RECOVERY GROWTH AND THE FUTURE OF WORLD OIL SUPPLY

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Richard Nehring

WHERE WILL THE WORLD'S FUTURE OIL RESOURCES COME FROM?

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WILL WE DISCOVER THEM?

- First subpoint

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LIMITATIONS ON FUTURE DISCOVERIES

- Known major and superprovinces are mature
- Major potential is concentrated in frontier provinces (Arctic and deepwater) and some Middle East (Iran and Iraq)
- No new megaprovinces

ESTIMATED UNDISCOVERED POTENTIAL

- Used augmented and amended USGS world assessment estimates
- Augmented to add recent Arctic and U.S.
- Amended to reflect 1996-2005 drilling results and recent reassessments
- Estimated undiscovered potential of 350 (95%) - 780 (50%) - 1310 (5%) billion barrels

FURTHER CONSTRAINTS

- Frontier provinces at boundaries of current exploration and production technology
- Middle East exploration is still constrained
- Most undiscovered resources are thus 10 - 40 years away from contributing to world production

WHAT ABOUT UNCONVENTIONAL OIL RESOURCES?

- First subpoint

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UNCONVENTIONAL OIL RESOURCES

- Limited to naturally occurring liquid hydrocarbons

- Three types:
  - extra-heavy oil/bitumen (tar sands)
  - oil from mature source rocks
  - “oil shale”

- Immense in-place resources of <u>each</u> source

UNCONVENTIONAL OIL RESOURCES (2)

- Poor fluid quality, poor rock quality, or both
- Central problem is ***Recoverability***
- Technology development critically needed
- Energy use and net energy are key issues

UNCONVENTIONAL POTENTIAL

- Estimated 340 (95%) - 560 (50%) - 860 (5%) billion barrels potential
- Very low recovery rates of massive in-place resources
- Technological breakthroughs could increase potential
- Slow rates of development using current technologies
- An oil resource for the next two centuries

WHAT ELSE IS THERE?

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THE PARADOX OF RECOVERY GROWTH

- **Most important source of recent oil reserve additions, yet least understood and appreciated**

- **Why is recovery growth so misunderstood?**
  - **Conceptually incomprehensible**
  - **Denial**
  - **Poorly explained**

WHAT IS RECOVERY GROWTH?

- The increase in known recovery of oil and gas over time

- Known recovery (cumulative production plus proved/probable developed reserves) is starting point for measuring increases
- Recovery growth depends on additional investment; hence emphasis on ***developed*** reserves

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HOW DOES RECOVERY GROWTH OCCUR?

- More intensive development of producing reservoirs
- Initial development of discovered, but undeveloped reservoirs
- New reservoir discoveries and their subsequent development
- Reservoir extensions

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WHY DOES GROWTH OCCUR?

- Past development was constrained
  - Size of oil demand (market)
  - Cost of development phases (supply curve)
- Key explanatory insight
- Counter to common view of development

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IMPACT OF GIANT FIELDS

- **Two bedrock facts of resource assessment**
  - **Concentration of oil in giant fields**
  - **Giant fields discovered early**
- **Implications for *undiscovered* assessments universally recognized**
- **Implications for *reservoir development* wholly ignored**

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HOW DOES RAPID INITIAL DEVELOPMENT OF GIANT FIELDS AFFECT THE OIL MARKET?

- Ruinous for oil producers
  - Los Angeles Basin, 1920-1923
  - East Texas field, 1930-1933
- Production controls are a defensive and desperate response

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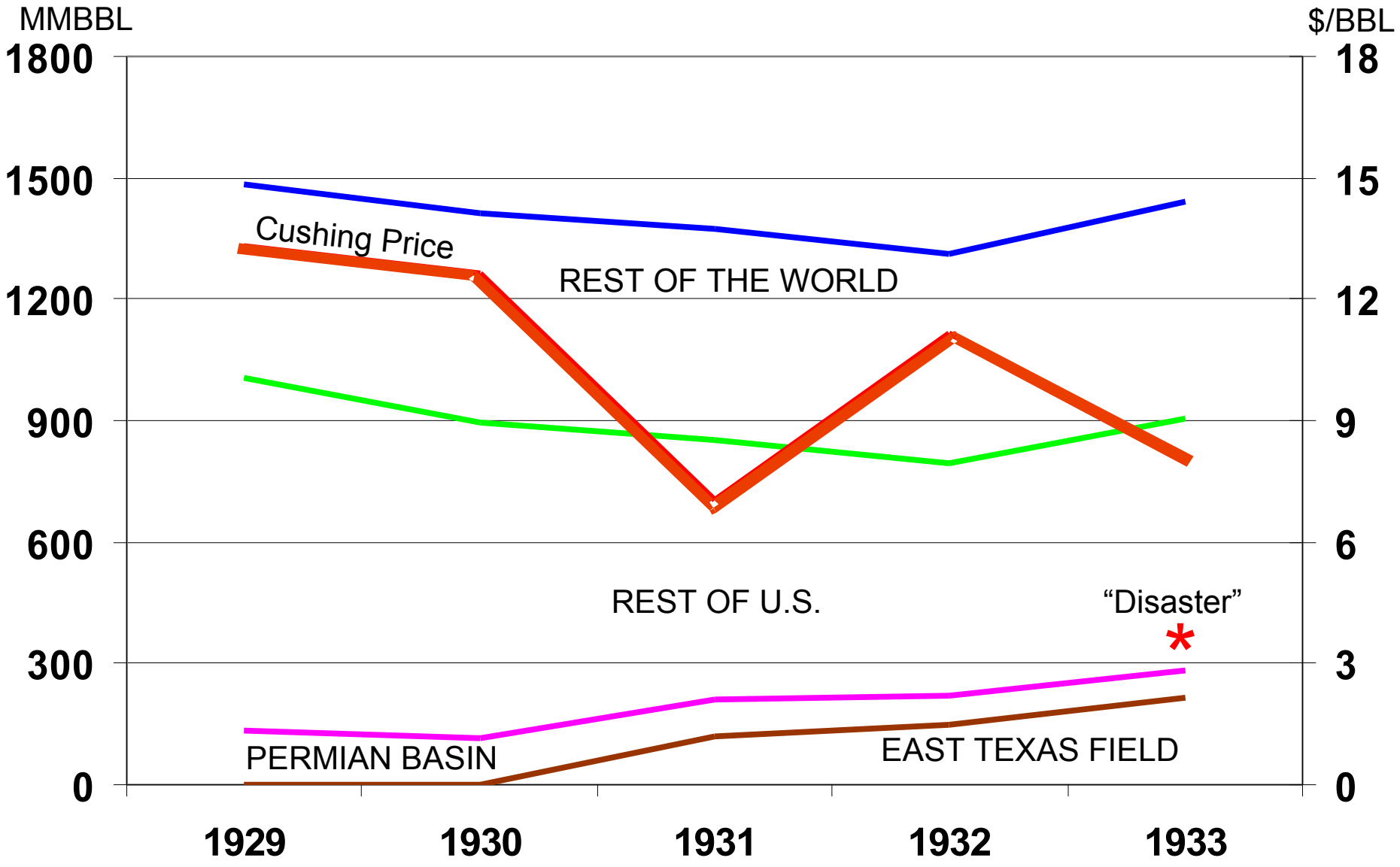
PRODUCTION AND PRICE



THE ROLE OF TIME

- Oil recovery (generally) grows over time
- The conventional model thus predicted growth as a function of the mere *passage* of time
- Rigorous application of this model led to weird results

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RETHINKING THE ROLE OF TIME

- **Substantial variation exists *when* growth occurs over a field history**
- **Growth usually occurs in irregular pulses**
- **Growth is a function of the historical context**

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KEY FACTORS IN CONTEXTUAL TIME

- Reservoir characteristics
  - Rocks and fluids
- World oil market
  - Aggregate demand
  - Oil price
- Oil development technology

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EXPLAINING OIL RECOVERY GROWTH

- Why does growth occur?
  - Past development was constrained
- Why was development constrained?
  - Production capacity overhang
- Why did production capacity overhang persist?
  - Resource concentrated, giants discovered early, demand was relatively low

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TWO TYPES OF CONSTRAINTS

- DIRECT - production quotas, market demand prorationing, development constraints
- INDIRECT - state of technology, prices

- Direct constraints are limited geographically, indirect constraints apply worldwide

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EFFECTS OF CONSTRAINTS

- Limit exploration
- Postpone initial development
- Restrain initial development
- Delay and restrict subsequent phases of development

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SAUDI ARABIA AS A TEST CASE

- Largest known recoverable oil resource
- Largest production capacity for the past 35 years
- Potential vigorously questioned by leading imminent peak oil theorists

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EXTREME CONCENTRATION

- Twelve supergiant fields
- 95% of OOIP in SG fields
  - c. 475 of 500 billion
  - c. 675 0f 710 billion
- Saudi SG OOIP = all U.S. OOIP

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MEASURED DISCOVERY RATE

- SG discovered from 1940 to 1968
- Slow rate due to extremely low rate of NFW drilling (0-2 wells per year)
- Drilling effort concentrated on appraisal drilling – Ghawar is 1440 mi2
- Amazing NFW success rate
  - 100% for 15 plus years
  - 5-10 million bbls/NFW foot drilled

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WORLD OIL MARKET LIMITATIONS

- Demand less than 15 million b/d when Ghawar was discovered
- Full development of Ghawar alone would have overwhelmed market
- Saudi development was major enabler of world oil production growth (7-8% per year) in 1950s and 1960s
- Despite rapid growth, development was still severely constrained

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DETERMINANTS OF DEVELOPMENT

- Order of discovery and reservoir quality (primarily permeability)
- First SG discovery – Abqaiq (1940) – was first developed
- Next group (1945-1957 discoveries) was developed based on productivity – Ghawar, Safaniya, Berri
- First four initial developments provided 8 million b/d capacity

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FORMAL CONSTRAINTS ON DEVELOPMENT

- From 1973 to 1990 capacity of big four equaled or exceeded OPEC quota
- Later discoveries and earlier low quality SG fields had only pilot production
- Initial development of these SG fields only occurred from 1990 to 2010
- Lag from discovery to initial development was 25–50 years

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RESTRAINED INITIAL DEVELOPMENT

- Low density spacing – 640 acres
- Only primary recovery initially
- Secondary began 15-20 years later
- Later initial developments usually primary with pressure maintenance
- Later have maintained low density
- Infill and horizontal drilling only in past decade

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IMPLICATIONS FOR GROWTH

- Current EUR c. 275-290 billion bbls (cumulative production plus 2P developed reserves)
- Undeveloped reserves c. 80-100 B bbls
- All Saudi SG fields subject to extensive reservoir modelling efforts

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IMPLICATIONS (2)

- "Gentle" production (at 10,000 bbls/well/day!)
- Likely 60-70% recovery rates from secondary and infill alone in high quality reservoirs
- Unknown recovery rates from poorer quality reservoirs – analogies with Permian Basin carbonates (30-50%)?

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WORLDWIDE RECOVERY GROWTH POTENTIAL

- Estimated 800 (95%)–1180 (50%)–1670 (5%) billion barrels
- Assumes future recovery factors of 35-40-45% of c. 7 trillion barrels of known original-oil-in-place (plus NGL)
- Includes 300-390-510 billion barrels from fields yet to be developed
- Will take 50 to 100 years to realize

RECOVERY GROWTH AND FUTURE WORLD OIL PRODUCTION

- Increases ultimate world oil resources significantly
- Increase will occur at slow rate
- Has only modest effect on the maximum level of world oil production
- Major effect on how long high levels of world oil production will last

ULTIMATE WORLD OIL POTENTIAL

(As of 12-31-2005)	Low	Medium	High
		(billion barrels)	
Cumulative Production	1110	1110	1110
Proved Dev. Reserves	670	670	670
Recovery Growth	800	1180	1670
Future Discoveries	350	780	1310
Unconventional	340	550	860
World Total	3270	4290	5620

IMPORTANCE OF ALL MAJOR RESOURCE CATEGORIES

- Estimates of ultimate world oil resources vary drastically

- Primary disagreement is NOT_ WITHIN any resource category

- Most differences depend on whether a particular category is included or not in estimate

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Recovery Growth	(800)	(1180)	(1670)
Future Discoveries	350	780	1310
Unconventional	(340)	(550)	(860)
Total (w/o RG & UC)	*2130*	*2560*	*3090*

CONCLUSIONS

- Most world oil remains to be produced
- Resources are being consumed at a very rapid rate
- The 21st Century will be the Age of Oil

CONCLUSIONS (2)

- **Maximum level of world oil production is**
  - **not imminent**
  - **foreseeable**
  - **likely to be a plateau**

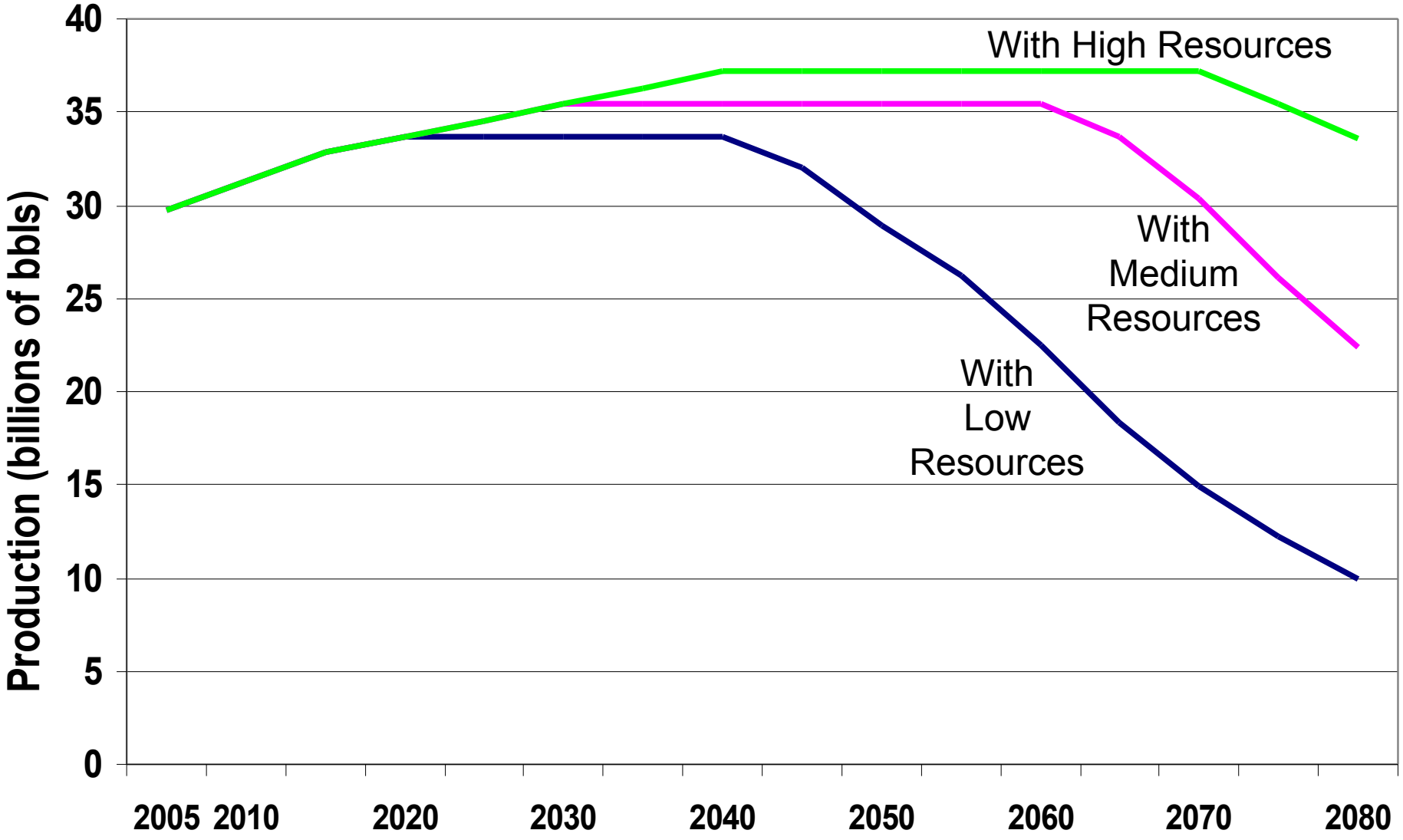
WHY A PLATEAU AT THE MAXIMUM?

- Most postulate sharp peak
- Peak implies sudden and sharp decline in capacity and reserve additions
- Plateau implies gradual slowing of these additions
- Plateau is more consistent with path of future additions

CONCLUSIONS (3)

- Production will grow slowly (0.5-1.0%/year) to the plateau
- Maximum plateau production at 90 to 100 million b/d
- Maximum annual production will be 0.75-1.0% of ultimate world oil resources
- Maximum plateau spans midpoint in world oil production

FUTURE WORLD OIL PRODUCTION



RESOURCE UNCERTAINTY AND FUTURE PRODUCTION

- New production capacity can only come from highly certain resources
- Projections for next decade must assume low resources
- Greater resource potential will be apparent only 10-40 years from now
- Resource constraint will lift gradually

CONCLUSIONS (4)

- Massive, sustained industry effort is necessary for 40-60 years to achieve projected world oil production levels
- Accommodating political environment is required
- These efforts are a key to a successful transition from oil to other sources of energy

Understanding World Oil Resources

AAPG Hedberg

Colorado Springs