



Using “Next Generation” CO₂-EOR to Decarbonize the Electricity Sector



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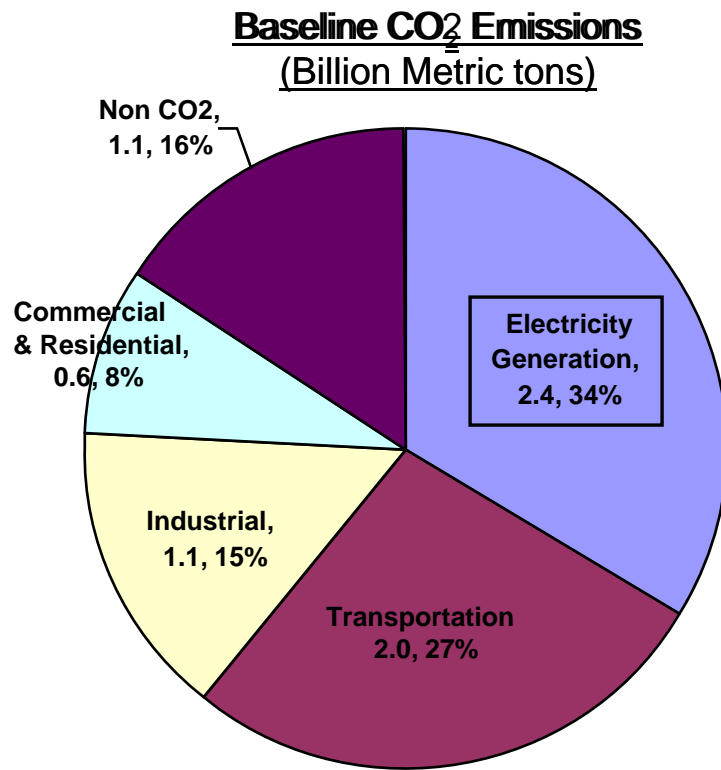


Outline

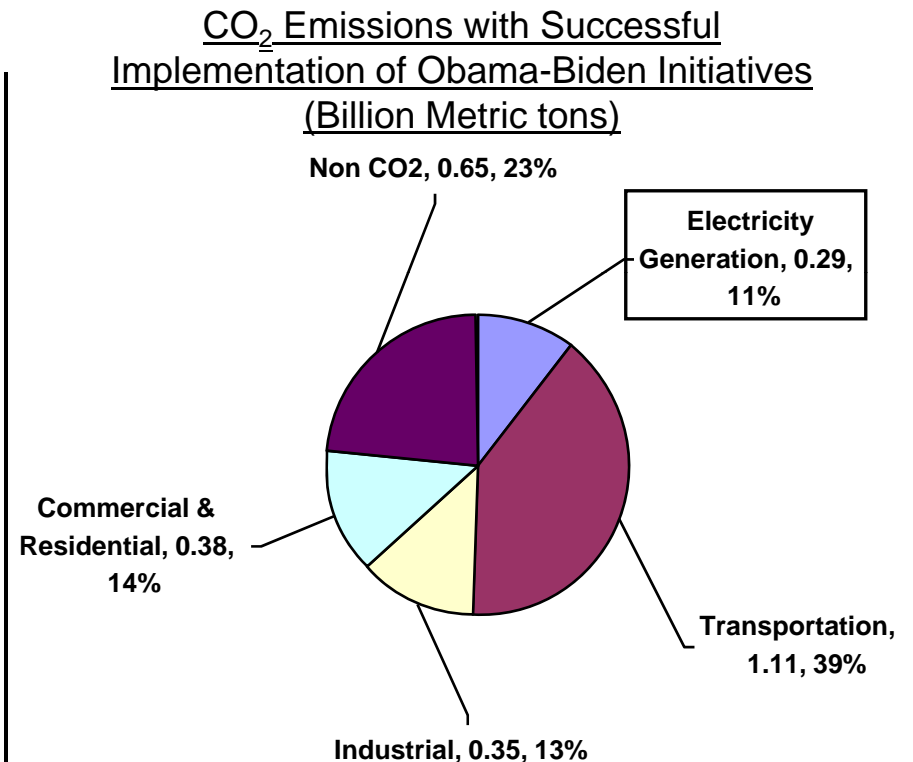
- **Background: The Climate Challenge**
- **Summary of Recent Work**
- **Potential for “Next Generation” CO₂-EOR to Decarbonize the Electricity Sector**
- **Summary remarks**

The Climate Change Challenge

The Obama-Biden Energy agenda calls for an 83% reduction in CO₂ emissions by 2050 (from 2005 levels). To meet the challenge, domestic electric power plants may need to reduce their CO₂ emission footprint by 90%.



**U.S. CO₂ Emissions in 2005:
5.7 Billion Metric Tons**



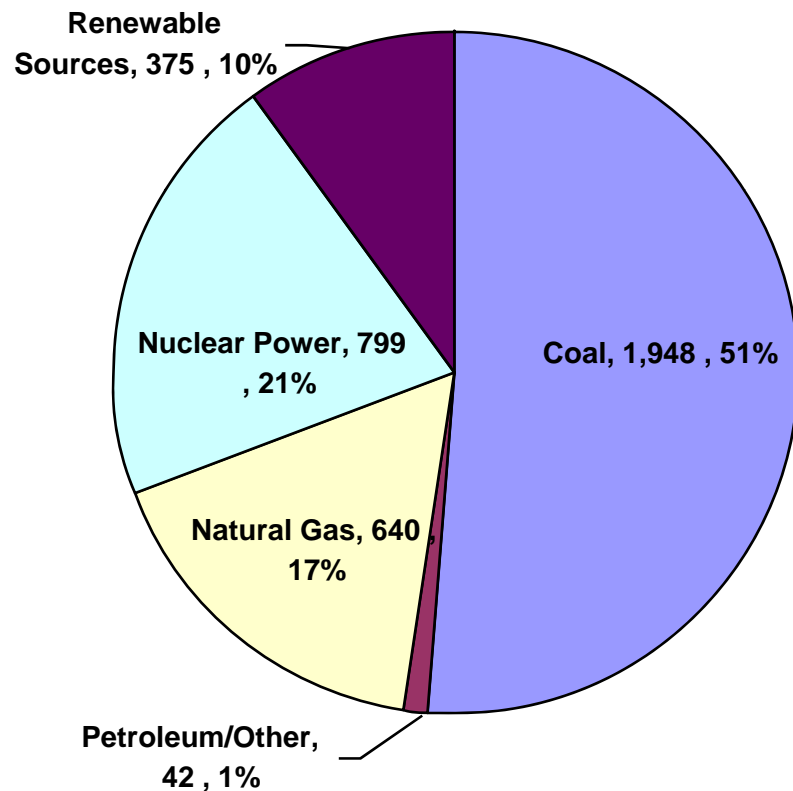
**U.S. CO₂ Emissions in 2050:
2.8 Billion Metric Tons***

Source: CarBen model, AEO 2008

* Meeting the goal requires an additional 1.5 billion metric tons of CO₂ emissions reduction through supplemental programs and offsets

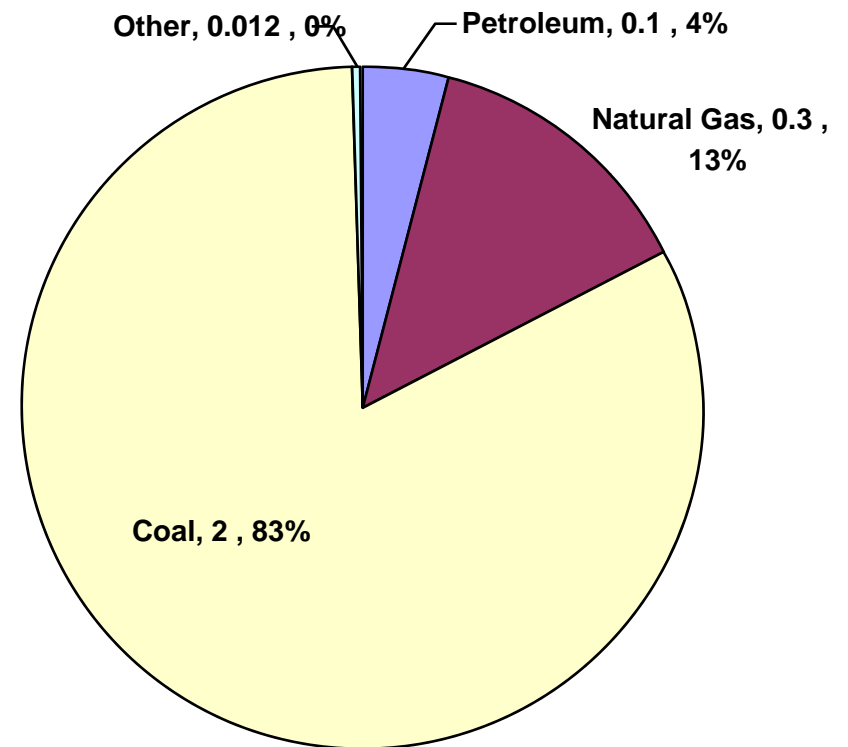
The Climate Change Challenge

Electricity Generation by Fuel
(Billion kWh)



Coal-Fired power plants are the backbone of our electricity supply

CO₂ Emissions by Fuel
(Billion Metric tons)



They are also the largest source of CO₂ emissions in the U.S. economy

One of The Climate Change Solutions

Our continued dependence on coal with our simultaneous need to reduce coal-fired power plant emissions make CCS uniquely suited for the Climate Change Challenge.

One of The Climate Change Solutions



March 17th, 2009

Why Clean Coal Is Years Away

Coal is here to stay, but efforts to cut emissions are ambitious, expensive, and have largely stumbled

“The [CCS] industry is locked in a vicious game of chicken and egg. In order for large-scale technology to be put in place, the costs need to come down, but for the costs to come down, the technology needs to be put in place, or "perfected," as officials say. ”

One of The Climate Change Solutions

SCIENTIFIC
AMERICAN

April 9th, 2009

Enhanced Oil Recovery:

How to Make Money from Carbon Capture and Storage Today

“All told, companies have injected some 10.8 trillion cubic feet of [CO₂] since the 1970s...

...with respect to carbon capture and storage (CCS), the [Great Plains Synfuels Plant](#) in North Dakota has pumped as much as two million metric tons of carbon dioxide a year to the Weyburn oil field in Saskatchewan since 2000.”

The Role of CO₂-EOR

The CO₂-EOR “Bridge”:

- Revenue from CO₂ sales can offset some costs of CO₂ capture from coal-fired power plants
 - CO₂-EOR operations will develop CO₂ sequestration infrastructure
- Early implementation of CCS will drive costs down through “learning by doing”



Small Scale,
Expensive
Demonstration
Projects



Widespread Market
Penetration of CCS
Technology

By HikingArtist.com

The “Poster Child” - Weyburn Enhanced Oil Recovery Project (Maximizing Oil Recovery and CO₂ Storage)



- Largest CO₂ EOR project in Canada:
 - 1.4 billion barrels (OOIP) oil field
- Outstanding EOR response
- World’s largest geological CO₂ sequestration project
 - 2.4 MMt/year
 - 23 MMt with EOR
 - 55 MMt with EOR/sequestration



Source: EnCana, 2005



Denbury Resources

- Infrastructure to bring captured CO₂ to the EOR market already exists.
- Denbury is actively perusing anthropogenic sources of CO₂ to supplement its natural reserves.
- They have identified seven potential anthropogenic sources that could provide 1,550 to 1,880 MMcfd of CO₂ starting in 2013-2014.

Potential Anthropogenic CO₂ Sources

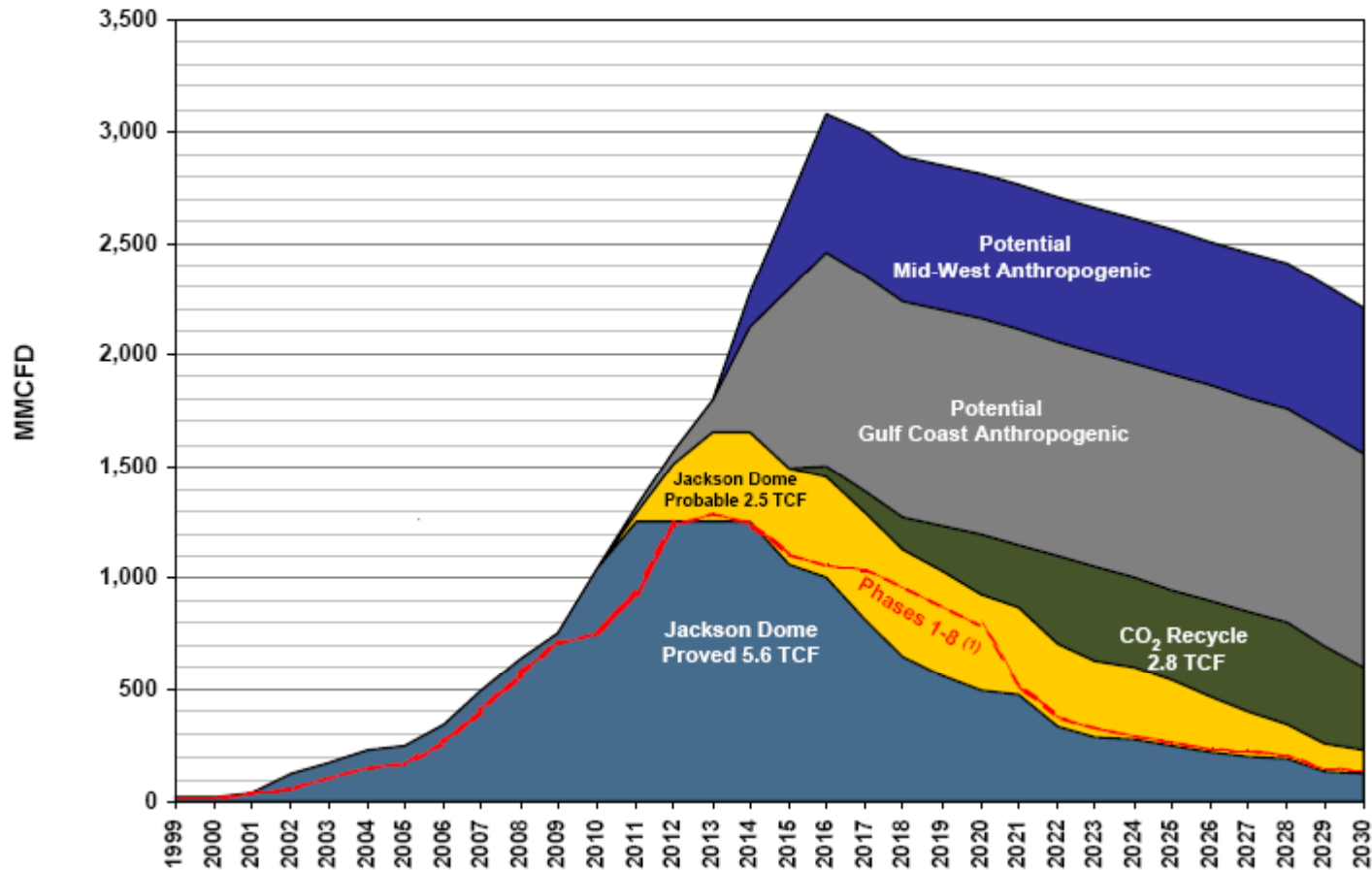
- **Denbury Purchase Contracts (contingent on plants being completed)**
 - **Committed to take 100% of daily volume of CO₂**

Source	MMCFD	Initial Production Expected
Faustina (Donaldsonville, LA)	190 – 225	2014
Rentech (Natchez, MS)	350 – 400	2013
Cash Creek Kentucky (SNG)*	190 – 210	2013
Power Holdings of Illinois (SNG)*	250 – 300	2013
Christian County Generation/Tenaska of Illinois (SNG)*	170 – 225	2013
Indiana Gasification of Indiana (SNG)*	230 – 300	2013
Mississippi Gasification of Mississippi (SNG)*	170 – 225	2013

*Requires additional supplies and additional pipeline

Source: Denbury Resources

Potential CO₂ Supply



Note: CO₂ recycle assumed to be 50% of proved; anthropogenic estimated based on anticipated pipeline capacity. Forecast based on internal management estimates. Actual results may vary.

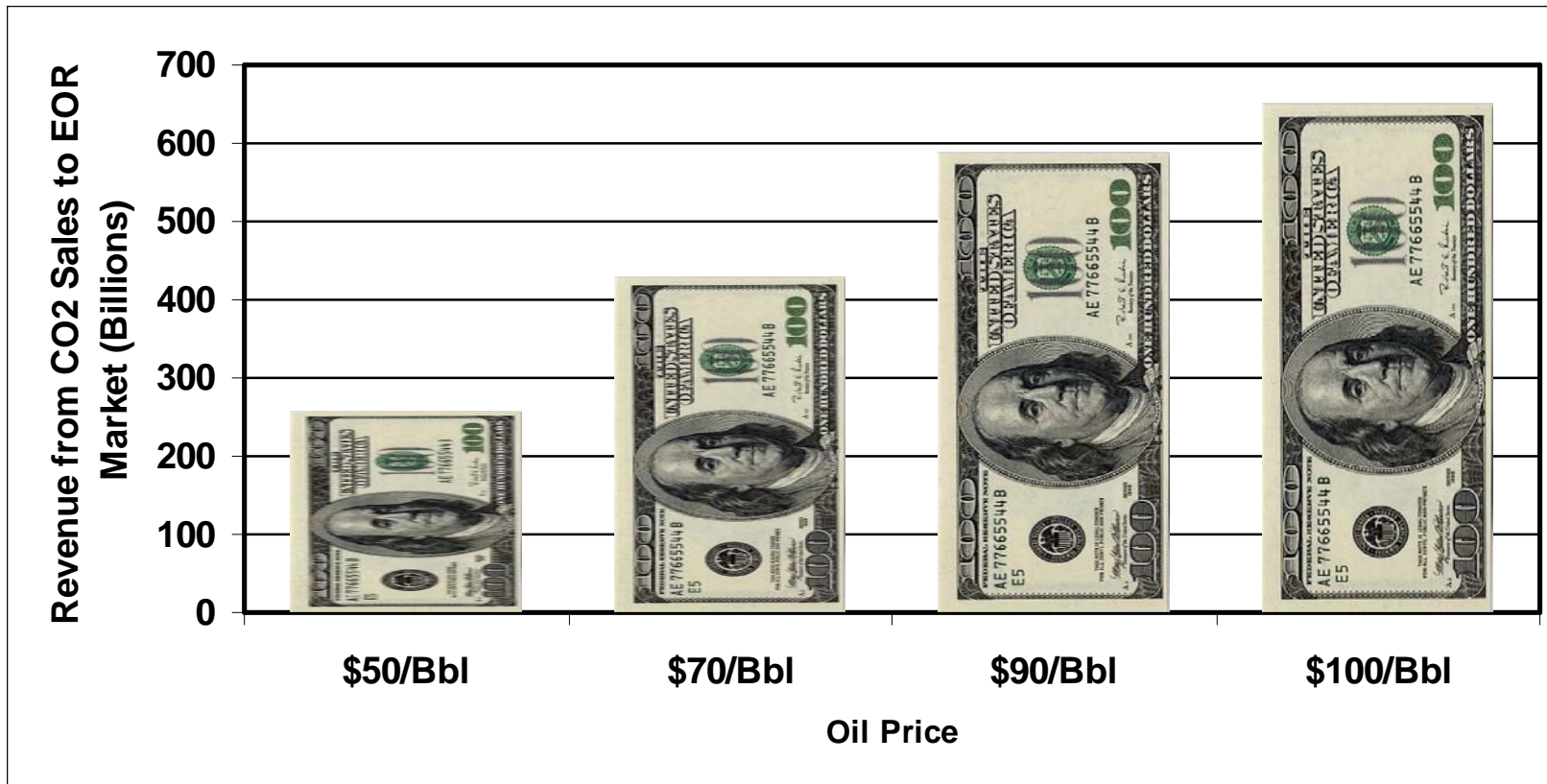
Source: Denbury Resources

CO₂-EOR's Potential Benefits for CCS

- **CO₂ demand from the EOR industry could absorb the captured CO₂ emissions from 40-60GW of coal-fired power plants with CCS technology (over a 30 year lifetime).***
- **Power plant operators could realize \$260-650 billion in revenues from CO₂ sales.**

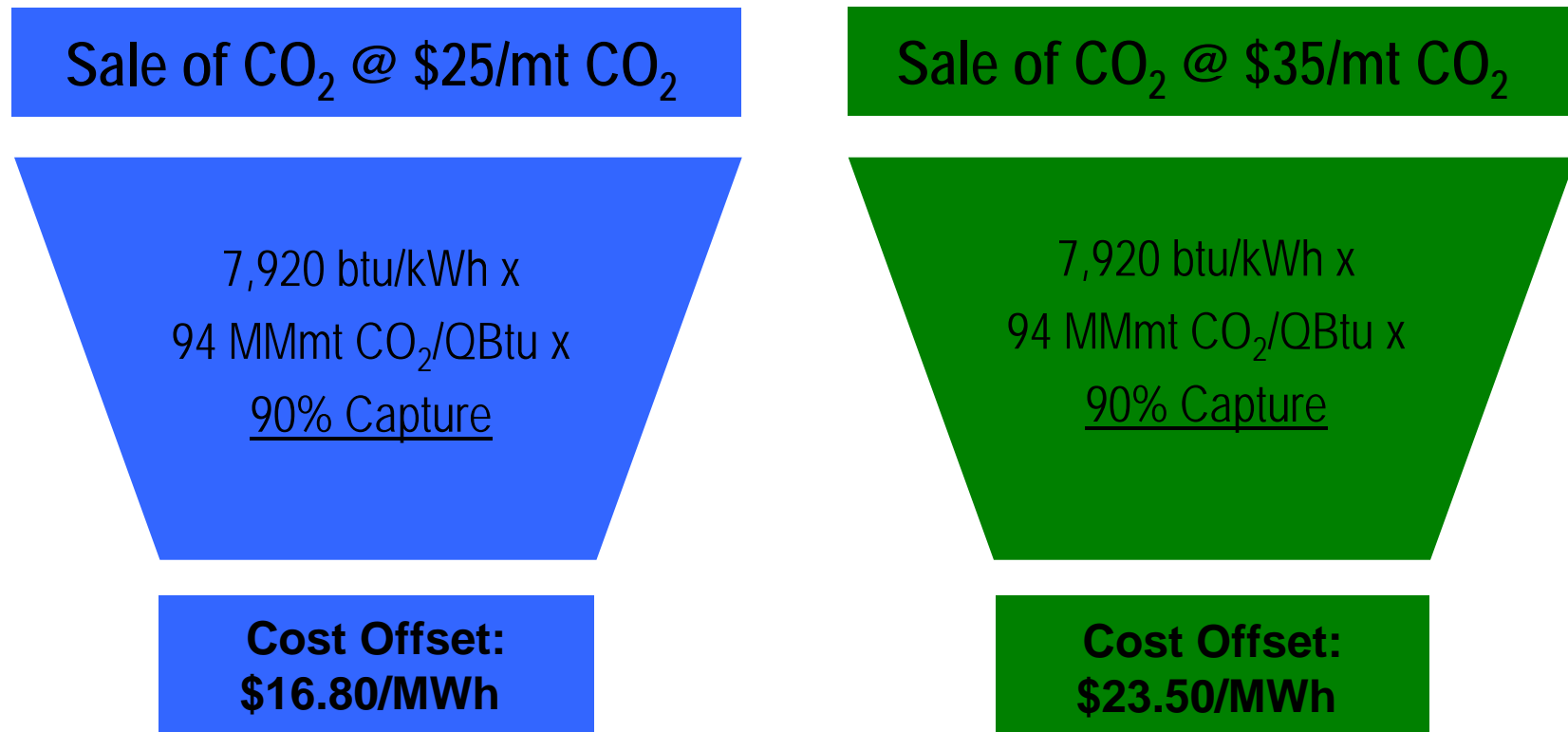
*Power plant data assumes an 85% capacity factor and 34% efficiency. A 1GW power plant with these specifications would generate 223 billion kWh of electricity in thirty years (1GW * 85% * 8.76 (conversion between GW and billion kWh/year) * 30 years). With a CO₂ intensity of .94 million tons CO₂/BkWh (thermodynamic equivalency based on efficiency of power plant and emissions profile of coal) and 90% capture, this power plant could supply 188 million tons of CO₂ in 30 years.

Market Demand for CO₂ by the Enhanced Oil Recovery Industry⁽¹⁾



(1) Total revenues over 30 year time horizon

Relationship of CO₂ Sales Price to Cost Offsets in the Coal-Fueled Power Sector (Year 2020)



Our Current Work

- In collaboration with NETL, Advanced Resources International (ARI) recently published a report, entitled “Storing CO₂ and Producing Domestic Crude Oil with Next Generation CO₂-EOR Technology.”

This report:



- Encompasses essentially all large domestic oil fields in 27 oil producing states
- Evaluates how a group of advanced or “Next-Generation” CO₂-EOR technologies could increase both oil recovery and volumes of CO₂ stored.
- Finds that, under certain situations, CO₂-EOR can yield “green oil,” by storing more CO₂ than contained in the produced oil.

“Next Generation” CO₂-EOR Technology

Reservoir modeling and selected field tests show that high oil recovery efficiencies are possible with innovative applications of CO₂-EOR.

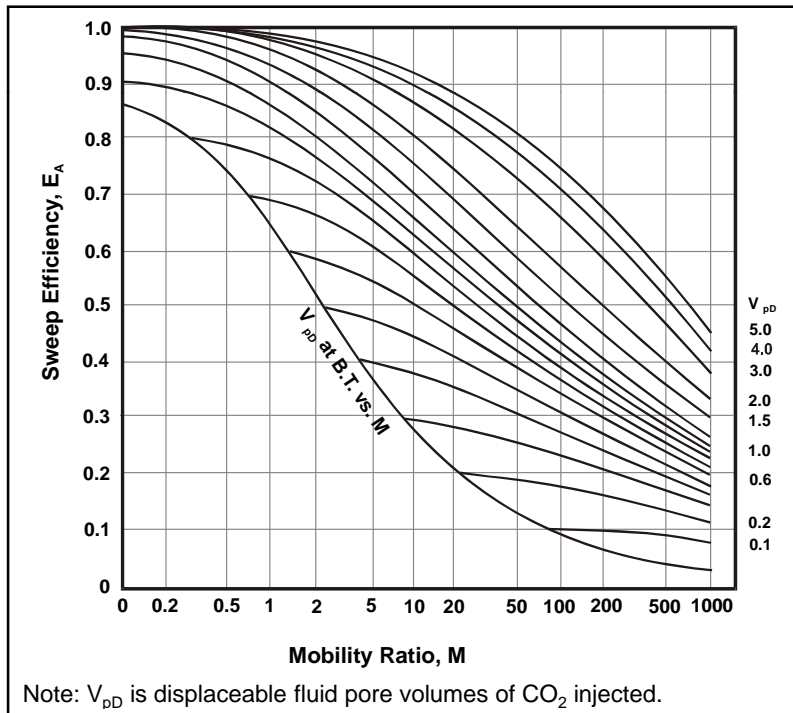
So far, except for a handful of cases, the actual performance of CO₂-EOR has been less than optimum due to:

- **Geologically complex reservoirs**
- **Limited process control**
- **Insufficient CO₂ injection**

Impact of Insufficient CO₂ Injection on CO₂-EOR Performance

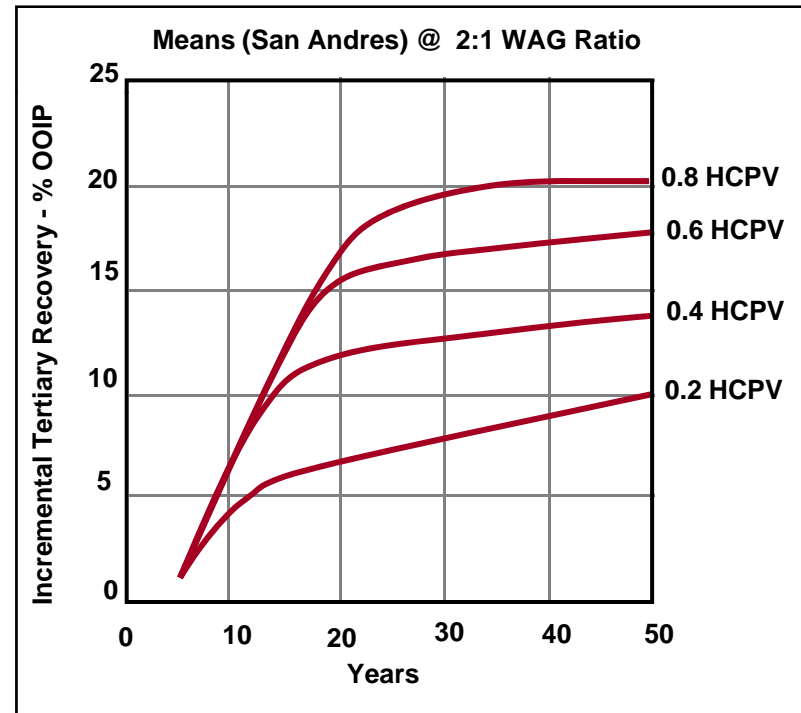
Because of high CO₂ costs and lack of process control, most older CO₂ floods used too little CO₂.

Sweep Efficiency in Miscible Flooding



Source: Claridge, E.L., "Prediction of Recovery in Unstable Miscible Displacement", SPE (April 1972).

Injected CO₂ vs Oil Recovery

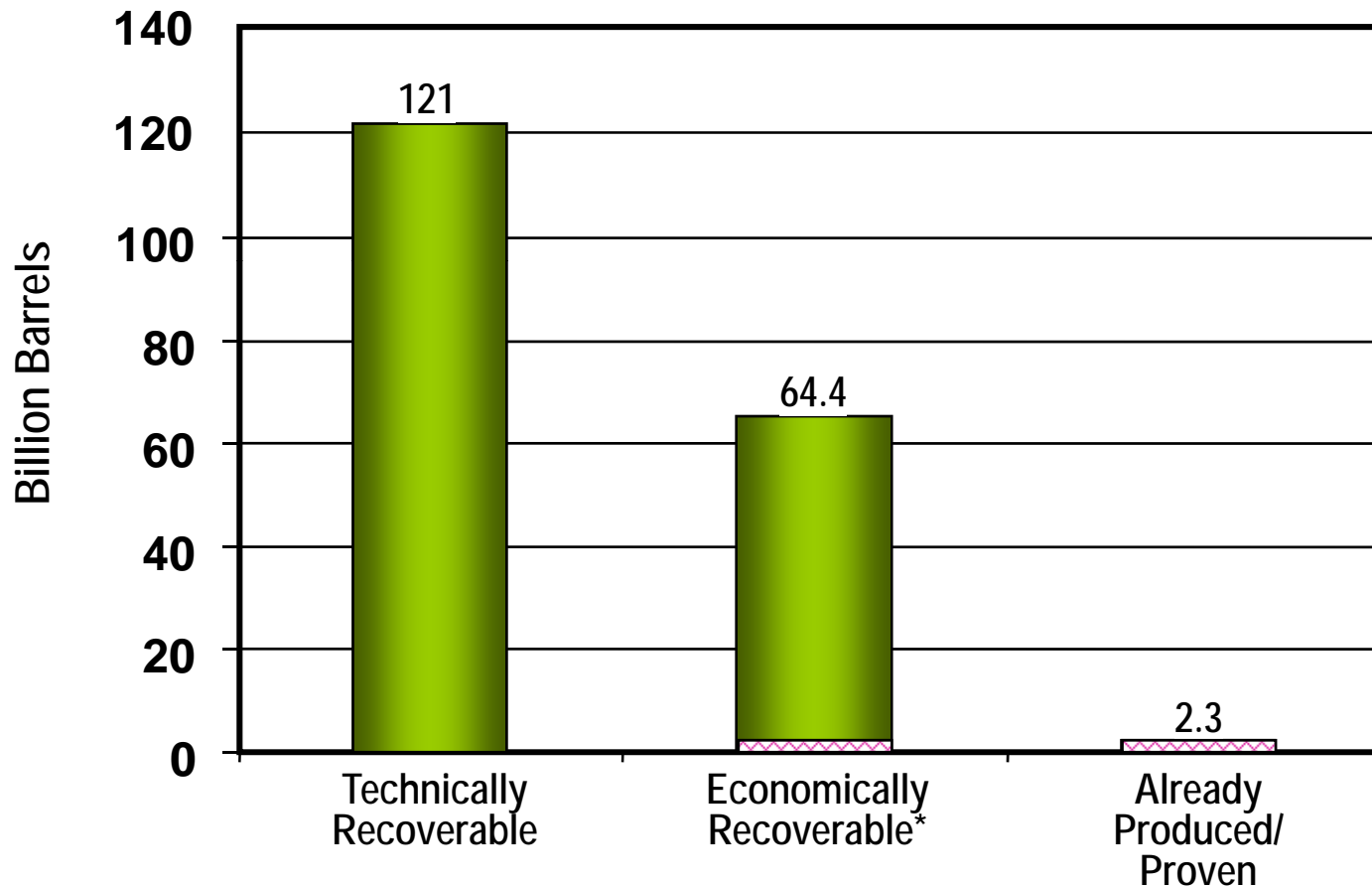


Source: SPE 24928 (1992)

Potential for “Next Generation” CO₂-EOR to Decarbonize the Electricity Sector

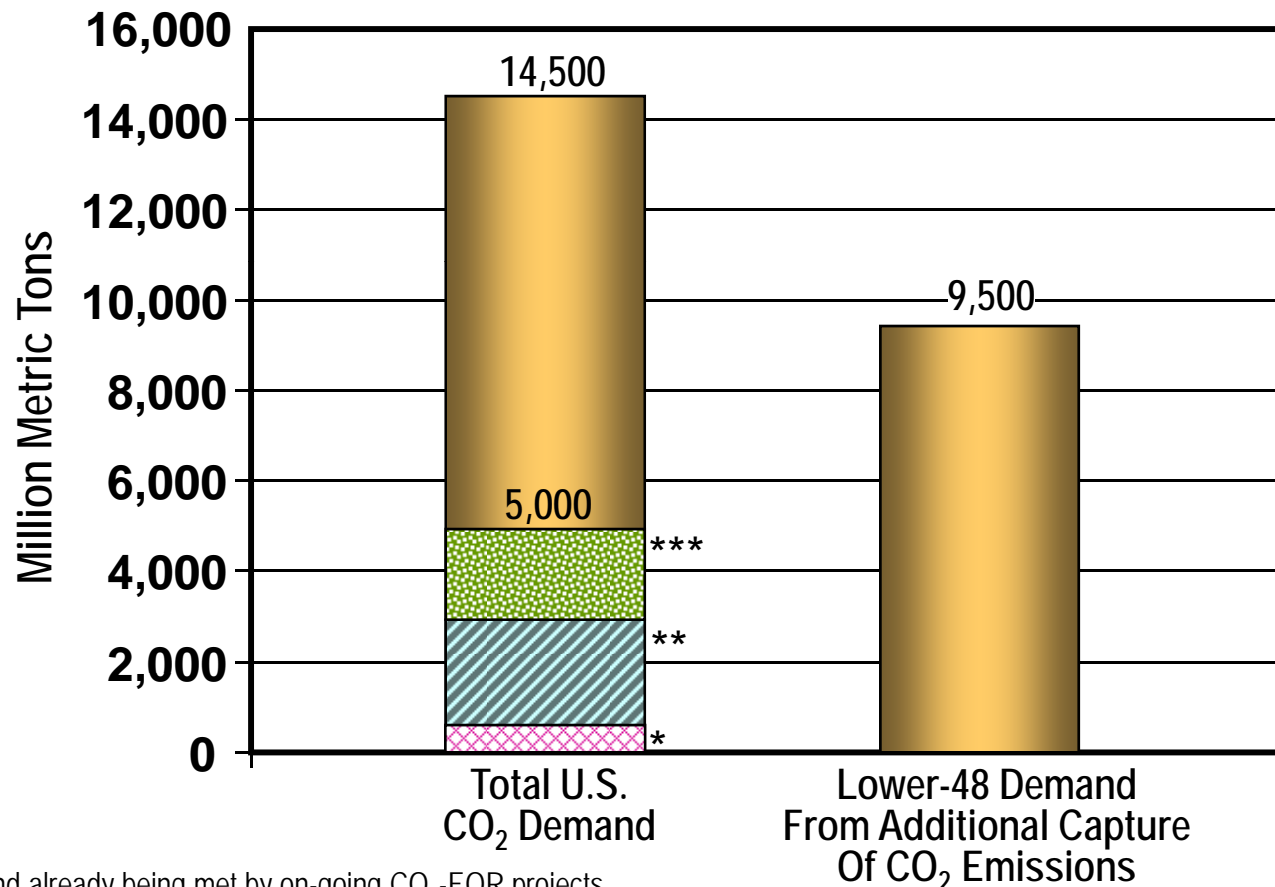
- Including use of larger volumes of CO₂, “Next Generation” CO₂-EOR technology provides two benefits
- Increasing the volume of domestic production, thereby reducing our dependence on imports, while creating a larger market for captured CO₂ emissions.

U.S Oil Resources Technically and Economically Recoverable w/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%, real).

Economic Market Demand for CO₂ by the Enhanced Oil Recovery Industry⁽¹⁾



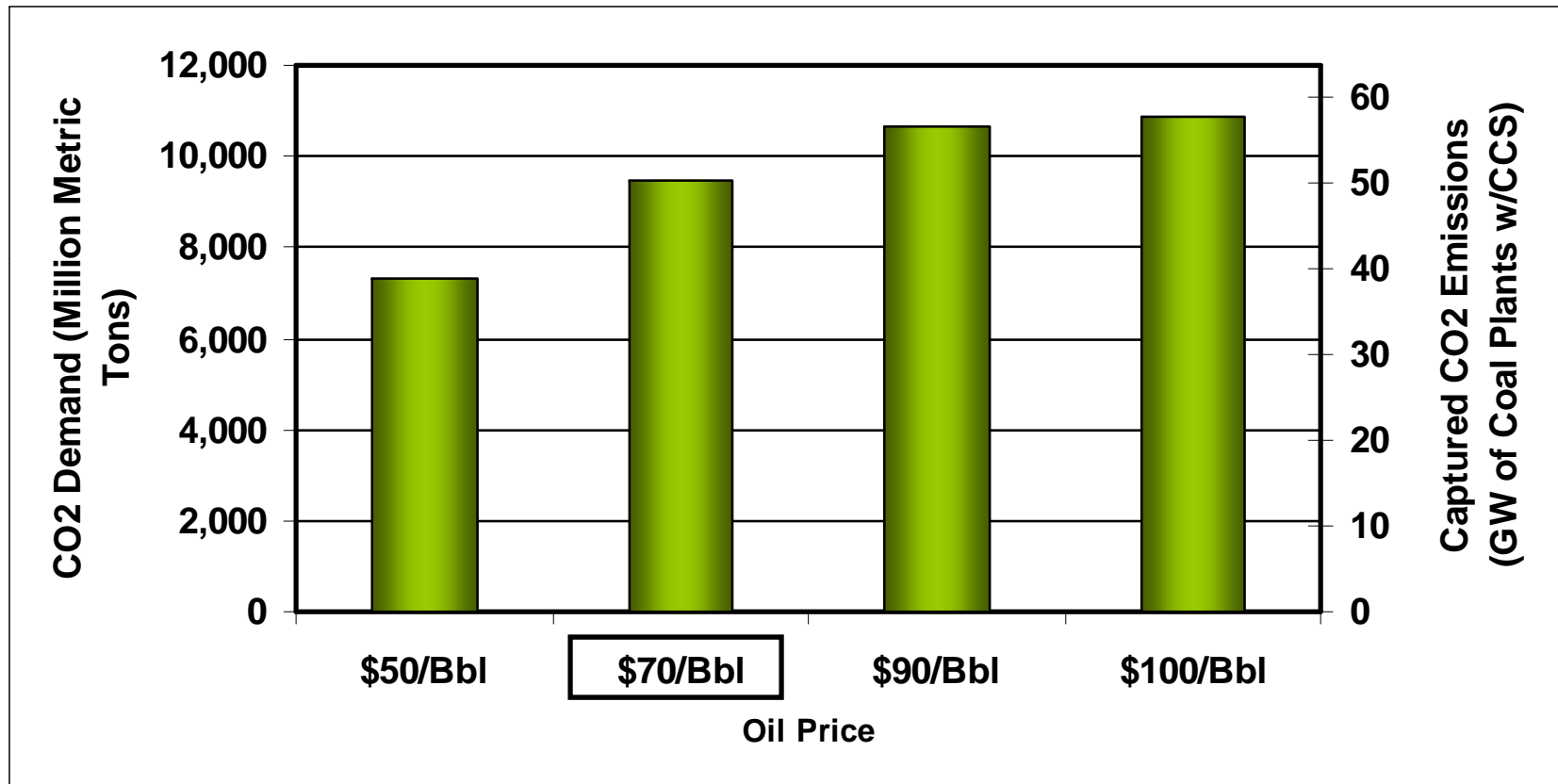
*CO₂ demand already being met by on-going CO₂-EOR projects.

**CO₂ demand in Alaska for EOR.

***CO₂ demand that can be met by natural CO₂ and already being captured CO₂ emissions.

(1) Economic CO₂ market demand for EOR at oil price of \$70/B (real), CO₂ cost of \$45/mt, and ROR of 15% (real, before tax).

Market Demand for CO₂ by the Enhanced Oil Recovery Industry⁽¹⁾



(1) Lower Oil Price Case: Oil price of \$50 per barrel; CO₂ cost of \$35 per metric ton. Higher Oil Price Cases: Oil price of \$90 and \$100 per barrel; CO₂ costs of \$55 and \$60 per metric ton.

Market Demand for CO₂ by the Enhanced Oil Recovery Industry



“Credit Suisse Group says \$15 billion needs to be invested in CCS over the next 10 years for it to play an important role in climate change. The International Energy Agency says \$20 billion. Pew's global warming center puts the number as high as \$30 billion”.

Summary Remarks

- **“Next Generation” CO₂-EOR is an important tool in promoting the near-term development of CCS technology**
 - **Revenue from CO₂ sales to the EOR market can promote early installation of CCS technology.**
 - **The emissions from 40-60GW of coal fired power plants can be stored through CO₂-EOR operations**
 - **CO₂-EOR operators could pay up to \$650 billion for captured CO₂ emissions**
 - **Experience gained from early projects will decrease the cost of additional CCS projects through “Learning-by-doing”**