[PS]Burnett Ranch: A CO_2 Flood on the Eastern Shelf of the Permian Basin, King County, Texas*

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Abstract

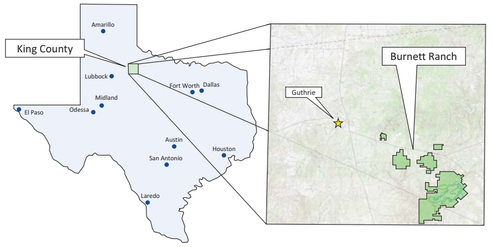
The Burnett Ranch Field, located in King County, lies on the Eastern Shelf of the Permian Basin. Consisting of multiple—and in certain areas, stacked—reservoirs and multiple fields, the Burnett Ranch boasts a long and storied history, both with regards to its geology and petroleum system. The primary reservoirs in this area are Pennsylvanian-aged Strawn sandstones, with secondary Strawn limestones, Permian-aged Tannehill sandstones, Pennsylvanian-aged Bend conglomerates, Mississippian-aged Marble Falls-equivalent limestones, and the Ordovician-aged Ellenburger carbonates. The first marginally successful well was drilled in the field in the 1950s, but it was not until the 1970s when primary production sharply increased with the discovery of the major oil fields in the area. The Burnett Ranch changed operators multiple times thereafter, and secondary production efforts began in the 1980s. Hunt acquired the acreage in the early 1990s and initiated tertiary production in the 2010s, which continues to this day. The primary reservoirs in the field are the Twin Peaks Sands, the Strawn Lower Sand, the Strawn 5400’ Sand, and the Strawn 5400’ Lime. All four of these reservoir intervals are alternately flooded with both CO_2 and water based on individual well production. There are currently 36 injectors and 46 producers, around which injection- centered patterns are drawn. The traditional five-spot injection pattern is not used in the field due to the considerations of topography, the use of existing wellbores, and the need to optimize locations with stacked reservoirs. The CO_2 flood is currently progressing from the northern end of the field to the south. Injectors on the outskirts of the CO_2 flood are used to create higher pressure in the downdip reservoir to keep the CO_2 inside the hydrocarbon-bearing portion of the reservoir. Once injected into the reservoir, CO_2 at certain temperatures and pressures will become miscible with the residual oil left behind after primary and secondary production. The resulting mixture of oil and CO_2 has a reduced viscosity, which allows it to flow more easily through the reservoir. The purpose of alternating CO_2 injection with water is to force the CO_2 down new pathways through the reservoir—the water fills the CO_2-created pathways and block them off from any CO_2 injected thereafter. This is the mechanism by which the life cycle of a field that otherwise would have been abandoned is extended, allowing it to produce an additional 10-15% OOIP.

Burnett Ranch: A CO_2 Flood on the Eastern Shelf of the Permian Basin, King County, Texas

Patricia Lee, Hunt Oil Company

Location

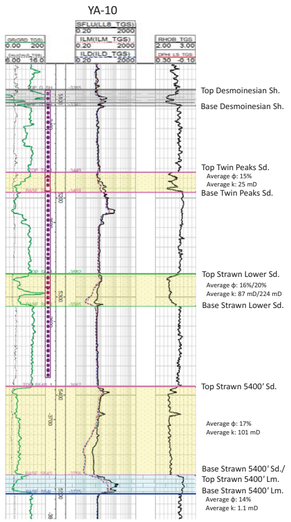
The Hunt Burnett Ranch is an amalgamation of multiple oil fields in the southeastern corner of King County. King County itself lies about 100 miles north-northwest of Abilene and 100 miles east of Lubbock. It is the second-least populous county in Texas with a population of around 300 people. The region is part of the southernmost reaches of the Great Plains, and the surface is used primarily for agriculture, ranching, and game hunting. The town of Guthrie is the county seat.

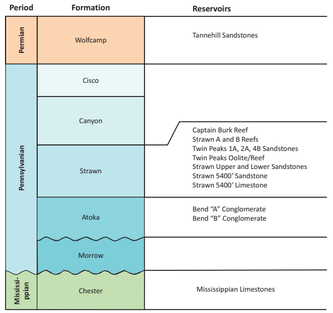


Above: *Location of King County with a zoom in of the Burnett Ranch and its associated leases held by Hunt.*

Stratigraphy and Depositional Environment

Multiple reservoirs within multiple fields make up the Hunt Burnett Ranch. The main reservoirs in Burnett Ranch are Pennsylvanian Strawn sandstones and limestones. The primary reservoir intervals consist of the Strawn 5400′ Sandstone and Strawn Lower Sandstone, and Strawn 5400′ Limestone. Secondary reservoirs include the Twin Peaks Sandstones, along with the Tannehill Sandstones, Strawn reefs and carbonates, Bend Conglomerates, and Mississippian carbonates.





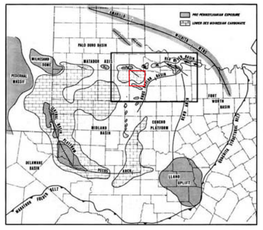
Right: *Simplified stratigraphic column of the region with targeted reservoirs listed.*
Left: *A type log of the Burnett Ranch reservoirs. YA-10 is centrally located on the property [for location, see pattern map in The Hunt Burnett Ranch at Present section on bottom far right].*

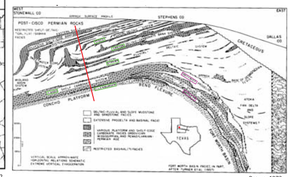
Well locations for the CO_2 flood are chosen based on a combination of the use of pre-existing wells, as well as targeting locations that will penetrate multiple reservoirs at a time. The overall stacking pattern and lithologies of these reservoirs are indicative of a retrogradational, tidally-influenced delta on a shallow marine shelf. The four stacked reservoirs targeted in the CO_2 flood portion of the Hunt Burnett Ranch acreage from youngest to oldest are:

- Twin Peaks Sand – Deltaic tidal bar sandstones with average porosity and permeability of 15% and 25 mD, respectively.
- Strawn Lower Sand – Delta-front sandstones in the northeast that grade to estuarine environment sandstones in the southwest with 16% porosity and 87 mD permeability in the northeast, and 20% porosity and 224 mD permeability in the southwest.
- Strawn 5400′ Sand – Fluvially-influenced delta-front bars with a porosity of 17% and a permeability of 101 mD.
- Strawn 5400′ Lime – Shallow marine ooid limestone interbedded with very thin sandstone laminations that has an overall porosity of 14% and permeability of 1.1 mD.

Structural Geology

During the Pennsylvanian, north Texas was divided primarily into two basins ringed by mountain belts and carbonate ramps with isolated platforms: the Permian Basin to the west and the Fort Worth Basin to the east. King County sits near the axis of the Knox-Taylor Trough, which funneled sediments from the Wichita-Arbuckle-Ouachita mountain belt. A west-dipping ramp formed the base the reservoirs were deposited over.

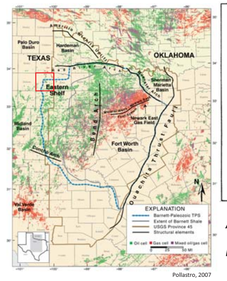

Gunn, 1982


Brown, 1973

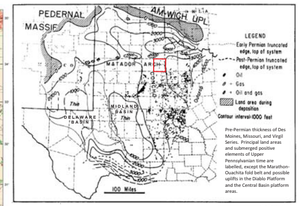
Far left: *Regional tectonic features of north Texas during the late Desmoinesian. King County is marked by the red square.*
Left: *Structural cross section of the Fort Worth Basin. The red line indicates formations found at Burnett Ranch. Green indicates potential reservoirs, while pink indicates potential source rocks. King County is marked by the tiny red square in the Texas inset.*

Regional Petroleum Systems

King County lies on the western edge of the Forth Worth Basin and the eastern edge of the Permian Basin. The source rock for Burnett Ranch is not in the immediate area, as wells drilled to the basement did not penetrate shales of both notable thickness and high total organic content. Several source possibilities for Burnett Ranch exist: the Pennsylvanian Smithwick Shale and Bend Group mudstones, Mississippian Barnett Shale, or the Upper Devonian Woodford Shale. As none of these shales exist with considerable quantity within the Hunt Burnett Ranch, extensive migration from either basin is assumed.



Pollastro, 2007

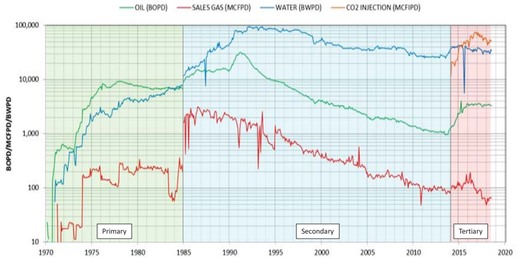


Galley, 1955

Above: *Permian Basin, showing proximity of oil and gas production. King County is marked by red square.*
Left: *Fort Worth Basin, showing proximity of oil and gas production. King County is marked by red square.*

Historical Production

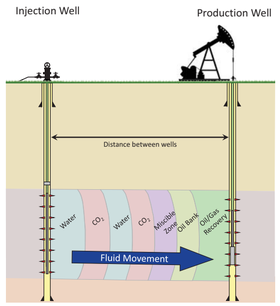
Shell first drilled several wells in the area in the 1950s. The well was marginally successful and the property changed hands several times afterwards. Gunn was responsible for the discovery of the major oil fields in the area and the start of a noticeable increase in primary production in the early 1970s. Secondary production in the form of waterflooding the reservoirs began in the mid 1980s. Hunt acquired the acreage in the early 1990s and initiated tertiary production in the mid 2010s, and the injection of CO_2 into the Burnett Ranch reservoirs continues to this day.



Above: *Historical gross oil, water, and gas production of the Burnett Ranch. Gross CO_2 injection is also included, beginning in 2014. The period of primary production is shaded green. Secondary production is shaded blue; tertiary production, red.*

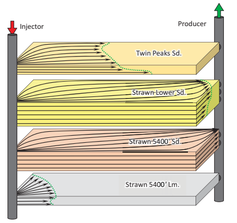
How CO_2 Floods Work

CO_2 floods operate through the combined use of injection and production wells. CO_2 is injected into the reservoir as a supercritical fluid. The CO_2 becomes miscible with the residual oil, and the resultant mixture is less viscous and therefore easier to mobilize. The injection of CO_2 is alternated with the injection of water—this method of enhanced recovery is known as water alternating gas, or WAG. Water is periodically injected into the reservoir after CO_2 to create new channels for the CO_2 to disperse through: the water follows the pathways through the reservoir created by the CO_2 and essentially blocks that pathway, thereby forcing the CO_2 injected after the water to create new pathways through the reservoir. Water curtain wells around the periphery of the reservoir help to contain the CO_2. Through this method, incremental recoveries of 10–20% OOIP may be achieved.



Right: *A generalized, schematic diagram of tertiary flooding with alternating water and CO_2 injection.*

The Challenges of a CO_2 Flood



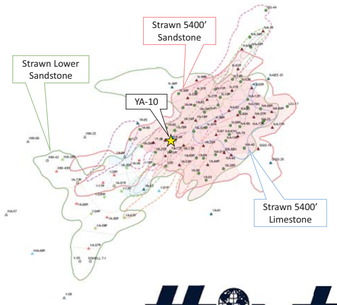
Above: *A schematic diagram of CO_2 flooding four reservoirs within Burnett Ranch. Arrows indicate reservoir processing speed, and the dotted green the location of the flood front.*

CO_2 floods pose a number of challenges. Points to consider include:

- Corrosion – The presence of carbonic acid translates to the need for specialized coatings and materials for any and all equipment that comes into contact with fluid produced from the reservoir.
- Fluid chemistry – The addition of CO_2 in the reservoir affects the chemistry of the fluids within the reservoir and can potentially change the precipitation threshold for certain compounds such as asphaltene.
- Processing speed – The reservoir processing speed is the amount of time it takes for injected CO_2 to show up in a nearby producer and is dictated by injection rate, injection pressure, and properties of the reservoir.
- Conformance – The uniformity of the flood front sweep; poor conformance in both the vertical and lateral directions are indicative of variabilities in permeability, which may lead to inefficient flooding.

The Hunt Burnett Ranch at Present

Burnett Ranch operates as a successful CO_2 flood. The flood consists of 70 wells total: 38 producers, 26 CO_2 injectors, and 6 water injectors which are split into 26 injector-centered patterns that cover the reservoir intervals earmarked for CO_2 flooding. CO_2 injection began in the northeast and progressed to the southwest. Water injectors outside the bounds of the flood help contain the CO_2 to the productive area. Up to four reservoir intervals may be simultaneously flooded by an injector, and the processing speed for each reservoir differs both laterally and vertically. To date, good response has been seen so far with peak tertiary production rates—which on average, have been 14x higher than pre-response rates. Continued development and expansion to the far southwest of the field have been planned for 2020.



Right: *A pattern map of the Hunt Burnett Ranch. Red outline is Strawn 5400′ Sandstone, green Strawn Lower Sandstone, blue Strawn 5400′ Limestone, and the various colored dashed outlines are Twin Peaks Sandstones. Red shading indicates both CO_2 and water injection, while the blue shading indicates water injection only. The yellow star indicates the location of the YA-10 type log.*