North American CO_2 Supply and Developments

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MIDLAND, TEXAS

ENHANCED OIL RECOVERY INSTITUTE
UNIVERSITY OF WYOMING

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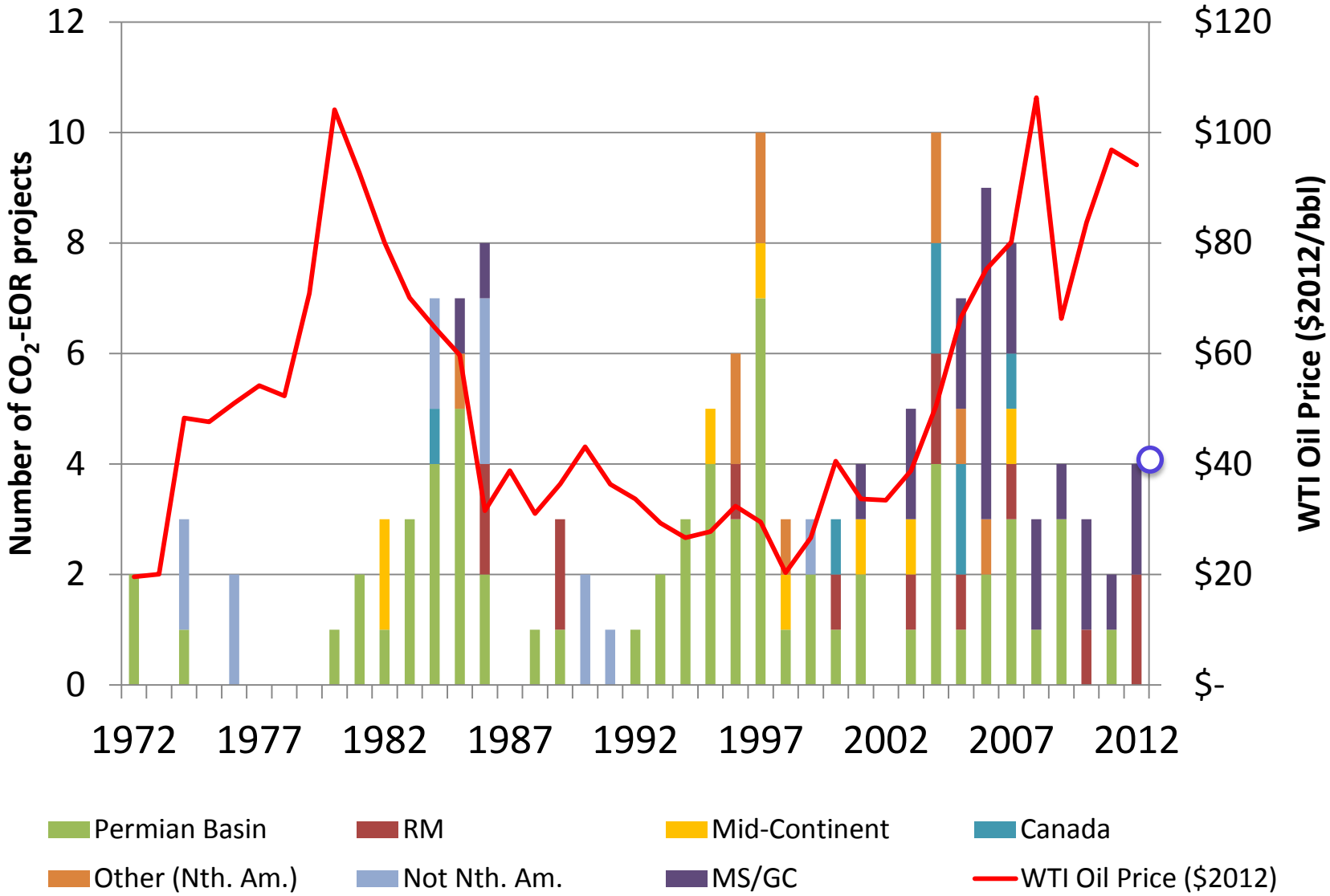
Agenda

- CO_2 Supply and EOR Projects
  - North American Status and Developments
  - Regional Developments
- Forecasting CO_2 EOR
  - Scheduled CO_2 supply developments
  - Using UR as a forecasting metric
- Natural Sources
  - NETL Catalogue

CO_2 Supply and EOR Projects

O&G Journal EOR Survey; EIA.gov

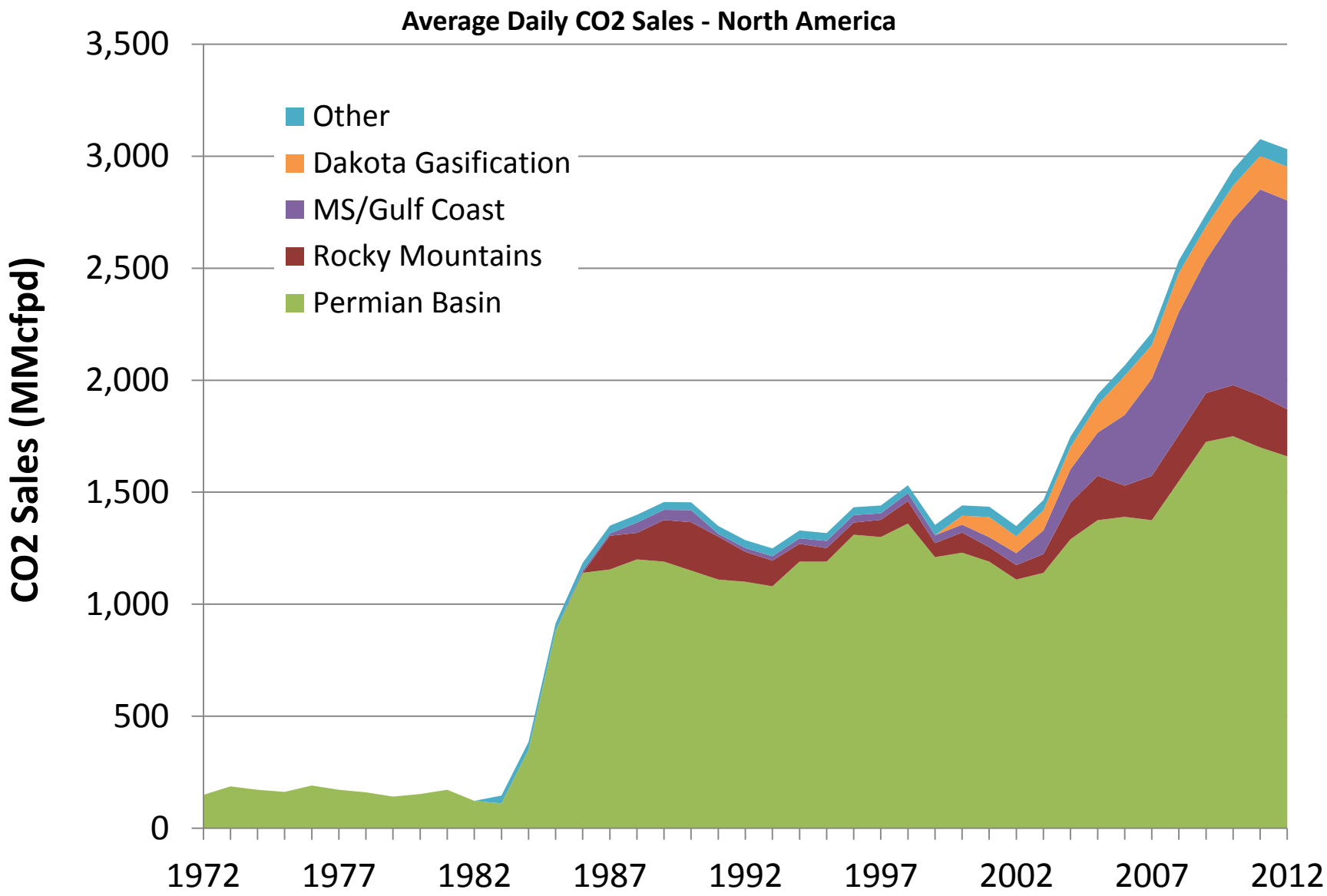
Project Development



4 projects started in 2013: East Seminole (Permian), Bell Creek and Greive (RM), and Burbank

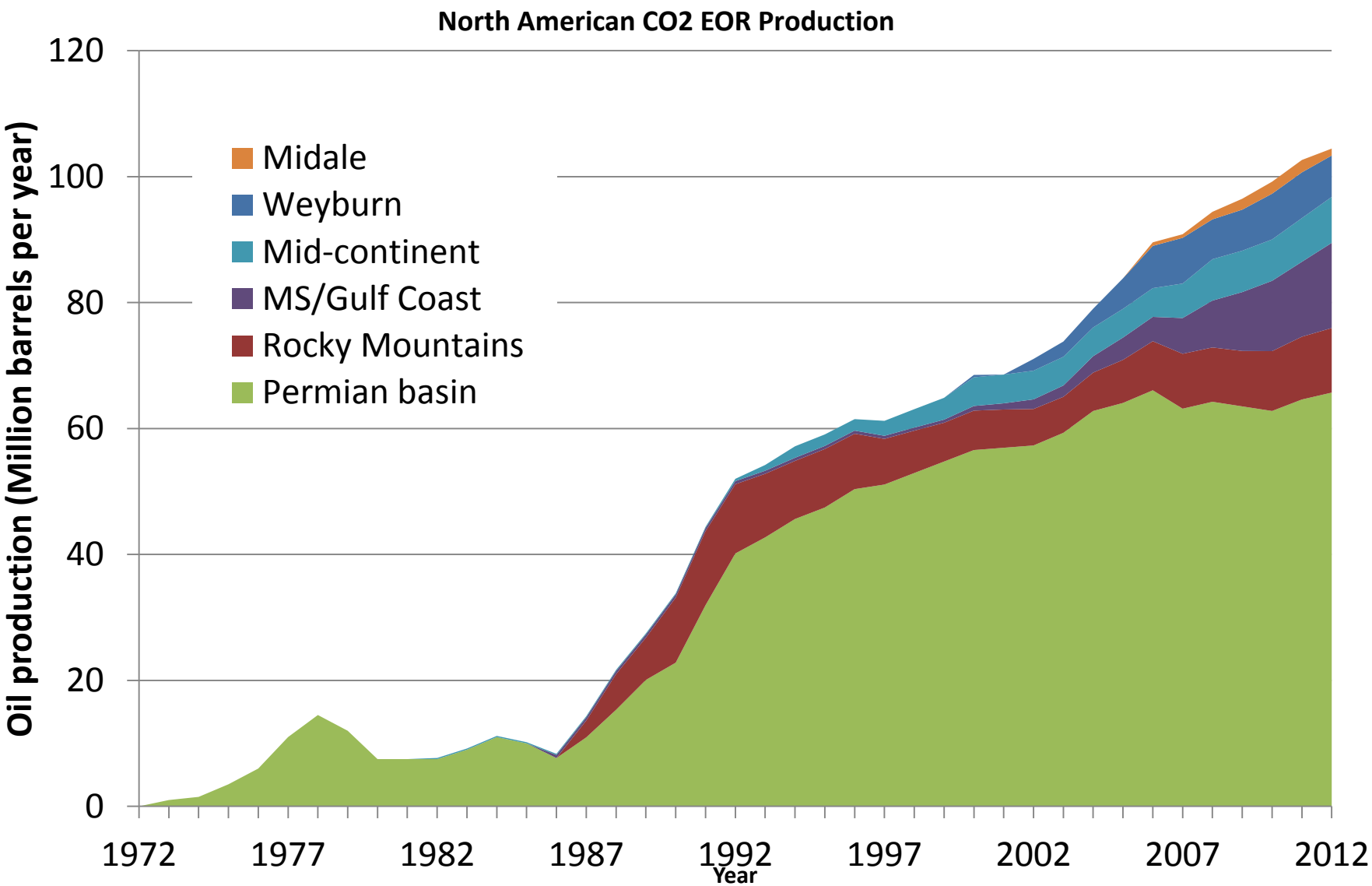
Doll et al., 2009 3rd Wyoming Annual CO2 Conf.; Murrell, 2013 7th Wyoming Annual Co2 Conf.; Denbury Resources 2011&2012 Annual Report; Melzer 2012 6th Wyoming Annual CO2 Conf.; DiPietro et al., 2012

CO2 Sales



KM 2000-2012 Annual Report; Murrell, 2013 7th Wyoming Annual Co2 Conf.; Denbury Resources 2005-2012 Annual Report; Melzer 2012 6th Wyoming Annual CO2 Conf.; Chaparral AR 2010-2012

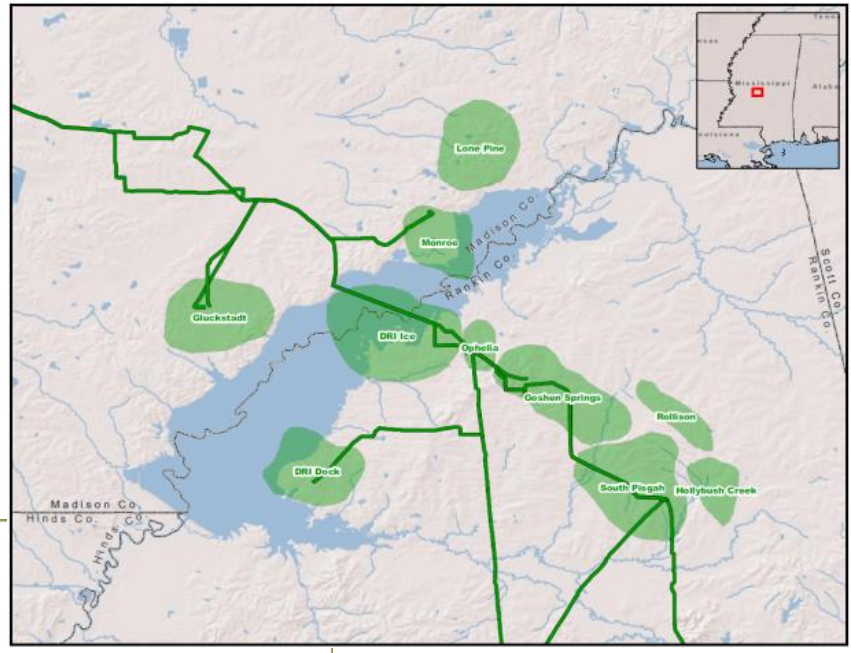
CO2 EOR Incremental Recovery

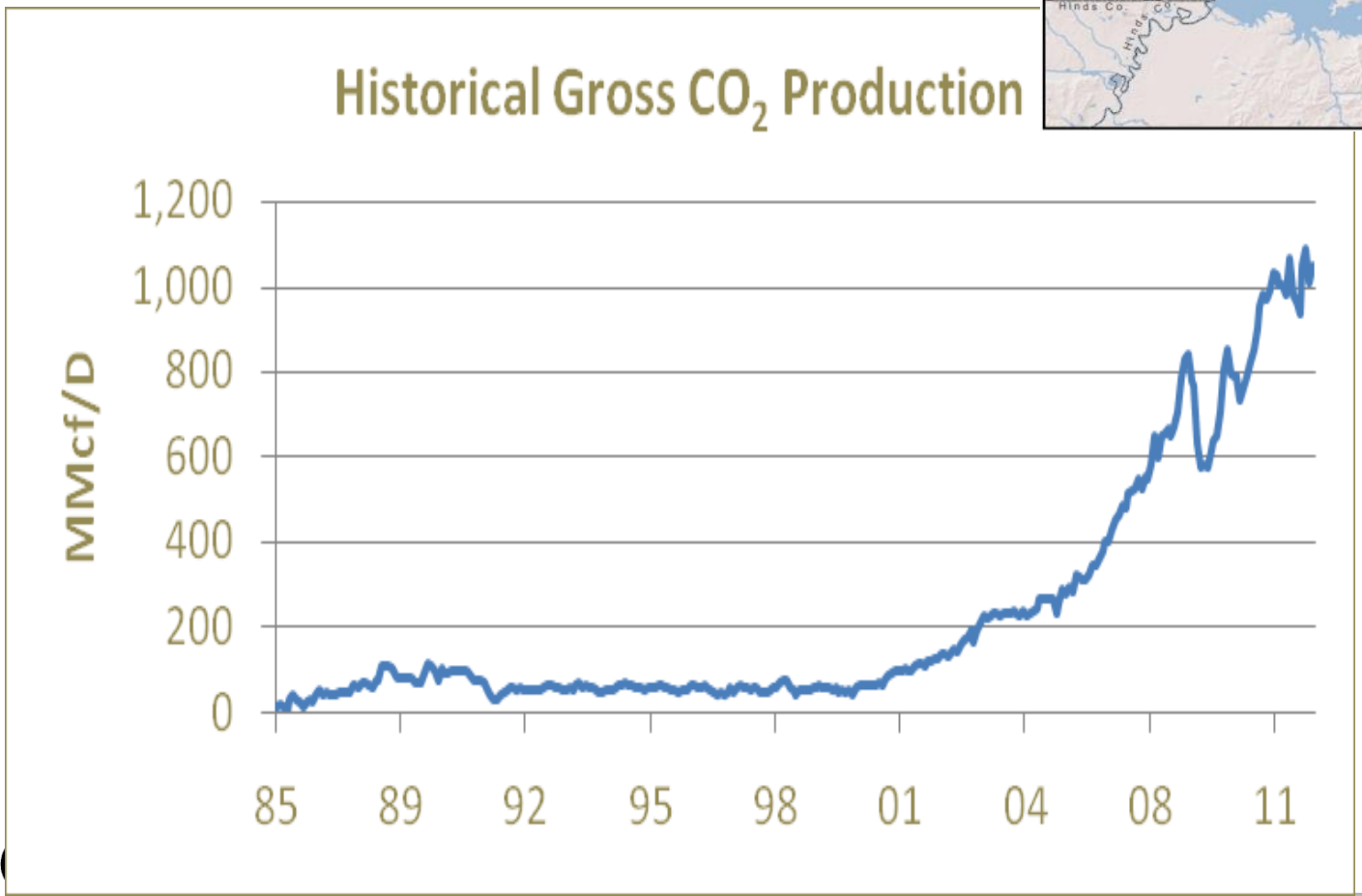


Jackson Dome Area

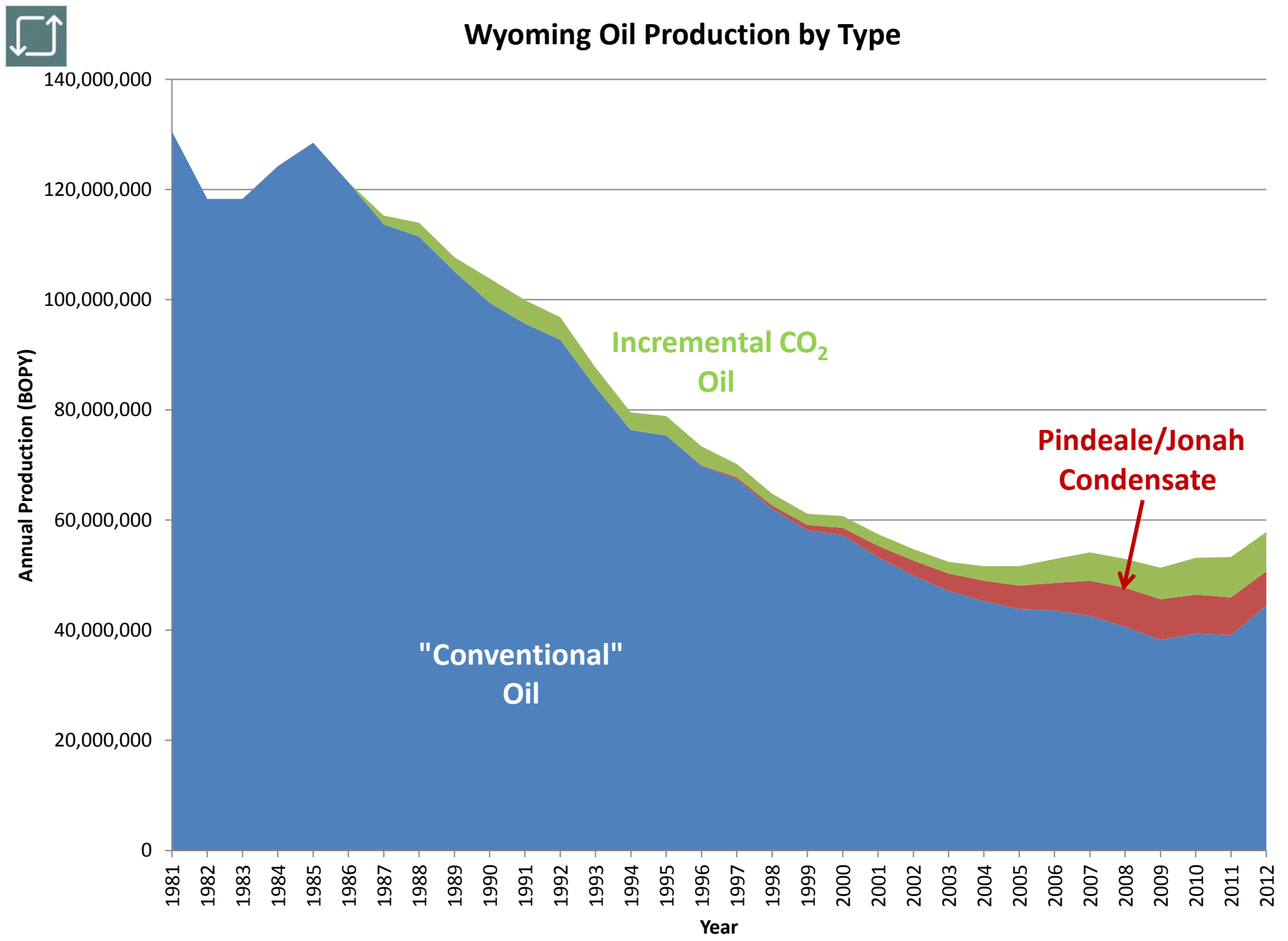
Jackson Dome Area

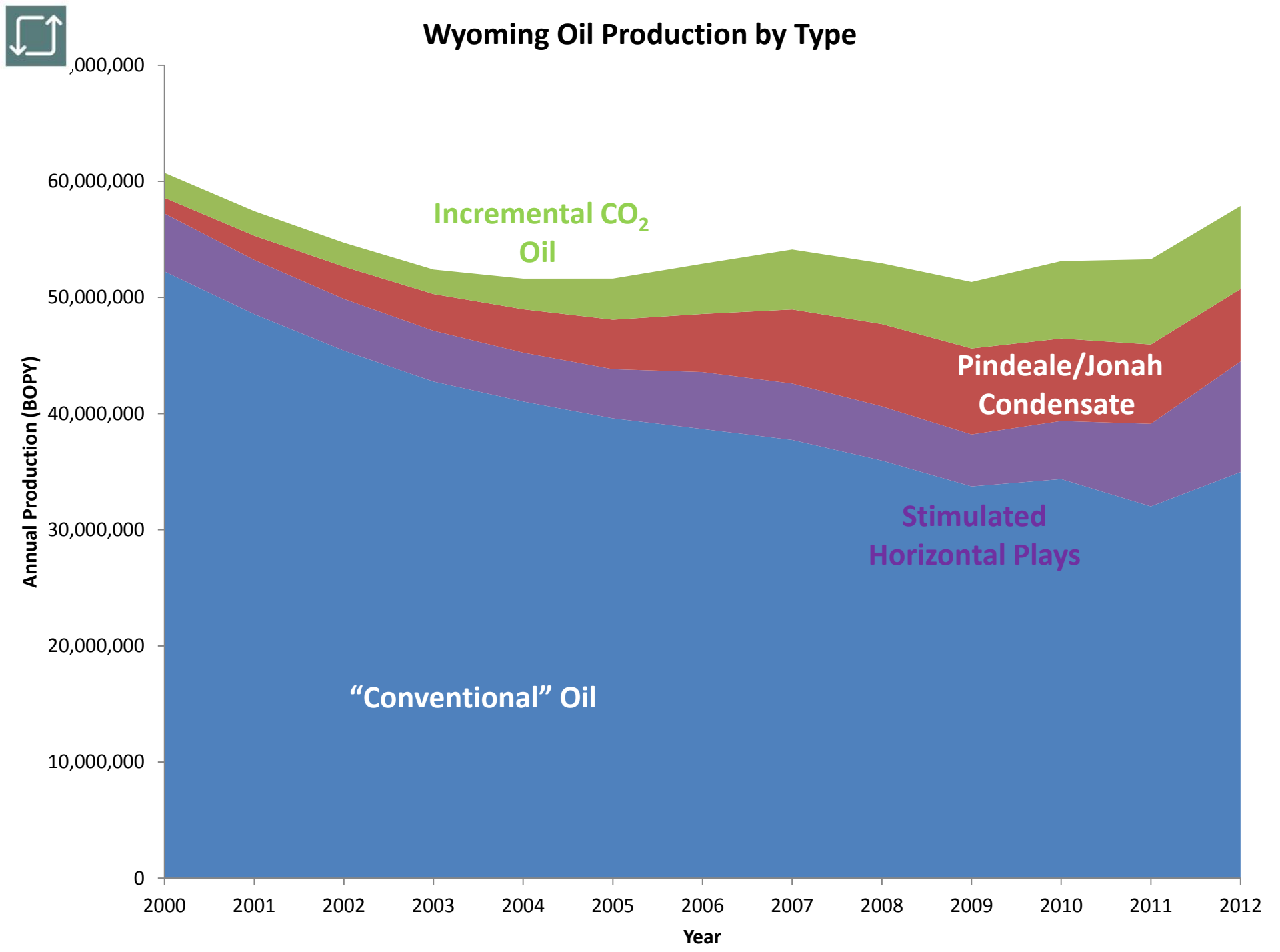
- 6.1 TCF Proved Reserves estimated at 9/30/12
- 3Q 2012 Average Daily Production – 1,036 MMcf/d
- 4 wells drilled in 2012





Denbury


Wyoming Oil Production by Type
Annual Production (BOPY)
140,000,000
120,000,000
100,000,000
80,000,000
60,000,000
40,000,000
20,000,000
0
Incremental CO_2 Oil
Pindeale/Jonah Condensate
"Conventional" Oil
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year


Wyoming Oil Production by Type
,000,000
60,000,000
50,000,000
40,000,000
30,000,000
20,000,000
10,000,000
0
Annual Production (BOPY)
Incremental CO_2 Oil
Pindeale/Jonah Condensate
Stimulated Horizontal Plays
"Conventional" Oil
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year

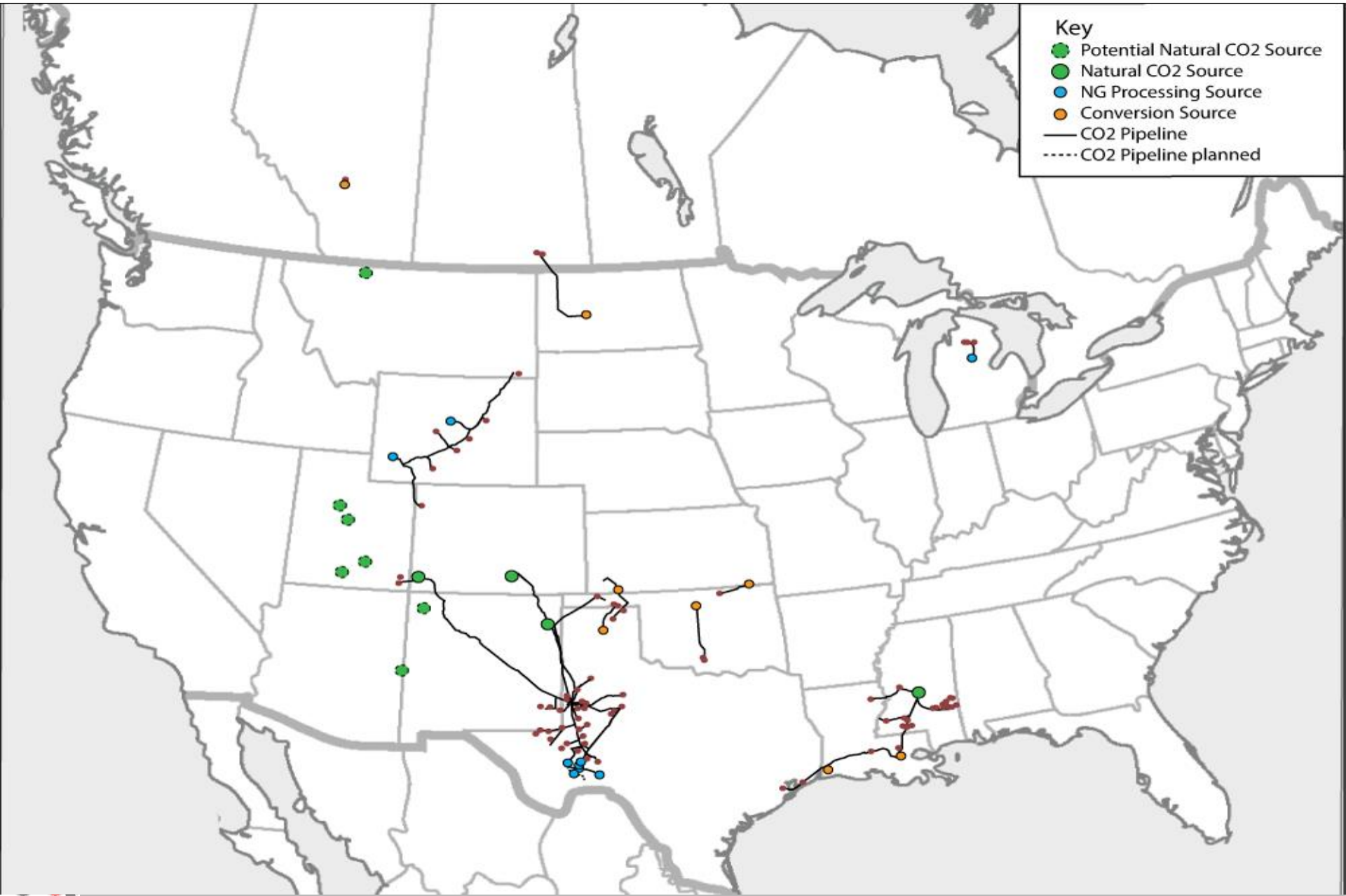
Modified from Melzer 2012. 6th Annual Wyoming CO2 Conference; Murrell, 2013; Denbury Resources Investor Report 12/2012; www.zero.no; and DiPietro et al., 2012

Current CO_2 Supply

Process	Project Name	Operator	Location	Stated Supply Capacity (MMcfpd) 2012	Actual Supply (MMcfpd) 2012	CO_2 Concentration, vol %
Natural Resources	Jackson Dome	Denbury	MS	1,000	1,025 (933 for EOR)	98
	McElmo Dome	Kinder Morgan, ExxonMobil	CO	1,150	1,150	98
	Bravo Dome	KM, Occidental, Amerada Hess	NM	445	300	99
	Sheep Mountain	Occidental	CO	50	25	97
	Doe Canyon	Kinder Morgan	CO	105	50	
Natural Gas Processing	LaBarge	ExxonMobil	WY	340	210	65
	Lost Cabin	ConocoPhillips	WY	50	0	20
	Val Verde Natural Gas Plants	Occidental, Sandridge Energy Inc.	Terrell and Pecos Counties, TX	450	135	65-75
	Turtle Lake	DTE Energy	MI	11	11	
	Lula	Petrobras	Brazil	35	?	8-15
Conversion	Agrium Fertilizer	Agrium, Inc.	Borger, TX	26	26	
	Koch Fertilizer	Koch Nitrogen Company, LLC	Enid, OK	35	35	
	Arkalon Ethanol	Conestoga Energy Partners	Liberal, KS	14	14	
	Boundary Dam	SaskPower	Estevan, SK	51	0	
	Bonanza BioEnergy Ethanol	Conestoga Energy Partners	Garden City, KS	8	0	
	Coffeyville Pet. Coke to Ammonia	CVR	Coffeyville, KS	42.5	42.5	
	PCS Nitrogen Ammonia	PCS Nitrogen - Denbury Resources	Geisma, LA	25	0	
	Valero Refinery - Steam Methane Reforming	Air Products - Denbury Resources	Port Arthur, TX	51	0	
	Great Plains Synfuels Plant	Dakota Gasification	Beulah, ND	150	150	

Modified from Melzer 2012, Murrell 2013; 6th Wyoming Annual CO2 Conf; DiPietro et al., 2012, Denbury Resources Investor Report 12/2011; www.zero.no.

CO2 EOR Supply in 2013



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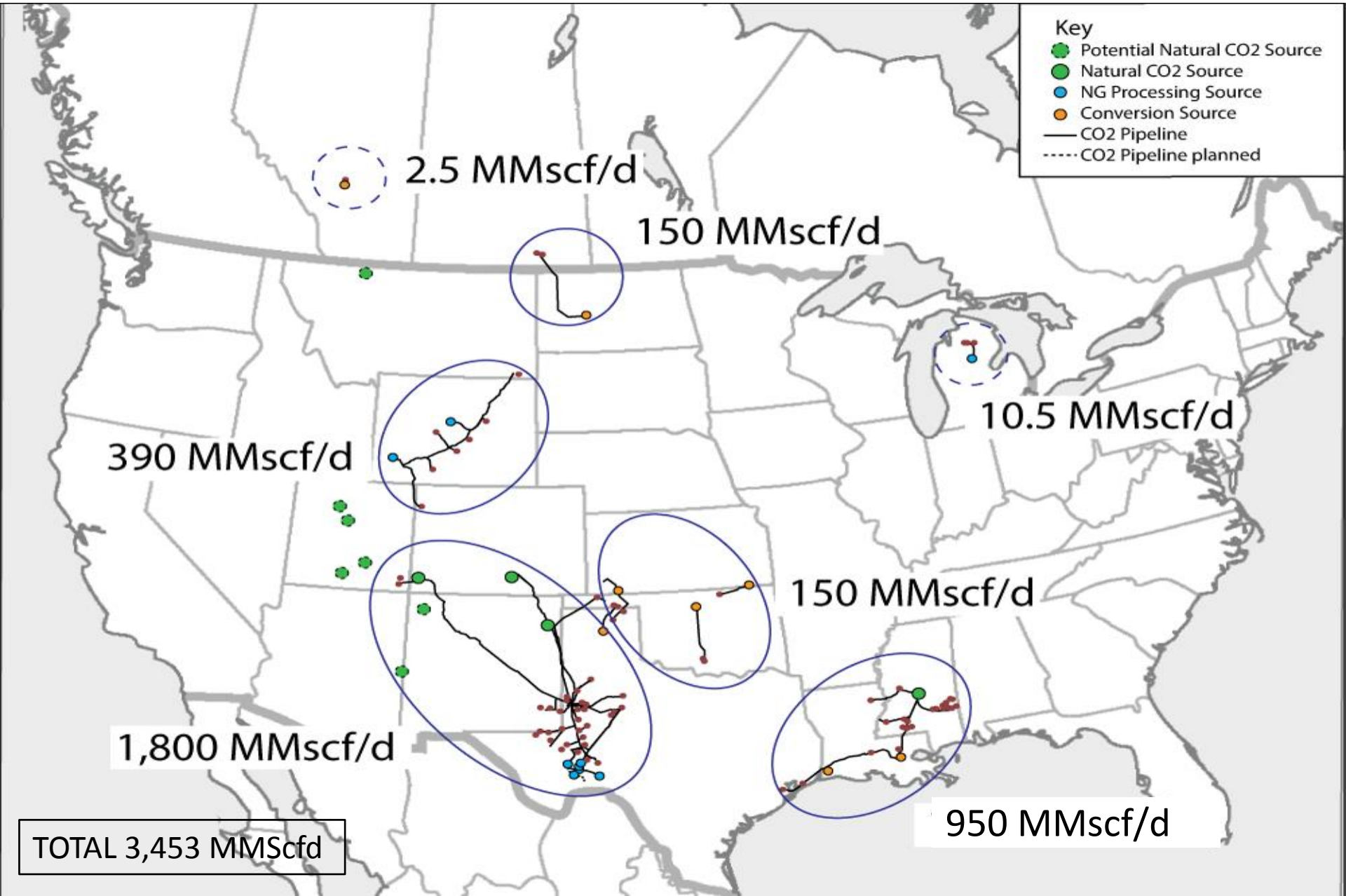

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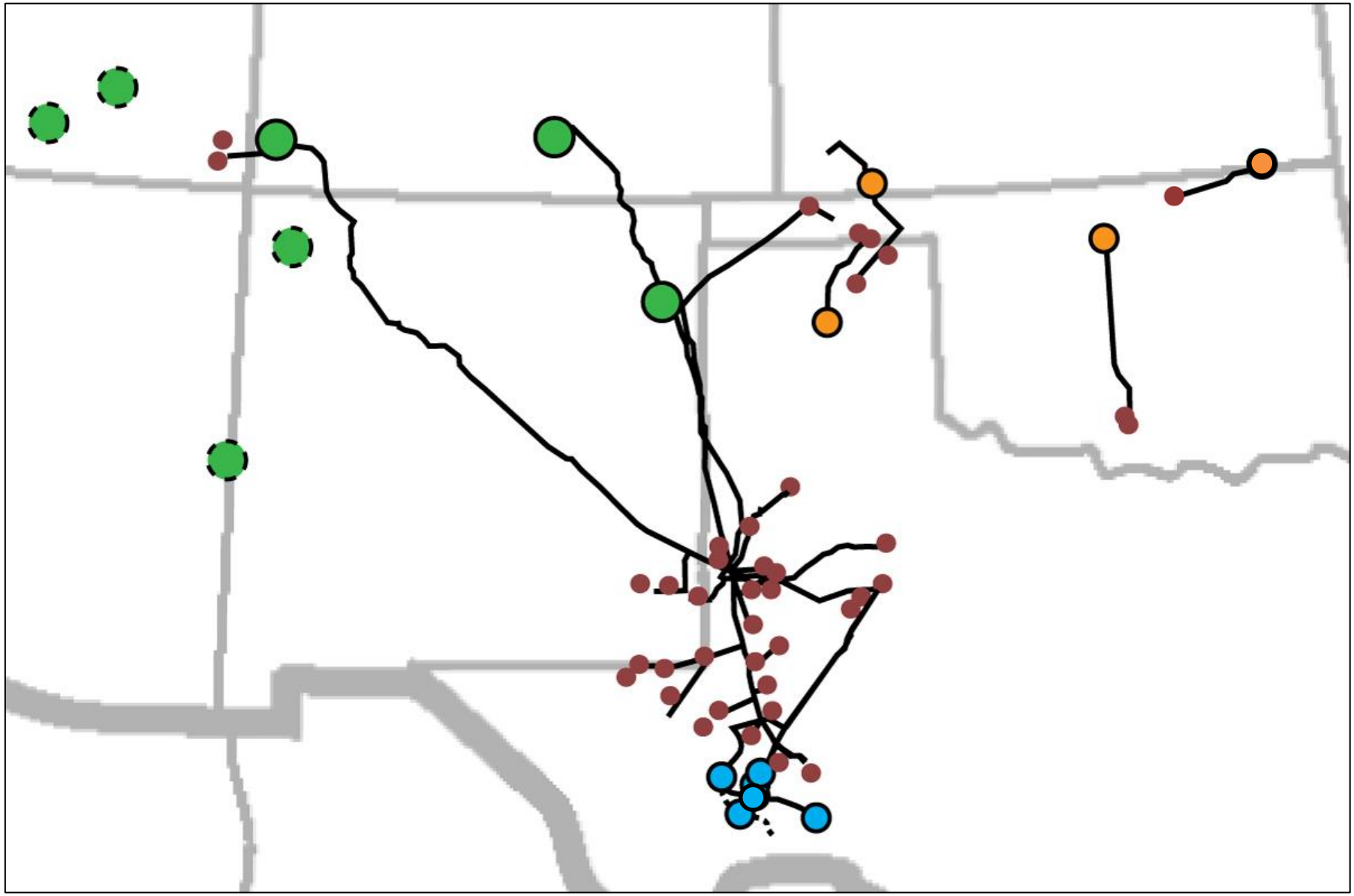
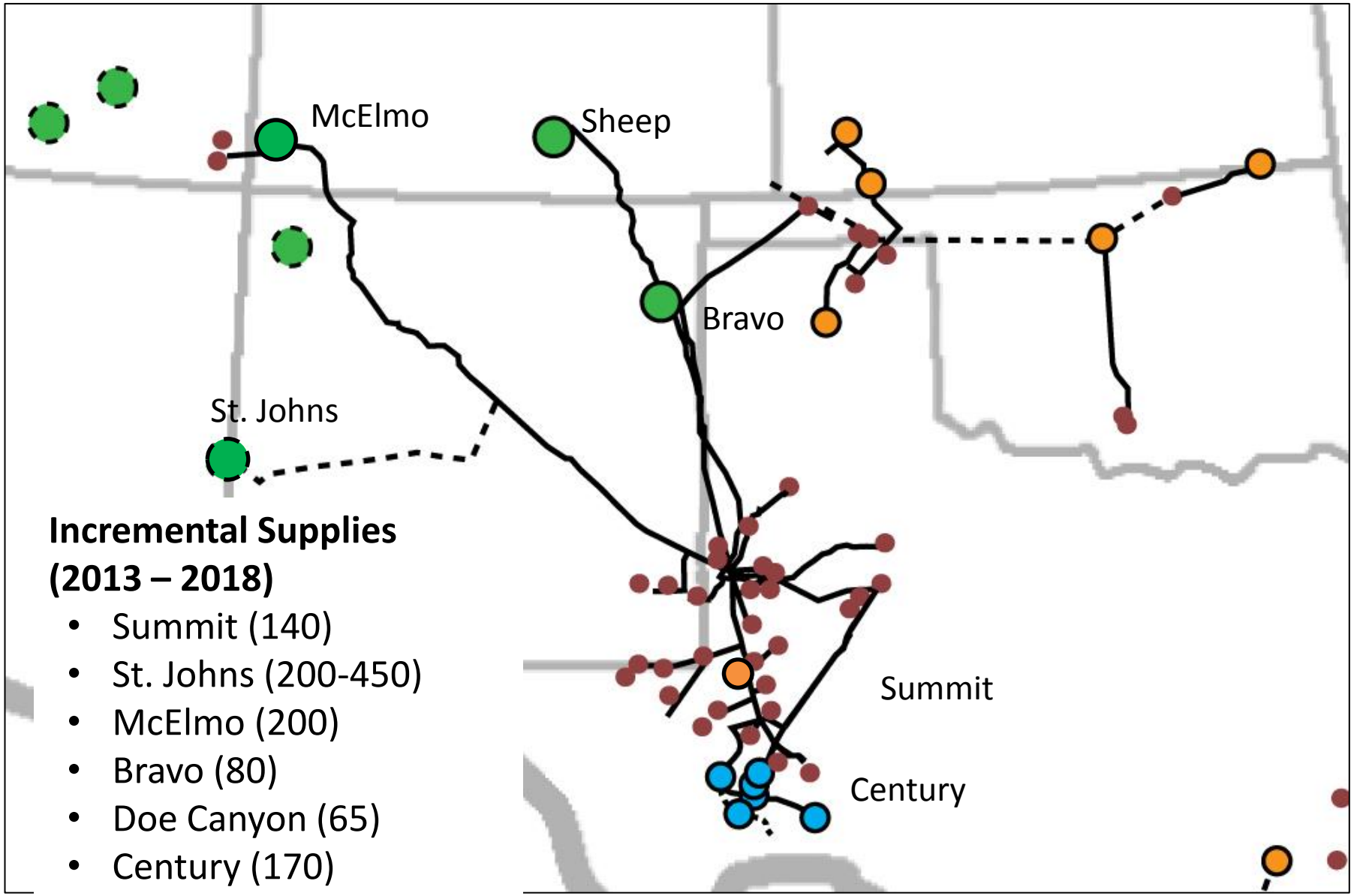
Supply Developments

Sink Location	Project	Status	Online date	Incremental CO_2		
				Rate (MMcfpd)	Total	% inc.
Rockies	DKRW Medicine Bow Fuel & Power Coal to Liquids (WY)	In Financing	2018?	100 initially (Phase II conditional but would add 100)	536-766	135% - 195%
	Linc Energy UCG (WY)	Planning	?	115		
	Carbon Energy (WY)	Planning	?	?		
	Riley Ridge (WY)	Plant w/o CO_2 Capture Currently Under Construction	2019	130 initially, phasing up to 260		
	~~Quintana South Heart Project~~	~~Permitting~~	~~2017?~~	110		
	Antelope Valley AVS CO2 Demo	on-hold (Cancelled)	?	51		
Permian Basin	Summit - Texas Clean Energy Project (TX)	Air Permit Approved, Near Closing.	2016	140	605-855	30-40%
	St. Johns Dome (NM)	Under Development	2016-2017	200-450		
	McElmo Dome (CO)	Upgrade AFE'd	2015	200		
	Doe Canyon (CO)	Upgrade AFE'd	2014	65		
Gulf Coast	Faustina Petroleum Coke Gasification Project, St. James Parrish (LA)	Under Study	2020	200	1155-1205	115% - 120%
	NRG W.A. Parish Plant, Houston (TX)	Status uncertain	2016	85		
	Mississippi Power (Southern Company) - IGCC Kemper County (MS)	Under Construction	2014	115		
	Indiana Gasification, LLC (IA)	Permitting, future uncertain	?	205		
	Cash Creek IGCC (KY)	Planning, Permitted, Future Indeterminate	?	100		
	"Chemical Plant" near Green Pipeline	Planning	~2020	150		
	"Other Plants" near Green Pipeline	?	2016	85		
	Power Holdings of Illinois (IL)	Planning	?	250-300		
	Leucadia Pet. Coke to Methanol Plant, Lake Charles (LA)	Permitted	2018	>200		
California	HECA (Elk Hills, CA) - Pet-coke to Hydrogen	Permitting	2017	135	135	
Canada	Alberta CO2 Trunkline Project -ACTL (AB, Ca) with Agrium	Capture facility under retrofit	2014	25	250	
	Alberta CO2 Trunkline Project -ACTL (AB, Ca) with Northwest Upgrading	Capture facility under construction	2015	62		
	SaskPower Boundary Dam Post-comb. Project (SK)	Under construction	2014-2015	51		
	Bow City (AB)	Planning	2017	51		
	Shell Quest Project (AB, Ca.)	Construction underway	2015	60 (currently for storage , but potential for EOR)		
Middle East	ESI CCS, Abu Dhabi, UAE	Planning	2015	41	141	
	Emirates Aluminium CCS Project, Abu Dhabi, UAE	Planning	2018	100		
Europe	Don Valley Power Project, UK	Planning, construction planned 2014	2016 or later	250	250	
	Nuon Magnum, NL	Planning	2020			
People's Republic of China	Dongying CCS Project, Dongying, Shandong Province	Planning	2020	51	350	
	HuaNeng GreenGen IGCC Project, Binhai New Area, Tianjin	Planning	2020	100		
	Jilin Oil Field EOR Project, Songyuan, Jilin Province	Planning	2015	45		
	Lianyungang IGCC with CCS Project, Lianyungang, Jiangsu Province	Planning	2015	51		

Permian Basin / Mid-Continent – 2013



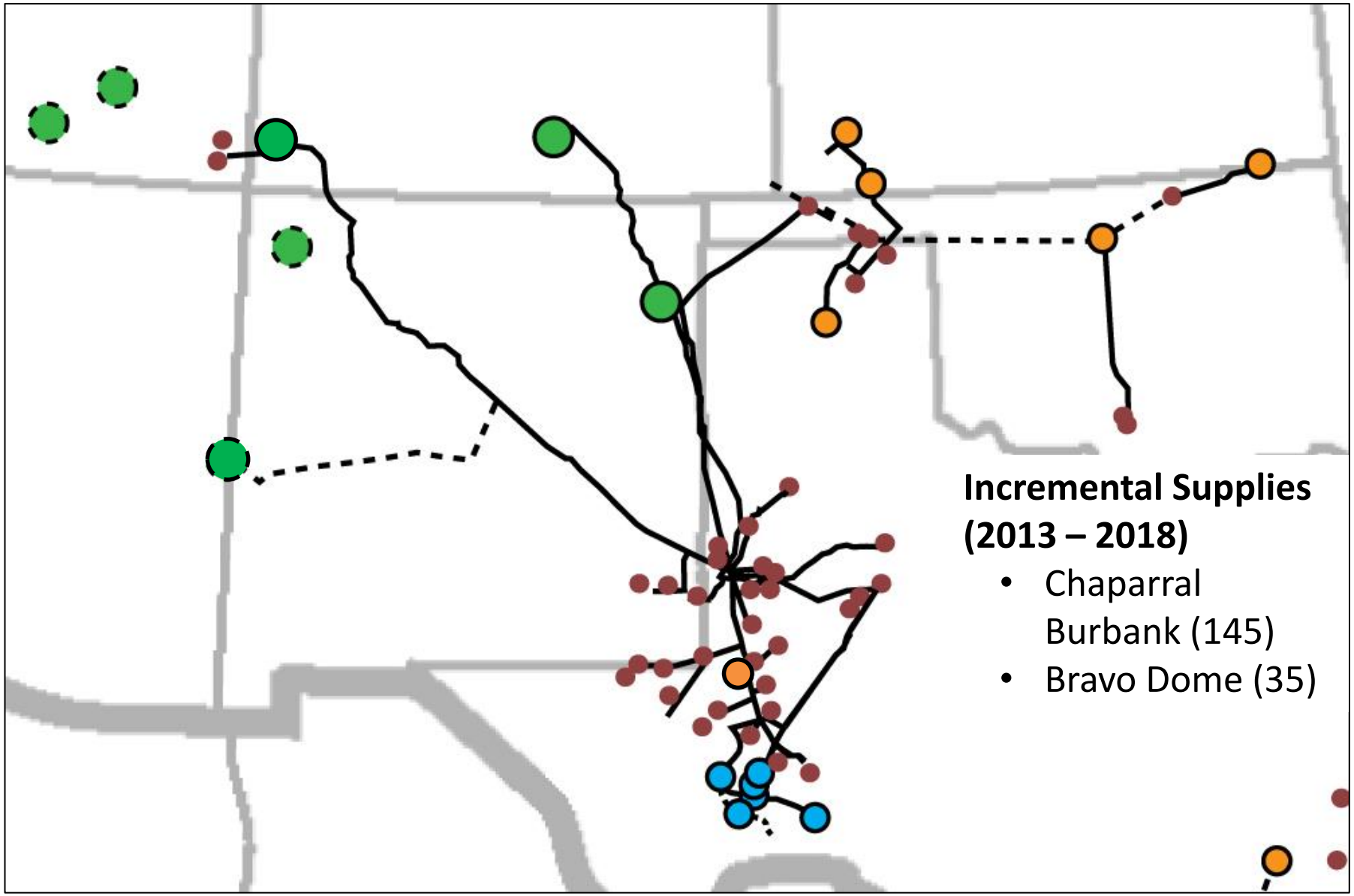
Permian Basin / Mid-Continent – 2018



Incremental Supplies (2013 – 2018)

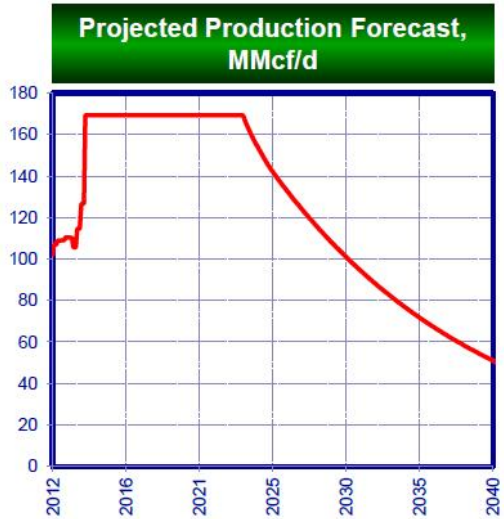
- Summit (140)
- St. Johns (200-450)
- McElmo (200)
- Bravo (80)
- Doe Canyon (65)
- Century (170)

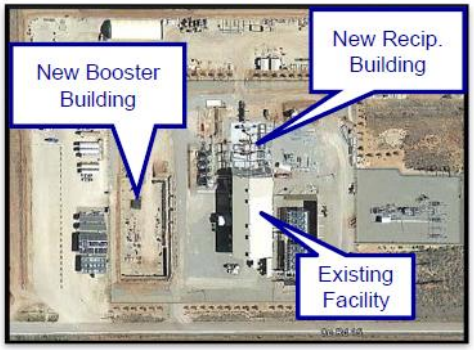
Permian Basin / Mid-Continent – 2018



Doe Canyon Field Expansion

$255 MM, 65 MMcf/d CO_2 increase



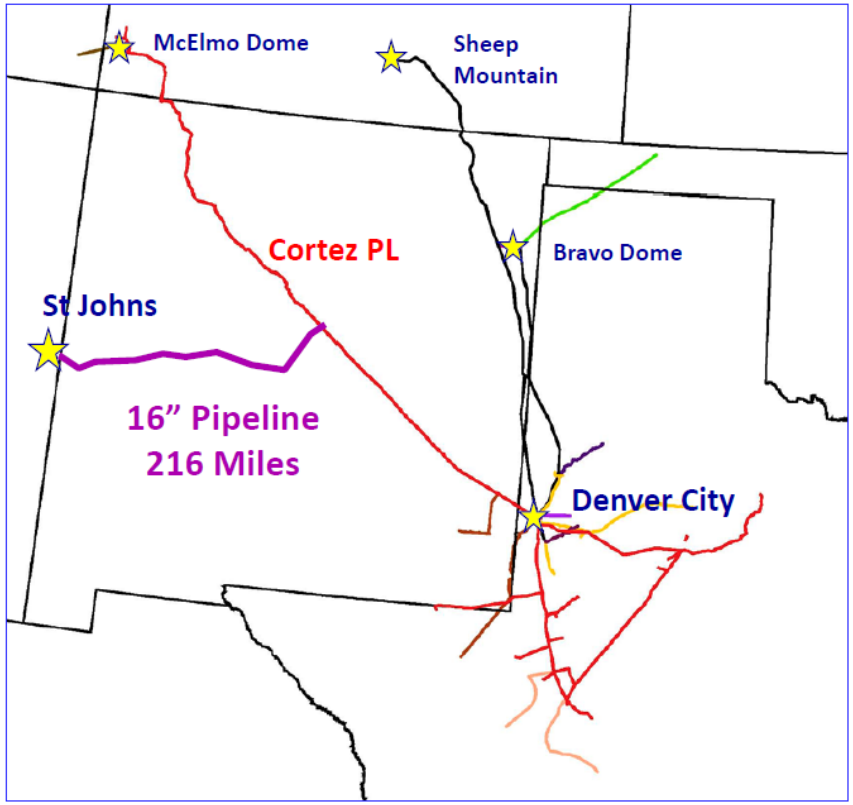


- **170 MMcf/d (from 105 MMcf/d)**
  - Adds 750 Bcf reserves
- **Timing : 2nd Quarter 2014**
  - Drilling underway
  - Parallel Compression Q4 2013
  - 170 MMCFD YE 2013
  - Booster Compression Q2 2014
- **Project delivers attractive returns based on contracts recently executed and currently being negotiated**

KINDER MORGAN

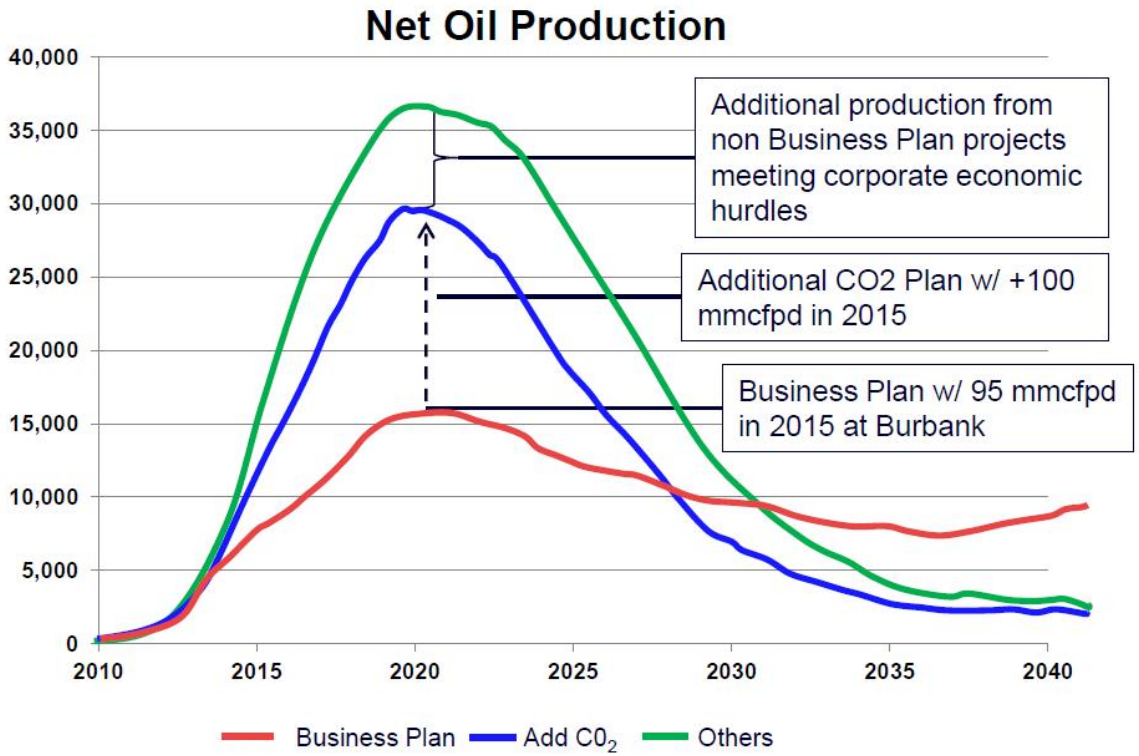
St. John's CO_2 Source Opportunity

Assessment drilling and testing ongoing



- **Evaluating pipeline & field development options**
  - 200 MMCFD ~$0.6 B
  - 450 MMCFD ~$1.3 B
- **Drilled/Recompleted 14 wells**
- **Established good deliverability in Granite Wash**
- **Deliverability in Amos Wash is being evaluated**
  - Testing completion strategies
- **Core analysis, log evaluation, geological/reservoir characterization and mapping is ongoing**
- **Target in service date 2016-17**

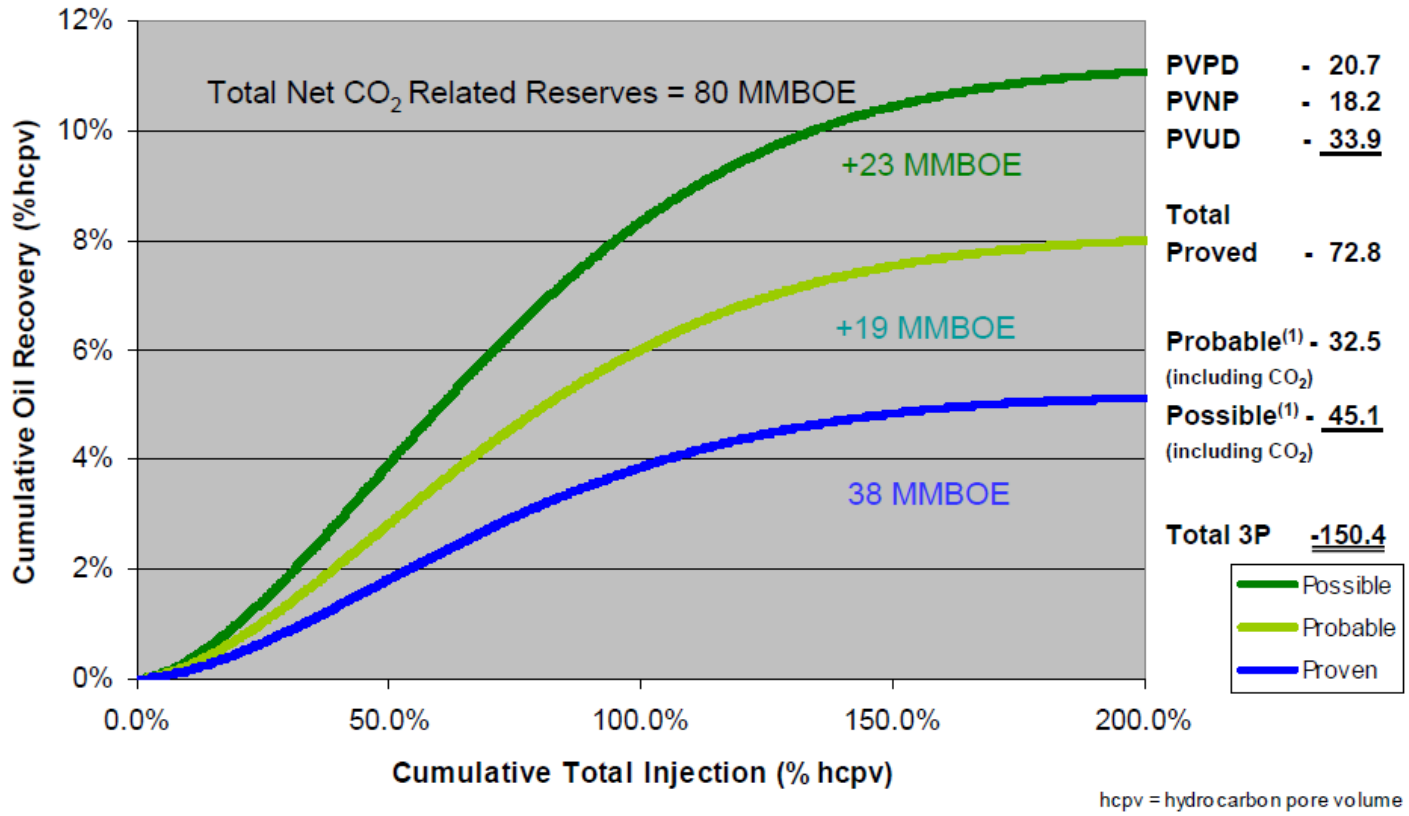
Chaparral – Potential EOR Production Growth



Chaparral ENERGY

Estimated Net Reserves from CO_2 Flood – North Ward Estes

Total Net Proved, Probable & Possible CO_2 Reserves at 12/31/08 = 80 MMBOE
Total Net Proved, Probable & Possible Reserves from All Sources at 12/31/08 = 150 MMBOE



PVPD	- 20.7
PVNP	- 18.2
PVUD	- 33.9
Total Proved	- 72.8
Probable[1] (including CO_2)	- 32.5
Possible[1] (including CO_2)	- 45.1
Total 3P	-150.4

hcpv = hydrocarbon pore volume

[1] Please refer to Slide #1 for disclosures regarding "probable" and "possible" reserves.

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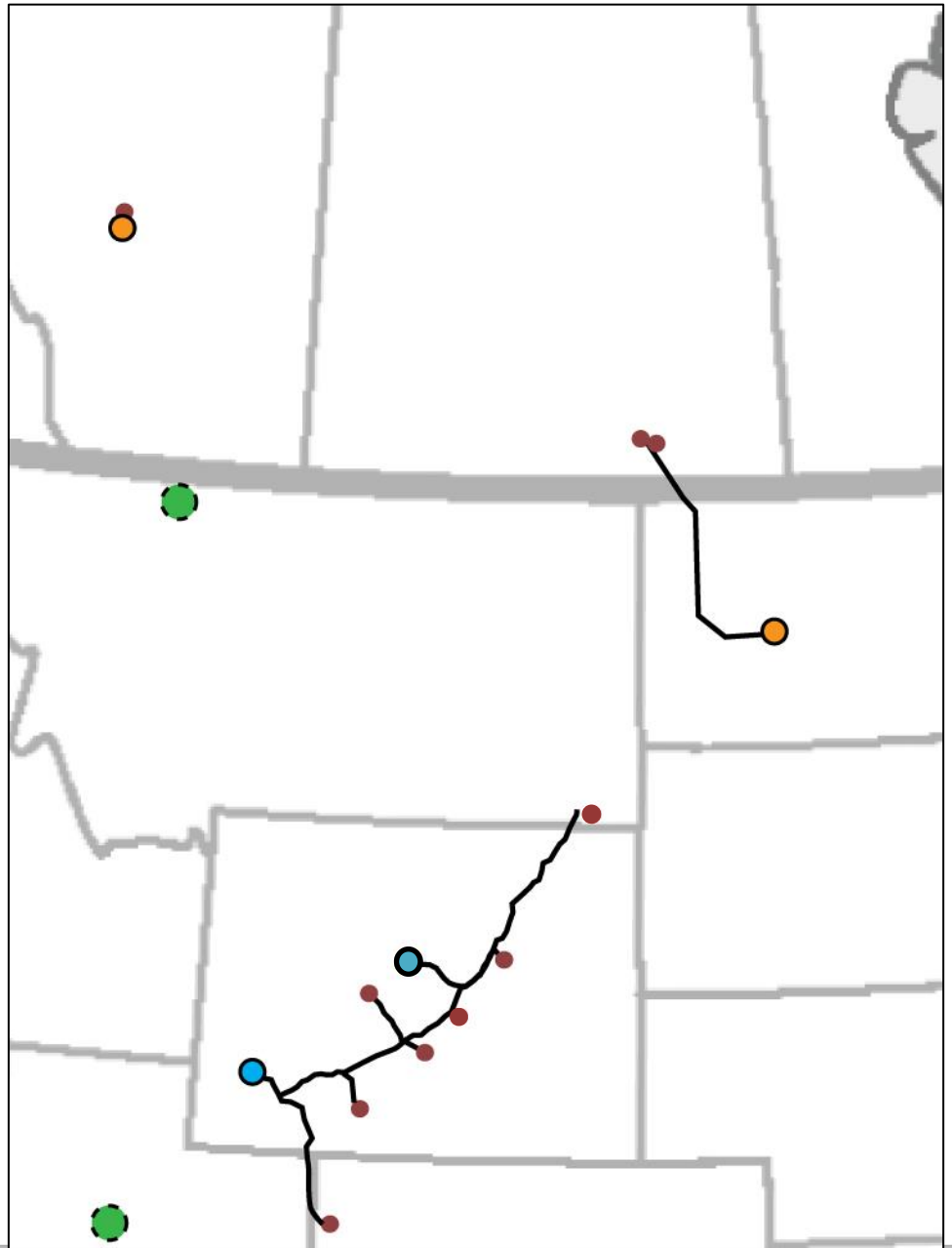
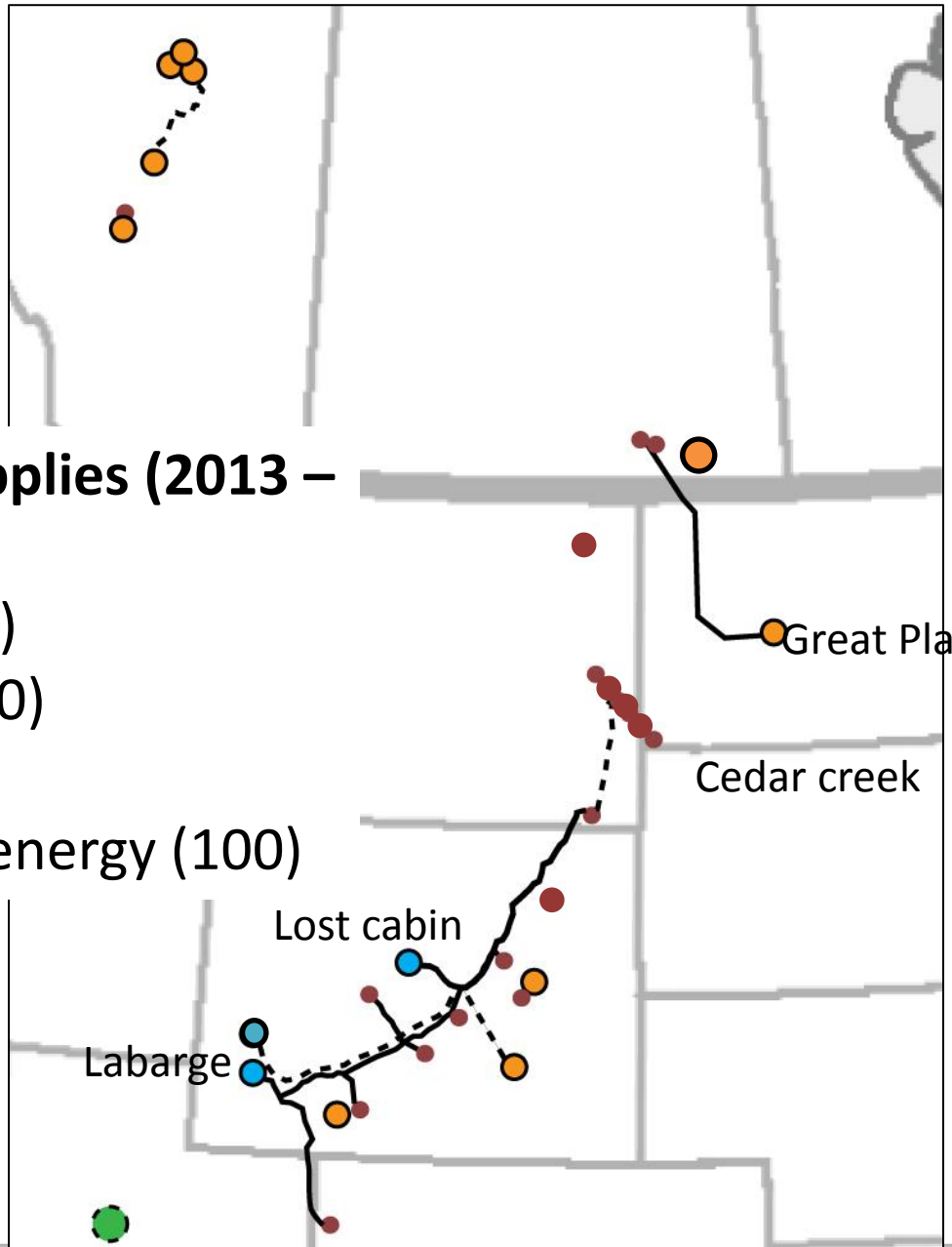
Rocky Mountain / Northern Plains – 2013



Rocky Mountain / Northern Plains – 2018

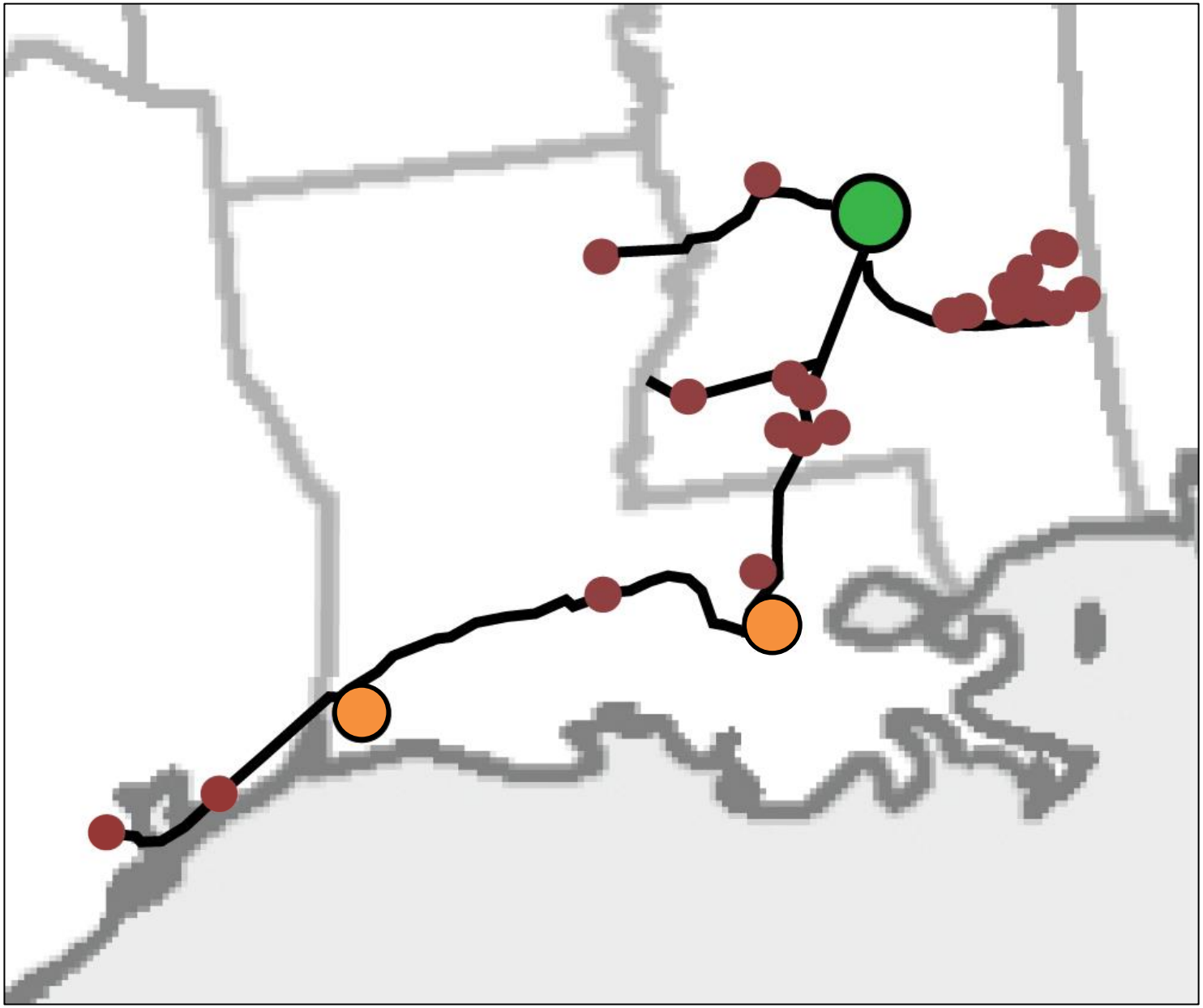
Or maybe a little later…



Incremental Supplies (2013 – 2018)

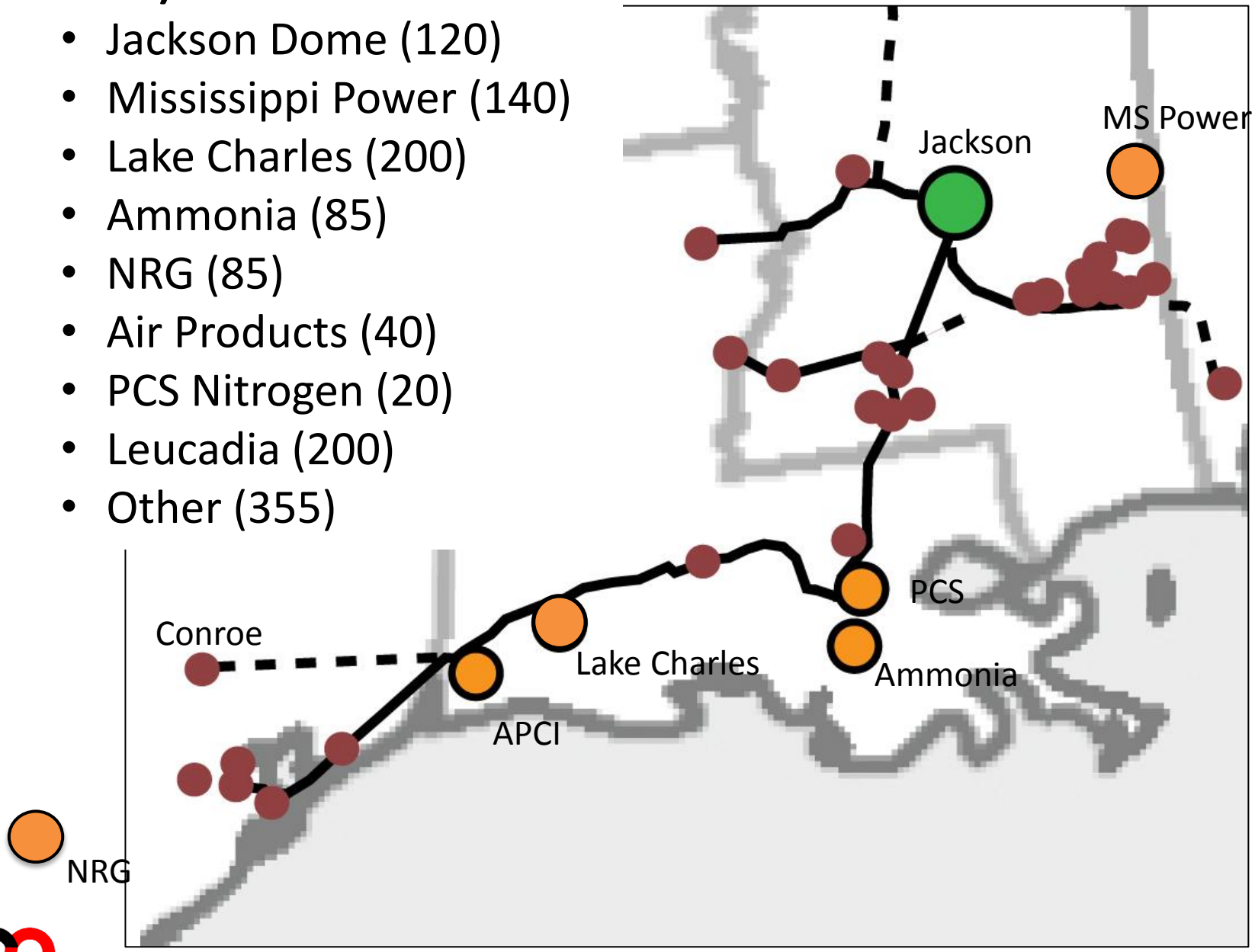
- LaBarge (130)
- Lost Cabin (30)
- CES (50)
- Linc/carbon energy (100)

Mississippi / Gulf Coast – 2013



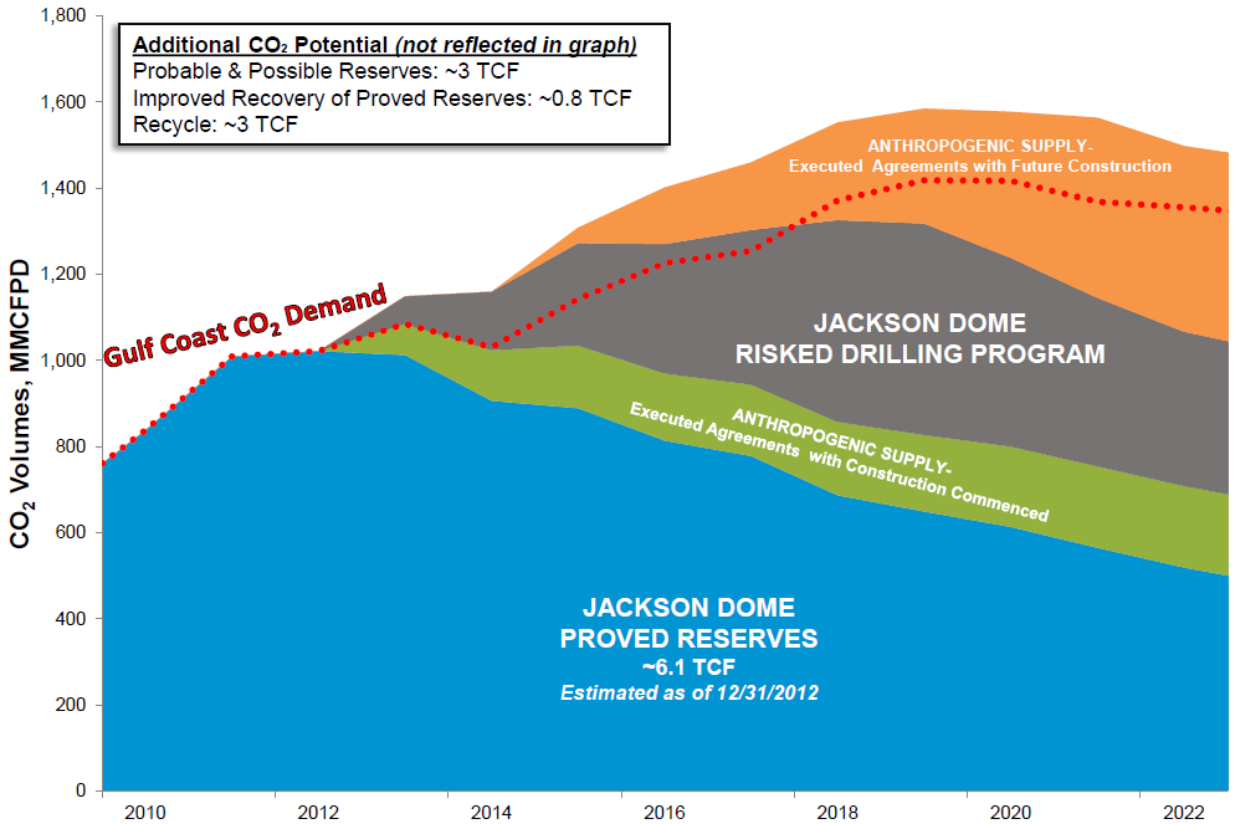
Incremental Supplies (2013 – 2018)

- Jackson Dome (120)
- Mississippi Power (140)
- Lake Charles (200)
- Ammonia (85)
- NRG (85)
- Air Products (40)
- PCS Nitrogen (20)
- Leucadia (200)
- Other (355)



CO_2 Supply to Support Gulf Coast Growth

PURE Denbury



Note: Forecast based on internal management estimates and includes fields currently owned. Actual results may vary.

Denbury

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Gulf Coast Industrial Partners

PURE Denbury

Currently Producing or Under Construction

Air Products
- Port Arthur, Texas
- Hydrogen Plant
- Capture Date: 1Q 2013
- Quantity: ~50 MMcf/d

PCS Nitrogen
- Geismar, Louisiana
- Ammonia Products
- Capture Date: 2Q 2013
- Quantity: ~20 MMcf/d

Mississippi Power – (Under Construction)
- Kemper County, MS
- Gasifier
- Capture Date: ~2014
- Quantity: ~115 MMcf/d

Future Construction (currently planned or proposed)

Lake Charles Cogeneration
- Lake Charles, Louisiana
- Petroleum Coke to Methanol Plant
- Capture Date: ~2018
- Quantity: >200 MMcf/d

Ammonia Plant
- Near Green Pipeline
- Capture Date: ~1Q 2016
- Quantity: ~85 MMcf/d

Chemical Plant
- Near Green Pipeline
- Capture Date: ~2020
- Quantity: ~200 MMcf/d

Denbury

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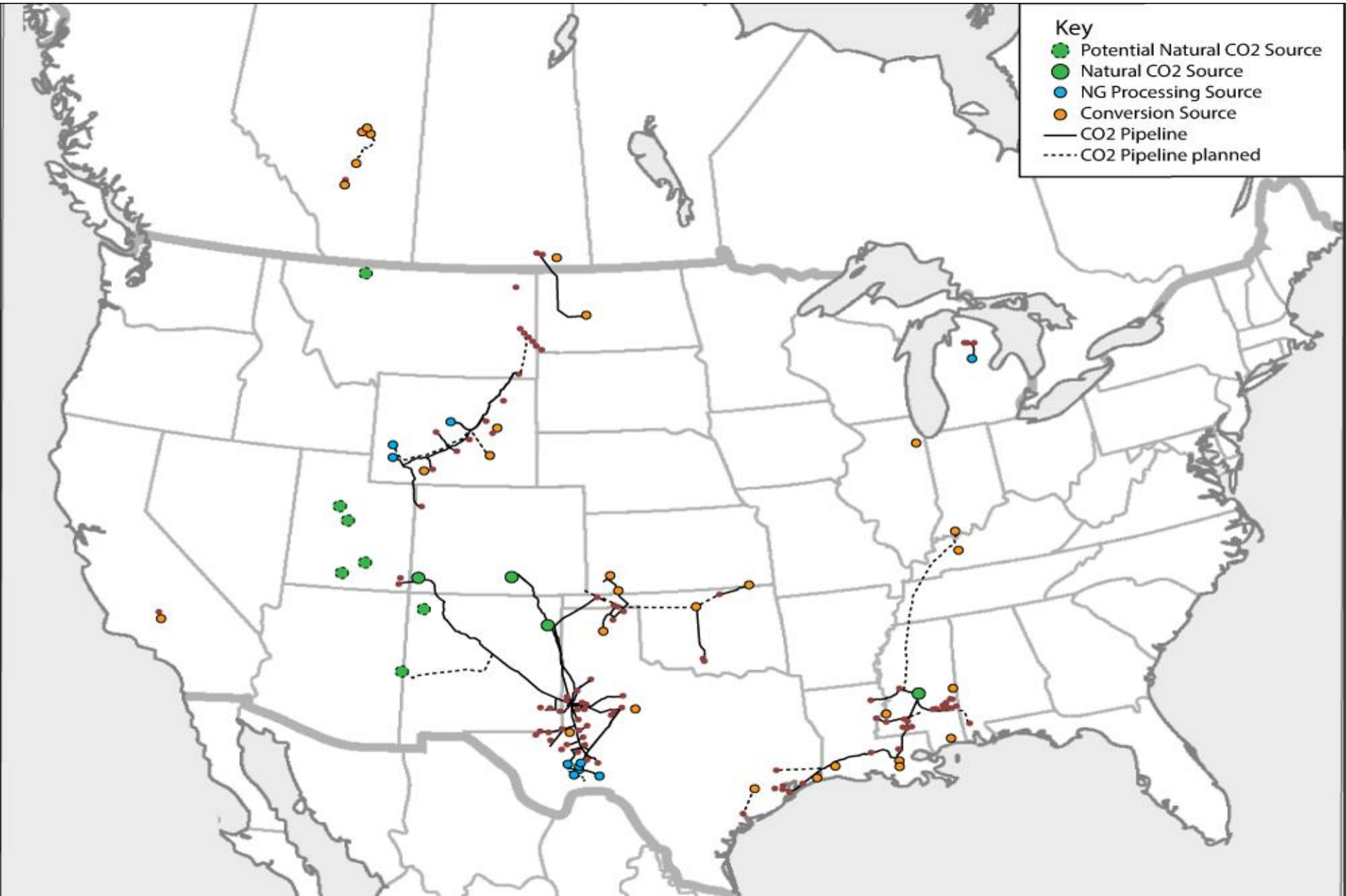
Modified from Melzer 2012, Murrell 2013; 6th Wyoming Annual CO2 Conf; DiPietro et al., 2012, Denbury Resources Investor Report 12/2011; www.zero.no; Chaparral Report to Investors. 2012 .

CO2 EOR Supply in 2018?



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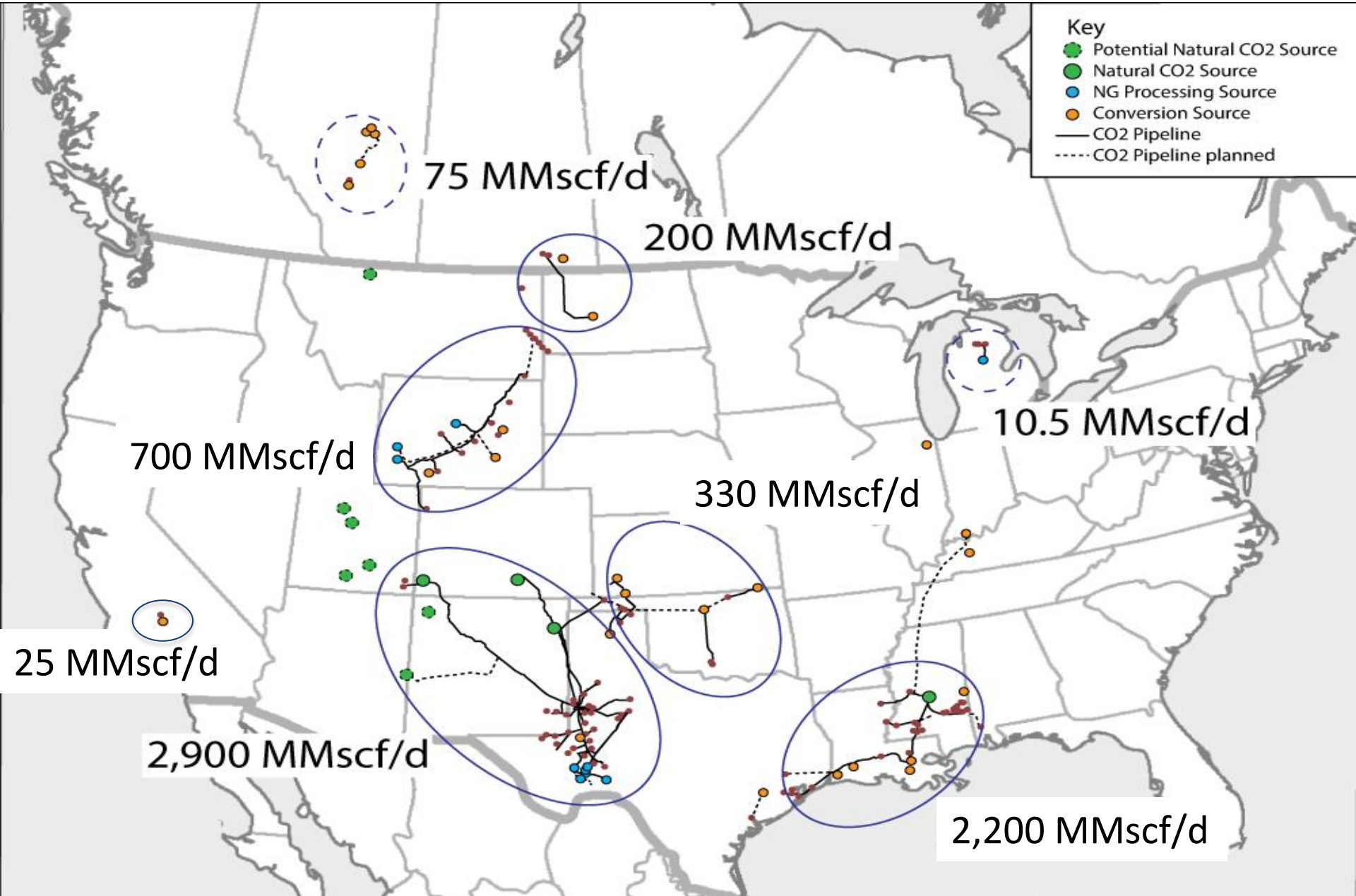
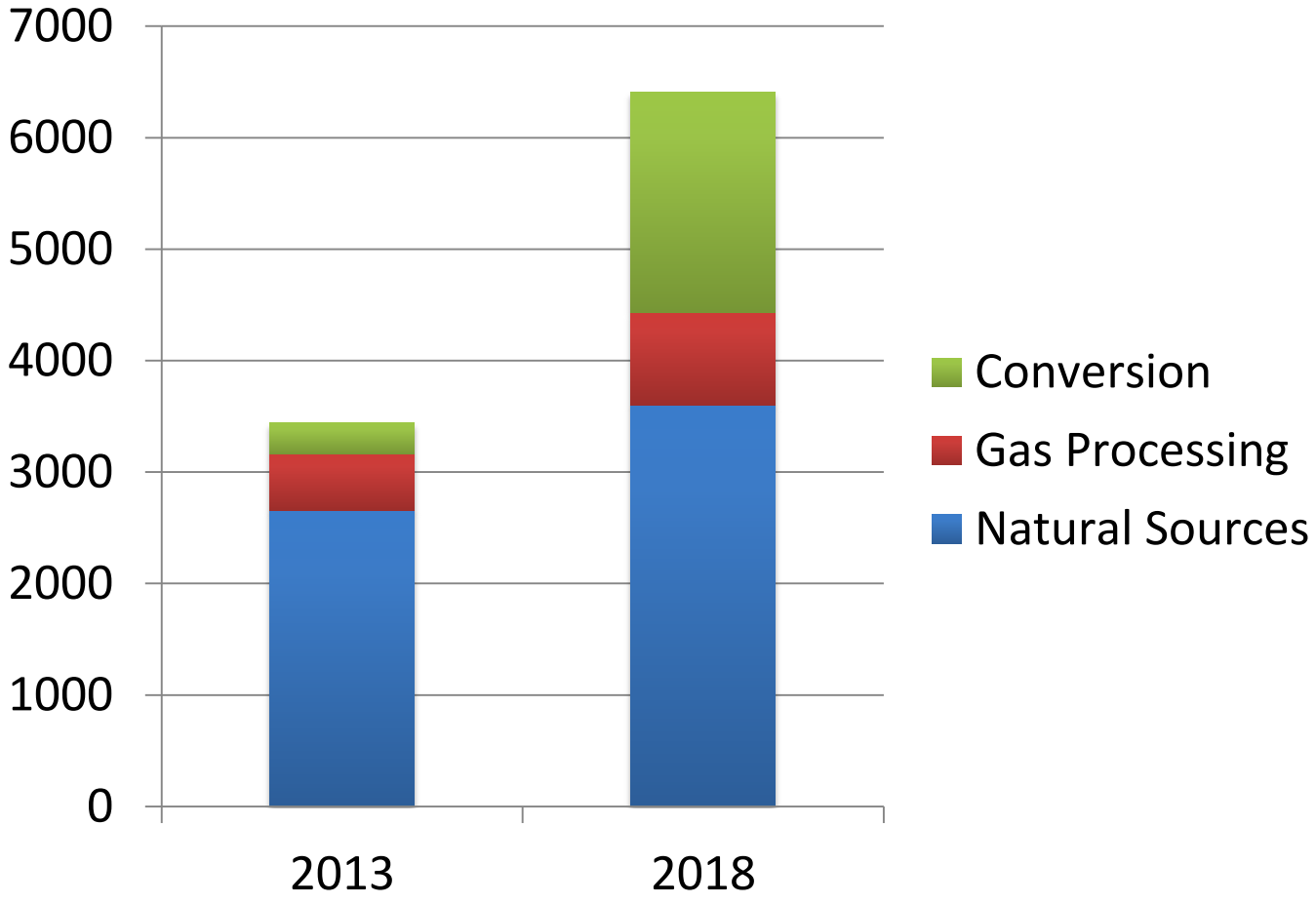
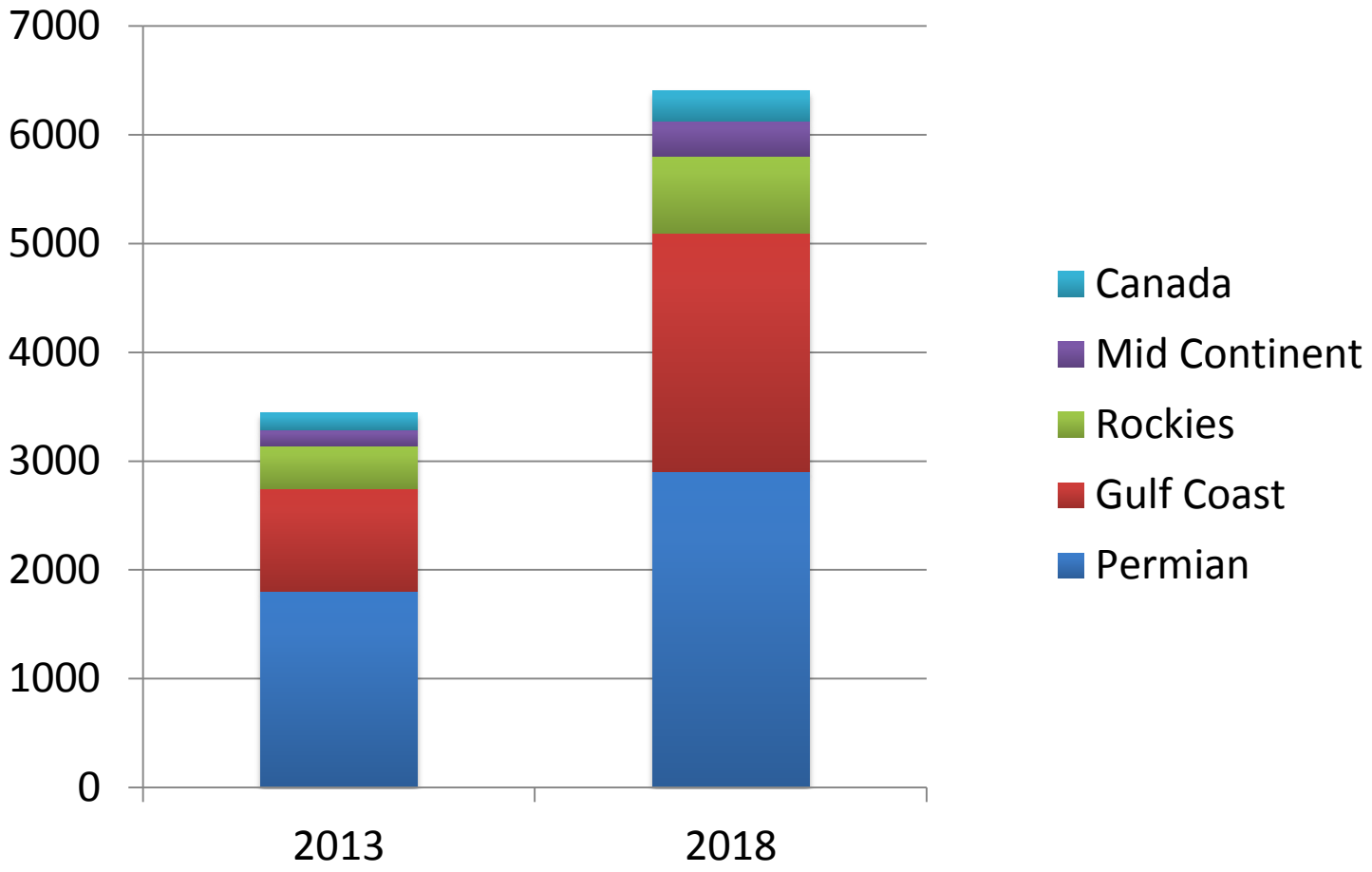
CO2 EOR Supply in 2018?



CO_2 Supply Trends, MMScfd



CO_2 Supply Trends, MMscfd



Supply Developments

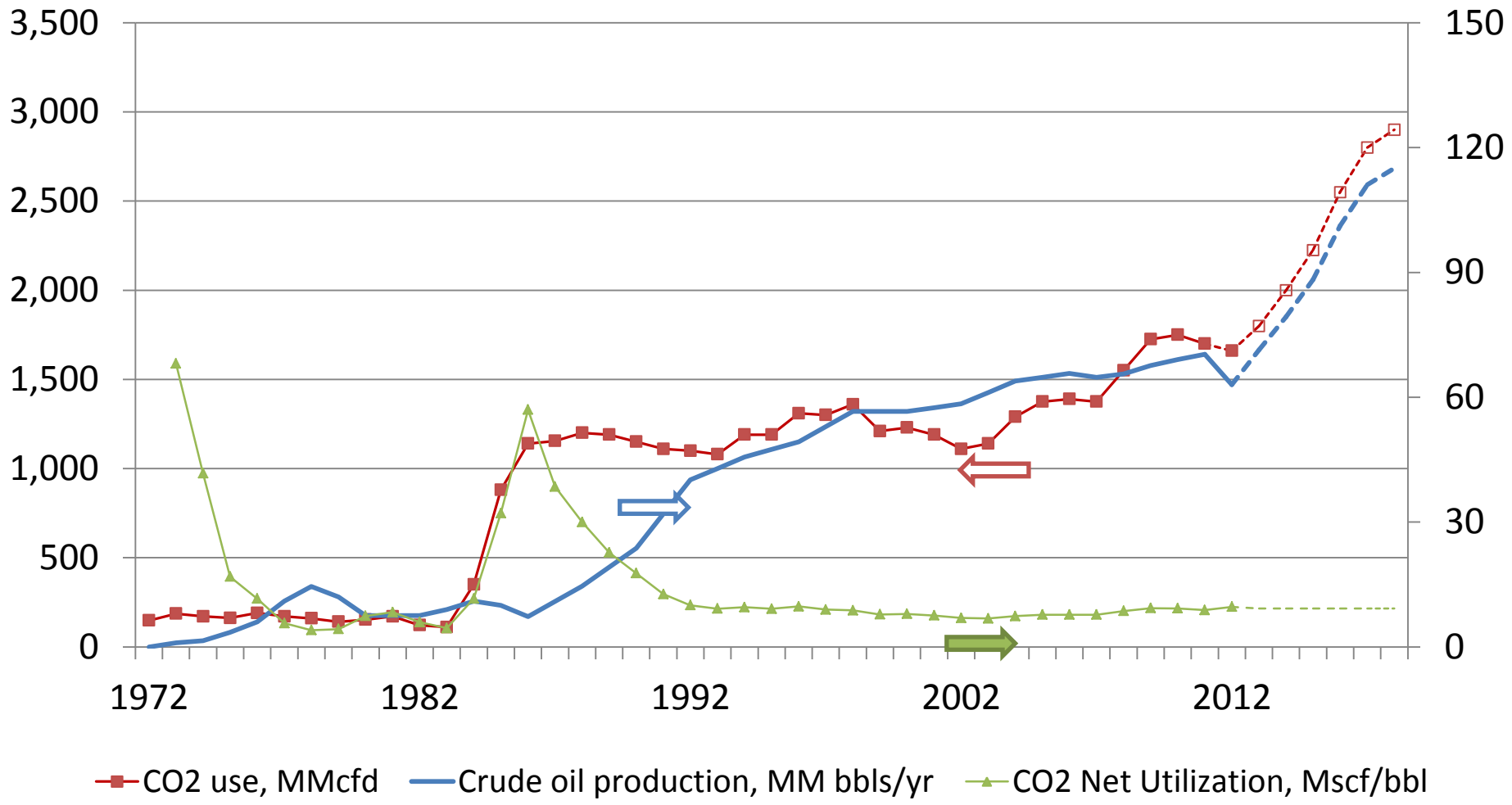
- Rockies:
  - CO_2 Supply in the Rockies will increase by as much as 1 Bcfpd over next 5-10 years. Mostly by development of Riley Ridge but also through several conversion projects. Supply, and CO_2 EOR industry, could quadruple in 5-10 years. Implications for oil industry in the region in general and consequent state economics.
- Permian Basin:
  - Natural source supply will be lifted incrementally, but significant volume of additional supply will come from NG processing plants and conversion technologies.
- Midwest/Mississippi/ Gulf Coast:
  - Natural source supply will be lifted incrementally, but supply will be supplemented massively by conversion project supply going forward. Ultimately, as Jackson Dome enters decline, majority of supply will be from anthropogenic sources.
- Mid-continent:
  - Possible tie-in to Permian Basin system. Additional supply provided by conversion projects.
- Canada:
  - Initiation of CO_2 Transport and Utilization system. CO_2 supply from upgrading processes.

CO_2 EOR Forecasting

Forecasting CO2 EOR Incremental production

- Collaboration with Phil DiPietro from NETL
- Normally need a dimensionless curve
  - Can be difficult, and at least very time consuming, to compile data.
- On a system and sub-system basis, we can use UR_{Net}
- Use sensitivity analysis on historic data to determine best model (nominal, cumulative, average, SLM) and forecast system of UR_{Net} in each system (e.g. Rockies, Permian, GC/MS)
- Assume 'perfect' knowledge of supply capacity past and future.
- Use probabilistic methods to forecast actual sales.
- Use UR_{Net} to calculate production from forecast sales.
- Not perfect but much better than resource based models currently used.

Permian Basin CO2 EOR: CO2 sales, Crude oil Production, and CO2 net utilization



Permian Basin

Incremental Supplies (2013 – 2018)

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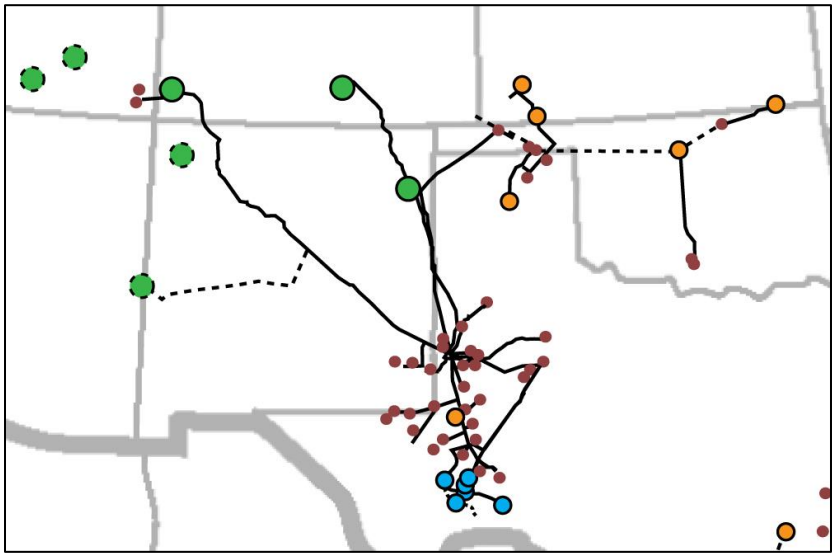
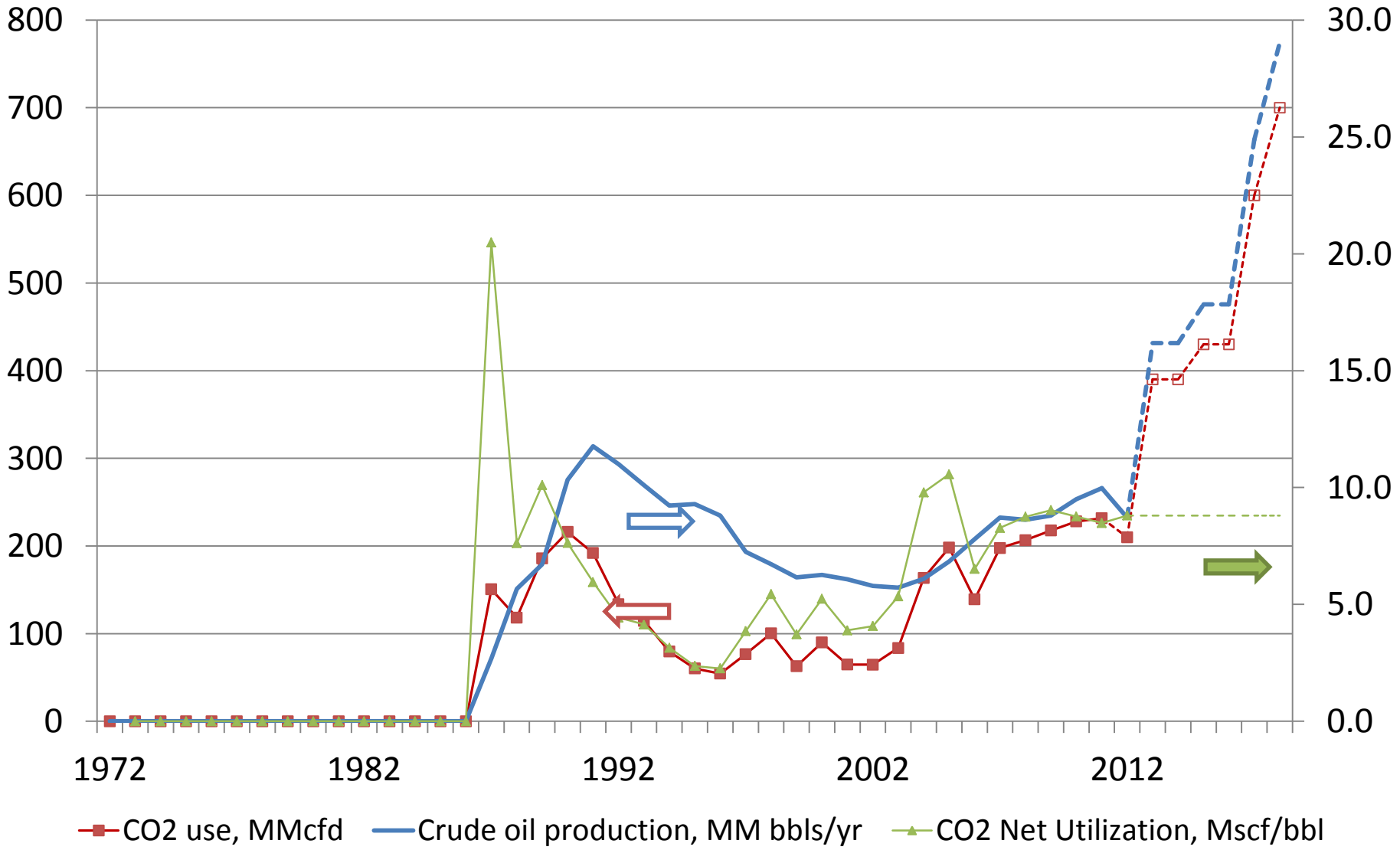
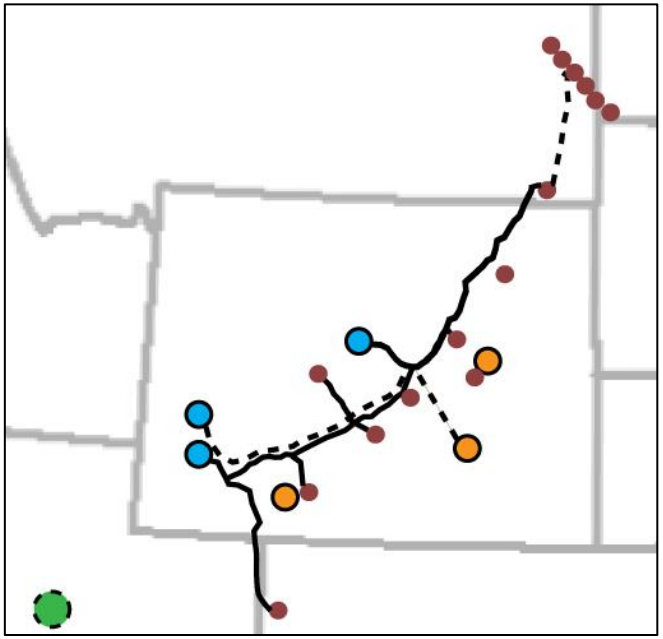


	2013	*2018*
CO_2 Supply (MMscfd)	1,800	*2,900*
Crude oil Prodn (Mbpd)	196	*315*
CO_2 Utilization Eff (scf/bbl)	9,200	*9,200*

Rockies CO2 EOR: CO2 sales, Crude oil Production, and CO2 net utilization



Rocky Mountain

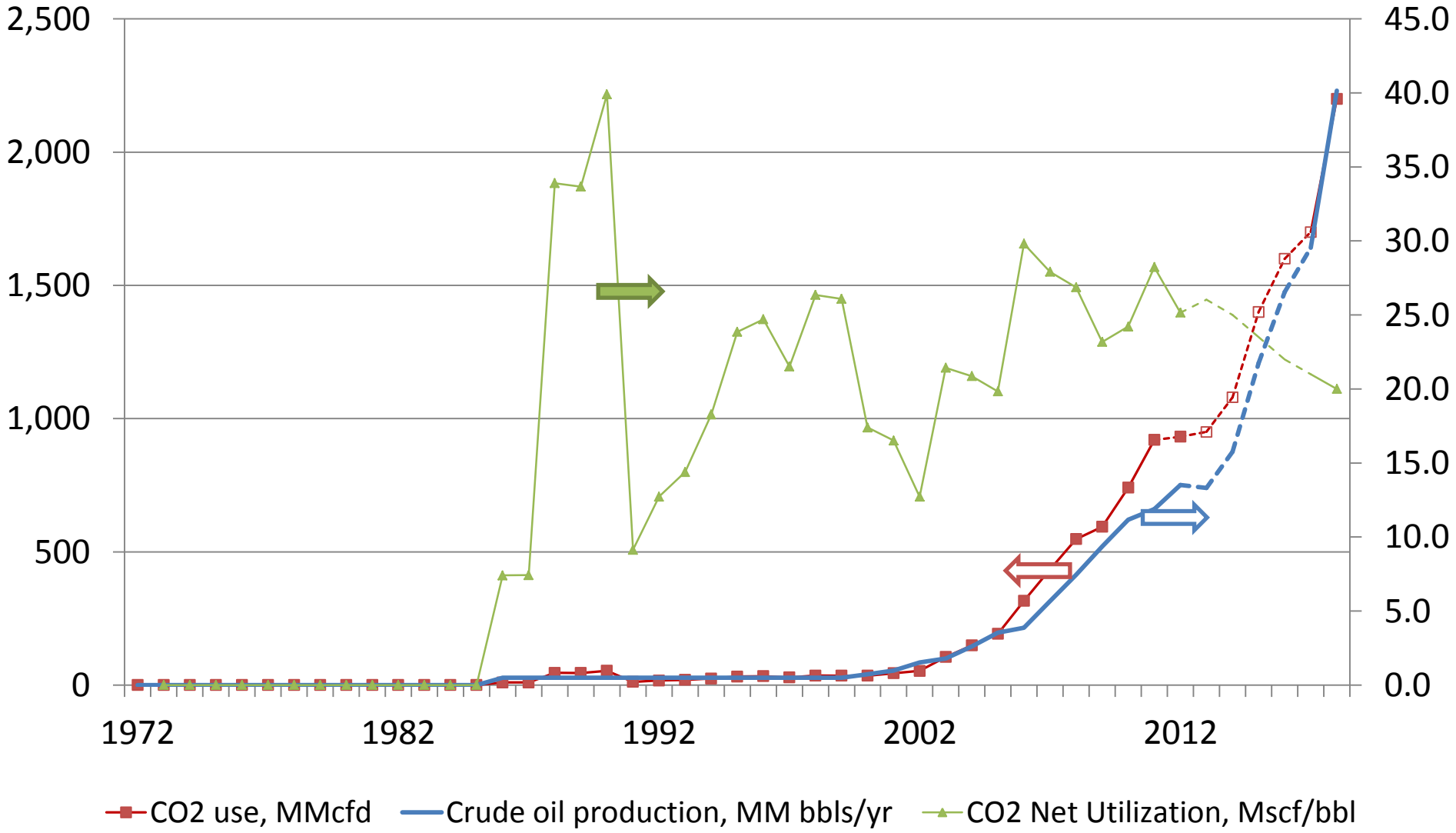


Incremental Supplies (2013 – 2018)

- LaBarge (130)
- Lost Cabin (30)
- CES (50)
- Linc/carbon energy (100)

	2013	*2018*
CO2 Supply (MMscfd)	390	*700*
Crude oil Prodn (Mbpd)	44	*80*
CO2 Utilization Eff (scf/bbl)	8,800	*8,800*

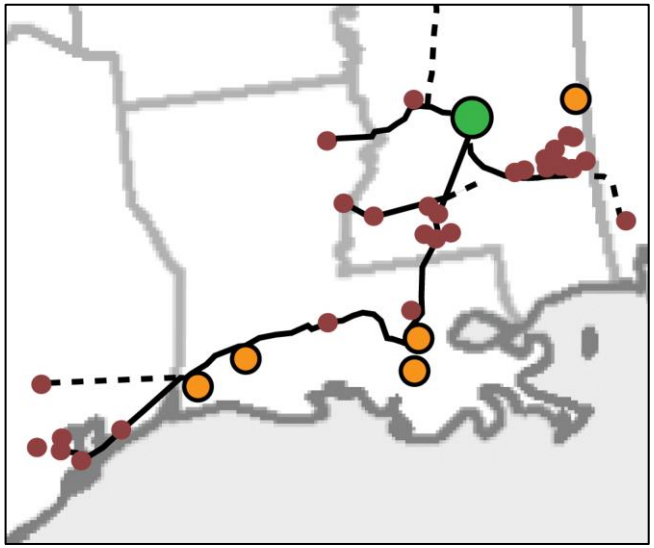
Mississippi / Gulf Coast CO2 EOR: CO2 sales, Crude oil Production, and CO2 net utilization



Gulf Coast

	2013	*2018*
CO_2 Supply (MMscfd)	950*	*2,200*
Crude oil Prodn (Mbpd)	36.5	*110*
CO_2 Utilization Eff (scf/bbl)	26,000	*20,000*

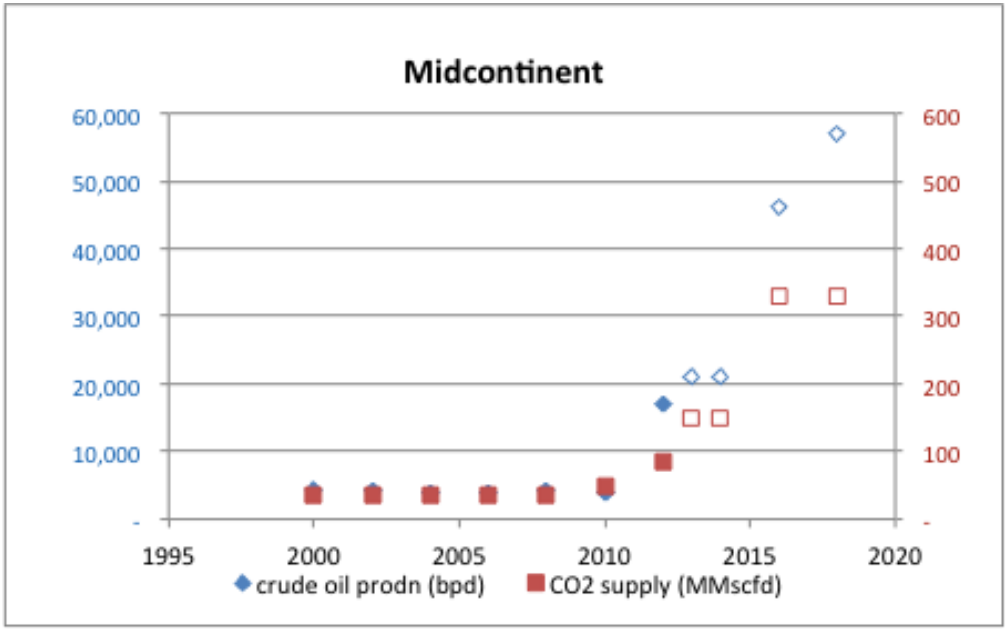
*supply for EOR only



Incremental Supplies (2013 – 2018)

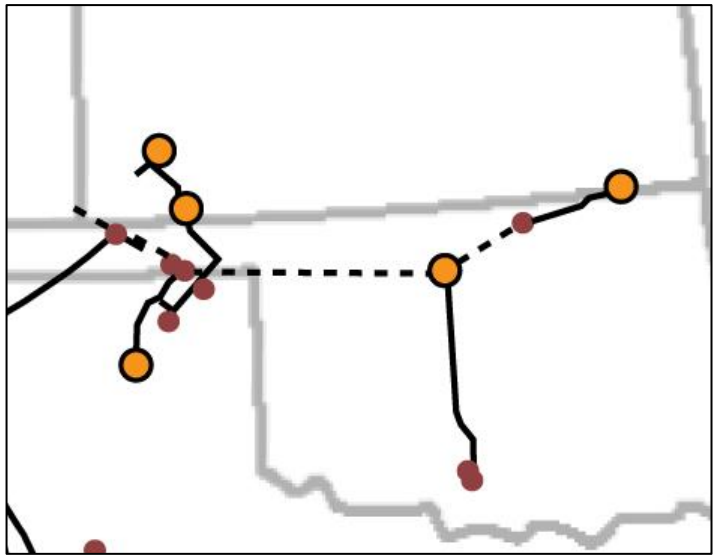
- Jackson Dome (120)
- Mississippi Power (140)
- Lake Charles (200)
- Ammonia (85)
- NRG (85)
- Air Products (40)
- PCS Nitrogen (20)
- Leucadia (200)
- Other (355)

Mid Continent



Incremental Supplies (2013 – 2018)

- Chaparral Burbank (100)
- Bravo Dome (35)
- Coffeyville (30)
- Enid, Borger, Garden City (15)

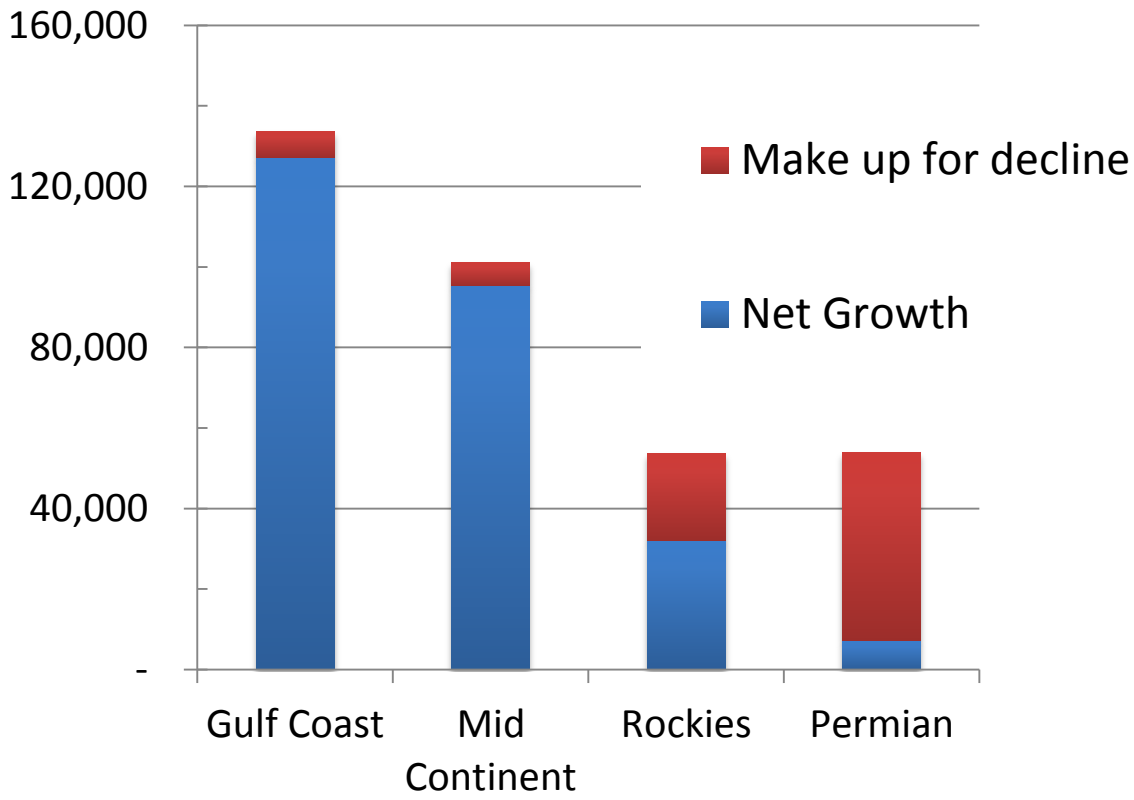


	2013	*2018*
CO_2 Supply (MMscfd)	150	*330*
Crude oil Prodn (Mbpd)	21	*47*
CO_2 Utilization Eff (scf/bbl)	7,100	*7,100*

Near Term CO_2 EOR Forecast

	CO_2 Supply		Crude Oil		CO_2 UR net	
	2013	2018	2013	2018	2013	2018
Permian	1,800	2,900	196	315	9,200	9,200
Rockies	390	700	45	80	8,800	8,800
Gulf Coast	950	2,200	36	110	26,000	20,000
Mid Continent	150	330	21	47	7,100	7,100
Canada	153	275	20	37	7,500	7,500
California		25		??		
Total	**3,443**	**6,430**	**318**	**590**	**10,800**	**10,900**

Growth in CO_2 EOR by Region, bpd



Source: draft report prepared by Advanced Resources International for NETL

The U.S. DOE Energy Information Administration's Forecast for CO_2 EOR

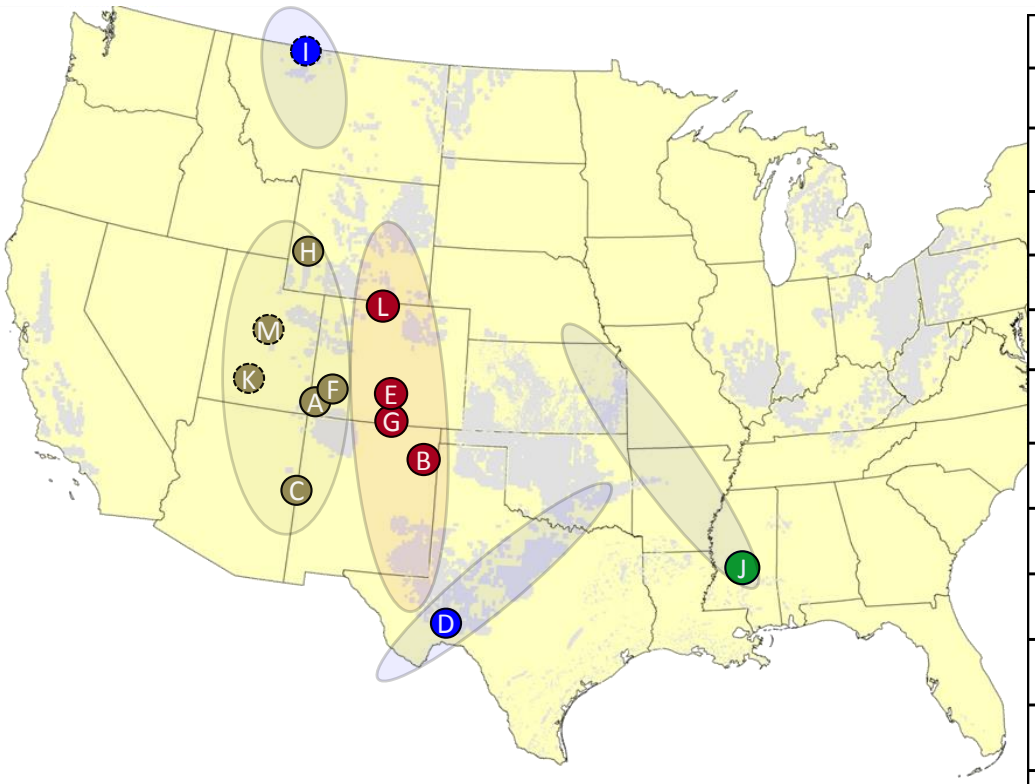
	2012	2016	2018	2030	2040
CO2 EOR (MMbpd)	0.24	0.22	0.26	0.56	0.66
Tight oil (MMbpd)	1.2	2.6	2.8	2.2	2.0
WTI price ($/bbl)	93	91	99	129	161
This analysis	0.28		0.59		
Source: Annual Energy Outlook 2013, Reference Case					

Natural Source Catalogue

Catalogue of Subsurface CO_2 Accumulations

- Work performed by Tom Heidrick, Jeff Eppink and Michael Marquis of Enegis LLC
- Assess the tectonics and genesis of subsurface CO_2 systems
- Compile data and develop volumetric estimates of CO_2 initially-in-place
- Derive estimates of TRR and ERR

Subsurface Sources CO_2 in the Contiguous United States



A. McElmo
B. Bravo
C. St. John
D. Val Verde
E. Sheep
F. Doe Canyon
G. Oakdale
H. Big Piney LaBarge
I. Kevin
J. Jackson
K. Escalante
L. McCallum
M. Gordon Creek

Discovered, producing

Discovered, not producing

Cretaceous

Laramide

Mid Tertiary

Late Tertiary

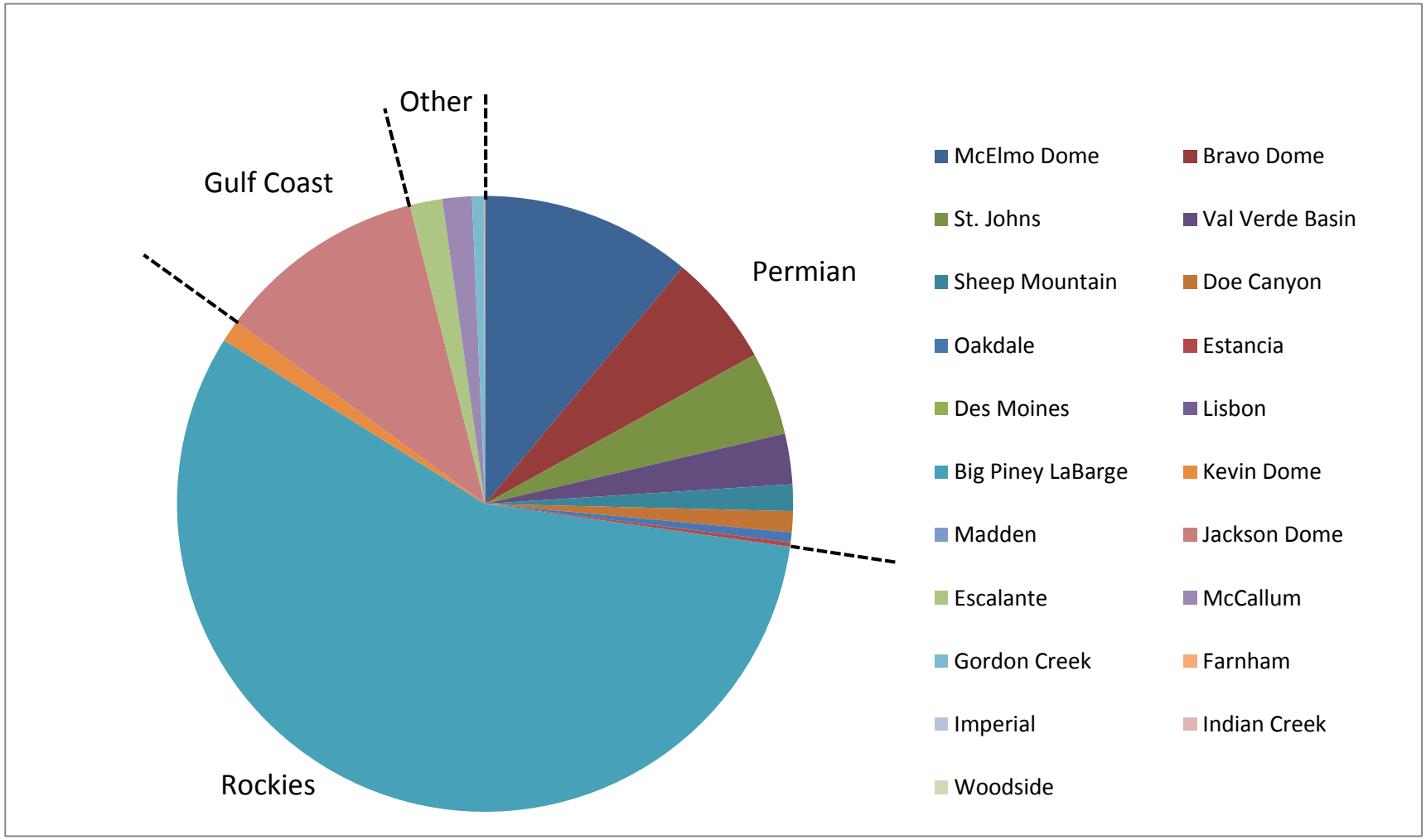
Field Name	State	Status	Depth	Area	Pay	Por	GIIP	Rec	Access	TRR	volume %					Cumm	ERR
			k ft	k acres	ft	%	10^6 mt	%	%	10^6 mt	CO_2	CH_4	N_2	He	H_2S	10^6 mt	10^6 mt
Permian Basin CO_2-EOR System																	
McElmo Dome	CO, UT	P	8.0	202	95	12	30,095	70	60	12,640	98	0	2	0.07	-	382	569
Bravo Dome	NM	P	2.3	1,000	40	20	24,584	65	90	14,381	97	-	-	0.02	-	154	303
St. Johns	NM, AZ	D	1.5	220	75	15	8,917	70	80	4,994	93	-	4	0.06	-	5	225
Val Verde Basin	TX	P	11.5	14	650	4	9,529	70	95	6,337	42	58	-	0.01	-	106	136
Sheep Mountain	CO	P	5.0	12	145	20	3,066	65	80	1,595	97	1	2	0.03	-	69	72
Doe Canyon	CO	P	9.0	82	60	10	5,095	70	75	2,675	95	-	-	-	-	5	56
Oakdale	CO	D	6.0	3	250	19	1,153	65	80	600	72	28	-	0.03	-	1	27
Estancia	NM	I	1.5	48	65	14	989	60	95	564	98	2	-	0.02	-	1	12
Des Moines	NM	I	2.3	58	50	20	1,003	65	90	587	99	-	-	0.02	-	1	-
Lisbon	UT	D	9.6	3	75	12	238	70	85	141	90	-	-	-	-	-	-
														Subtotal			1,400
Rocky Mountain CO_2-EOR System																	
Big Piney LaBarge	MY	P	16 - 18	79	275	9	173,021	70	74	90,213	74-85	9-15	3-6	0.5	2.4-4.2	159	2,914
Kevin Dome	MT	P	3.6	261	67	9	13,824	75	95	9,850	88	-	12	-	-	-	59.5
Madden	WY	P	23.7	80	175	15	3,828	70	95	2,545	20	67	-	-	12	4	-
														Subtotal			2,974
Mississippi Gulf CO_2-EOR System																	
Jackson Dome	MS	P	15.5	90	185	13	24,245	70	95	16,123	90	5	-	0.00	5	95	566
Not within a major CO_2-EOR System																	
Escalante	UT	D	2.3	37	172	7	10,082	55	45	2,495	95	-	4	0.01	-	-	87.6
McCallum	CO	P	5.5	15	100	20	2,797	70	90	1,762	92	-	-	0.11	-	46	79.4
Gordon Creek	UT	D	12.6	8	135	9	1,720	65	90	1,006	99	0	0	-	-		32.1
Farnham	UT	I	4.0	4	40	12	202	70	45	64	99	-	1	-	-	-	2.2
Imperial	CA	I	0.6	2	230	12	158	65	80	82	95	-	-	-	-	-	0.6
Indian Creek	WV	P	6.7	18	10	10	85	70	95	57	66	30	4	0.15	-	1	-
Woodside	UT	D	3.5	13	45	9	111	60	90	60	32	-	62	-	-	-	-
														Subtotal			202
Region Coding: Colorado Plateau, Rocky Mountains, Permian Basin, Other															Total		5,142

Notes: GIIP=Gas Initially in Place, TRR=Technically Rec. Resources, ERR= Economically Rec. Resources, CO2 =Carbon Dioxide. Tcf=Trillion cubic feet. Bcf=Billion cubic feet. ERR is inclusive of estimated cumulative production through 2012. ERR based on CO2 price of $20 per tonne at the field gate at pipeline pressure and purity.

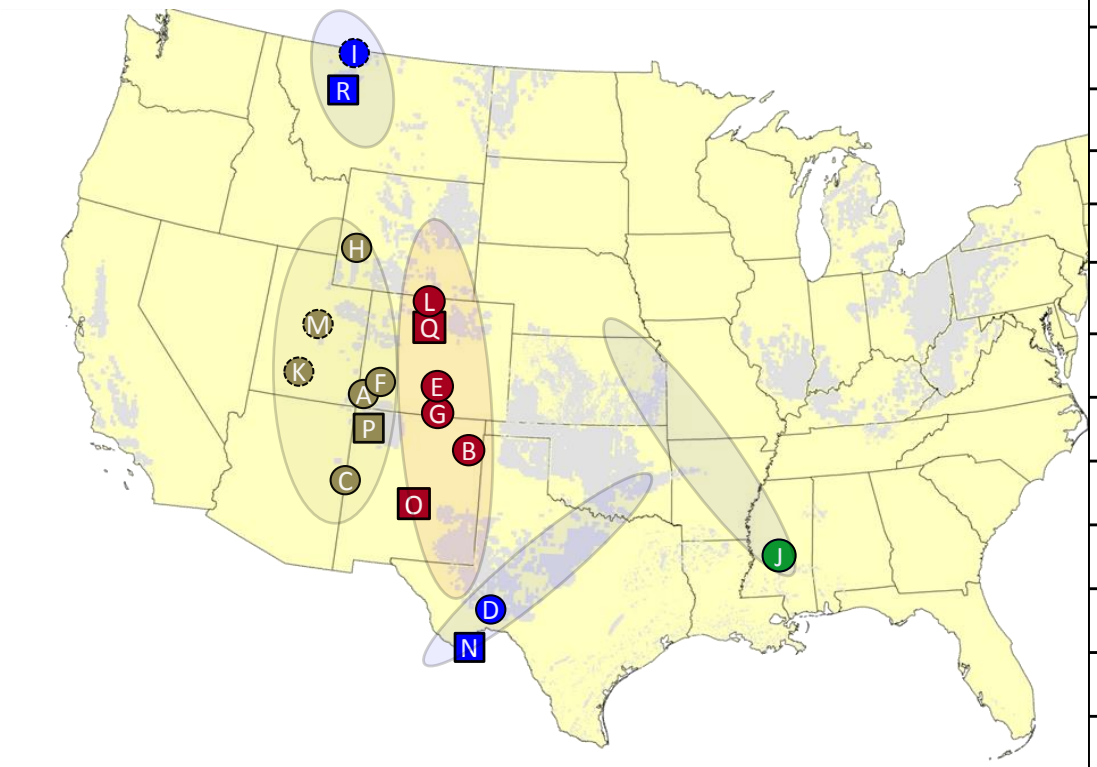
Conversion factor = 53 million tonnes CO_2 per Tcf

Discovered Subsurface Sources of CO_2 in the Contiguous United States

Economically Recoverable Resource (Total 5,100 $BmtCO_2$)



Un-discovered Subsurface Sources of CO_2

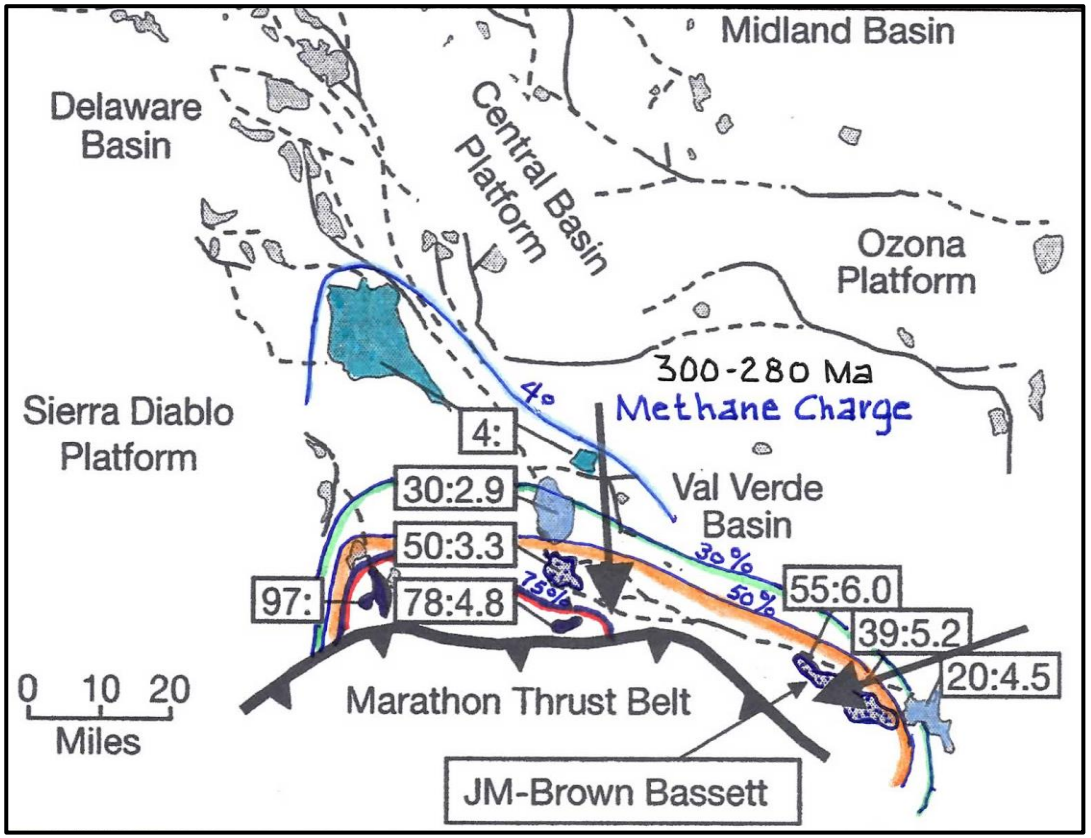


A. McElmo
B. Bravo
C. St. John
D. Val Verde
E. Sheep
F. Doe Canyon
G. Oakdale
H. Big Piney LaBarge
I. Kevin
J. Jackson
K. Escalante
L. McCallum
M. Gordon Creek
N. Valverde thrust
O. Lincoln County
P. San Juan
Q. North Park
R. Sweetgrass

- ○ Discovered, producing
- ◌ Discovered, not producing
- □ Un-discovered leads

- Cretaceous
- Laramide
- Mid Tertiary
- Late Tertiary

Un-discovered Lead: Val Verde Thrust



Val Verde Lead	
Area (k acres)	150
Depth (k ft)	12 - 15
TRR (Tcf, risked)	11

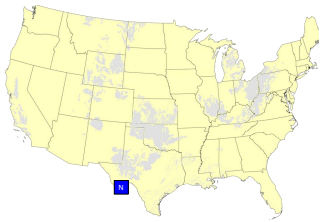
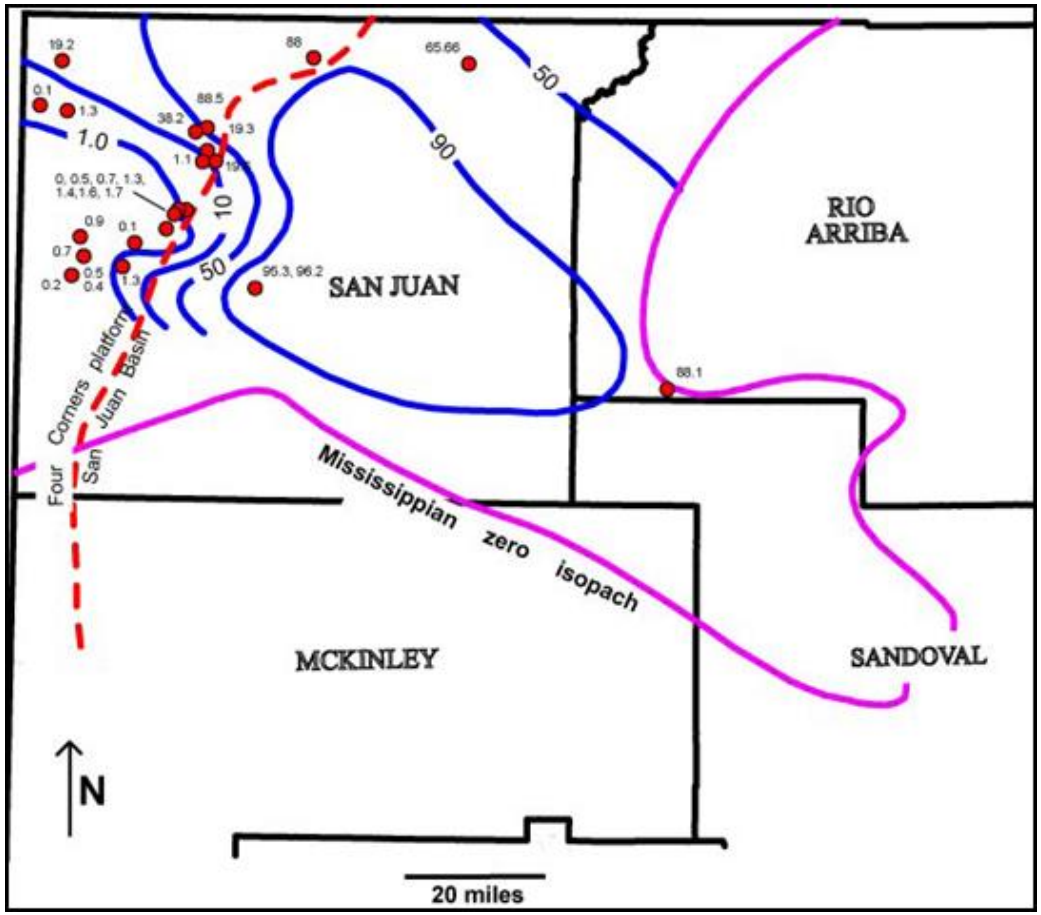


Figure 3.1.3-20. Map of the Val Verde subbasin specifies the direction of increase in $CO_2/^3He$ Ratios toward the Marathon fold-thrust belt (black arrows). CO_2 gas emplacement precedes CH_4 generation according to Ballentine et al., 2001. Contours (4, 30, 50 of 75 percent) added by Enegis, LLC).

Un-discovered Lead: San Juan Basin



San Juan Lead	
Area (k acres)	1,000
Depth (k ft)	13.5
TRR (Tcf, risked)	22

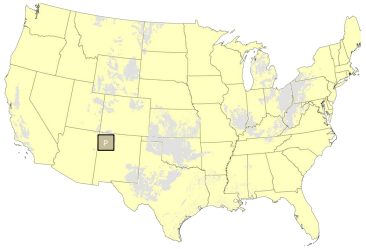


Figure 3.3.1-11. Map of CO_2 content in gases from Mississippian reservoirs in the San Juan basin, New Mexico shows the progressive basinward increase in contained CO_2 and He gases (0.1→95.3% CO_2). Figure adapted from Broadhead et al., 2009 (used with permission).

Questions?

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