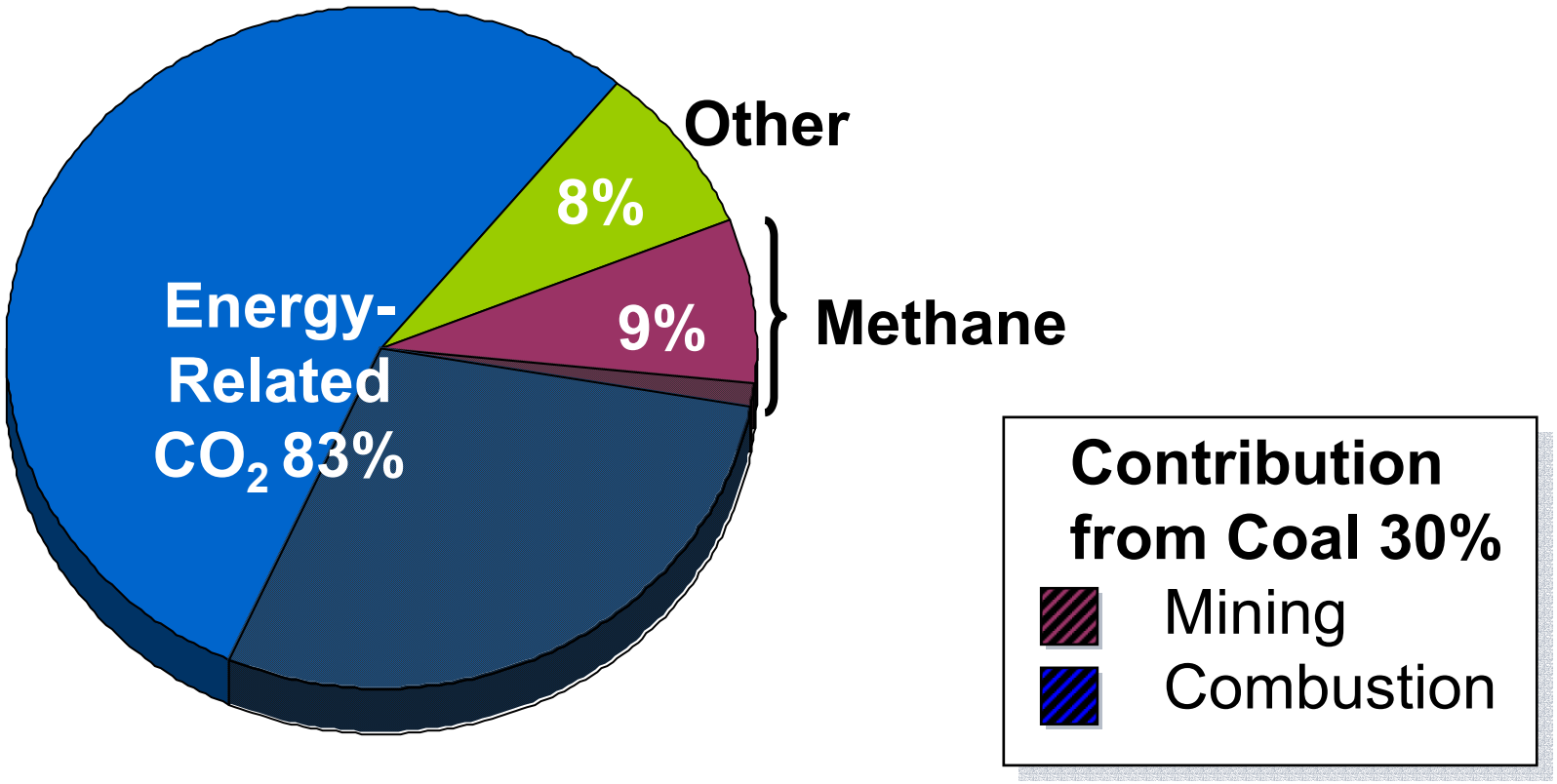
McDermott Enhanced FGD

Michigan SC Power
Endicott Plant

CINergy
Zimmer Plant

CO_2 From Energy Is Major Contributor

U.S. GHG Emissions Weighted by Global Warming Potential



EIA Report #EIA/DOE-0573 "Emissions of Greenhouse Gases in the U.S. 2002," Executive Summary (Oct. 2003)
Coal mining and coal combustion breakouts estimated from US EPA's "Inventory of Greenhouse Gas Emissions and Sinks: 1990-2001

The Climate Change Problem

Stabilizing CO_2 concentrations
(for any concentration from 350 to 750 ppm)
means that global net CO_2 emissions
must peak in this century,
and
begin a long-term decline
ultimately approaching zero

… The Pre-Industrial Concentration Was 280 ppm

Technological Carbon Management Options

Reduce Carbon Intensity

- Renewables
- Nuclear
- Fuel Switching

Improve Efficiency

- Demand Side
- Supply Side

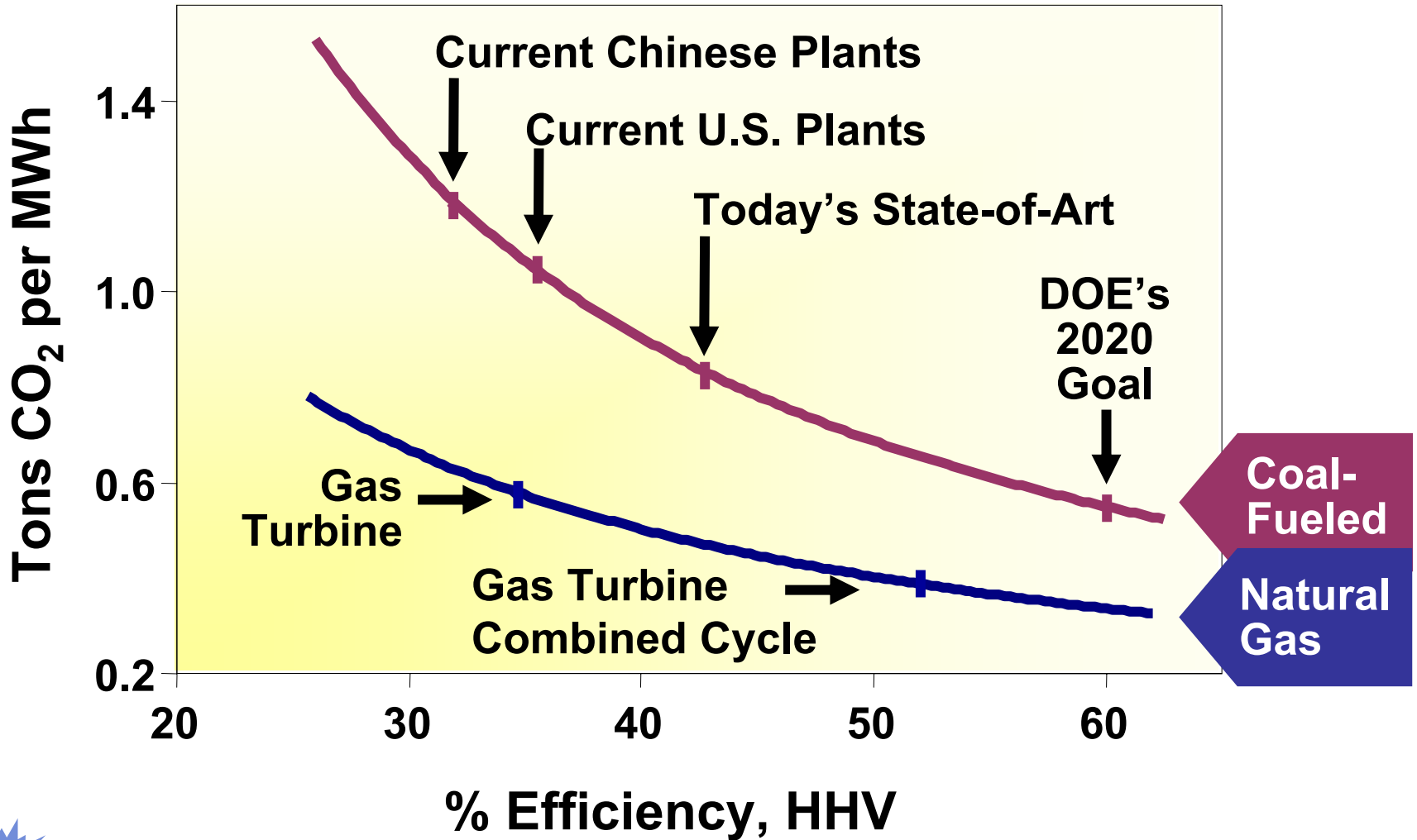
Sequester Carbon

- Capture & Store
- Enhance Natural Processes

All options needed to:

- Supply energy demand
- Address environmental objectives

Improved Efficiencies Reduce Carbon Emissions



Integrated Gasification Combined Cycle (IGCC)

Promising Pathway to Zero-Emission Plants

- Fuel and product flexibility
- Environmentally superior
- High efficiency
- Sequestration ready

Producing concentrated stream of CO_2 at high pressure

- Reduces capital cost
- Reduces efficiency penalty

IGCC Technology in Demonstration Stage
U.S. Coal-Fueled Plants

- **Wabash River**
  - 1996 Powerplant of Year Award*
  - Achieved 95% availability

- **Tampa Electric**
  - 1997 Powerplant of Year Award*
  - First dispatch power generator

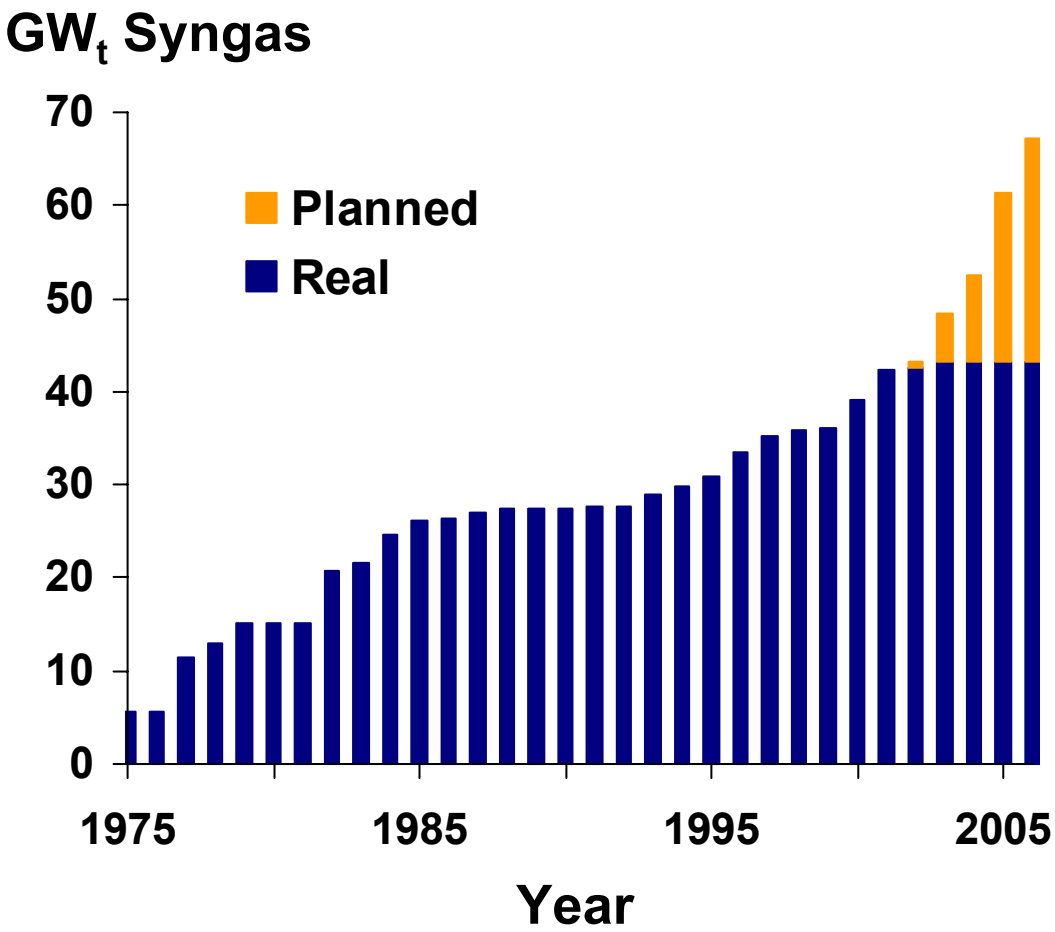
*Power Magazine

IGCC Issues

- **Capital cost of 300-MW IGCC plants 5-20% higher than pulverized coal units**
  - Economics for 600-MW IGCC plants appear more favorable
- **Longer shakedown to achieve high availability**
- **Chemical plant image**

Significant Worldwide Gasification Capacity

Cumulative Capacity



130 Operating Gasification Plants

- 400 gasifiers
- 43 GW_t syngas
- 24 GW IGCC equivalent

DOE's Worldwide Gasification Database, 2001

Approaches to Sequester Carbon

Separation and Storage

Unmineable Coal Seams

Deep Ocean Injection

Depleted Oil / Gas Wells, Saline Reservoirs

Enhance Natural Processes

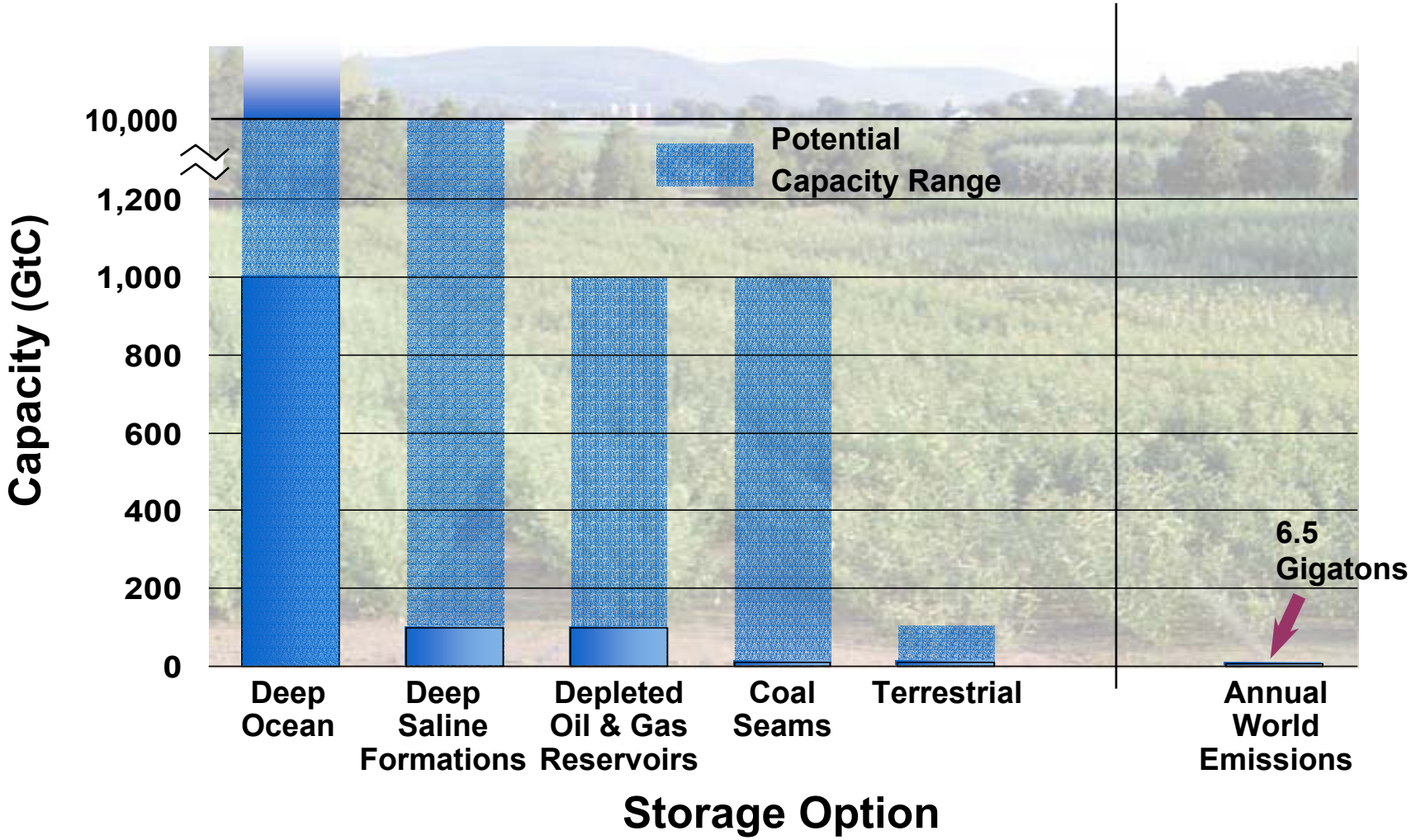
Forestation

Iron or Nitrogen Fertilization of Ocean

Enhanced Photosynthesis

NETL

Large Potential Worldwide Storage Capacity



Storage Options: Carbon Capture & Sequestration Program @MIT
World Emissions: DOE/EIA, International Energy Outlook 2003, Table A10

Sequestration Is Feasible

One Million TPY CO_2 Sequestration Projects

Weyburn CO_2 Project

- Pan Canadian Resources
- Enhanced oil recovery coupled with sequestration

Sleipner North Sea Project

- Statoil
- Produces natural gas with high CO_2 content
- CO_2 sequestered in saline reservoir under sea

NETL

Sleipner Photo from USGS Website

Sequestration Costs Appear Reasonable

Sum of costs for

- **Separation**
- **Compression**
- **Transport**
- **Sequestration**

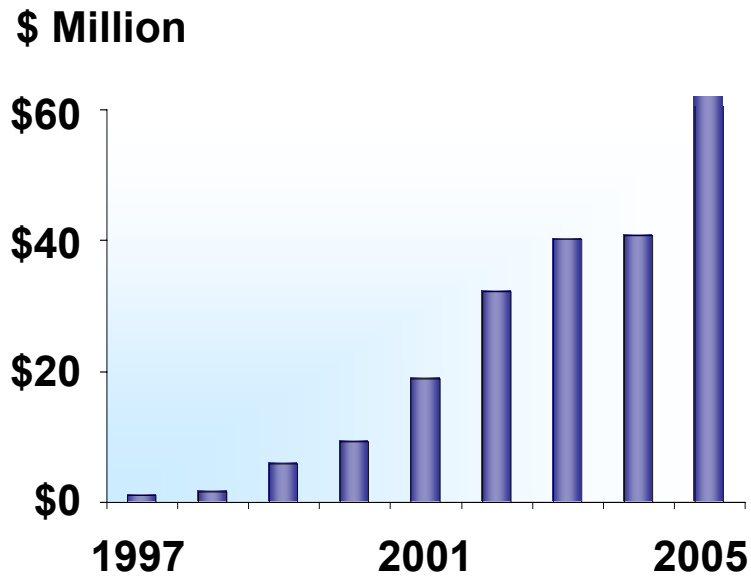
- **Incremental "average" impact on new IGCC**
  - 25% increase in COE relative to non-scrubbed counterpart
- **DOE's goal is < 10% increase in COE**
- **Retrofiting CO_2 controls expensive unless plant designed for sequestration**

DOE/EPRI report "Evaluation of Innovative Fossil Fuel Power Plants with CO_2 Removal," EPRI Technical Report 1000316, December 2000

Economic Evaluation of CO2 Sequestration Technologies Report from DEFC-26-00NT-40937, April 2002

Sequestration: A Dynamic Program

- **Diverse research portfolio**
  - >60 projects
  - $140M portfolio
- **Strong industry support**
  - 36% cost share
- **Industry participation**
  - AEP
  - Alstom
  - BP
  - ChevronTexaco
  - Consol
  - EPRI
  - McDermott
  - Shell
  - TVA
  - TXU



Growing Funding

Carbon Sequestration Could . . .

- Remove enough carbon to stabilize CO_2 concentrations in atmosphere
- Be compatible with existing energy infrastructures
- Be lowest cost carbon management option

FutureGen: A Global Partnership Effort

One billion dollar, 10-year demonstration project to create world's first coal-based, zero-emission electricity and hydrogen plant

President Bush, February 27, 2003

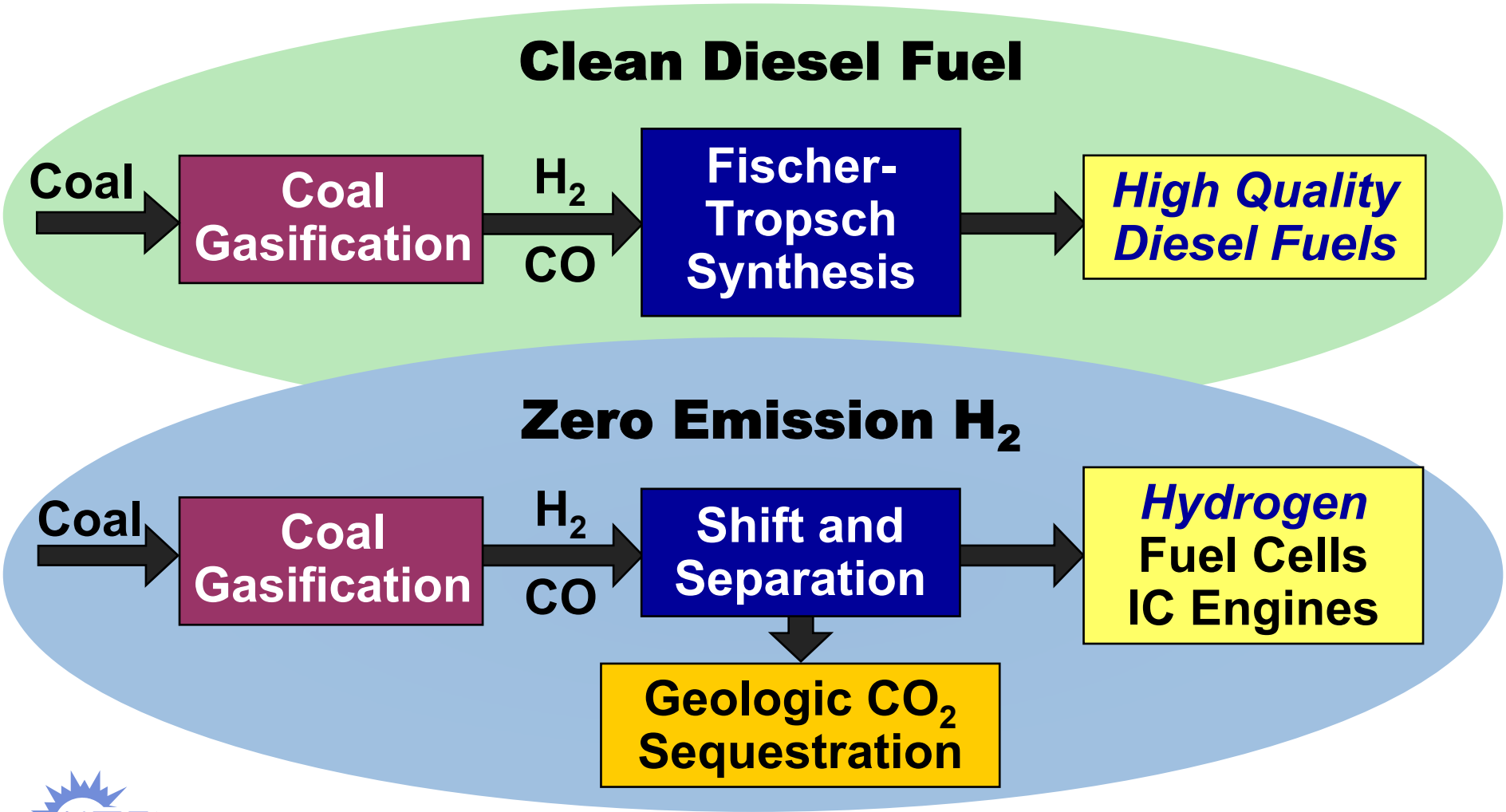
- **Broad U.S. participation**
  - DOE contemplates implementation by consortium
- **International collaboration**
  - Carbon Sequestration Leadership Forum

Industry Group Announced Formation of FutureGen Consortium

- American Electric Power
- CINergy
- PacifiCorp
- Southern Company
- TXU (Texas Utilities)
- CONSOL
- Kennecott Energy
- North American Coal
- Peabody Energy
- RAG American Coal Holding

Charter members represent ~1/3 coal-fired utilities and ~1/2 U.S. coal industry

FutureGen Opens Door to "Reuse" of Coal in Transportation Sector

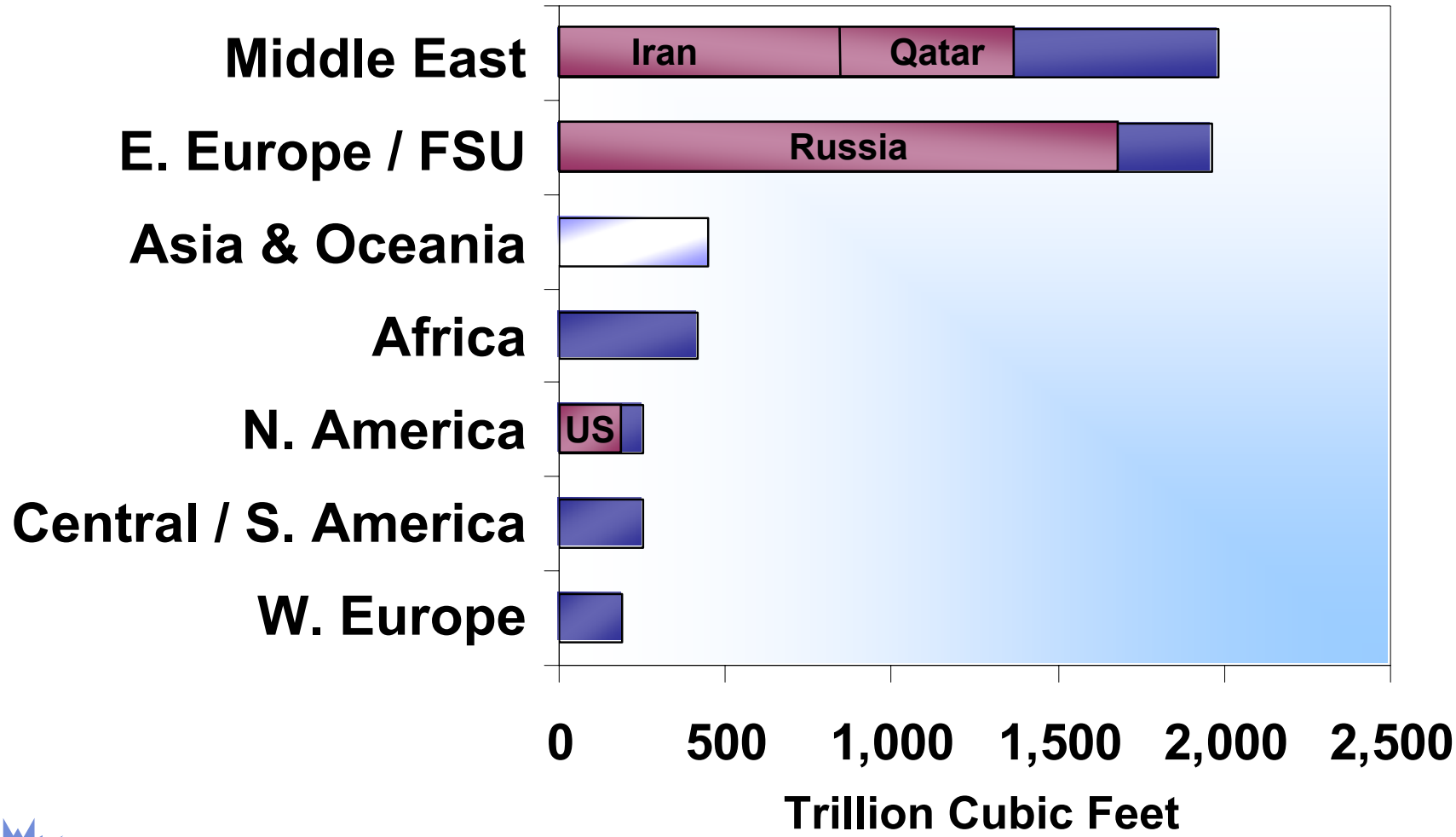


Why Coal Is Important

- **Coal remains the largest energy source for power generation**
  - Potential future source for transportation sector
- **Abundant reserves — particularly in U.S.**
  - Contribute to energy security
- **Relatively low and stable prices**
- **But coal has environmental impacts**
  - Increasingly, technology available to address

World Proved Natural Gas Reserves

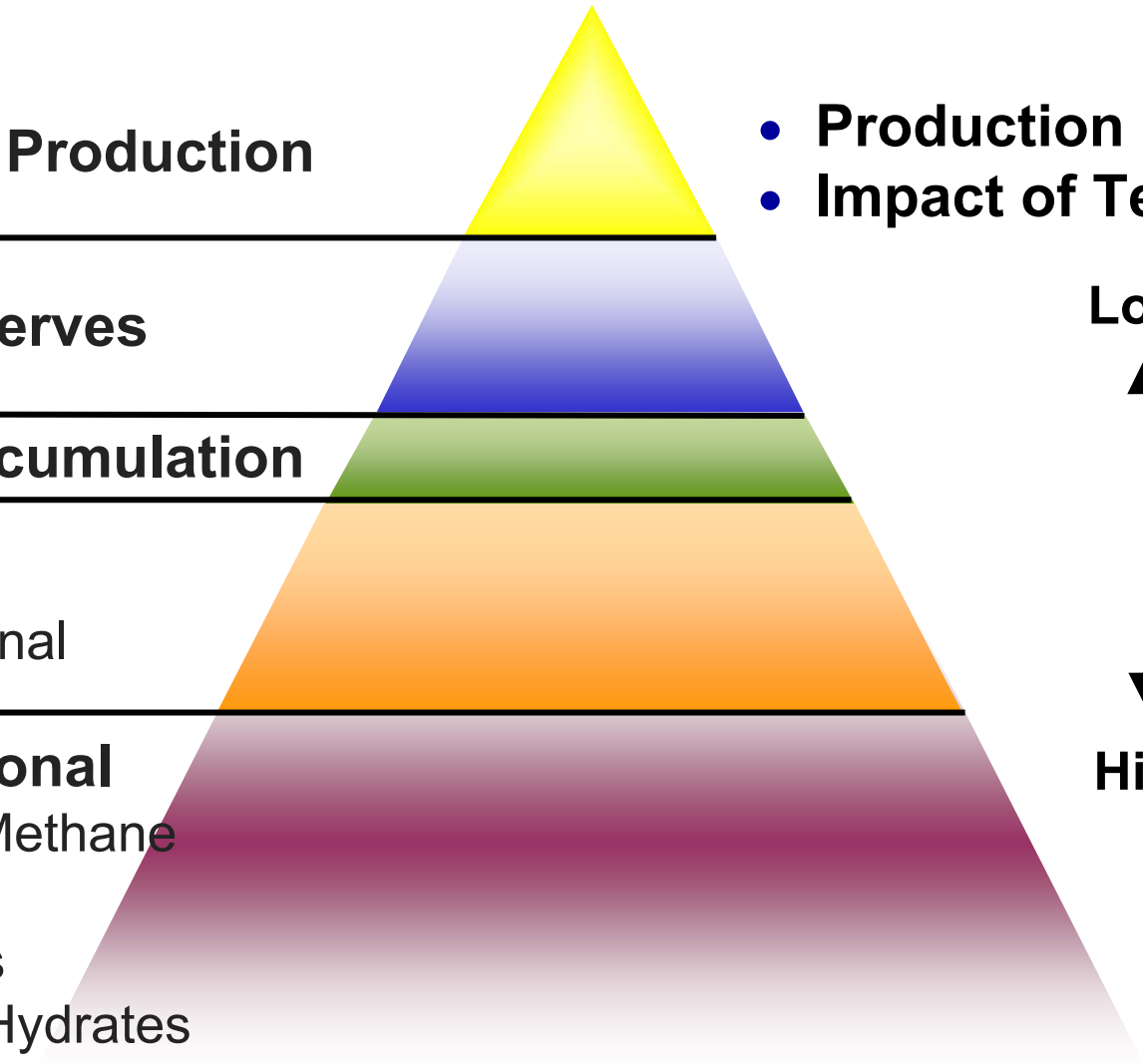
5,500 Tcf – 62-Year Supply at Current Use Rates



Oil & Gas Journal, December 2002, on DOE EIA website, accessed 2/26/04

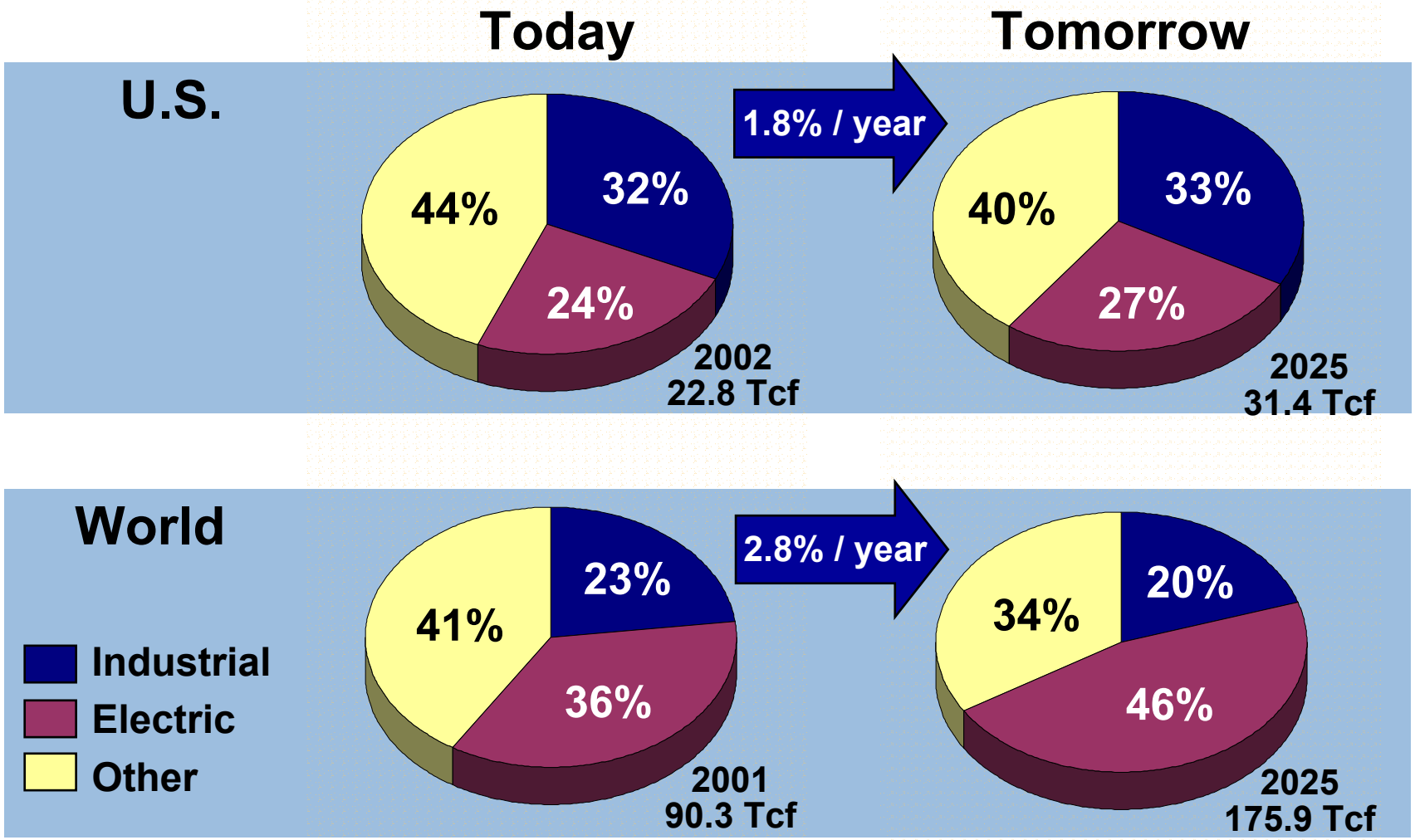
Natural Gas Pyramid

Notional View



Based on Advanced Resources International and 1999 NPC Assessment

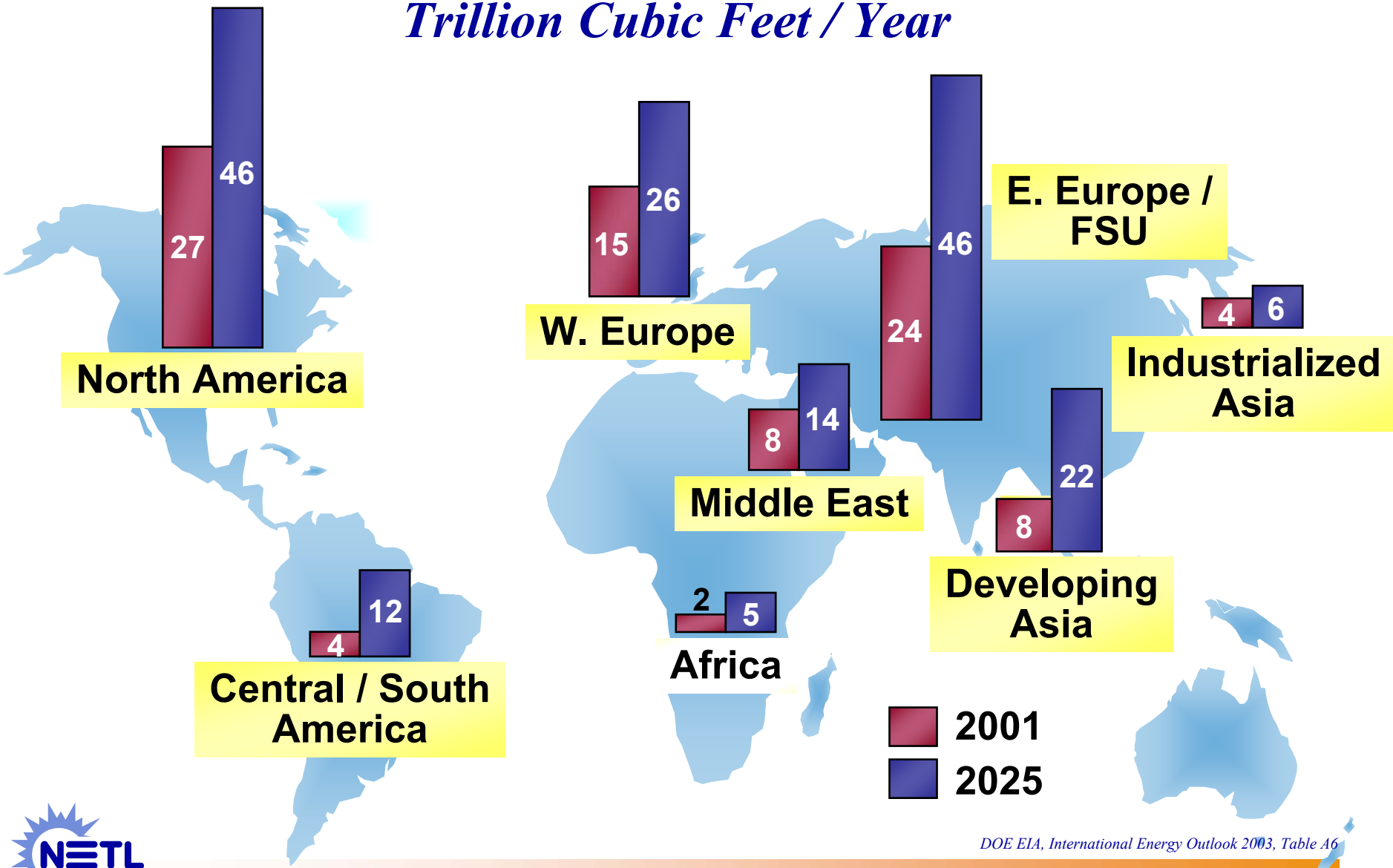
How Natural Gas Is Used



U.S. data: EIA, AEO 2004, Table A13
World data: EIA, IEO2003, Table A5,except for sector splits estimated from IEA WEO, Figure 3.9

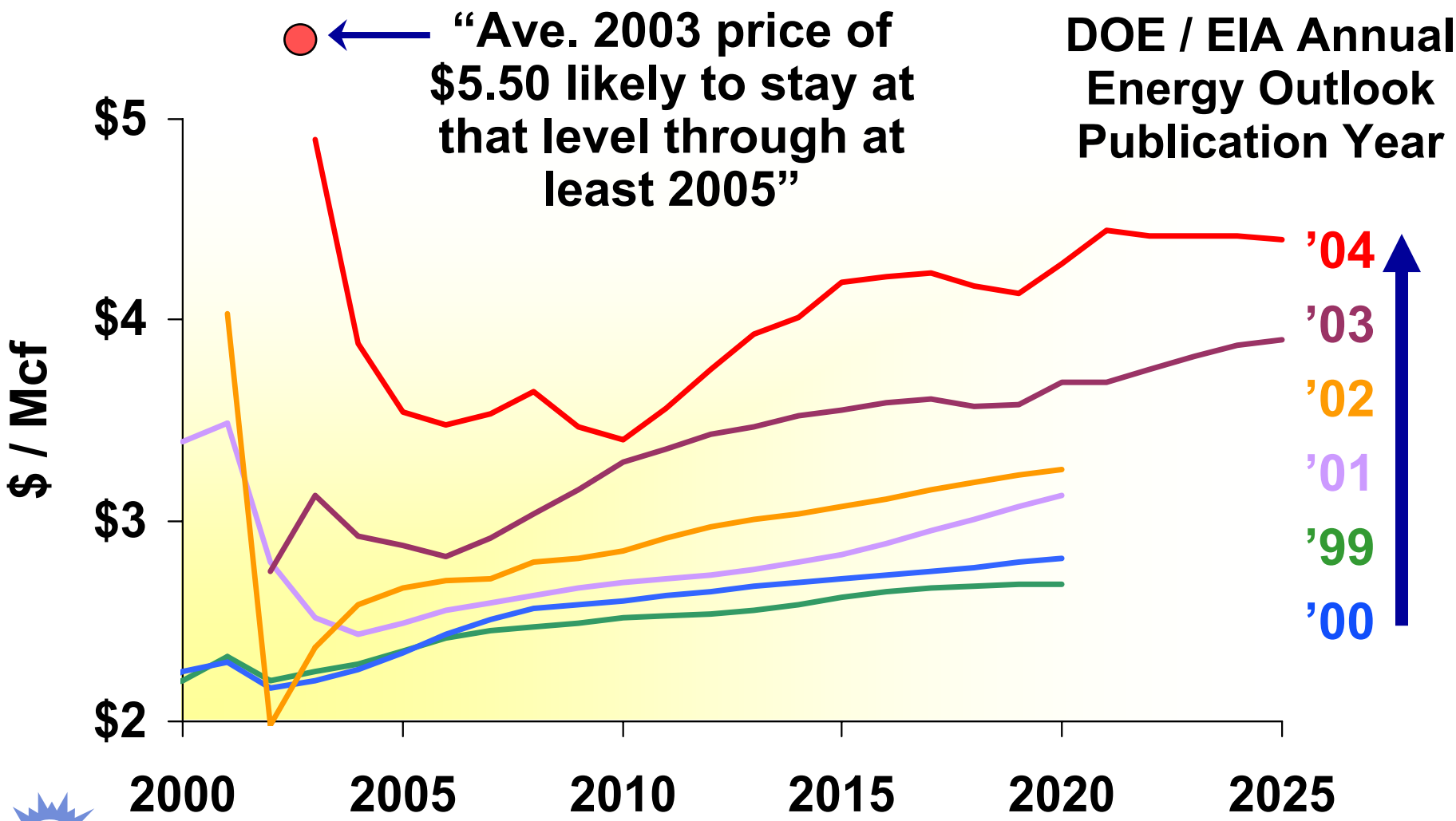
Natural Gas Consumption by Region

Trillion Cubic Feet / Year



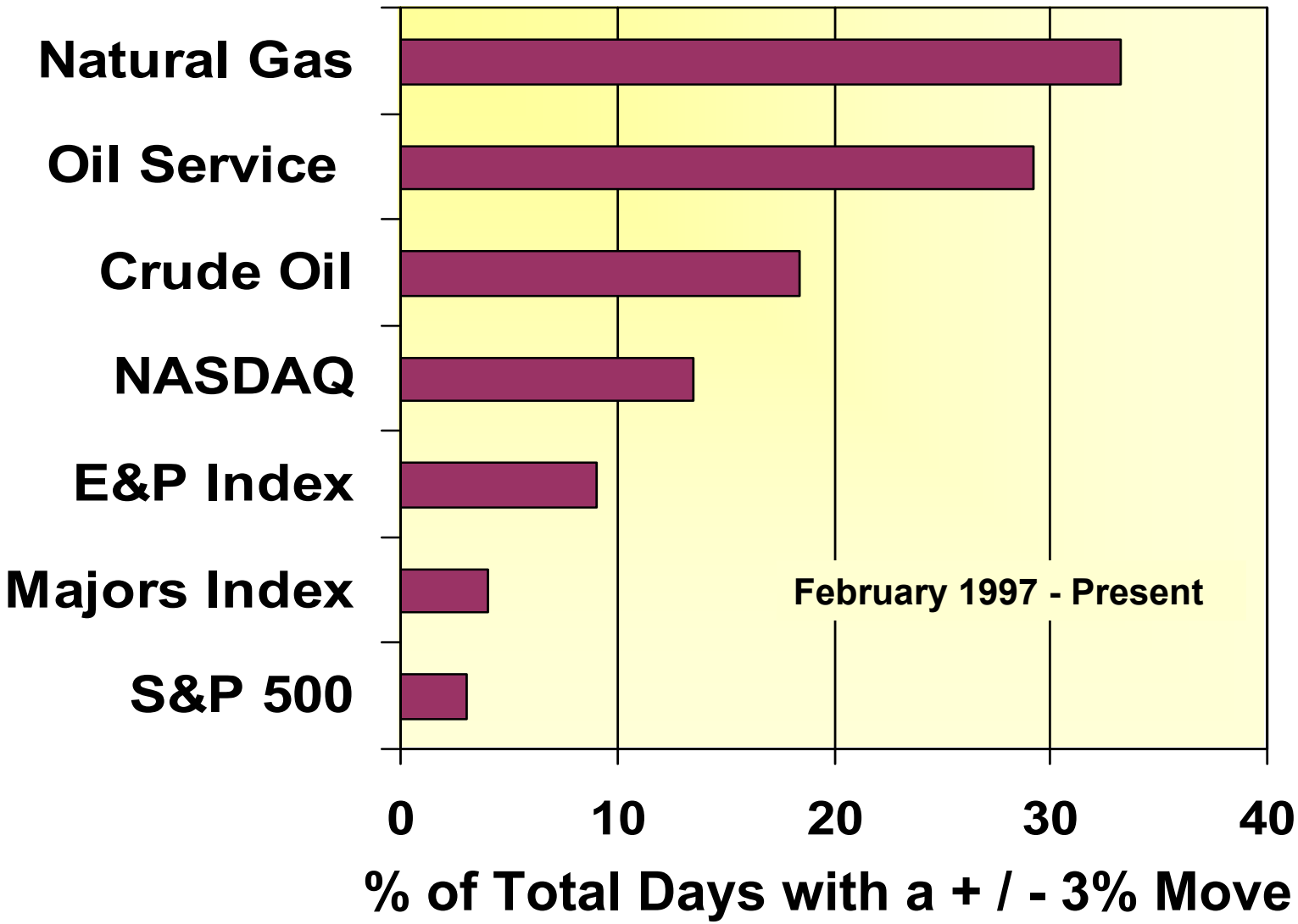
DOE EIA, International Energy Outlook 2003, Table A6

Increasing Natural Gas Prices in U.S.



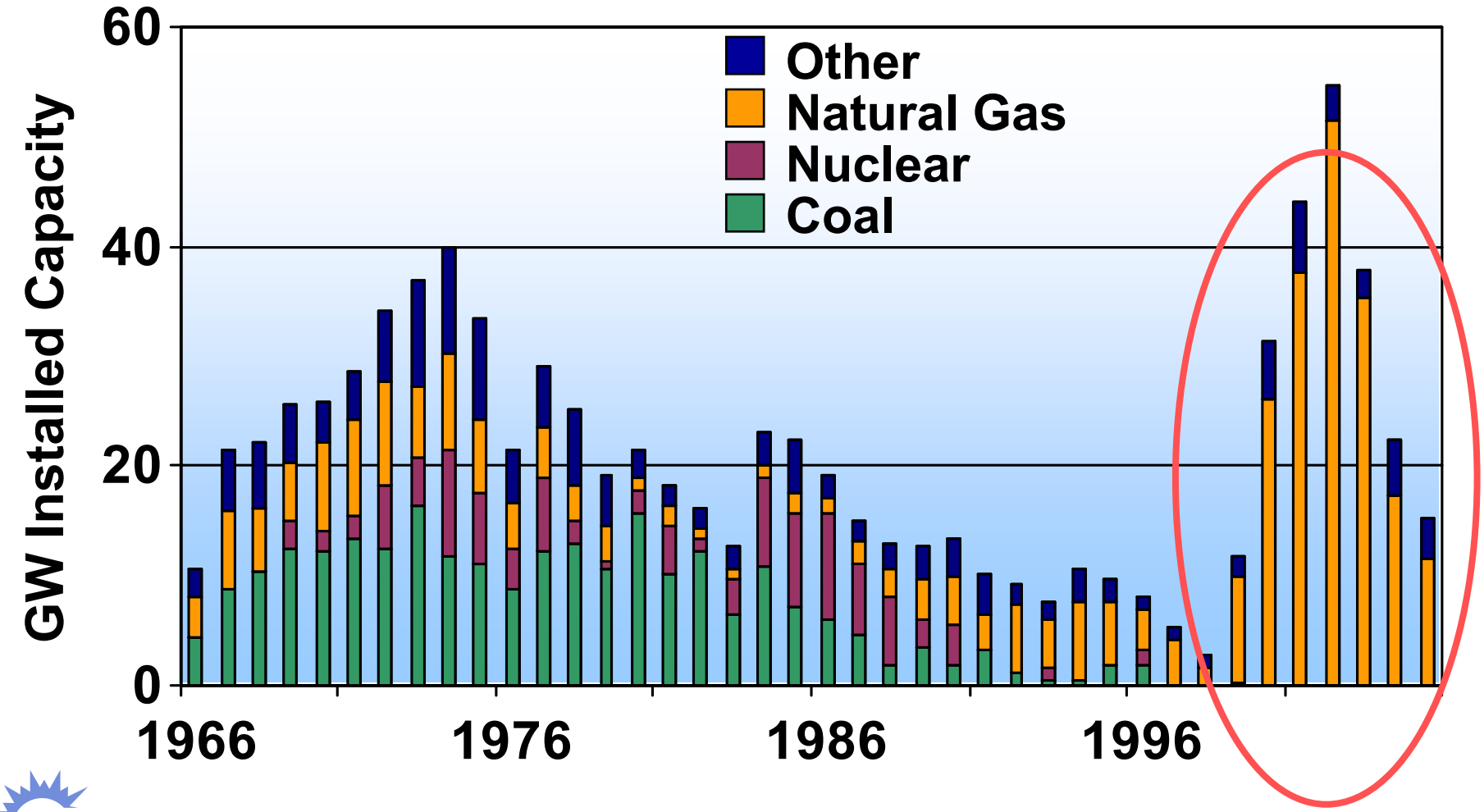
Lower-48 Well-head Price in 2002; Quote from Guy Caruso in March 4, 2004 hearing

U.S. Natural Gas Prices Are Volatile



200 GW of New Gas-Fired Capacity Since 1998

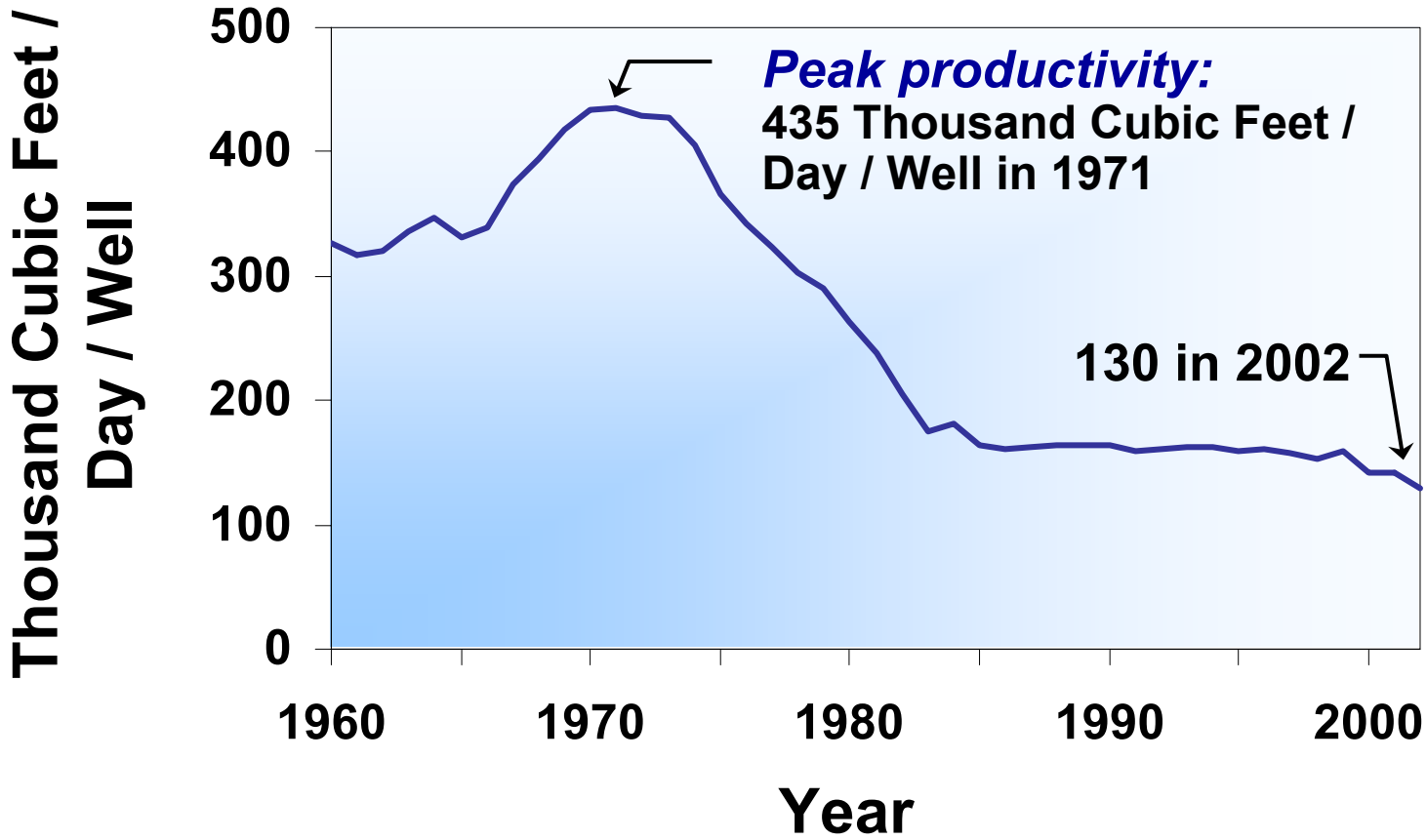
U.S. Generation Capacity Additions



NPC Study 2003 based on EIA, Platt's , AEP

Major North American Supply Basins Mature

U.S. Gas Well Productivity Drops 2/3

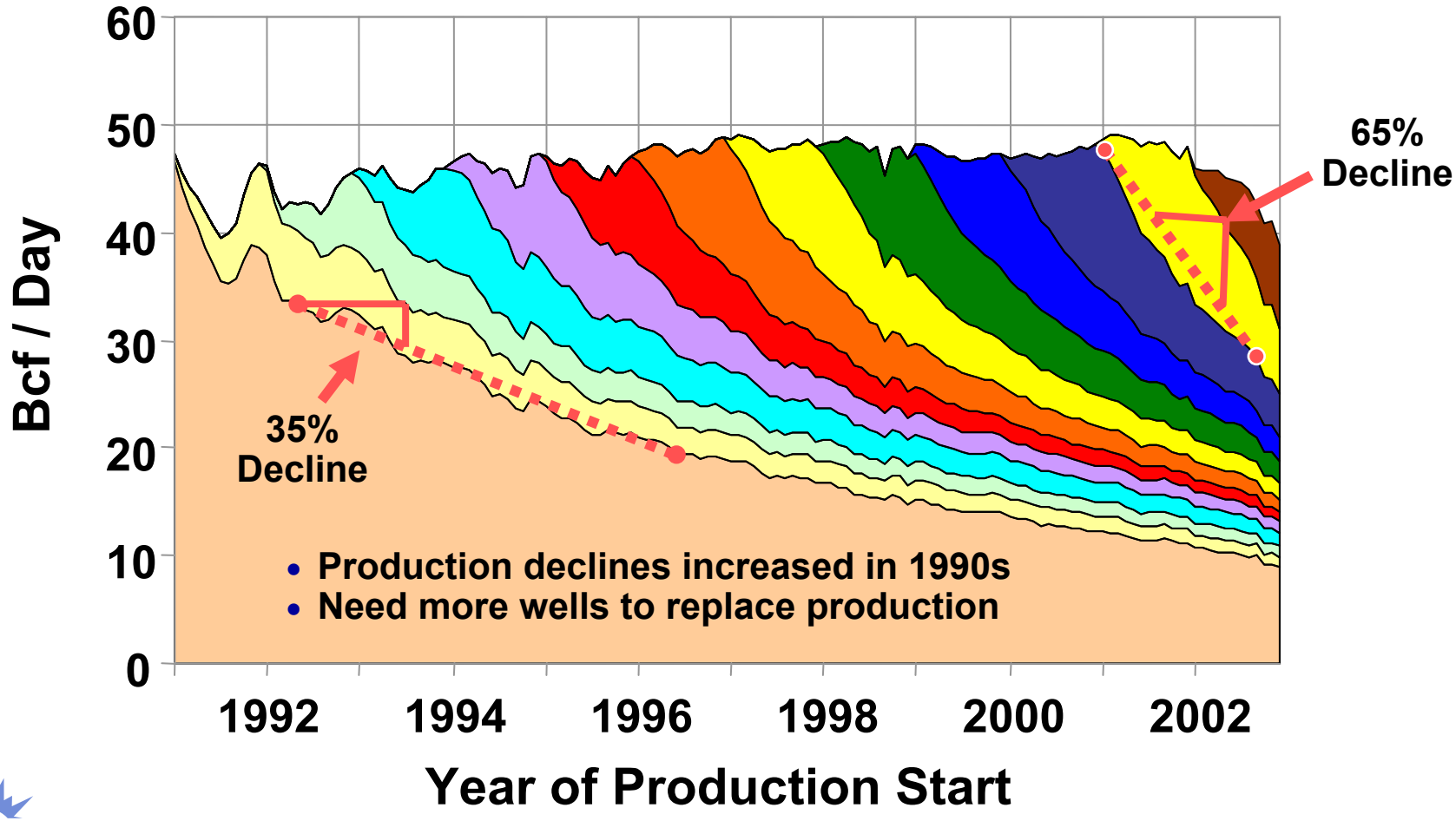


DOE EIA, Annual Energy Review 2002, Figure 6.4

On a Treadmill!

We Are Draining Wells Quicker

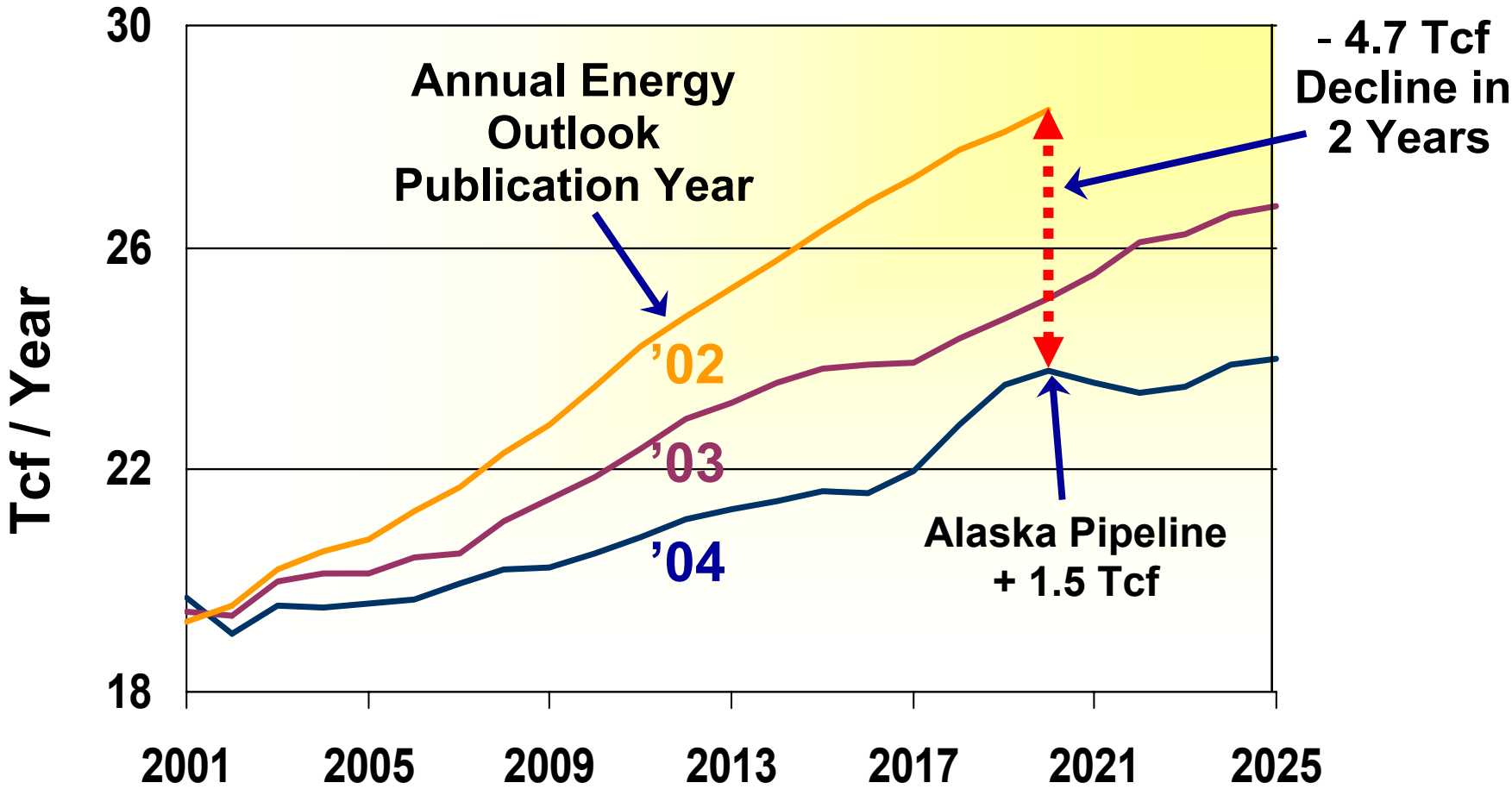
Lower-48 Production Decline Trends



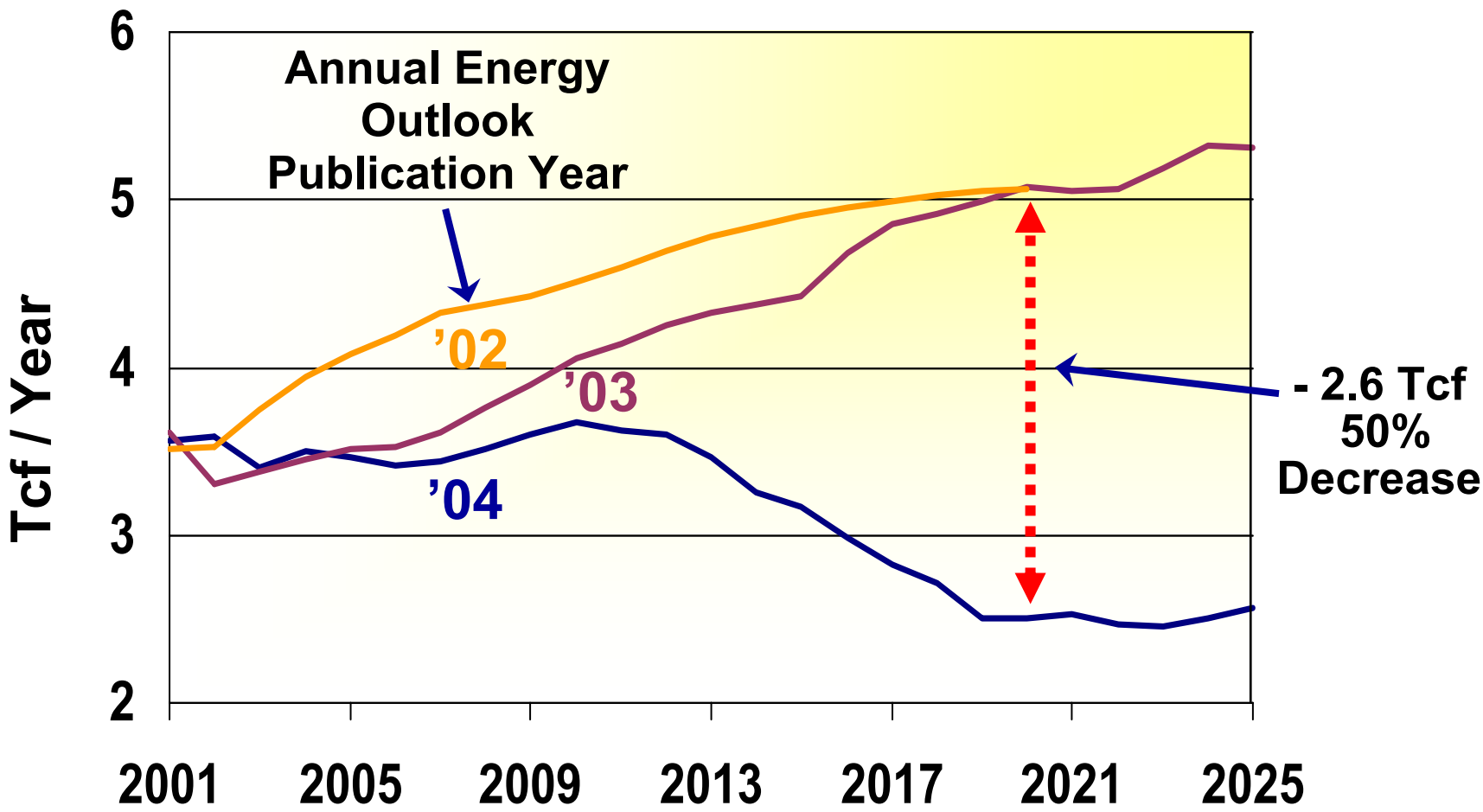
NPC Study September 2003; Base Data from IHS

Gas Production Forecast Changed Quickly

Domestic Natural Gas Forecast

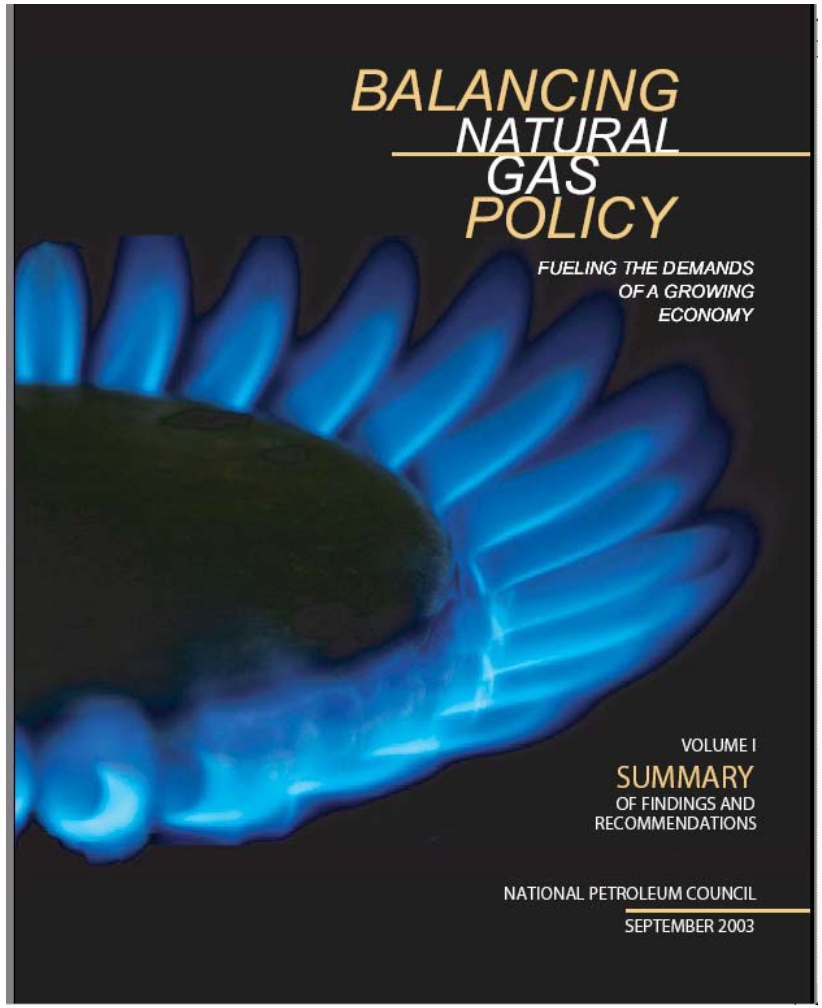


Reduced Imports of Canadian Gas Also Forecasted



NPC 2003 Natural Gas Study
September 2003

- 18-month comprehensive assessment of N.A. supply & demand
- Broad industrial participation



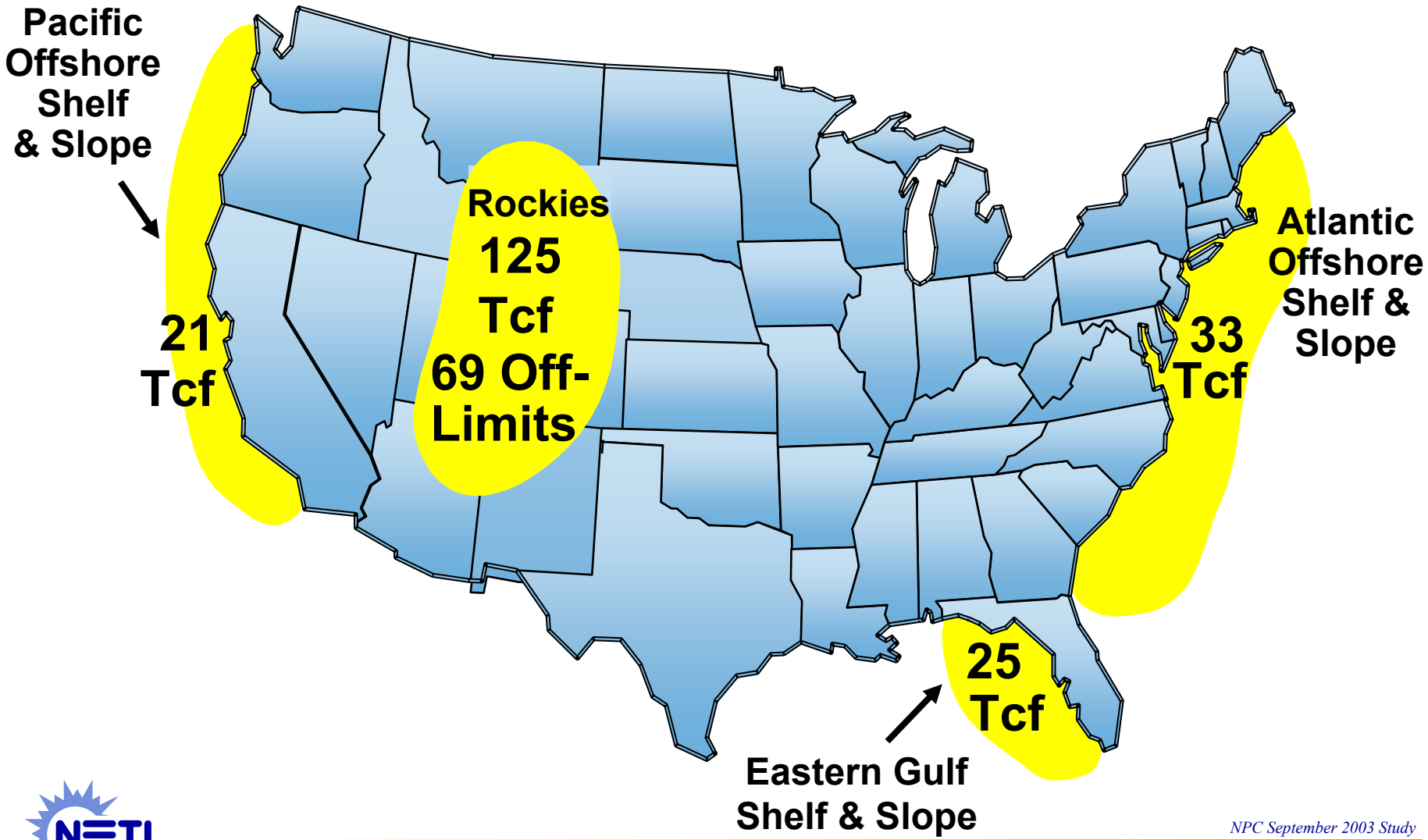
Higher Prices Reflect Fundamental Shift in Supply / Demand Balance

Traditional North American gas producing areas

- Can only supply 75% of projected demand
- At best, production remains flat

- **New large-scale resources (LNG, Arctic) could meet 20-25% of demand**
  - Have higher cost, long lead times, development barriers

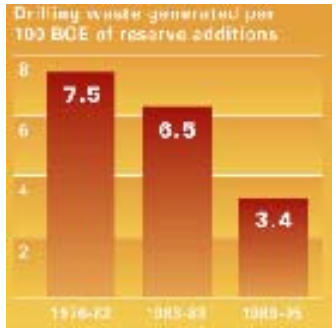
Technical Resource Impacted by Access Restrictions



Technology Reducing Environmental Impact

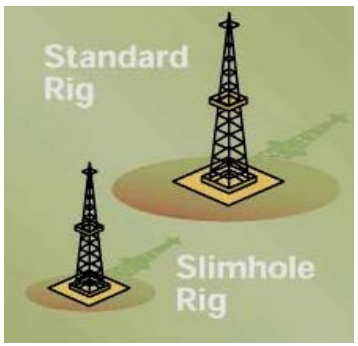
Natural Gas & Oil Supply

Fewer wells to add same level of reserves



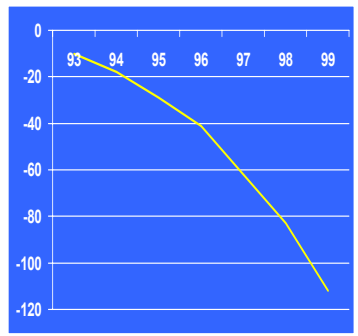
Lower drilling waste volume

Lower produced water volumes



Smaller footprints

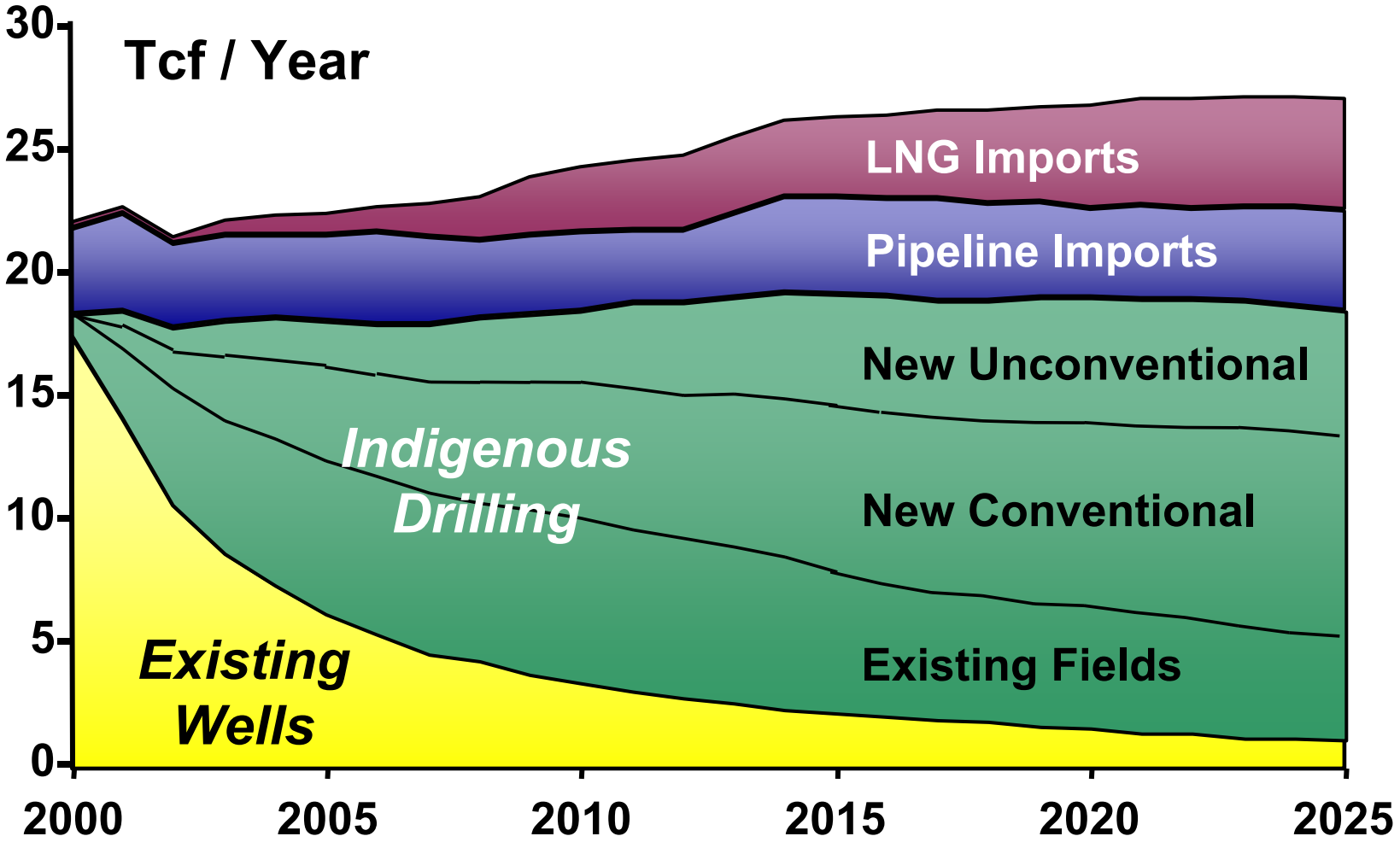
Greater protection of unique and sensitive environments



Reduced air pollutants and greenhouse gas emissions

Future Supplies Come from Traditional /New Sources

U.S. Natural Gas Supplies: 2000-2025



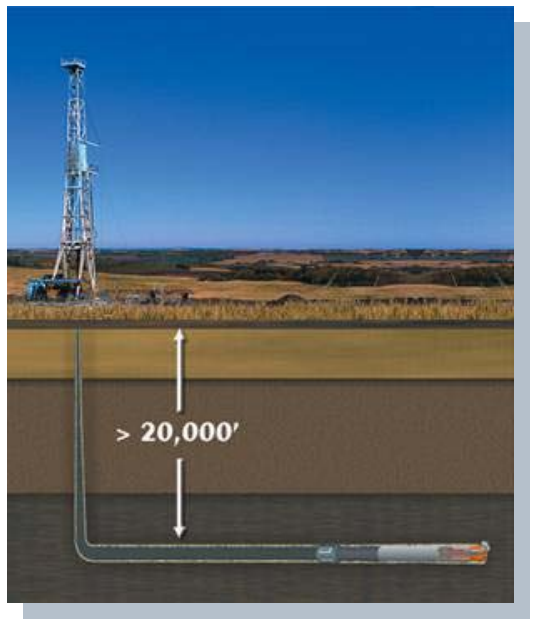
DOE Developing Improved Technology for Near-Term Unconventional Gas

Coal-Bed Methane

Improved technologies for handling produced water

Deep Trek

Improved technologies for high-temperature, high-pressure, corrosive conditions found at depths greater than 20,000 feet



For Longer Term, Methane Hydrates May Be Promising

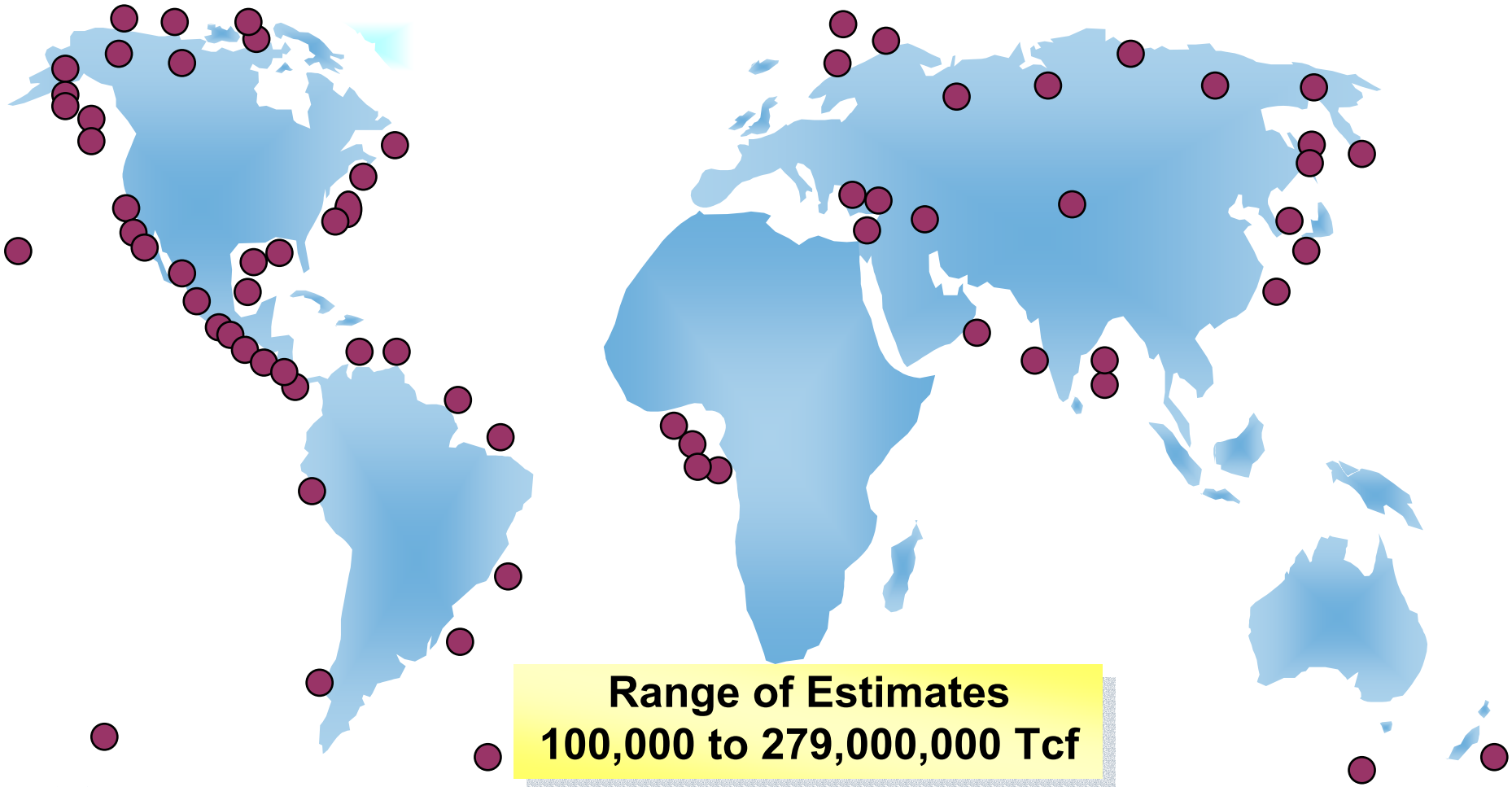
Mallik Gas Hydrate Project

- **First dedicated hydrates test wells**
  - Depressurization proved more effective than heating
- **Mackenzie Delta, Canada**
- **International team**

Well photo by Hideaki Takahashi, Japex Canada Ltd., courtesy of Natural Resources Canada

Methane Hydrate Deposits

World's Known and Expected Locations

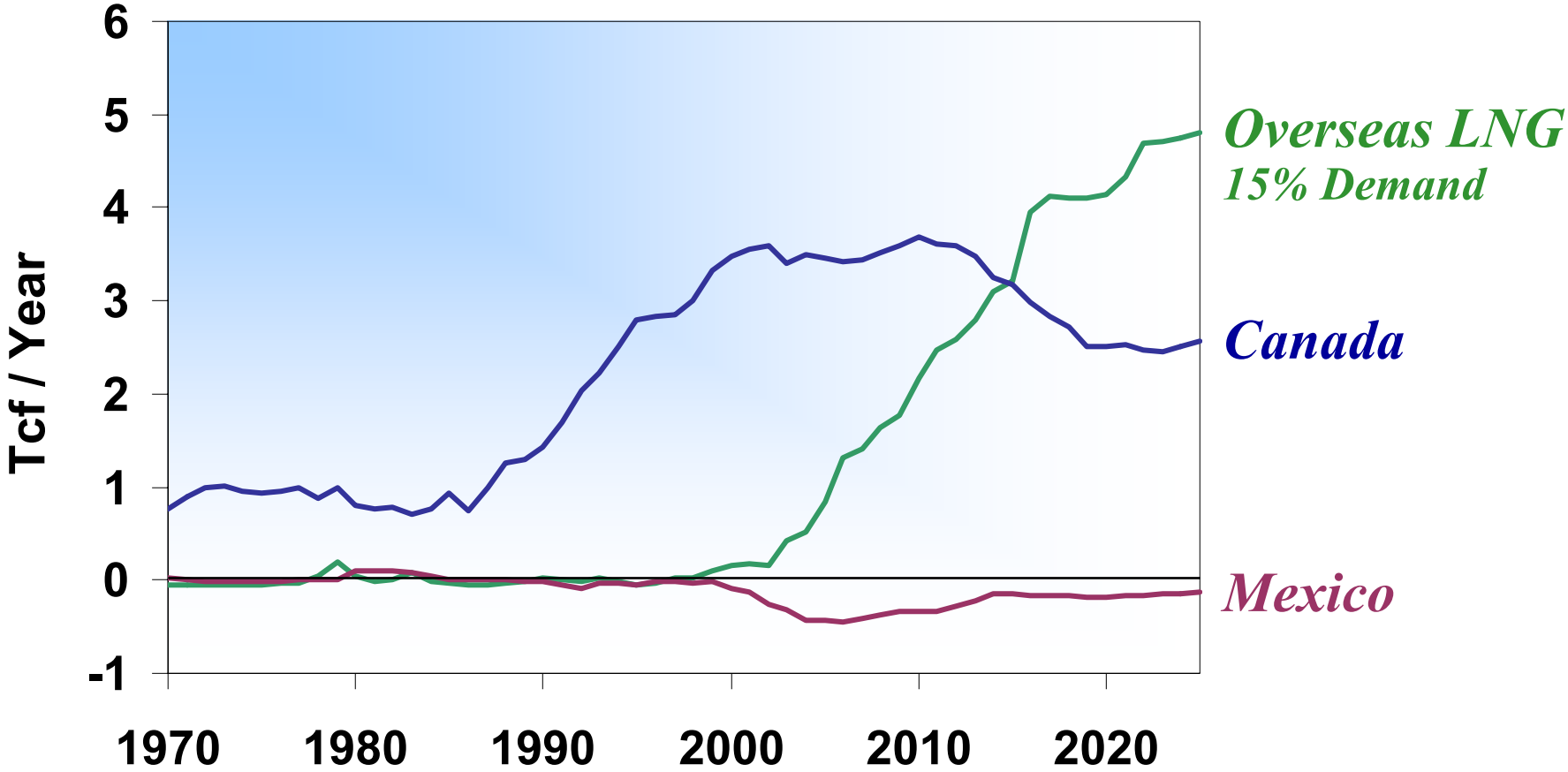


Range of Estimates
100,000 to 279,000,000 Tcf

Adapted from U.S. Geological Survey, based on K.A. Kvenvolden, "Methane Hydrate – A Major Reservoir of Carbon in the Shallow Geosphere?" Chemical Geology, Vol. 71 (1988)

Increasing U.S. Reliance on Imported LNG

Net U.S. Imports of Natural Gas 1970 – 2025

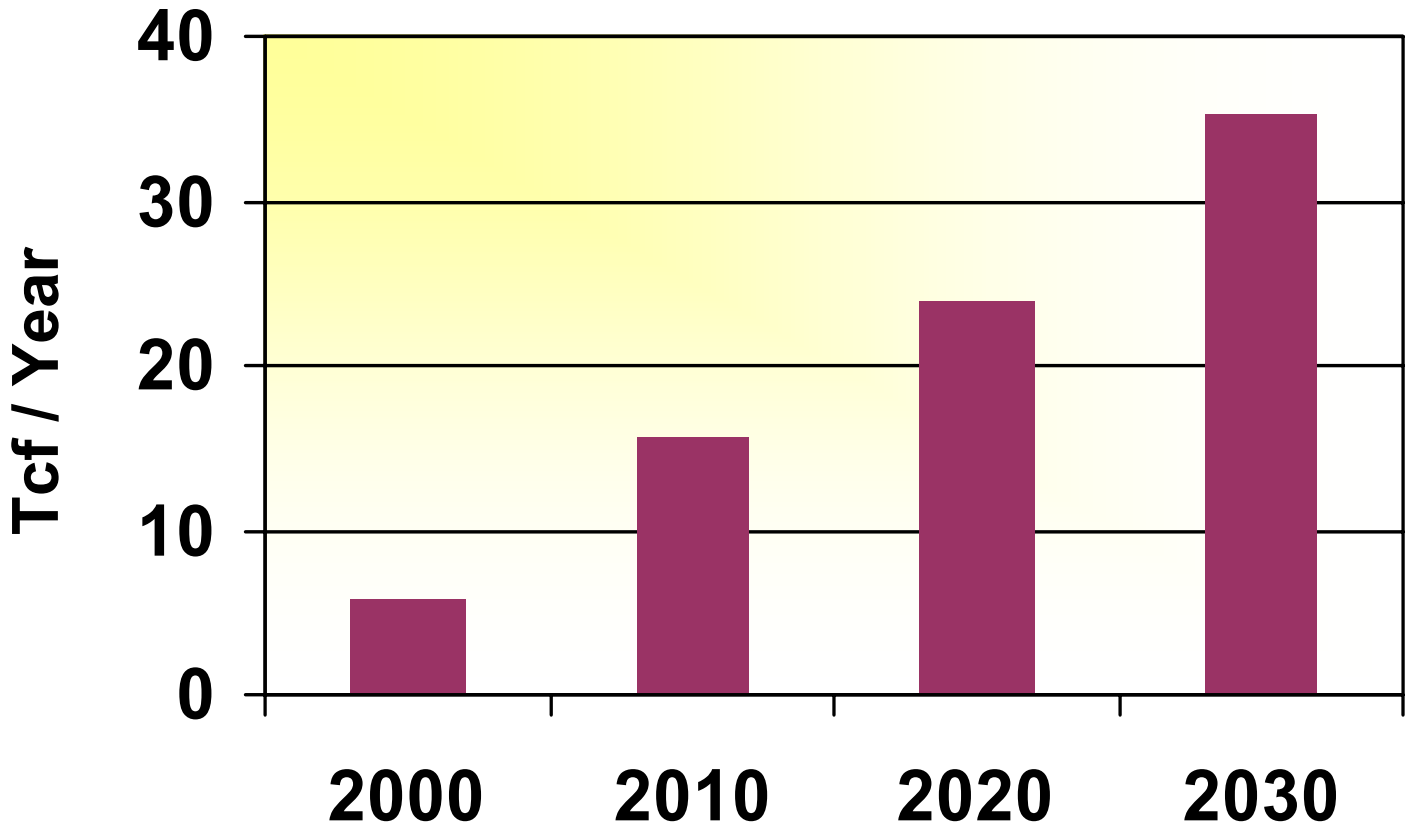


Ten-Fold Increase from 2003 to 2025

DOE EIA, Annual Energy Outlook 2004, Figure 89

World LNG Capacity

6 to 10-Fold Increase Over 30 Years



IEA, World Energy Investment Outlook 2003

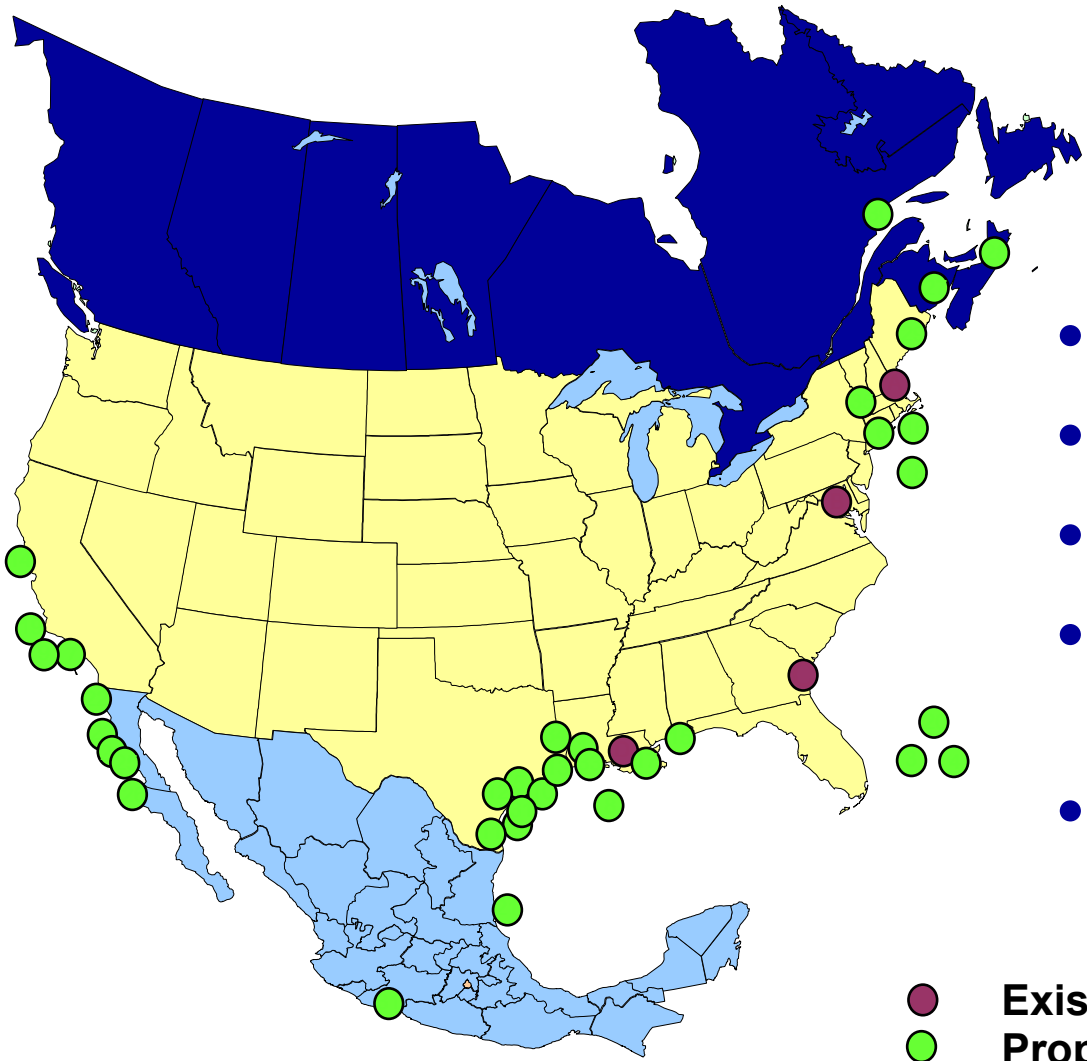
World LNG Infrastructure

- **6 Tcf capacity in 2003**
- **17 liquefaction terminals**
- **40 regasification terminals**
- **151 tankers**
  - 55 under construction
- **12 exporting countries***
- **12 importing countries***
  - Japan imports ½ world production

Photo from Conversion Gas Imports, A Texas Limited Liability Company, Under DOE Cooperative Agreement DE-FC26-02NT41653

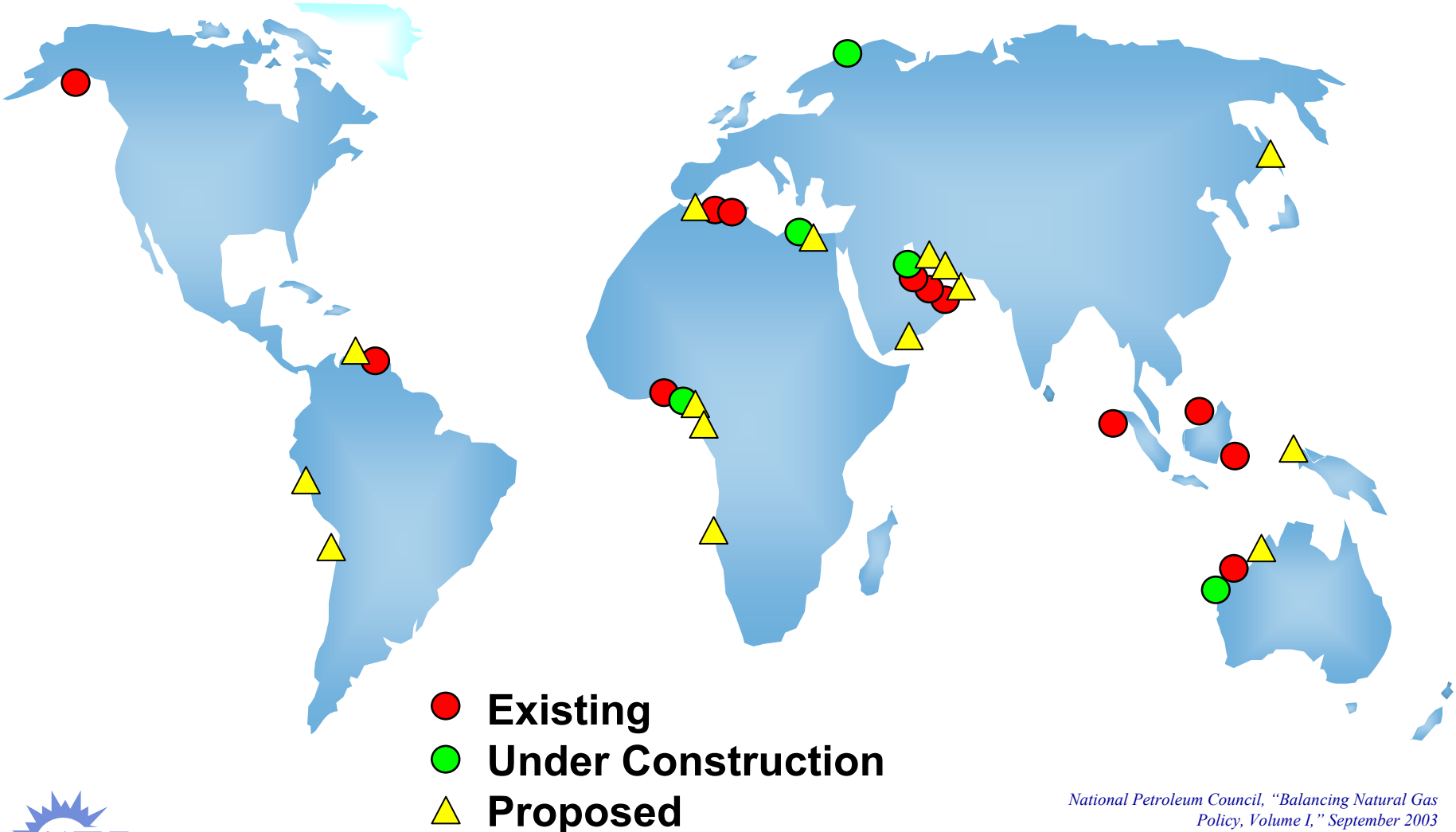
**2002*

North American LNG Regasification Terminals



- 4 existing terminals
- 32 active proposals
- 15 Tcf if all built
- None under construction
- 7-year construction

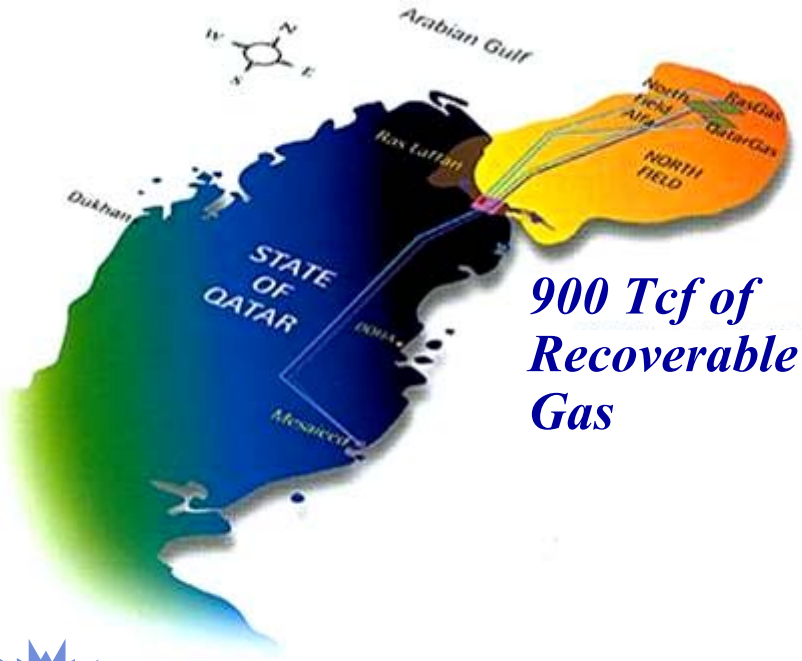
Numerous Global LNG Liquefaction Projects Competing to Meet Growing Demand



National Petroleum Council, "Balancing Natural Gas Policy, Volume I," September 2003

Qatar Has Massive LNG Potential

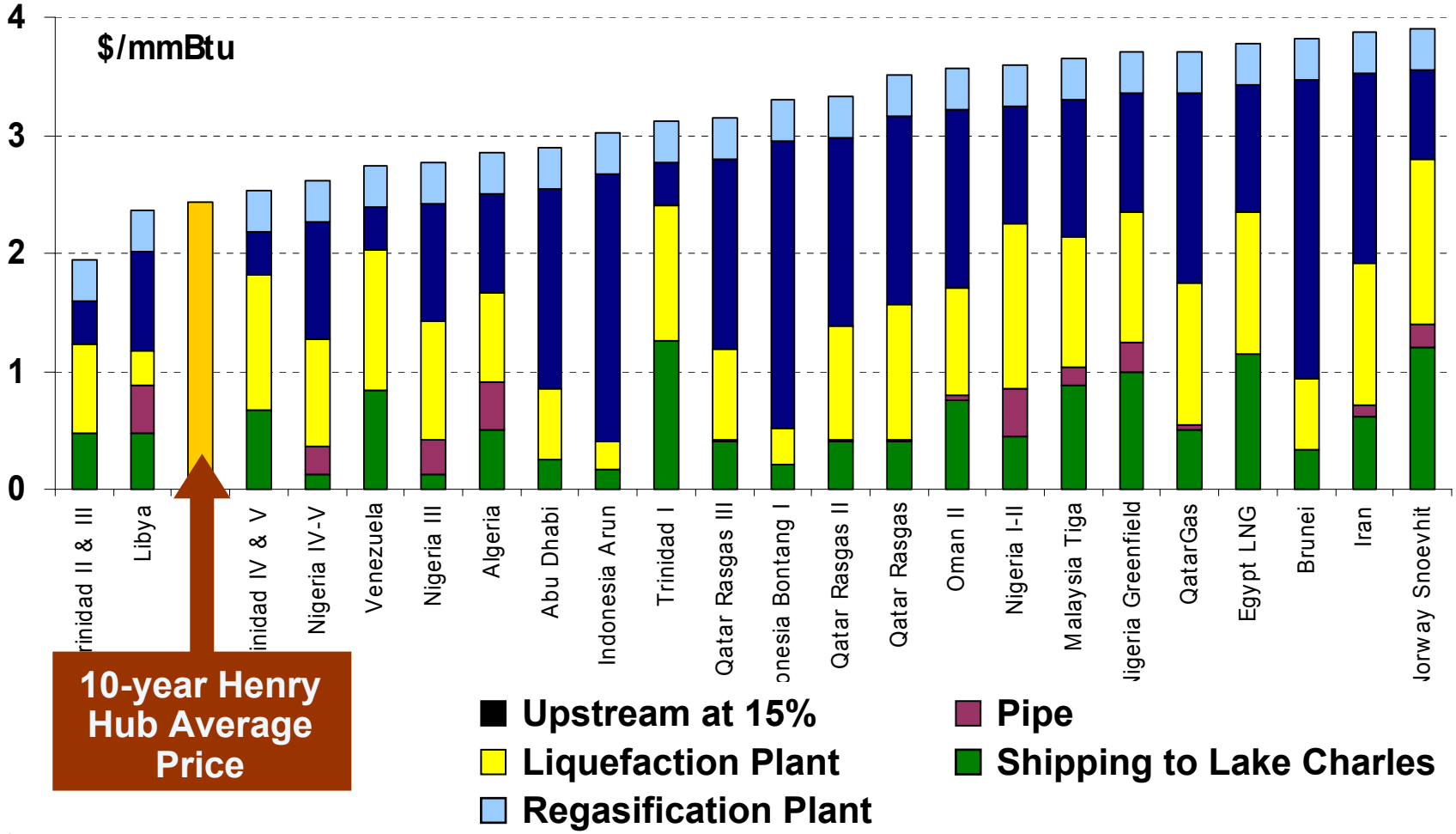
- **More reserves in one field than entire U.S.**
- **Higher gas prices leading to:**
  - Development of very large, low-cost gas reserves
  - Large scale LNG and GTL facilities



900 Tcf of Recoverable Gas

Delivered LNG Costs to Lake Charles

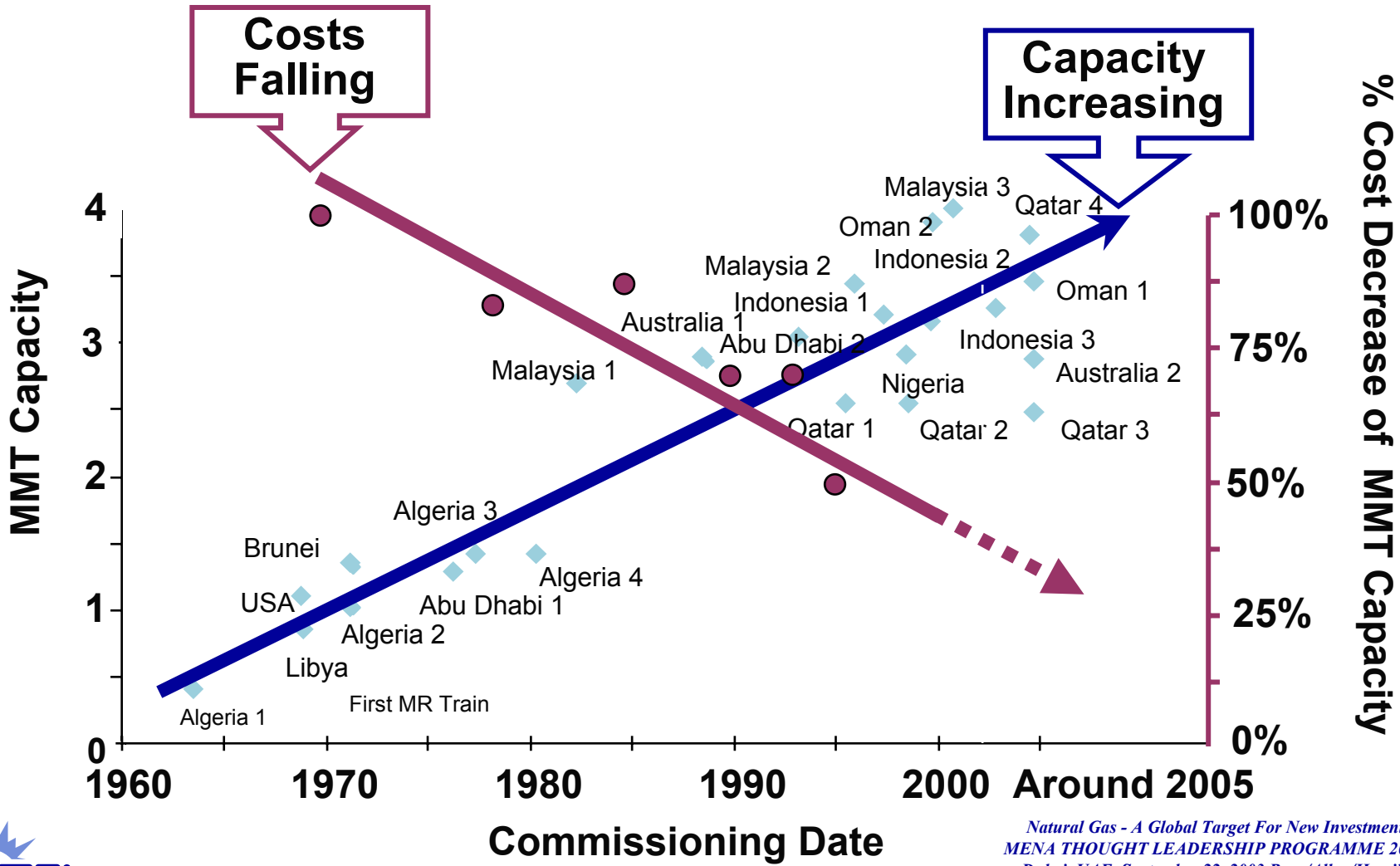
All-in Costs of $2 - $4 /mmBtu



Source: Deutsche Bank estimates 2002

LNG Gasification Plants

Technology Improving; Plant Sizes Increasing



LNG (and Pipeline) Safety

Rescue Worker at Algeria LNG Plant Disaster

- 40-year history; 33,000 tanker voyages; no major accidents
- January 2004 accident at Algerian LNG complex killed 27
- Regasification has fewer complications
- FERC / DOT / Coast Guard report in March on LNG terminal safety

Photo from California Energy Commission Website

Dramatically Changed Perspectives On Infrastructure Security

Tanker Docked at Everett, Massachusetts

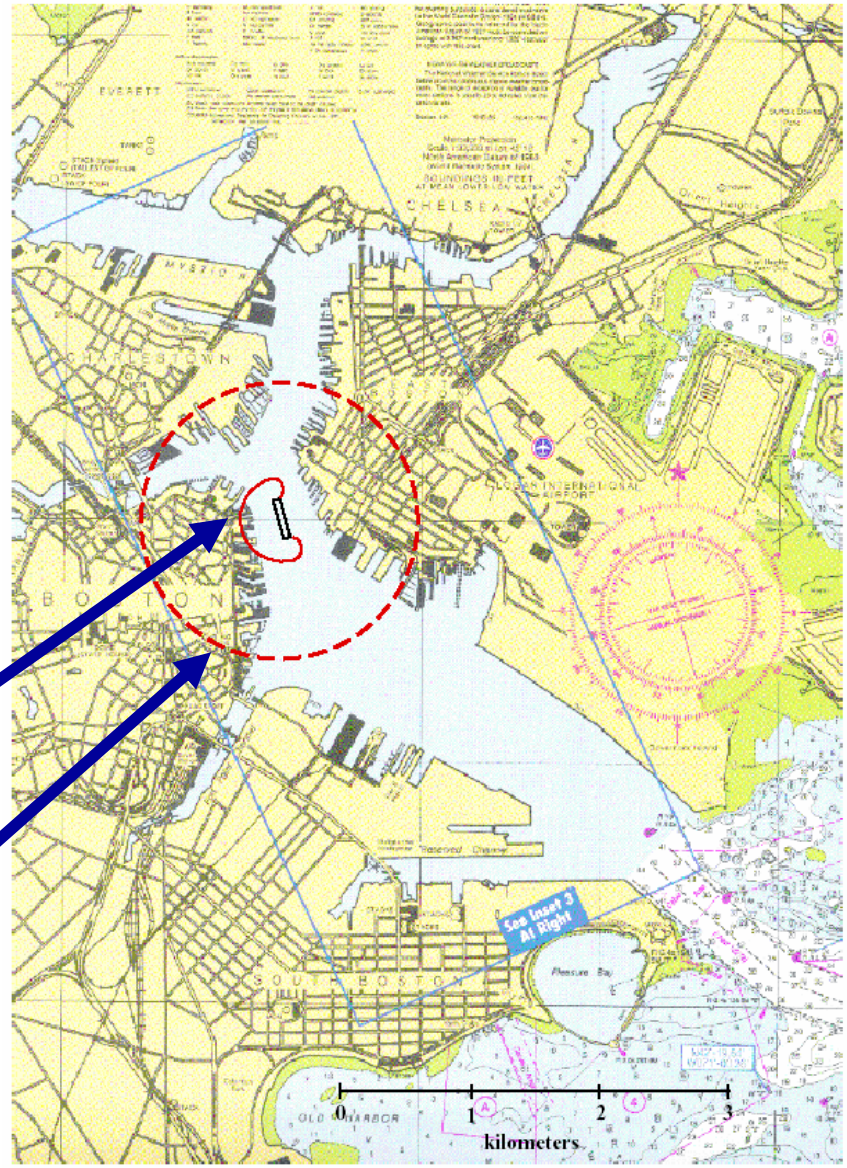
Is It Safe?, Boston Globe, July 27, 2003

FERC's LNG Safety Review Includes This Type of Concern

Typical Danger Zone from LNG Spill and Pool Fire in Boston Harbor

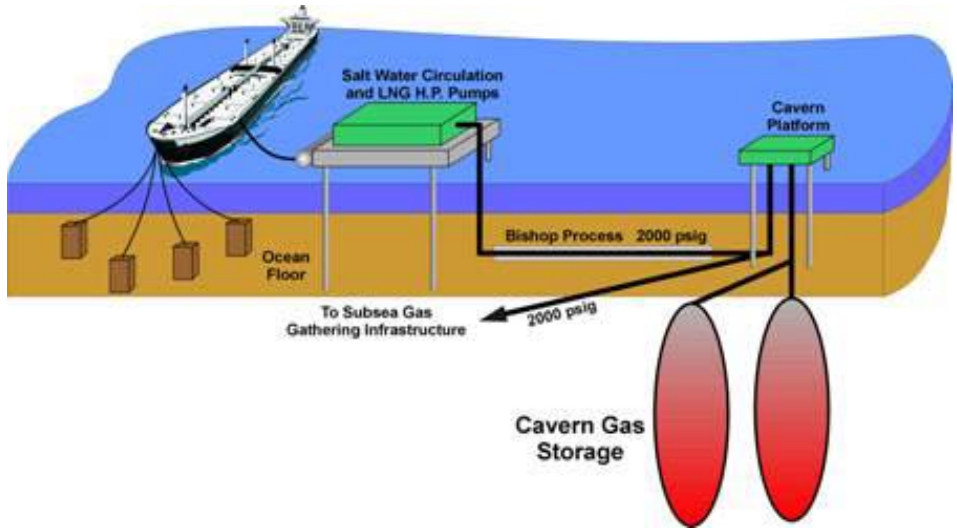
Outer Edge Of Thermal Radiation Zone (5kW/m2)

Maximum Extent Of Fire Pool



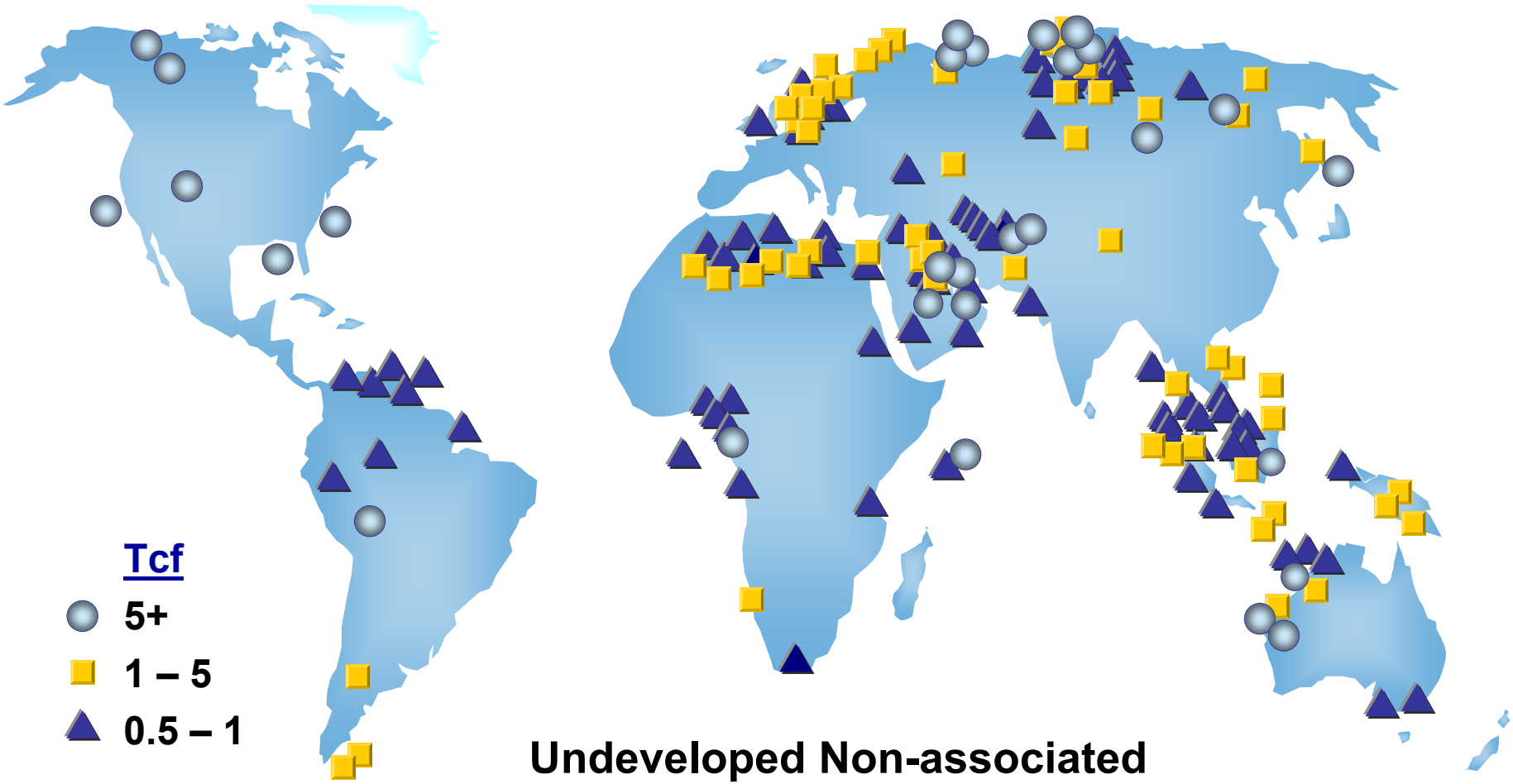
Siting Options
LNG Regasification Terminals

- **On shore**
- **Crossboarder**
  - Mexico
  - Bahamas
- **Offshore**
  - El Paso Energy Bridge
  - Bishop Process



Bishop Process
- **Offloading**
- **Regasification**
- **Salt Cavern Storage**

Worldwide Stranded Gas



Undeveloped Non-associated Gas Fields Larger Than 0.5 Tcf

Source: Petroconsultants S.A.

Options for Stranded Gas Resources

- **Reinject**
- **Flare**
- **Expand local uses**
  - Petrochemicals
  - Basic industries, e.g., aluminum
- **Build pipeline**
- **Convert to transportable product**
  - Gas-to-liquids
  - LNG
  - Gas-by-wire

Gas-Fired Distributed Generation

DG Benefits

- Defer new capacity
- Relieve transmission congestion
- Enhance reliability
- Improve efficiency
- Promote green image

Fuel Cells

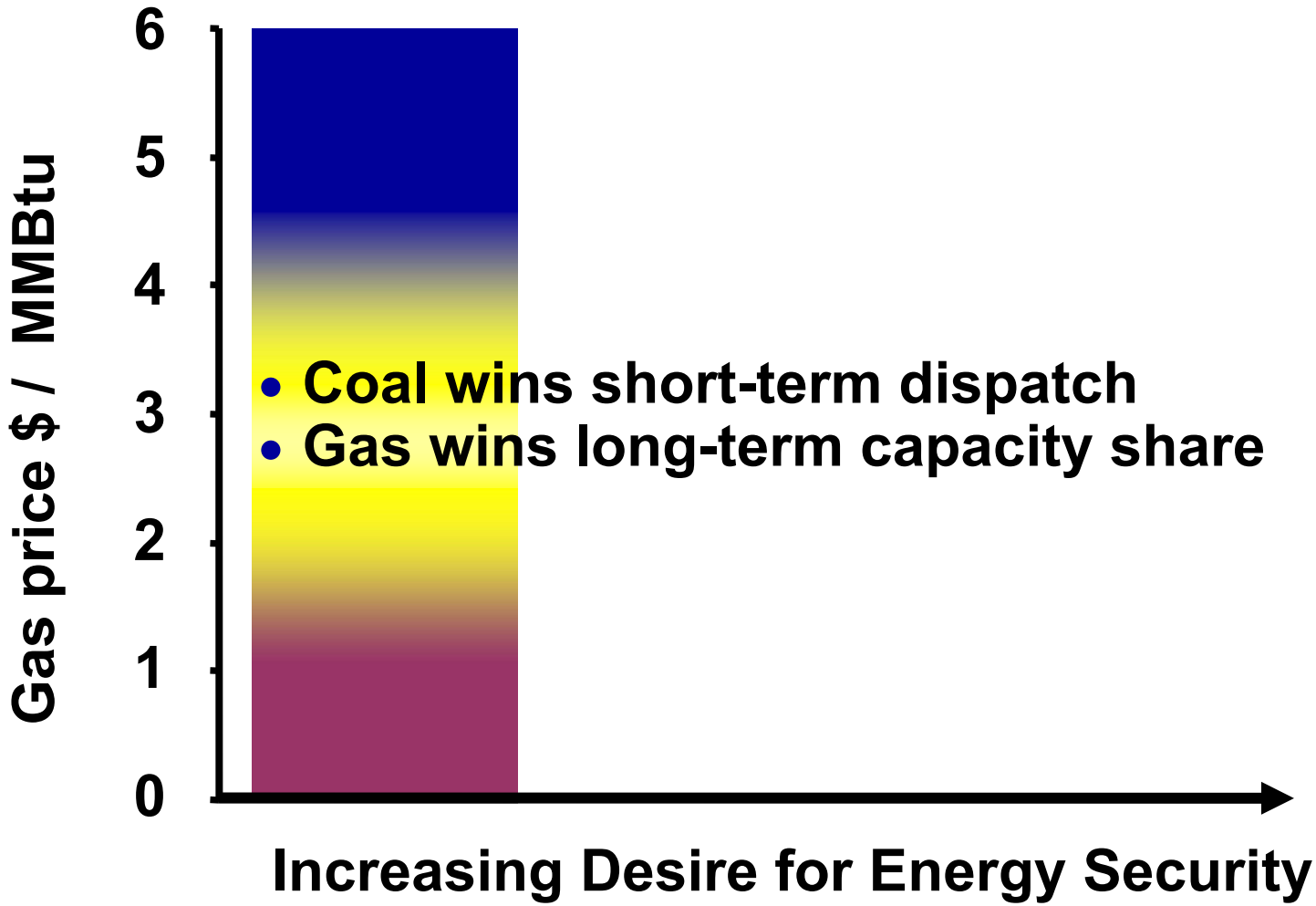
Reciprocating Engines

Small Turbines

Microturbines

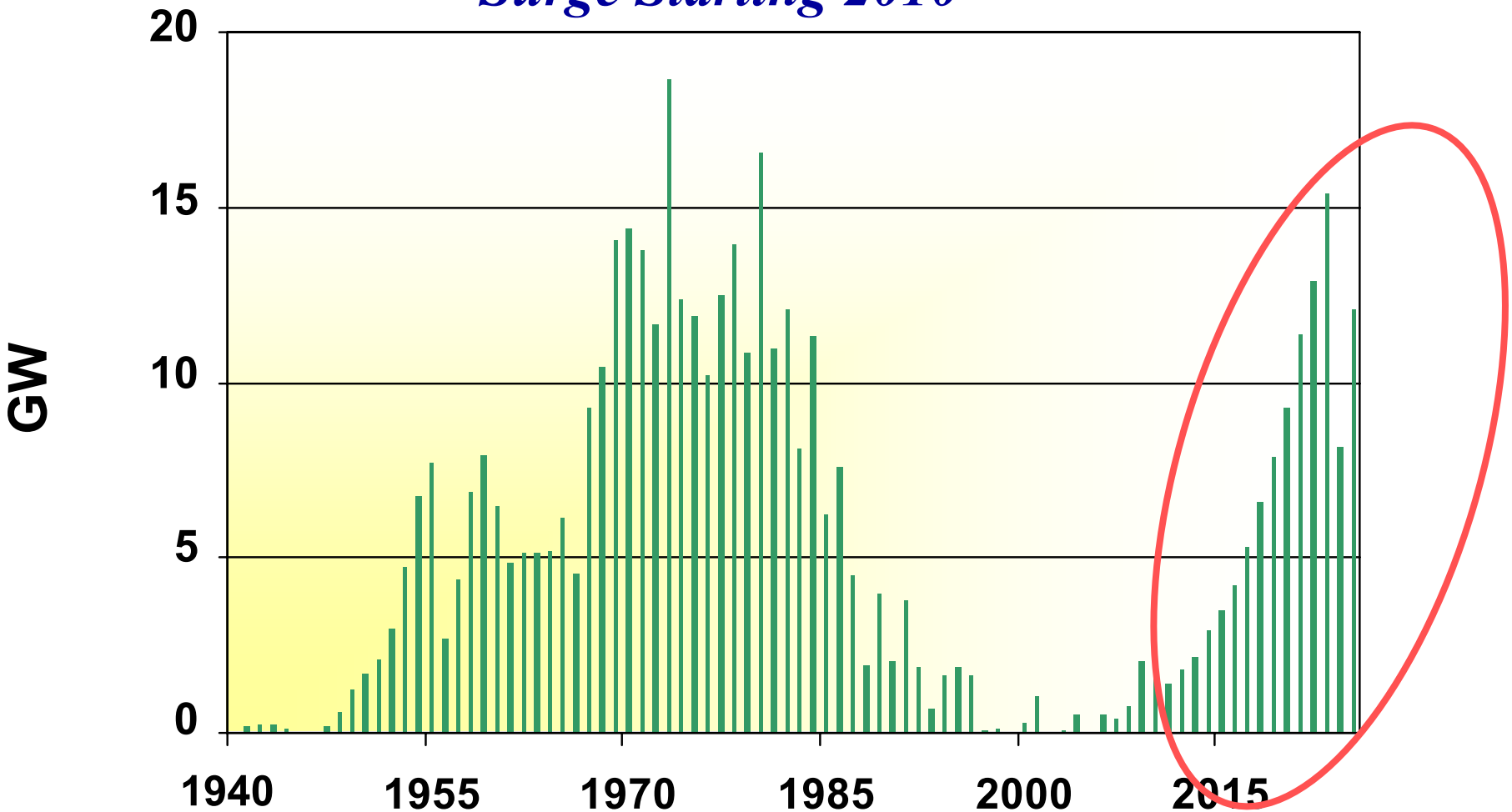
Natural Gas / Coal Competition

New Plants



Coal Capacity History and Forecast

Surge Starting 2010

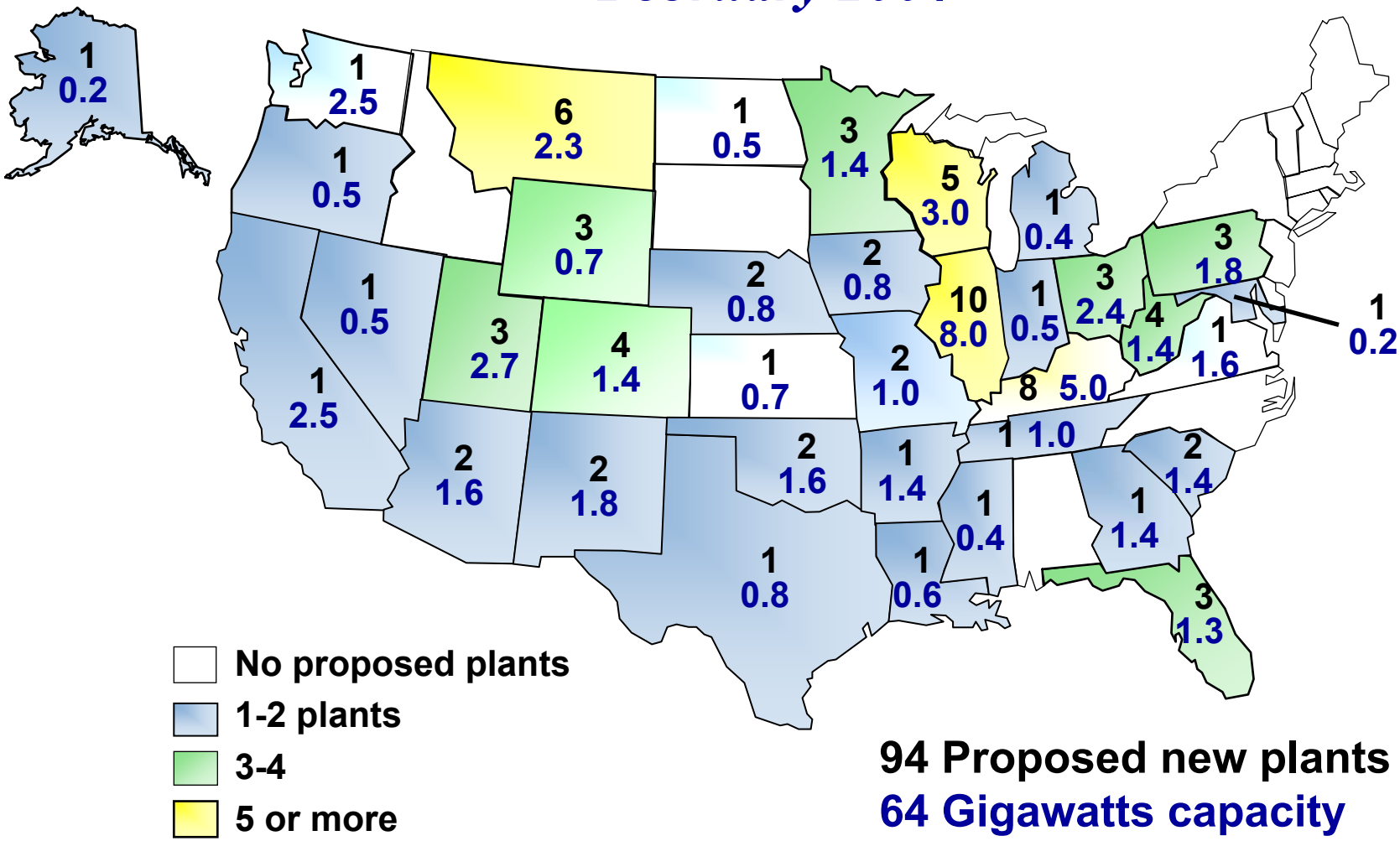


Will Nation Be Prepared to Meet This Forecast?

Forecast - Annual Energy Outlook 2004; Historic Data - UDI 2001 Operating Data

Proposed New Coal Power Plants

February 2004



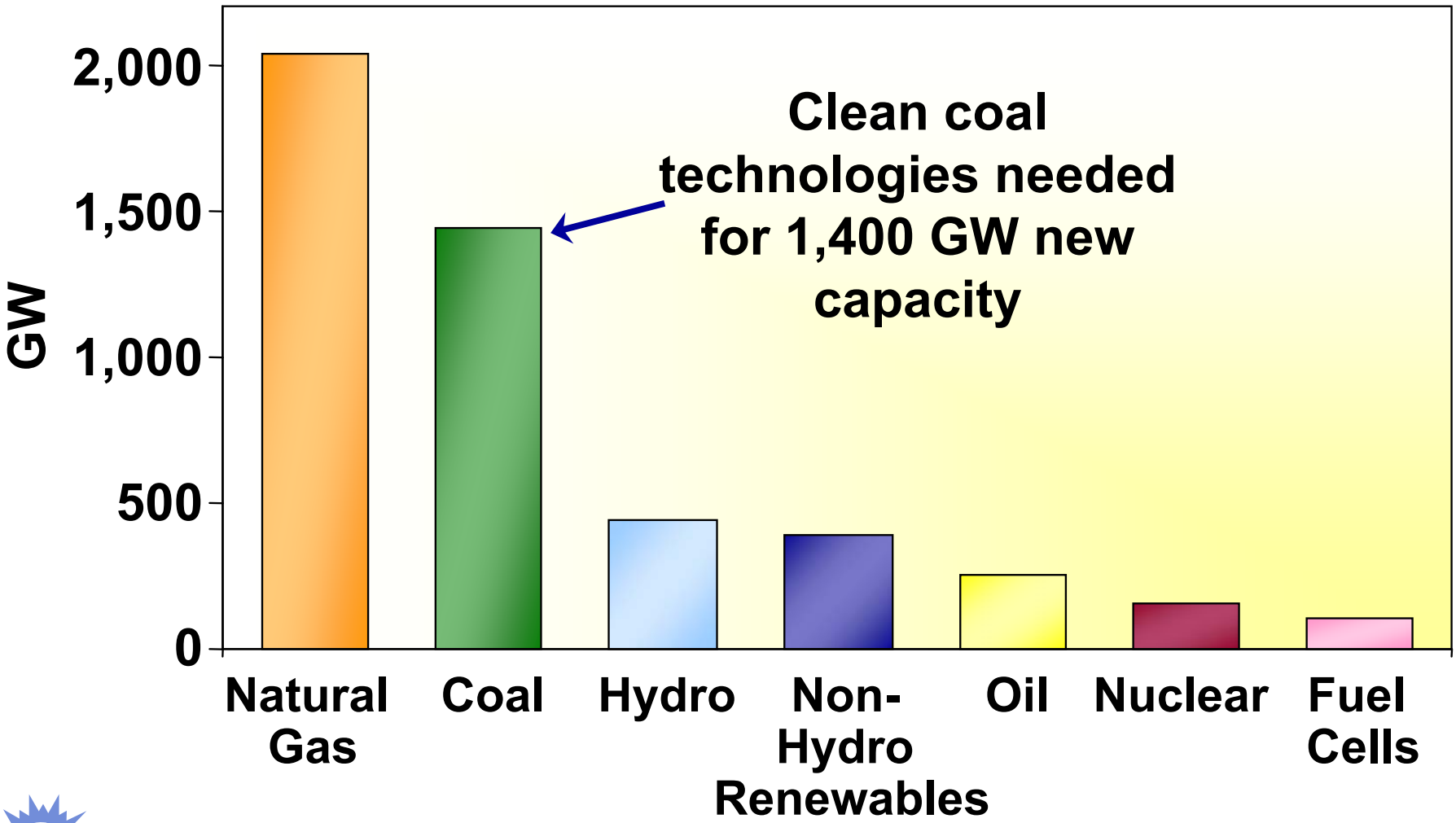
94 Proposed new plants

64 Gigawatts capacity

http://www.netl.doe.gov/coalpower/oces/pubs/ncp.pdf

World Power Generation Capacity Additions

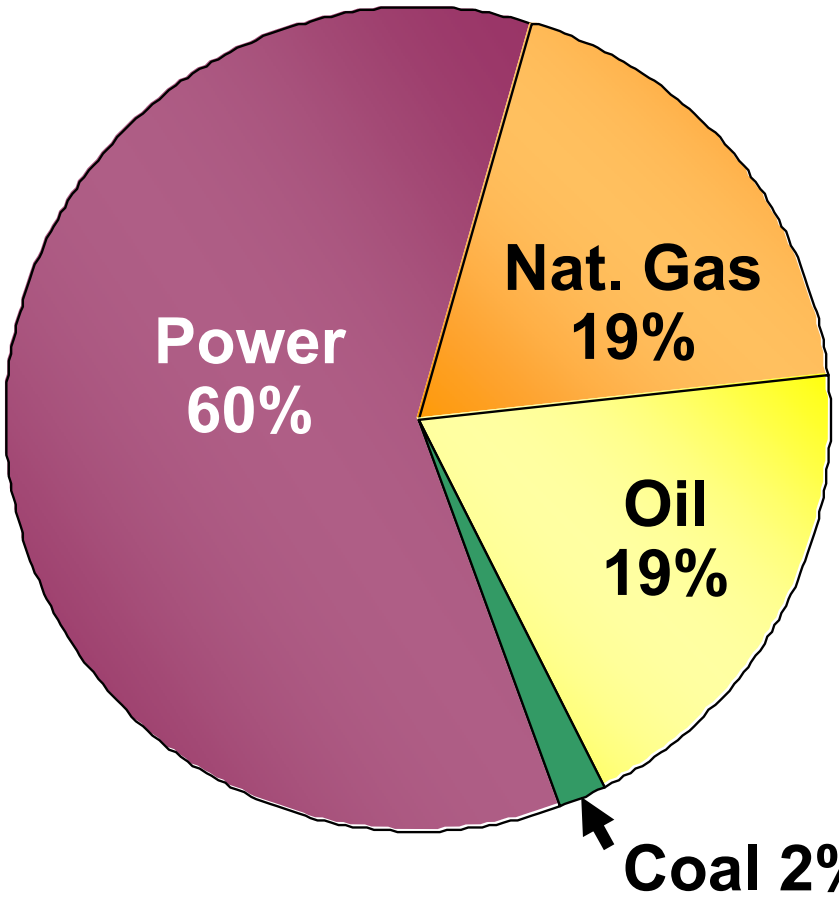
2000 – 2030



International Energy Agency, World Energy Outlook 2002

Global Energy Investment Required

Next Three Decades



Total Investment

U.S.$16,096 billion

And Therefore . . .

- Coal and natural gas will continue to be major part of U.S. and global energy mix for at least next 50 years
- Maintaining fuel diversity and flexibility is important for price stability and continued economic growth
- LNG use will increase; meeting 5 Tcf demand will be challenging
- Carbon sequestration at scale envisioned is still a young technology
- Near-zero emission technologies (SO_2, NO_x, CO_2, Hg) will be necessary to secure long-term future for coal