Maximizing Subsurface Storage Capacity in Sedimentary Systems by Combined CO_2-H_2O Injection*

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Abstract

Large-scale CO_2 injection into the subsurface is a key technology to lower CO_2 emissions from point sources such as power plants. Deep saline aquifers have by far the largest capacity of potential storage space; however, many are poorly characterized, which increases risk of leakage through undetected faults or gaps in the cap rock. Gas and oil fields are much less extensive but are secure storage locations for CO_2 as the presence of hydrocarbons proves their ability to contain buoyant fluids for geological timescales. Moreover, a great deal is known about their size and ability to conduct fluids efficiently and the profits from enhanced oil recovery (EOR) as a result of CO_2 flooding may offset the cost of storage.

In this work, we propose using combined CO_2 and water injection to engineer a more secure storage strategy in both aquifers and oilfields. Injection of water and CO_2 increases the volume of the reservoir that comes in contact with CO_2, allowing for substantially increased capillary trapping of the supercritical CO_2 phase during the injection phase of the project and decreasing the reliance on an impermeable cap rock to contain buoyant CO_2. Counter-intuitively, injection of water and CO_2 has the further benefit of increasing the oil recovery and volume of CO_2 that can be stored in a combined CO_2/EOR project because of minimized gas cycling.

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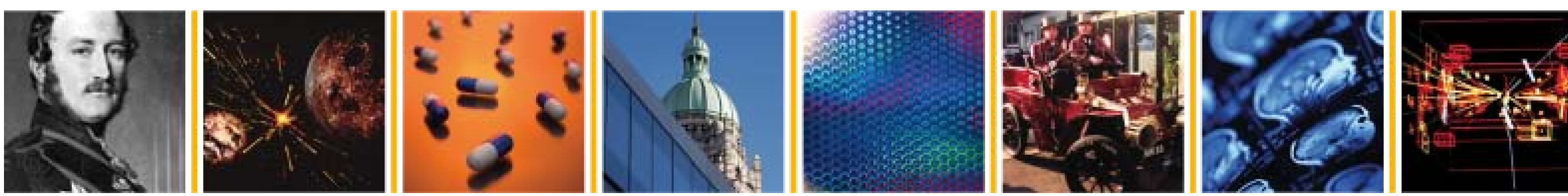

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Tara C LaForce, Martin J Blunt

April 13, 2010

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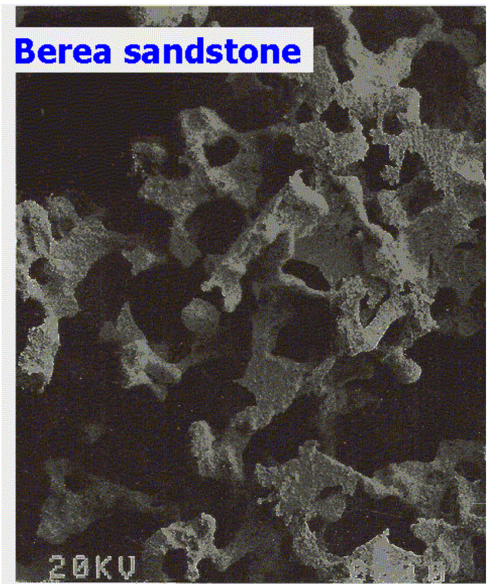
Why aquifers and oilfields?

- ❖Technology already established – many carbon dioxide injection projects in the world
- ❖Allows smooth transition away from a fossil fuel economy
- ❖Economic benefit of enhanced oil/gas recovery
- ❖Has potential to have a large impact on carbon dioxide emissions quickly
- ❖Low emission option for developing countries – e.g. China and India

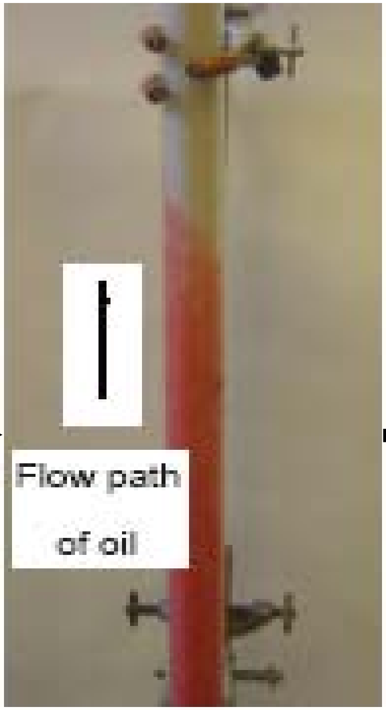
Notes by Presenter (for previous slide):

One thing we can do with CO_2 is to store it underground in deep saline aquifers, oil or gas reservoirs, or deep unmineable coal seams. This is an attractive option because the technology is already established –there are many CO_2 injection projects in the world, most to improve oil recovery. CO_2 injection buys us time until more alternative energy options are available, allowing for a smooth transition away from our fossil fuel based economy. There can be an economic benefit if CO_2 injection into reservoirs increases oil or gas recovery, which can defray the cost of carbon capture. Because much of the technology exists already, geological storage will have a large and immediate impact on CO_2 emissions. Finally, CO_2 capture and storage is a low emission option that we can offer to developing countries that are going to build coal-burning power plants anyway.

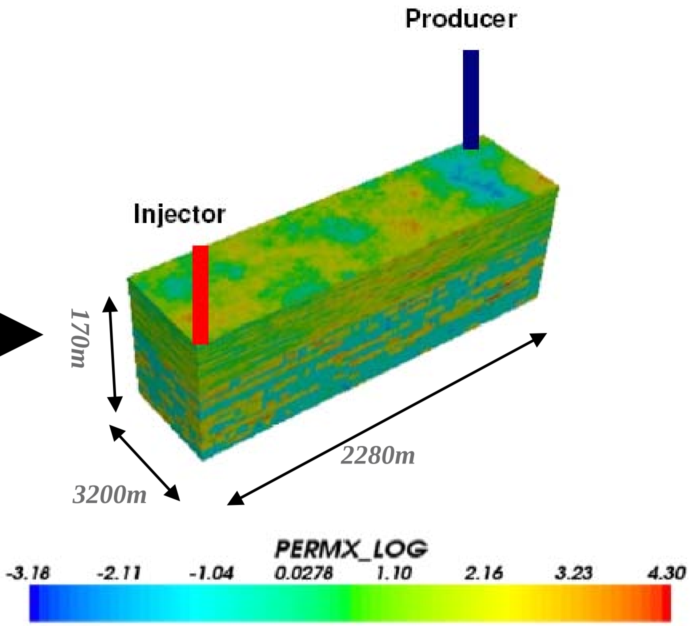
Spread of CO_2 is an inherently multi-scale process



Pore scale:
Model flow through pores directly
µm-mm



Laboratory scale:
Model flow using continuum approximation
cm-m



Field scale:
Model flow using continuum approximation
m-km

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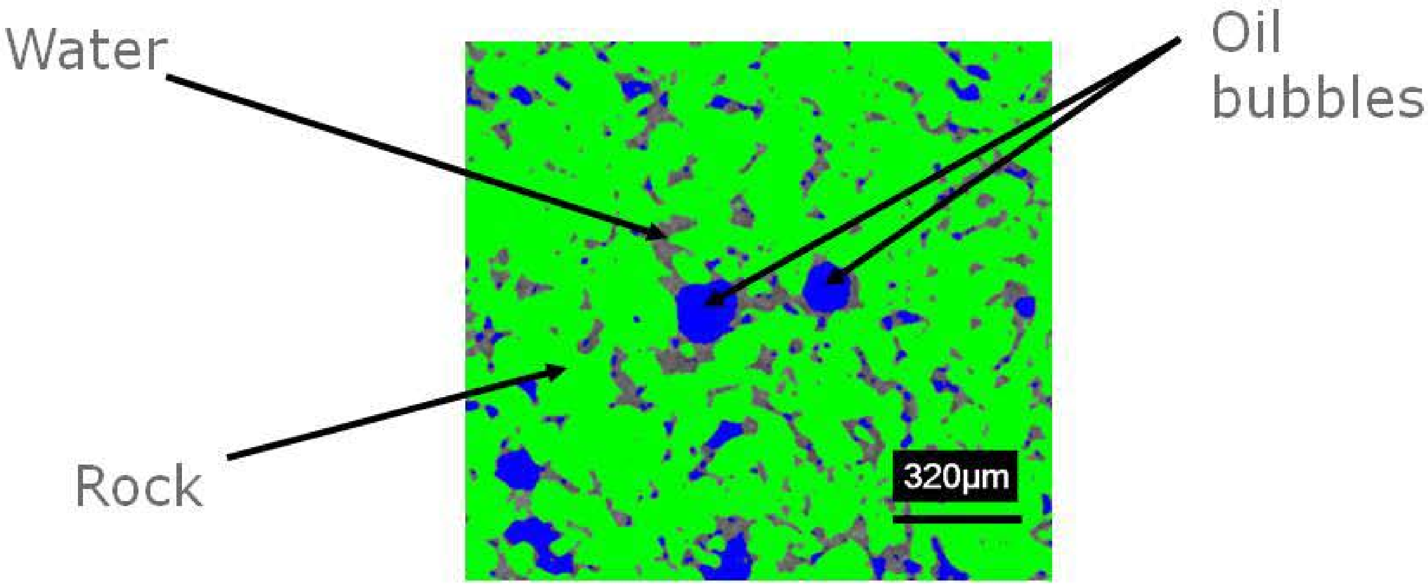
How is the CO_2 immobilized?

As CO_2 migrates through the rocks, it is trapped in tiny bubbles that can not move further



Dong, 2007

Notes by Presenter: So how far does the CO_2 spread? Fortunately, we know that it does not keep on spreading forever. As the CO_2 moves through the rocks, it leaves behind a trail of tiny bubbles of CO_2 that are effectively immobilized. This picture is a CT image of 100-200 um-sized bubbles of blue CO_2 trapped in pores in the grey rocks in the presence of green water.

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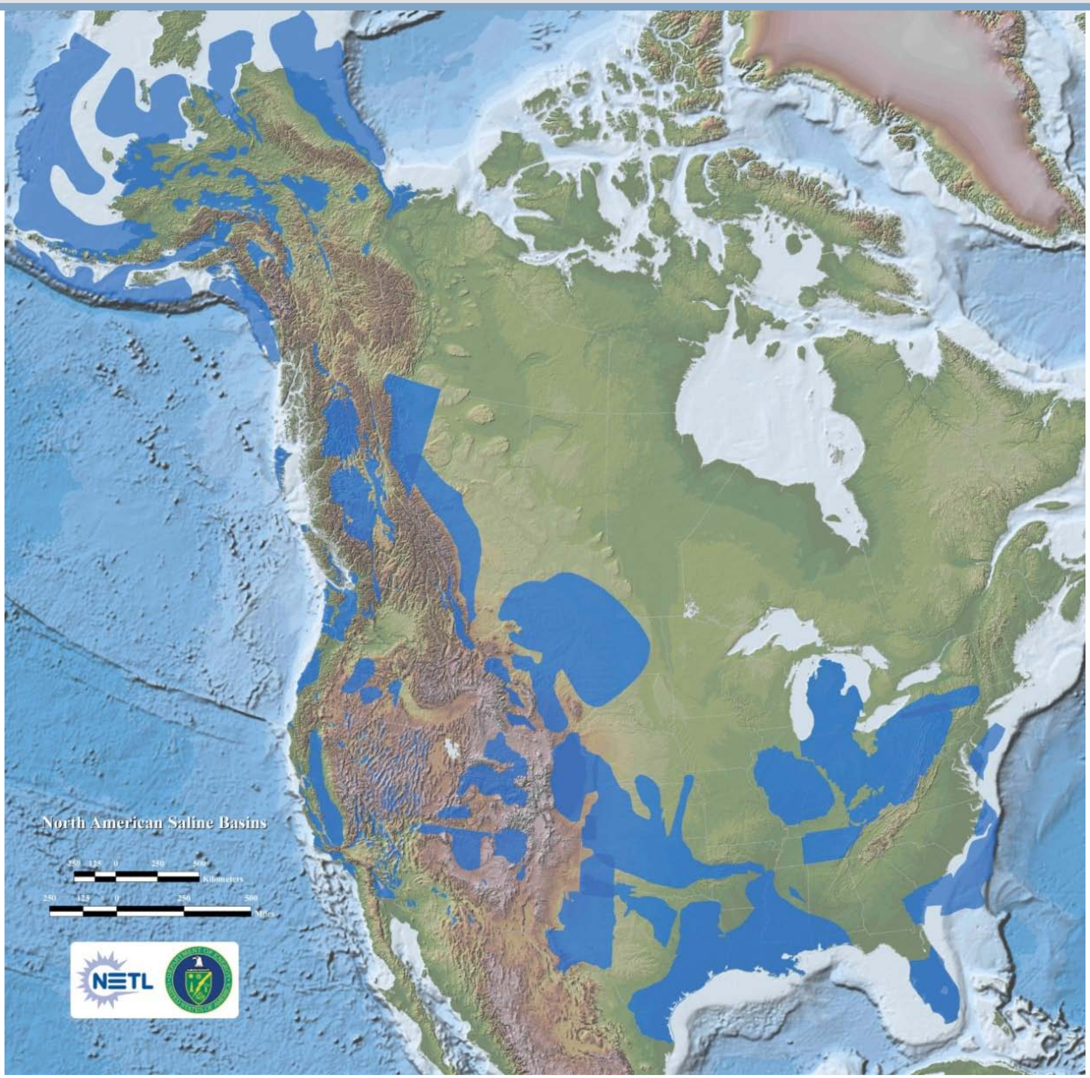
Storage in aquifers

- ❖ By far the largest volume of potential storage space

- ❖Often has poorly-characterized geology



http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlas/index.html

Notes by Presenter (for previous slide):

Aquifers are a very attractive option because they have the largest potential volume, and because most major urban areas, hence most power plants, are near one or more deep saline aquifers, which substantially lessens the transportation costs and problems. The main drawback of saline aquifers is that since they have not historically been useful for anything, the geology of aquifers does not tend to be as well understood as say oil or gas reservoirs.

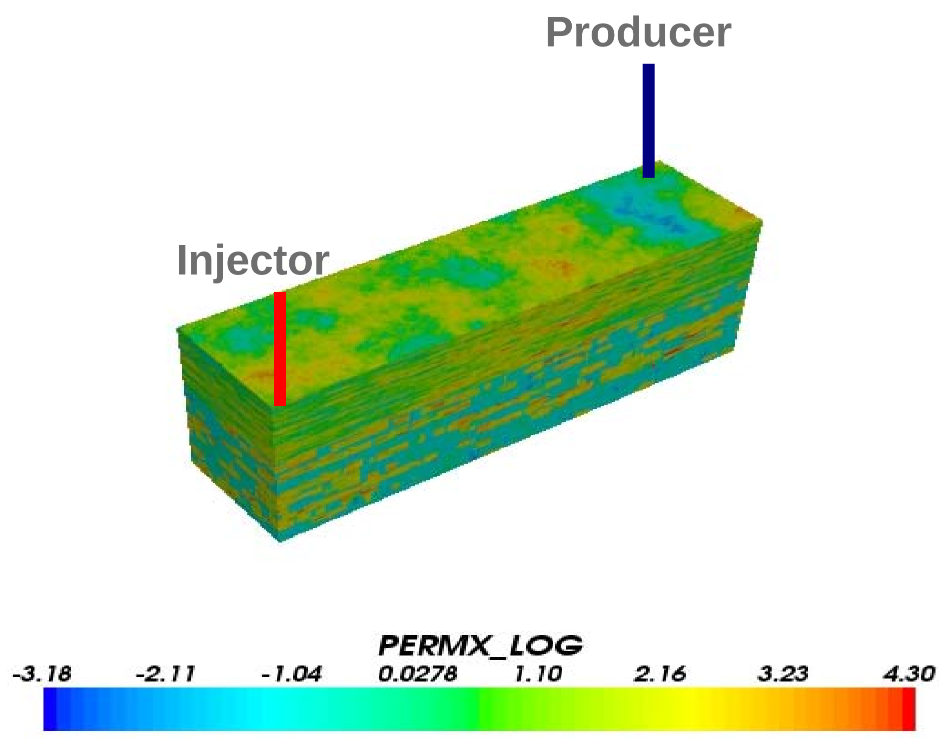
A better design of CO_2 storage

A case study on a highly heterogeneous field:

❖ Use chase water to trap CO_2 during injection

❖ 1D results are used to design a stable displacement

❖ Simulations are used to optimize trapping

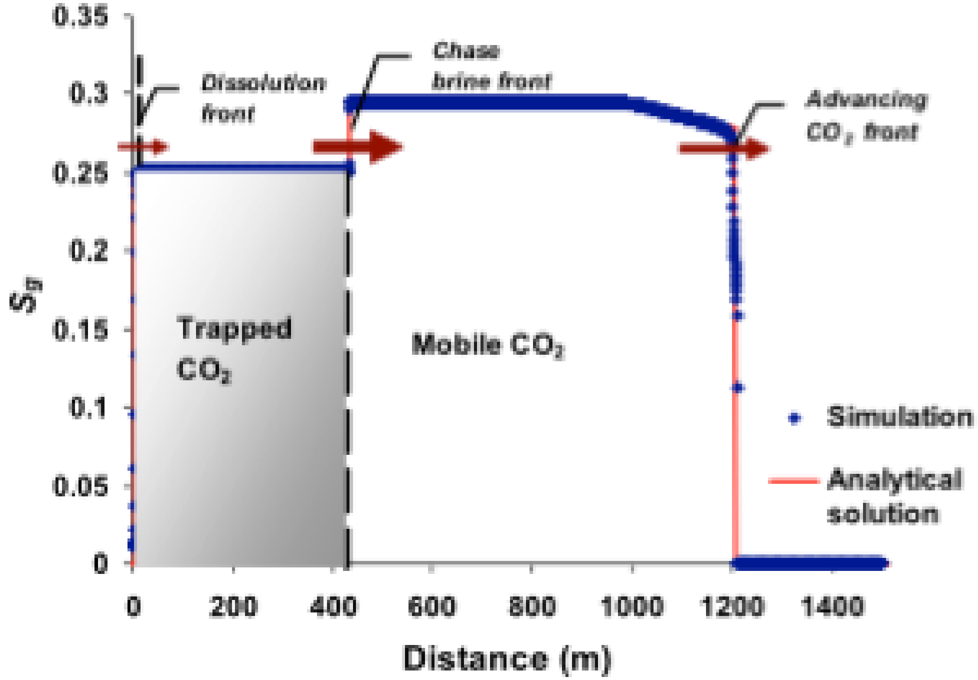


SPE 10 reservoir model, 1,200,000 grid cells (60X220X85), 7.8 Mt CO_2 injected.

Qi et al., JGGC 2008

A better design of CO_2 storage

1D analysis: injection of 85% CO_2 is most favorable



$f_{gi} = 0.85$

Qi et al., JGGC, 2008

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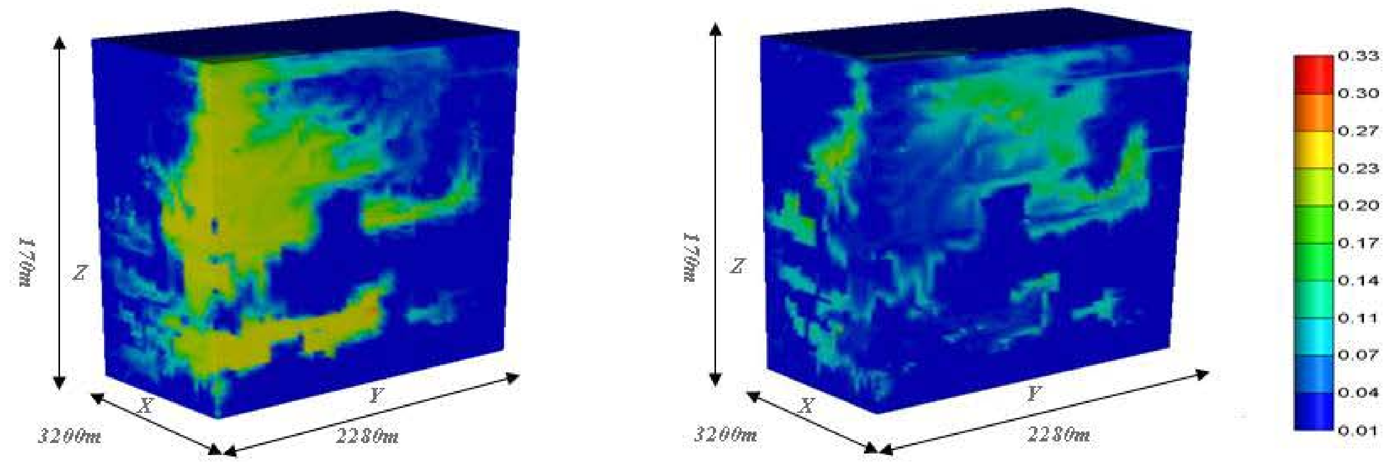
How long to immobilize the CO_2?

20 years of water and CO_2 injection followed by 2 years of water injection

95% of CO_2 trapped after 4 years of water injection



Trapped CO_2 saturation **Mobile CO_2 saturation**

Qi et al., JGGC 2008

Notes by Presenter: In a more realistic aquifer setting, we inject water and CO_2 for 20 years and then inject just water for two years into a well in the front bottom corner of the aquifer. At this time, much of our aquifer is filled with trapped CO_2, as shown on the left. Meanwhile, far from the well, particularly at the top of the reservoir there is still some mobile CO_2. If we continue to inject water for two more years, we will trap 95% of the water in this way.

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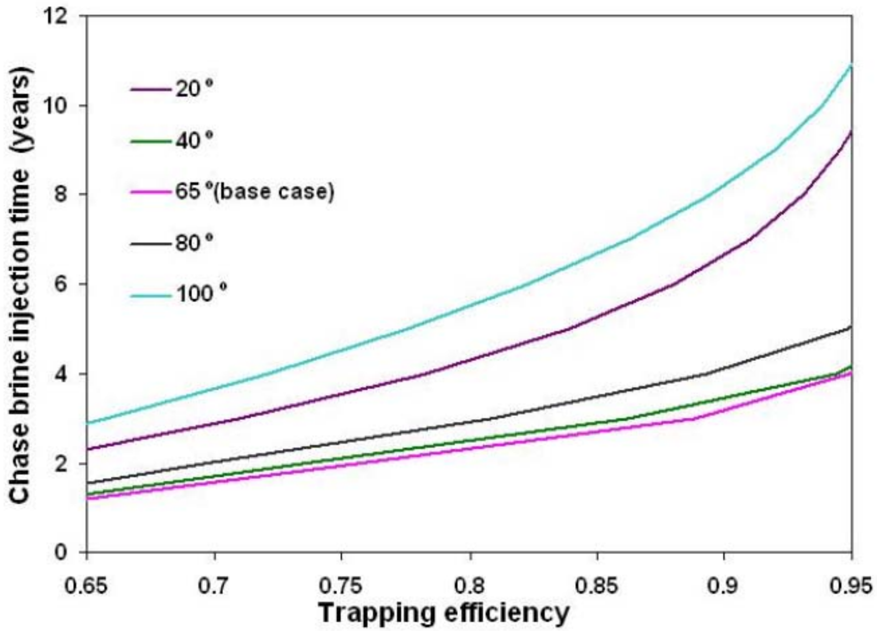
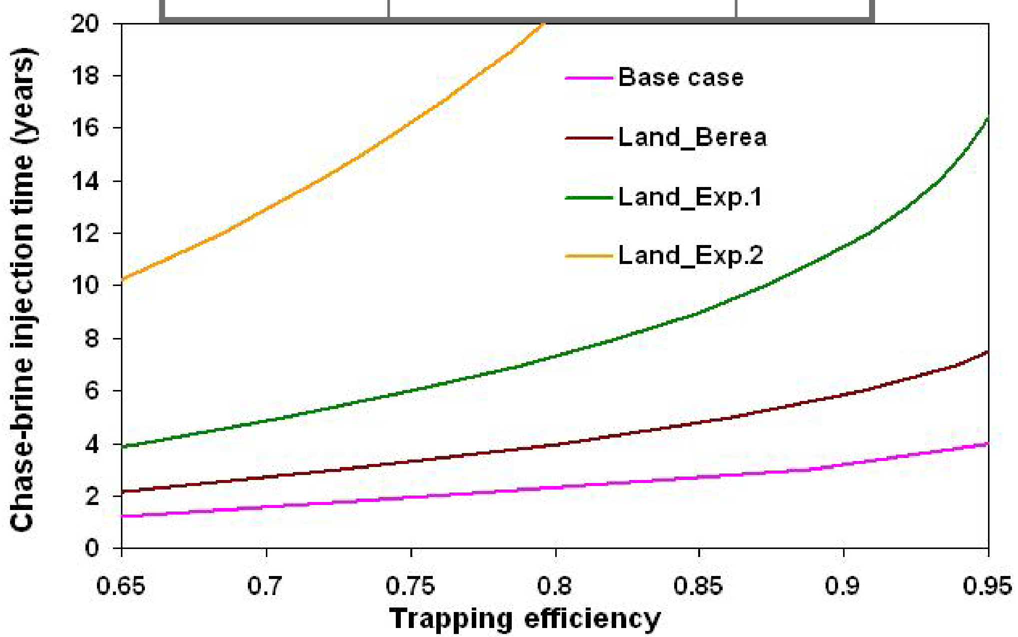
How long to immobilize the CO_2?

❖ Depends on wettability of rock and trapping model



	Ref.	S_{gt_max}
Land_Berea	Oak (1990)	0.37
Land_Exp.1	Suekane et al.(2008)	0.275
Land_Exp.2	Iglauer et al.	0.13



❖Must be measured directly…

Qi et al., JGGC 2008

Notes by Presenter (for previous slide):

In a geological model of a North Sea aquifer, SPE 10, we simulate injection of water and CO_2 for 20 years and then inject chase water for two years into a well in the front bottom corner of the aquifer. At this time, much of our aquifer is filled with trapped CO_2. At the top of the reservoir and far from the injection well, there is still some mobile CO_2, but if we continue to inject water for two more years, we will trap 95% of the water in this way. The model on the left is using a trapping model based on pore-network simulation results and assuming intermediate wetability of the CO_2 in the aquifer, as experimental studies have shown that supercritical CO_2 and water systems are intermediate wet. On the right we study the trapping efficiency for various CO2/water contact angles ranging from strongly water wet to weakly CO_2 wetting. As you can see, for intermediate contact angles 95% of the CO_2 is trapped the fastest, while for strongly water wet and strongly oil wet systems it takes much longer to trap the CO_2.

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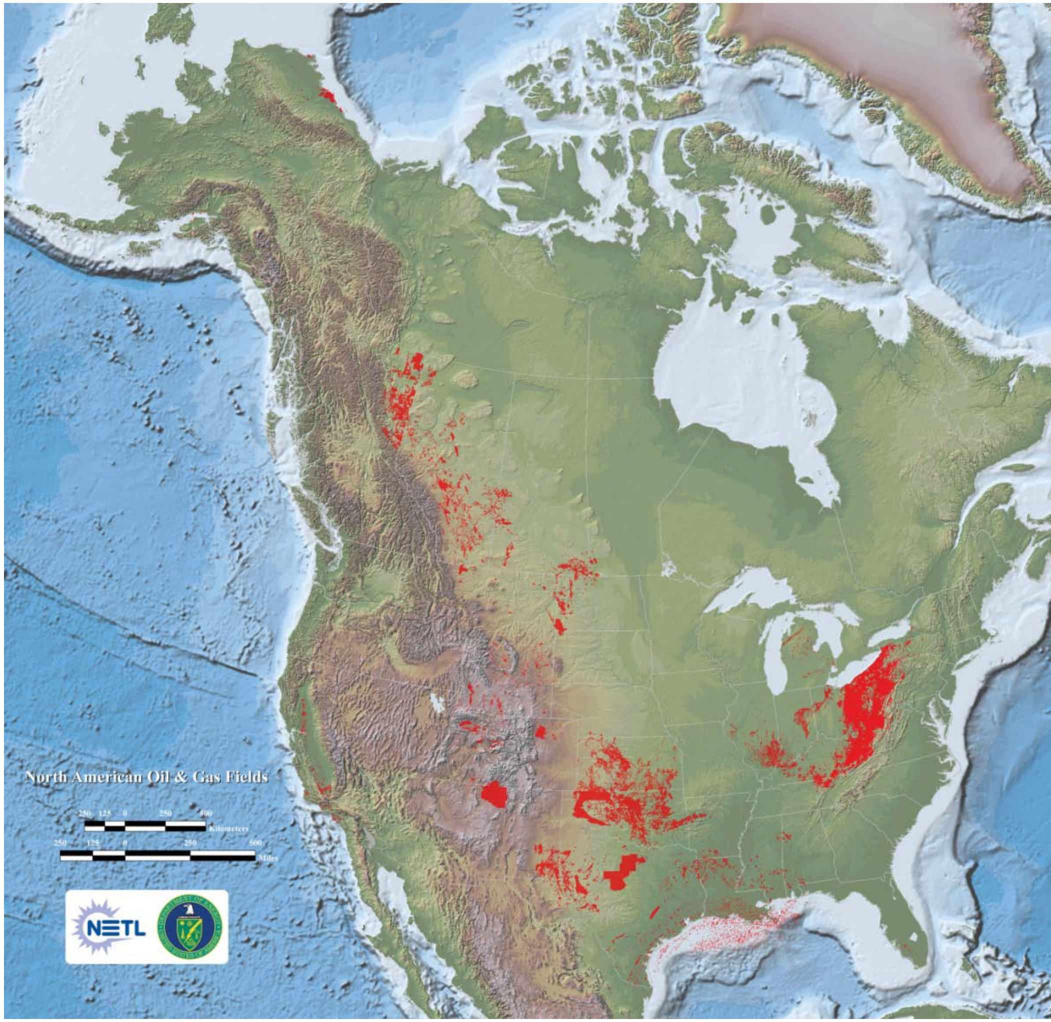
Storage in oil and gas reservoirs

- ❖ Existing infrastructure
- ❖ Practical experience injecting CO_2 into oil reservoirs
- ❖ Detailed knowledge of geology
- ❖ Far from emission sources



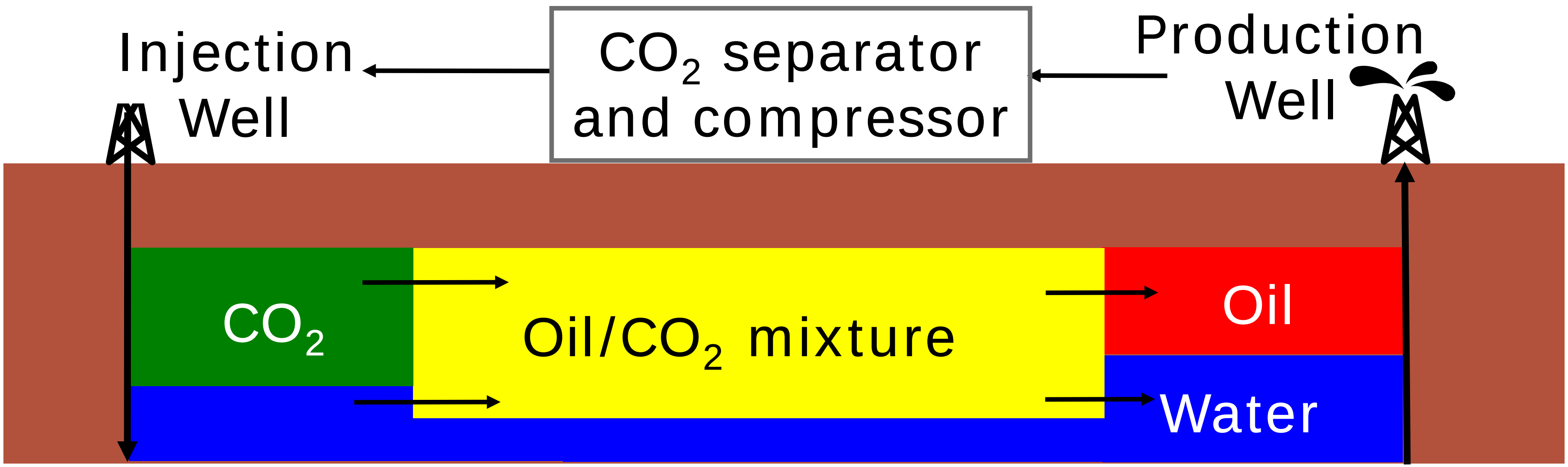
http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlas/index.html

Notes by Presenter (for previous slide):

The next largest possible geologic formation for CO_2 storage is oil and gas reservoirs. Oil and gas have many advantages for storage. They have existing infrastructure, including wells that can be used for CO_2 injection, pipelines to populated areas (currently in use to bring hydrocarbons to cities, but they could be used for CO_2 transport). Oil companies also have practical experience in injecting CO_2 into oil reservoirs to improve their oil recovery (more on that in a couple of Notes by Presenter (for previous slide):s), so it is known that the technology does work in practise. Given that oil companies have a great economic incentive to know the geology of their reservoirs, many geological data is typically available for oil and gas reservoirs. The bad thing about oil reservoirs is that they are often far from populated areas, and hence it is necessary to transport CO_2 a long ways to the reservoirs.

Storage in oil and gas reservoirs

- As CO_2 migrates through the rocks, it will be trapped in tiny bubbles (just like in an aquifer)
- CO_2 can also mix with oil
  - Spread throughout reservoir
  - Increases oil recovery
  - Will be produced with oil



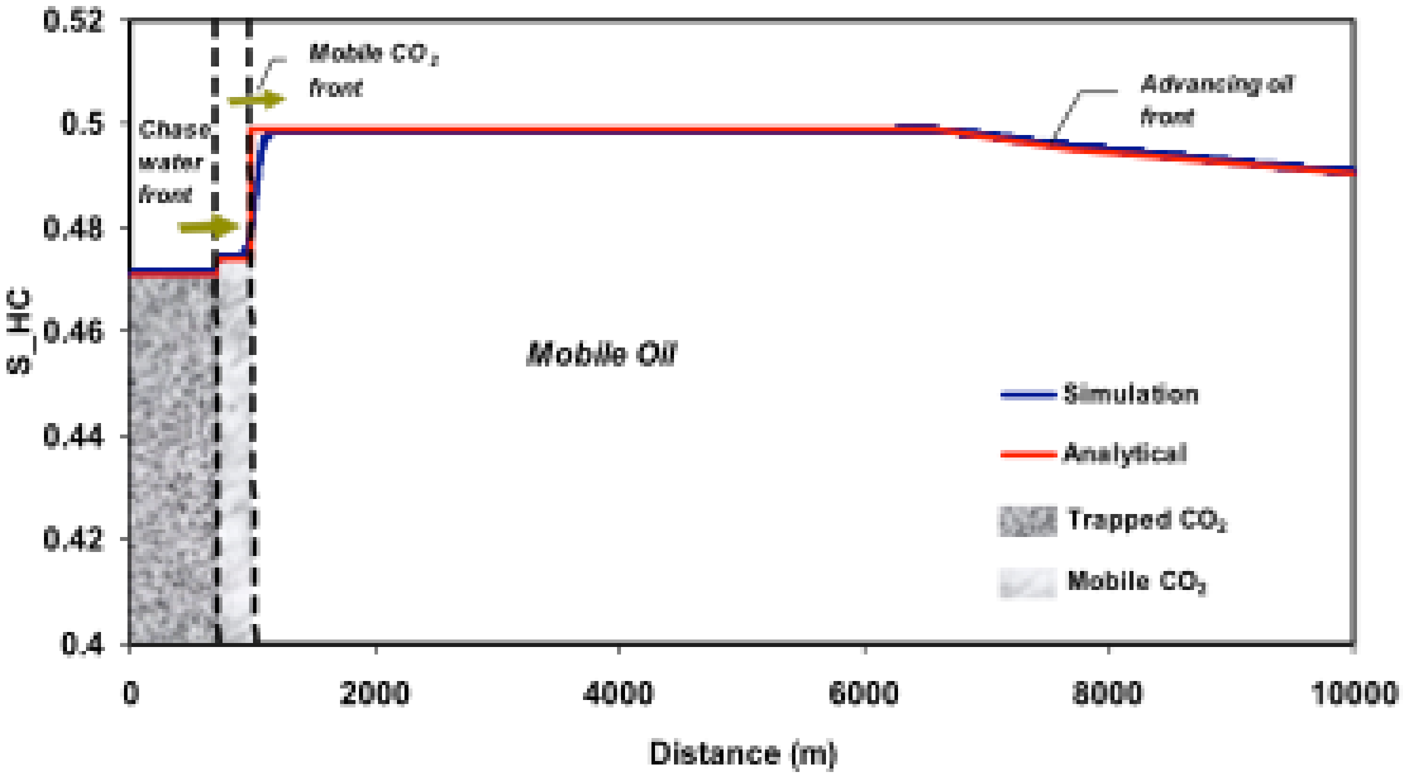
Notes by Presenter (for previous slide):

As is spreads CO_2 will be trapped as tiny bubbles like in an aquifer. The CO_2 can also mix with the oil and spread throughout the reservoir. If the reservoir is still being produced, it is likely that the CO_2 will spread all the way to production wells and be produced with oil. In that case, the CO_2 will be separated, compressed and reinjected. This makes the injection process less efficient, but because the CO_2 can help the oil to flow, an increase in oil production can help defray the cost of CO_2 capture and storage (and reinjection).

CO_2 storage for enhanced oil recovery?

- CO_2 injection is a very effective EOR technique that has been used since the 1960’s
- Doesn’t that defeat the purpose of CO_2 injection? Partly, but…
  - Increased oil recovery offsets the cost of capture, making CO_2 storage more economic
  - A small fraction of injected CO_2 is produced
  - Technology and infrastructure already in place
  - If CO_2 is available oil companies will do this anyway

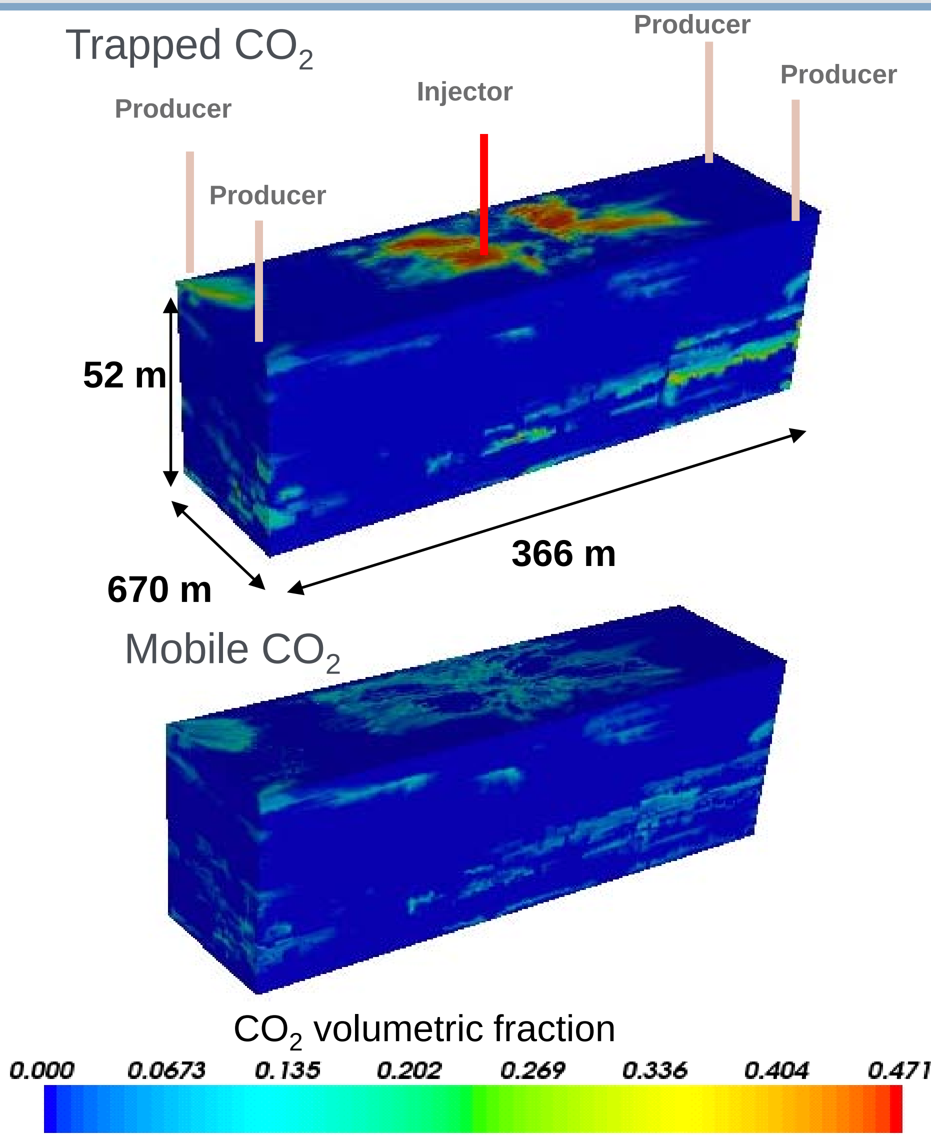
ID results for reservoir storage



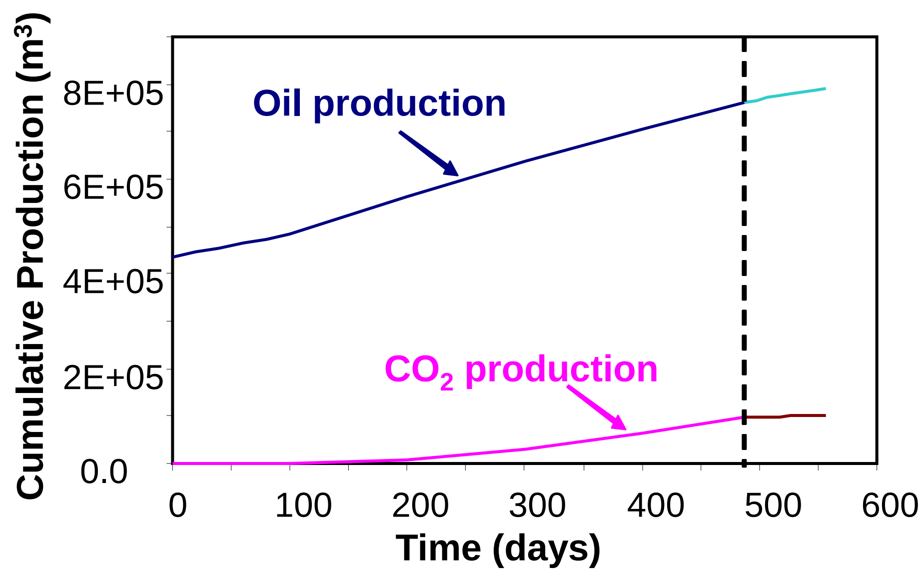
- ❖First-contact miscible CO_2 injection
- ❖CO_2 injection at f_{CO2}=0.7 followed by chase water injection

Qi et al., SPE 115663

3D results for reservoir storage



- ❖Waterflood the reservoir until WC = 70%
- ❖CO_2 injection until 20% CO_2 is produced – 487 days in this case
- ❖Chase water injection – 70 days, 75% CO_2 trapped



Qi et al., SPE 115663

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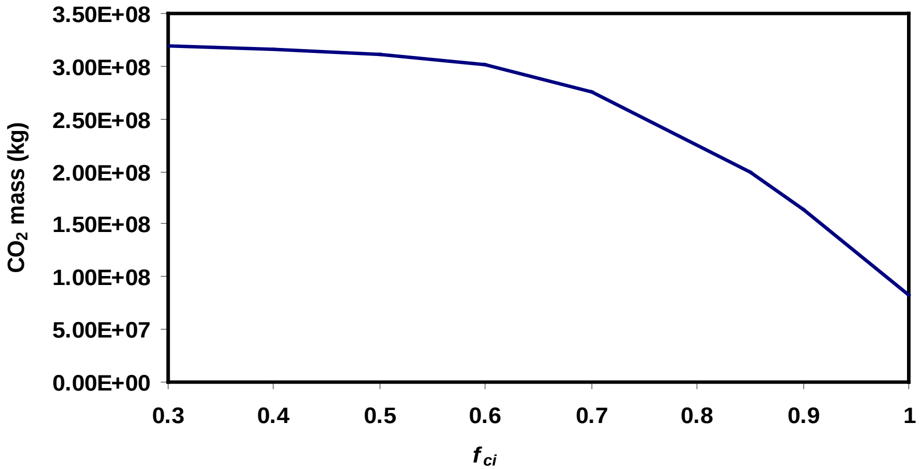
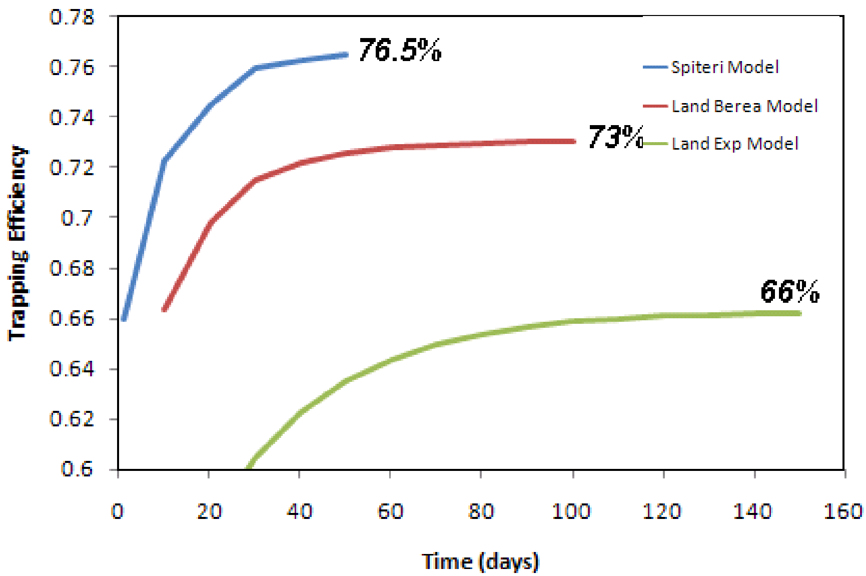
3D results for reservoir storage



Mass of CO_2 stored when excessive gas cycling ends project

❖SWAG Injection at WAG ratio = 0.5 is suggested in this case.



❖ Maximum trapping efficiency and time are dependent on the trapping model used.

Qi et al., SPE 115663

Conclusions

❖ Trapping is an important mechanism to store CO_2 securely as an immobile phase

❖Brine + CO_2 injection can trap more than 90% of the CO_2 in the subsurface during the injection lifetime of the project

❖ Results are very sensitive to trapping model, we need to gather more experimental data

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Thanks To:

All of you for listening!

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