



Development Philosophy of an Assessment Methodology for Hydrocarbon Recovery Potential Using CO₂-EOR Associated with Carbon Sequestration

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**U.S. Geological Survey
Department of the Interior**

U.S. Congress Mandate to USGS for CO₂ Project

The U.S. Geological Survey is authorized by the Energy Independence and Security Act of 2007 (Public Law 110-140, 2007) [EISA] to:

1. Conduct a national assessment of geologic storage resources for carbon dioxide (CO₂)
2. Estimate the “potential volumes of oil and gas recoverable by injection and sequestration of industrial carbon dioxide in potential sequestration formations”.

Objectives

Development of an assessment methodology to estimate technically recoverable hydrocarbon potential using CO₂-EOR within the sedimentary basins of the United States.

The recoverable hydrocarbon volume occupies potential pore space that may be available for sequestration of anthropogenic CO₂ in sub-surface hydrocarbon reservoirs.

CO₂-EOR USGS Workshop

- ❖ **Workshop** : Hosted by the USGS in collaboration with Stanford University;
- ❖ **Objectives** : To establish guidelines for the assessment methodology;
- ❖ **Attendees** : A total of 28 experts from academia, natural resources agencies and laboratories of the U.S. Government, State and international geologic surveys, and representatives from oil and gas industry;
- ❖ **Publications** : A USGS factsheet on the findings of the workshop. (Verma and Warwick, 2011; <http://pubs.usgs.gov/fs/2011/3075/>);
- ❖ **Developments** : A framework containing recommended assessment methodology (to be discussed later in this presentation);

Background

Most successful EOR methods: CO₂-EOR & thermal recovery;

CO₂-EOR under miscible conditions (Taber and others, 1997) :

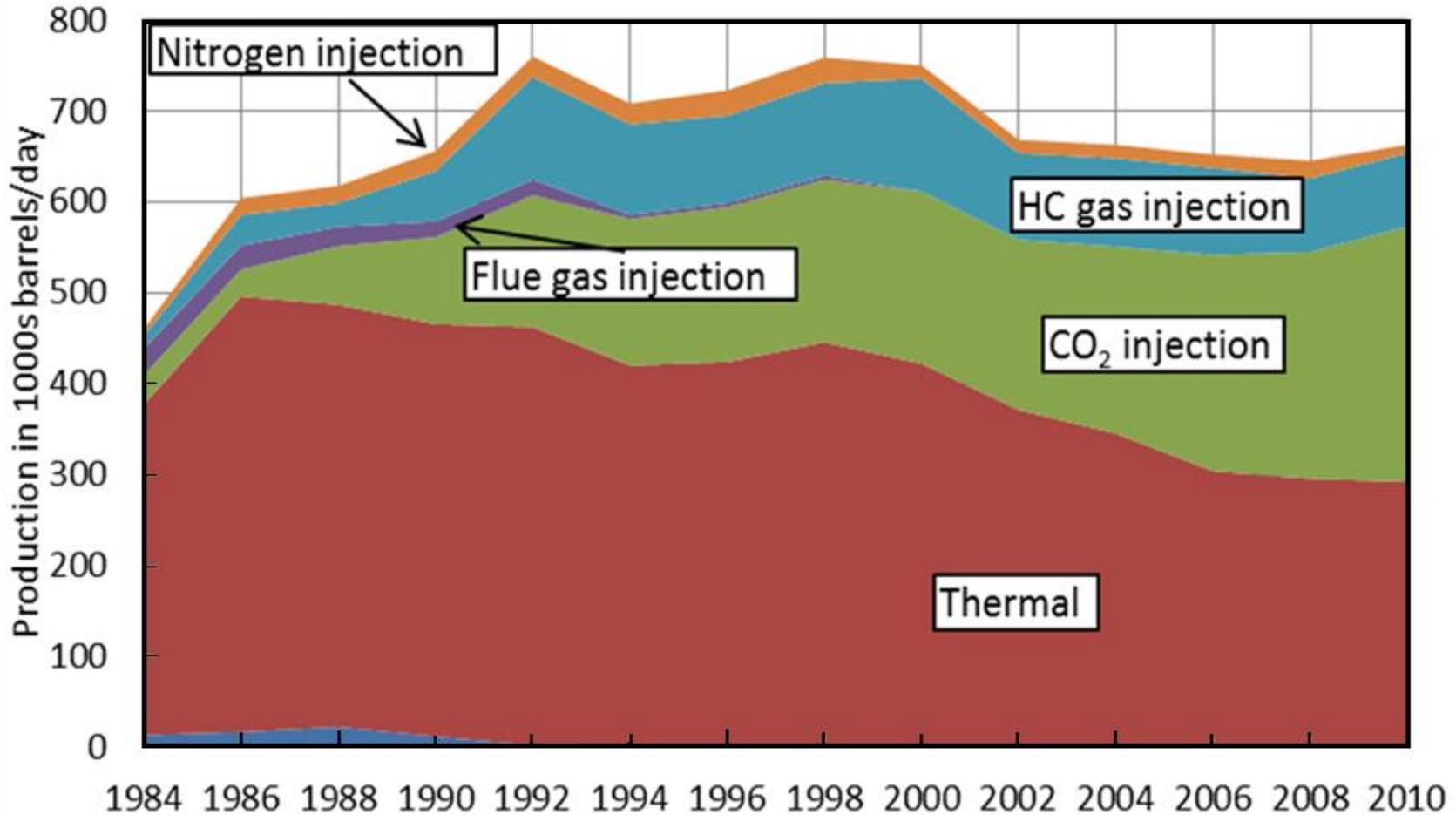
- ❖ Under ideal conditions as high as 90 percent recovery of the original oil-in-place (OOIP) in the swept region;
- ❖ In practice lower recoveries due to geologic, reservoir engineering and other factors;

CO₂-EOR projects status within the U.S. (Kuuskraa, 2012):

Year	# Projects	Production Rate, bbls/day
2010	114	272,169
2012	123	284,193

Historical EOR Production

U.S. EOR Production



Koottungal (2010, Oil & Gas Journal)

CO₂-EOR Process: Immiscible CO₂-EOR

CO₂ improves oil recovery by:

- ❖ Remaining on the top of oil;
 - Maintains gas-cap pressure,
 - The process performs like a gas-cap drive,

- ❖ Dissolving in oil;
 - Causes oil swelling & reduces oil viscosity,
 - Improves sweep efficiency,
 - The process performs like a solution-gas drive,

CO₂-EOR Process: Miscible CO₂-EOR

- ❖ Miscibility occurs as a result of:
 - Vaporization of intermediate hydrocarbon components into CO₂ ,
 - CO₂ condensation into reservoir oil,
- ❖ Miscibility improves oil recovery by:
 - Eliminating the interfacial tension & capillary effects,
 - Improving sweep efficiency,
- ❖ Recovery Factor (Remson, 2010):
 - 4-15% primary recovery
 - Up to 30-45% additional secondary recovery
 - As high as 22% additional recovery by CO₂-EOR (result of some pilot studies)

Previous Resource Assessments for Lower 48 U.S. States

1. National Petroleum Council (NPC) based on EIA data base (NPC, 2011);
2. Advanced Resources International, Inc (ARI, 2010);
3. National Energy Technology Laboratory, Department of Energy (DOE) (Kuuskraa and Ferguson, 2008):

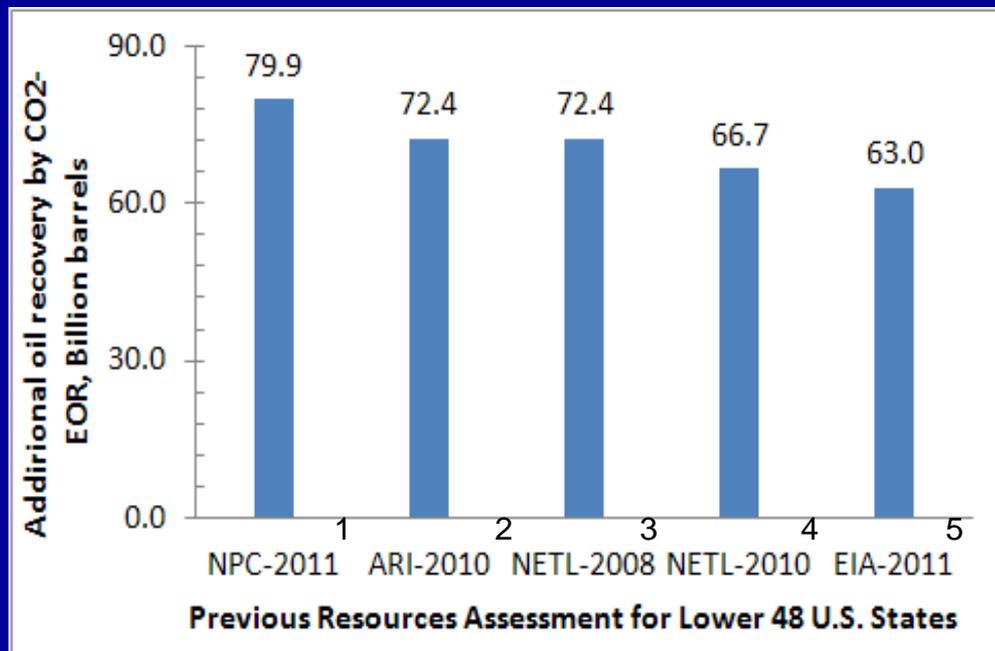
- ❖ Included 2012 large reservoirs

4. National Energy Technology Laboratory, DOE (Remson, 2010):

- ❖ Included 6,344 large reservoirs

5. Energy Information Administration (EIA), DOE (Van Wagener and Mohan, 2011):

- ❖ 2,235 fields (10,097 reservoirs) for all EOR applications.



USGS Methodology: Volumetric Approach

- ❖ Build a comprehensive dataset for all reservoirs/fields within U.S. basins using:
 - Subscribed data sources: IHS Energy Group (2012) and Nehring Associates (2012),
 - Unsubscribed data sources: Such as publicly available data,
- ❖ Populate dataset for missing data using:
 - Analogs,
 - Algorithm,
 - Simulation,

USGS Methodology: Volumetric Approach

For reservoirs that either have gone or are currently under CO₂-EOR process:

- Gather geologic, reservoir and fluid property data
- Gather production/injection data such as duration, rates, number of wells, well spacing, etc.
- Perform Decline Curve Analysis (DCA) for before and after CO₂-EOR
- Validate the results of DCA for each reservoir
- Estimate decline parameters before and after CO₂-EOR
- Estimate variations in oil production rate and recovery factor due to CO₂-EOR
- Establish mathematical relationships between changes in recovery factor and geologic, reservoir and fluid properties

USGS Methodology: Volumetric Approach

For the estimated changes in recovery factor due to CO₂-EOR :

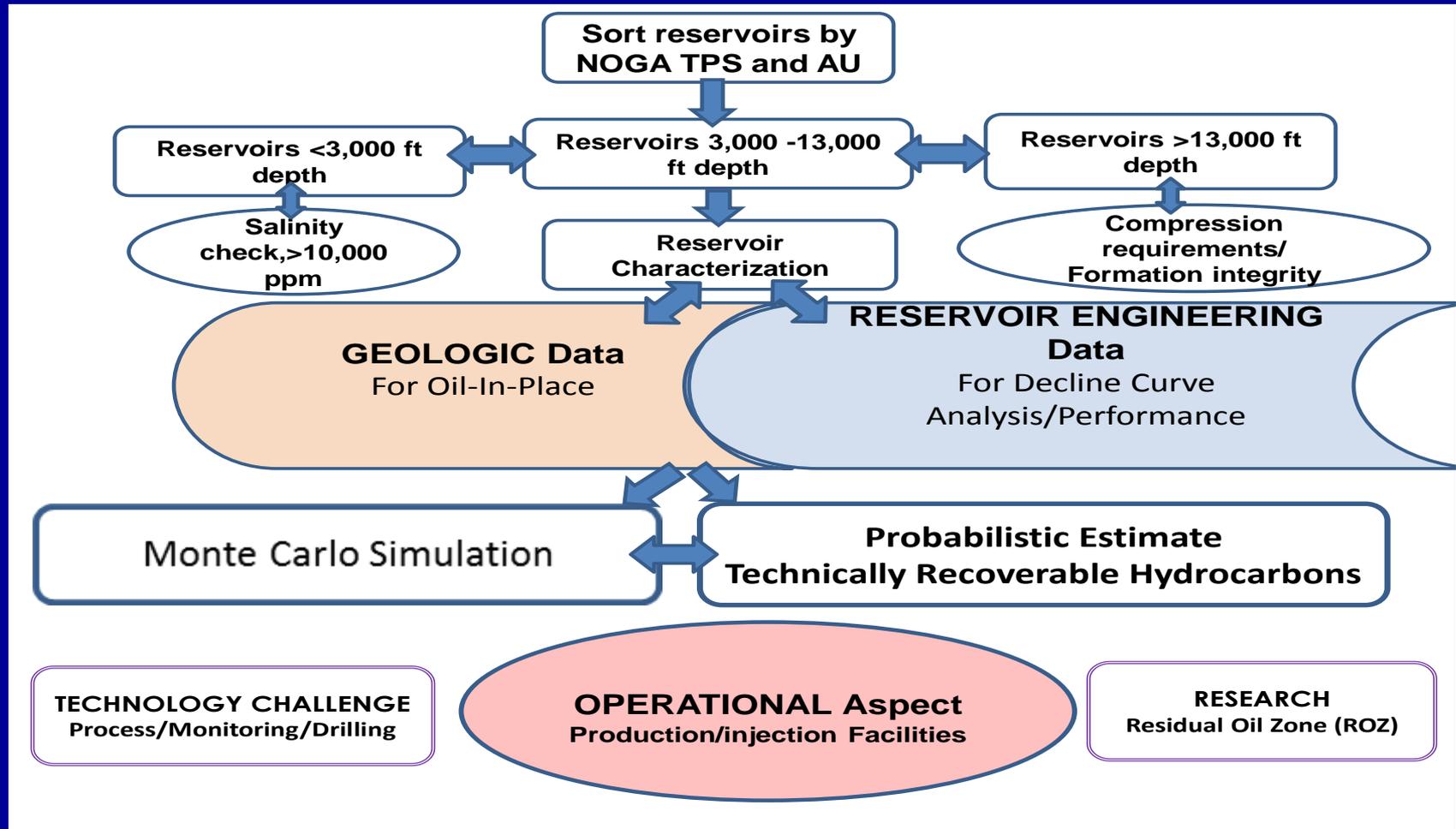
- Carry out statistical analysis for evaluating the impact of various production scenarios;
- Develop generalized models for various group of reservoirs formed on the basis of lithology, oil gravity, etc.
- Perform Monte-Carlo simulation to evaluate impact of variables that make up OOIP and technically recoverable hydrocarbon volume such as area, thickness, porosity, connate water saturation;
- Produce probabilistic estimates of minimum, maximum and most likely case CO₂-EOR hydrocarbon potential for various group of reservoirs;

USGS Assessment Methodology: Volumetric Approach

Apply the described methodology and obtained generalized mathematical relationships to:

- Aggregate the technically recoverable hydrocarbons from each individual reservoir by field and basin nationwide,
- Estimate maximum, minimum and most likely increases in recovery factor values due to CO₂-EOR,
- Apply the developed framework presented on next slide for assessment methodology.

USGS Assessment Methodology: Framework and Screening Criteria



NOGA: National Oil and Gas Assessment; TPS: Total Petroleum System; AU: Assessment Unit;

Project Status: Work in Progress

- ❖ In collaboration with Stanford University, the USGS organized a CO₂-EOR workshop to develop guidelines for assessment methodology to estimate the potential for (Verma and Warwick, 2011):
 - Additional oil recovery due to CO₂-EOR in oil/gas fields within U.S. basins
 - CO₂ sequestration as side advantage of CO₂-EOR process within U.S. basins
- ❖ The process of building a comprehensive dataset using the subscribed databases and publicly available data is currently ongoing;
- ❖ Decline curve analysis has been performed on several reservoirs to establish a generalized calculation mechanism for additional recovery factors due to CO₂-EOR;
- ❖ Development philosophy has been formulated for the assessment methodology.

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