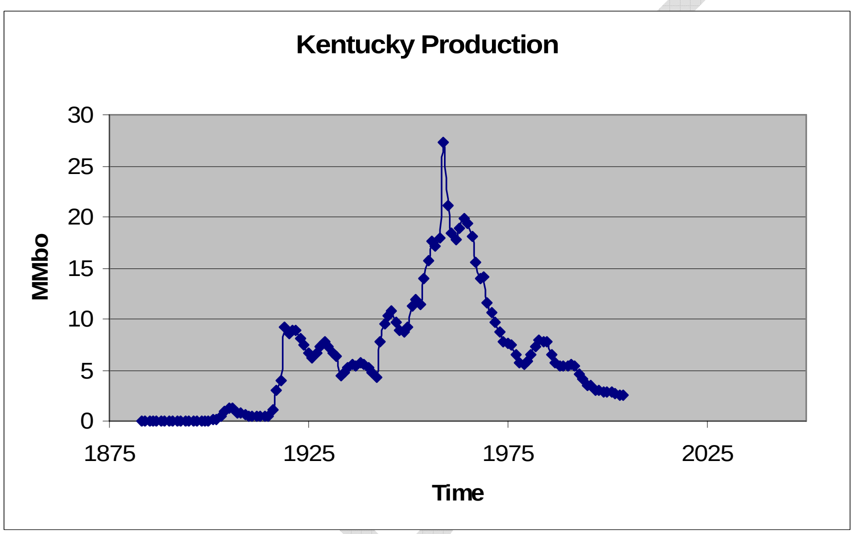
## Introduction

This is a working document that has been revised multiple times over the course of several years. The main purpose is to provide documentation for various figures on resources and reserves. This current document differs in two respects from preceding versions:

1. In estimating Kentucky's original oil in place (OOIP), yearly production data have varied. Three sets of calculations were made using productions for 2005, 2006, and 2007. The average decline rate and remaining production were used to determine OOIP, abandonment year, and total oil recovered to the abandonment year.
2. Original estimates of $CO_2$ availability assumed $CO_2$ could be captured from all sources. The current estimate assumes only about 57% of Kentucky's total emissions can be captured based on the emissions from coal-fired electric generation utilities. This revision only changes the total amount of $CO_2$ available which (still) vastly exceeds the estimated amount that could be used for EOR.

## Future Recovery of Oil in Kentucky

More than 780 million barrels of oil produced in Kentucky from 1883 to 2007. Peak production occurred in 1959 with over 27 million barrels of oil. Future reserves and original oil in place may be calculated by decline analysis. Fluctuations of the well head price of oil and production over the years 2005 to 2007 suggest an average of the decline rates for these three years be used for projections. These analyses indicate that, if no new discoveries are made and no new enhanced recovery technologies are applied to Kentucky's existing fields, 45 million barrels of oil remain to be produced. Calculations also indicate that as much as 1.6 billion barrels remain in place. When the tar sand resources are incorporated, an indicated 5 billion barrels of known oil resources are potentially available. If an incremental one fourth of this potential resource can be recovered using carbon dioxide injection or other enhanced recovery technology, an additional 409 million barrels of oil could be available for recovery from Kentucky's oilfields. Several $CO_2$ enhanced oil recovery scenarios are examined to investigate future recovery.



| | | |
|---|---|---|
| Initial year, $T_i$ | 1959 | 27,271,998 Stock tank barrels (STB) |
| Final year, $T_t$ | 2005<br>2006<br>2007 | 2,453,942 STB<br>2,170,806 STB<br>2,617,725 STB<br>2,414,158 STB (avg) |
| Abandonment rate (less than 10 barrels per well per year) | $q_{abnd}$ | 100,000 STB/year |
| Recovery factor | $rf$ | 40 % |
| Cumulative production (to 2007) | $Q = \sum_{j=1}^{n} q_j$ | 779,774,633 STB |
| Nominal decline rate | $D = \frac{-\ln\left(\frac{q_i}{q_t}\right)}{T_t - T_i}$ | 5.235 % (2005)<br>5.385 % (2006)<br>4.882 % (2007)<br>5.167 % (avg) |
| Remaining production | $R = \frac{(q_t - q_{abnd})}{D}$ | 44,964,254 STB (2005)<br>40,276,714 STB (2006)<br>53,571,740 STB (2007)<br>46,270,903 STB (avg) |
| Abandonment year | $T_{abnd} = \frac{\ln\left(\frac{q_{abnd}}{q_t}\right)}{-D} + T_t$ | 2125 (from averages) |
| Total oil recovered | $R_{total} = Q + R$ | 826,045,536 STB |
| Original oil in place | $OOIP = \frac{R_{total}}{rf}$ | 2,065,113,839 STB |

Available production records indicate Kentucky has produced a total of 779 million barrels of oil (MMbo, 1883 to 2007). Using standard exponential decline modeling, future oil production volumes may be expected to decline by 5.2% (average) yearly to an abandonment rate of 100,000 barrels of oil per year in 2125. This method predicts production of an additional 46 MMbo for a total of 826 MMbo in a conservative, “business as usual”, scenario in which no extraordinary or innovative technologies are applied. Using these data, if the 826 MMbo of expected production represent a recovery efficency of approximately 40%, Kentucky’s total original oil in place is 2,065 MMbo. This figure will be used as the basis for determining incremental oil recovery in various $CO_2$ EOR scenarios.

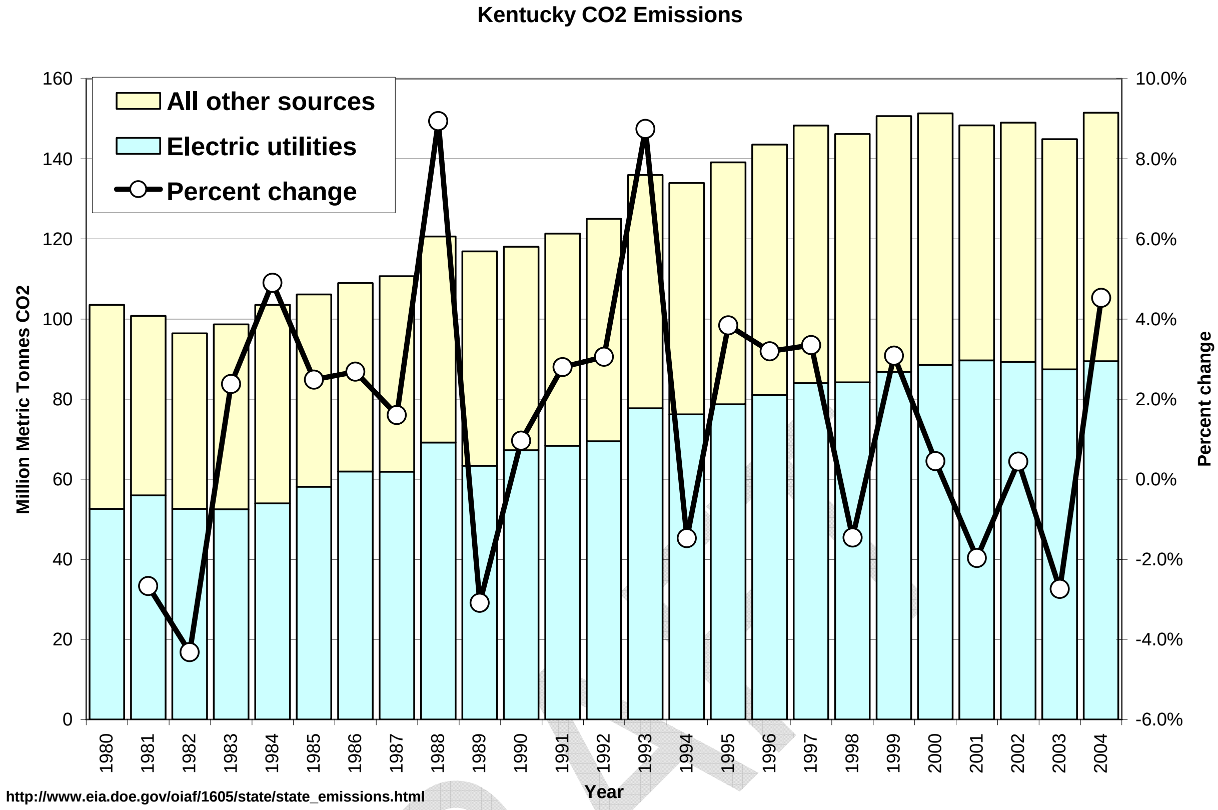
## How much $CO_2$ can you use for EOR in Kentucky?

To answer this question, two additional questions must be addressed:

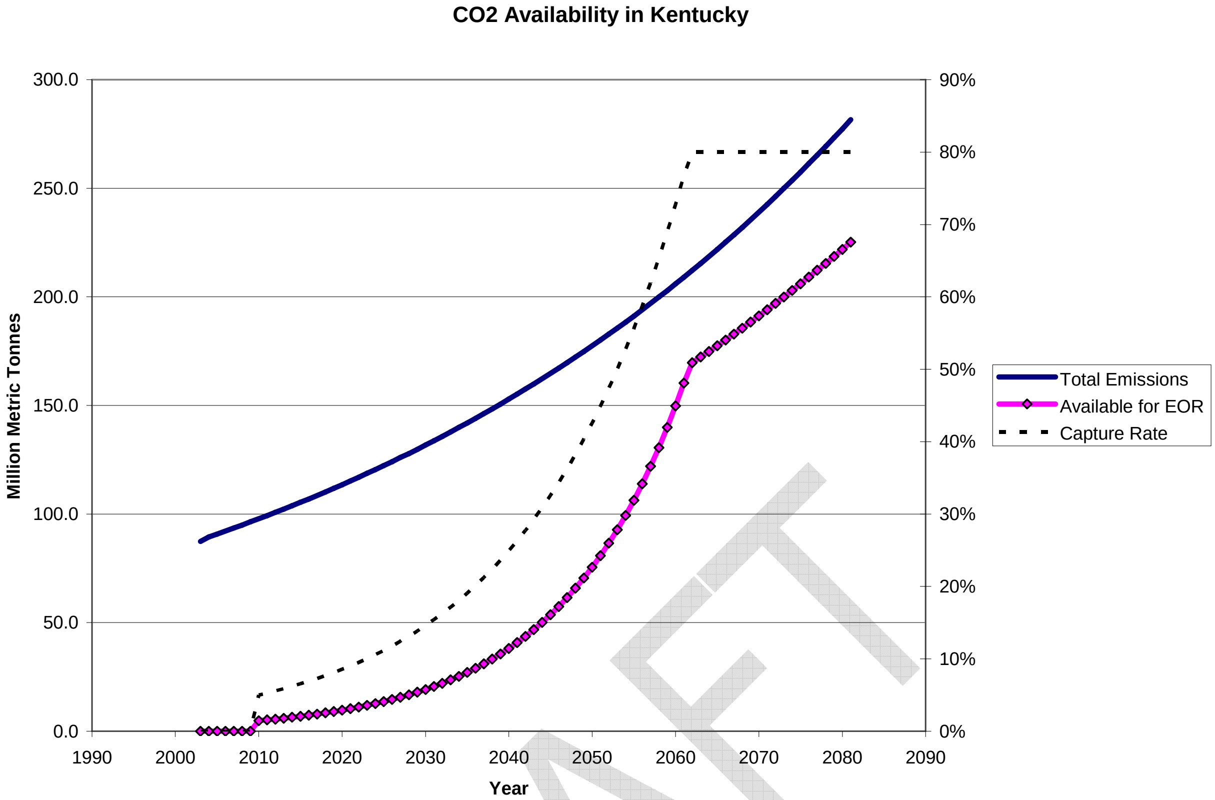
1. How much $CO_2$ might be available as IGCC, CTL, Ethanol, and other plants implement carbon capture technologies?
2. How much oil could be produced using $CO_2$ EOR in Kentucky?

***Caveat: all modeling is “back of the envelope” at best and is made using prevailing assumptions that may prove significantly different from actual experience. All estimates will be strictly volumetric; <u>no economics</u> are considered (capital investment in capture technology, recurring cost of capture, $CO_2$ transportation between capture and EOR site, etc.).***

## $CO_2$ Availability:




- Total Kentucky $CO_2$ emissions from all sectors have exceeded 140 million metric tonnes (MMt) per year since 1996.
- Emissions were declined slightly since a high of 150 MMt in 2000.
- Assume emissions will increase 1.5% per year beginning with 89 MMt (2004 emissions from electric power sector, 59% of Kentucky's total emissions). The original estimate of $CO_2$ availability was based on 100% of the total Kentucky emissions and didn't account for large stationary sources where $CO_2$ capture was most likely to occur.
    - o EIA indicates eastern Kentucky (Appalachian) coal production will remain steady and western Kentucky (Interior) coal production will increase by 1.1% per year.
    - o Kentucky's total coal production increased by 4.8% from 2004-2005.
    - o Assume emissions will grow at a rate greater than production, but less than Kentucky's annual production (increasing efficiency in generation).
- Assume carbon capture will begin no sooner than 2010 at 5% of the total emissions and will increase 5.5% per year for the next 50 years to a maximum capture rate of 80%.






Discussion: It appears that sufficient volumes of high-grade $CO_2$ will be available for EOR. The 80% cap on the efficiency of the capture process reflects: the efficiency of capture processes, possible loss of $CO_2$ during transportation, and possible loss during recycling/reusing $CO_2$ in the EOR process.

## *$CO_2$ EOR Scenarios:*

Shallow high-pressure miscible flooding is a novel and untested concept in which $CO_2$ is injected into a reservoir present at depths shallower than the minimum miscibility pressure (MMP) of $CO_2$ for the oil present in the reservoir. Injection rates are maintained at levels that ensure pressures exceed the critical pressure for $CO_2$ but remain lower than the fracture gradient of the reservoir rock thus maintaining the $CO_2$ in a supercritical state. No information is available on which to base recovery efficiencies for this EOR method.

Three basic scenarios were considered based on the range of incremental recovery efficiencies cited by Steve Melzer (personal communication) for immiscible $CO_2$ EOR.

- 3% — Minimum incremental recovery rate for immiscible $CO_2$ repressurization projects.
- 8% — High end of range cited for incremental recovery rate for immiscible $CO_2$ repressurization projects.
- 10% — Possible incremental recovery rate using $CO_2$ for immiscible repressurization, miscible flooding (below 2,500 feet), and shallow high-pressure miscible flooding (shallower than 2,500).

| Scenario | Incremental recovery ($Q_{inc}$ MMbo) | Peak production rate (MMbo/yr) | Peak year after onset of EOR | Model Parameter, a | Model Parameter, b |
|---|---|---|---|---|---|
| 3% | 60 | 2.1 | 41 | 250 | -0.14 |
| 8% | 160 | 5 | 51 | 140 | -0.1 |
| 10% | 200 | 10 | 50 | 2000 | -0.1 |

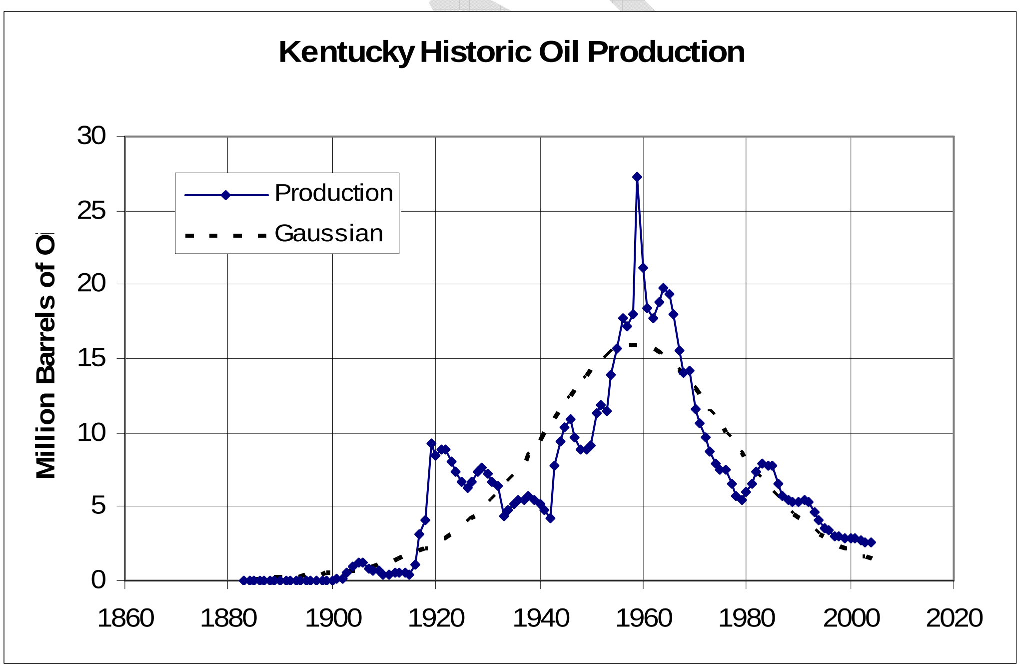
A Gaussian model is used to represent the incline to a production peak followed by a decline toward abandonment. Cumulative production to time $t$ in years, $Q_t$, is computed:

$$Q_t = \frac{Q_{inc}}{(1 + a * \exp(b * t))}$$

Production at time $t$ (for $t$>0) is $Q_t - Q_{(t-1)}$.

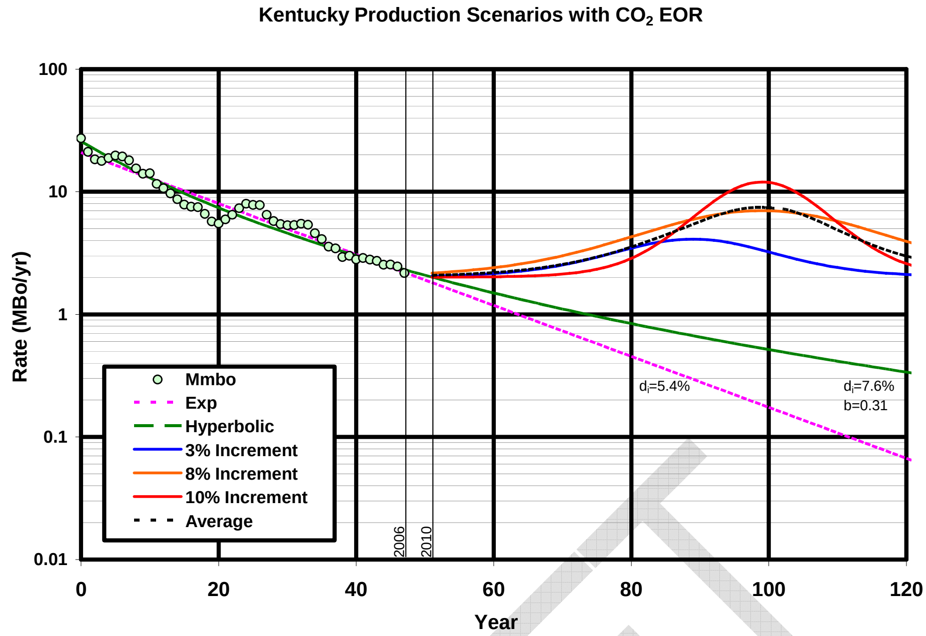
Rationale for the Gaussian model:

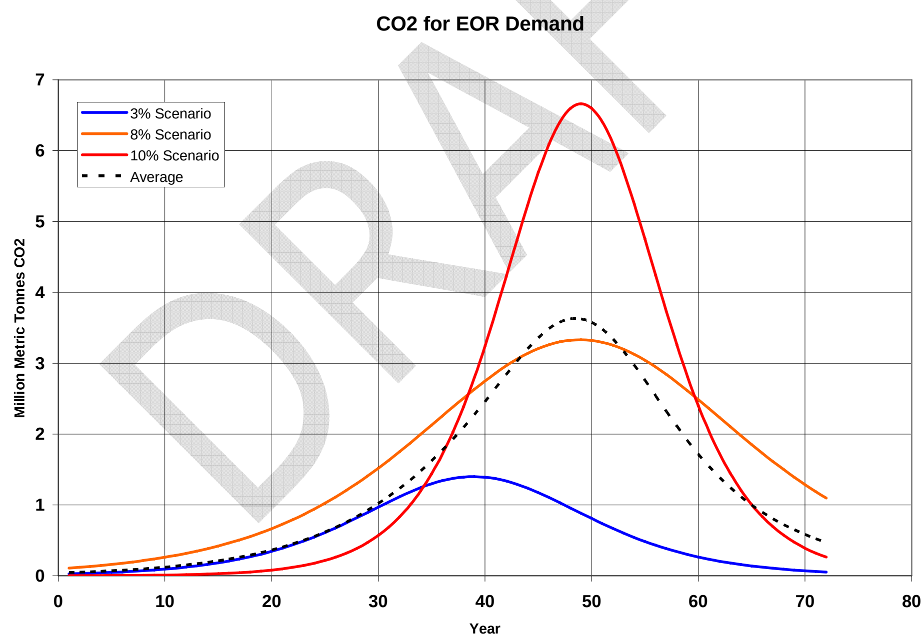
1. A Gaussian model can be fit by calculating and minimizing the root mean square deviation of the available annual Kentucky oil production data.
2. This model has been used by M. King Hubbert, A. A. Bartlett, and others to model oil production histories.




Assumptions: 1-2 barrels of oil can be recovered per metric tonne of $CO_2$ injected (immiscible repressurization). Use 0.667 tonnes of $CO_2$ per barrel of oil (1.5 bbls/tonne).

The scenarios compared:



## Conclusions:

1. Abundant $CO_2$ for EOR in Kentucky would be available from carbon capture facilities in Kentucky.
2. Up to 7 MMt of $CO_2$ per year could be employed for EOR (more with more fields, new technology, higher efficiency, etc).
3. From 60 to 200 million barrels of additional oil could be produced using $CO_2$ EOR.
4. With $CO_2$ EOR, Kentucky's annual oil production could increase to nearly 12 million barrels per year (best case) representing up to an additional $54 million annual severance tax collected (assuming $100/bbl crude oil price) with a likely average increasing to 7.5 million barrels of oil per year ($34 million severance tax).

Notes:
m:\my documents\co2proj.xls for data, calculations, and charts
m:\my documents\ky_future_oil_analysis.xls
m:\my documents\eia_ky_04_details.xls
c:\python24\ooip_2008.py