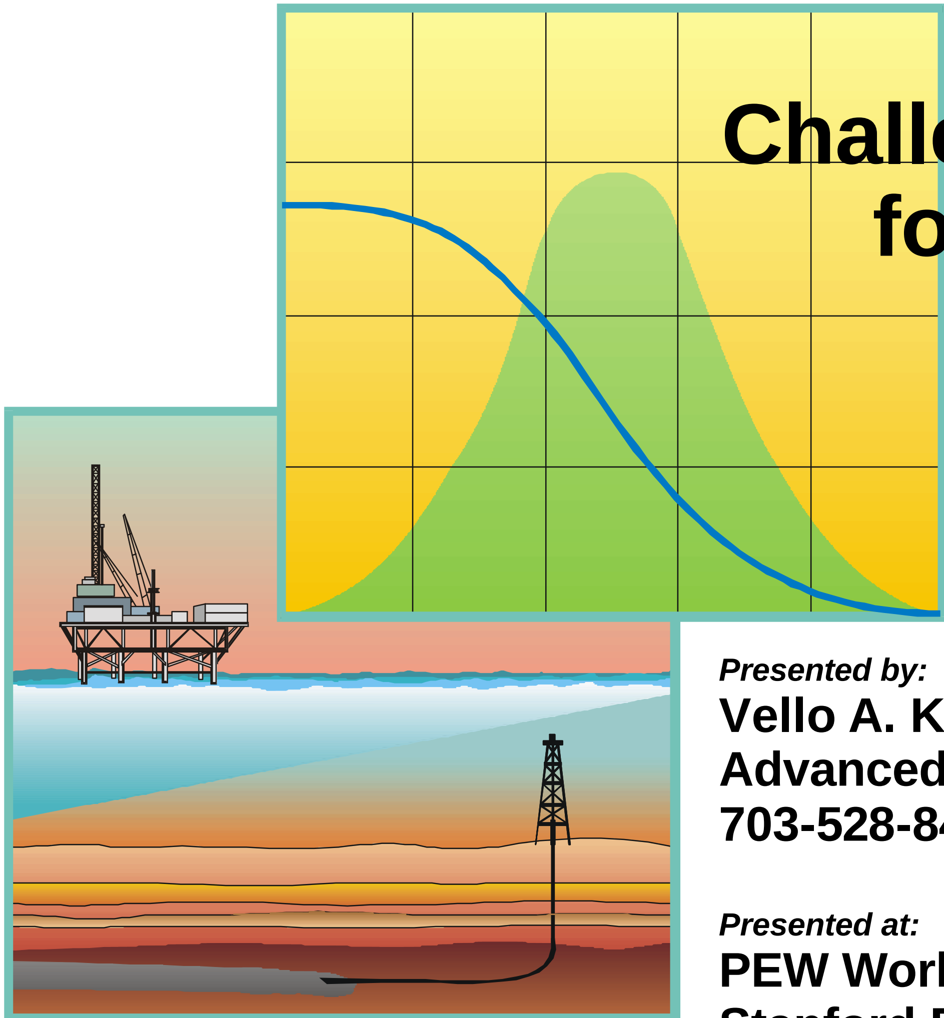

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Challenges and Concepts for Long Term Oil and Natural Gas Supply Modeling

Presented by:

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Introduction

Long term oil and natural gas supply modeling has been (and continues to be) challenging, requiring that we address a series of questions and observations:

1. **Why have we not yet "run out of oil and gas"? Why is the recoverable resource base larger today than 20 years ago?**
2. **Why is the cost of oil and natural gas about the same (in real terms)as 20 years ago?**
3. **With most of the world's "giant fields" already discovered and depleting, why does production continue to climb?**

Discussion Outline

I. Challenges to Conventional Views

1. Dynamic Resource Base
2. Downward Shifting Cost-Supply Curve
3. Importance of Medium and Small Fields

II. Resource Depletion vs. Technology Progress

III. Examples of Technology Progress

Issue #1: Dynamic Resource Base

The *conventional view* is that the recoverable resource base is fixed, linked to the knowledge and technology of today.

An *alternative view* is that the recoverable resource base expands, based on continued pursuit of knowledge and advanced technology.

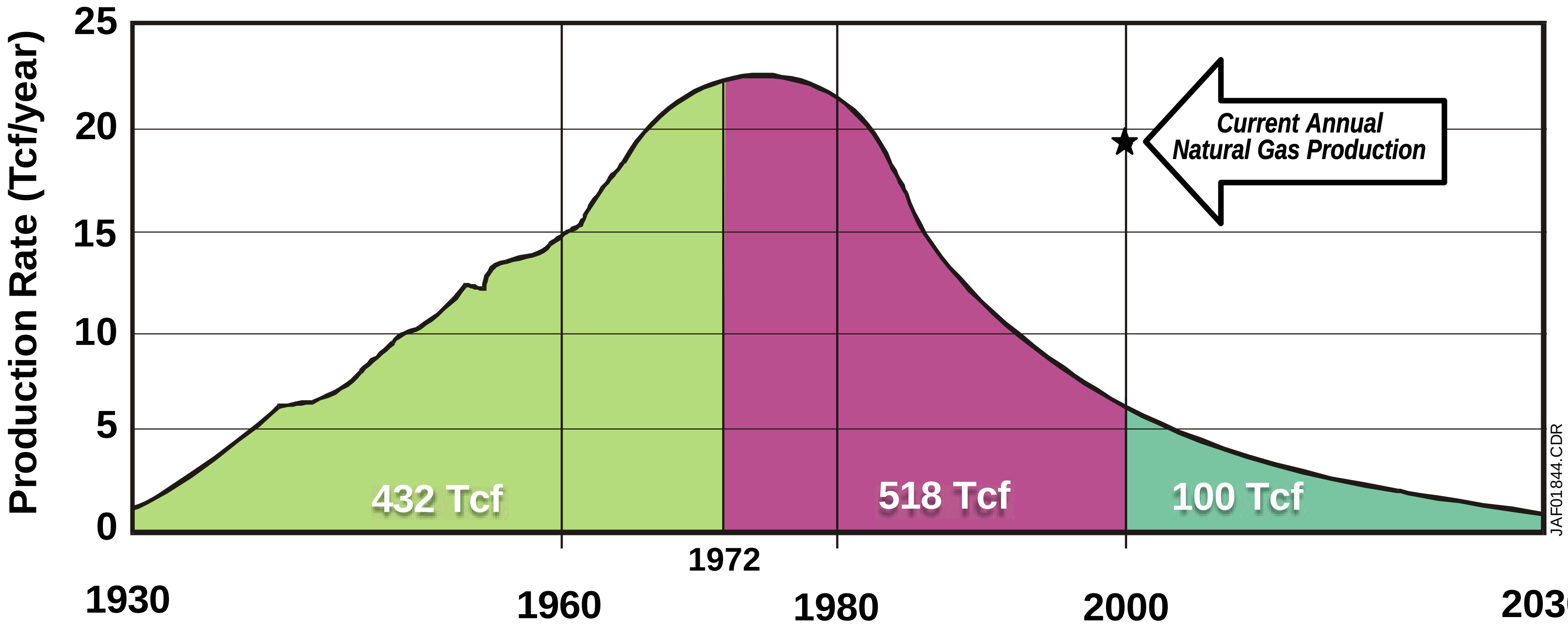
Case For Fixed Resource Base

The most compelling argument for a fixed resource base was made by M. King Hubbert in his classic 1967 AAPG paper, *"Degree of Advancement of Petroleum Exploration in United States."*

In this paper, and in subsequent publications and presentations to Congress, Hubbert stated that:

- **The peak in domestic crude oil would occur about 1970 with ultimate oil production less than 200 billion barrels,**
- **The peak in domestic natural gas production would occur in the late 1970s, with ultimate production of about 1,050 trillion cubic feet.**

Hubbert's Outlook For U.S. Natural Gas



(Modified from Hubbert, 1974)

Why Hubbert Was Pessimistic!

In hindsight, M. King Hubbert's use of a natural gas resource base fixed to the knowledge and technology of the 1970s led to an overly pessimistic outlook.

Improved Resource Knowledge

- ✓ **Offshore (shelf and slope)**
- ✓ **Unconventional Gas**
- ✓ **Deep Gas**
- ✓ **Reserve Growth**

Significant Technology Progress

- ✓ **3D Seismic**
- ✓ **Horizontal Drilling**
- ✓ **Advanced Stimulation**
- ✓ **Reservoir Characterization**

Case For Alternative View

Natural gas resources can be arrayed using a resource pyramid:

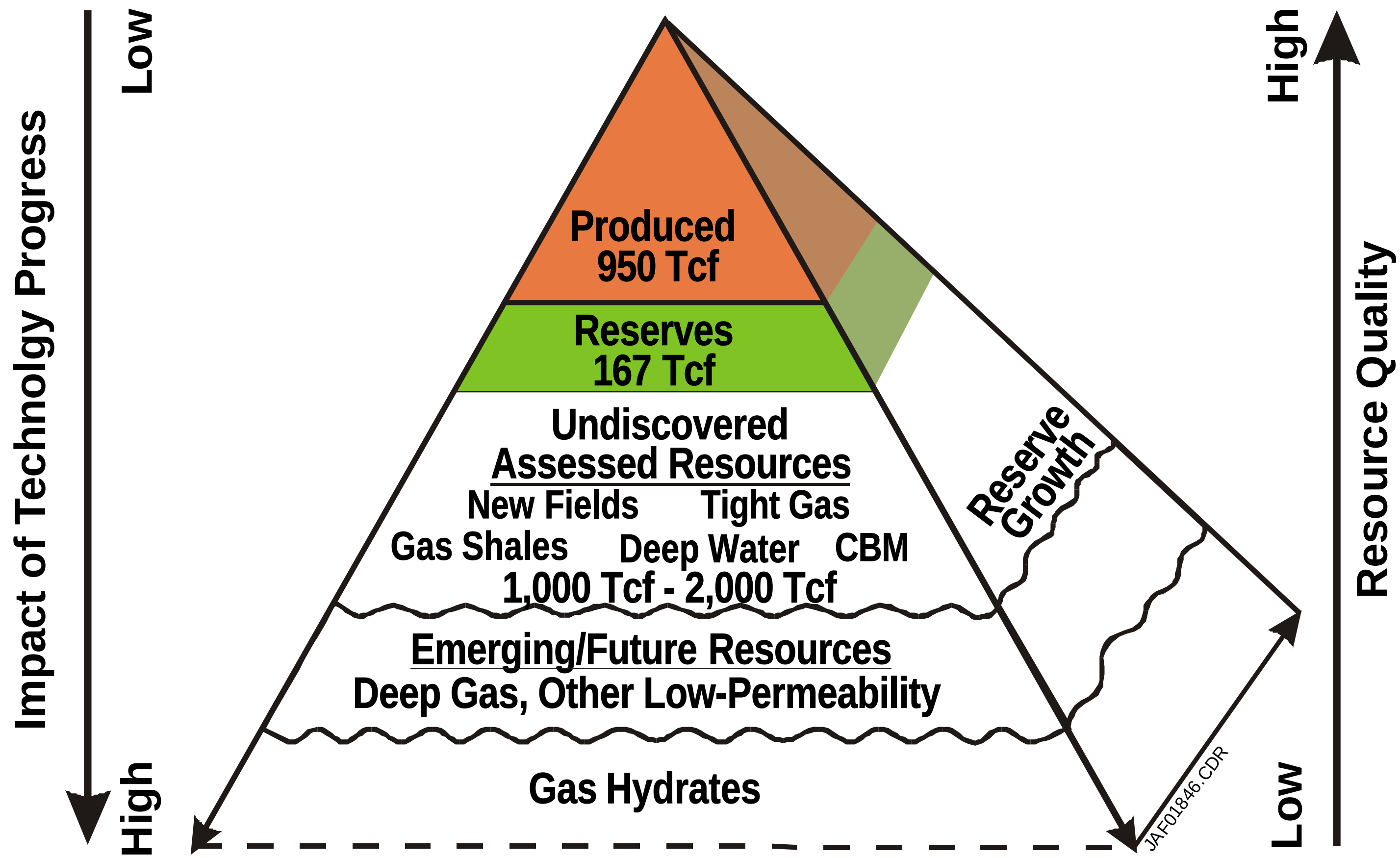
- **Small volumes of high quality, low cost resources are at the apex of the pyramid,**
- **Progressively larger volumes of lower quality, higher cost resources exist toward the base.**

The ultimate size and full contents of the resource pyramid are not yet in sight:

- **Improved geologic knowledge and extraction technology continue to expand the resource pyramid,**
- **The resources within the pyramid are dynamic; advances in technology can change a resource's quality and economic position.**

Natural Gas Resource Pyramid

(as of year 2000)



Expansion of Natural Gas Resource Base

USGS/MMS estimates of recoverable U.S. natural gas resources have expanded steadily in the past twenty years:

	1981 (Tcf)	1989 (Tcf)	1995/2000 (Tcf)
Future Resources	**594**	**492**	**1,375**
Proved Reserves	**178**	**167**	**167**
Past Production	**596**	**730**	**950**
TOTAL	**1,368**	**1,389**	**2,492**

The growth in the past ten years is from the deepwater, from low permeability reservoirs, and from more intense development of fields.

Expansion of Natural Gas Resource Base
(Cont'd)

Other resource assessments have had the same history as the USGS/MMS:

- **The Potential Gas Committee (PGC) has steadily increased its estimates of the ultimate size of the domestic (lower-48) recoverable natural gas resource base - - from 1,184 Tcf in 1964 (initial year) to 1,642 Tcf thirty years later and to 1,944 Tcf for 2000.**
- **The National Petroleum Council (NPC) increased its estimate of the domestic recoverable natural gas resource base from 2,238 Tcf in its '92 study to 2,669 Tcf in its '99 study.**

Rates of Resource Growth

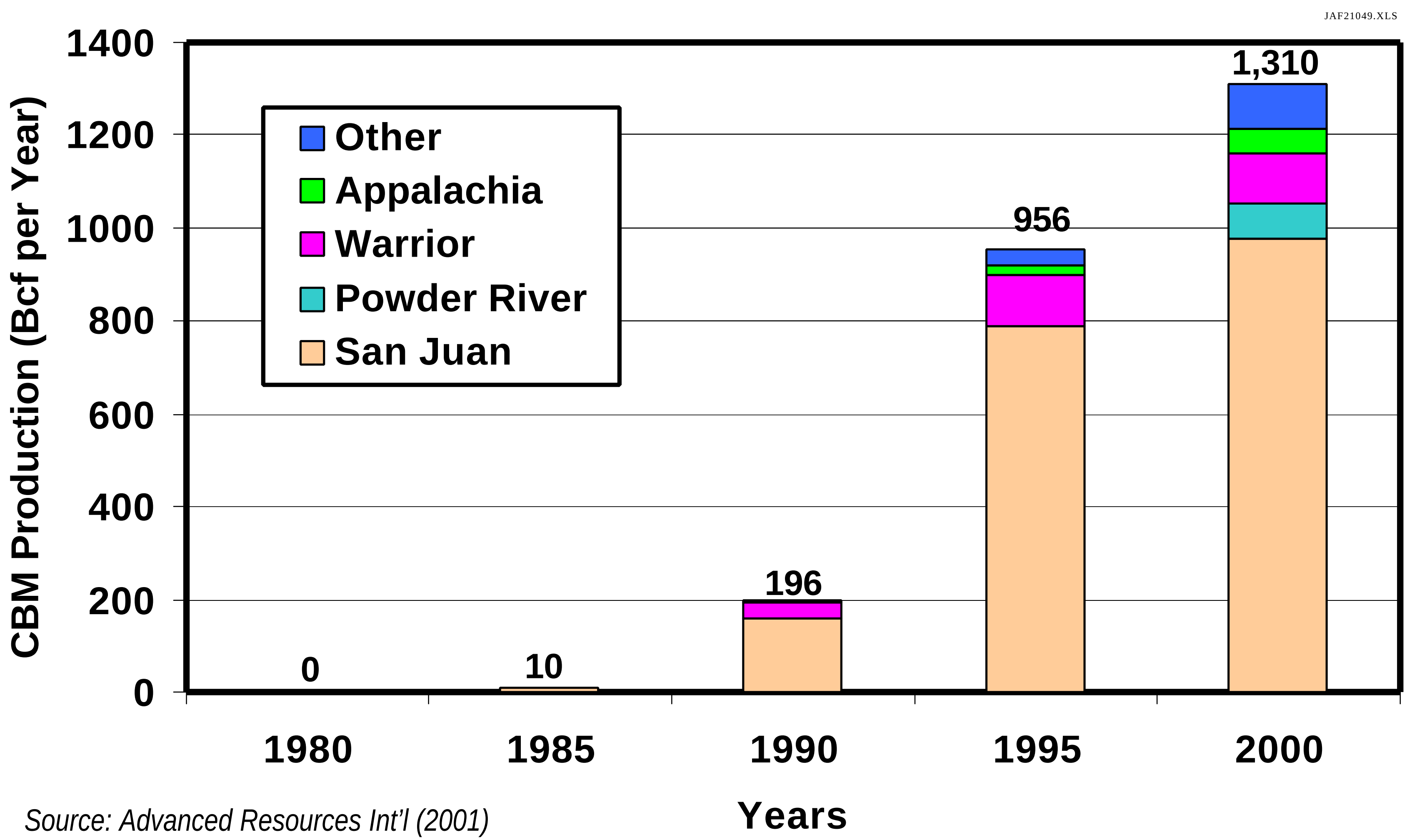
The longest, consistent and readily accessible domestic natural gas assessments are by the PGC. The PGC records 760 Tcf of resource base growth in 36 years (lower-48), about 20 Tcf per year.

NPC's 1999 natural gas resource assessment added 430 Tcf in 7 years, about 60 Tcf per year.

USGS/MMS assessments have added over 1,000 Tcf in 20 years, about 50 Tcf per year.

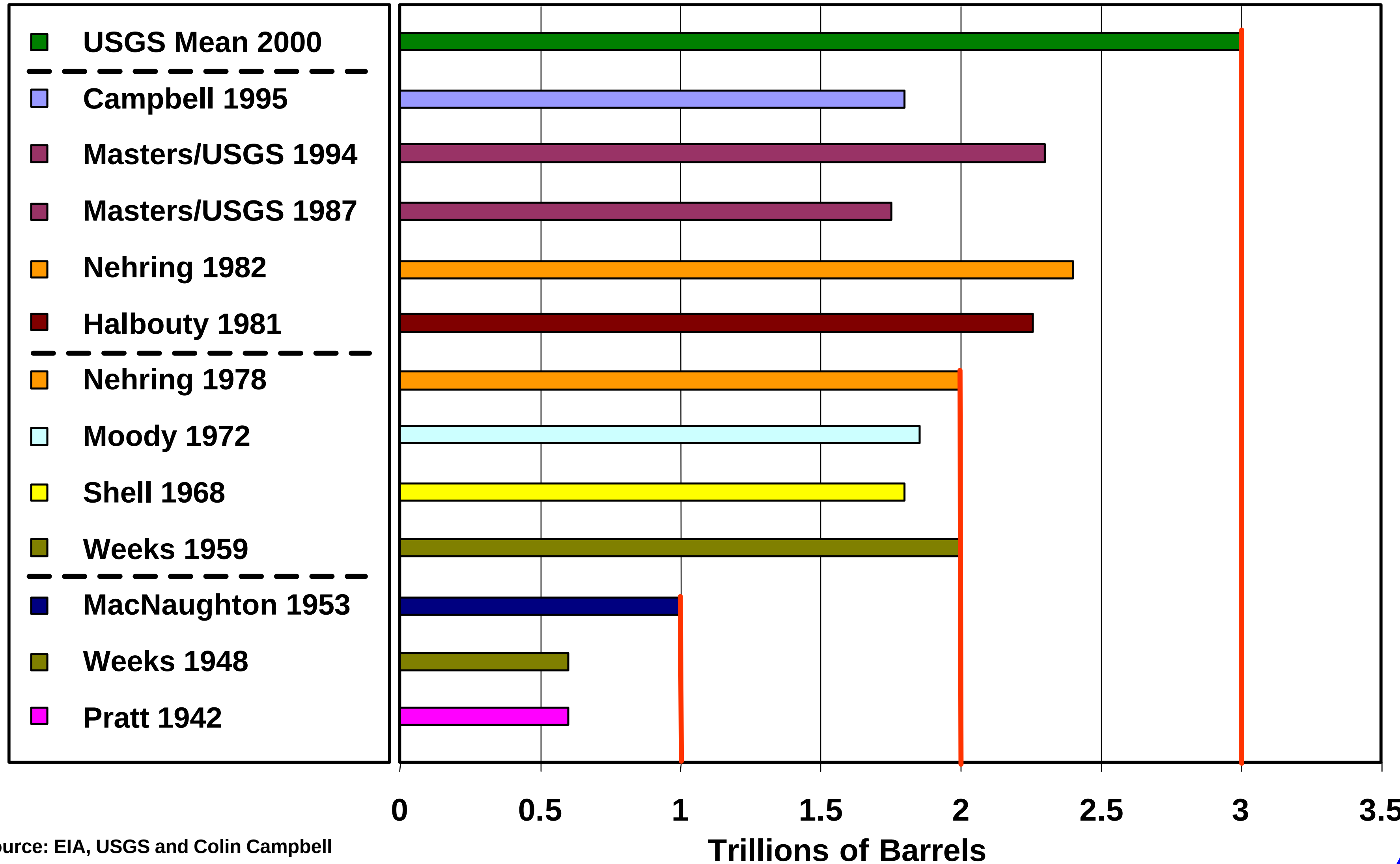
Dynamic Nature of Natural Gas Resource Base

Growth in Coalbed Methane Production (1980 – 2000)



Source: Advanced Resources Int'l (2001)

Estimates of Ultimate World Crude Oil Resources



Source: EIA, USGS and Colin Campbell

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Examination of Alternative Resource Base Views

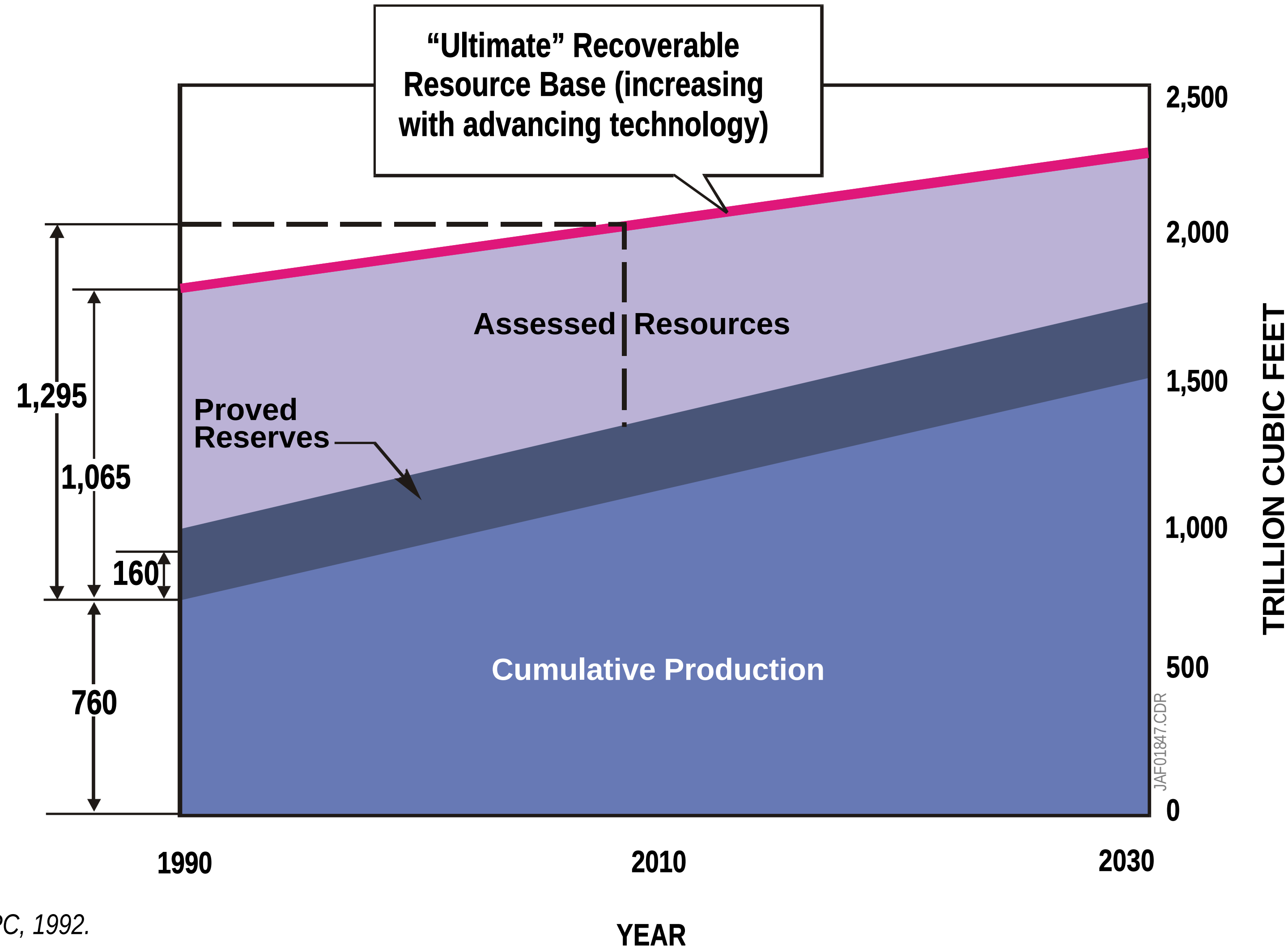
Production Curve #1 reflects the *<u>conventional view</u>*:

- Starts with a fixed resource base of 1,200 Tcf,
- Converts resources to reserves at 2%/yr; R/P of 8.

Production Curve #2 reflects the *<u>alternative view</u>*:

- Starts with a larger resource base of 1,800 Tcf,
- Converts resources to reserves at 1.33%/yr (increasing with time); R/P of 8.
- Adds 115 Tcf every 10 years ('92 NPC Natural Gas Study).

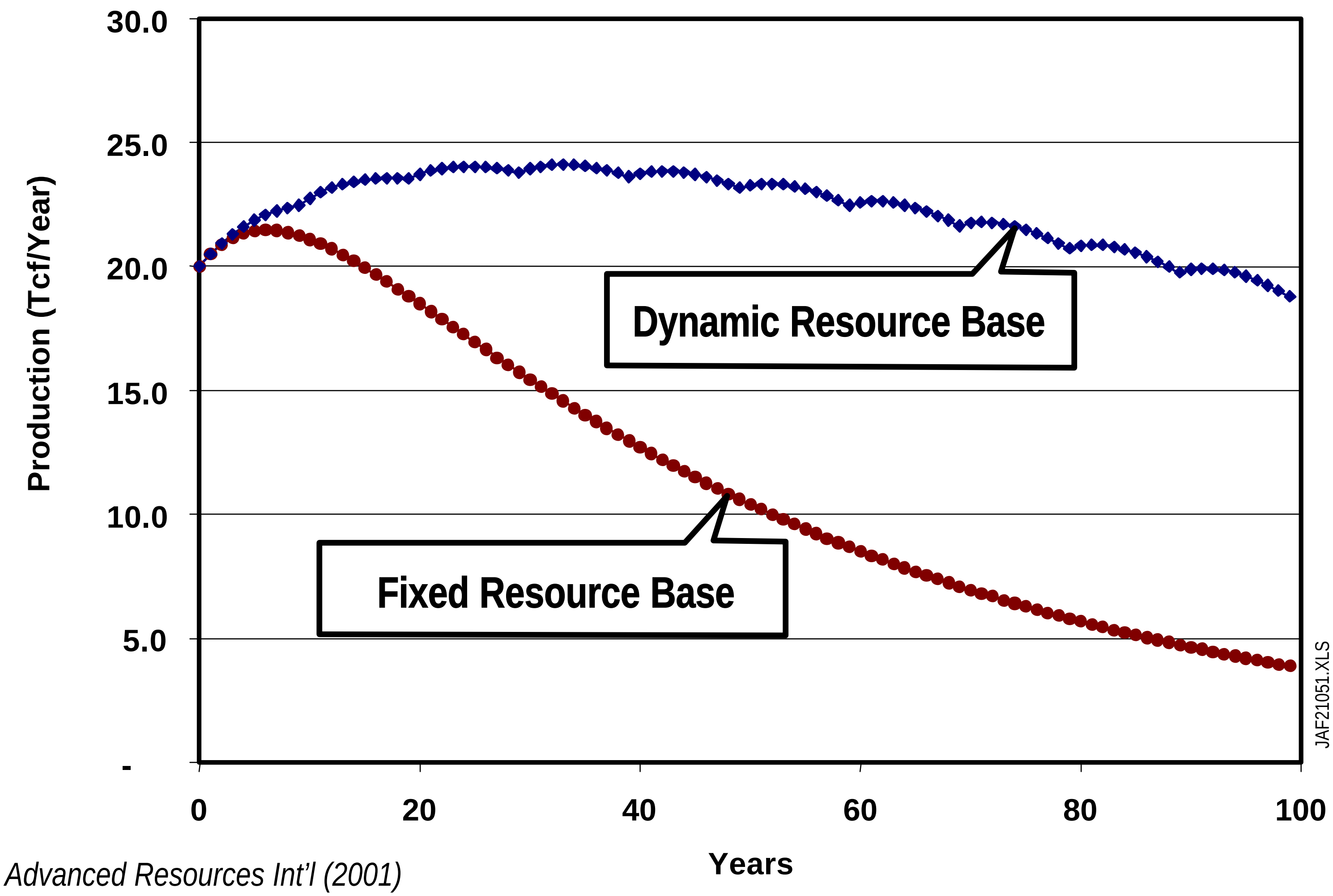
Dynamic U.S. Natural Gas Resource Base



Source: NPC, 1992.

Production Curves: Fixed vs. Dynamic Resource Base

Long Term U.S. Natural Gas Production



Source: Advanced Resources Int'l (2001)

How Might The Resource Base Continue To Expand?

Likely candidates for expanding the oil and natural gas resource base include:

1. **Inclusion of unconventional gas in world resource assessments.**
2. **Increased recovery of oil and natural gas using CO_2-EOR/ECBM with CO_2 sequestration.**
3. **Deep gas formations, ultra-deep water areas, frontier Arctic areas and more intense development of discovered fields.**

Should an autonomous or induced resource base growth factor (analogous to the AEEI) be incorporated into Long Term Energy Models?

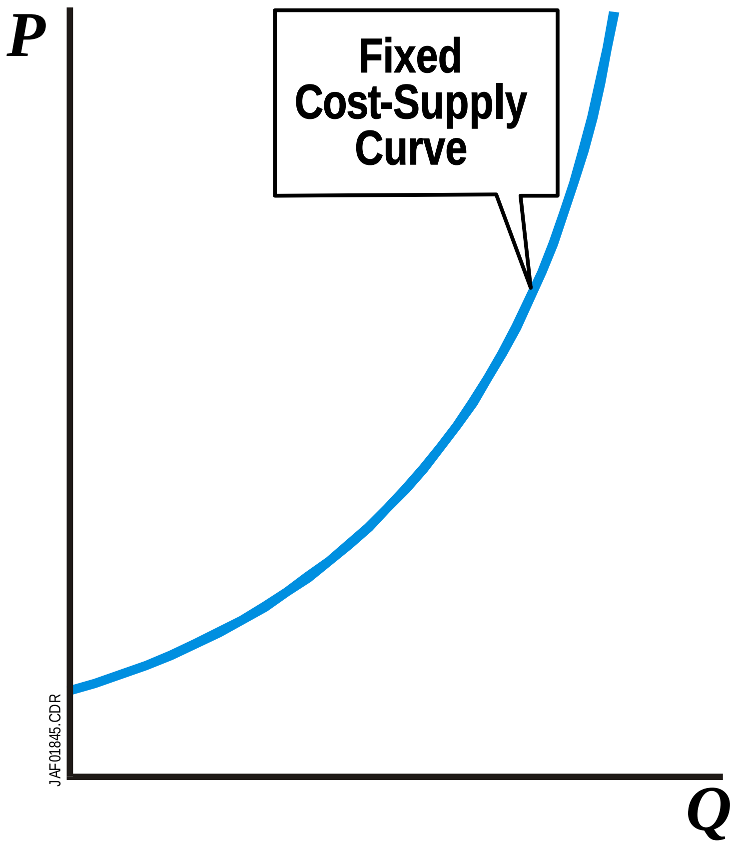
Issue #2: Decreasing Cost-Supply Curve

The ***conventional view*** is that the resource cost-supply curve is fixed over time and remains relatively inelastic.

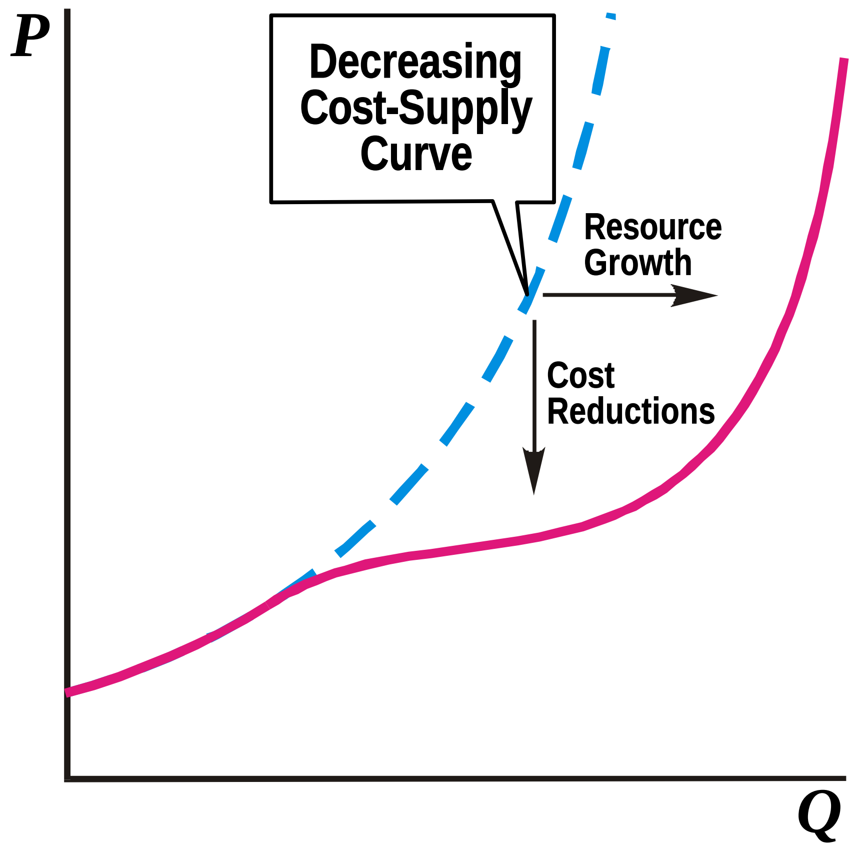
An ***alternative view*** is that the resource cost-supply curve decreases with time becoming increasingly elastic.

Two Views of Resource Cost-Supply Curves

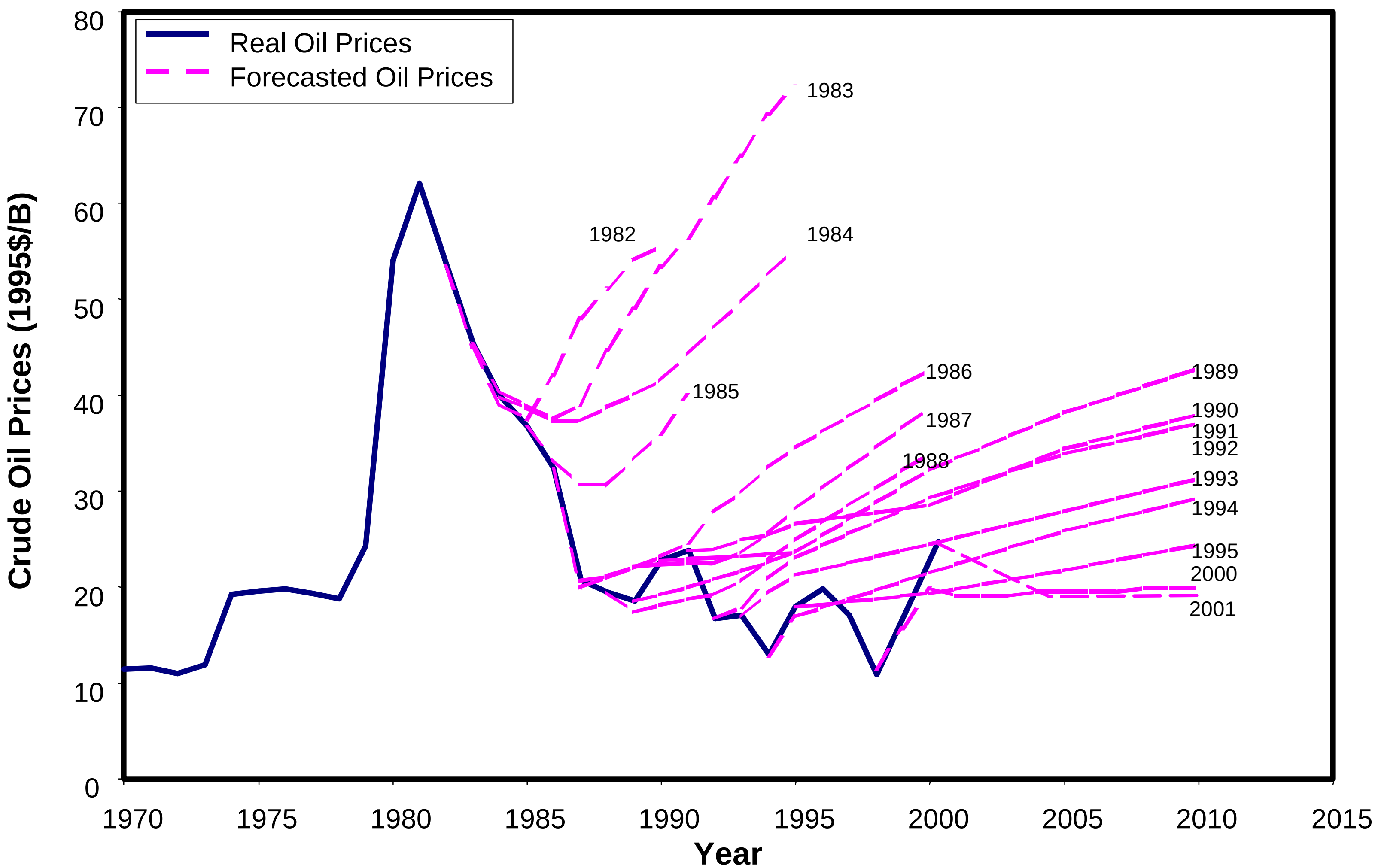
Conventional View



Alternative View



Comparison of Actual Oil Prices With EIA Oil Price Forecasts



Source: DOE/EIA

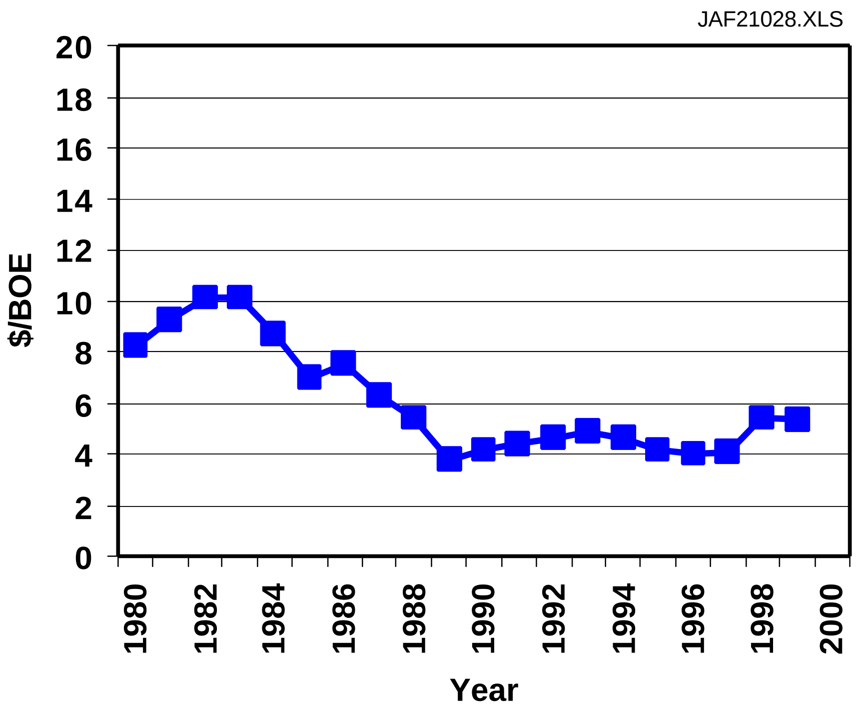
Domestic Finding Costs for Major Energy Producers

Technology progress and improvements in efficiency have significantly lowered domestic finding costs for oil and natural gas, particularly when measured in real dollars.

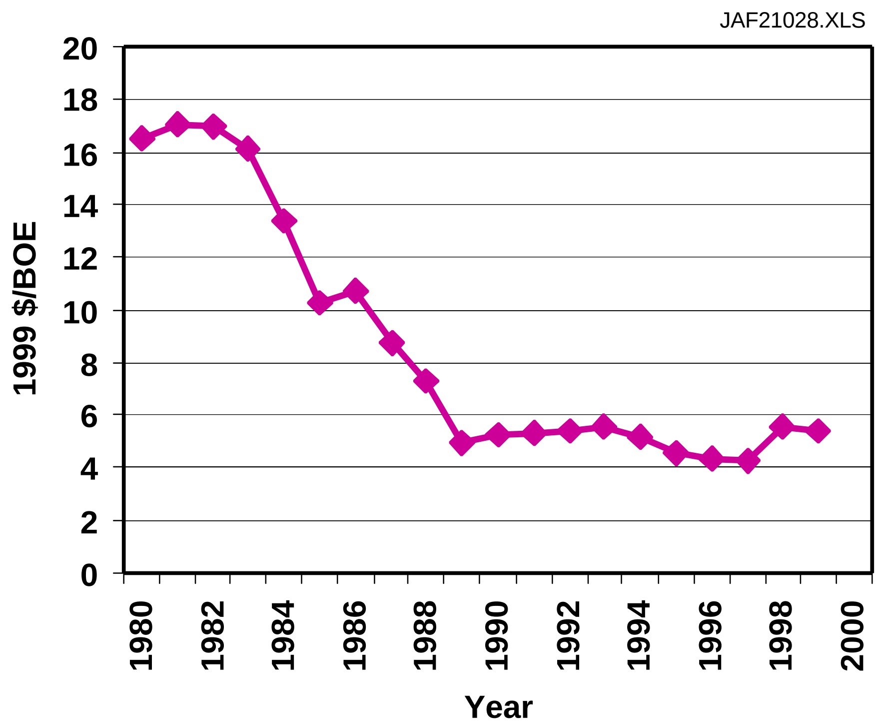
Three-year average onshore finding costs (in 1999$/BOE) show a steep decline through the 1980s, plateauing at about $5 per BOE during the 1990s.

Reduction in Domestic Oil and Gas Finding Costs

U.S. Onshore Finding Costs*
(Nominal Dollars)



U.S. Onshore Finding Costs*
(Real 1999 Dollars)



**3 Year Moving Average for Major Energy Producers.*

Source: Advanced Resources Int'l (2001); USDOE.EIA (2000).

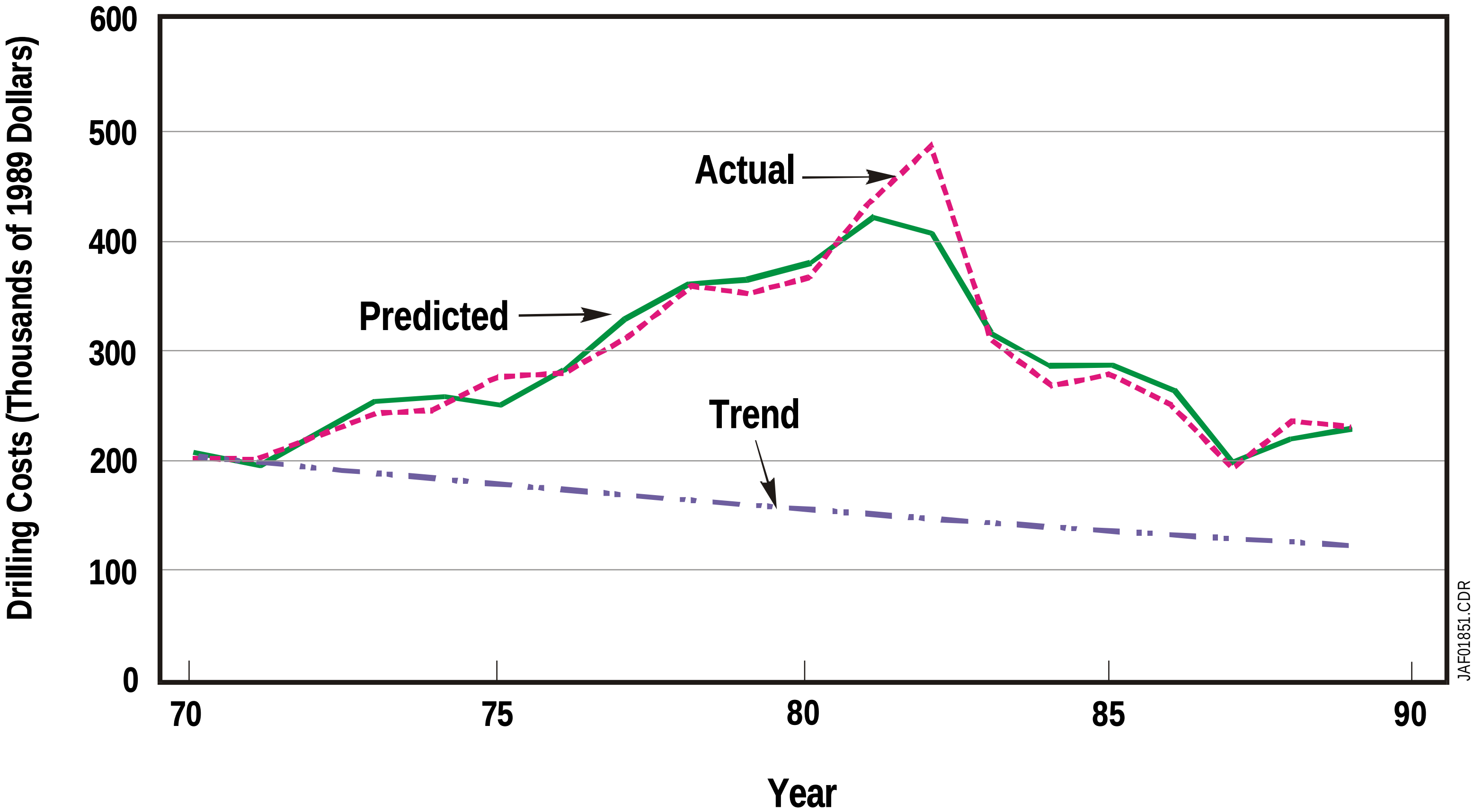
Herold's Report for 2000

Domestic finding and development costs, for oil and gas reserves, declined to $5.17/BOE in 2000.

Reserve replacement rates set all time records, with companies replacing 272% of oil production and 251% of gas production.

Top 50 U.S. Companies
John S. Herold (2001)

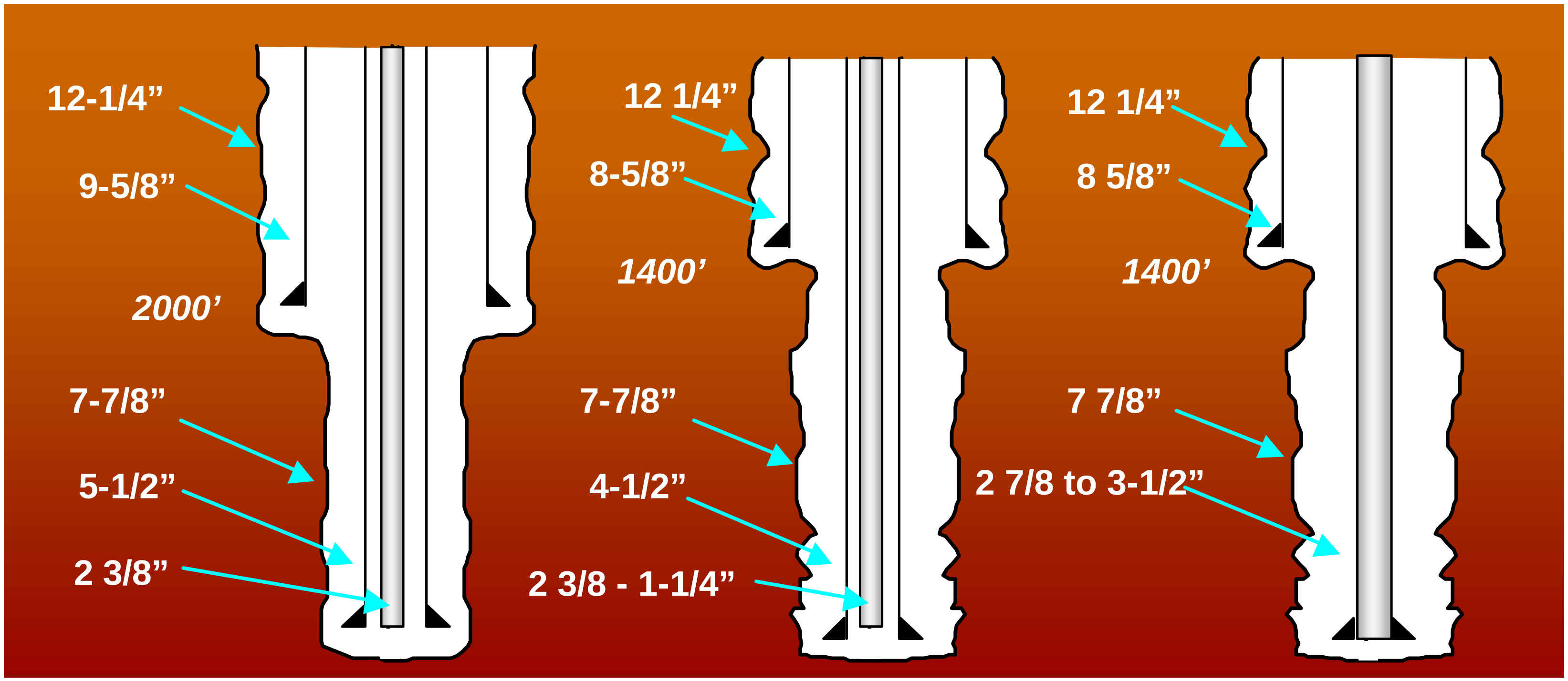
Lower-48* Drilling Costs Per Well



**Excluding Illinois, Indiana, Kentucky, Michigan, New York, Ohio, Pennsylvania, and West Virginia*

Evolution in Vertical Well Design Leads to Cost Reductions

(Wammsutter Field, Green River Basin)



Prior to 1993
$900,000

1994-95 Industry Standard
$650,000

Current Design
$570,000

Technology Levers Contributing to Decreasing Cost-Supply Curves

Several of the oil and natural gas supply models, such as NEMS (DOE/EIA), include reductions in their cost-supply curves:

- **Drilling, operating, and lease equipment costs are expected to decline by 0.5 to 2% per year, countering other factors (such as greater well depths and increasing environmental requirements) tending to increase costs;**
- **Success rate are assumed to improve by 7 to 8% per year.**

Should induced (or autonomous) resource cost reduction factors be incorporated into Long Term Energy and Climate Change Models?

Issue #3: Size and Nature of Petroleum Accumulations

The ***conventional view*** **is that the great bulk of oil and gas resources are in "giant fields." Once these fields are discovered and depleted, the "end of the hydrocarbon era" is at hand.**

An ***alternative view*** **is that large volumes of oil and natural gas exist in moderate size and small fields. For many emerging resources, such as basin center formations and coalbed methane, the concept of fields and field size no longer holds.**

The Case for Giant Fields

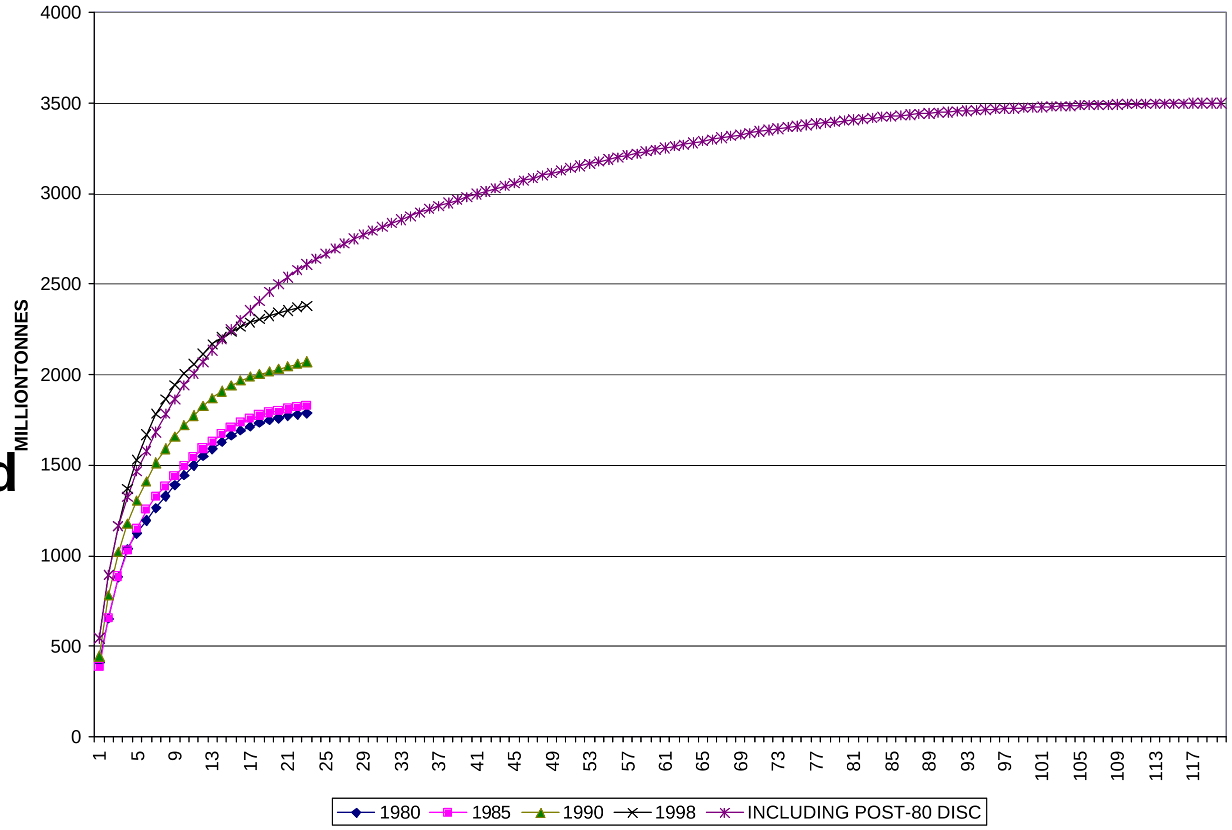
The case for the dominance of giant fields on resources is sometimes made with so-called "creaming curves" (Laherrere, 1999) using volume of discovery versus number of fields to establish an ultimate resource asymptote.

Application of this methodology to the UK North Sea illustrates its shortcoming at any point in time:

- **1980 – 13 billion barrels**
- **2000 – 25 billion barrels**
- **2020 – ?**

Creaming Curves for the U.K. Offshore

The asymptote of the so-called "creaming curve", an estimate of the ultimate resource size, has increased in each of the past four assessments.



Source: Michael C. Lynch (2001)

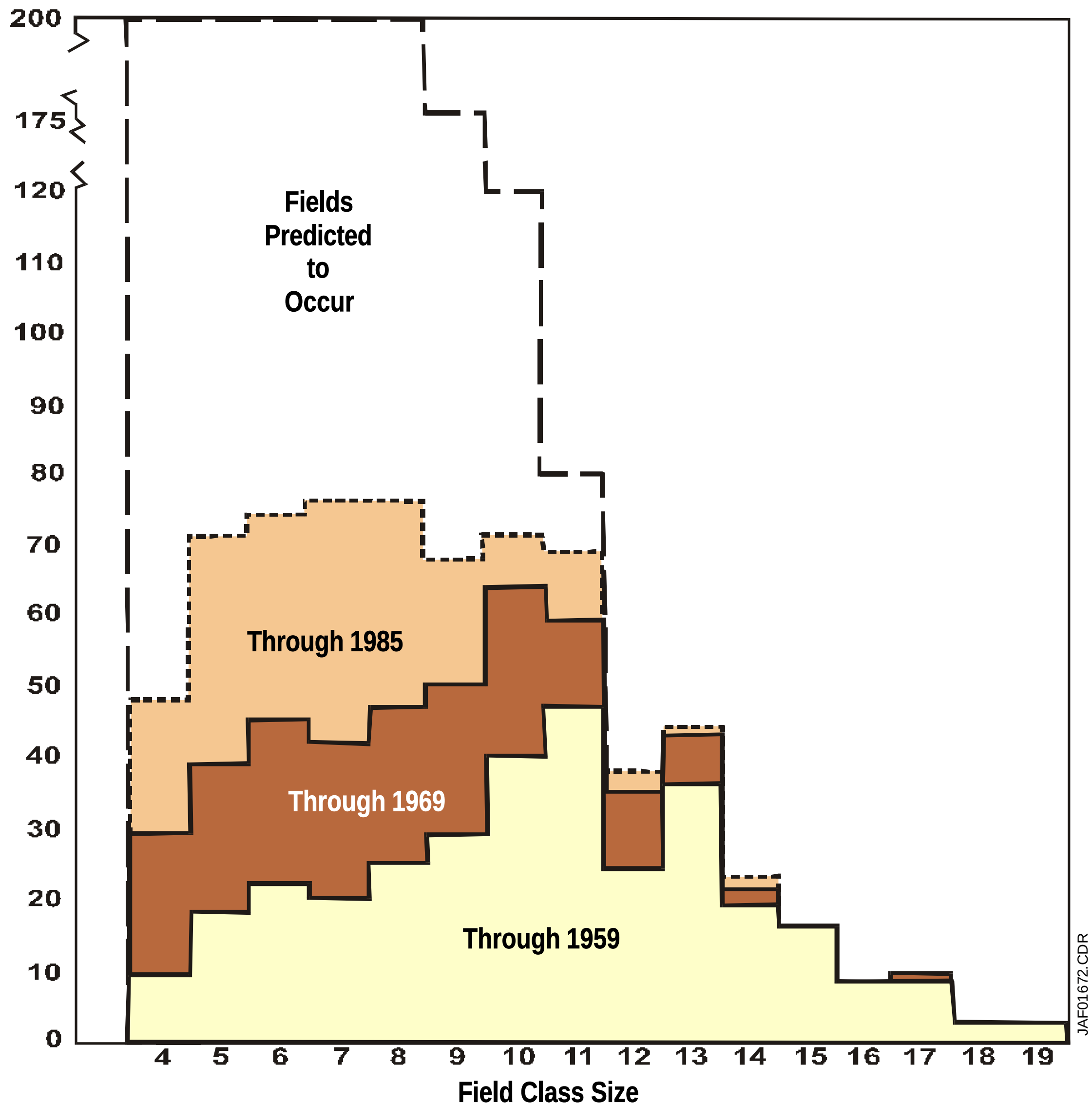
Evidence for Broad Distribution of Field Sizes

The alternate theory of field size distributions, for any given play or basin, is that there are:

- **A few large to very large fields that anchor the distribution.**
- **A progressive increase in the number of smaller fields.**
- **A peak in the number of "discovered" fields at some intermediate field size, reflecting an economic limit.**
- **A steady progression toward development of smaller fields as a basin matures, due to changing technology and economics.**

This process repeats as new frontier areas are discovered and developed.

Empirical Field Size Distribution for Frio Strandplain Play



USGS Field Size Classes
(Million BOE)

Size Class	Reserve Range
19	800-1,600
18	400-800
17	200-400
16	100-200
15	50-100
14	25-50
13	12-25
12	6-12

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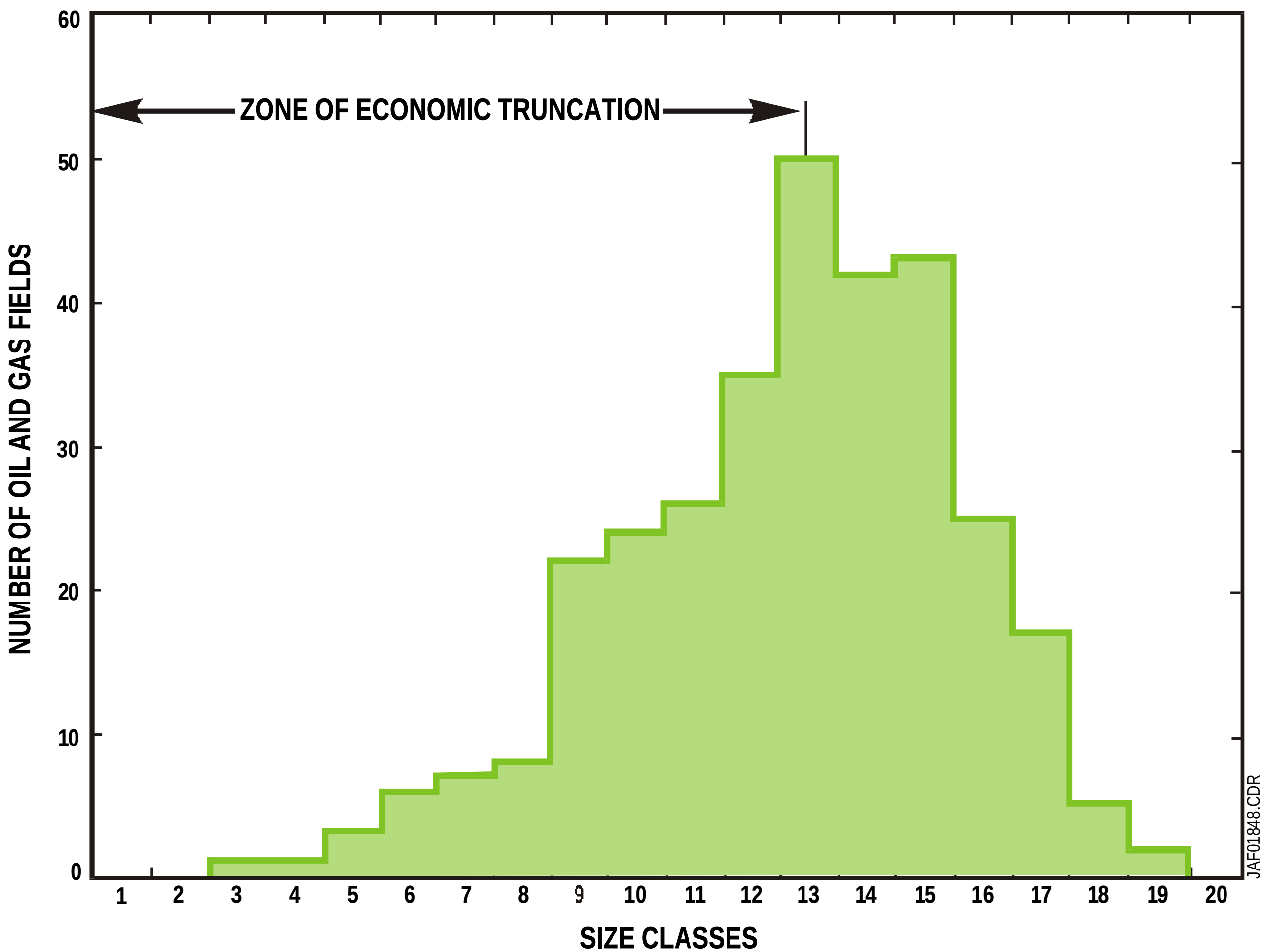
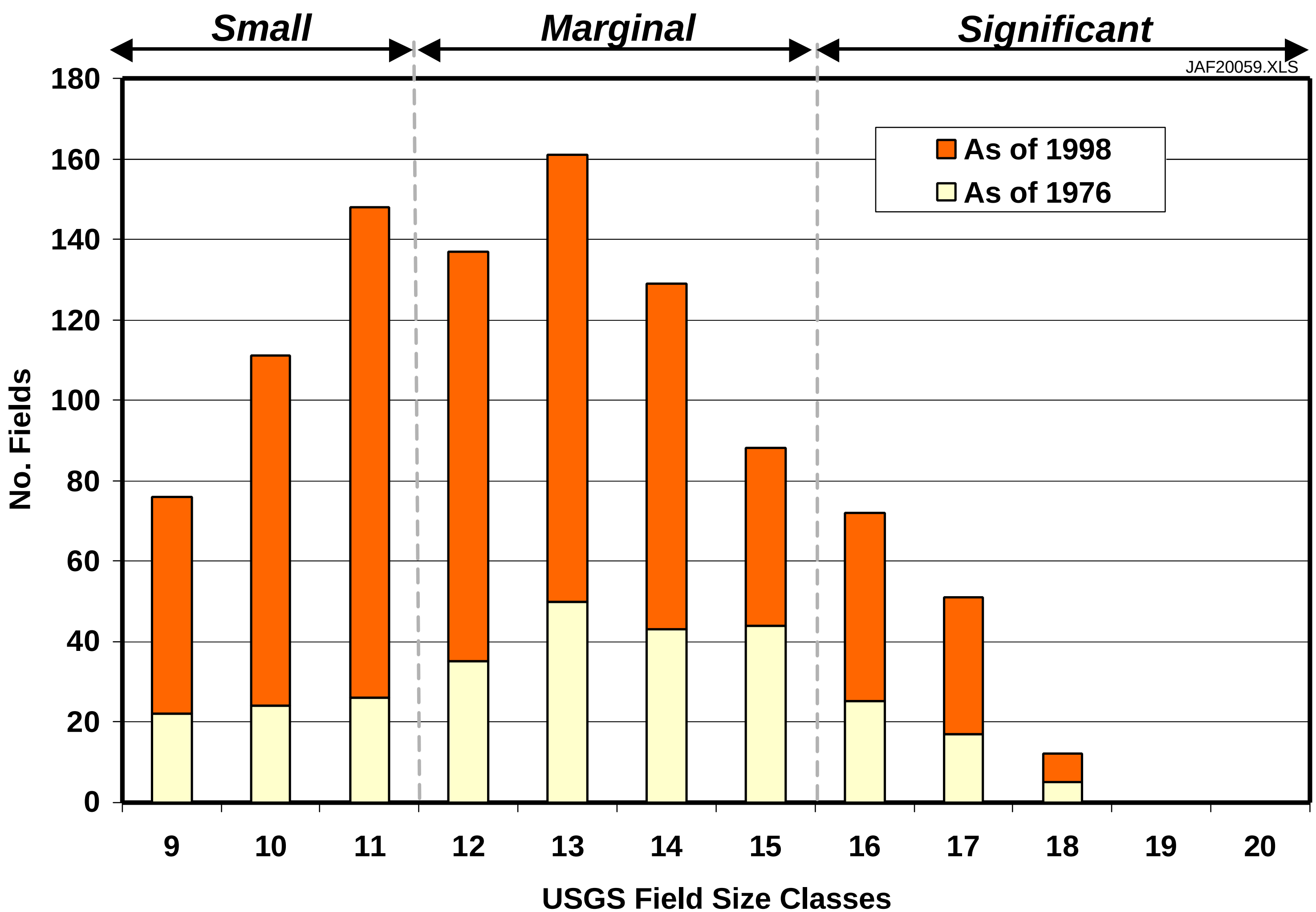
Size Distribution of Oil and Gas Fields Discovered in the Miocene-Pliocene Trend

(State and Federal Waters, 0-200 m, 1976)



Empirical Field Size Distribution, Gulf of Mexico Shallow Water



II. Resource Depletion vs. Technology Progress

Twenty years ago, the U.S. oil and natural gas provinces were already among the most mature and heavily drilled in the world.

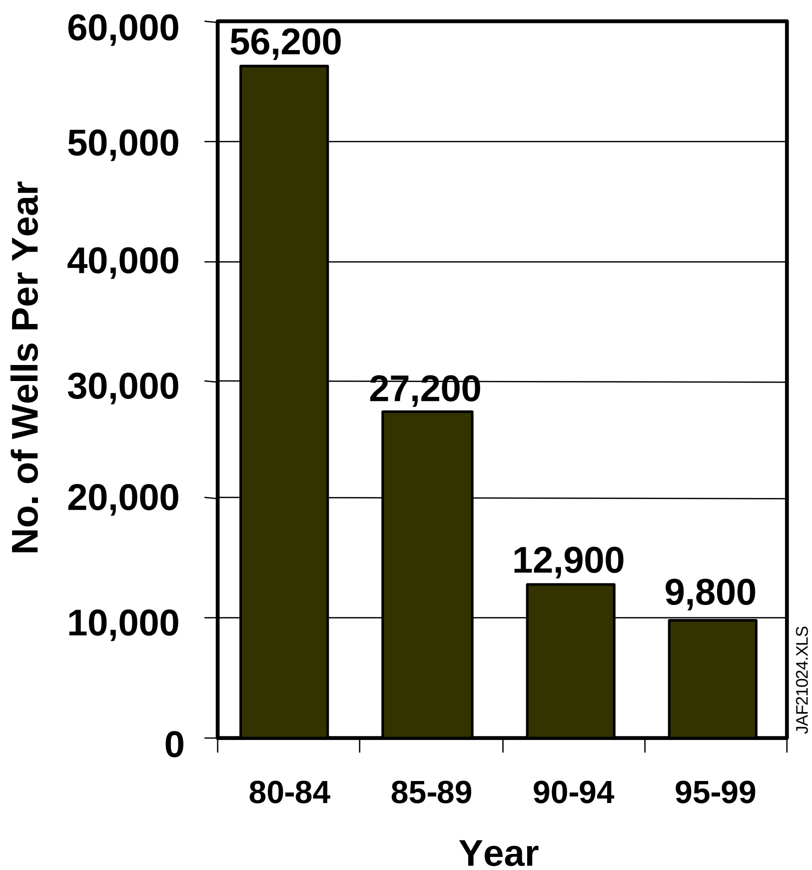
The past two decades of oil and natural gas development have furthered this degree of maturity:

- **Nearly 860,000 wells and over 4 billion feet have been drilled,**
- **Nearly 120 billion barrels (BOE) of oil, natural gas and natural gas liquids have been discovered and proved.**

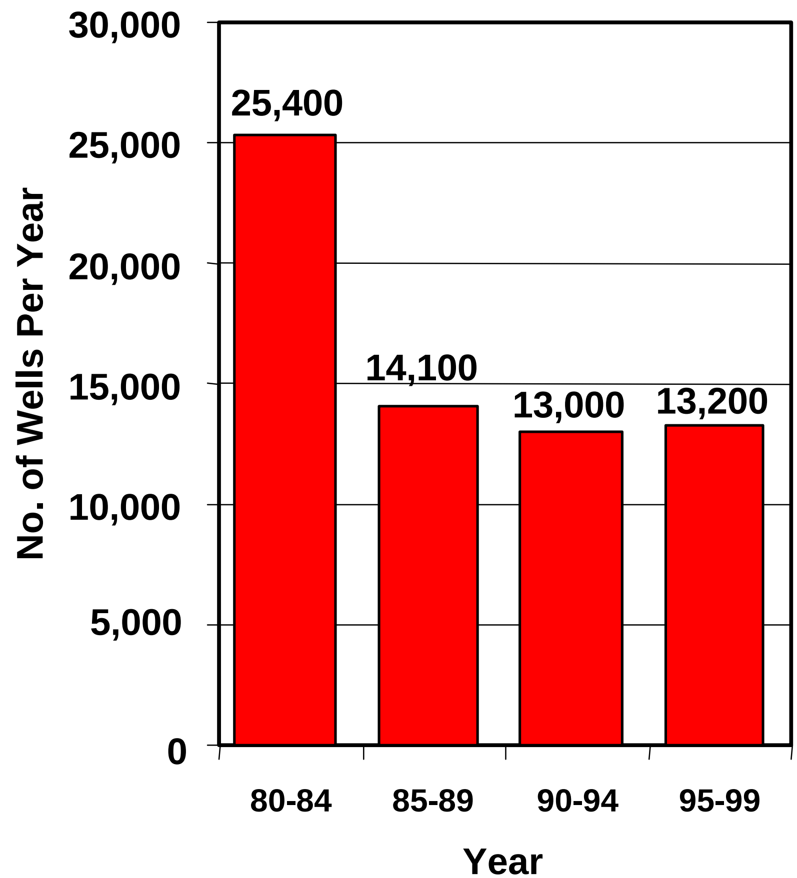
If the issue of "Resource Depletion versus Technology Progress" can be assessed, at any time or in any area, it can best be examined by these past 20 years of intensive domestic oil and gas development.

Two Decades of Oil and Natural Gas Development

Crude Oil Wells*



Natural Gas Wells*



Includes allocation of dry holes.

Assessing Resource Depletion

Three key benchmarks can be used to assess the presence and severity of resource depletion:

1. **Changes in the undiscovered resource base,**
2. **Time-series data on reserve additions,**
3. **Effort adjusted data on reserve additions.**

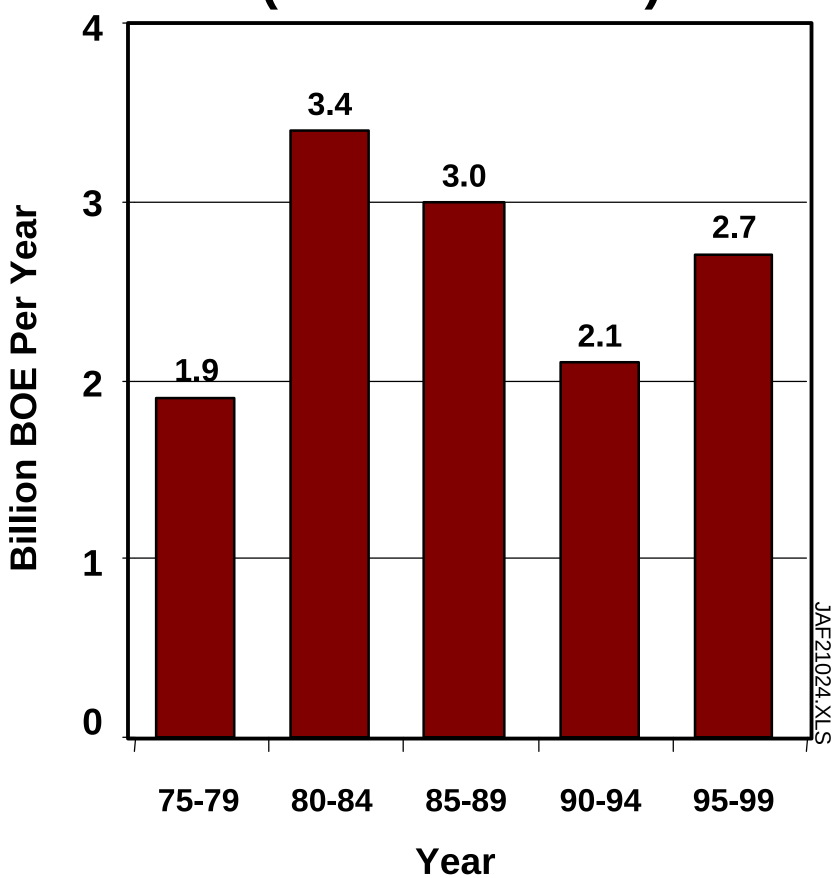
Is There Evidence for Resource Depletion?

Time-series data on reserve additions for crude oil and natural gas, show the following:

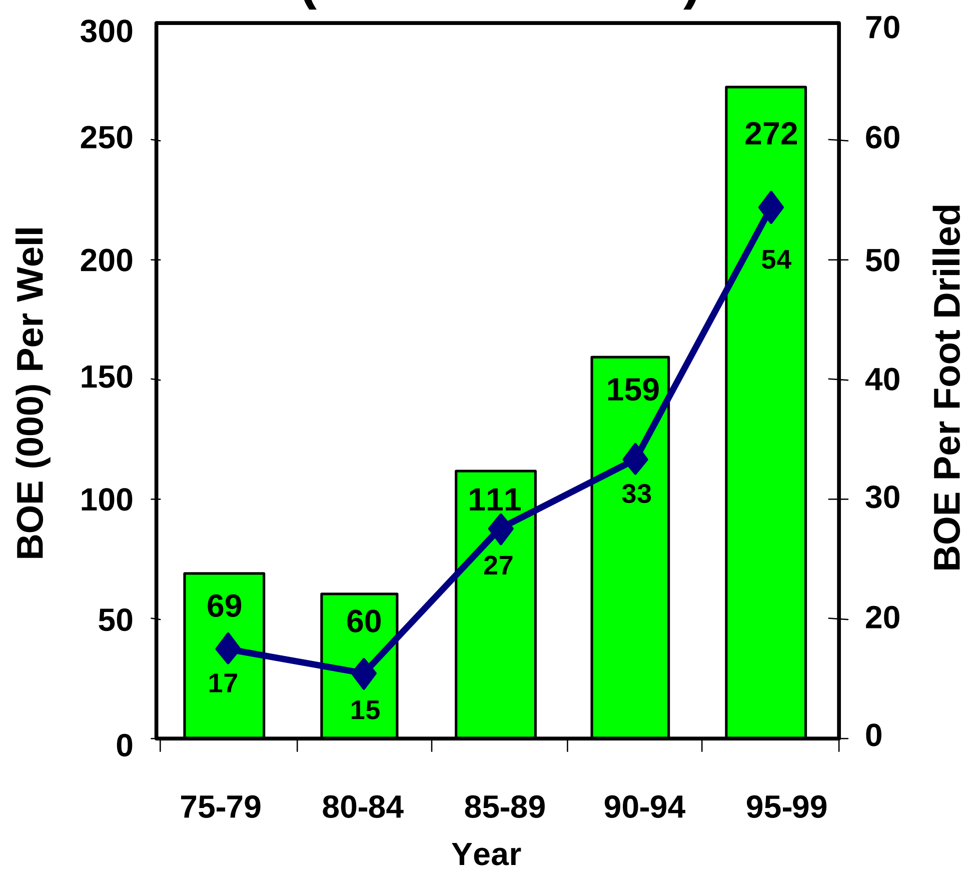
- **Crude Oil/NGLs indicate a moderate level of time-based resource depletion; however, when adjusted for effort (wells or feet drilled) no evidence for depletion exists.**
- **Natural Gas displays no level of depletion for either time or effort; reserve additions are up from the 1970s and 1980s and productivity (per well or foot drilled) is up by two fold.**

Evidence for Resource Depletion vs. Technology Progress

Time-Series Data on Reserve Additions (Crude Oil/NGL)

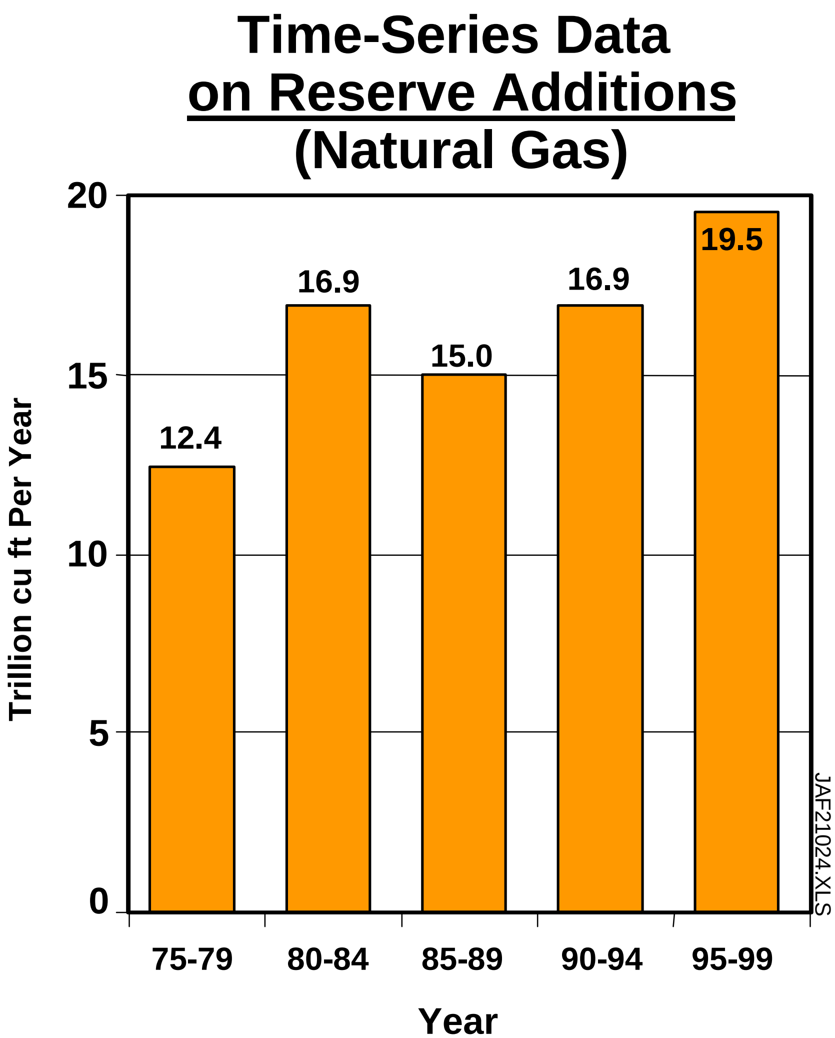


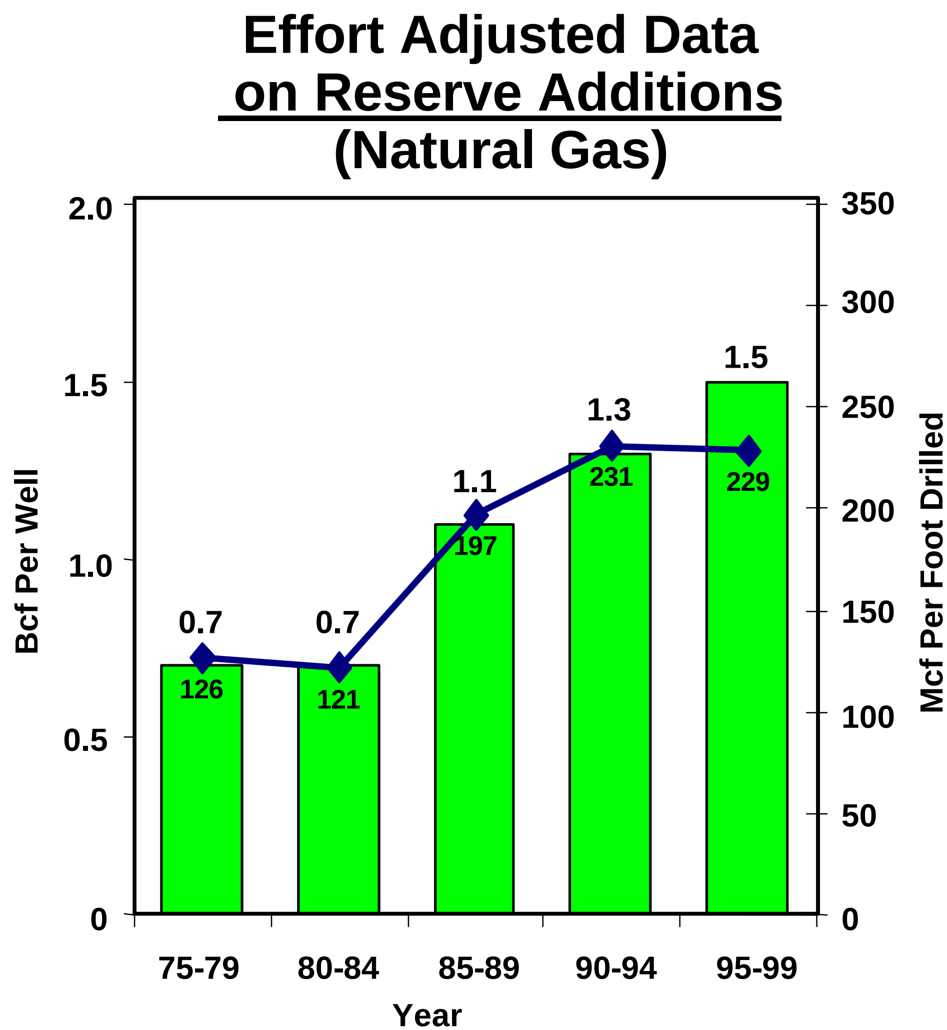
Effort Adjusted Data on Reserve Additions (Crude Oil/NGL)



Source: Advanced Resources Int'l (2001)

Evidence for Resource Depletion vs. Technology Progress





Source: Advanced Resources Int'l (2001)

III. Examples of Technology Progress

The evidence for technology progress is vast. A few examples serve as illustrations:

- **Deepwater GOM "Canyon Express"**
- **Central Texas Horizontal Drilling**
- **Piceance Basin Geomechanics and 3-D Seismic**
- **San Juan Basin CBM Well Cavitation**

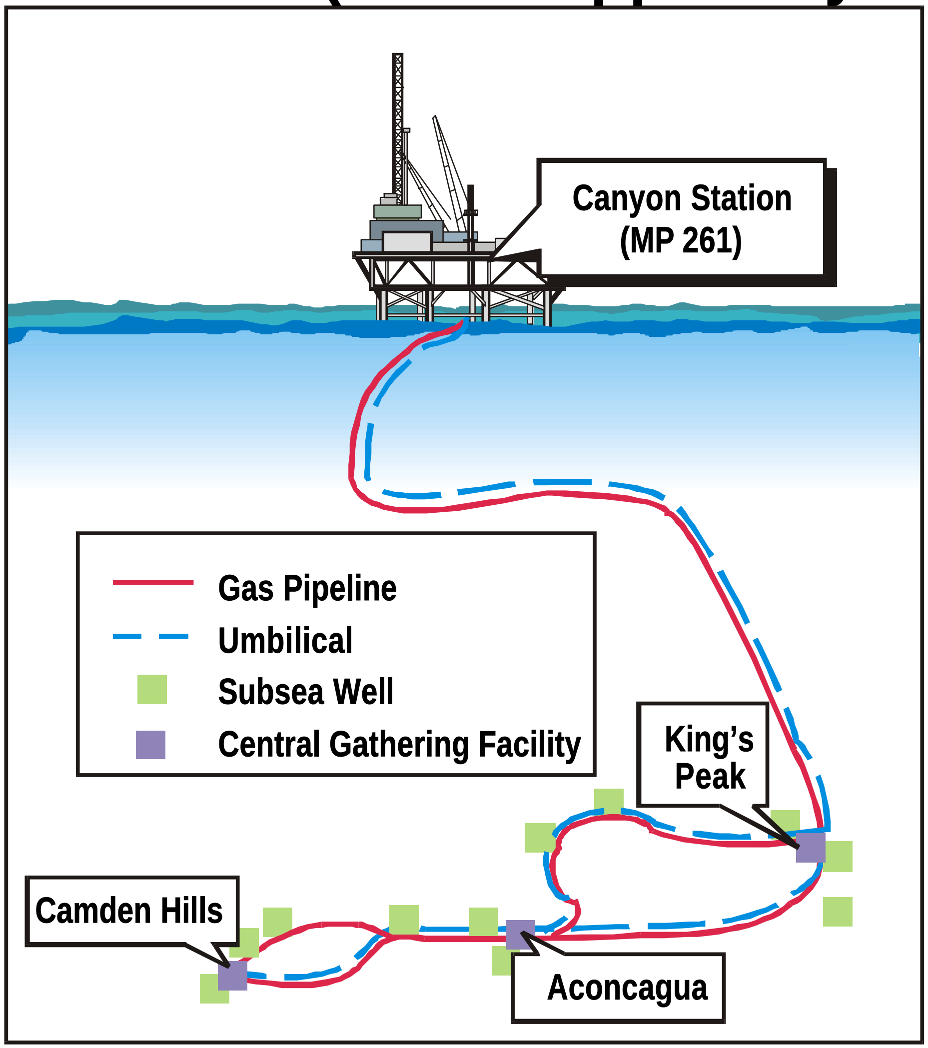
Deepwater Technology

The Canyon Express subsea tieback project, at 7,250 feet of water in the Gulf of Mexico, is a blueprint for marginal deepwater field development:

- Links three smaller fields to a shallow water platform called Canyon Station:
  - Aconcagua (MC 305) operated by Total Fina Elf,
  - King's Peak (MC 217) operated by BP,
  - Canada Hill (MC 348) operated by Marathon
- Peak gas production of 500 MMcfd is expected by Summer 2002.
- Other innovations have saved $20 million per field.

Sub-Sea Wells and Tiebacks Provide Blueprint for Marginal Deepwater Field Development

(Mississippi Canyon, Gulf of Mexico)



"Canyon Express" Project

	Sub-Sea Wells (#)	Field Size (Bcfe)	Water Depth (ft)
Aconcagua (MC 305)	3-4	300	7,070'
Camden Hills (MC 348)	2	500	7,200'
King's Peak (MC 217)	4	100	6,500'

Horizontal Drilling

Anadarko Petroleum is using horizontal wells to re-enter old wells and drill deeper in the Giddings and Navasota River fields of Central Texas:

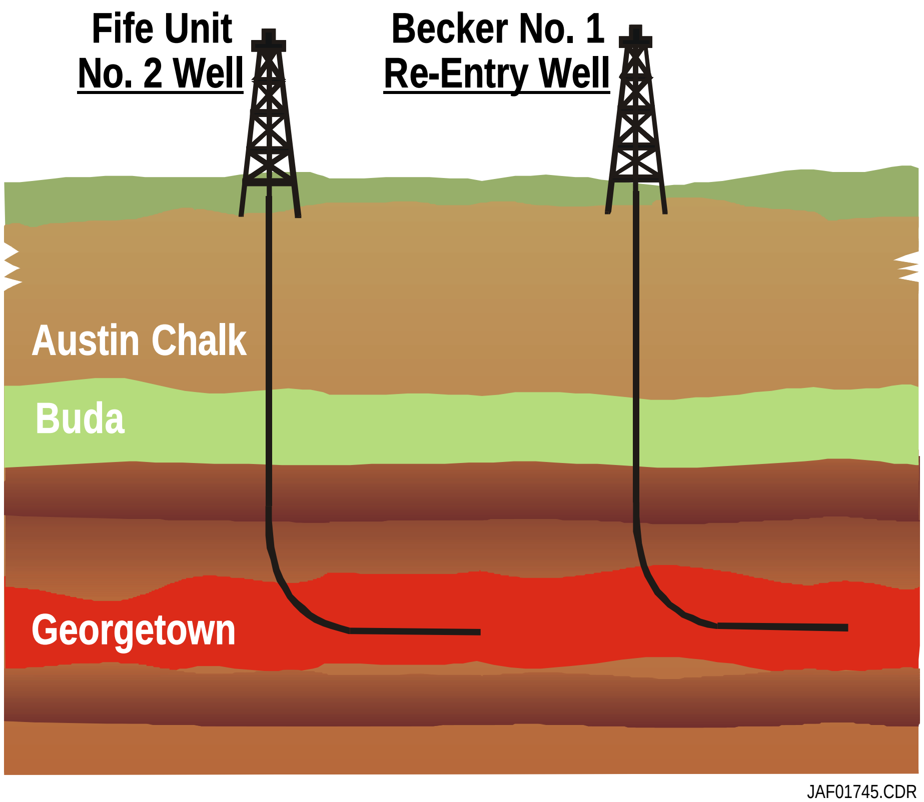
- Becker No. 1 well, with an initial rate of 50 MMcfd (July 2000), has produced 6 Bcf and is flowing at 25 MMcfd.
- Fife Unit No. 2 well, (confirmation of the Becker No. 1) was drilled vertically to 14,080 feet and then laterally for 5,000 feet. It flowed natural gas at 51 MMcfd.

"By drilling deeper, we're finding much stronger results than anyone thought possible. We're putting our intellectual capital to work. . ."

John N. Seitz,
President and COO, Anadarko Petroleum

Horizontal Wells Revitalize Deep Gas Play

(Giddings Field Area, Central Texas)



	Becker No. 1 Re-Entry Well	Fife Unit No. 2 Well
Date	7/'00	3/'01
Vertical Depth	14,370'	14,080'
Lateral	3,500'	5,000'
Initial Rate	50 MMcfd	51 MMcfd
Cum. Recovery	6 Bcf	n/a

"We're putting our intellectual capital to work, finding new ways to produce more natural gas."

John N. Seitz
President and COO
Anadarko Petroleum Corp.

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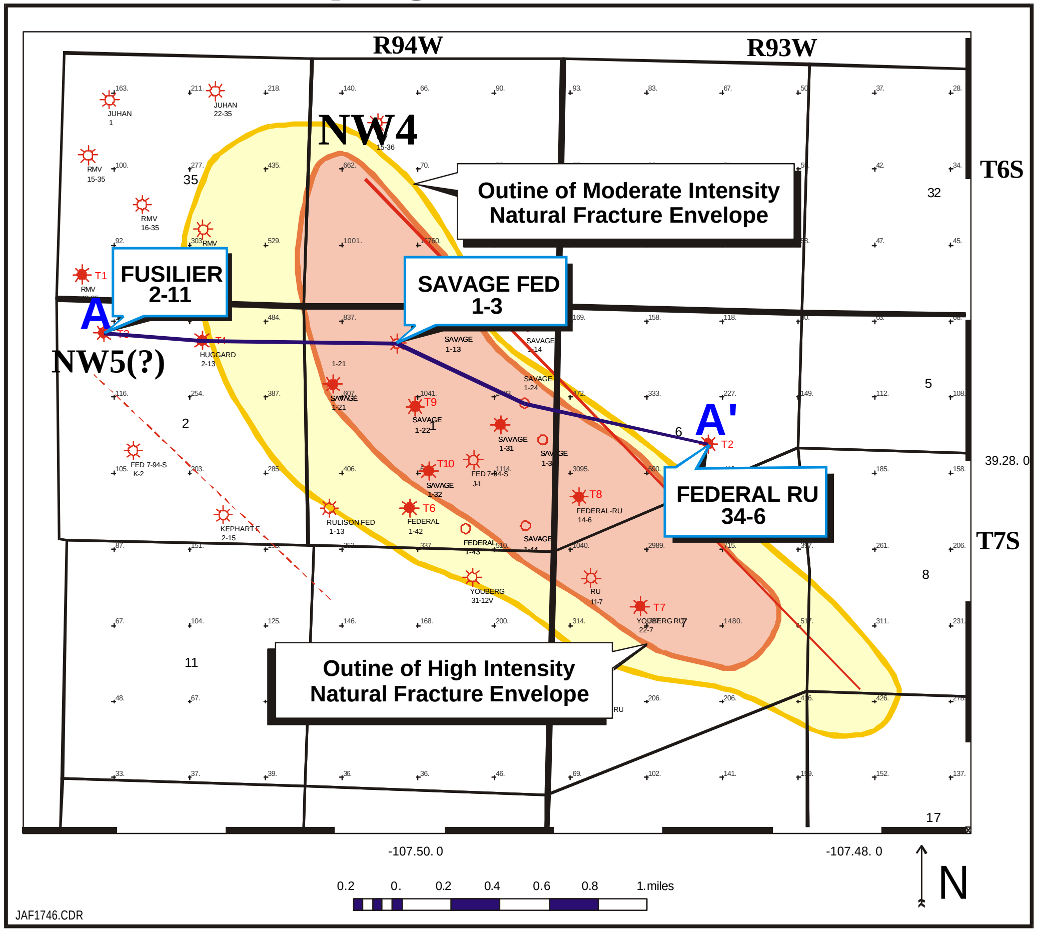
Integration of Geomechanics and 3-D Seismic Offers Promise for Defining "Sweet Spots"

(Tight Gas, Rulison Field, Piceance Basin)



Results of Geomechanics/3-D Seismic Technology Test

Natural Fracture Cluster Area	Cum. Recovery (Bcf)	Est. Ult. Recovery (Bcf)
Inside Envelope (12 wells)		**3.4/Well**
• Savage Fed . 1-3	1.7	4.5
Outside Envelope (23 wells)		**1.0/Well**
• Fed. RU 34-6	0.2	0.3
• Fusiler 2-11	0.3	0.9

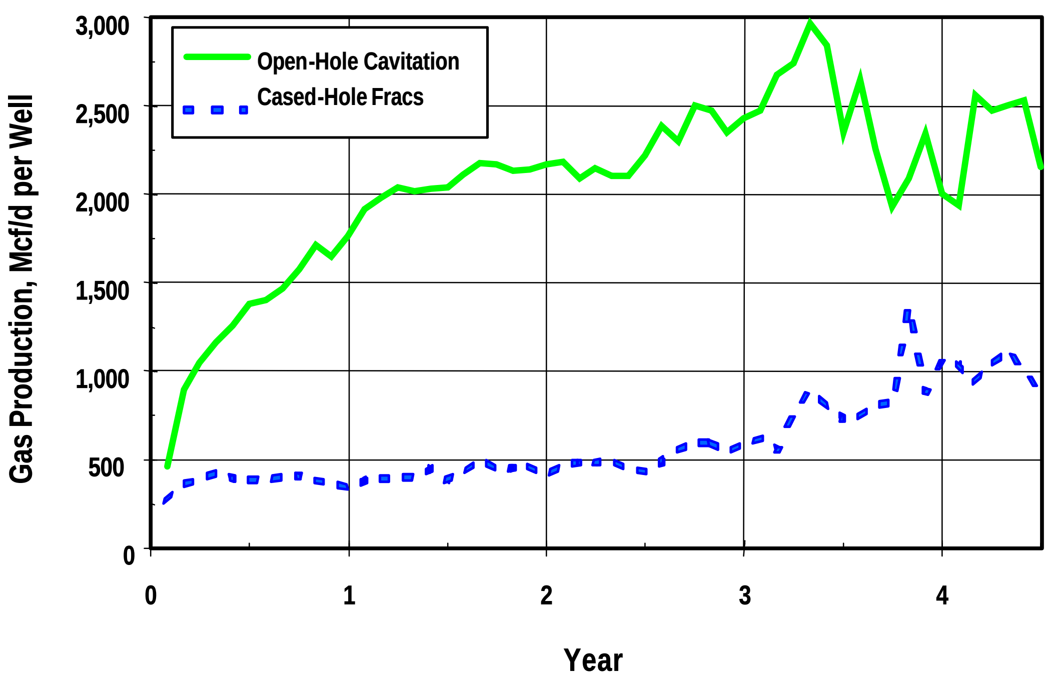
Source: Advanced Resources Int'l (2001)

Innovative Well Stimulation Technology Boosts Reserves of Coalbed Methane Wells

(CBM Well Performance, "Fairway" of San Juan Basin)

Number of Wells:

Open-Hole	598	477	366	263	185	117	75	38	19	17
Cased-Hole	230	207	169	140	114	74	57	24	12	8



	Cavitation (Open Hole)	Hydraulic Fracturing (Cased Hole)
Gas Recovery		
• Five Yrs.	4 Bcf	1 Bcf
• Ultimate	6-10 Bcf	3-5 Bcf
Well Costs (000)		
• Avg.	$700	$650
• Risk	±$100	±$50

Source: Advanced Resources Int'l (2001)

Closing Observations and Questions

1. It's too easy, even tempting, to adopt a view of pessimism and scarcity for natural resources. Technology progress has, so far, been able to outrun resource depletion.
2. At the same time, it is dangerous to become complacent and assume that model runs and "cheerleading" will assure adequate future resources. Strong investments in R&D, economic incentives and transfer of knowledge are the keys.
3. Technology progress in oil and gas extraction rest more on investment in new knowledge than on repeated use of past practices.
4. Should an "induced resource base growth" factor (IRBG) linked to investment in new resource knowledge be incorporated into long term energy models?
5. Should "induced resource cost reduction" factors (IRCRs) directly linked to investment in technology progress be incorporated into long term energy models?