Storing CO_2 with Enhanced Oil Recovery

Prepared for:
2008 CCS Conference

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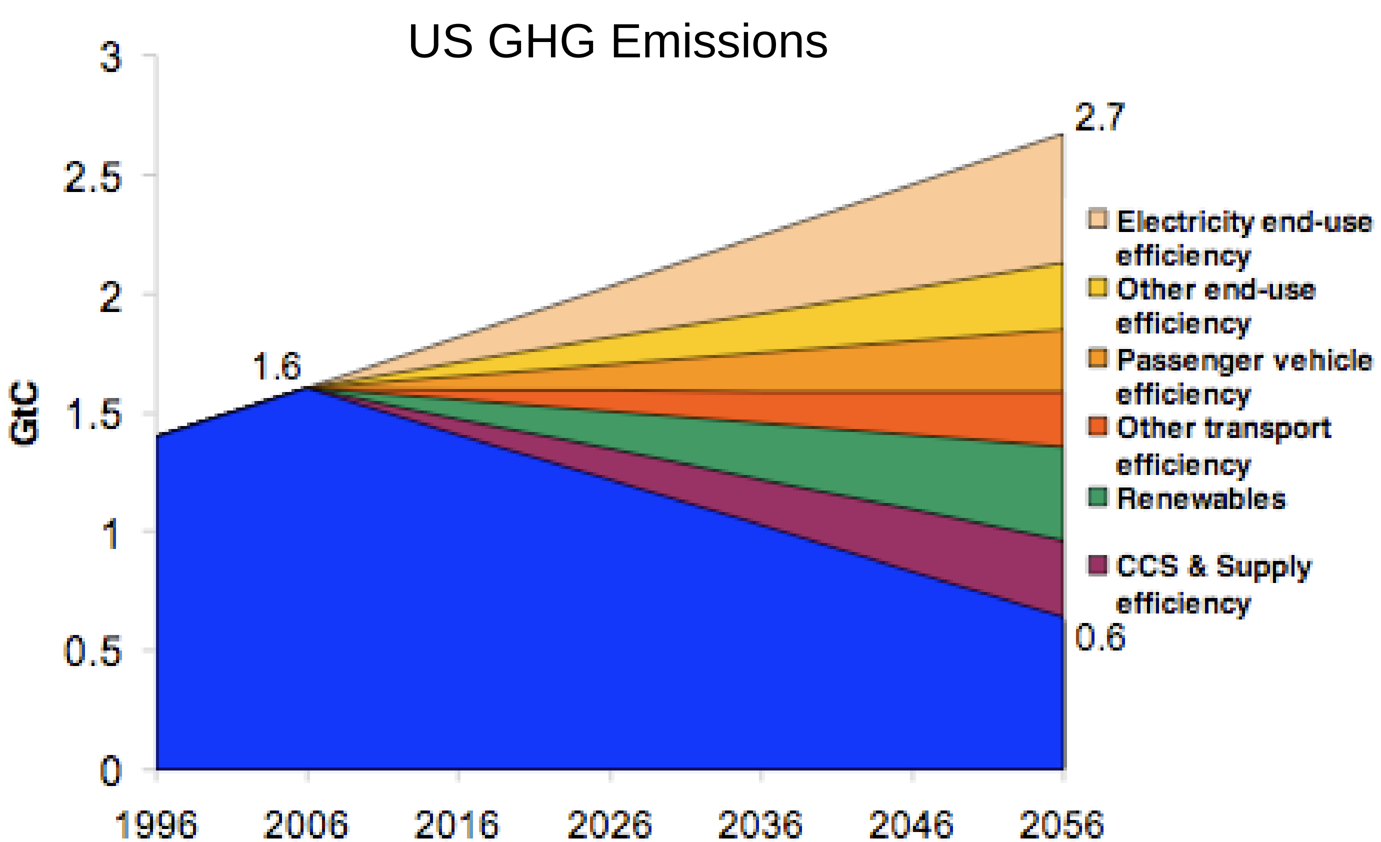
May 6, 2008
Pittsburgh, PA

Outline

- Background
- Methodology
- Technically Recoverable Resource
- CO_2 Demand and Recoverable Oil Resource
- Market Demand for CO_2: Power Plant Perspective
- Summary Remarks

The Goal

Reduce Emissions



Source: Lashof, Hawkins. NRDC 2006

Challenges and Barriers

- **GHG Reduction "Solutions"**
  - **Carbon Capture & Storage**
  - **High Efficiency Electric Vehicles**
  - **Nuclear Power**
  - **2nd Generation Biofuels**
- **Are 10 years away**
  - **Climate scientists tell us GHG emissions need to peak in 10-15 years, then begin dramatic decline.**

The Role of CO_2-EOR in Reducing GHG Emissions

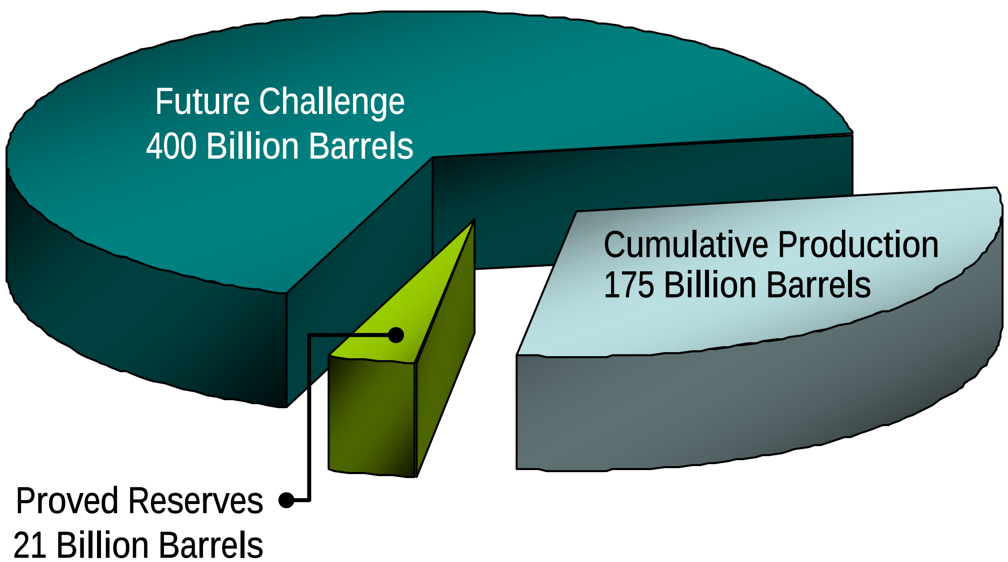
- **Revenues from sale of captured CO_2 can Jump-start the application of CCS technology**
- **Oil produced from CO_2-EOR has lower carbon impact than traditionally produced oil.**

Storing CO_2 with EOR: A Large “Value-Added” Market for CO_2 Emissions

Large Volumes Of Domestic Oil Remain “Stranded” After Traditional Primary/Secondary Oil Recovery

Original Oil In-Place: 596 B Barrels*

“Stranded” Oil In-Place: 400 B Barrels*



*Based on field-by-field assessment of over 2,011 large U.S. oil fields accounting for 74% of domestic oil production; excludes deep-water GOM.
Source: Advanced Resources International (2008)

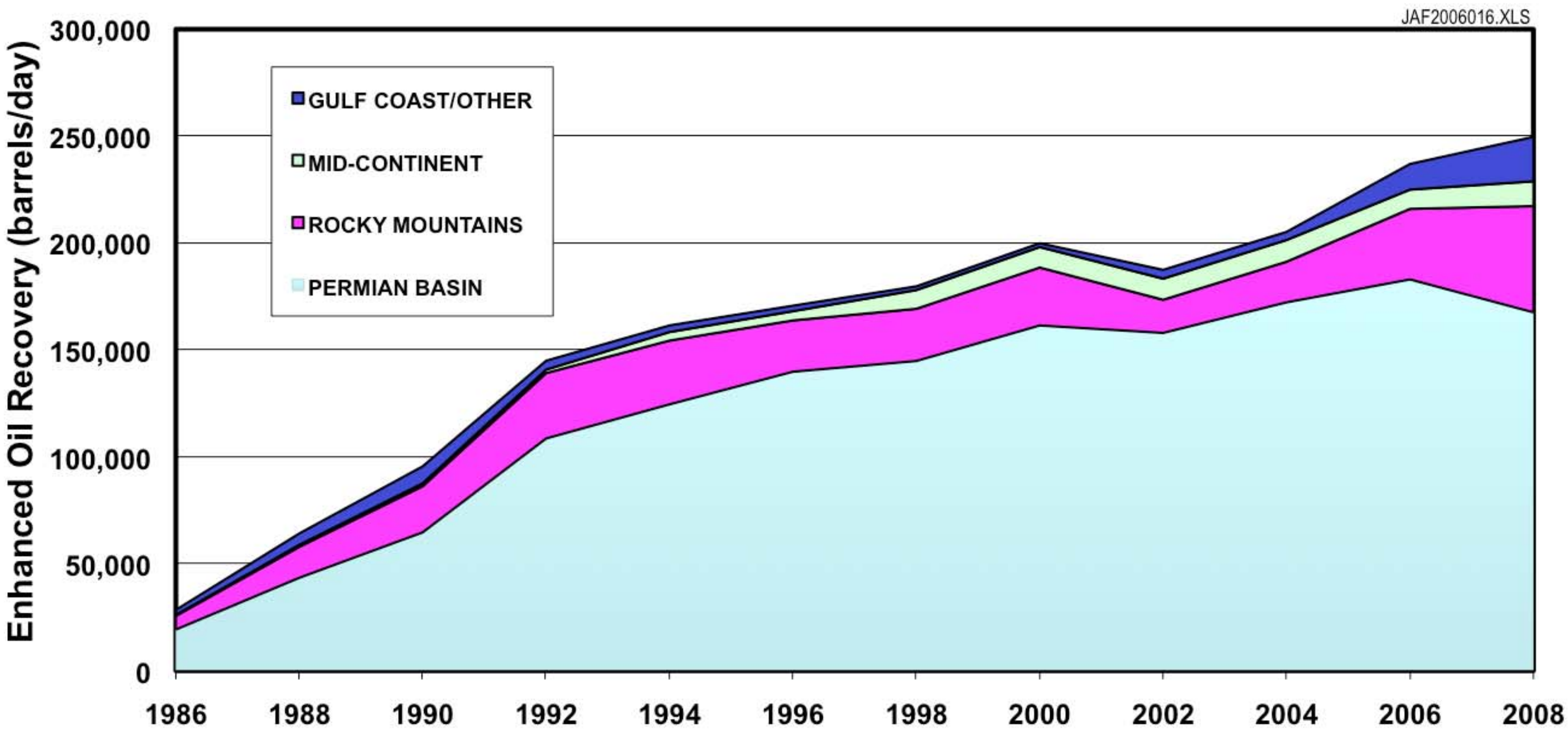
Storing CO_2 with Enhanced Oil Recovery

Storing CO_2 with Enhanced Oil Recovery (EOR) provides an "early action pathway" for overcoming the initial barriers:

- **Regulatory / Public Acceptance**
- **Long-term Liability**
- **Pore space Ownership to Geological Storage of CO_2**

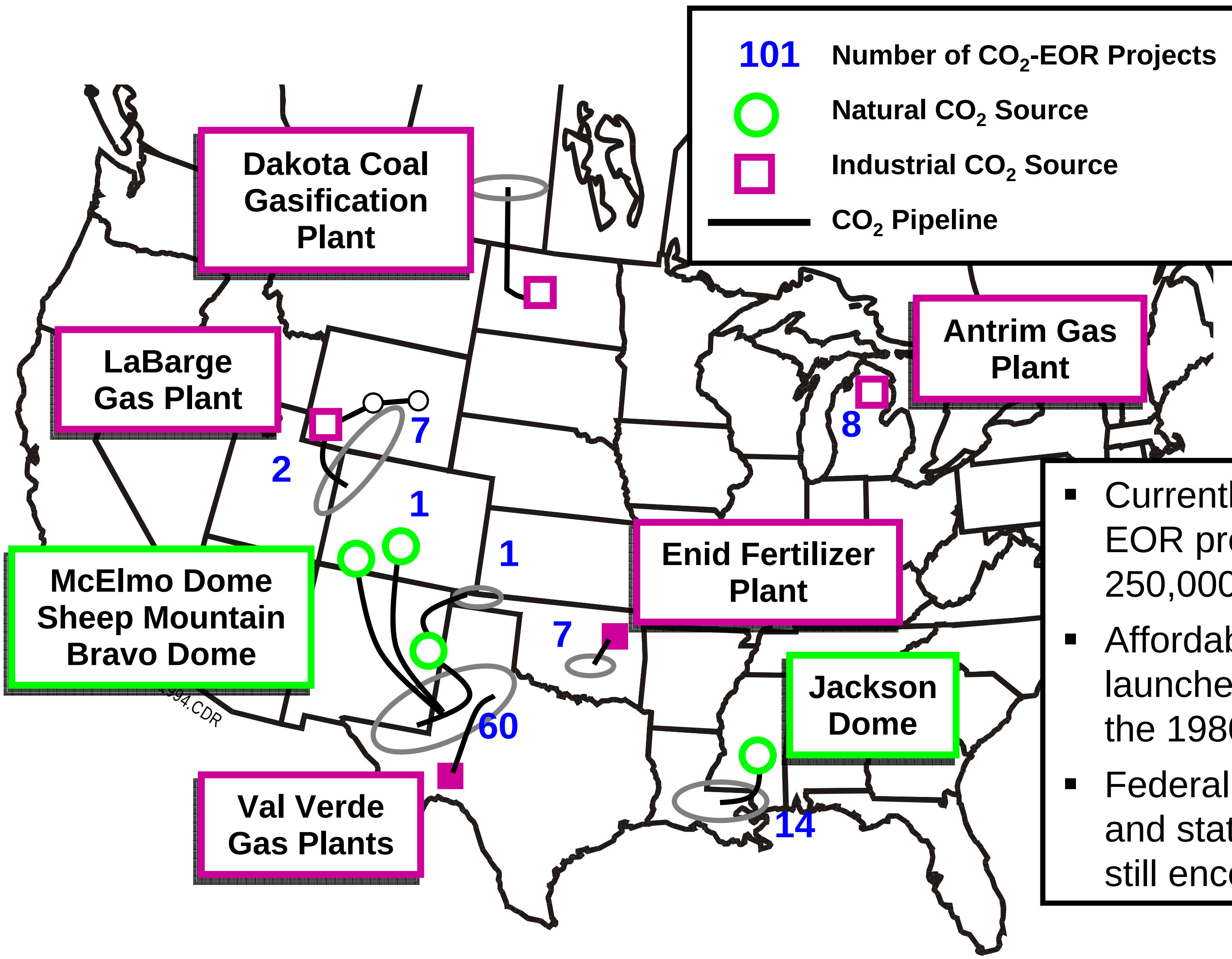
It can also provide significant revenues. For example, a one GW size coal-fired power plant emitting 6 MMmt of CO_2 a year and selling this CO_2 (at pressure and at the plant gate) for $35 per mt would realize $6.3 billion in 30 years.

GROWTH OF CO_2-EOR PRODUCTION IN THE U.S.



Oil and Gas Journal, 2008.

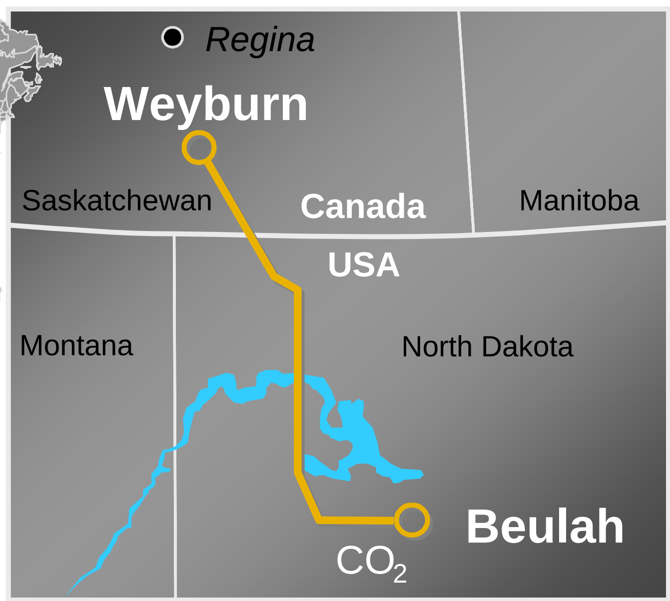
U.S. CO_2-EOR ACTIVITY



- Currently, 100 Domestic CO_2-EOR projects provide 250,000 B/D
- Affordable natural CO_2 launched CO_2-EOR activity in the 1980's
- Federal tax credits (Sec.43) and state severance tax relief still encourage CO_2-EOR

The “Poster Child” - Weyburn Enhanced Oil Recovery Project

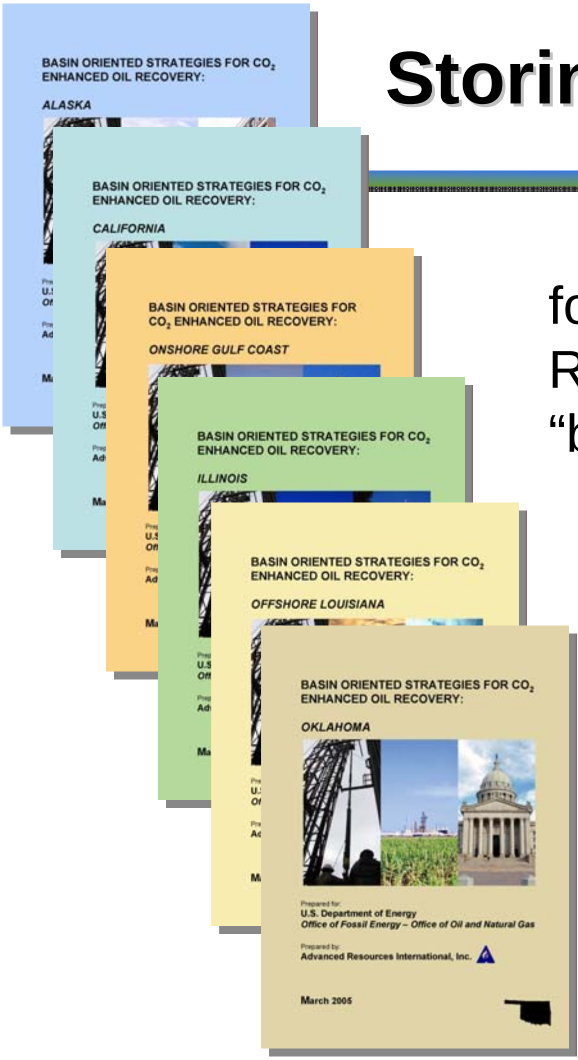
(Maximizing Oil Recovery and CO_2 Storage)



Source: EnCana, 2005

- **Largest CO_2 EOR project in Canada:**
  - **1.4 billion barrels (OOIP) oil field**
- **Outstanding EOR response**
- **World’s largest geological CO_2 sequestration project**
  - **2.4 MMt/year**
  - **23 MMt with EOR**
  - **<u>55 MMt with EOR/sequestration</u>**

Methodology



Storing CO_2 with Enhanced Oil Recovery

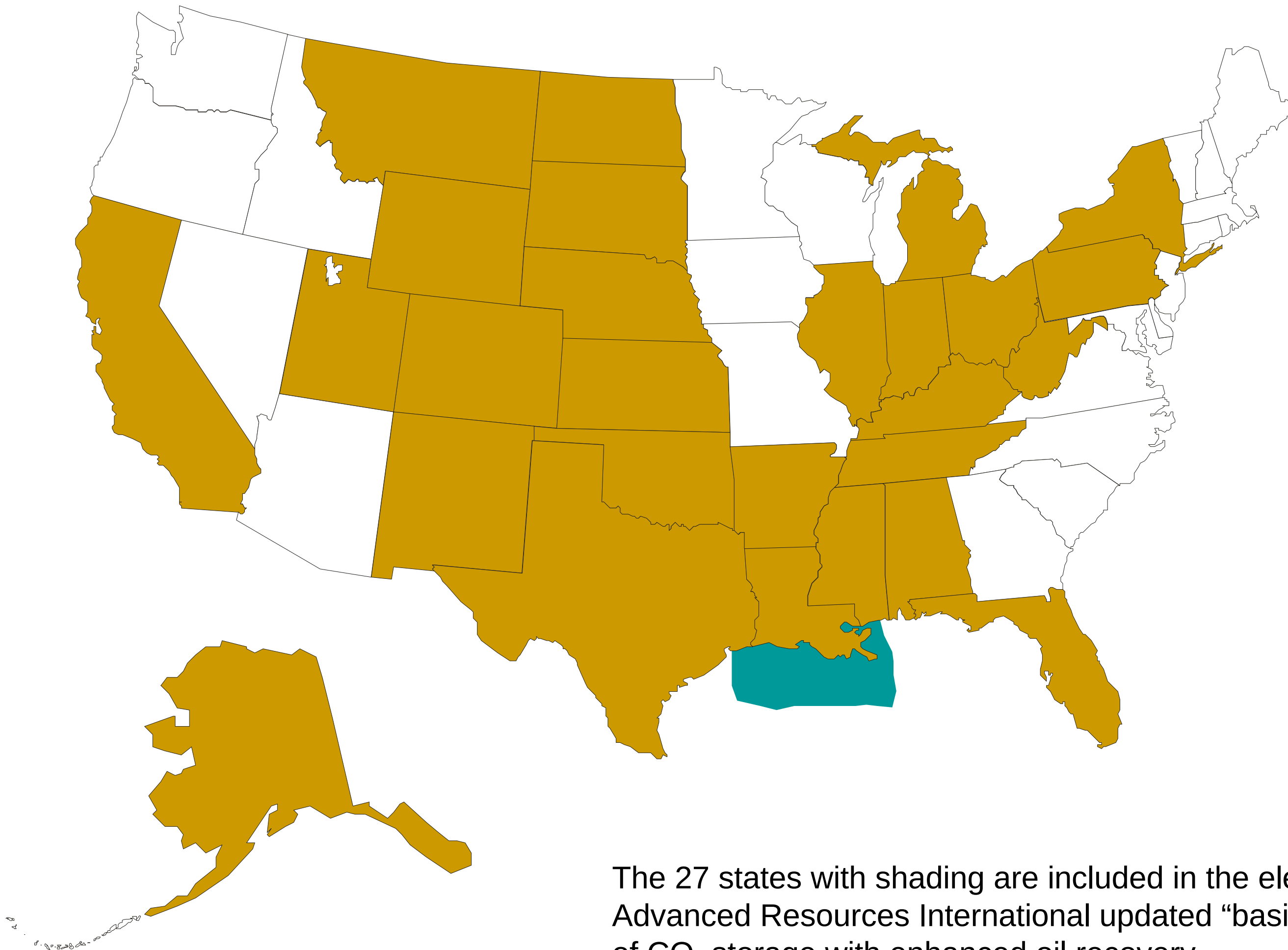
Advanced Resources recently completed a report for DOE/NETL entitled "Storing CO_2 with Enhanced Oil Recovery,"* an update to the previously published "basin studies".**

- Examines economically recoverable oil from applying CO_2-EOR (oil price $70/B; CO_2 cost $45/mt),
- Addresses market demand for CO_2 by the EOR industry
- Uses a streamline reservoir simulator and a data base of 2,012 large oil reservoirs (74% of U.S. oil production),
- Covers 27 producing states plus offshore Louisiana.

*Available on the U.S. DOE web site. http://www.netl.doe.gov/energy-analyses/pubs/Storing%20CO2%20w%20EOR_FINAL.pdf

**Available on the U.S. DOE web site. http://www.fe.doe.gov/programs/oilgas/eor/Ten_Basin-Oriented_CO2-EOR_Assessments.html

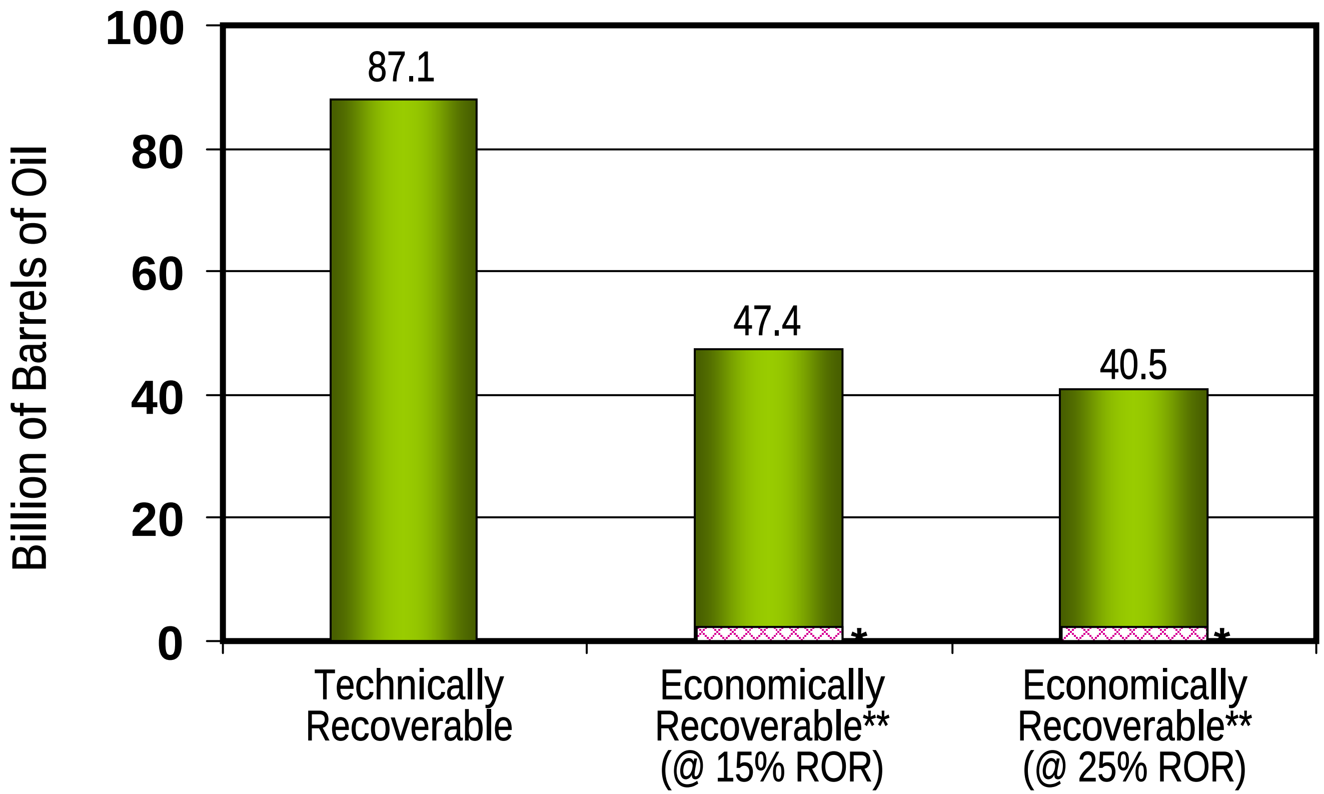
U.S. Basins/Regions Studied For CO_2 Storage and Enhanced Oil Recovery



The 27 states with shading are included in the eleven Advanced Resources International updated "basin studies" of CO_2 storage with enhanced oil recovery.

CO2 Demand
and
Recoverable Oil Resource

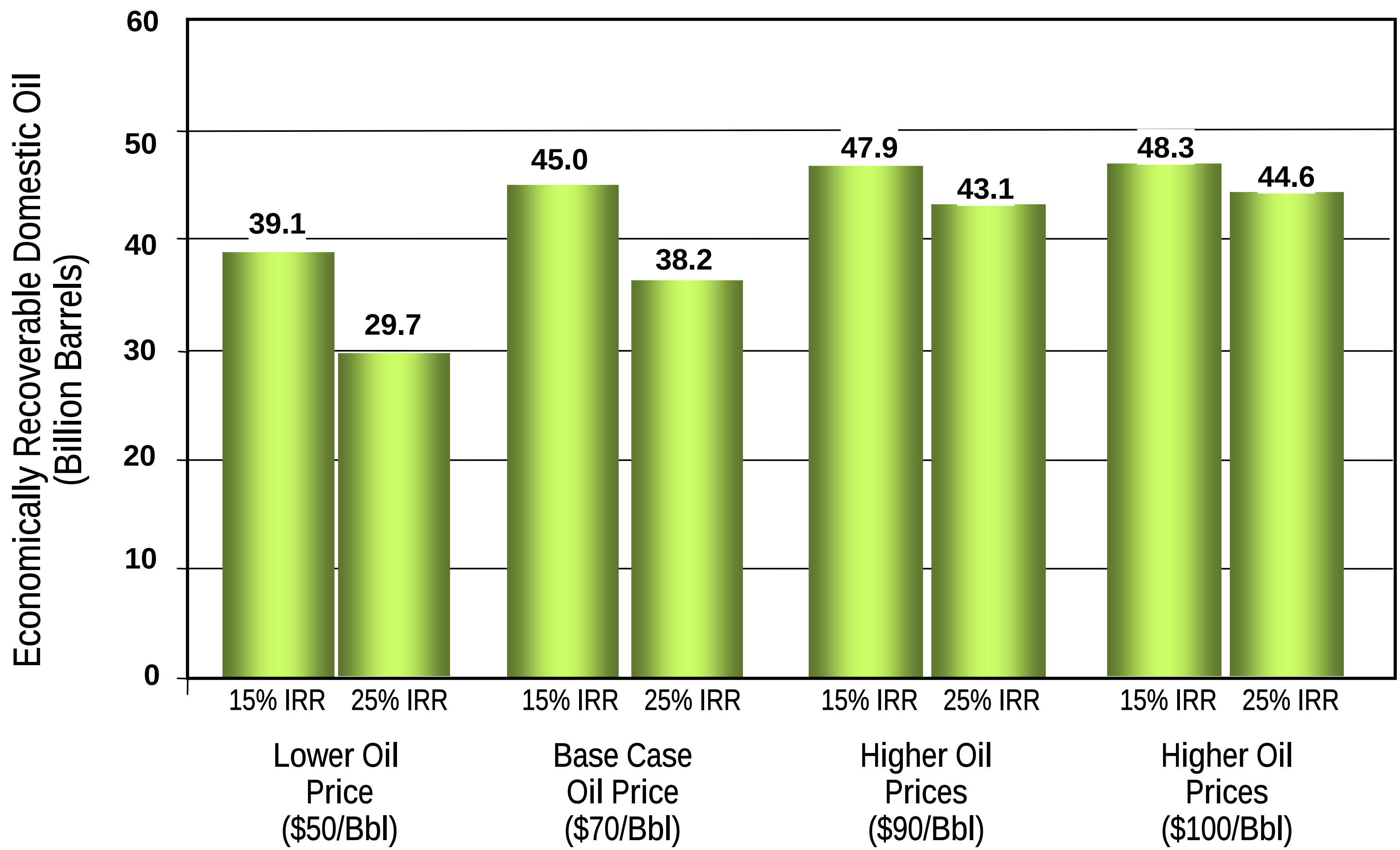
Domestic Oil Resources Technically and Economically Recoverable w/CO_2-EOR



*Already produced or place into proved reserves with CO2-EOR.

**Assuming oil price of $70/B (real); CO2 costs (delivered to field at pressure) of $45/metric ton ($2.38/Mcf); investment hurdle rate (15% and 25% ROR, real).

Economically Recoverable Domestic Oil Resources from Applying CO2-EOR



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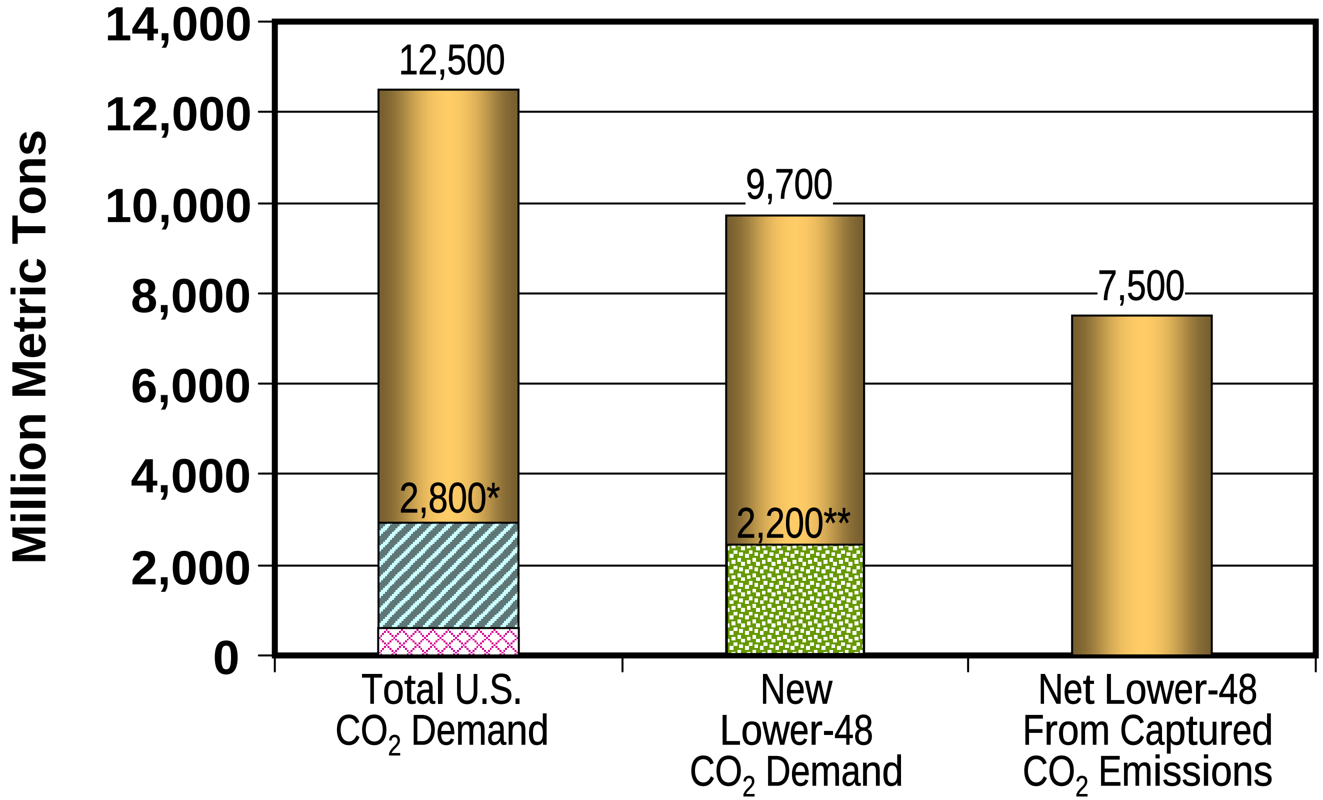
Market Demand for CO_2 by the Enhanced Oil Recovery Industry(1)

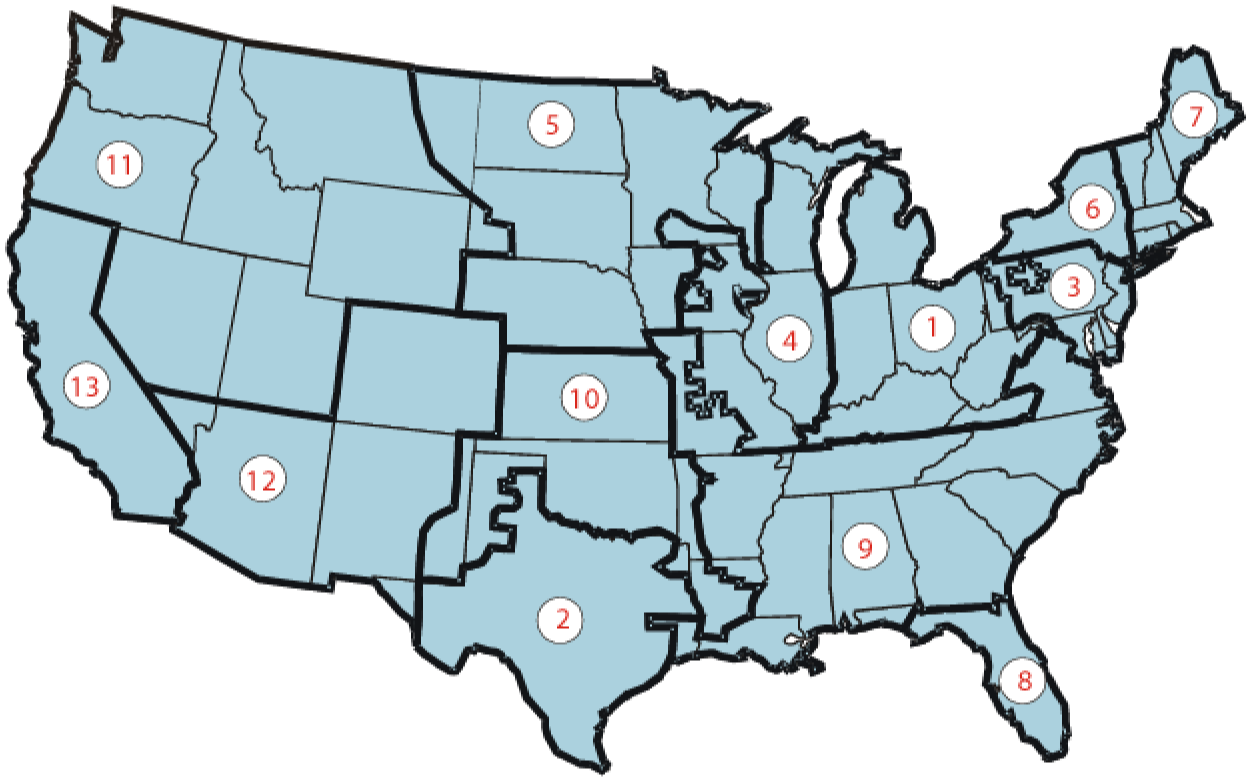


*CO_2 demand being met by on-going CO_2-EOR projects and CO_2 demand in Alaska.
**CO_2 demand that can be met by natural CO_2 and already being captured CO_2 emissions.
(1) Economic CO_2 market demand for EOR at oil price of $70/B (real), CO_2 cost of $45/mt, and ROR of 15% (real).

Market Demand for CO2: Power Plant Perspective

The NEMS Electricity Market Module

<u>NEMS Regions</u>: CO2 supply and demand have been organized according to the 14 NEMS regions (13 lower-48 plus Alaska) in the Electricity Market Module



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Market Demand for CO_2 by EOR

Electricity Regions	New Coal Plants: GW Capacity	New Coal Plants: 30 years of CO_2 Emissions (MMmt)	Market Demand for CO_2 Emissions (MMmt)	Ability to Meet Market Demand (%)
Region 2 – ERCOT (Texas)	16 GW	2,480	2,440	98%
Region 9 – SERC (AR,LA, MS, AL, FL, TN, GA, SC, NC)	34 GW	5,270	1,700	32%
Region 13 – WECC/CA (California)	-	-	1,380	-
Region 10 – SWPP (OK, KS, NM)	7 GW	1,080	1,290	100+%
Region 11/12 (WA, OR, ID, MT, WY, UT, NV)/(NM, CO, AZ)	26 GW	4,030	390	10%
All Others	14 GW	2,170	300	14%
TOTAL	97 GW	15,030	7,500	50%

*After subtracting EOR market demand met by natural CO2 and being captured industrial sources.
Source: AEO 2008 (March, 2008) and Advanced Resources International.

Relationship of CO_2 Sales Price to Cost Offsets in the Coal-Fueled Power Sector (Year 2020)

Sale of CO_2 @ $25/mt CO_2

7,920 btu/kWh x

94 MMmt CO_2/QBtu x

90% Capture

Cost Offset: $16.80/MWh

Sale of CO_2 @ $35/mt CO_2

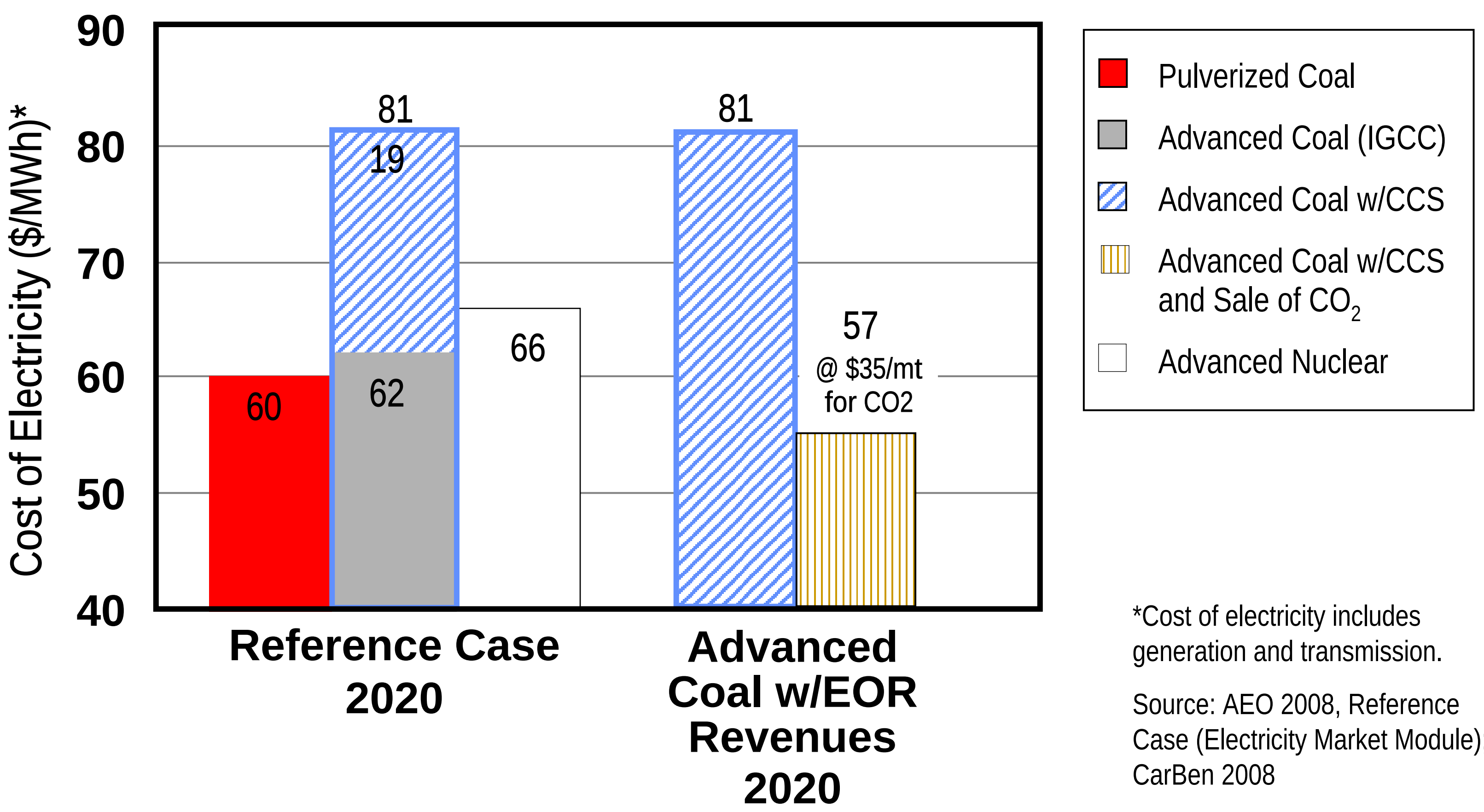
7,920 btu/kWh x

94 MMmt CO_2/QBtu x

90% Capture

Cost Offset: $23.50/MWh

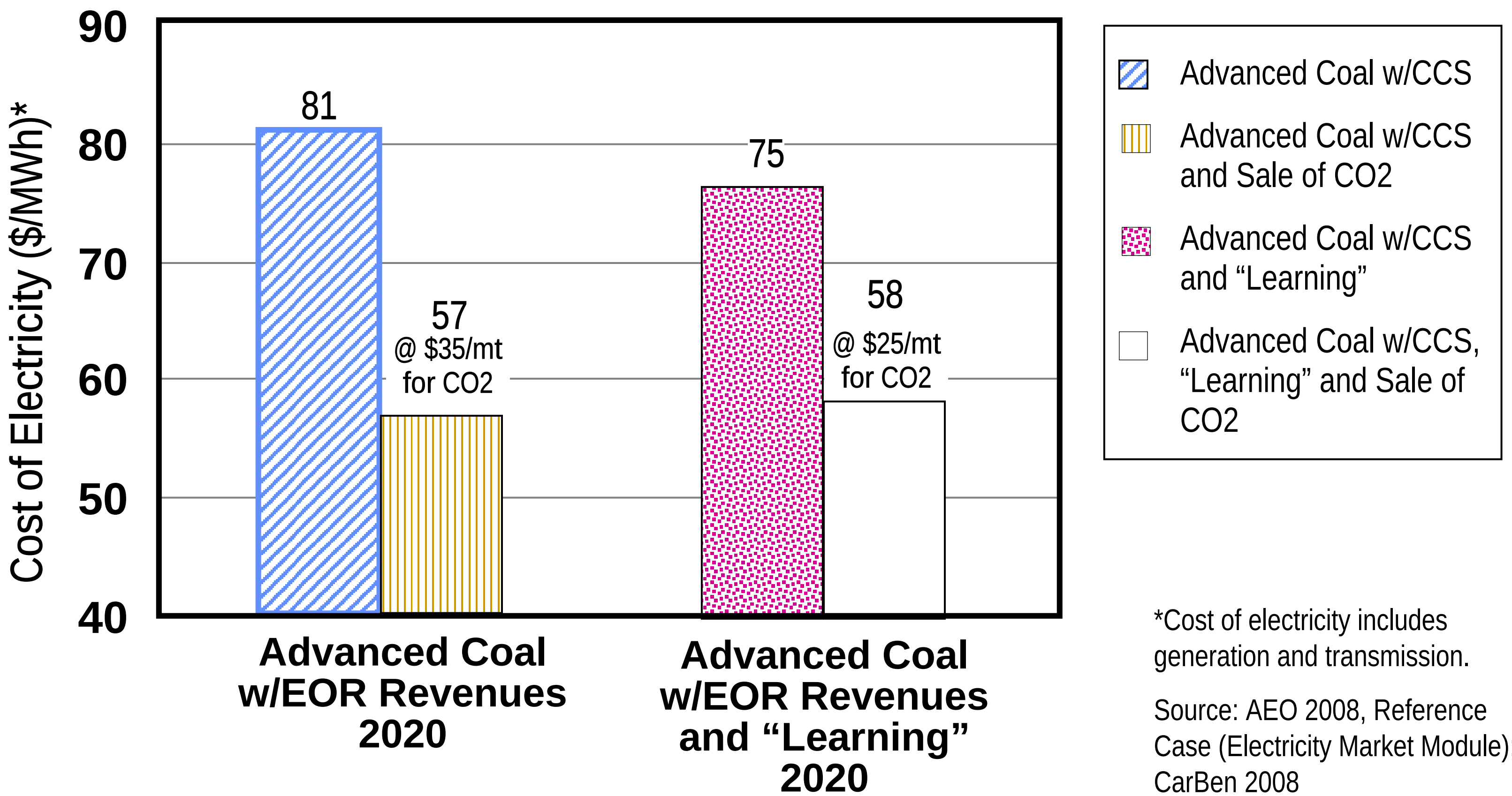
Sale of Captured CO_2 Emissions Can Help Make Coal Plants w/CCS Competitive (Year 2020)



*Cost of electricity includes generation and transmission.

Source: AEO 2008, Reference Case (Electricity Market Module); CarBen 2008

"Learning by Doing" can further decrease costs of deploying CCS in the Future



*Cost of electricity includes generation and transmission.

Source: AEO 2008, Reference Case (Electricity Market Module); CarBen 2008

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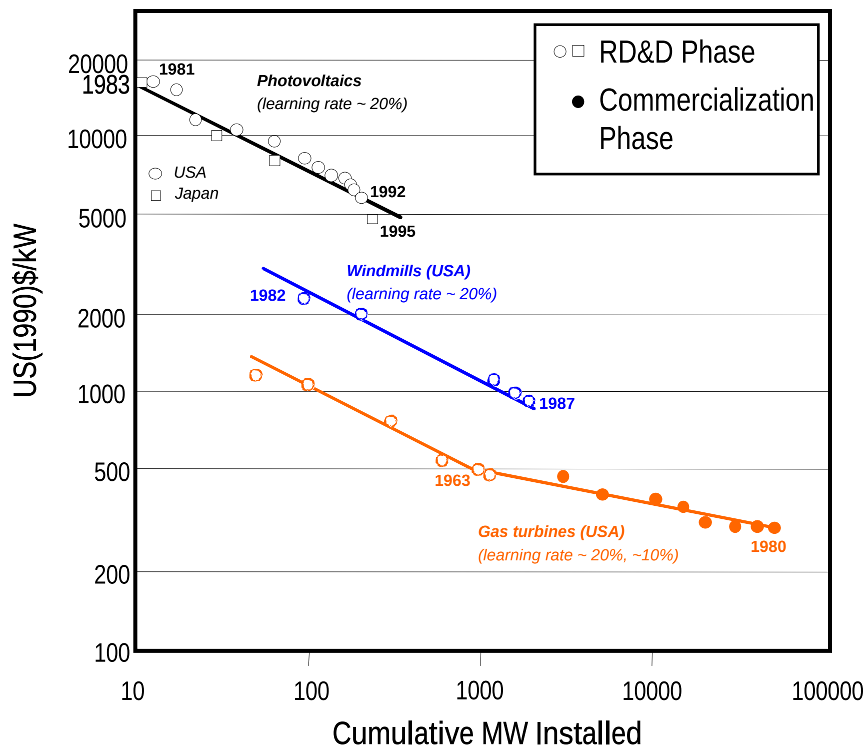
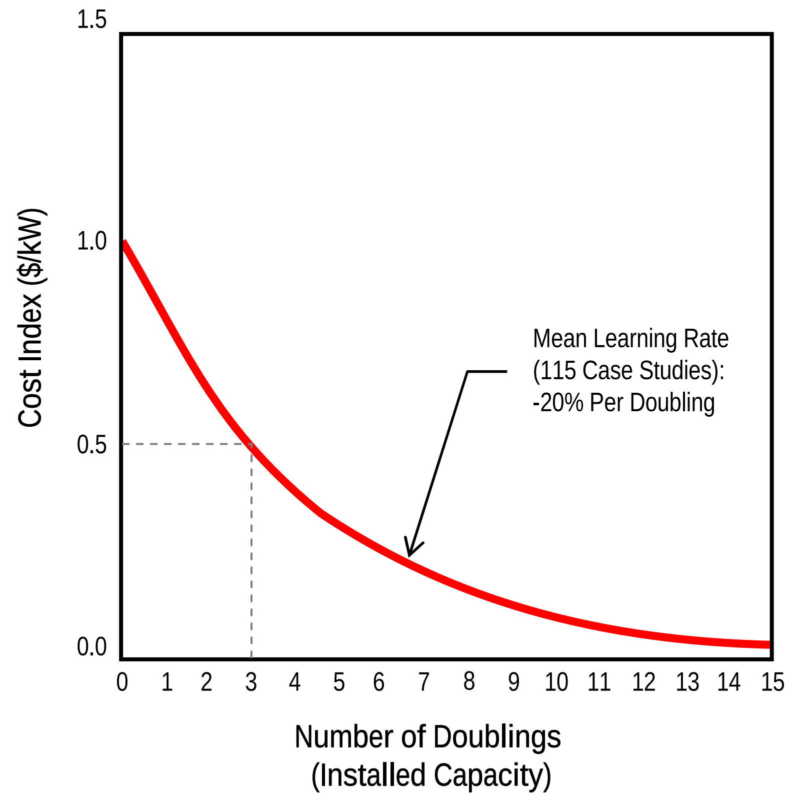
Costs of New CCS Technology Will Decline Due to "Learning"

Learning Curves for Energy Technologies



Source: Nakicenovic, N., Grubler, A., and MacDonald, A., "Global Energy Perspectives", ISBN-10: 0521645697, Cambridge University Press (1998).

Historical Cost Reductions Rates from Learning Curves



Modified from Nakicenovic (1998).

Integrating CO_2-EOR and CO_2 Storage

Integrating CO_2-EOR and CO_2 Sequestration shows that much more CO_2 can be stored, making the additional oil produced “GREEN OIL”*.

	“State of the Art”	“Next Generation”		
	(millions)	EOR	Seq.	Total
CO_2 Storage (tonnes)	19	76	33	109
Storage Capacity Utilization	13%	52%	24%	76%
Oil Recovery (barrels)	64	180	-	180
% Carbon Neutral (“Green Oil”)	70%	100%	-	160%

*”Green Oil” means that more CO_2 is injected and stored underground than the volume of CO_2 contained in the produced oil, once burned.

Summary Remarks

- CO_2-EOR offers a large, "value added" market for captured CO_2 emissions of 7,500 million metric tons (equal to 49 GWs of advanced coal-fired power).
- Storing CO_2 with EOR helps bypass three of today's barriers to geological storage of CO_2 - - regulatory/public acceptance, mineral (pore space) rights and long-term liability;
- The oil produced with CO_2–EOR is 70% "carbon-free". It can become 100+% "carbon-free" with "next generation" technology.

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Appendix Slides

Economics and Cost Model

- **Costs Accounted For:**
  - **Drilling new wells or reworking existing wells**
  - **Surface equipment for new wells**
  - **CO_2 recycle plant and CO_2 spurline from main trunkline to the oil field**
  - **Operation and Maintenance (O&M)**
    - **Lifting produced fluids**
    - **Capturing, Separating, and Reinjecting CO_2**
- **Economics:**
  - **Economic model uses an industry standard cash flow that can be run on a pattern or a field-wide level and it accounts for:**
    - **Royalties**
    - **Severance and Ad Valorem Taxes**
    - **Oil Gravity and Market Location Differentials**
    - **Oil Prices, CO_2 Costs, and Other Variables**

CO_2 Injection and Storage Process

- Initially, purchased CO_2, equal to 1 HCPV is injected with water for mobility control.

- As oil is produced, CO_2 is separated from the oil and reinjected. As produced volumes of CO_2 increase, these larger volumes are reinjected.

- At the end of the project, operator can close the field at pressure, storing essentially all of the injected CO_2, or inject a large (1 to 2 HCPV) slug of water to recover any remaining oil and CO_2. This CO_2 may be used again.

Injection of Natural and Anthropogenic CO_2 for EOR

State/ Province (storage location)	Source Type (location)	CO_2 Supply MMcfd**	
		Natural	Anthropogenic
Texas-Utah-New Mexico-Oklahoma	Geologic (Colorado-New Mexico) Gas Processing (Texas)	1,700	110
Colorado-Wyoming	Gas Processing (Wyoming)	-	340
Mississippi	Geologic (Mississippi)	700	-
Michigan	Gas Processing Plant (Michigan)	-	15
Oklahoma	Fertilizer Plant (Oklahoma)	-	35
Saskatchewan	Coal Gasification (North Dakota)	-	145
TOTAL		2,400	645

* Source: 12th Annual CO2 Flooding Conference, Dec. 2006
** MMcfd of CO2 can be converted to million metric tons per year by first multiplying by 365 (days per year) and then dividing by 18.9 * 10^3 (Mcf per metric ton).

Market Demand for CO_2 by EMM Region

NEMS EMM Region	Purchased CO2 Requirements	Natural CO2*	Industrial CO2*		Unmet (Net) Demand for CO2	
	(Tcf)	(Tcf)	(MMcfd)	(Tcf)	(Tcf)	(Million mt)
Region 1 - ECAR	1.1	-	15	**	1.1	58
Region 2 – ERCOT	72.3	25	110	1.2	46.1	2,438
Region 3 – PJM (MAAC)	0.1	-	-	-	0.1	4
Region 4 – MAIN	1.9	-	-	-	1.9	100
Region 5 – MAPP	2.1	-	-	-	2.1	109
Region 6 – NY ISO	-	-	-	-	-	-
Region 7 – NW ISO	-	-	-	-	-	-
Region 8 – Florida	0.2	-	-	-	0.2	9
Region 9 – SERC	40.0	8	-	-	32.0	1,695
Region 10 – SWPP	29.7	5	35	0.4	24.3	1,286
Region 11 – WECC/NWPP	7.8	-	175	1.9	5.9	311
Region 12 – WECC/RMPP	2.3	-	65	0.7	1.6	83
Region 13 – WECC/CA	26.0	-	-	-	26.0	1,377
Region 14 - Alaska	39.6	5	-	-	34.6	1,831
TOTAL U.S.	223.0	43	385.0	4.2	175.8	9,302
Lower-48	183.4	38	385.0	4.2	141.2	7,470

*Assumed available to be produced and productively used by the CO2-EOR industry in the next 30 years.

**Less than 0.01 Tcf and therefore not included in totals