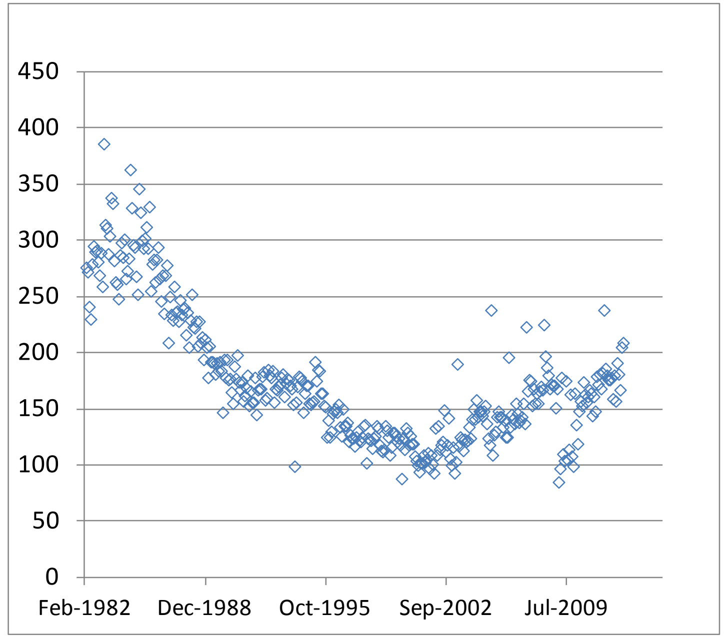
NATIONAL ENERGY TECHNOLOGY LABORATORY



Carbon Dioxide Enhanced Oil Recovery

Presented at Governor Tomblin’s 2012 Energy Summit

West Virginia: Partnerships for Energy Development

Presented by Phil DiPietro, National Energy Technology Laboratory

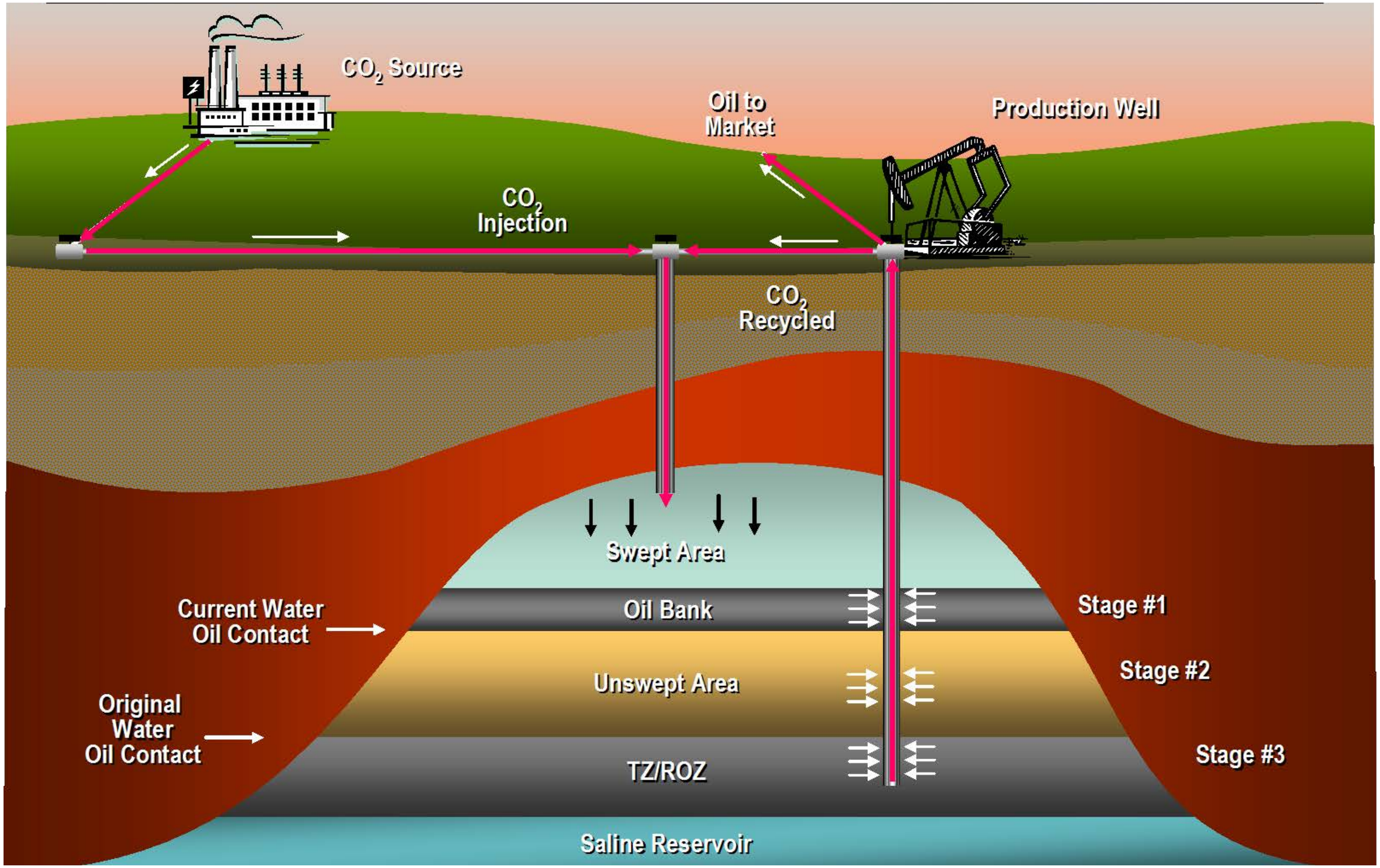
December 10, 2012

U.S. DEPARTMENT OF ENERGY

Summary

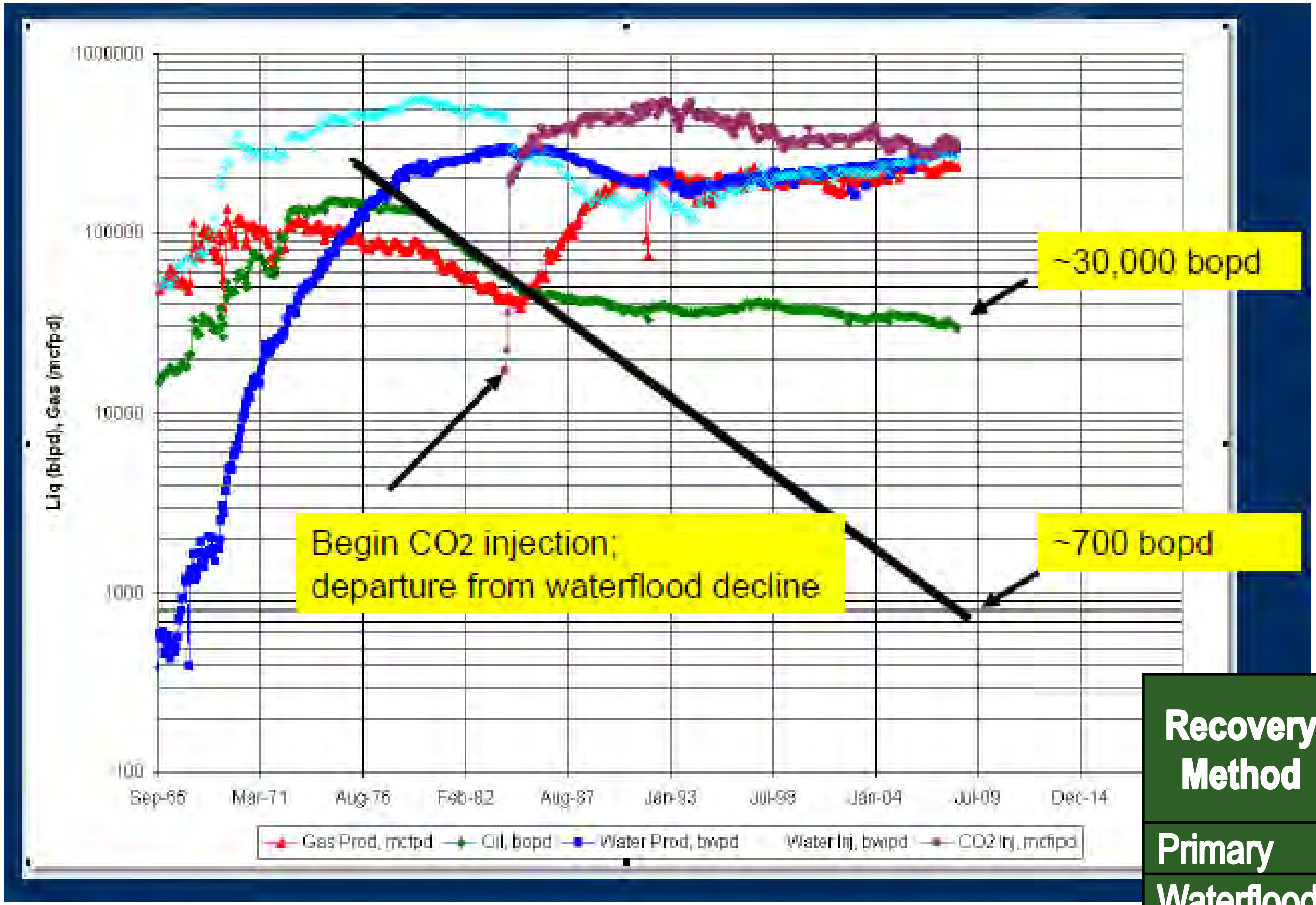
- **In 2012 CO_2 EOR will provide 5% of domestic crude oil production** (100 million barrels per year). It is growing, but slowly.
- **The potential for CO_2 EOR to be much larger than current deployments, 24 to 137 billion barrels of resource (NETL estimate)**.
- **The CO_2 EOR resource in West Virginia is small compared to the United States total** (Original-Oil-in-Place OOIP is 0.6% of the total).
- . . . . **but the technically recoverable CO_2 EOR resource in West Virginia is 183 million barrels of crude oil production, instate revenues of ~ \$16 B over 30 – 50 years** (\$85/bbl * 183 MMbbls = 15.6 B\$).

Two-page primer on CO_2 EOR



Source: Advanced Resources International

CO_2-EOR results from the Denver Unit of the Wasson Oil Field (Occidental Petroleum)

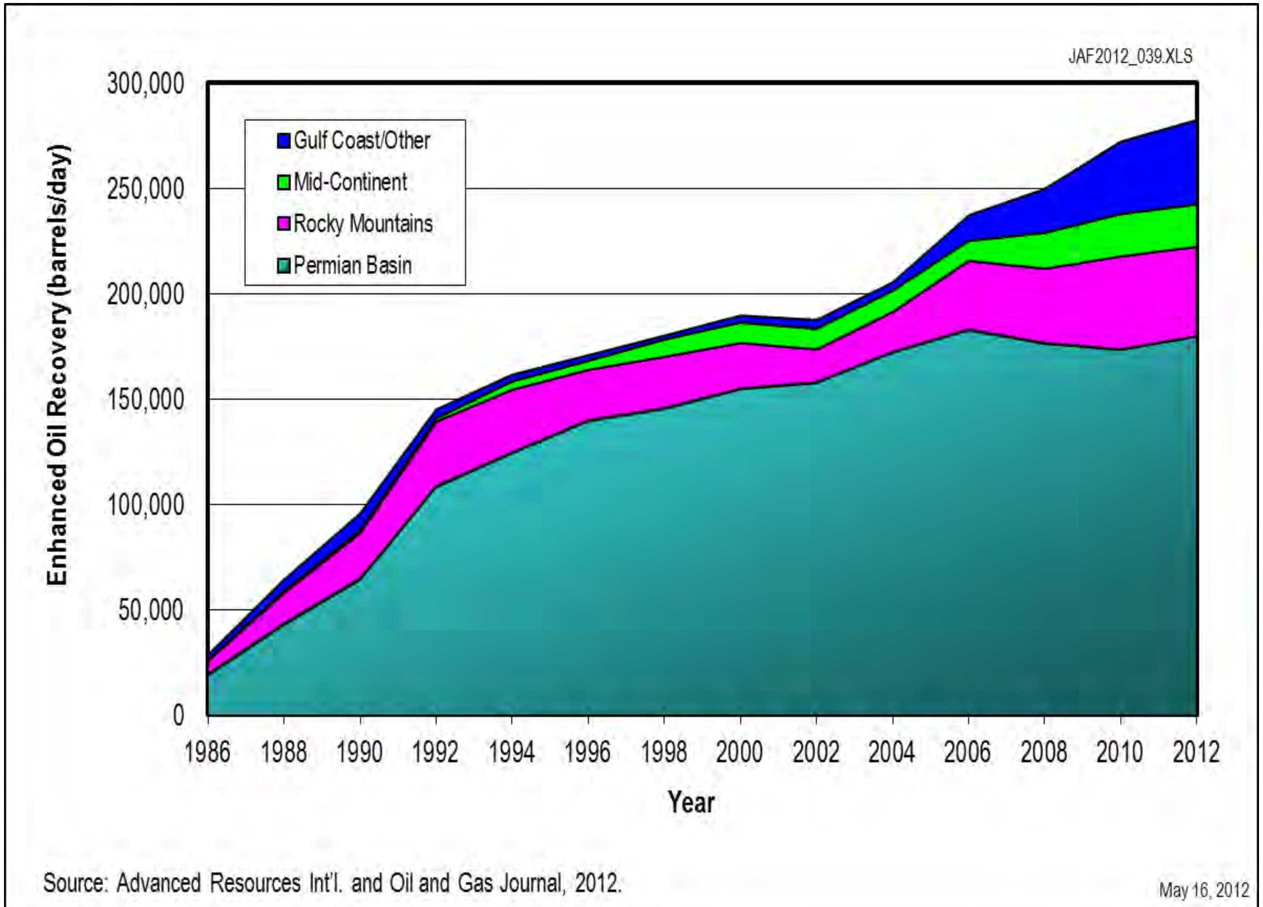


Recovery Method	Oil Recovery Efficiency (%OOIP)
Primary	17.2%
Waterflood	30.1%
CO2 Flood	19.5%
Total	66.8%

Source: NETL 2011 http://www.netl.doe.gov/energy-analyses/refshelf/PubDetails.aspx?Action=Vie

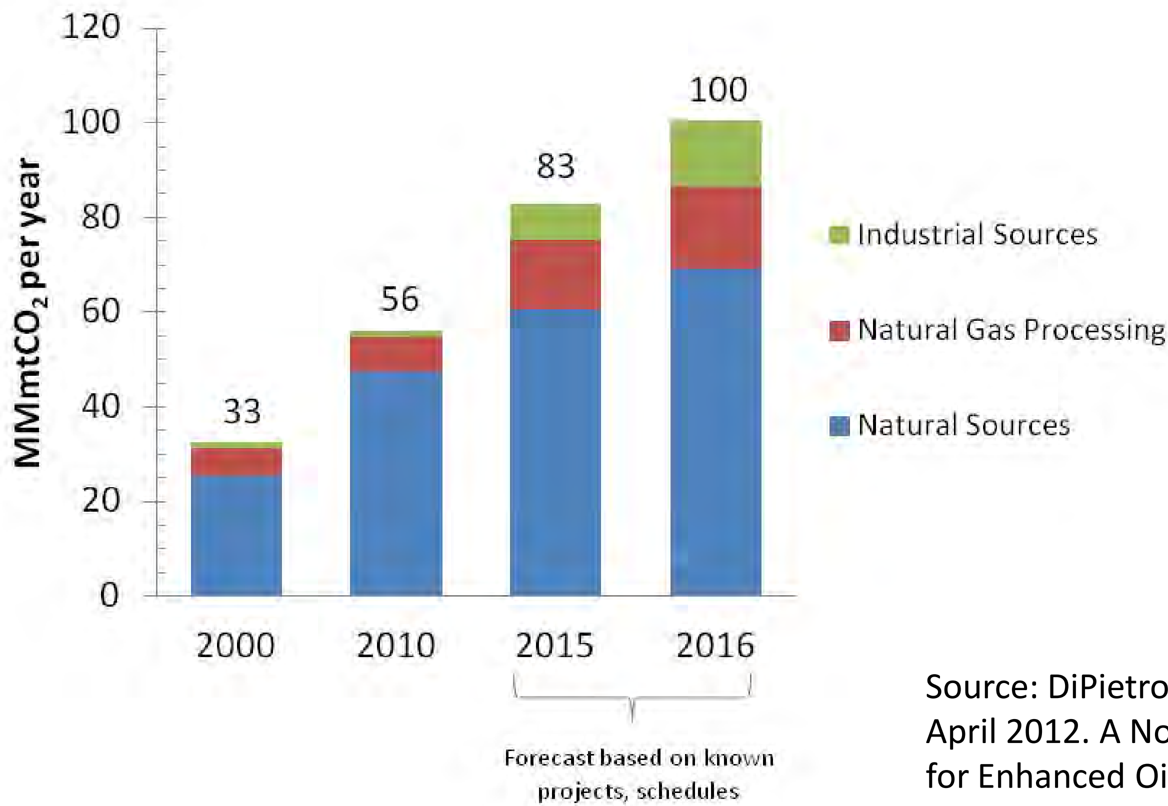
Snapshot of CO_2 EOR in the United States

Crude Oil Production from CO_2 EOR in the United States



Reference point: between 2010 and 2012, total U.S. crude oil production increase by ~ 900,000 bpd

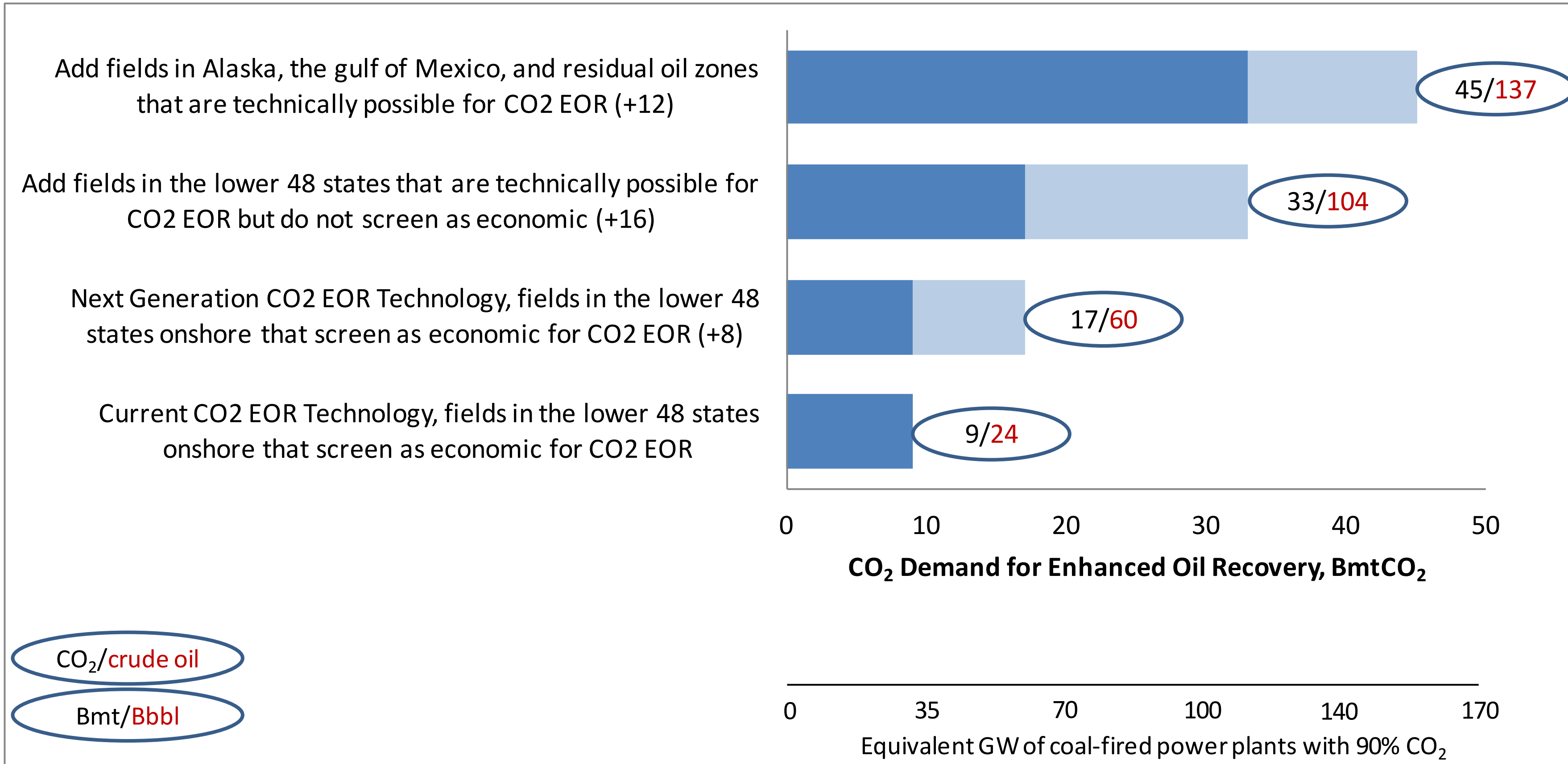
Sources of CO_2 Supply for Enhanced Oil Recovery Operations in the United States



Source: DiPietro P., Balash, P. and Wallace, M. April 2012. A Note on Sources of CO2 Supply for Enhanced Oil Recovery Operations. SPE Economics and Management (figure revised based on latest information October 2012)

CO_2 EOR Resource Assessment

Potential Crude Oil Supply and CO_2 Demand from CO_2 EOR in the United States

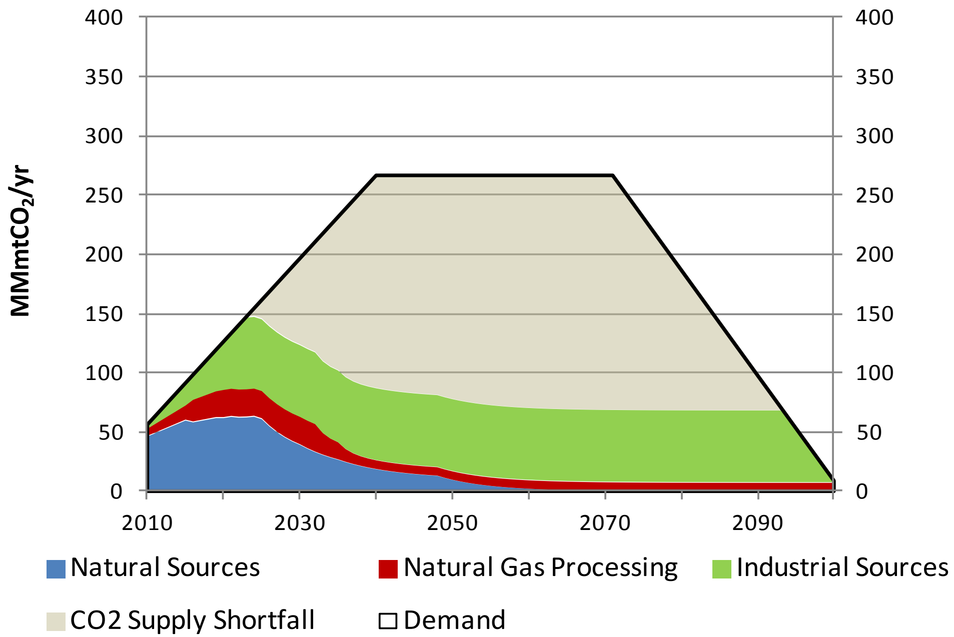


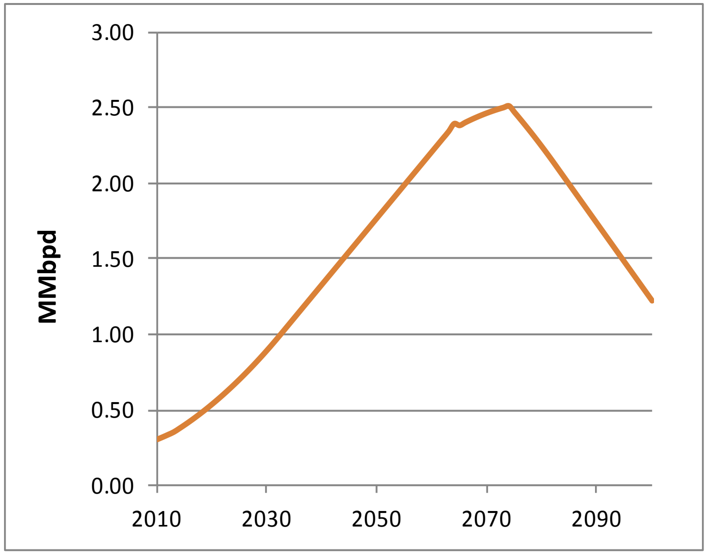
Source: DOE/NETL Report 2011/1504

http://www.netl.doe.gov/energy-analyses/refshelf/PubDetails.aspx?Action=View&PubId=391

Next Generation CO_2 EOR Technology Scenario

20 Billion metric tons of CO_2 demand, 60 billion barrels of crude oil production

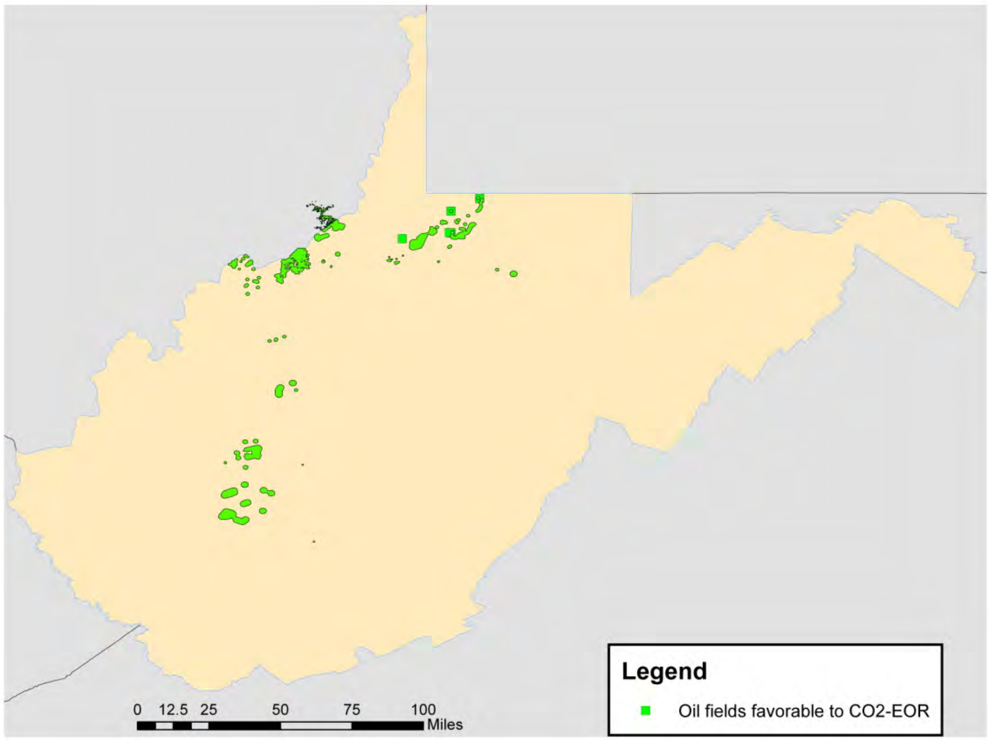




Source: DiPietro and Nichols. 2012. “Scenarios for CO_2 EOR in the United States through 2100” draft NETL report

CO_2 EOR in West Virginia

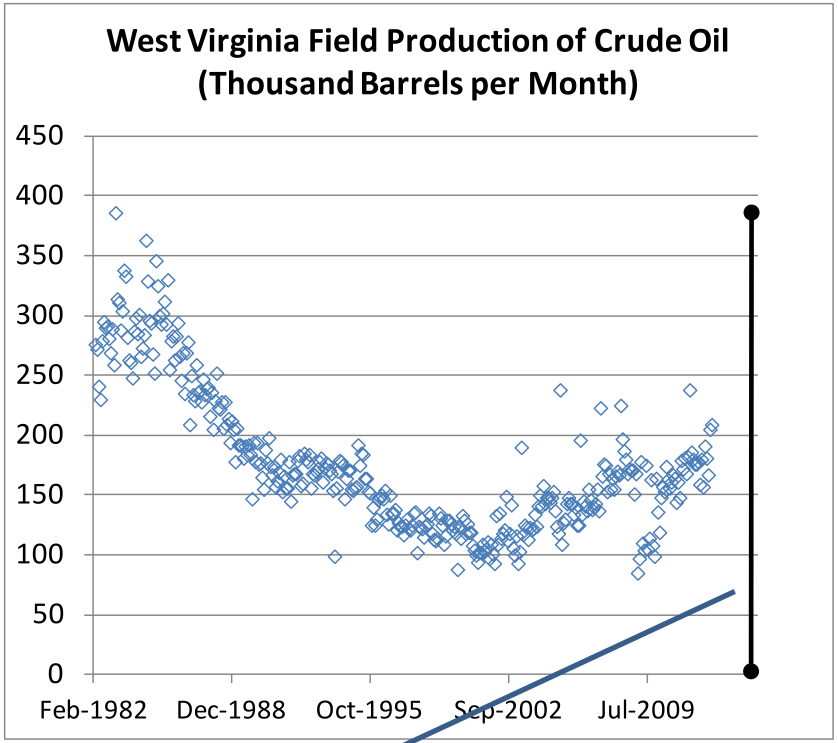
Oil-bearing Geologic Formations in West Virginia

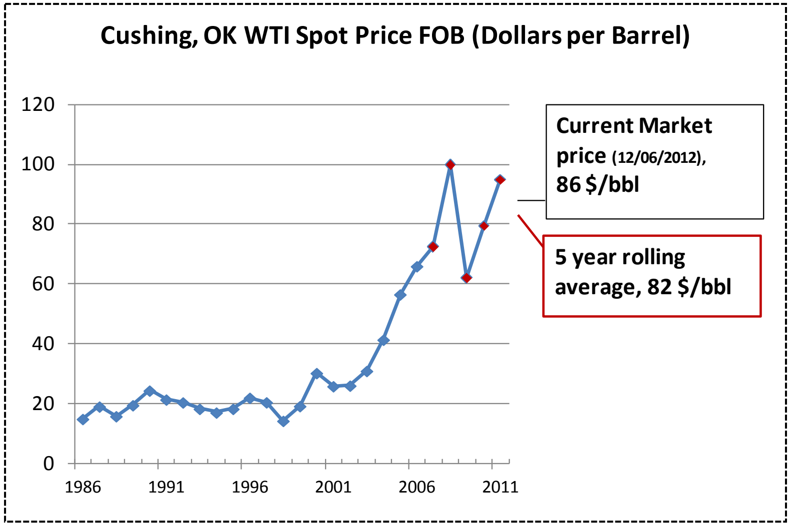


Primary data sources: ARI's Big Fields Database, EIA's Appalachian Basin Oilfield map, EPA's Greenhouse Gas Reporting Program and Ventyx's Energy Velocity data

- The Big Oil Fields Database contains 51 oil-bearing reservoirs in West Virginia, total OOIP 2.4 Bbbls OOIP
- The reservoirs in the database represent 74% of oil production in the state
- 32 reservoirs in the database screen as amenable to miscible CO_2 EOR (OOIP 2.0 Bbbls)
- Technically recoverable resource based on current best practices CO_2 EOR technology is 183 million barrels of crude oil (9% OOIP)
- More study required to estimate how much may be economic to produce

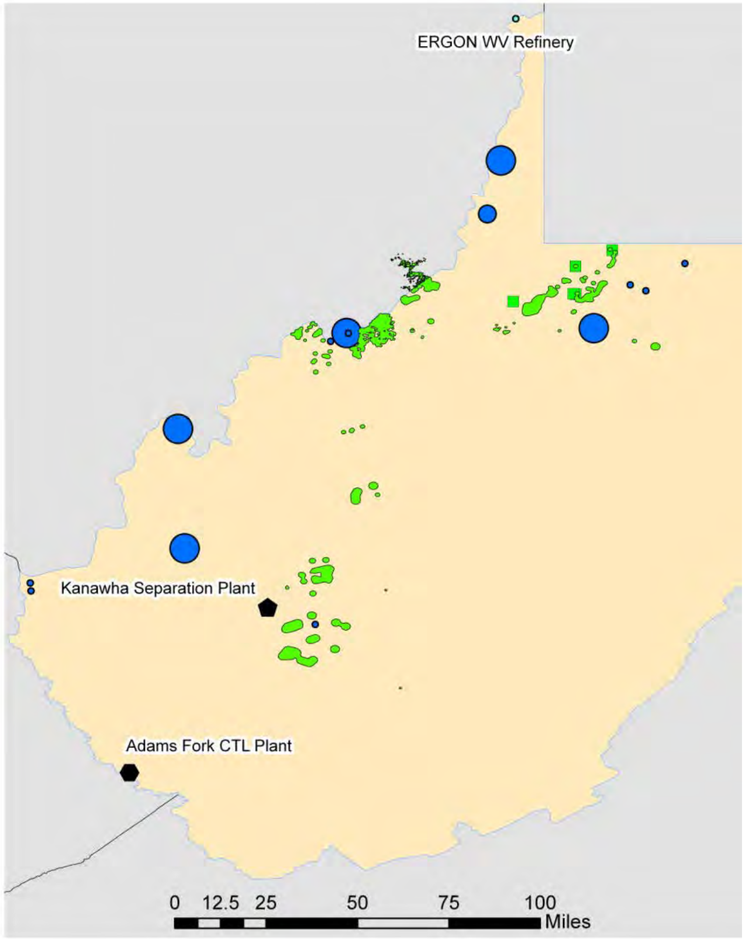
Production Potential from CO_2 EOR in West Virginia Relative to Current Production





183 MMbbls / 40 years * 12 months/yr = 380 Mbbls/month

Oil-bearing Formations and Sources of CO_2 in West Virginia



- Power plant
- Oil fields prospective for CO_2 EOR

Source Data: Advanced Resources International Big Fields Database, EIA's Appalachian Basin Oilfield map, EPA's Greenhouse Gas Reporting Program and Ventyx's Energy Velocity data

Getting to Market with Produced Crude Oil

- Ergon refinery
  - Newel West Virginia
  - Capacity: 20,000 barrels per day
  - 100% Appalachian grade paraffinic crude oils
- Marathon Oil
  - Cattletsburgh, KY
  - Capacity: 233,000 barrels per day
  - Variety of crudes, topping
- Refineries responding to recent increase in regional crude oil supply
- 183 MMbbls over 40 yrs – 12,000 barrels per day

Marathon Oil Company

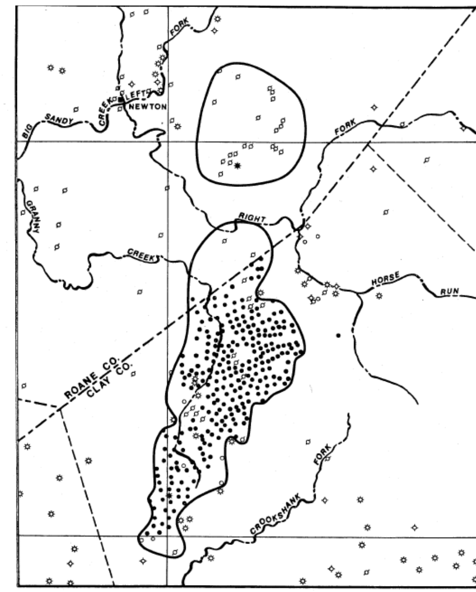
Challenges to Overcome for Economic CO_2 EOR in West Virginia

	Average Net Pay (feet)	Average Permeability (milliDarcy)
West Virginia	17	21
Rest of United States	123	377
Source: Advanced Resources International, Big Oil Fields Database. Numbers are OOIP weighted average from all fields that have positive technically recoverable resource		

Challenges to Overcome for Economic CO_2 EOR in West Virginia

Other challenges:

- Heterogeneous rock makes uniform sweep difficult to achieve
- Mountainous terrain increases the cost of drilling
- Existing wells likely not usable
- Scant data from P/S recovery increase uncertainty of oil response
- State unitization laws
- No big, cheap source of CO_2 (a la McElmo/Jackson Dome) to get things started



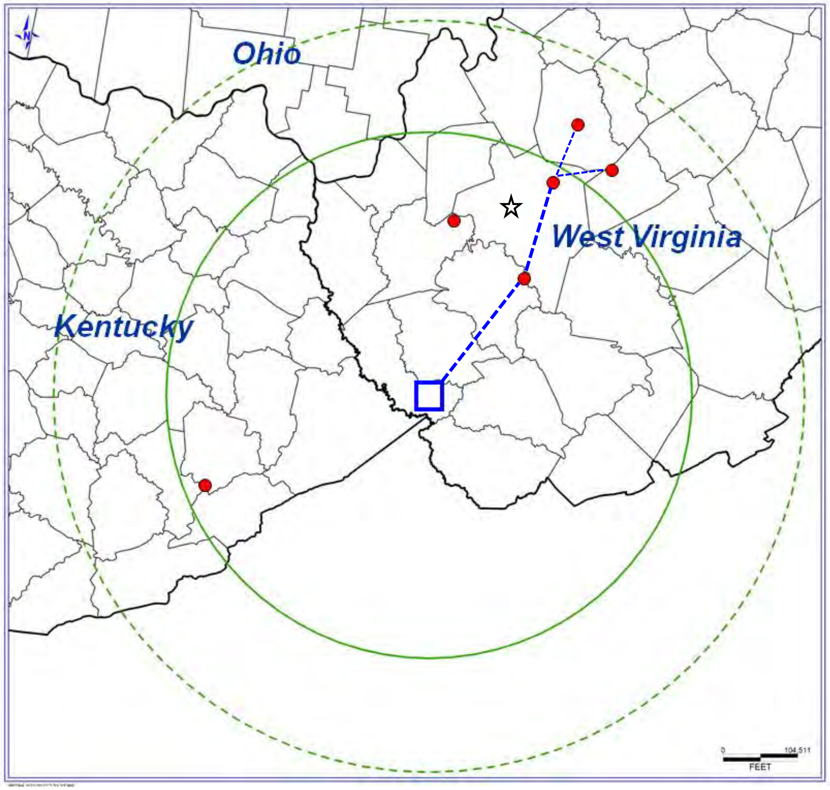
Well Placement Information for the Granny Creek Oilfield, from a 1979 NETL Pilot Test

Positives:

- Heterogeneity, low perm, and undocumented P/S operations are double-edged swords: there may be a lot of un-swept oil!
- Nearby refineries represent market for produced crude oil

Case Study: Oil Fields Prospective for CO_2 EOR in Southwest West Virginia

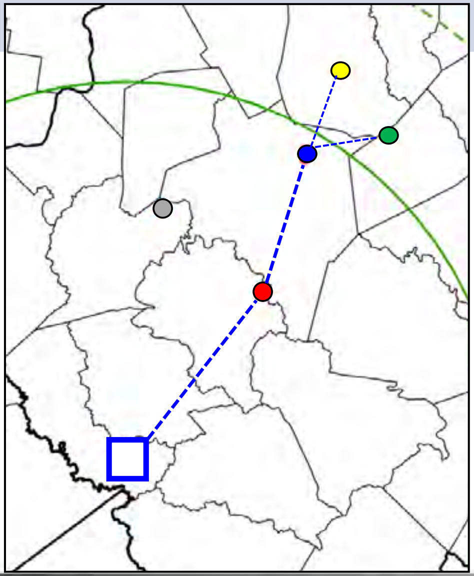
- Six oil fields within 100 miles of Mingo County are prospective for miscible CO_2-EOR
- Four of the oil fields fall along a straight line. In concept, they could be developed sequentially along a single CO_2 pipeline
- The key insight was that four marginal reservoirs could be combined to form one good target



Source: Kuuskraa and Petrusak. 2012. CO2 Storage and Utilization Options Near Mingo County West Virginia. Draft NETL report

Case Study: Four fields in the Mingo County CO_2 EOR Concept

		Depth (ft)	Pay (ft)	Acreage	Temp (ºF)	APIº	OOIP (Million Bbls)	CO_2 demand (Million $mtCO_2$)
🟡	Walton*	2000	29	6,740	75	43	>100	14.1
🟢	Granny Creek*	1940	40	3,840	73	45	20-100	6.5
🔵	Blue Creek	1700	10-30	16,000	85	43	>100	20.6
🔴	Cabin Creek	3000	20	4,600	84	44	10-20	5.8
							Total	47



Source: Kuuskraa and Petrusak. 2012. CO_2 Storage and Utilization Options Near Mingo County West Virginia. Draft NETL report

Summary

- There are challenges to developing CO_2 EOR in West Virginia, but the prize is big, ~ 16 B$ in revenue from crude oil sales over 30-50 years
- CO_2 EOR is established and growing in other parts of the United States, needed capability exists
- Many of the technologies being developed at the National Energy Technology Laboratory can enable CO_2 EOR in more complex settings like exist in West Virginia

Thank you!

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Crude Oil Production from CO_2 EOR Compared to Total U.S. Production

year	U.S. Crude Oil Production* (Mbbls/day)	U.S. Crude Oil from CO2 EOR** (Mbbls/day)	CO2 EOR as a percent of total U.S. production	Annual increase/decrease in total U.S. crude oil production (Mbbls/day)	Annual increase/decrease in U.S. crude oil production from CO2 EOR (Mbbls/day)
2006	5089	240	4.7%		
2007	5077	245	4.8%	-12	5
2008	5000	250	5.0%	-77	5
2009	5353	261	4.9%	353	11
2010	5479	272	5.0%	126	11
2011	5658	278	4.9%	179	6
2012***	*6365*	284	4.5%	707	6
* Energy Information Administration					
** Kuuskraa OGJ 2012					
*** Total U.S. crude oil production estimated to be 12.5% higher than 2011 based on monthly data through July					

Top CO_2 EOR Companies in the United States

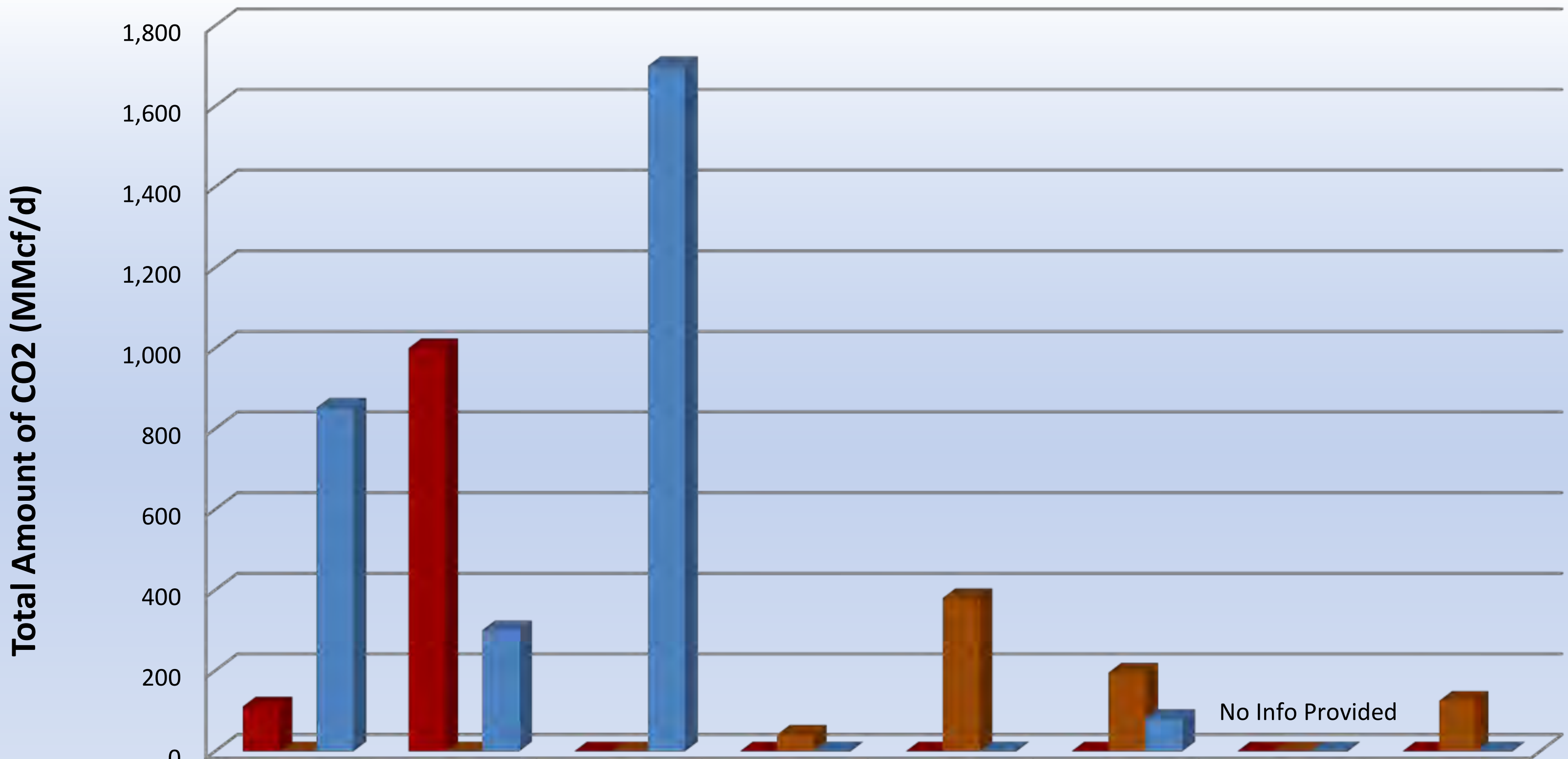
Company	2012 Crude Oil Production from CO_2 EOR (Mbbl/d)	# of Active Projects in 2012	Cumulative percent of total production from CO_2 EOR
Occidental	88.0	31	31%
Denbury Resources	39.7	22	45%
Kinder Morgan	31.6	3	56%
Chevron	24.2	7	65%
Hess	20.5	4	72%
Whiting Petroleum	20.0	4	79%
Anadarko	13.8	7	84%
Merit Energy	13.6	7	88%
Other	32.8	39	
Total	**284.2**	**124**	

Other includes: ExxonMobil, ConocoPhilips, Apache, Chaparral Energy, XTO Energy, Devon, Energen Resources, Legado, Fasken, Resolute Natural Resources, Core Energy, Great Western Drilling, Orla Petco, Stanberry Oil, and George R. Brown.

Source: Kuuskraa, V.A. July 2012. QC updates carbon dioxide projects in OGJ's enhanced oil recovery survey. Oil&Gas Journal.

Different Approaches to CO_2 Supply

Amount Sold, Purchased, and Produced in 2010



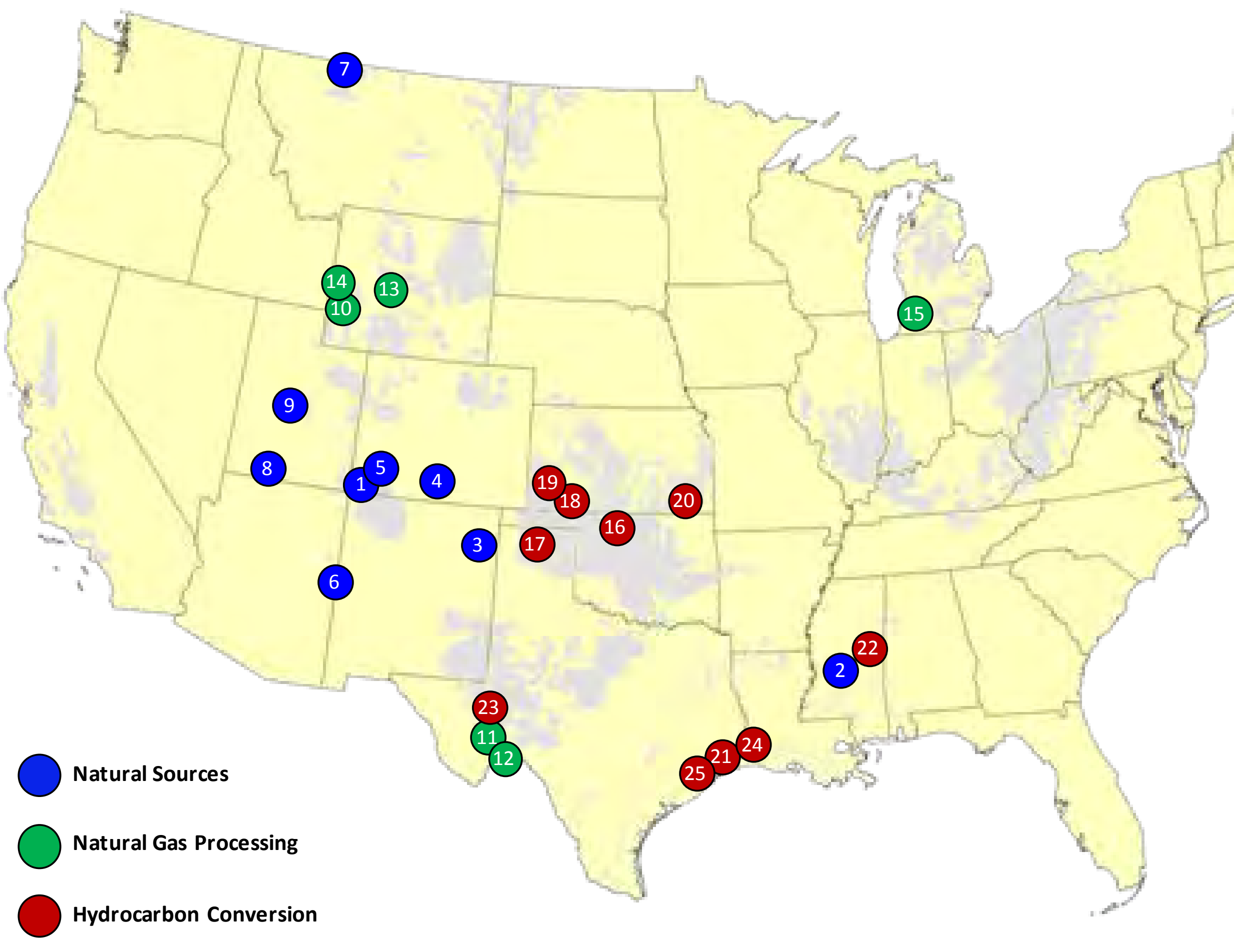
	Denbury Resources	Kinder Morgan	Occidental Petroleum	Chaparral Energy	Whiting Petroleum	Hess Corporation	Chevron Corp.	Anadarko Petroleum
Sold to 3rd Parties	111	1,000	0	0	0	0	0	0
Purchased from 3rd Parties	0	0	0	41	380	195	0	125
Produced & Utilized Internally	852	300	1,700	0	0	80	0	0

Information compiled from SEC filings

Components of Next Generation CO_2 EOR

- Improved conformance and mobility control
  - Increase viscosity of CO_2
  - Plug up high permeability channels.
- Locate and contact unswept pay
  - Better “see” CO_2 plume
  - Precisely locate CO_2 injection
- Increase CO_2 injection
  - Primarily a function of inexpensive CO_2
  - Also need ability to CO2 plume to have confidence to inject at higher rate
- Achieve near miscible behavior
  - Model and predict oil production response.

Figure 3. Sources of CO_2 for Domestic EOR Floods

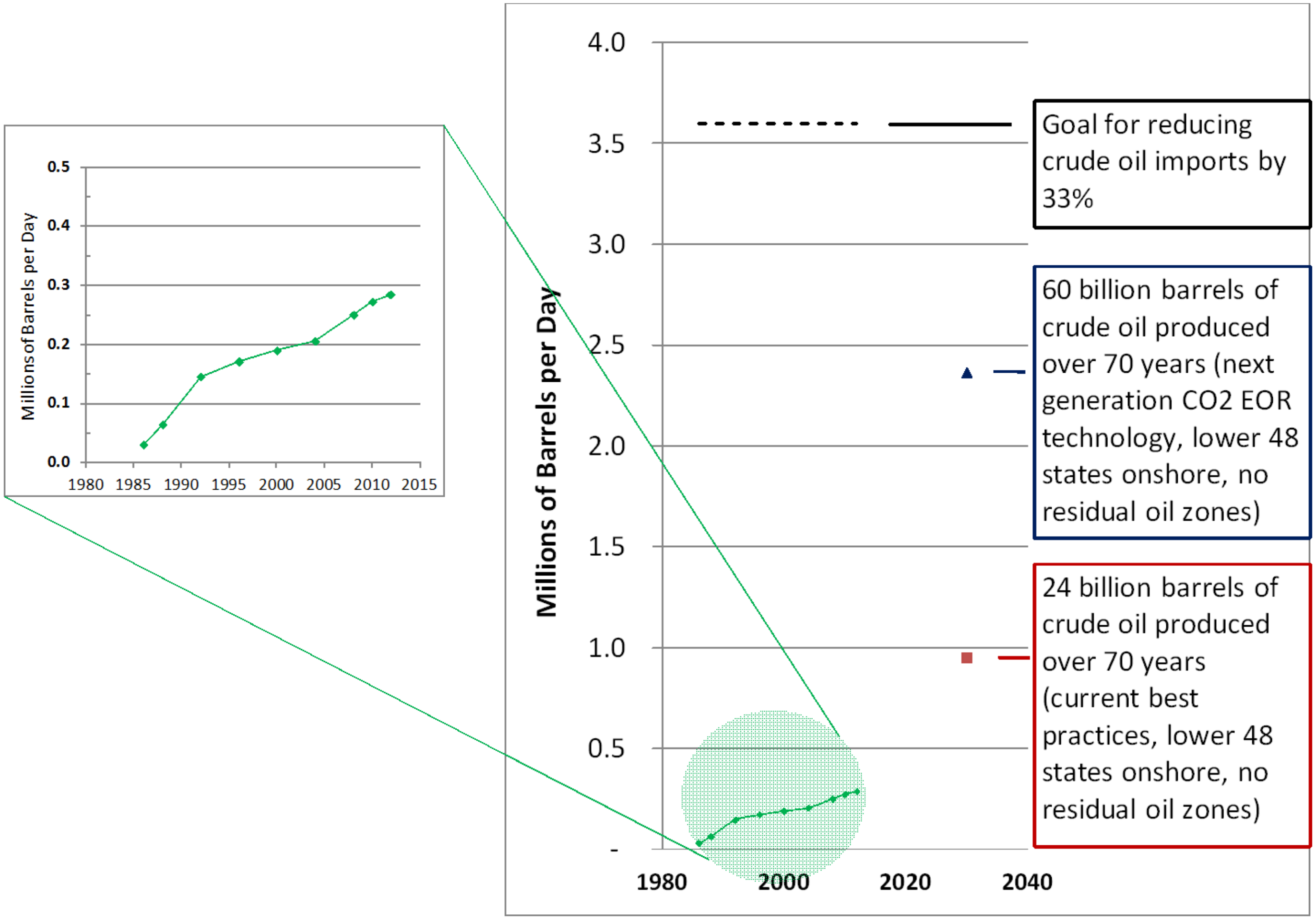


1. McElmo
2. Jackson
3. Bravo
4. Sheep
5. Doe Canyon
**6. St. John's*
**7. Kevin*
**8. Escalante*
*9. Gordon Creek
10. LaBarge
**11. Century*
12. TGRMP
*13. Lost Cabin
*14. Riley Ridge
15. Turtle Lake
16. Koch Nitrogen
17. Agrium, Inc.
18. Conestoga
19. Bonanza Energy
**20. CVR Energy*
**21. Air Products*
**22. Mississippi Power*
**23. Summit Texas*
**24. Leucadia*
**25. NRG*

* Not operational in 2010

Source: DiPietro P., Balash, P. and Wallace, M. April 2012. A Note on Sources of CO2 Supply for Enhanced Oil Recovery Operations. SPE Economics and Management

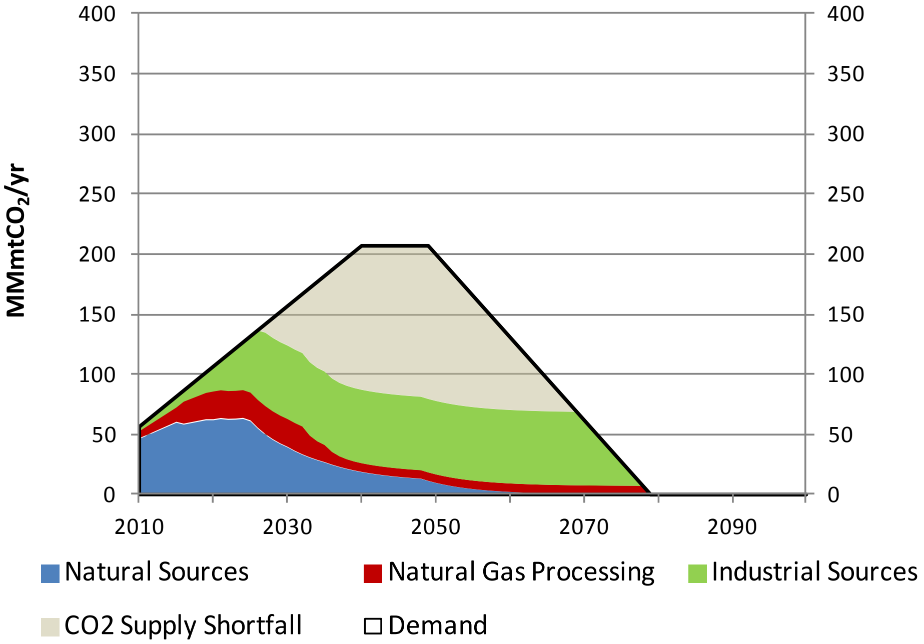
Crude Oil Production from CO_2 EOR, Potential

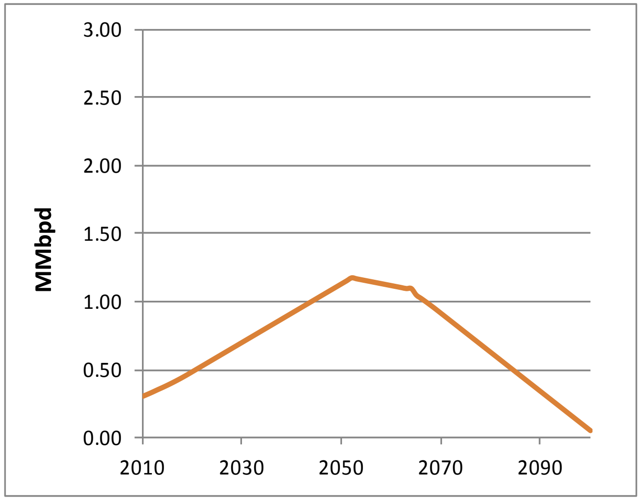


Information sources: Kuuskraa DOE/NETL 2011/1504; Kuuskraa OGJ 2012; Calmes and Broder NY Times March 30, 2011

Current Best Practices CO_2 EOR Technology Scenario,

9 Billion metric tons of CO2 demand, 24 billion barrels of crude oil production





Source: DiPietro and Nichols. 2012. “Scenarios for CO_2 EOR in the United States through 2100” draft NETL report

Typical Permian Basin CO_2 EOR Project Cost Structure (Occidental Petroleum)

JAF028238.PPT

Source: NETL 2011 http://www.netl.doe.gov/energy-analyses/refshelf/PubDetails.aspx?Action=View&PubId=391