16th Annual Ryder Scott Reserves Conference

Panel Discussion

“CO2 Capture and Management - Why Should A Reserves Evaluator Care?"

RON HARRELL

SEPTEMBER 2020

OUR WELCOMED PANELISTS

Money:		Logan Burt Managing Director Morgan Stanley – Investment Management
Operator:		John Hessenbruch Geological Consultant Retired- Occidental Petroleum
Research:		Christine Ehlig-Economides Professor & Hugh Roy and Lilly Cullen Distinguished University Chair University of Houston – Petroleum Engineering Program
Moderator:		Ron Harrell Chairman Emeritus Ryder Scott Company

Ryder Scott Reserves Conference

"CO2 Capture and Management - Why Should A Reserves Evaluator Care?"

LOGAN BURT

SEPTEMBER 2020

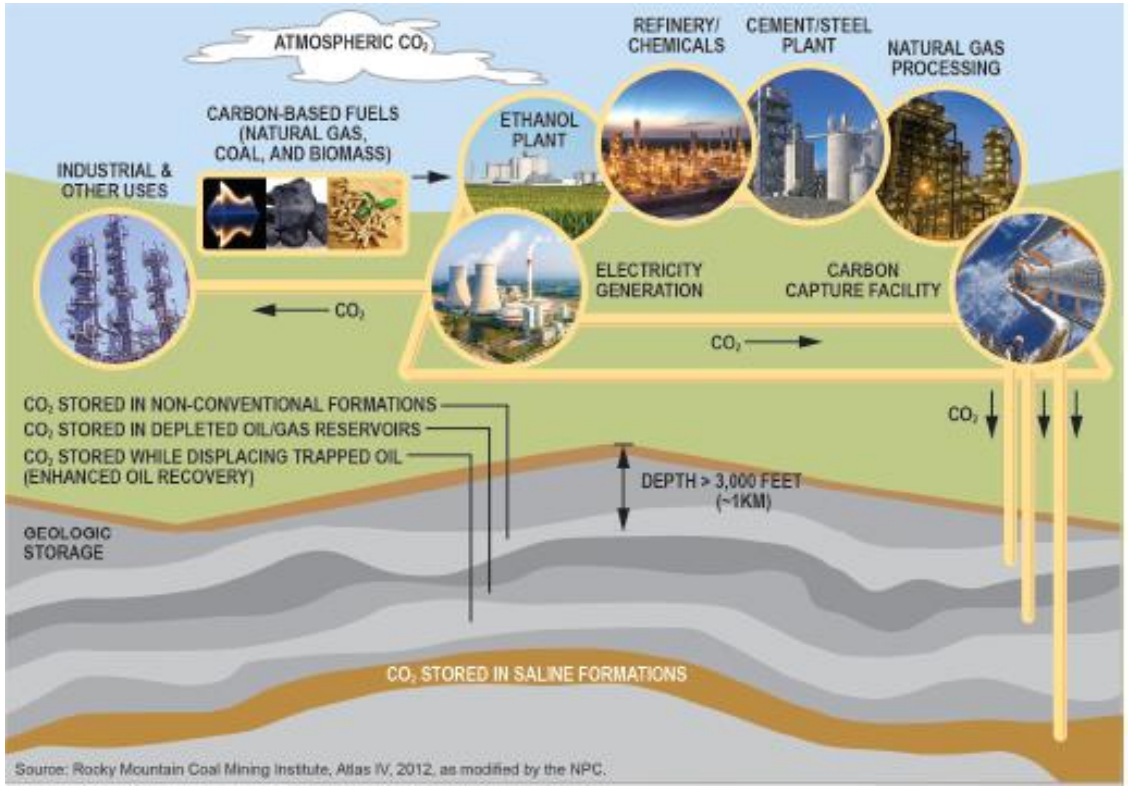
RYDER SCOTT

Numbers to *Count On*. Experts to *Trust*.

Introduction: CO2 Carbon Capture

Emerging Opportunities in Carbon Capture, Use and Storage

- Carbon capture technologies have been deployed for decades
  - Since the early 1970s, 20 large-scale carbon capture use and storage ("CCUS") projects have been constructed, with 24 additional projects in development[1]
  - 80% of existing projects use captured CO2 for enhanced oil recovery ("EOR")
- Over the next three decades, world GDP and energy consumption expected to grow 138% and 43%, respectively[2]
  - Driven by emerging economies (~3x higher GDP in 2050)[2]
  - "Dual challenge" of meeting rising energy needs at low cost and reducing GHG emissions
- CCUS considered a critical strategy for meeting global emission objectives
  - IPCC and IEA models assume extensive deployment of CCUS likely required to achieve de-carbonization goals
  - Over 46 countries (including the US) have adopted carbon pricing / financial incentives related to emissions/carbon capture[3]
- CCUS implementation has potential for significant new sources of captured CO2 (at scale) for beneficial use and/or storage
- Energy industry uniquely qualified to lead CCUS development due to relevant expertise, capability and resources



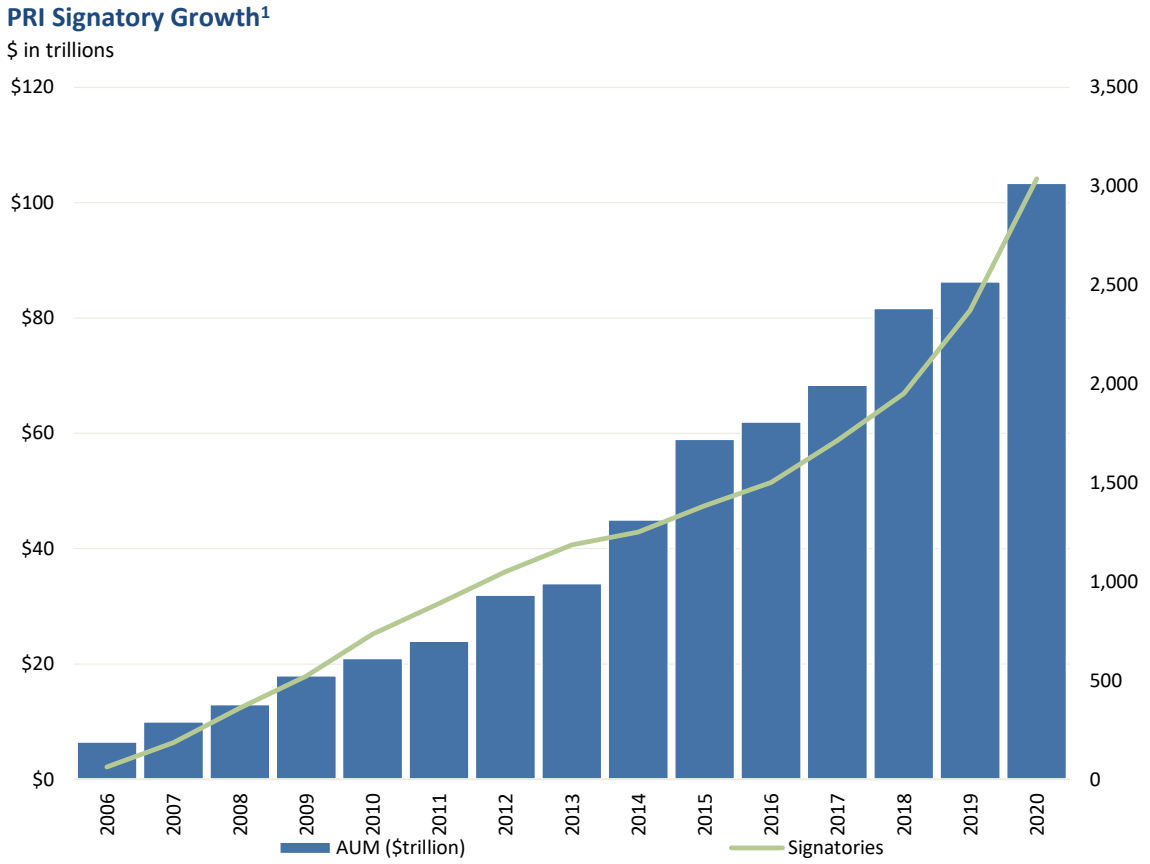
Carbon .Capture	Transport	Use	Storage
Industrial or direct air capture and separation (e.g. amine absorption) from power plants, gas processing, refineries and manufacturing	Typically pipelines at high pressure for dense phase CO2 delivery at use or storage points	Injection for enhanced oil recovery, building materials, cement, chemicals, fuel feedstock	Underground saline formations, depleted O&G reservoirs, coal seams

Notes:
1. Source: Global CCS Institute (2019 Global Status of CCS report).
2. Source: EIA International Energy Outlook 2019 (Reference Case). World GDP expressed in purchasing power parity.
3. Source: The World Bank (Carbon Pricing Dashboard). Accessed 14 Jul 2020.

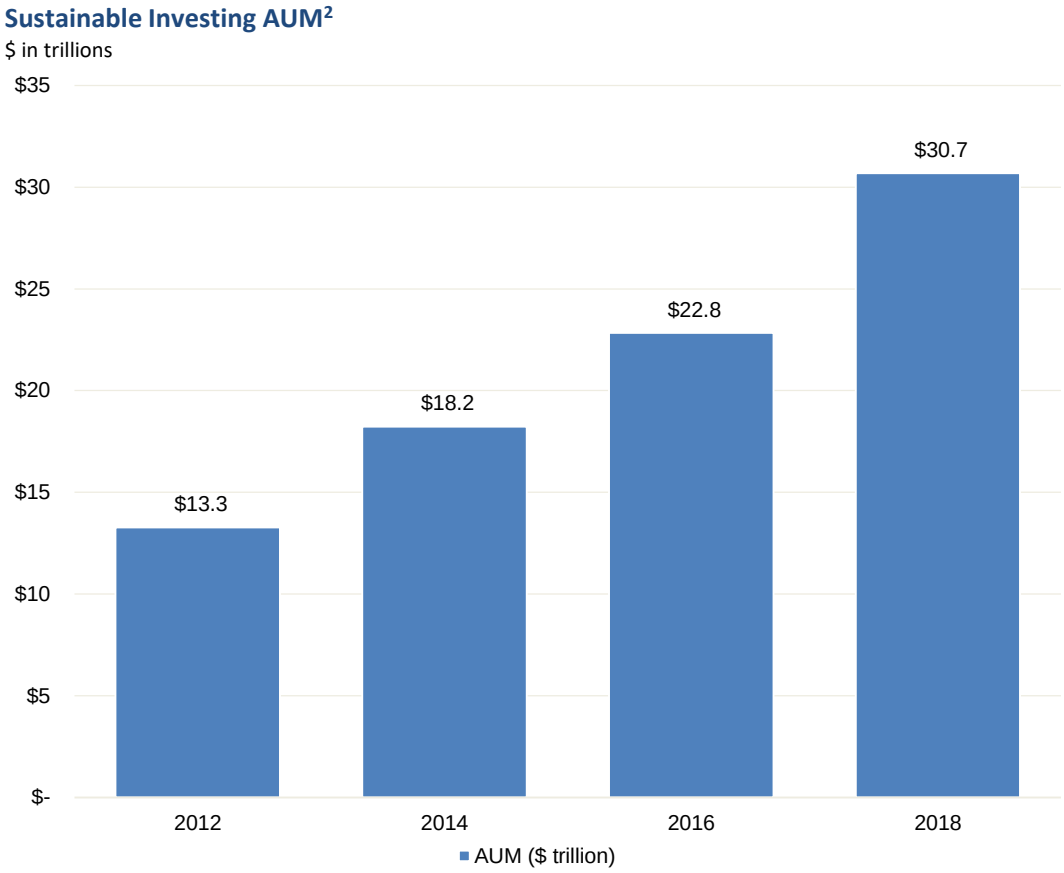
Capital Markets Perspective

Increasing Focus on Responsible and Sustainable Investments

PRI Signatory Growth[1]



Sustainable Investing AUM[2]



Notes:

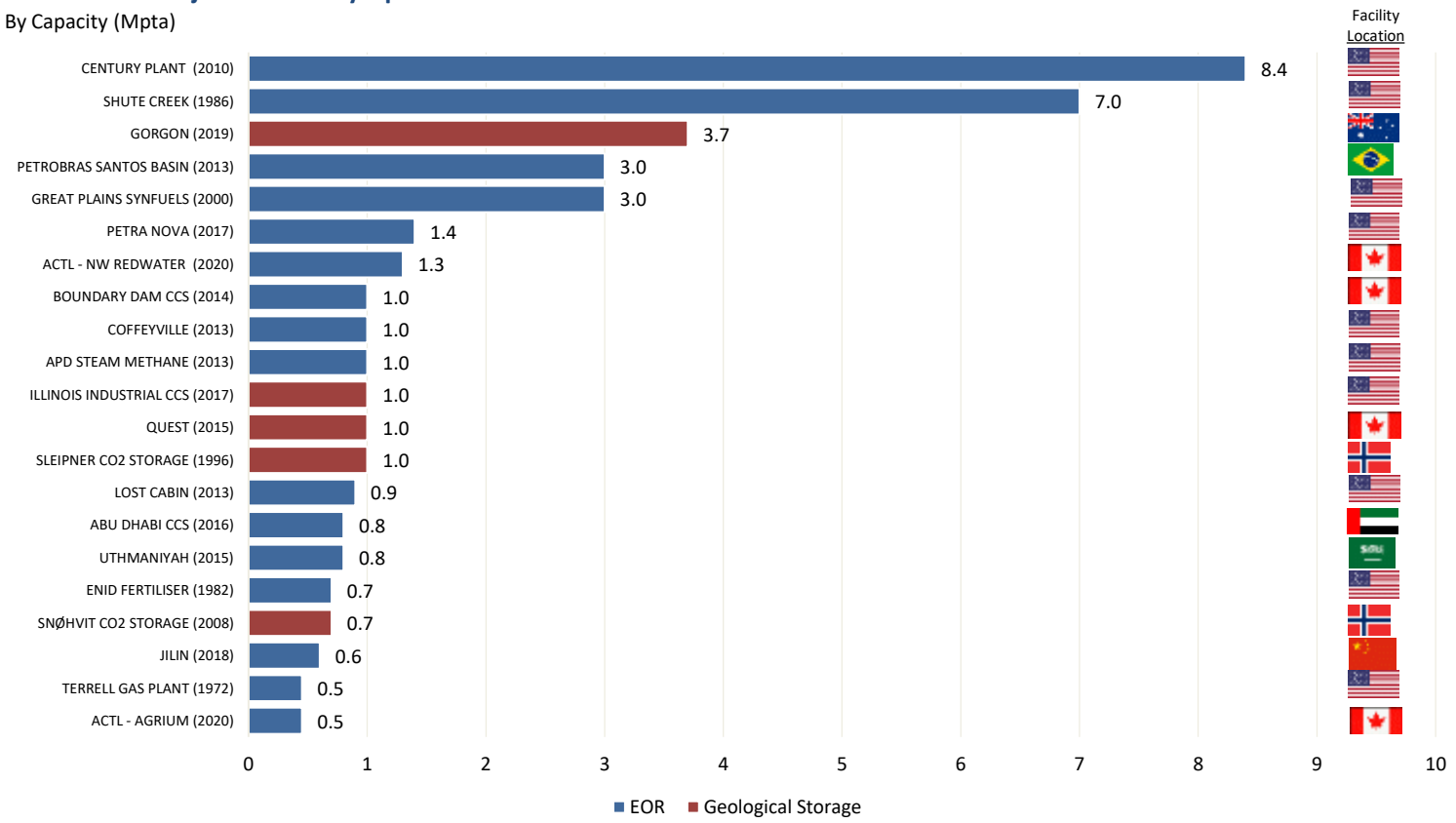
1. Source: Principals for Responsible Investment (www.unpri.org). Accessed 15 Jul 2020. Total Assets under management (AUM) include reported AUM and AUM of new signatories provided in sign-up sheet that signed up by end of March of that year.
2. Source: Global Sustainable Investment Alliance (GSAI). 2018 Global Sustainable Investment Review report.

Global CCUS Landscape

39 Mtpa of Total Capture Capacity Installed from 1970 – Current[1]

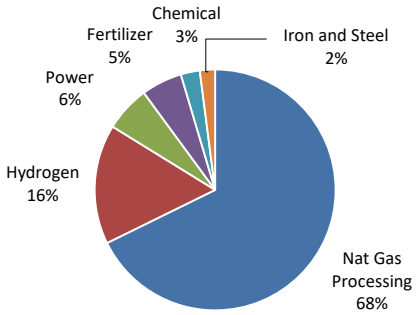
Global CCUS Projects Currently Operational[1]

By Capacity (Mpta)



Industry CO2 Source[1]

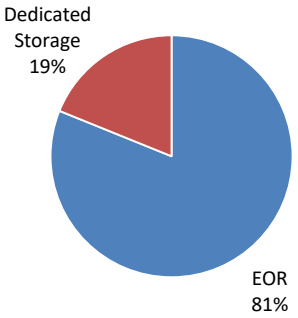
(Existing Projects - % aggregate capacity)



Source:

Carbon Capture Use[1]

(Existing Projects - % aggregate capacity)



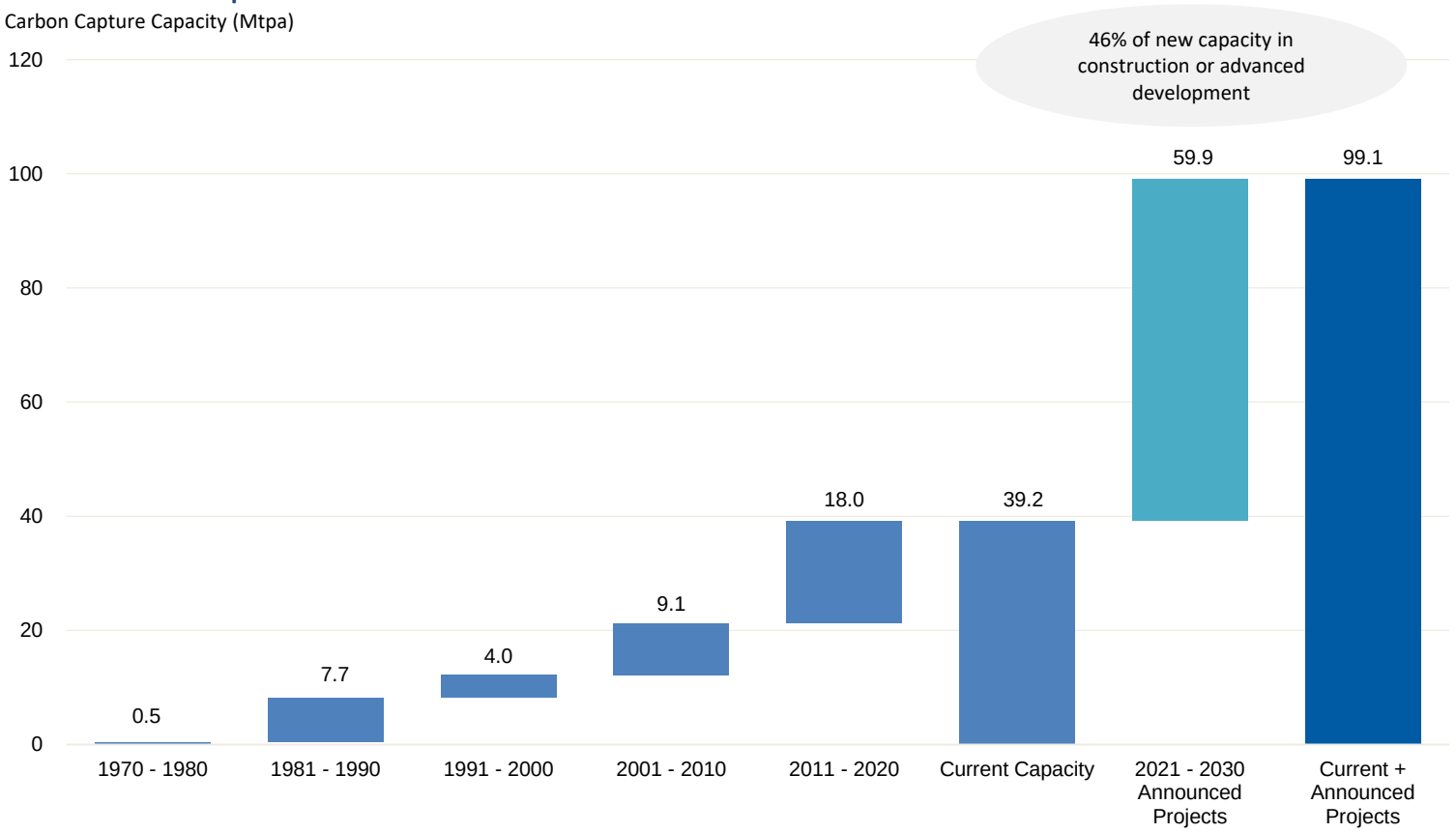
Notes:

1. Source: Global CCS Institute (2019 Global Status of CCS report). Represents large scale CCS facilities in operation (not all inclusive).

Global CCUS Development Pipeline

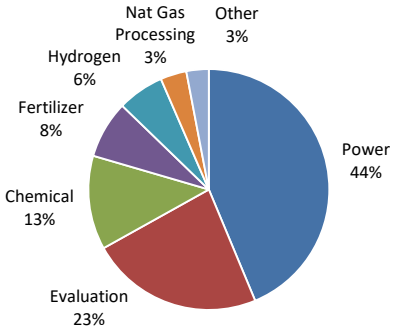
30 New Projects in Development with Total Capture Capacity of 60 Mtpa[1]

Global CCUS Development Outlook[1]



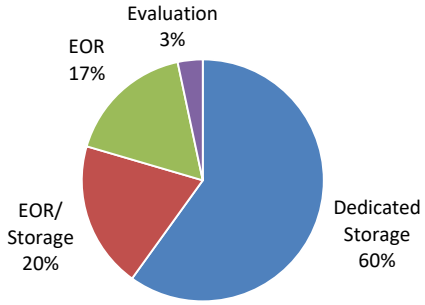
Industry CO2 Source[1]

(Announced Projects - % aggregate new capacity)



Carbon Capture Use[1]

(Announced Projects - % aggregate new capacity)



Notes:

1. Source: Global CCS Institute (2019 Global Status of CCS report). Represents announced large scale CCS facilities in construction, development or evaluation (not all inclusive).

ALL FORECASTS ARE SUBJECT TO CHANGE AT ANY TIME AND MAY NOT COME TO PASS DUE TO CHANGES IN MARKET OR ECONOMIC CONDITIONS.

Section 45Q Tax Credit

US Has Recently Enhanced Tax Credits for Carbon Capture Projects

- Section 45Q of the IRS provides performance-based tax credit to incentivize carbon capture deployment in multiple industries
  - Broad bipartisan support to expand and reform 45Q as part of Bipartisan Budget Act of 2018
  - Qualified carbon oxide captured using equipment placed into service between 2/9/2018 – 1/1/2024
  - Projects include secure geologic storage (e.g. oil fields or saline formations), EOR and other beneficial uses (e.g. fuel feedstock, concrete, chemicals) which demonstrate emission reductions
  - Capture equipment owner is credit recipient, but transferable to party that puts CO2 in storage or beneficial use
  - Credits available for 12 years from date equipment placed in service

Section 45Q Tax Credit for Different Sources and Uses of CO2[1]

TYPE OF CO2 STORAGE/ USE	MINIMUM SIZE OF ELIGIBLE CARBON CAPTURE PLANT BY TYPE (KILOTONNES OF CO2/YR)			RELEVANT LEVEL OF TAX CREDIT IN A GIVEN OPERATIONAL YEAR ($/TCO2)									
	POWER PLANT	OTHER INDUSTRIAL FACILITY	DIRECT AIR CAPTURE	2018	2019	2020	2021	2022	2023	2024	2025	2026	BEYOND 2026
DEDICATED GEOLOGICAL STORAGE	500	100	100	$28	$31	$34	$36	$39	$42	$45	$47	$50	INDEXED TO INFLATION
STORAGE VIA EOR	500	100	100	$17	$19	$22	$24	$26	$28	$31	$33	$35	
OTHER UTILIZATION PROCESSES[2]	25	25	25	$17[2]	$19	$22	$24	$26	$28	$31	$33	$35	

Notes:

1. Source: Energy Futures Initiative, 2018. Closely adapted from Simon Bennett and Tristan Stanley: US budget bill may help carbon capture get back on track, International Energy Agency.
2. Each CO2 source cannot be greater than 500 kilotonnes of CO2 (KTCO2) per year. Any credit will only apply to the portion of the converted CO2 that can be shown to reduce overall emissions.

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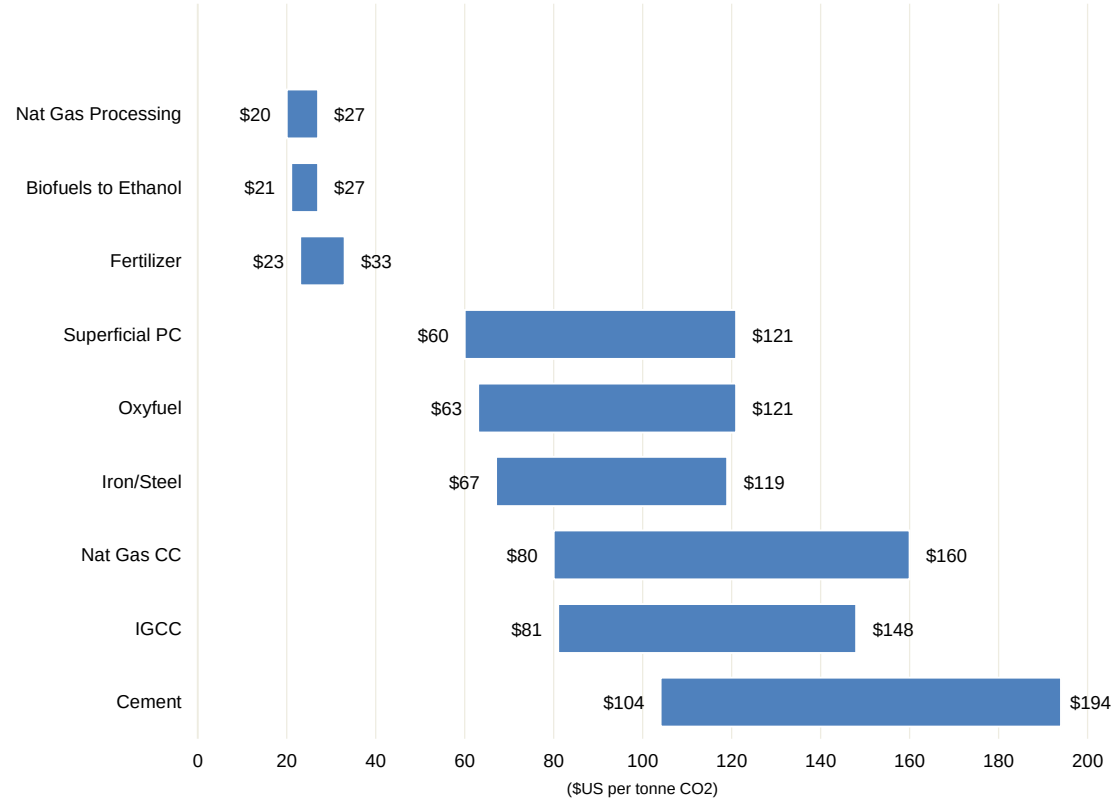
Carbon Capture Costs and Incentives

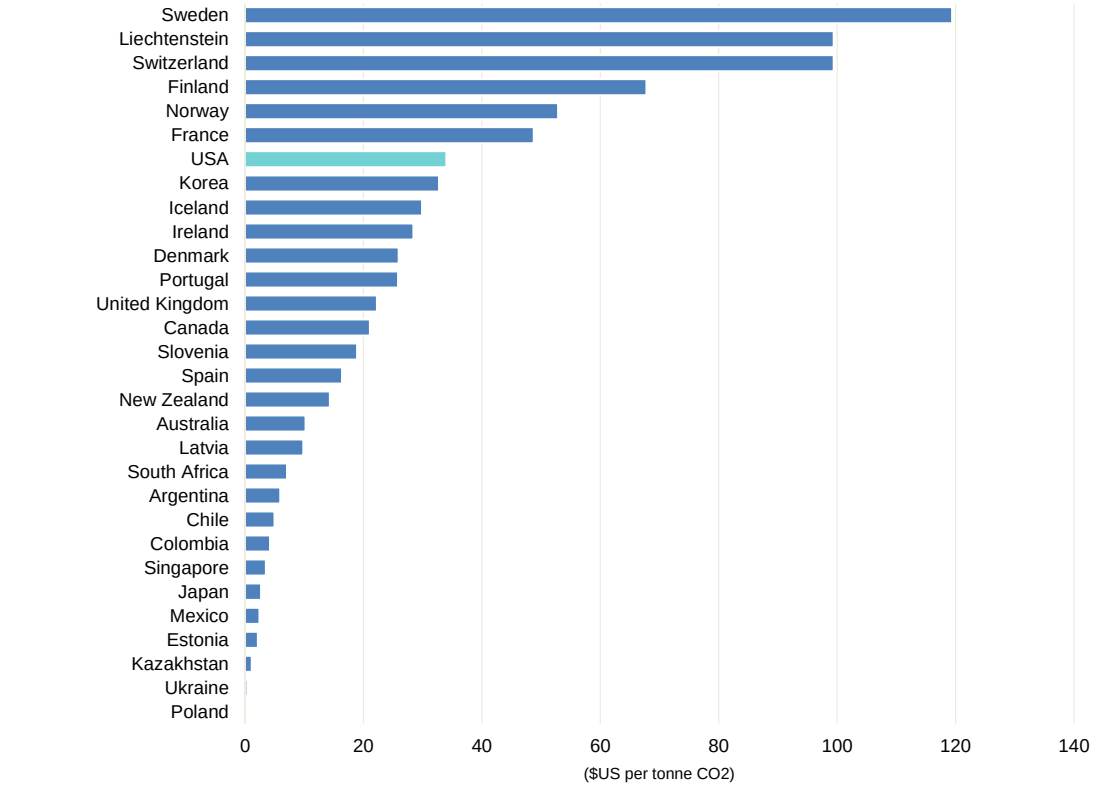
Global CCUS Incentives are Growing in Scope and Value

CCS Costs by Industry[1]



Source: Global CCS Institute, The Global Status of CCS: 2017

Carbon Price/Credits by Country (2019)



Source: The World Bank (Carbon Pricing Dashboard). Accessed 14 Jul 2020. Morgan Stanley research

Notes:

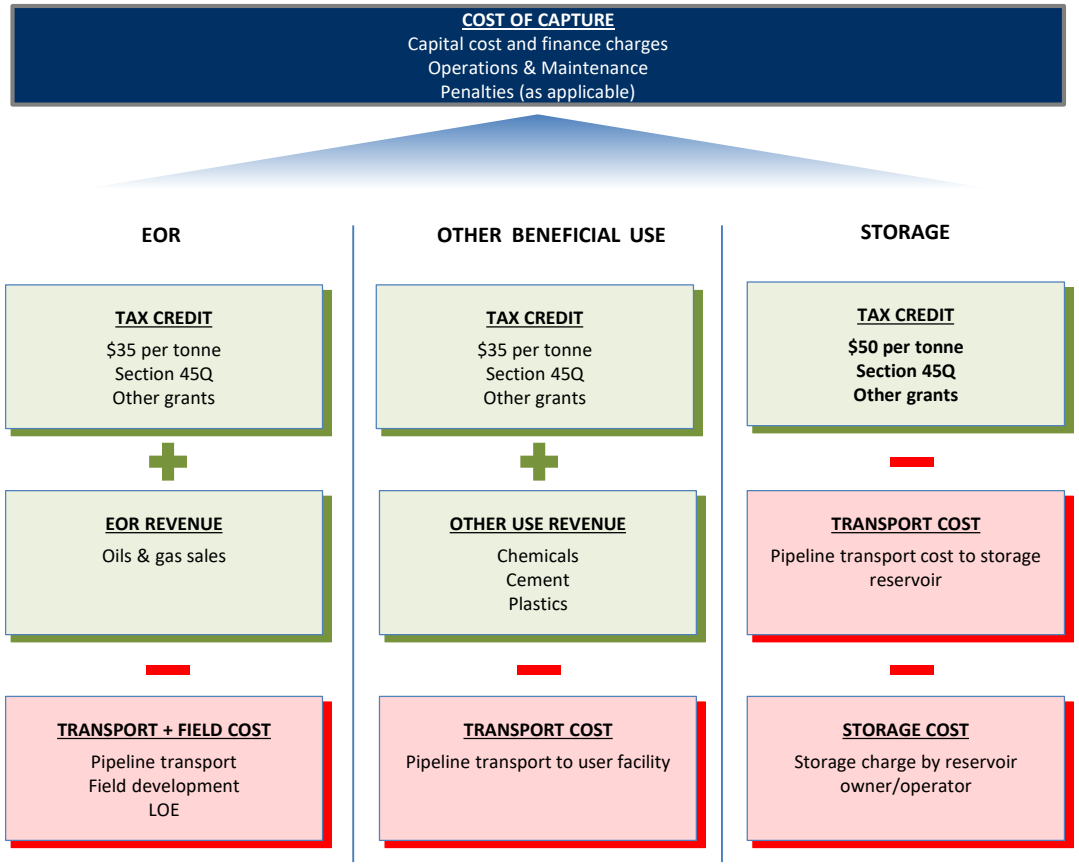
1. For illustrative purposes only. Represents estimated "first of a kind" CCS costs in different industries. The costs of implementing CCS technologies can vary considerably across different plant types, technology mix, and geographies in the power and industrial sectors. These costs are for new-build systems and retrofits with current technology, and include capture, compression, transportation, and storage costs. They do not include revenues from EOR or utilization.

Carbon Capture Opportunities

Project Economic Considerations

- **Large Scale**
  - Large volume emission stream, ideally with multiple emitter source options (hub and spoke)
- **Stable Emission Streams**
  - Long-life assets with predictable and consistent supply sources
- **Desirable Emission Quality**
  - High purity CO2 with low level of sulfur/particulates
- **Beneficial Use Case**
  - CO2 EOR or other beneficial use such as fuel feedstock, chemicals, concrete, plastics
  - Brownfield development required for most EOR
  - Opportunities for continued area use expansion
  - Vertical integration
- **Proximate to Use/Storage Location**
  - Close proximity between emitter(s) and use/storage site minimizes midstream costs
  - Tie-in to existing infrastructure networks
  - Areas with large "natural sinks" for storage (e.g. Gulf Coast)
- **Favorable Regulatory / Tax Environment**
  - Geographies with favorable, long-term carbon incentives (i.e. credits/grants) and/or penalties (i.e. tax)

High Level Framework[1]



Notes:
1. Adapted from NPC Study Meeting the Dual Challenge: A Roadmap to At-Scale Development of Carbon Capture, Use and Storage (Topic Paper #1). December 12, 2019.

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JOHN HESSENBRUCH

SEPTEMBER 2020

RYDER SCOTT

Numbers to *Count On*. Experts to *Trust*.

OIL AND GAS CLIMATE INITIATIVE

Climate Investment Fund Launched in 2014

- Goal: Reduce manmade greenhouse gas emissions from production and use of oil and gas in power, heating, industry and transport.
- Recognizes and supports Paris Agreement.

Energy Members: 13 firms (Each will contribute $100 mil)

- BP
- Chevron
- CNPC
- Eni
- Equinor
- ExxonMobil
- Occidental
- Pemex
- Petrobras
- Repsol
- Saudi Aramco
- Shell
- Total

Supports development and deployment of low-emissions technology & business models.

Collective Reduction Targets

- Reduce upstream methane intensity to below 0.25% by 2025
- Achieve zero routine flaring by 2020
- Promote carbon sequestration implementations
- Provide innovative energy solutions

OIL AND GAS CLIMATE INITIATIVE

IEA RECOMMENDATIONS TO ACHIEVE DE-CARBONIZATION BY 2040

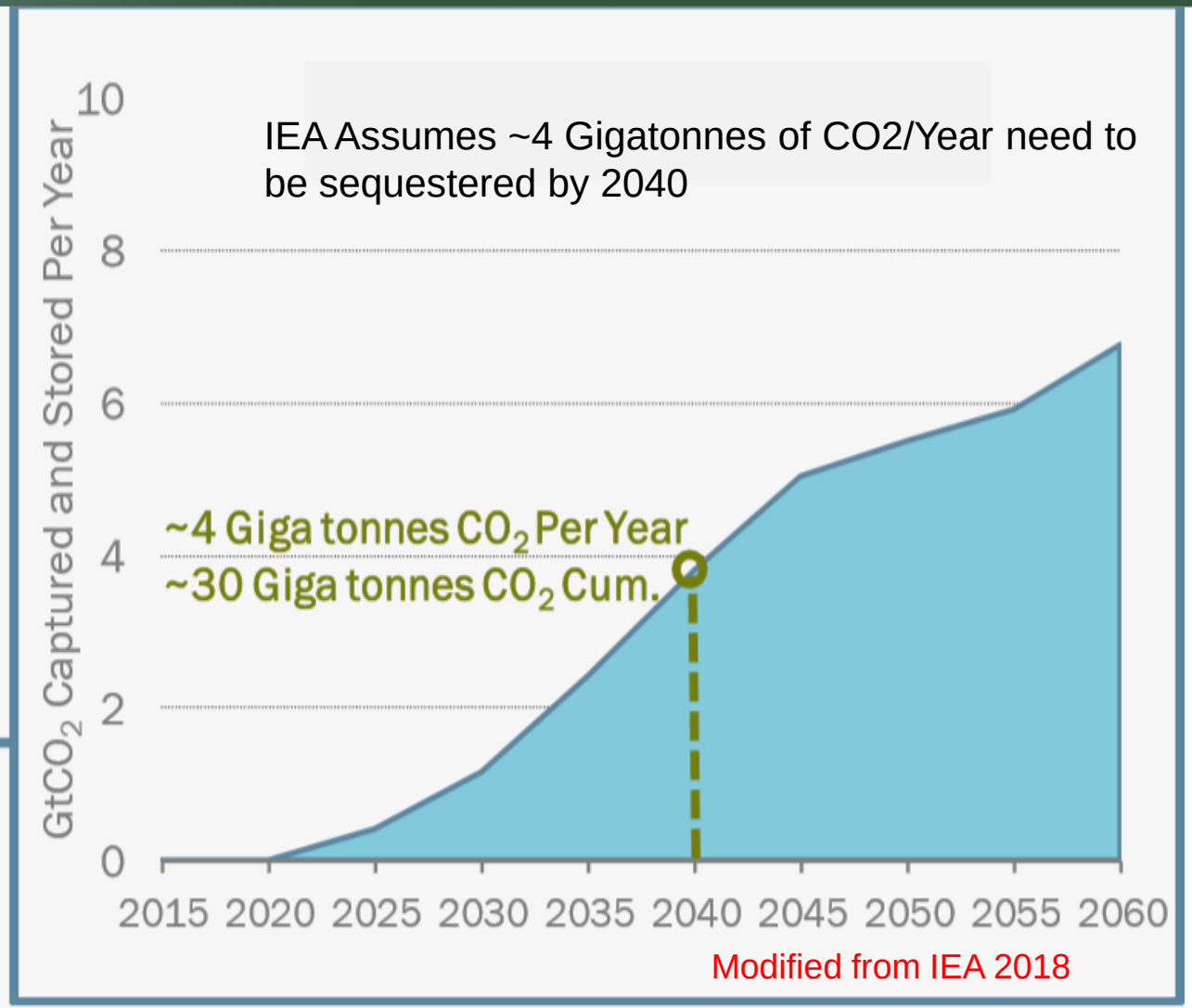
EV Deployment
40% passenger cars worldwide

Renewables
20% electric generation

Nuclear
Capacity doubles

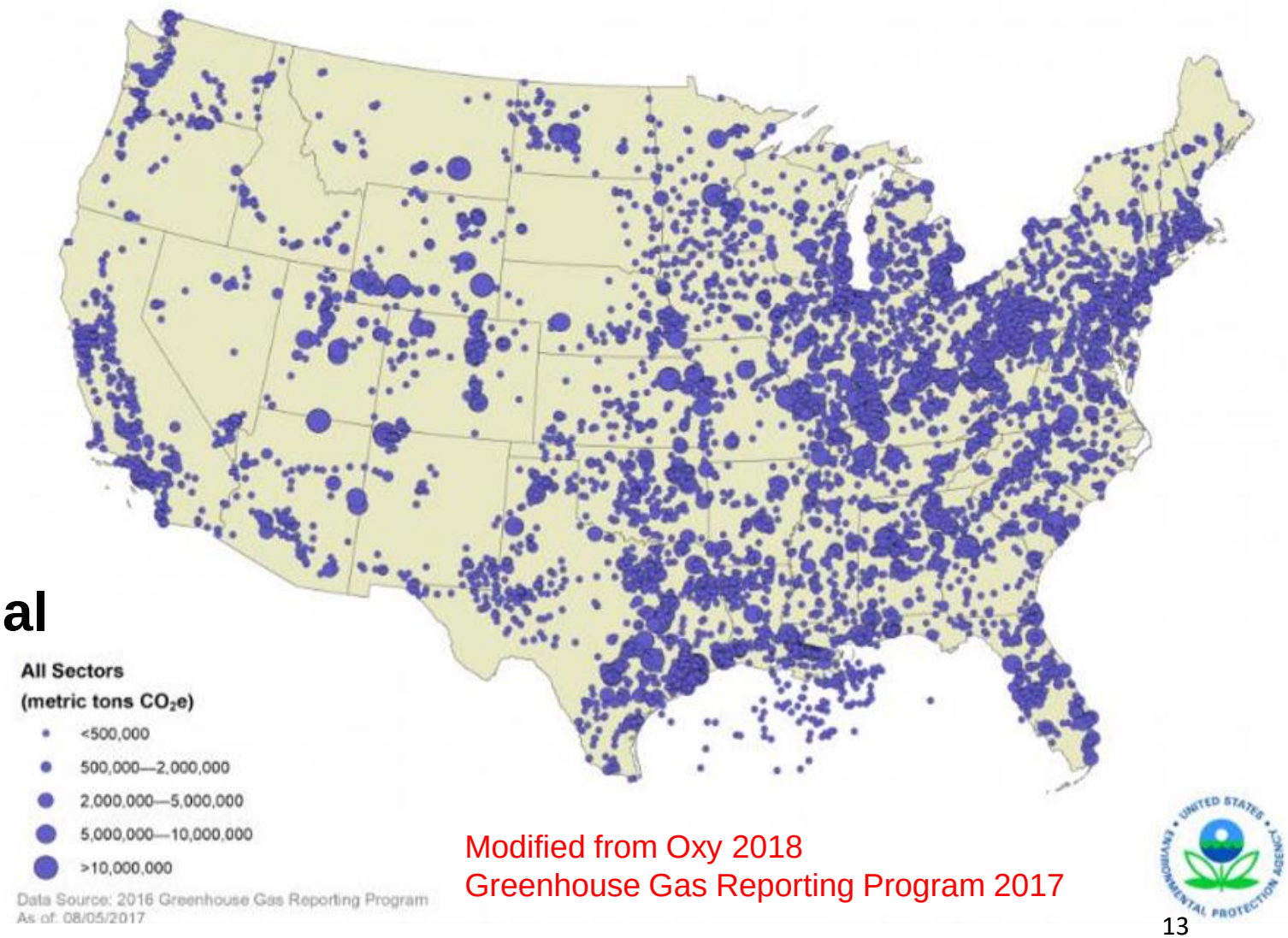
Biofuels
17% of world transport demand

Carbon Capture & Sequestration
80% of coal-fired generation capacity equipped



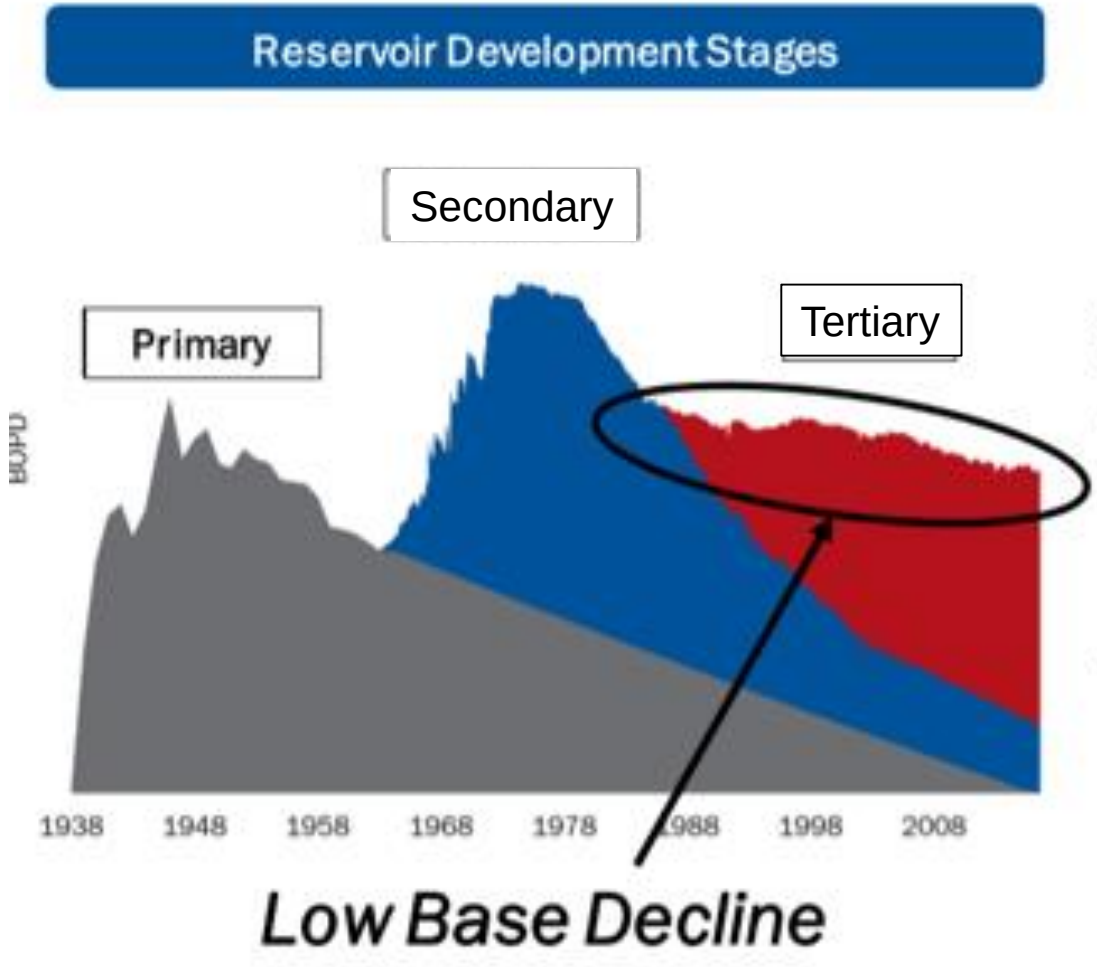
CURRENTLY EMITTING SOURCES FOR POTENTIAL CO2 SEQUESTRATION

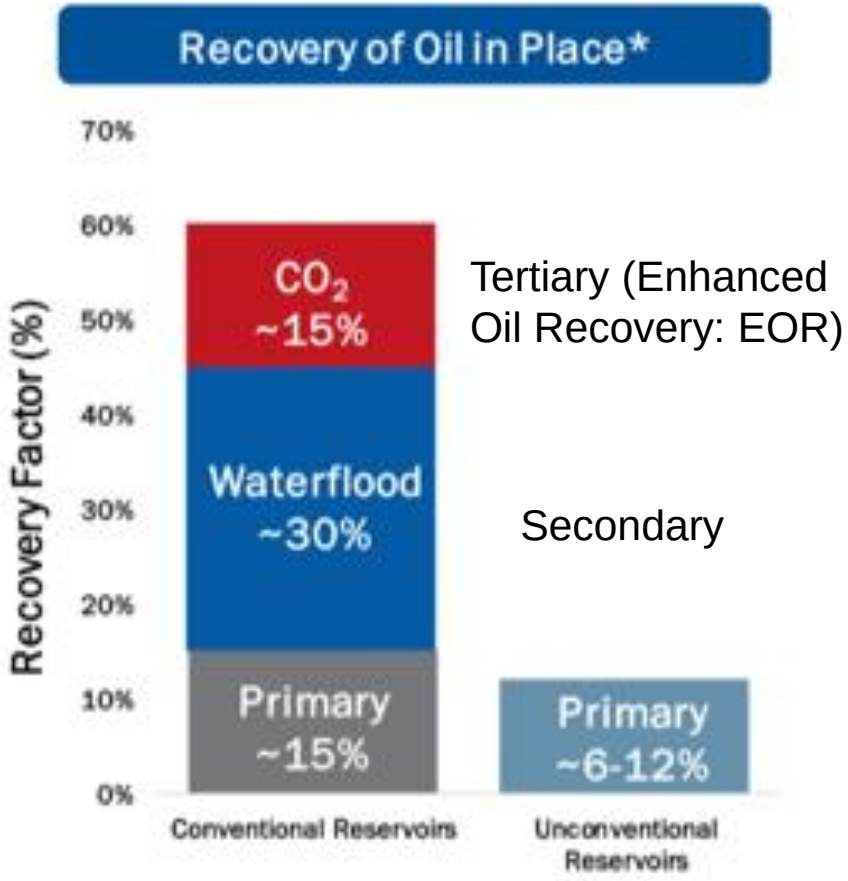
- **Potential CO2 sources include power generation, refining and industrial sources**
  - Current strategy targets primarily ethanol and coal-fired electric generation plants
  - Excludes plants with low utilization rates and high probabilities of retirement
- **Permian Basin: largest potential anthropogenic CO_2 is in Central Texas and Gulf Coast**
  - High concentration of coal-fired electric generation plants



Modified from Oxy 2018
Greenhouse Gas Reporting Program 2017

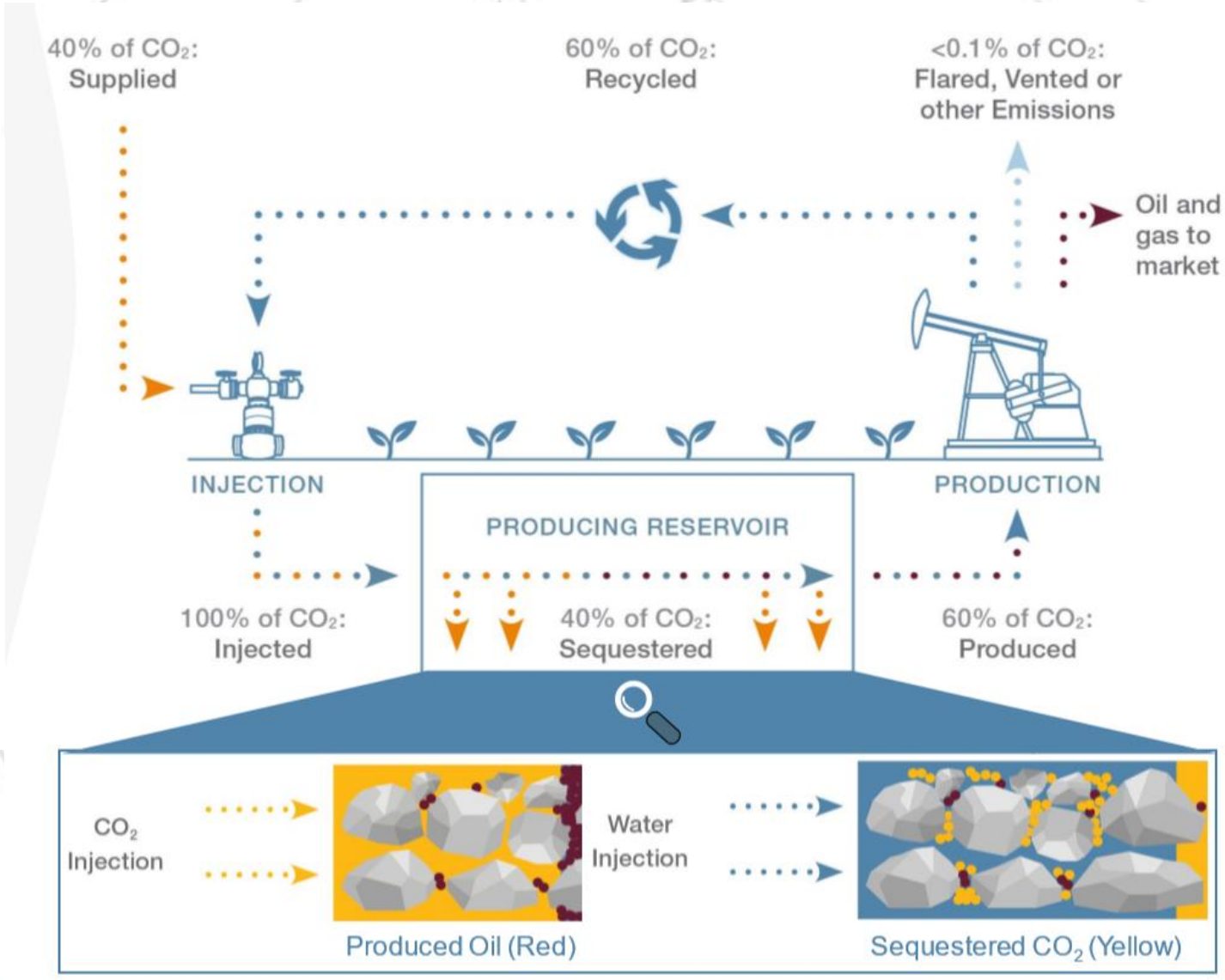
CONVENTIONAL OIL FIELD DEVELOPMENT STRATEGIES





Modified from Oxy, 2018

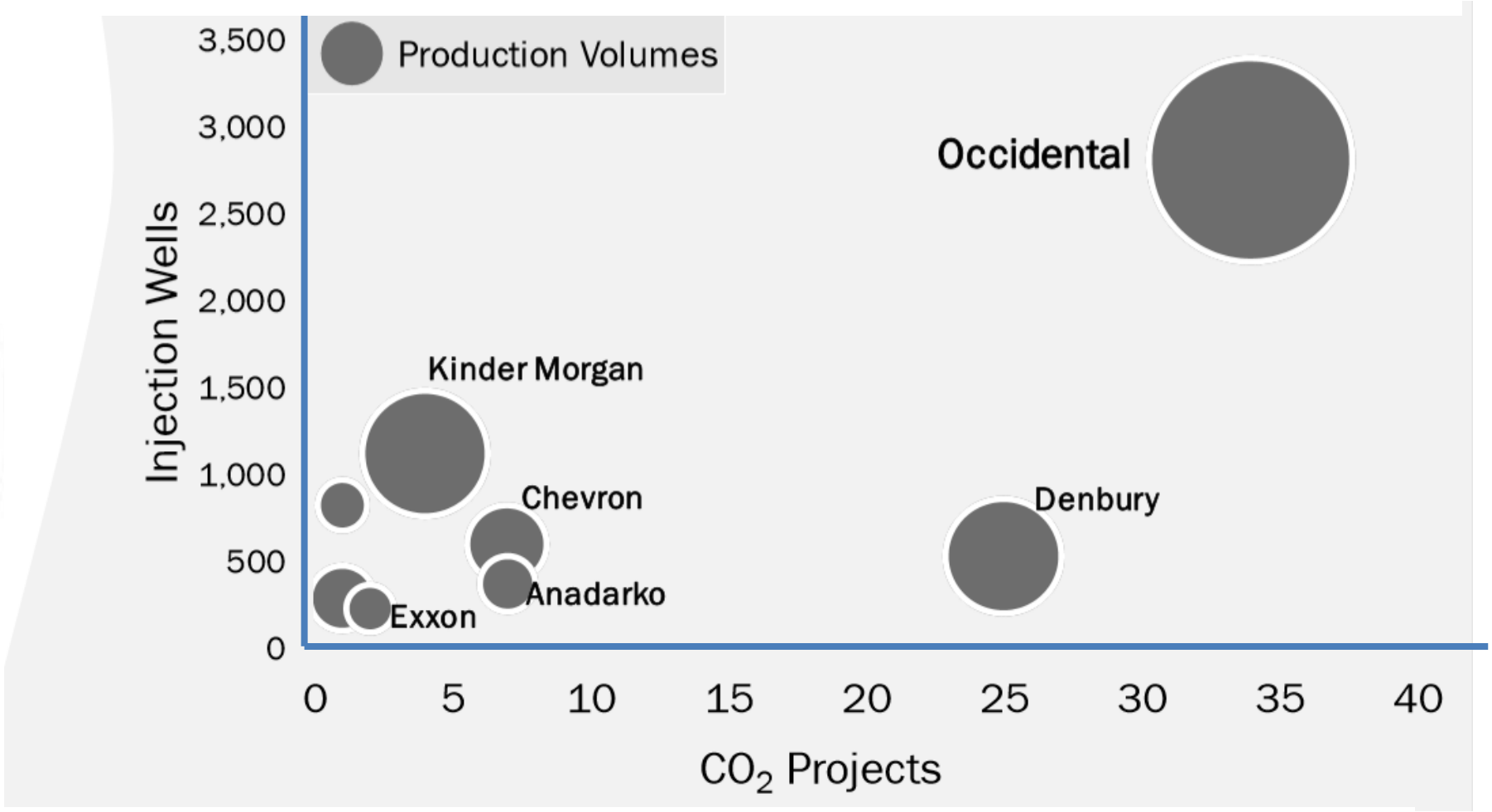
EOR LEVERAGES CARBON CAPTURE & SEQUESTRATION



Closed Loop System

Oxy 2018

CO2 ENHANCED OIL RECOVERY (EOR) AND SEQUESTRATION PROGRAMS



Oil and Gas Journal 2016

SELECTED EOR PUBLICATIONS USING CO2

- **Enhanced Oil Recovery – The History of CO2 Conventional WAG Injection techniques developed from Lab in the 1950's to 2017**
  David Merchant, Merchant Consulting, 2017
  https://www.aiche.org/system/files/aiche-proceedings/conferences/404771/papers/502866/P502866.pdf

- **A Regional Assessment of Residual Oil Zones in the Permian Basin and their potential for potential carbon dioxide capture, usage and storage**
  Logan M. West, 2014
  https://www.sciencedirect.com/science/article/pii/S1876610214026393

- **Performance Evaluation of CO2 Huff-n-Puff Gas Injection in Shale Gas Condensate Reservoirs**
  Xingbang Meng, Zhan Meng, Jixiang Ma and Tengfei Wang, 2018
  https://www.mdpi.com/

- **A Review of Gas Injection in Shale Reservoirs: Enhanced Oil/Gas Recovery Approaches and Greenhouse Gas Control**
  Fengshuang Du and Bahareh Nojabaei, 2019
  https://www.mdpi.com/

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CHRISTINE EHLIG-ECONOMIDES

SEPTEMBER 2020

FUNDING SOURCES

- National Energy Technology Laboratory (NETL)
- National Science Foundation
- Industry Consortia

NETL FUNDING

- Carbon Capture
  - 18% to universities at $6.8M
  - GT (3%), MIT (2%), OhioSU (6%), UIllinois (32%), UKentucky (39%)
- Advanced Storage
  - 25% to universities at $11.1M
  - Clemson (16%), CSM (10%), MontanaSU (18%), NMTech (9%), PSU (13%), UT-BEG (22%)
- Storage Infrastructure
  - 52% to universities at $56M
  - UIllinois (19%), UND-EERE (40%), UT-BEG (23%), UWyoming (18%)
- Carbon Use and Reuse
  - 44% to universities at $12.7M
  - CSM, GT, MI SU, NC SU, OU, UCLA, UD, UIllinois, UIowa, UKentucky, UMI, UWis, WVU

https://netl.doe.gov/

NSF FUNDING

- Engineering
  - No petroleum engineering supported
  - Chem E, Bio E, Env E, and Transport Systems (CBET)
    - Carbon capture supported at nearly 40% of total funding (U Pitt, NDU, PSU, UAlabama, NWestern, NJ); average grant of ~$400K
    - CCUS to materials supported at ~$2.1M (U Mich, U Del, U Pitt, Ariz St U)
- Geoscience
  - < 6% to carbon storage at ~$1.876M
  - CSM, Indiana U, U Wisconsin, U Wyoming, Virginia Polytechnic

https://www.nsf.gov/awardsearch/

PRIVATELY FUNDED OFFERINGS

- Research
  - Stanford Center for Carbon Storage https://sccs.stanford.edu/
  - Columbia University Park Group https://parklab.engineering.columbia.edu/
- Education
  - **ENERGY 253. Carbon Capture and Sequestration. 3-4 Units. – Stanford U**
  - **CARBON CAPTURE, UTILIZATION & STORAGE (CCUS) - IFP**
  - **Geoengineering: CO_2 Capture and Sequestration - coursera**
  - Global CCS Institute – webinars
  - Carbon Management Courses – Arizona State University
  - Columbia Climate Center MS in Carbon Management
  - Heriot Watt MSc in Carbon Capture and Storage

CONCLUDING REMARKS

- Point source capture and storage does not address transportation emissions.
- Addressing transportation GHG emissions is not cost prohibitive, and keeps infrastructure, but this does not address urban pollution.
- Natural gas with CCUS offers carbon neutral electricity.
- Hydrogen generation from natural gas with CCS (blue hydrogen) offers potential solutions for carbon neutral electricity and transportation.
- Switching transportation to electricity and/or hydrogen addresses both GHG emissions and urban pollution.
- CCS and CCUS employ core petroleum engineering skills.

SPE 201613

RON HARRELL, P.E.

Chairman Emeritus Ryder Scott Company

Mr. Harrell is a Petroleum Engineering graduate of Louisiana Tech University and continues as Chairman Emeritus of Ryder Scott Company. Ron remains active in the industry as a licensed engineer in three states and serves on several Management and Advisory Boards including corporations, not-for-profit organizations and three universities. He is a Senior Advisor to RSK (UK) LTD, Board Member of eCORP International plus holds energy advisory positions for The Carlyle Group and Morgan Stanley private equity energy divisions. He is a founding member and past Chairman of the UH Petroleum Engineering Advisory Board and an active member of the UH Subsea Engineering Program since its formation.

Mr. Harrell is also a founding member and Vice Chairman of the College of Engineering Advisory Board for Houston Baptist University. He served as an SPE Distinguished Lecturer in 2007-2008. He remains a member of SPE's Distinguished Lecturers Selection Committee and is a peer reviewer for SPE M&I technical papers. Further, he serves as SPEE's Observer on the SPE Oil & Gas Reserves Committee (OGRC).

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