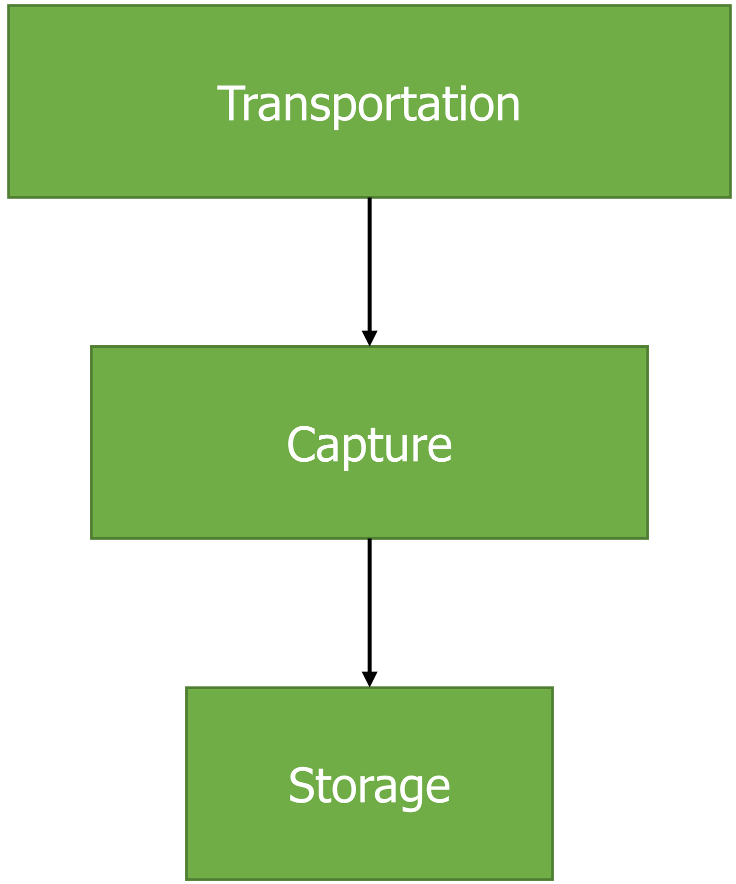
WINDY COVE ENERGY II

CO_2, EOR and Carbon Capture: Regulators in the Know

November 9, 2020

What is Carbon Storage?

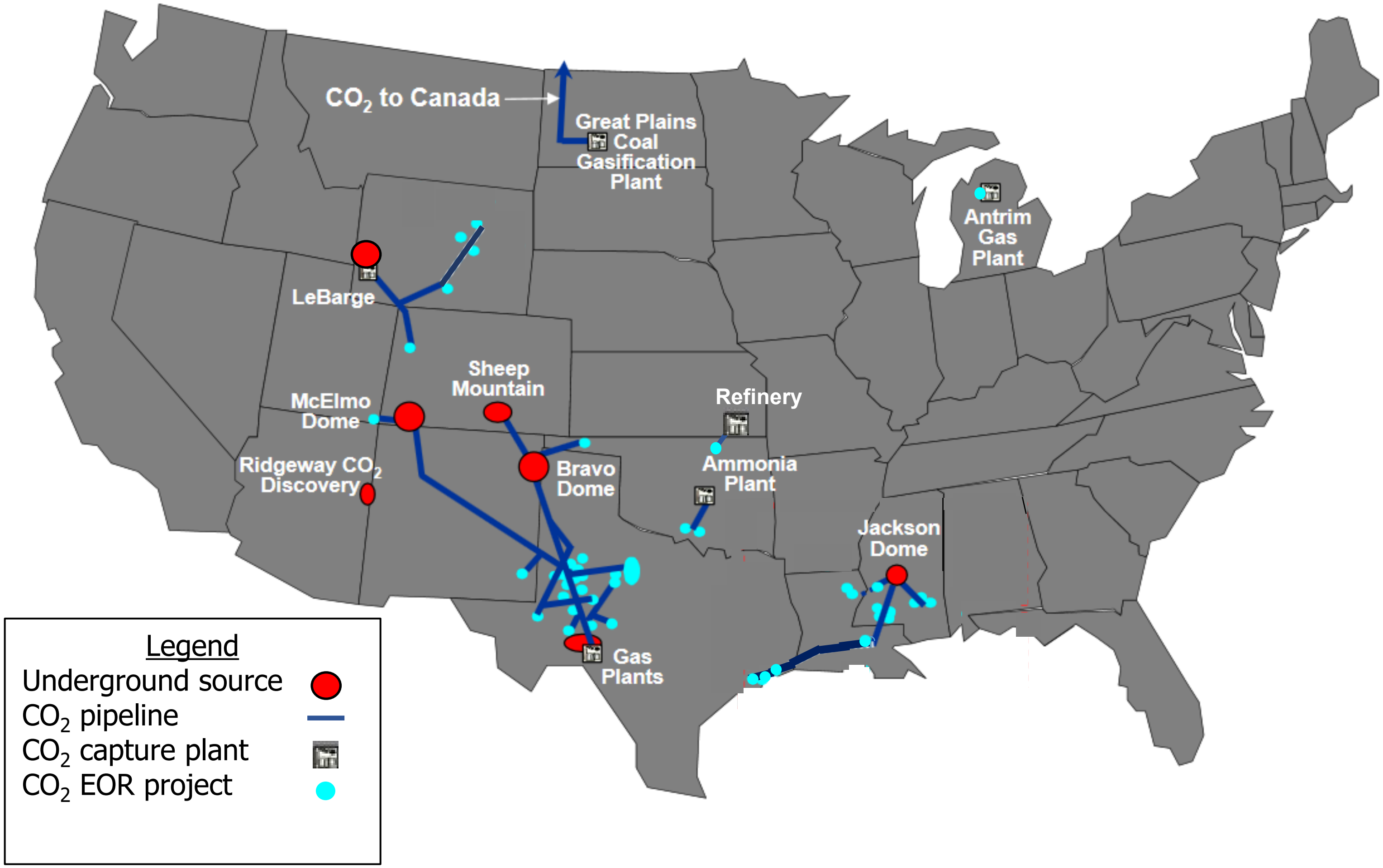


What is CCUS?

- Carbon Capture Utilization and Storage
- CCUS technologies involve the capture of carbon dioxide (CO_2) from fuel combustion or industrial processes, the transport of this CO_2 via ship or pipeline, and either its use as a resource to create valuable products or services and/or its permanent storage deep underground in geological formations. (International Energy Agency, IEA)
  - I added the and/
- It seems that the IEA's definition allows for CO_2 storage in a saline reservoir. Where is the utilization?
- CO_2 could be used to make other substances such as plastics, concrete or biofuels.
- The utilization that we will discuss is the use of CO_2 to produce oil. This process is followed by its internment in the subsurface.

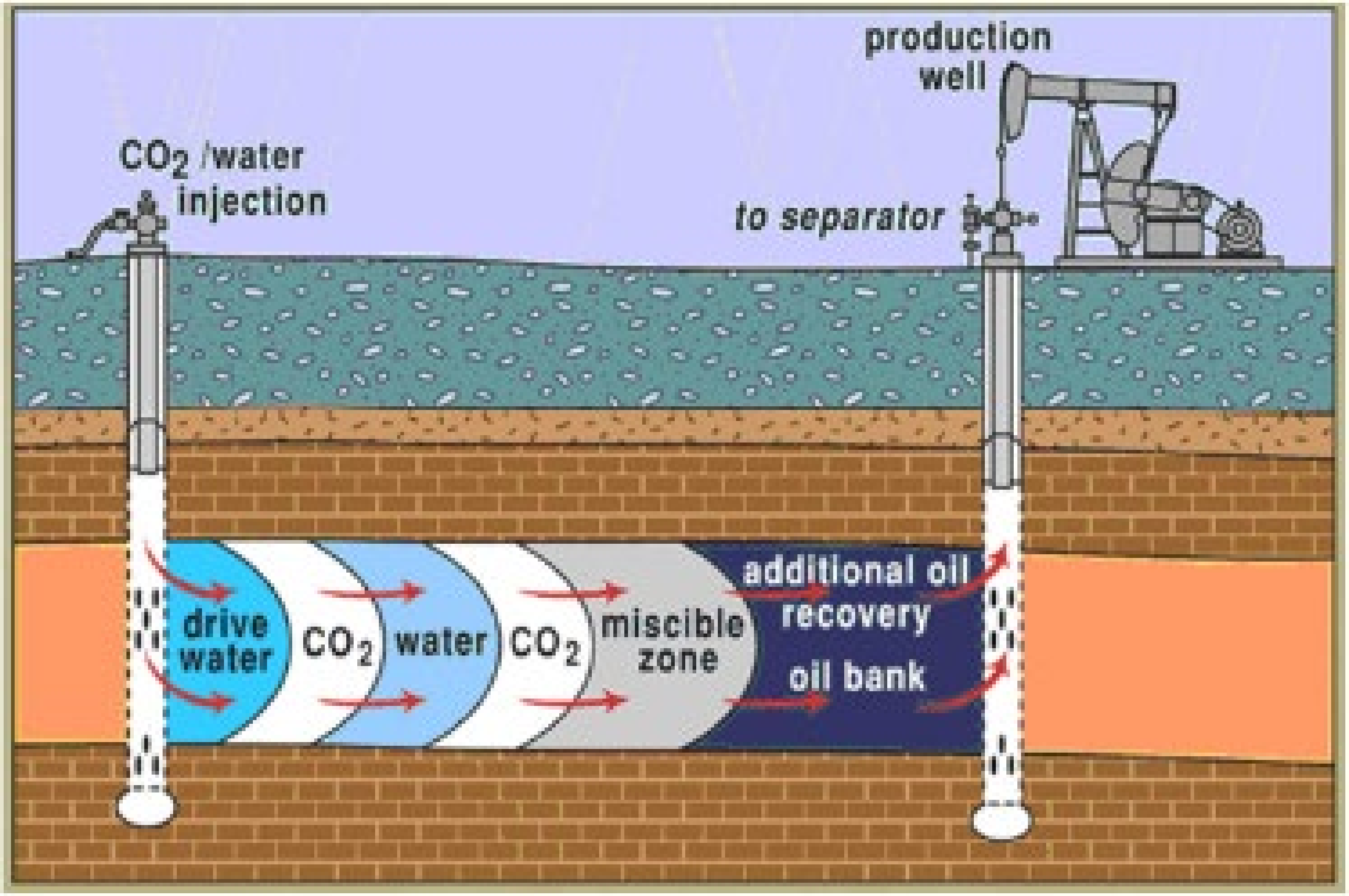
U.S. CO_2 EOR & CCUS Infrastructure

Over 250,000 BOPD were produced due to CO_2 injection in 2014



The map is updated from the source: Denbury Resources Inc. – "CO_2 Pipelines: Infrastructure for CO_2-EOR & CCS" (2009)

CO_2 Flooding Schematic



Beginnings – 1970s

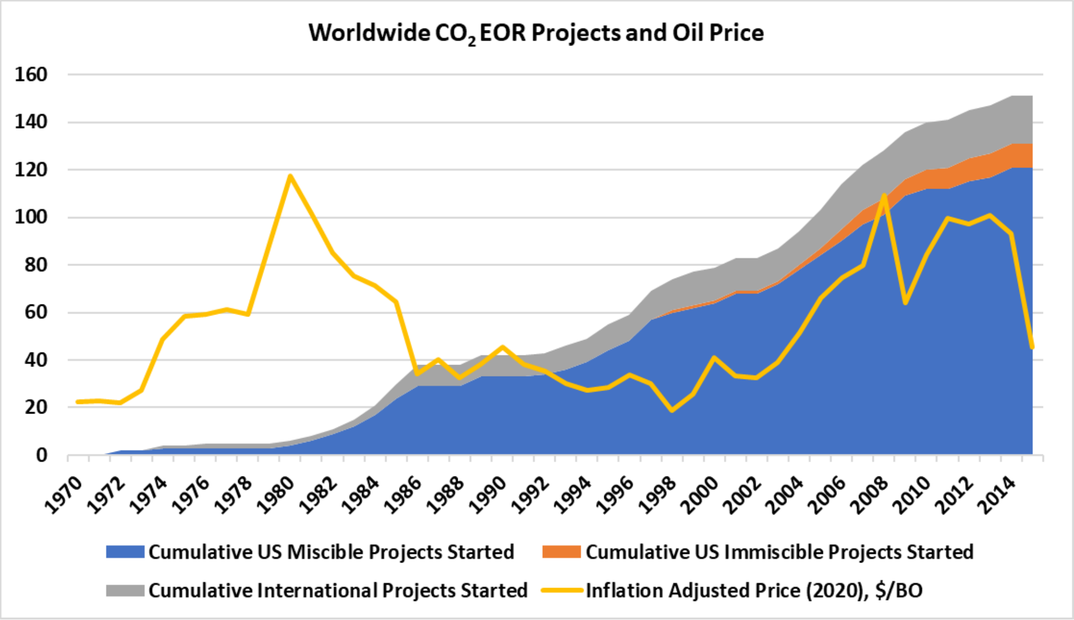
- CO_2 flooding began in earnest in January 1972 when Chevron began injection at the SACROC oil field
- Shell soon followed in April at North Cross
- Two years later in 1974, a small company, Orlapetco, began injection at Two Freds
- All the fields were connected to natural gas plants located in the Val Verde Basin via pipelines
- CO_2 was being separated from the natural gas sales stream and vented at these plants
- This CO_2 was captured, dehydrated and compressed into pipelines
- Initial successes and the energy crisis caused by the Arab oil embargo led to the search for more and larger CO_2 sources to expand CO_2 flooding to other reservoirs

Growth & Retrenchment – 1980s & 1990s

- Major sources of CO_2 and associated pipeline infrastructure were developed in the late 1970s and early 1980s
  - McElmo Dome, Bravo Dome and Sheep Mountain serviced the Permian Basin
  - Jackson Dome serviced the Gulf Coast
  - The Enid ammonia plant serviced Oklahoma
  - LaBarge serviced Wyoming and Colorado (LaBarge produces 30-40% of the world's Helium)
  - Enid and LaBarge are anthropogenic sources
- The oil price drop in 1986 stalled growth until the mid-1990s
- The number of US projects increased from 3 in 1974 to 29 in 1986 to 39 in 1994 and 65 in 2000

Source: "Industry Experience with CO_2 for Enhanced Oil Recovery" Workshop on California Opportunities for CCUS/EOR (2012)

Rebirth & (Perhaps) Stagnation – 2000s



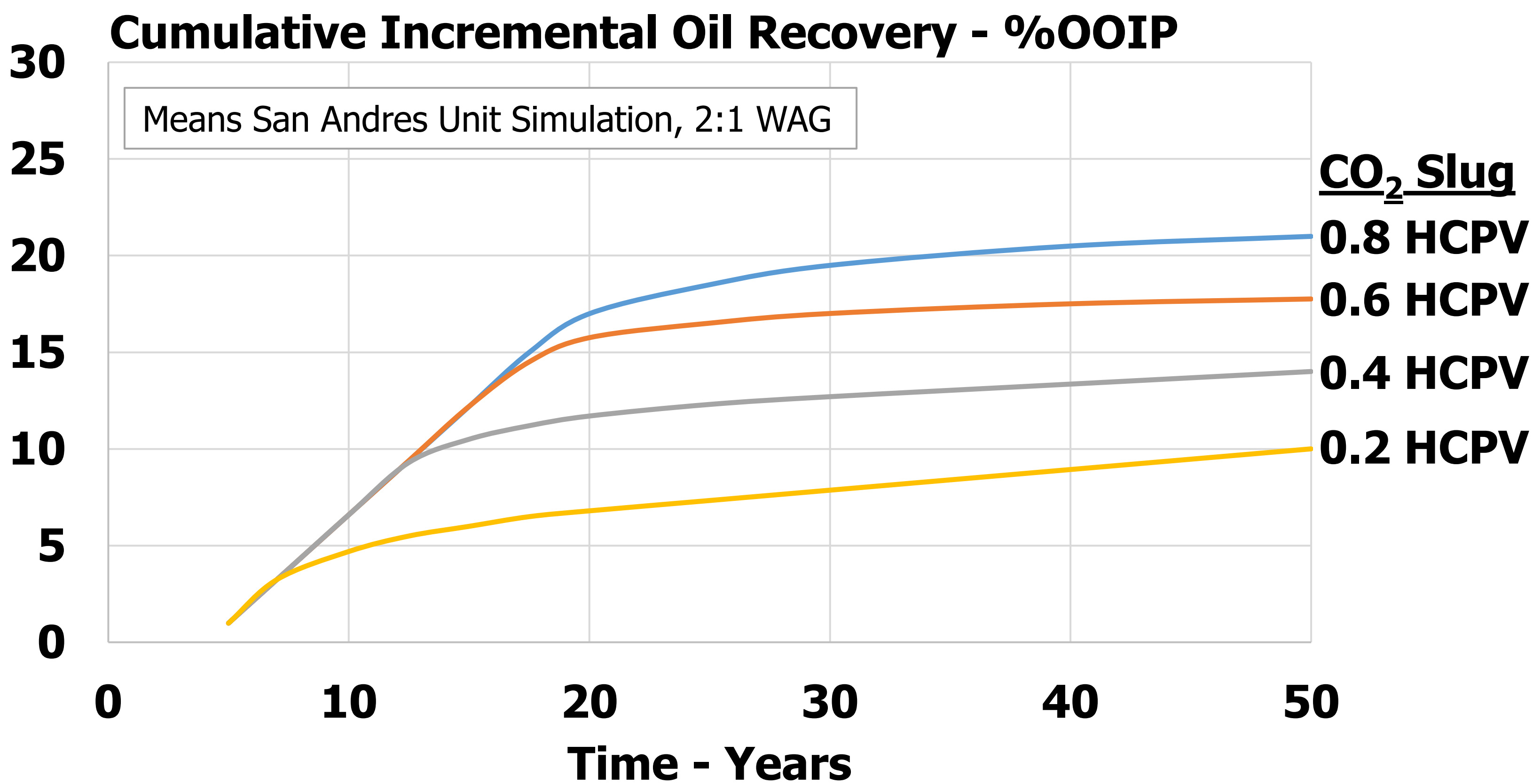
Sources: Oil & Gas Journal, 2010 Worldwide EOR Survey, April 19, 2010 & 2014 Worldwide EOR Survey April 7, 2014

- By 2000 and with over 25 years of CO_2 flood experience, the industry thought that the technical risks were well known
- The number of US projects doubled from 2000 to 2014 (but the projects were not as large as those started in the 1980s and which underwrote the CO_2 source and transportation infrastructure)
- No projects commenced after 2014 when the oil price crashed (twice)
- Will the industry sanction long term projects while the memory of price volatility remains vivid?
- Have all the good floods been done?

Solvents – Propane, NGLs, CO_2

- Have you ever tried to rinse oil-based paint off a paintbrush with a garden hose?
  - Turpentine, a solvent, works much better
  - Propane, natural gas liquids and CO_2 can act like solvents in the reservoir and move oil that is trapped in the pores during a waterflood
- Miscibility
  - Substances are miscible if, when they are mixed, they form one phase
  - CO_2 acts like a solvent when it becomes miscible with the oil
- First contact vs. multiple contact miscibility
  - Oil is a complex substance comprised of carbon chains with different numbers of carbon atoms
  - CO_2 is not miscible with all the components upon initial contact with the oil
  - As CO_2 moves through the reservoir the lighter components of the oil vaporize into the CO_2 ...causing the mixture to become more like the heavier components, eventually leading to its miscibility with the oil.
  - Similarly CO_2 condenses into the oil as it passes, making the oil more like CO_2

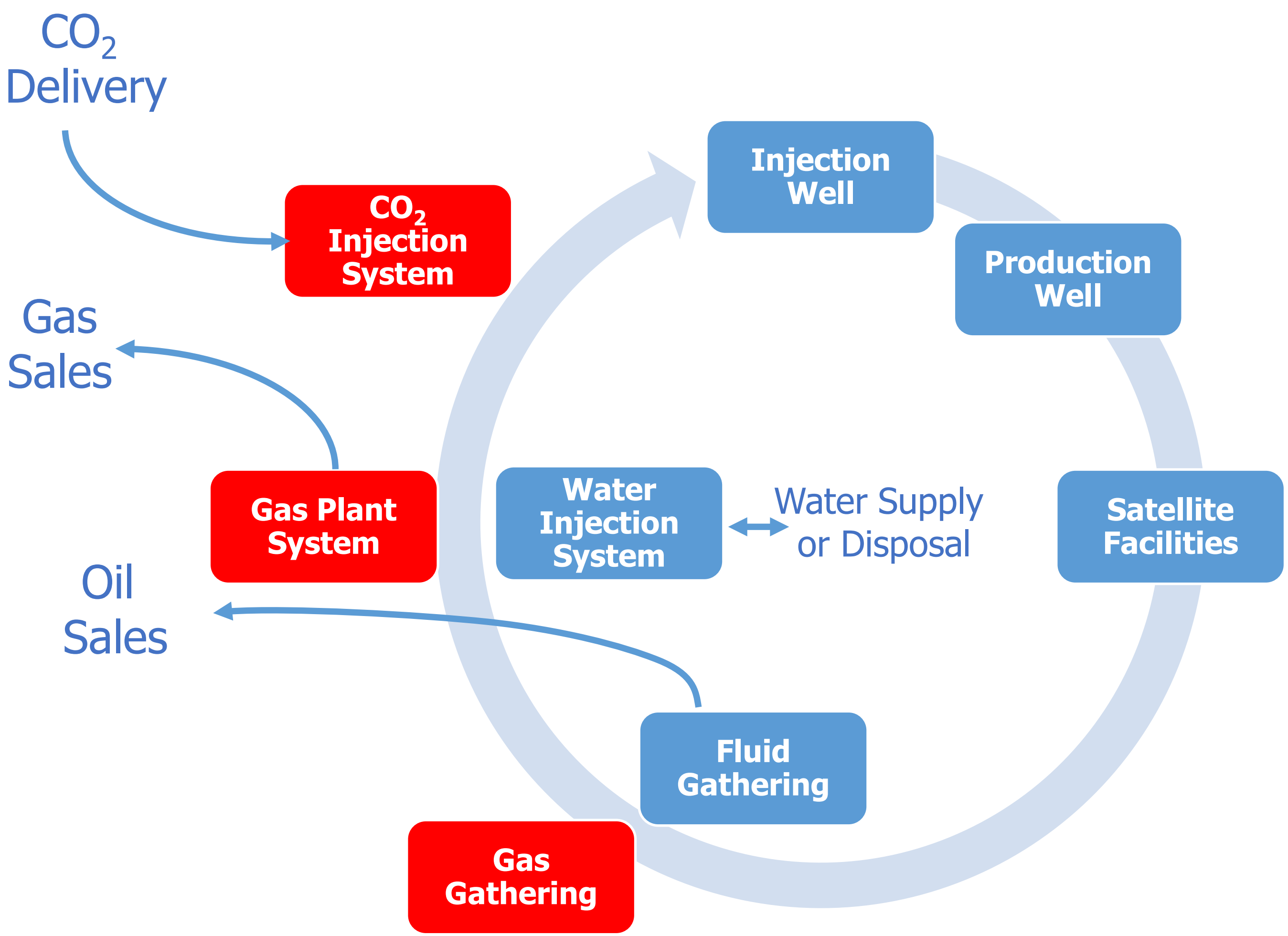
More CO_2 More Oil



The difference after 50 years between 0.2 HCPV and 0.4 HCPV ~ 4% OOIP
The difference after 50 years between 0.6 HCPV and 0.8 HCPV ~ 3.25% OOIP

After Hadlow, SPE 24928 (1992)

CO_2 Flood Production Systems



Potential for major alterations shown in red

Regulations

- Class II
  - Inject fluids associated with oil and natural gas production. Class II fluids are primarily brines (salt water) that are brought to the surface while producing oil and gas.
  - Categories: disposal wells, enhanced recovery wells, hydrocarbon storage wells
  - Enhanced recovery wells - fluids consisting of brine, fresh water, steam, polymers, or carbon dioxide are injected into oil-bearing formations to recover residual oil and in limited applications, natural gas.
- Class VI
  - Inject CO_2 into deep rock formations for the purpose of long-term underground storage or geologic sequestration (GS)

Source: epa.gov/uic

Class VI

- Focused both on protecting drinking water and assuring long term storage of CO_2
- Address the unique nature of CO_2 injection for long term storage
  - Relative buoyancy of CO_2
  - Subsurface mobility
  - Corrosivity in the presence of water
  - Large anticipated injection volumes
- Requirements for
  - Siting (an additional requirement vs. Class II)
    - Extensive site characterization requirements
  - Construction
    - Materials must withstand contact with CO_2 over the life of the project
  - Operation
  - Monitoring and testing
    - Comprehensive monitoring requirements addressing well integrity, CO_2 injection & storage and groundwater quality during injection and post-injection site care
  - Reporting
  - Closure
  - Financial responsibility
    - Assure the availability of funds for the life of the project, including post-injection care and emergency response

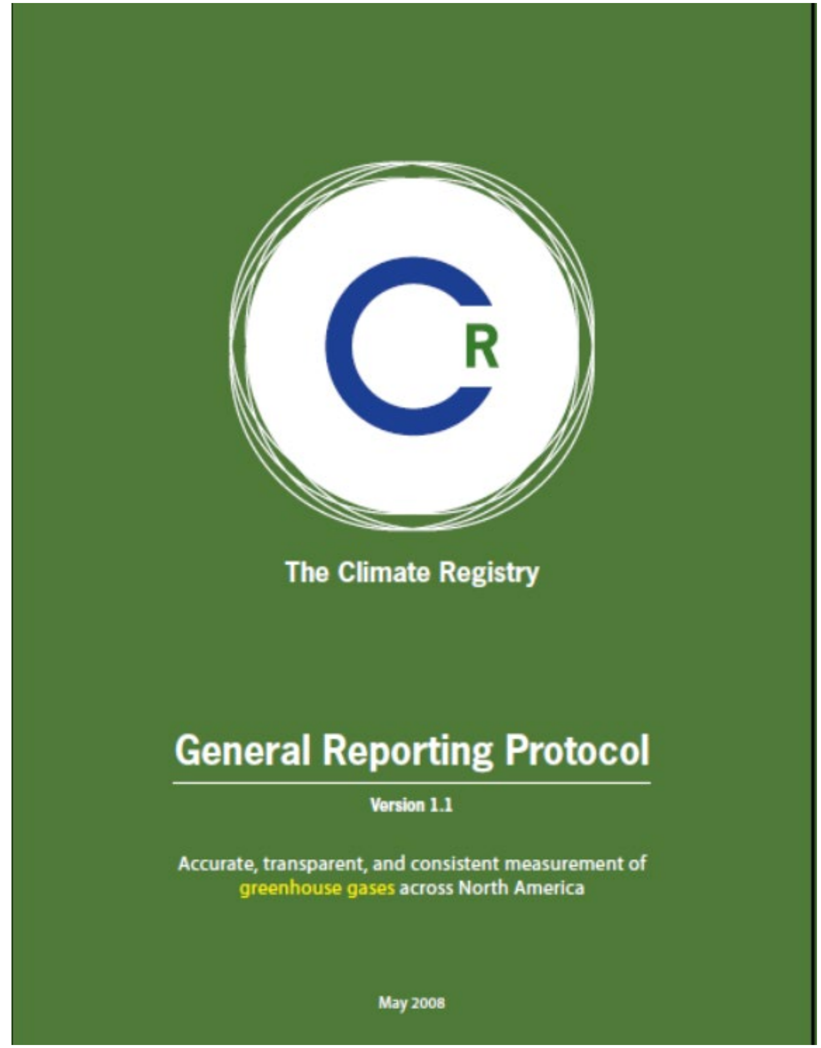
Transition of Class II to Class VI

- Geologic storage of CO_2 can continue to be permitted under the Class II program
- Use of anthropogenic CO_2 in enhanced recovery (ER) operations does not necessitate a Class VI permit
- Class VI site closure requirements are not required for Class II CO_2 injection operations
- ER operations that are focused on oil or gas operations will be managed under Class II. If O&G recovery is no longer a significant aspect and if Class II cannot manage the increased risk to USDWs, then the operation should be transferred to Class VI.

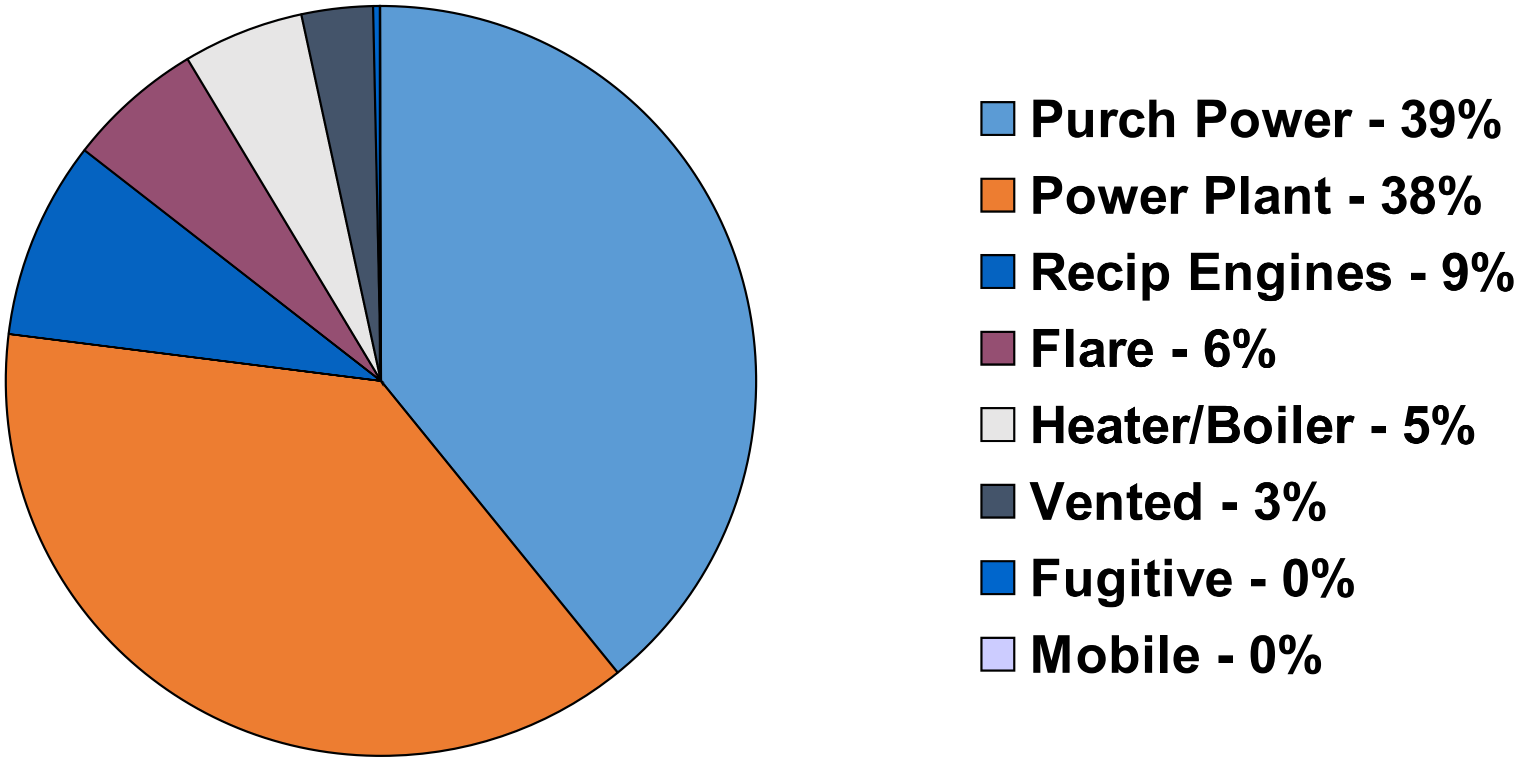
From: Key Principles in EPA's Underground Injection Control Program Class VI Rule Related to Transition of Class II Enhanced Oil or Gas Recovery Wells to Class VI

EOR Carbon Balance

- Calculate carbon emissions for SACROC in 2007 using CA Registry methods (mostly)
- Compare various emission sources
- Look at long-term carbon balance calculations for the SACROC oil field



2007 SACROC Complex GHG Emissions



1,046,000 Tonnes Total Complex

972,800 Tonnes CO_2 Flood

Field Life Carbon Balance

EOR Production[1]	185 million BO
Purchased[2]	260.0 Mt
Direct/Indirect Emissions[3]	- 18.5 Mt
Capital Emissions[4]	- 2.0 Mt
Total Sequestered	239.5 Mt

92% stored

[1] 10% of 1.85 billion bbl OOIP

[2] Not all purchased CO_2 was anthropogenic

[3] CO_2e emitted 0.1 t/BO

[4] 530 tonnes/$1 million GDP, $3.5 billion of capital

Time Scales and Permanence

- Physical trapping dominates early
- Residual and solubility trapping dominates in the 10s to 100s of years time frame
- Mineral precipitation will typically be a long timeframe mechanism
- For oil, gas and saline reservoirs

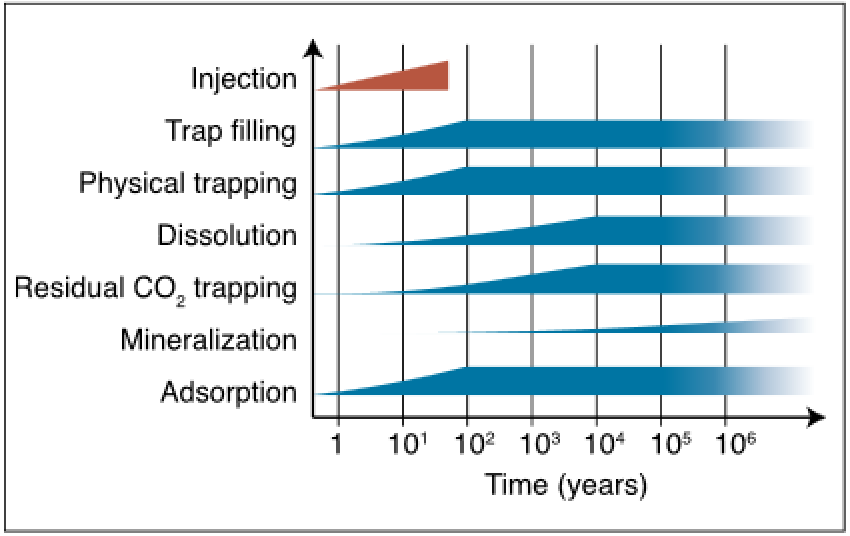


Figure 5.18 Schematic showing the time evolution of various CO_2 storage mechanisms operating in deep saline formations, during and after injection. Assessing storage capacity is complicated by the different time and spatial scales over which these processes occur.

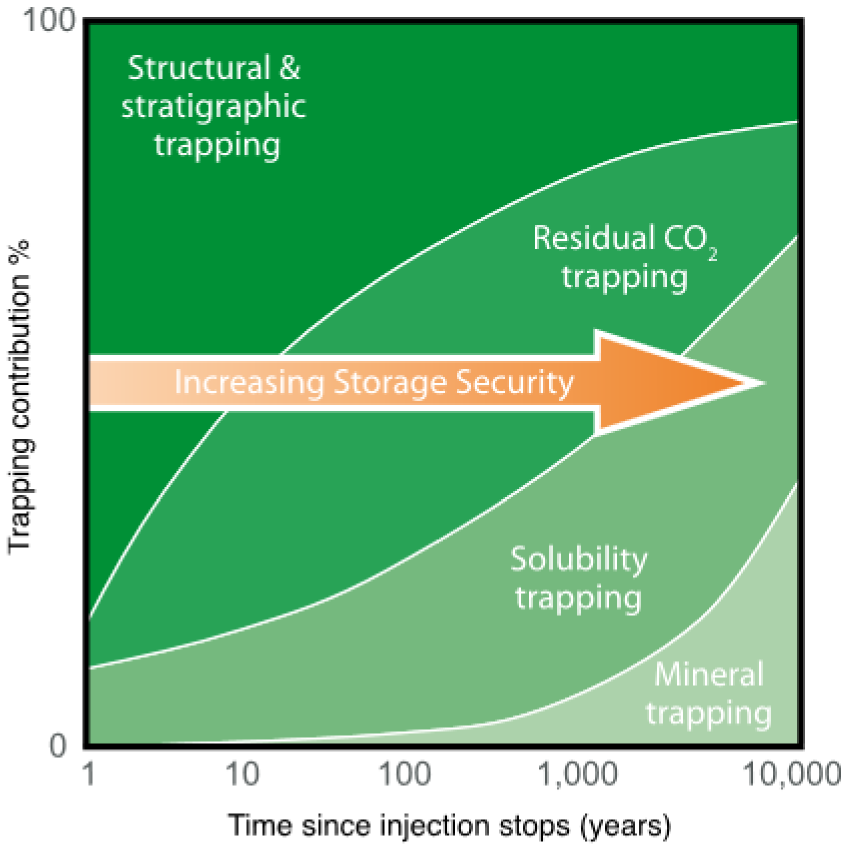


Figure 5.9 Storage security depends on a combination of physical and geochemical trapping. Over time, the physical process of residual CO_2 trapping and geochemical processes of solubility trapping and mineral trapping increase.

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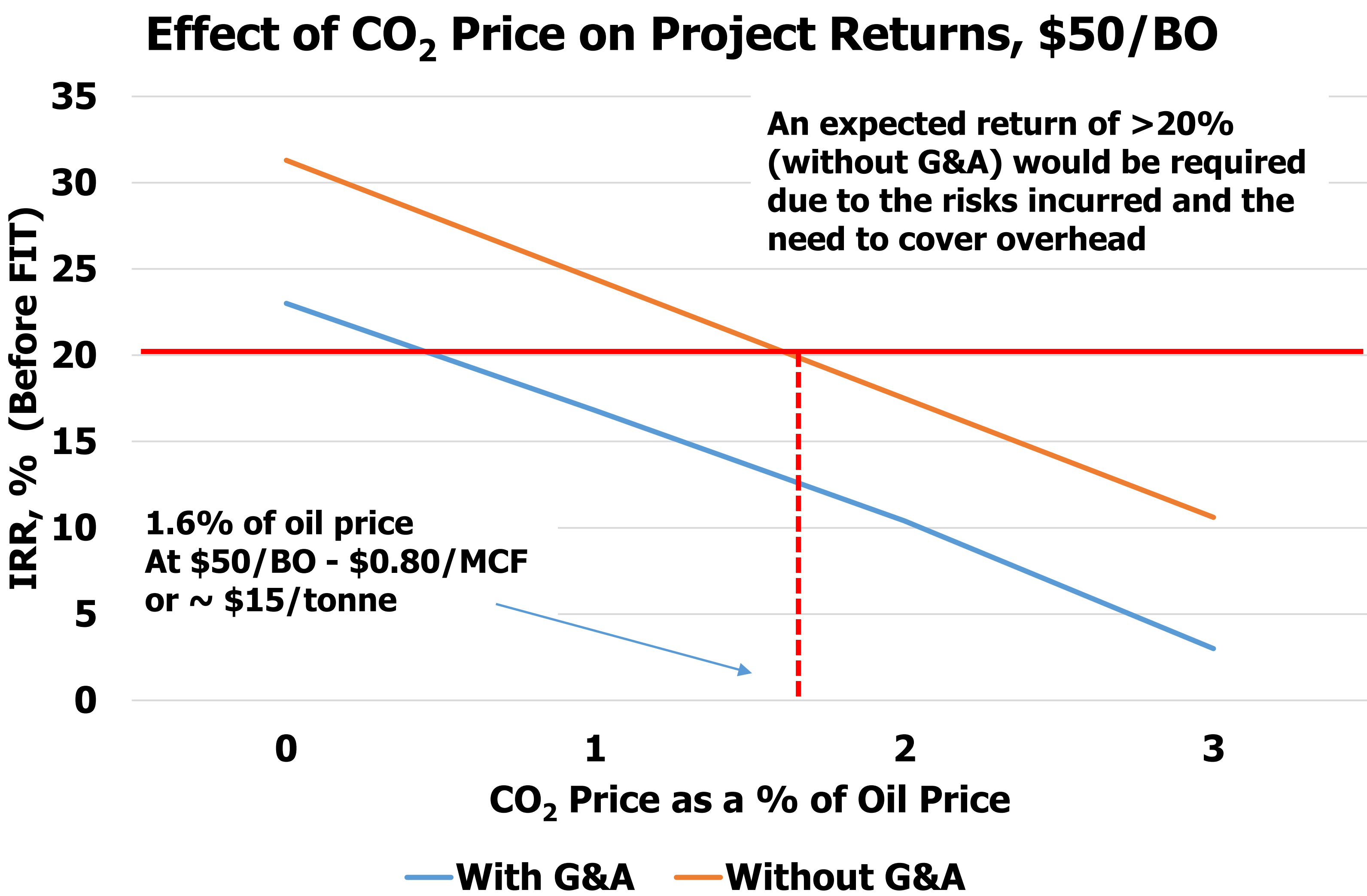
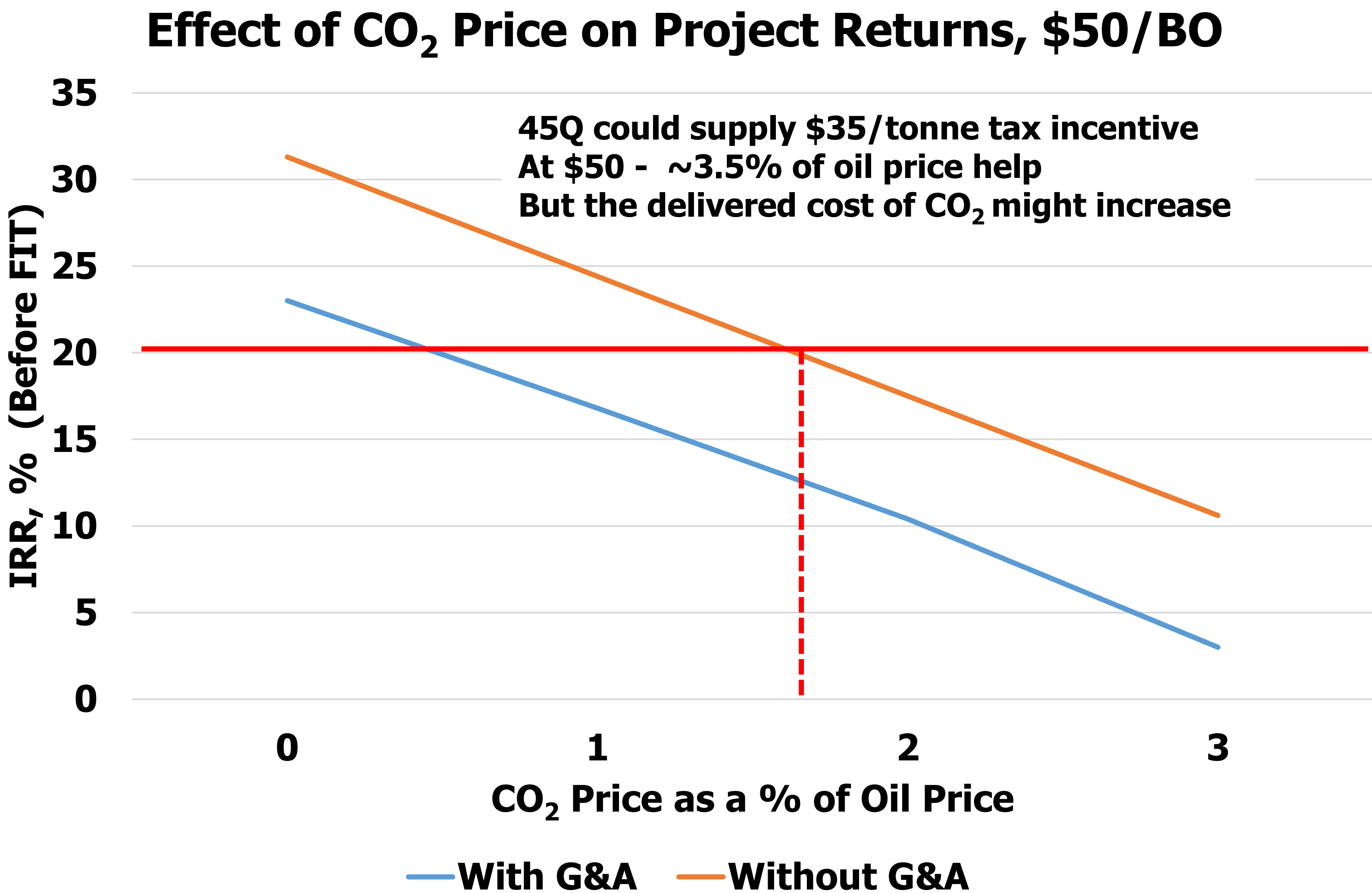
Source: IPCC, Carbon Dioxide Capture and Storage

Lower CO_2 Prices Are Critical



But Wait – 45Q to the Rescue



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Cost

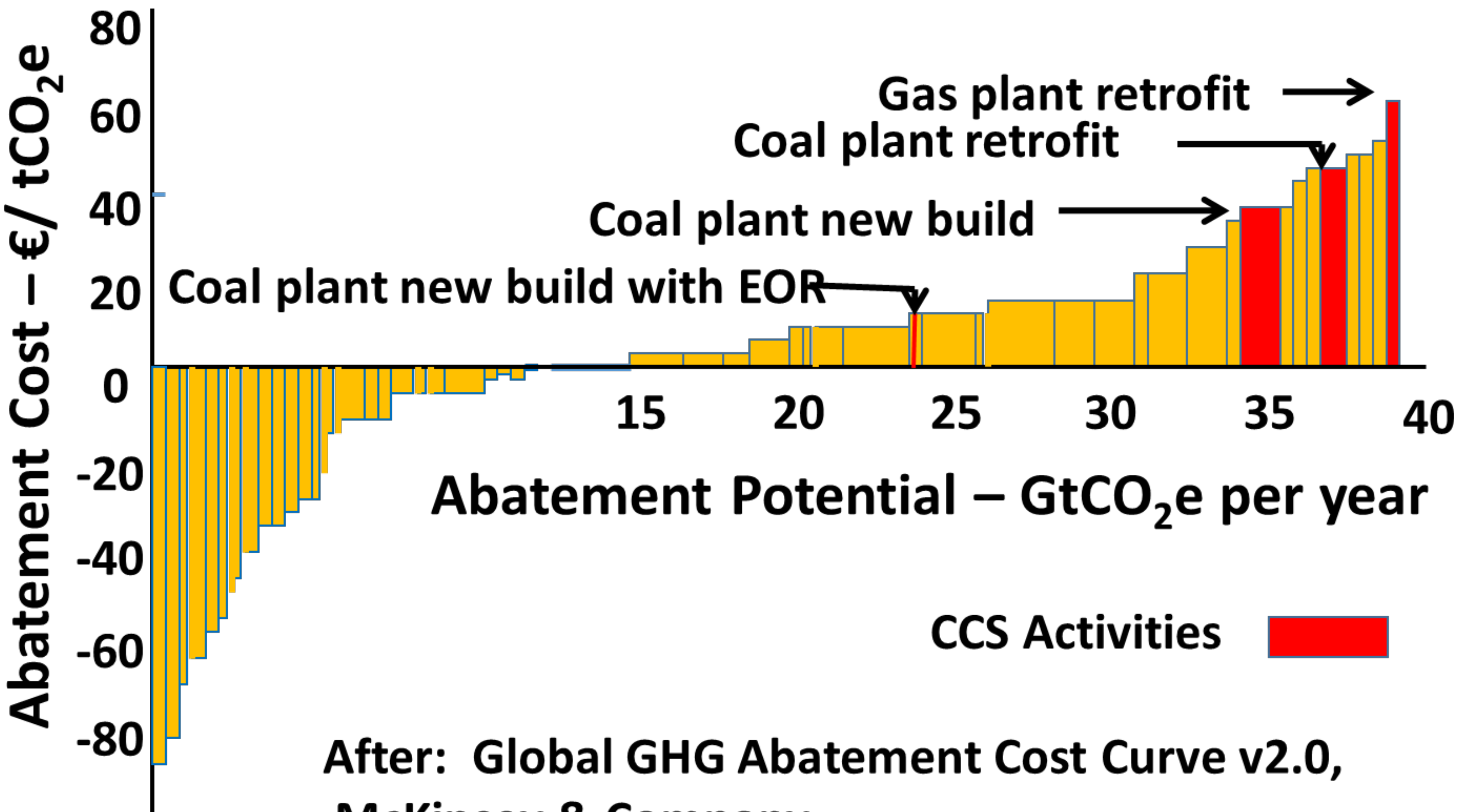
- According to a 2017 Forbes article*
  - Used data from U.S. EIA and NETL
  - Capturing CO_2 from a new supercritical coal plant adds $59/MW-hr to electricity costs
  - Or the CO_2 capture cost is $70.70/tonne ($3.70/MCF)
  - Tax credits for wind and solar are ~$20-$25/MW-hr
- Capturing CO_2 from a natural gas plant likely costs more
- The cost to capture, dehydrate and compress pure CO_2
  - From 0 to 2000 psig is approximately $11/tonne ($0.60/MCF)
- Principle: If you have nearly pure CO_2, you can capture it at a price that an oil field can pay for if you are close enough even without tax incentives. If you don't have government incentives, you won't capture non-pure CO_2 for use in oil fields.

Kemper County Coal Plant
Source: Wiki Commons

Southern Company's Kemper County IGCC plant with CO_2 capture was originally forecast to cost $2.2 billion. As of 2017 the completion cost had risen to $7.3 billion. Southern decided to switch to natural gas.

*Forbes Online: Carbon Capture And Storage: An Expensive Option for Reducing U.S. Emissions

CCS Has Unfavorable Economics



After: Global GHG Abatement Cost Curve v2.0, McKinsey & Company

CCUS Is Also Challenged

- But …
- We know based on studies at SACROC and elsewhere that CO_2 will stay in the ground
- We know CCUS can work economically in some cases
  - Val Verde Basin natural gas/CO_2 separation plants provided CO_2 to start CO_2 flooding in 1970s
  - Dakota Gasification Plant supplies Canadian floods
  - CVR Refinery in Coffeyville, KS supplies the Burbank field in OK
  - Ethanol plants in Michigan supply oil fields
- What works - nearly pure CO_2 sources near oil fields which only require dehydration and compression
- Tax credits such as 45Q help pay to transport CO_2 farther from the pure CO_2 sources
- If CCUS (or CCS) is to expand beyond nearly pure sources, society must provide more incentives than it has, or a technological breakthrough (direct air capture?) must occur