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King Abdullah Petroleum Studies and Research Center

CO_2-EOR for emissions reduction: identifying opportunities

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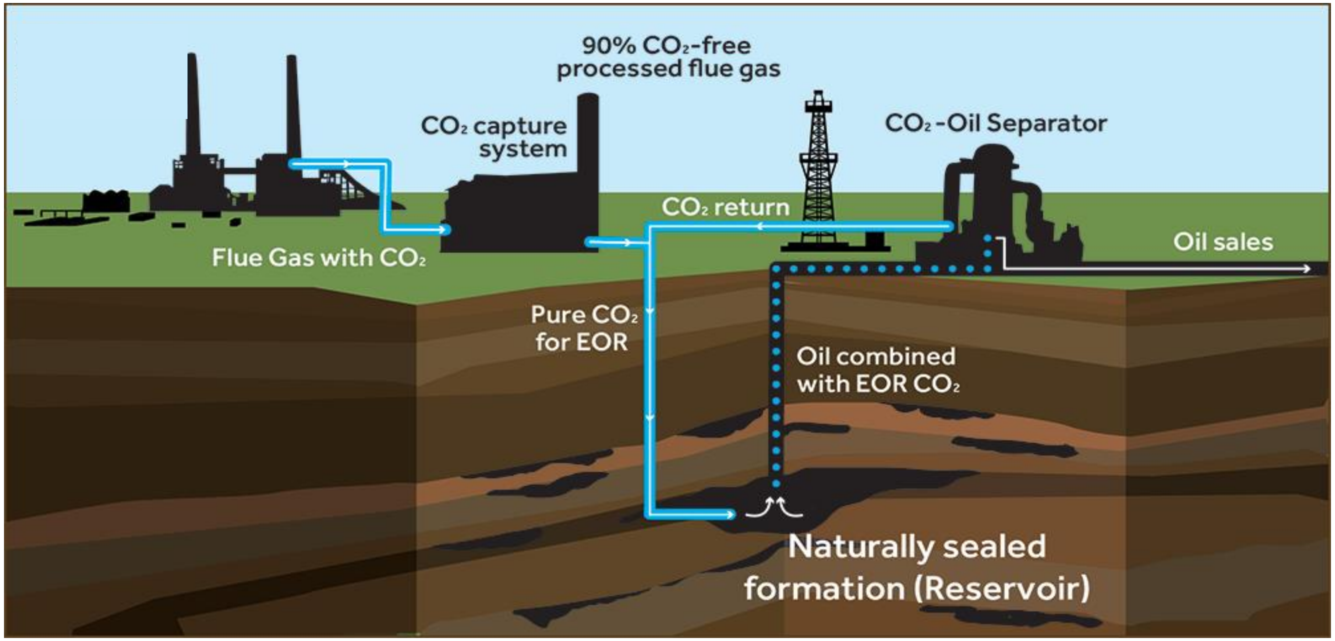
How does it work?

- CO_2 from industrial sources is injected into reservoirs to boost oil recovery
- Injected CO2 is produced with the oil, the CO_2 is separated from the oil and re-injected for further oil recovery. Ultimately almost all of the CO2 injected is trapped in the reservoir
- Physical and chemical process operate to effectively contain CO_2 for thousands of years



CO_2-EOR: a potential win-win situation

- Injecting carbon dioxide CO2 into oil reservoirs to enhance oil recovery EOR has been commercially used for several decades in the petroleum industry (mainly US). Business objective so far has been on producing more oil.

- With increasing attention to the climate change the option of using CO2-EOR for emission reduction has moved into focus.

- Application in various industry sectors, including
  - Electric power
  - Steel
  - Cement
  - Refining
  - other

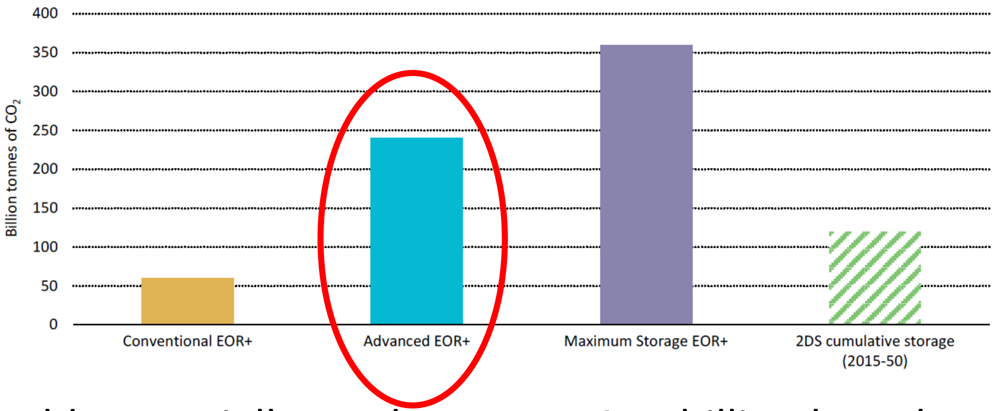
Specification of EOR practices

Scenario	Description	Incremental recovery % OOIP	Utilisation tCO_2/bbl
Conventional EOR+	Miscible WAG flood with vertical injector and producer wells in a "five spot" or similar pattern. Operational practices seek to minimise CO_2 use.	6.5	0.3
Advanced EOR+	Miscible flooding following current best practices optimised for oil recovery. May also involve some "second-generation" approaches that boost utilisation and recovery.	13	0.6
Maximum Storage EOR+	Miscible flooding where injection is designed and operated with the explicit goal of increasing storage. Could include approaches in which water is removed from reservoir to increase available pore volume.	13	0.9

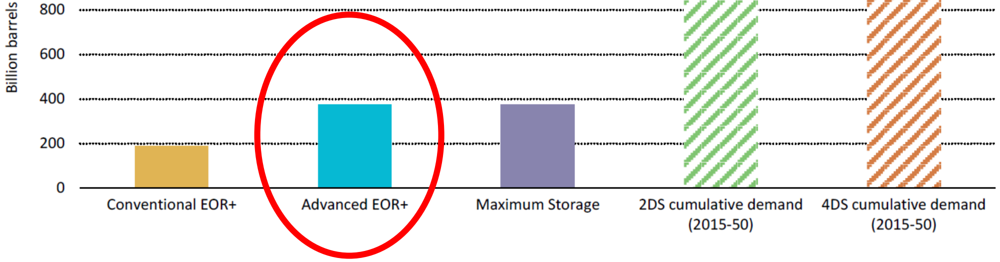
Source: OECD/IEA, 2015

Technical potential

- Opportunities for CO_2 storage via EOR are substantial. IEA estimates ranges from 50% to more than three times the amount of total CO_2 storage required under the IEA 2DS scenario through 2050.



- Advanced EOR could potentially produce up to 375 billion barrels.



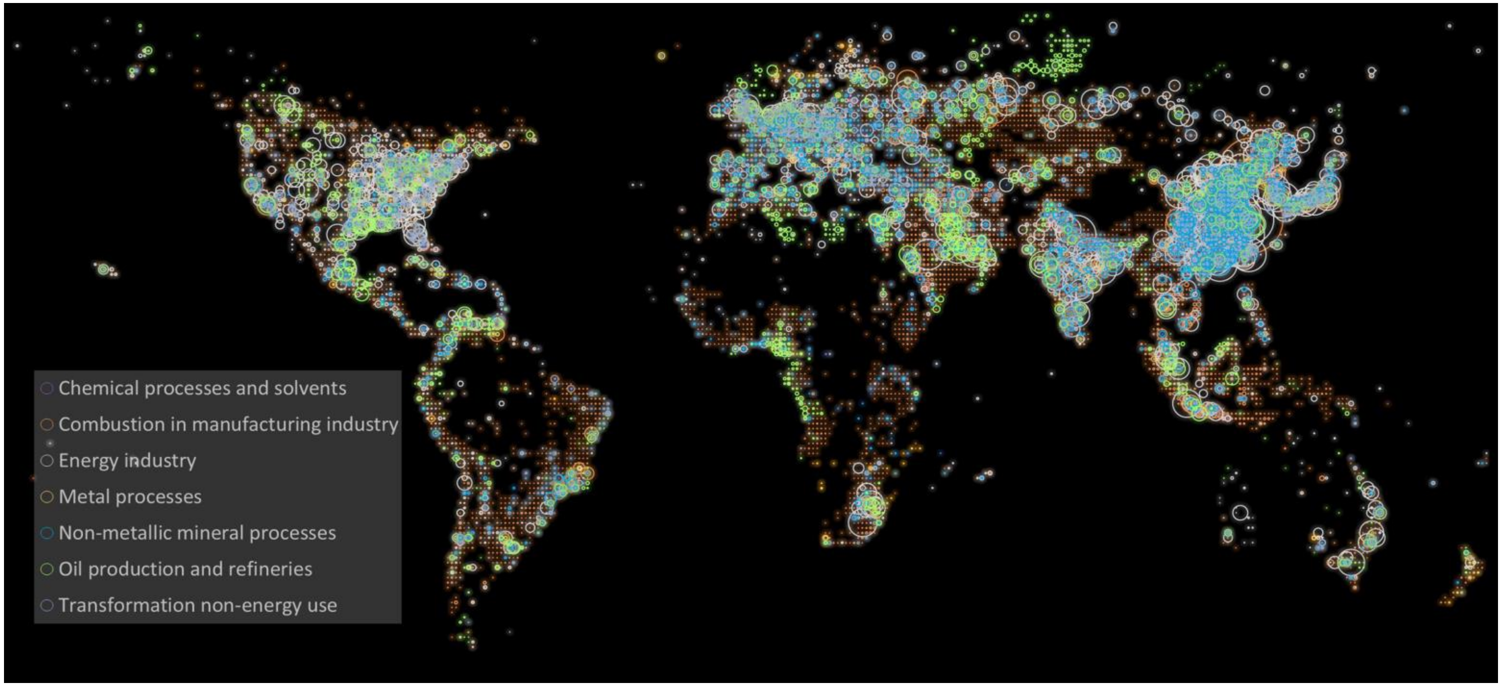
Data: OECD/IEA, 2015

Matching sinks to sources: data

- Oil field data from Rystad Energy – UCube
  - reservoir screening criteria as in 2015 IEA report

- CO_2 supply from EDGAR (Emission Database fro Global Atmospheric Research) and IEA's CO_2 emissions from World Energy Outlook 2015

- North America excluded



Work flow

All relevant fields

The screening is done on all known oil fields globally that are either producing or expected to start production before 2025

Field level screening

1. Candidate fields

Fields matching the local field characteristics/ and reservoir-level screening criteria, either for miscible or immiscible CO_2 EOR flood are identified. Potential for additional production and storage potential is calculated

2. Potential projects

Potential CO_2 EOR projects are identified by considering that expected incremental production must be large enough to enable good return on necessary investments of a CO_2 EOR project.

Geographical screening

3. CO_2 availability

Projects that are located too far from large enough stationary CO_2 sources are screened-out

4. Clusters

Geographical high-potential clusters of projects are identified based on proximity to nearby fields and resource potential

Hotspots

5. Hotspots

The clusters are evaluated along multiple dimensions and the most promising clusters, the "hotspots" are identified and analyzed

Scoring of identified CO_2 EOR clusters (1/3)

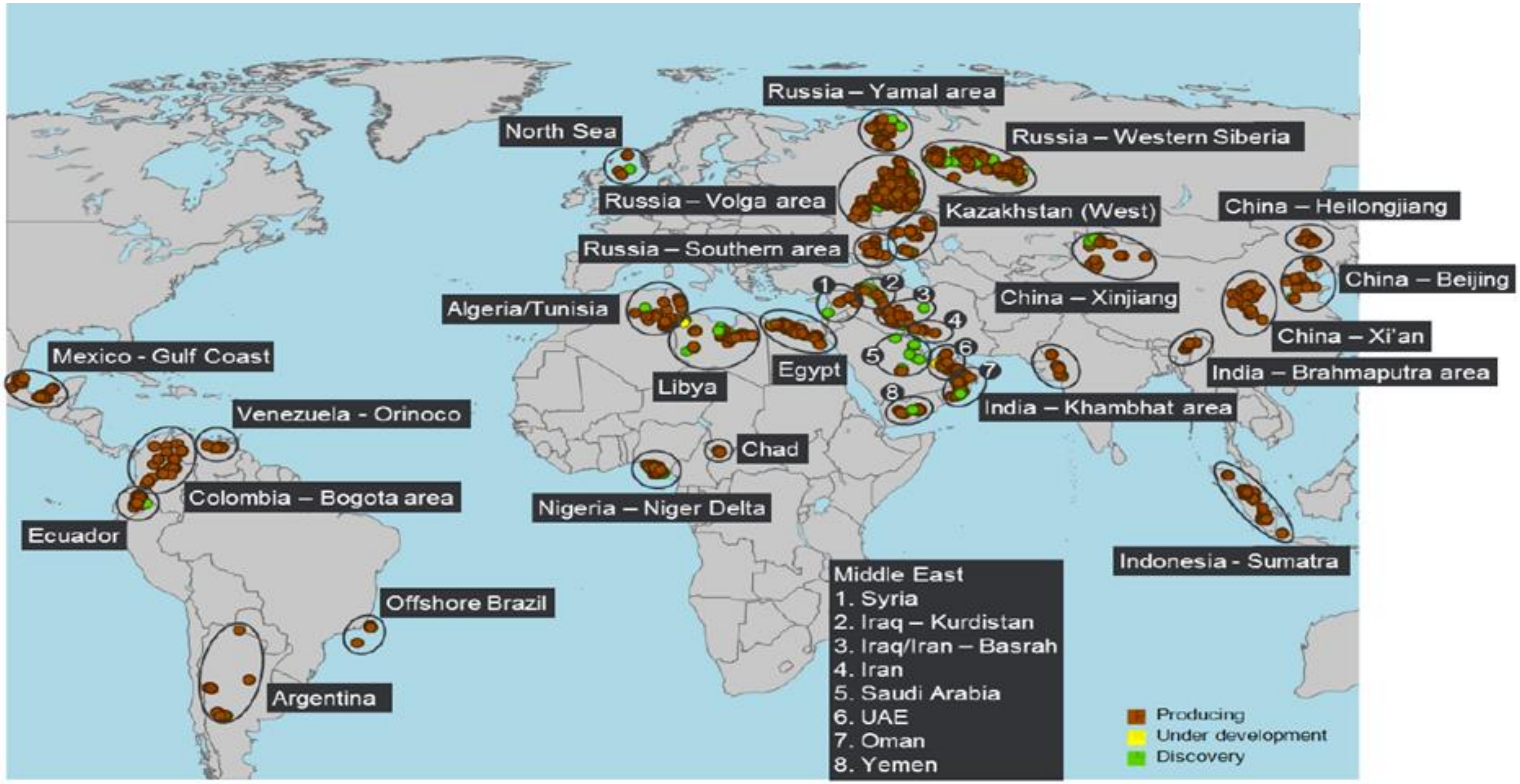
	Resources / Economics				CO_2 Supply		Hotspot	
Cluster	Production profile for cluster '16-'30 [kbbl/d]*	Incremental barrels [mmbbl]	Inc. barrels / # of fields [mmbbl/field]	CO_2 supply / demand [%]	Average distance to supply source [km]	Identified	Reasoning
Russia - Volga area	1,090 → 480 (-56 %)	12,500	20	19 %	361		Few incremental barrels per field. Low CO_2 supply.
Iran	360 → 490 (+36 %)	4 880	195	61 %	304	✓	Large EOR potential. Good CO_2 supply.
Russia - Western Siberia	510 → 330 (-37 %)	4 400	27	30 %	409		Few incremental barrels per field.
China - Xi'an	660 → 240 (-63 %)	4 380	125	107 %	408	✓	Large EOR potential. Large CO_2 supply.
UAE	380 → 480 (+27 %)	3 580	224	25 %	252	✓	Large EOR potential. Sufficient CO_2 supply
Iraq - Basrah	520 → 270 (-48 %)	2 980	166	20 %	273		Low CO_2 supply combined with high initial demand
China - Beijing	450 → 160 (-64 %)	2 400	42	151 %	368	✓	Good EOR potential. Large CO_2 supply.
Niger Delta	110 → 160 (+49 %)	2 220	27	3 %	315		Low CO_2 supply. Few incremental barrels per field.
Indonesia - Sumatra	70 → 20 (-66 %)	2 110	20	98 %	299		Few incremental barrels per field.
Oman	180 → 130 (-27 %)	1 730	24	94 %	393		Few incremental barrels per field.
Egypt	270 → 60 (-79 %)	1 520	14	46 %	381		Few incremental barrels per field.

Production profile: 2016 – 2030

Offshore
Onshore

Producing
Under development
Discovery

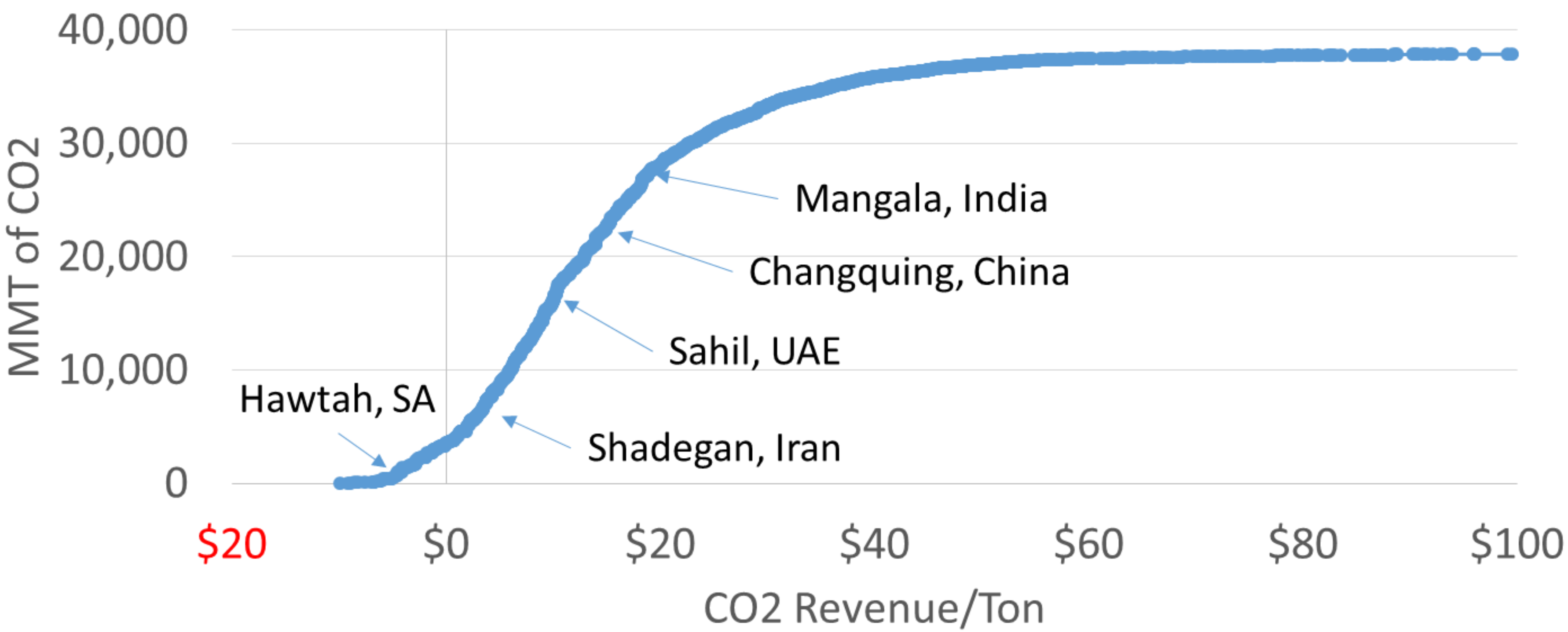
Clusters


Russia – Yamal area
North Sea
Russia – Western Siberia
Russia – Volga area
Kazakhstan (West)
China – Heilongjiang
Russia – Southern area
China – Beijing
Algeria/Tunisia
China – Xinjiang
China – Xi'an
Mexico - Gulf Coast
India – Brahmaputra area
Egypt
Libya
Venezuela - Orinoco
India – Khambhat area
Chad
Colombia – Bogota area
Nigeria – Niger Delta
Ecuador
Indonesia - Sumatra
Offshore Brazil
Argentina
Middle East
1. Syria
2. Iraq – Kurdistan
3. Iraq/Iran – Basrah
4. Iran
5. Saudi Arabia
6. UAE
7. Oman
8. Yemen
Producing
Under development
Discovery

- Iran
  - Very large potential of almost 5 bn bbl potential incremental production. Many CO2-EOR candidates located in proximity to power plants
- China Xi'an
  - Mature region with inherently low recovery rates and large potential for CO2 capturing
- UAE
  - Potential of incremental recovery both onshore and offshore of about 3.5 bn bbl
- China – Bejing area
  - One of the regions with the highest CO2 emissions globally and several large fields in late life
- Saudi Arabia
  - Large potential incremental production of 1.3 bn bbl and very significant CO2 supply
- North Sea
  - Most promising offshore regions with about 1 bn bbl potential incremental recovery. Significant CO2 sources in UK, Denmark and the Netherlands

CO2 prices and impact on storage

- With the UCube-EDGAR data, we ran a cost analysis on 2500 onshore fields (excluding North America)
- A breakeven price for CO2 was calculated for each field, @NPV 10% and $50/bbl oil, no taxes



Further Development

- Expand economic modelling to include effects of taxation, royalty etc.

- Determine biggest opportunities based on
  - Economics of current conditions
  - Largest increases in CO_2 storage based on minimal policy adjustments

- Determine the carbon intensity of upstream oil production using CO_2 EOR
  - Relative carbon intensity against other energy sources
  - Ranking of most-to-least carbon intensive reservoirs

- Joint workshop with Lawrence Livermore National Labs, Q4 -2017