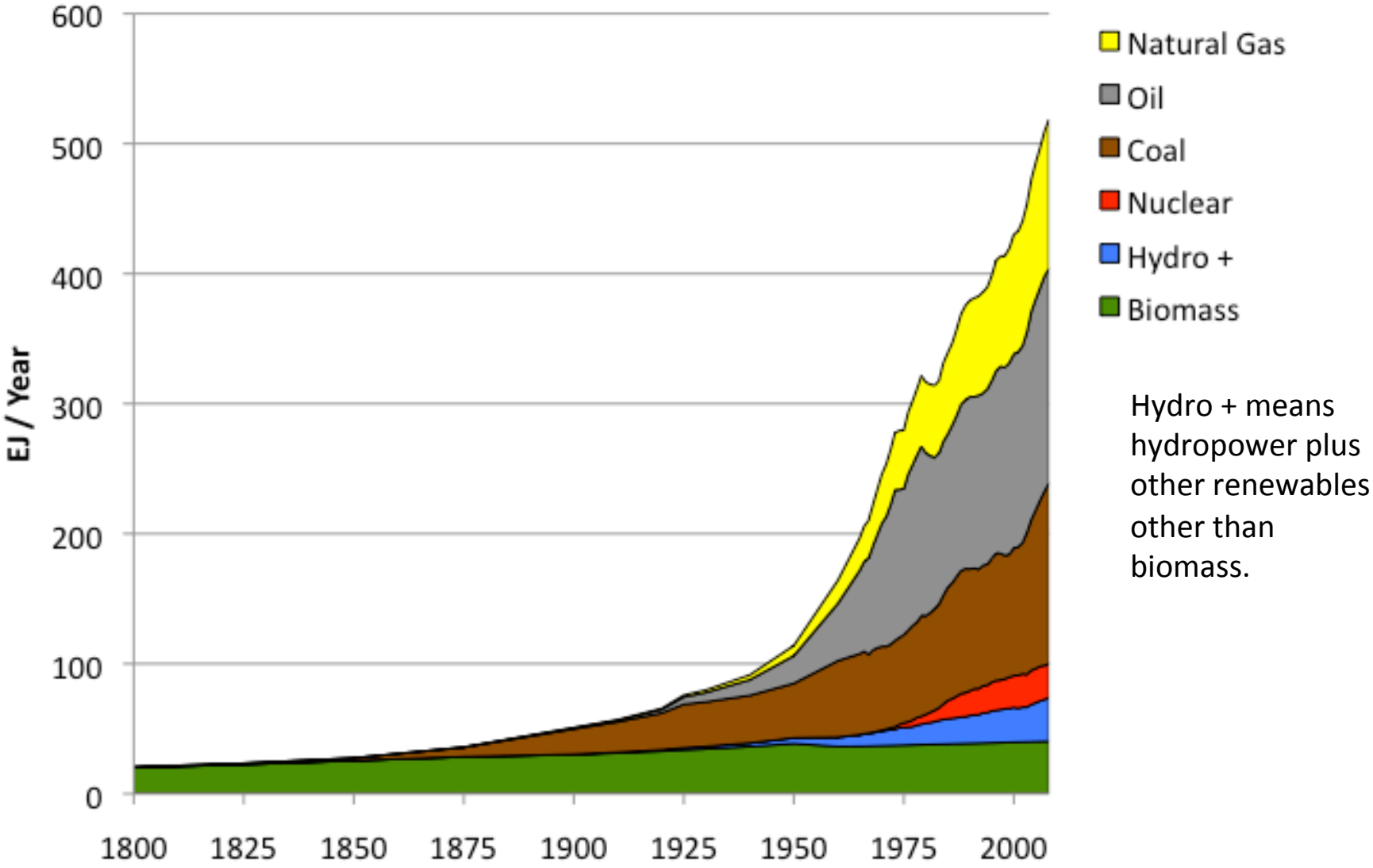
# World Primary Energy Supply: 1800 – 2008

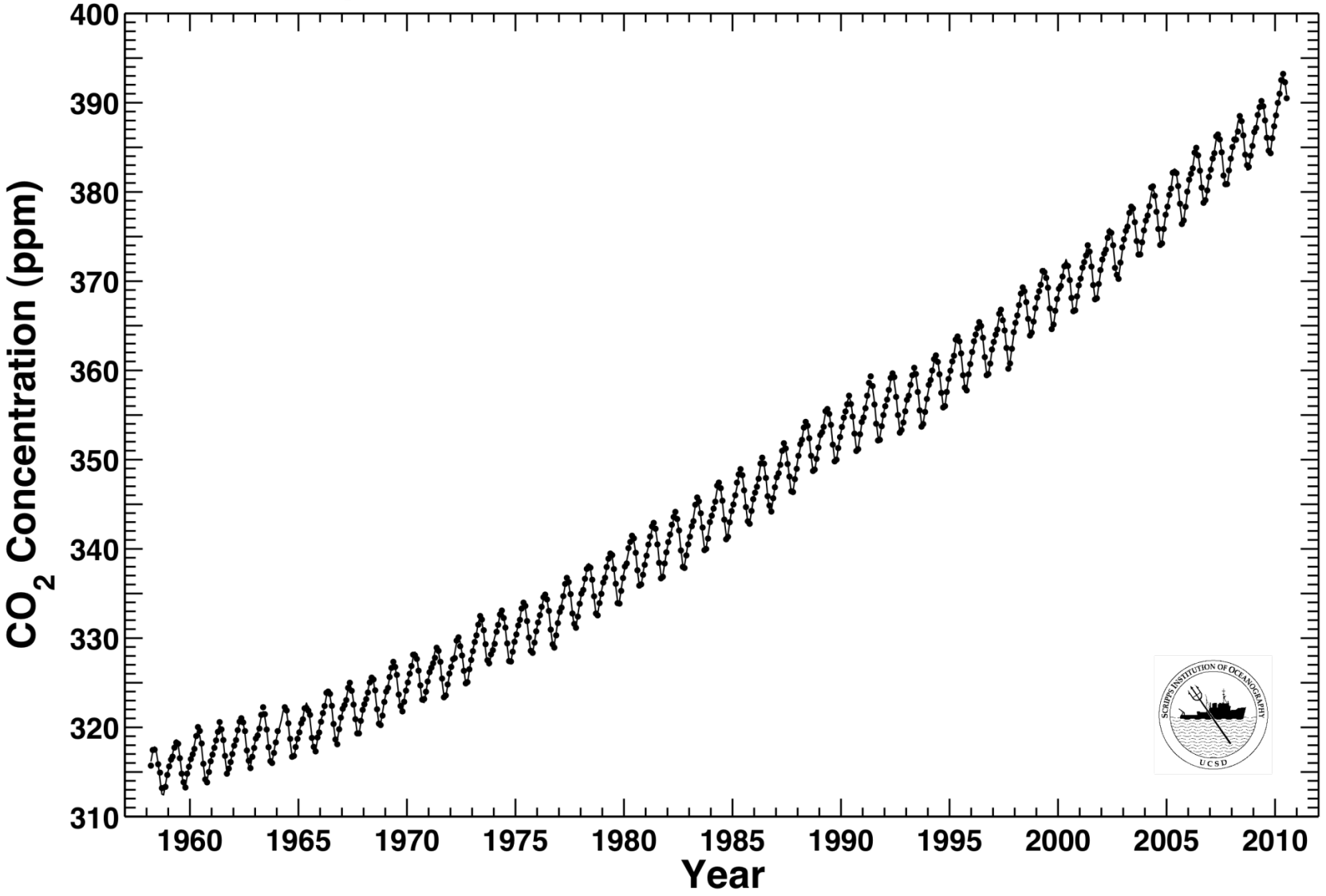



Hydro + means hydropower plus other renewables other than biomass.

Sources: Grubler (2008) - Energy Transitions, BP (2009) – Statistical Review of World Energy, EIA (2009) – International Energy Annual

# Mauna Loa Observatory, Hawaii
# Monthly Average Carbon Dioxide Concentration

Data from Scripps $CO_2$ Program  Last updated August 2010



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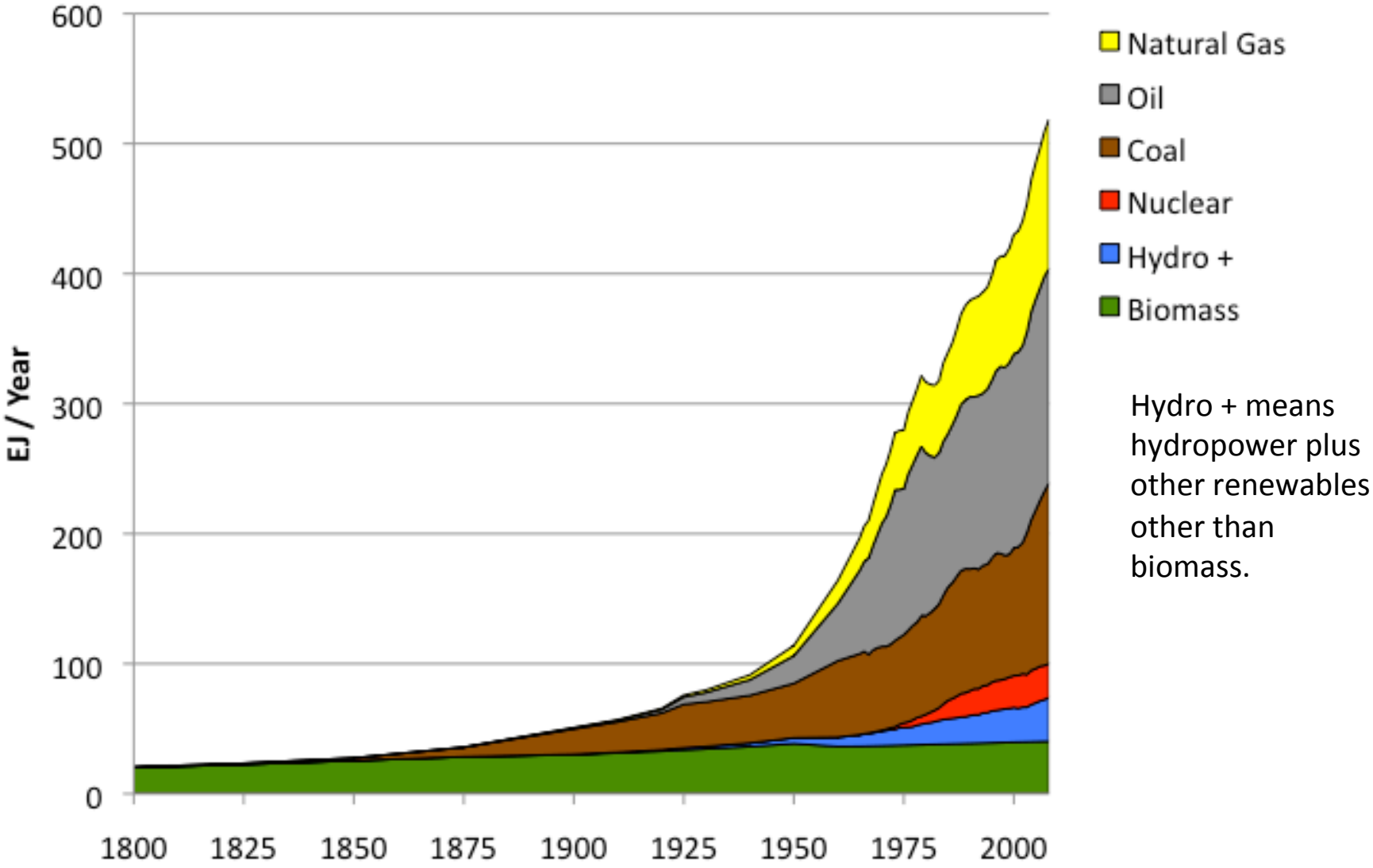


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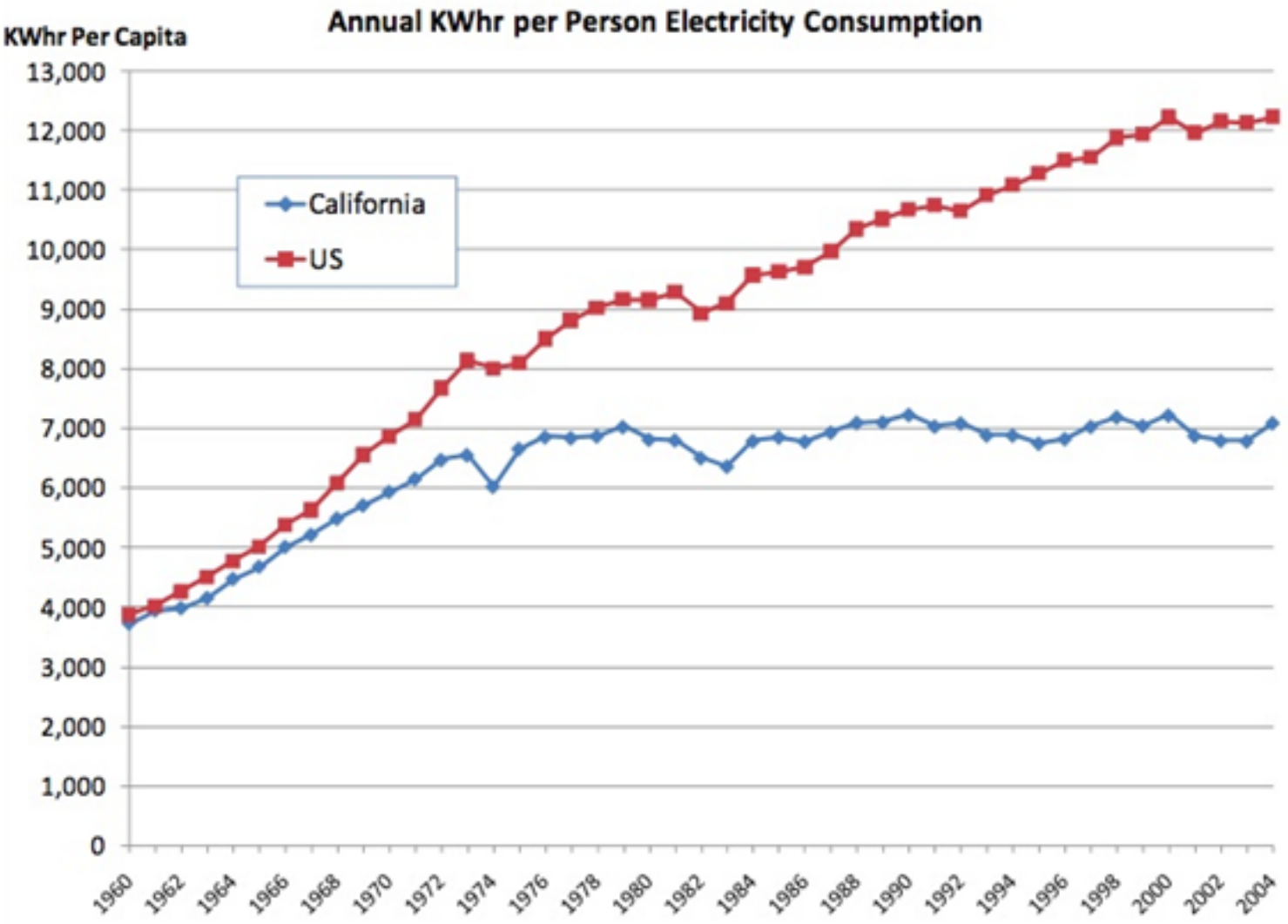
There are three ways to reduce carbon dioxide emissions:

1) Efficiency/conservation

2) Non-fossil fuel energy
(renewables and nuclear)

3) Carbon capture and storage


Annual KWhr per Person Electricity Consumption
KWhr Per Capita
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
California
US
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004

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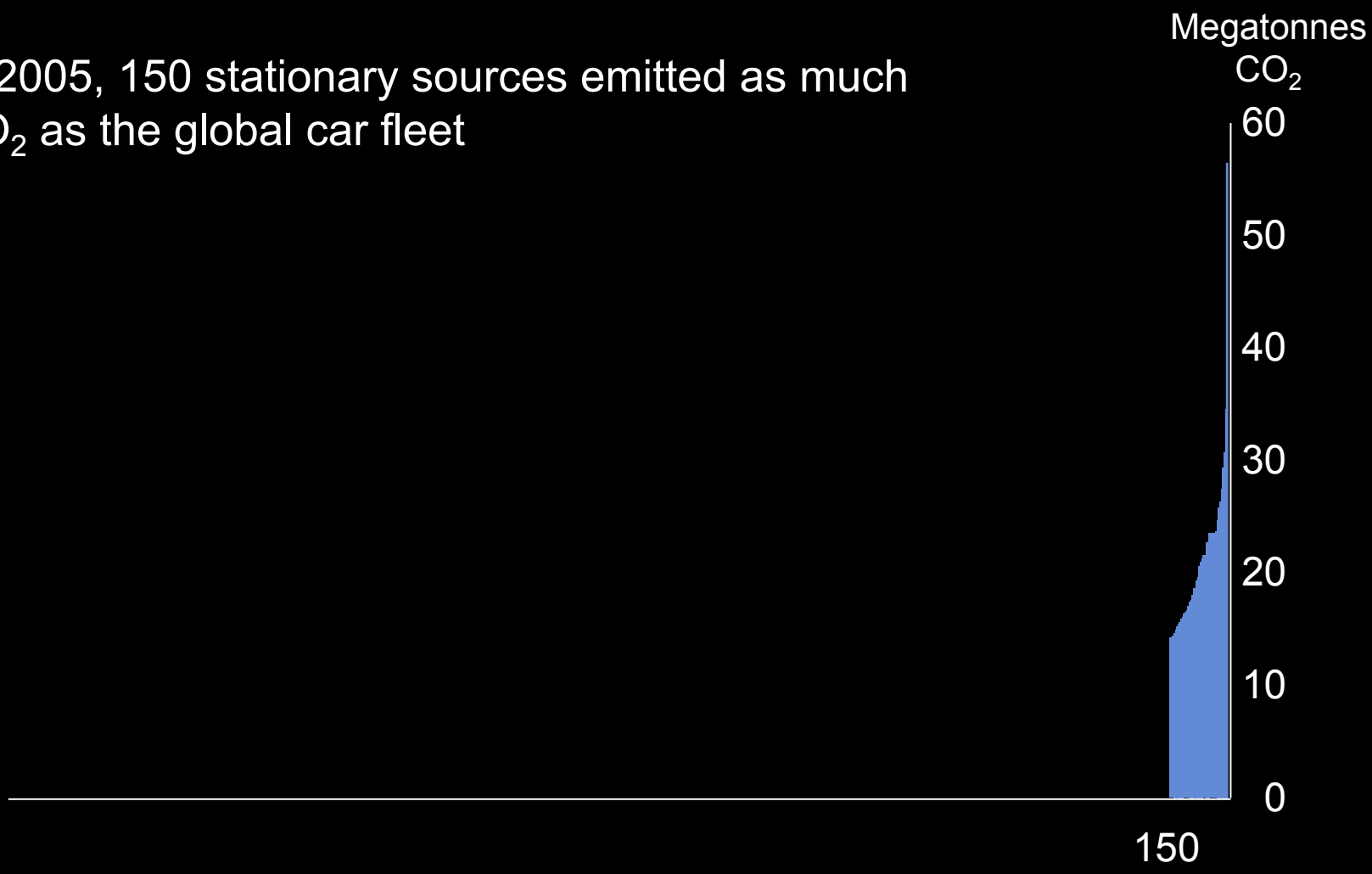
# Most Emissions Come from Relatively Few Sources

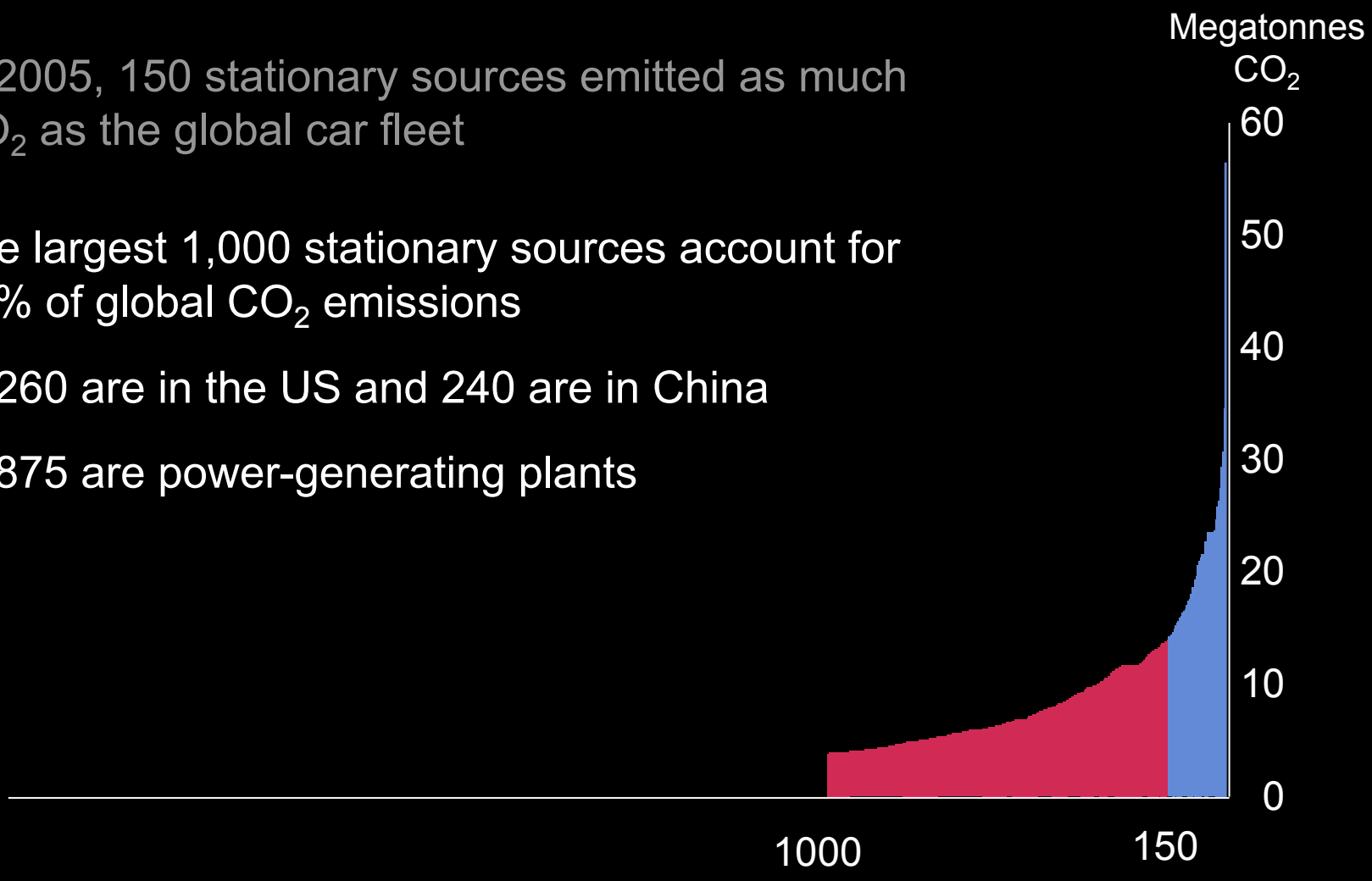
- In 2005, 150 stationary sources emitted as much $CO_2$ as the global car fleet




Source: IEA and AllianceBernstein

# Most Emissions Come from Relatively Few Sources

- In 2005, 150 stationary sources emitted as much $CO_2$ as the global car fleet
- The largest 1,000 stationary sources account for 31% of global $CO_2$ emissions
  - 260 are in the US and 240 are in China
  - 875 are power-generating plants

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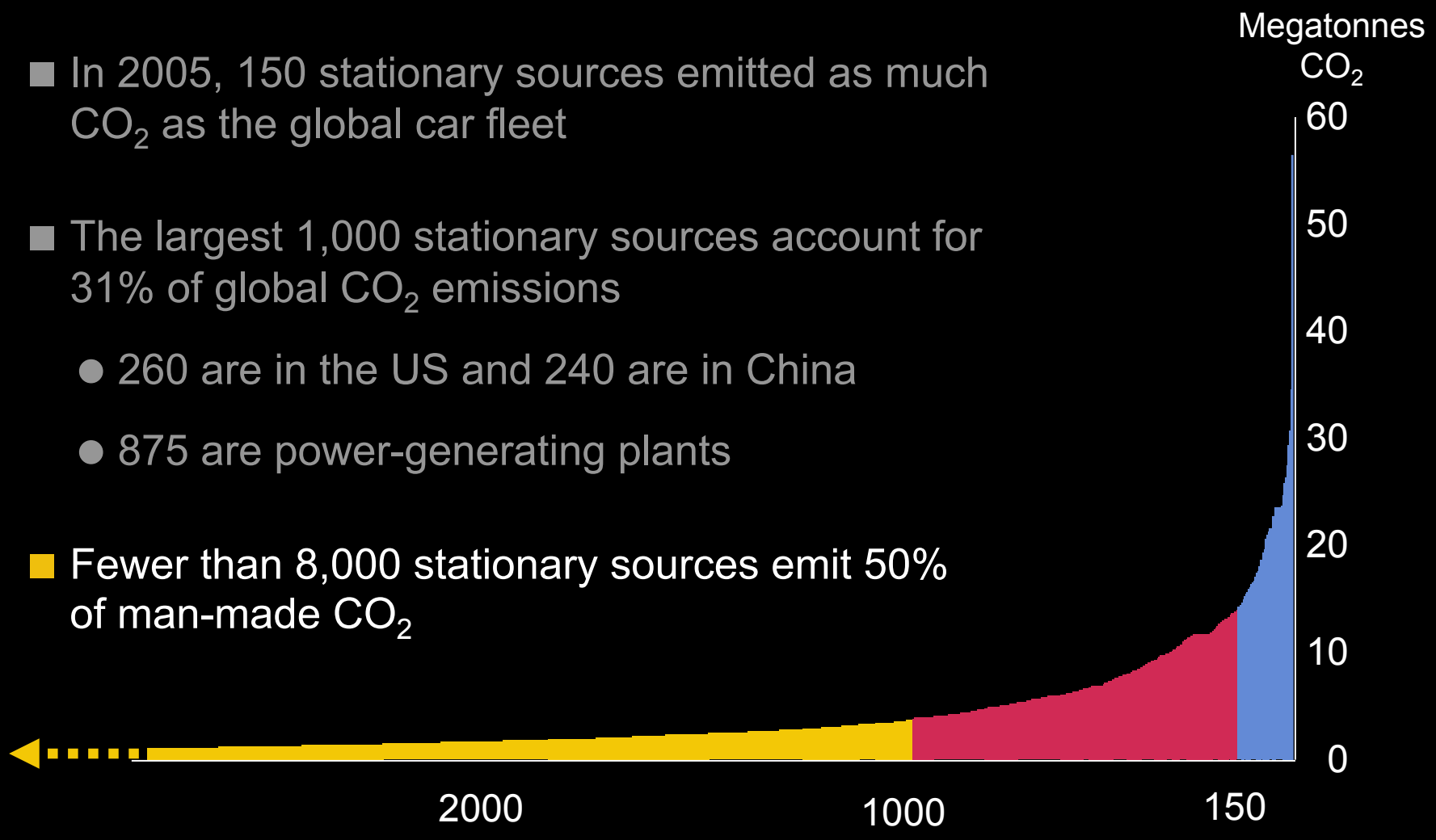
  - 875 are power-generating plants
- Fewer than 8,000 stationary sources emit 50% of man-made $CO_2$



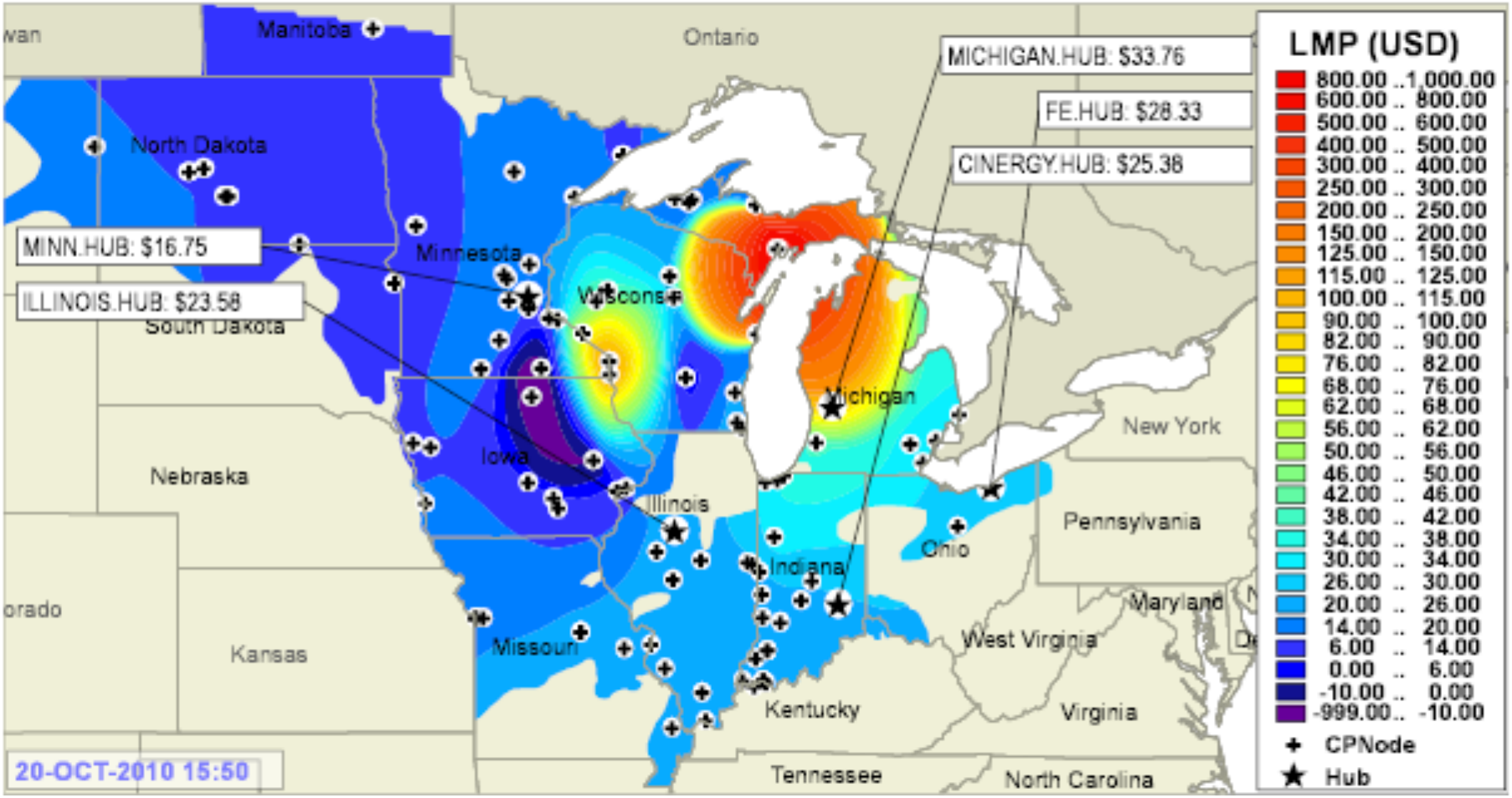

Source: IEA and AllianceBernstein

What about wind and solar? Why can't we simply replace all the existing power generation facilities with renewable sources?

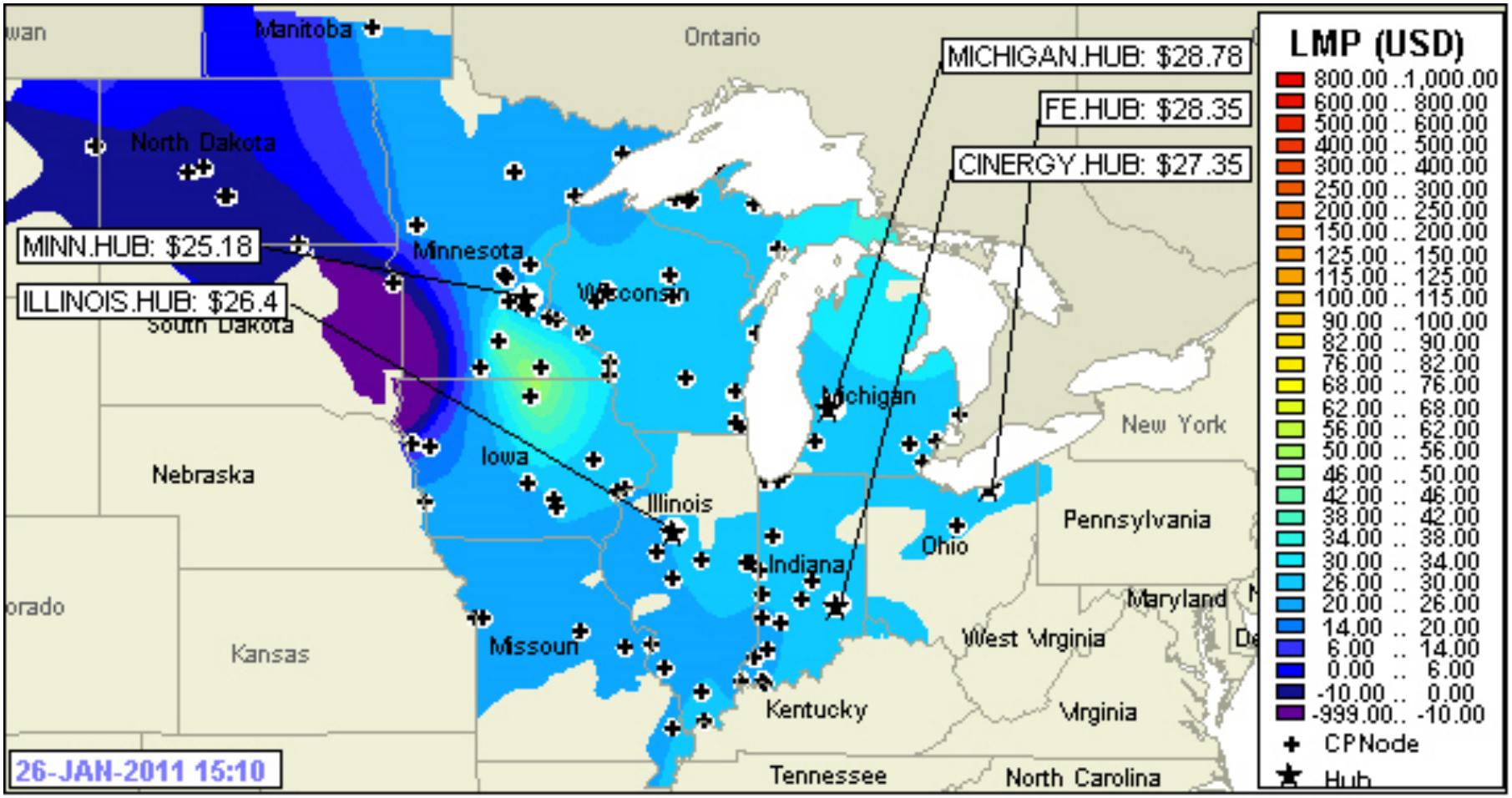
- Industrial uses of energy that will be very difficult to replace with electricity

- intermittency of wind and solar

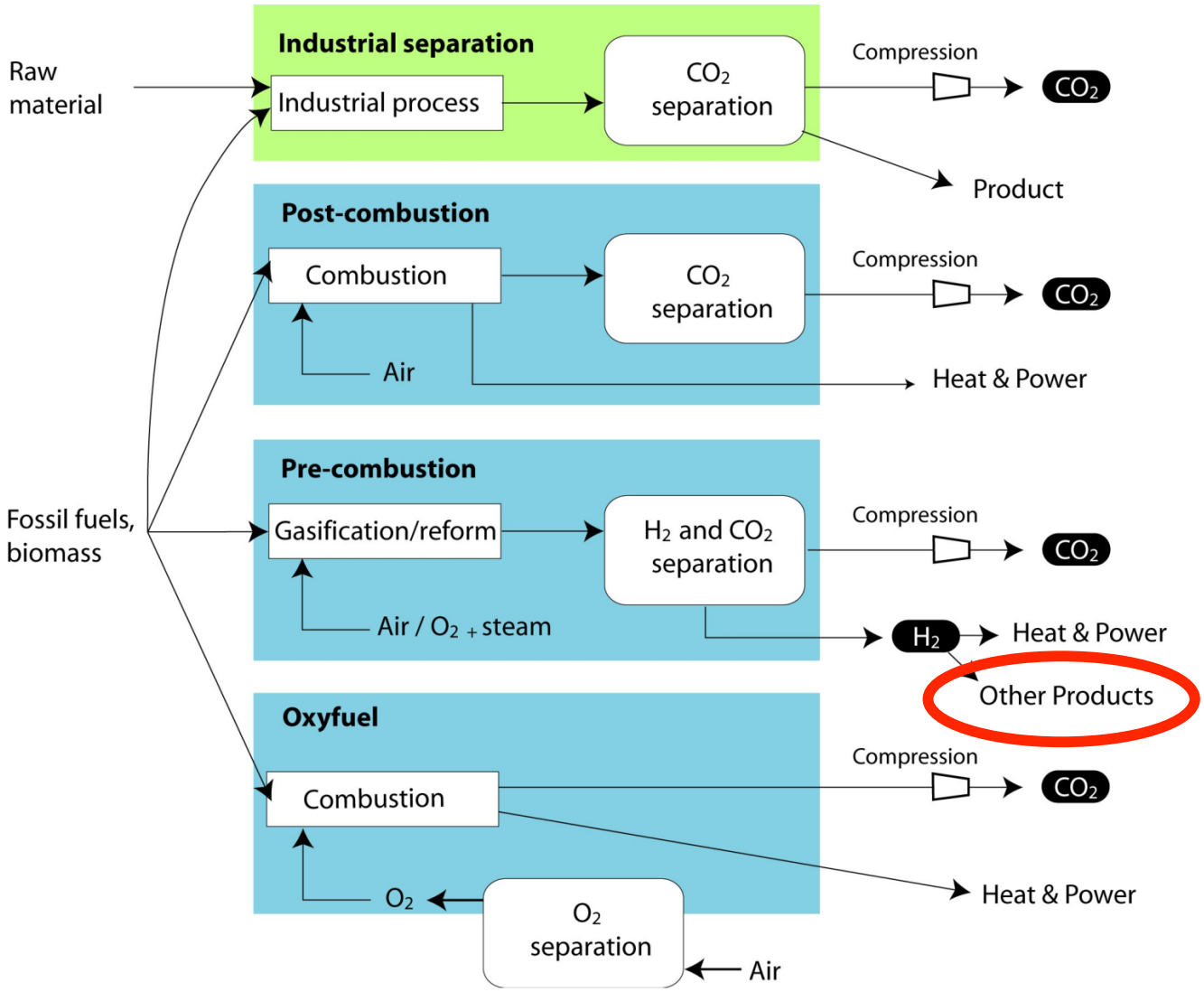
# Grid Congestion



# Grid Congestion



# Capture of $CO_2$



In 2008, U.S. Electricity came from:

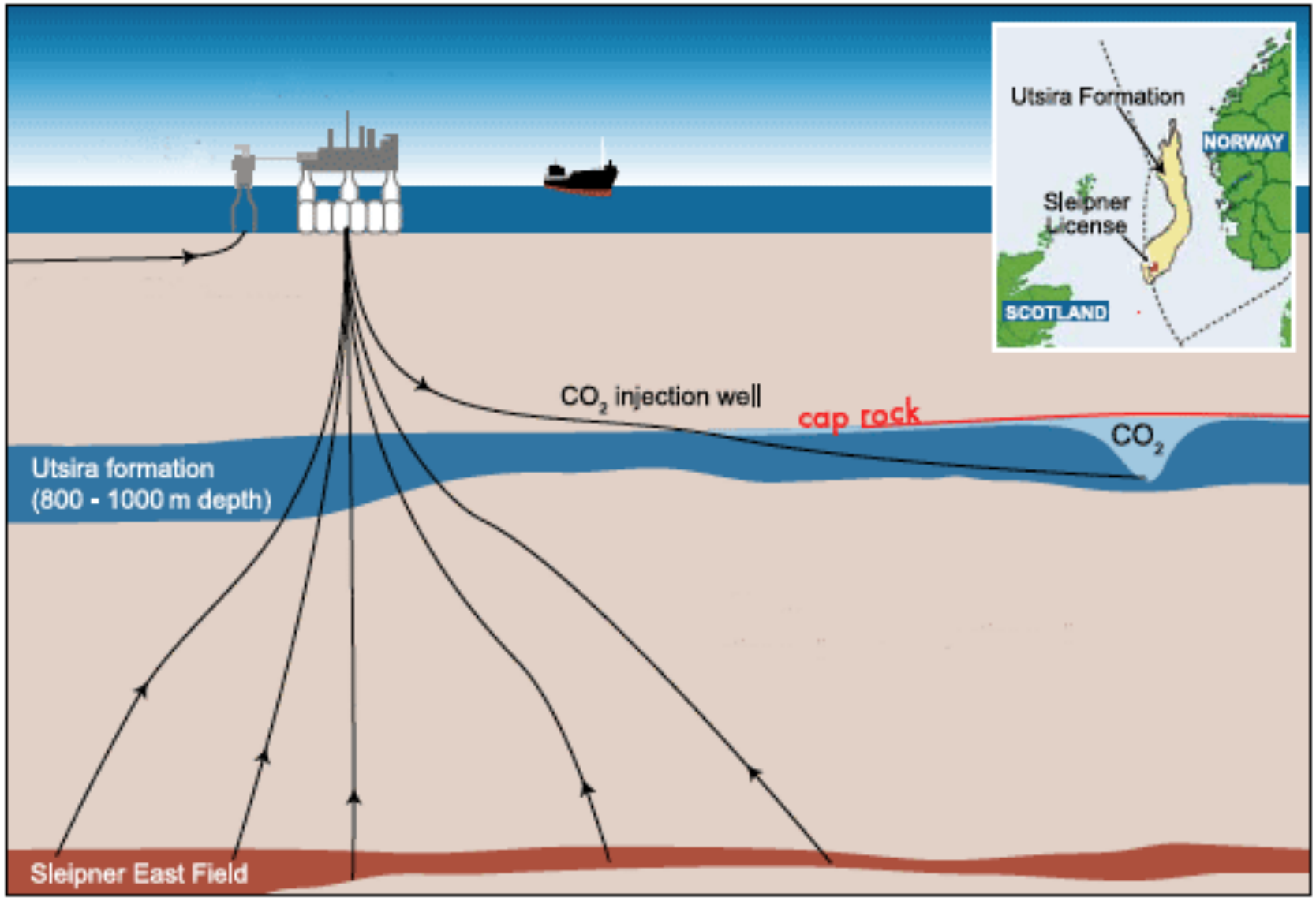
| | |
|---|---|
| Coal | (1,994 Terawatt hours equivalent to 15 tcf of natural gas) |
| Natural Gas | (877 Terawatt hours – 6.66 tcf) |
| Nuclear | (806 Terawatt hours) |
| Hydroelectric | (248 Terawatt hours) |
| Other renewables | (123 Terawatt hours) |
| Petroleum | (31 Terawatt hours) |

Carbon capture and storage (CCS) is an essential part of a low-carbon energy economy, mostly for dispatchable, intermittent power generation, fuel production, fertilizer production, and other industrial processes.

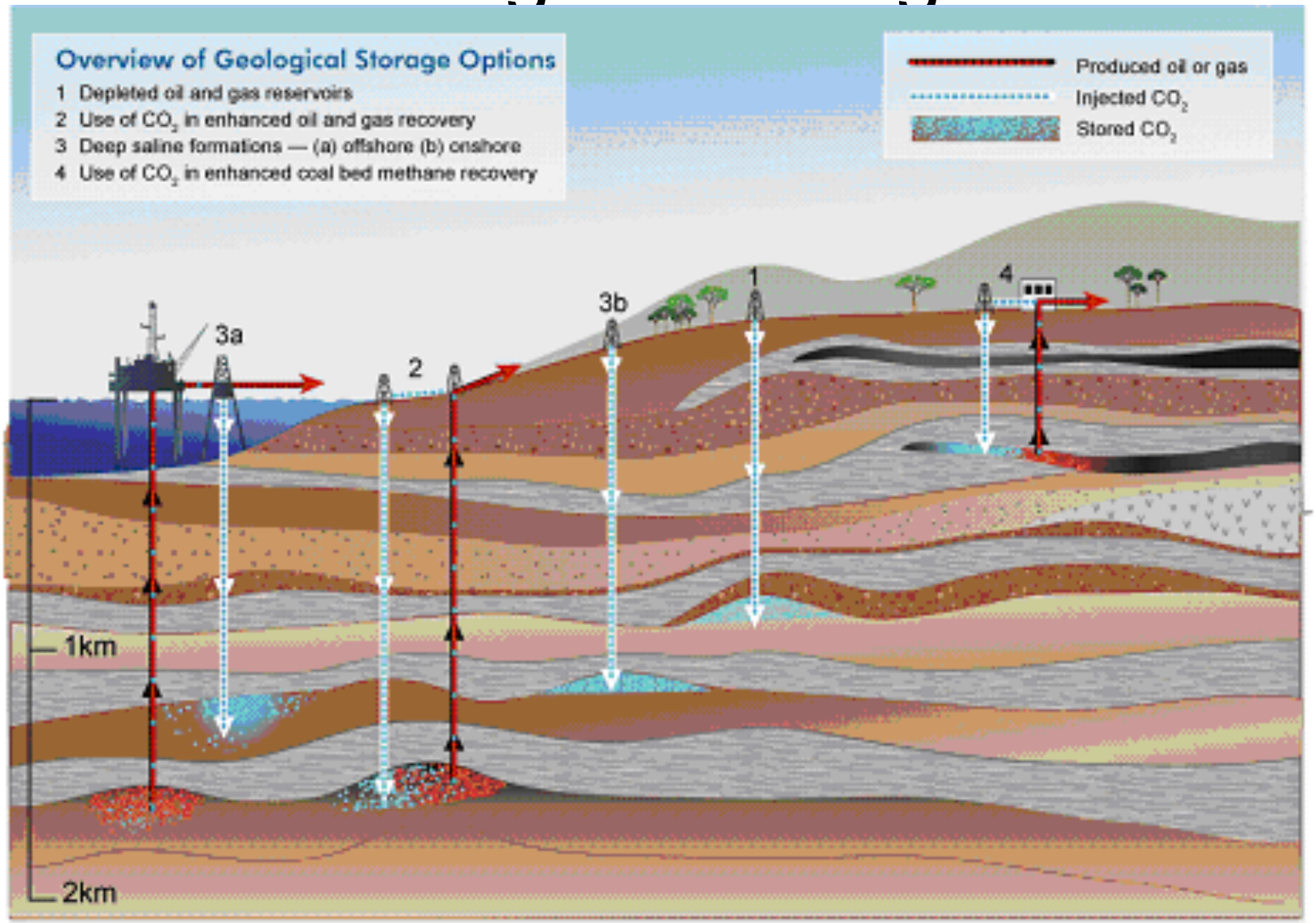
Retrofitting most existing coal plants in the U.S. is highly unlikely, as many are too old and inefficient. CCS is not an excuse to keep operating our existing coal plants.

Polygeneration with pre-combustion capture is an excellent way to make CCS affordable by allocating capital in a more efficient manner.

Sleipner Project, Norwegian North Sea (Statoil)


Utsira Formation
NORWAY
Sleipner License
SCOTLAND
$CO_2$ injection well
cap rock
$CO_2$
Utsira formation
(800 - 1000 m depth)
Sleipner East Field

# Geological storage



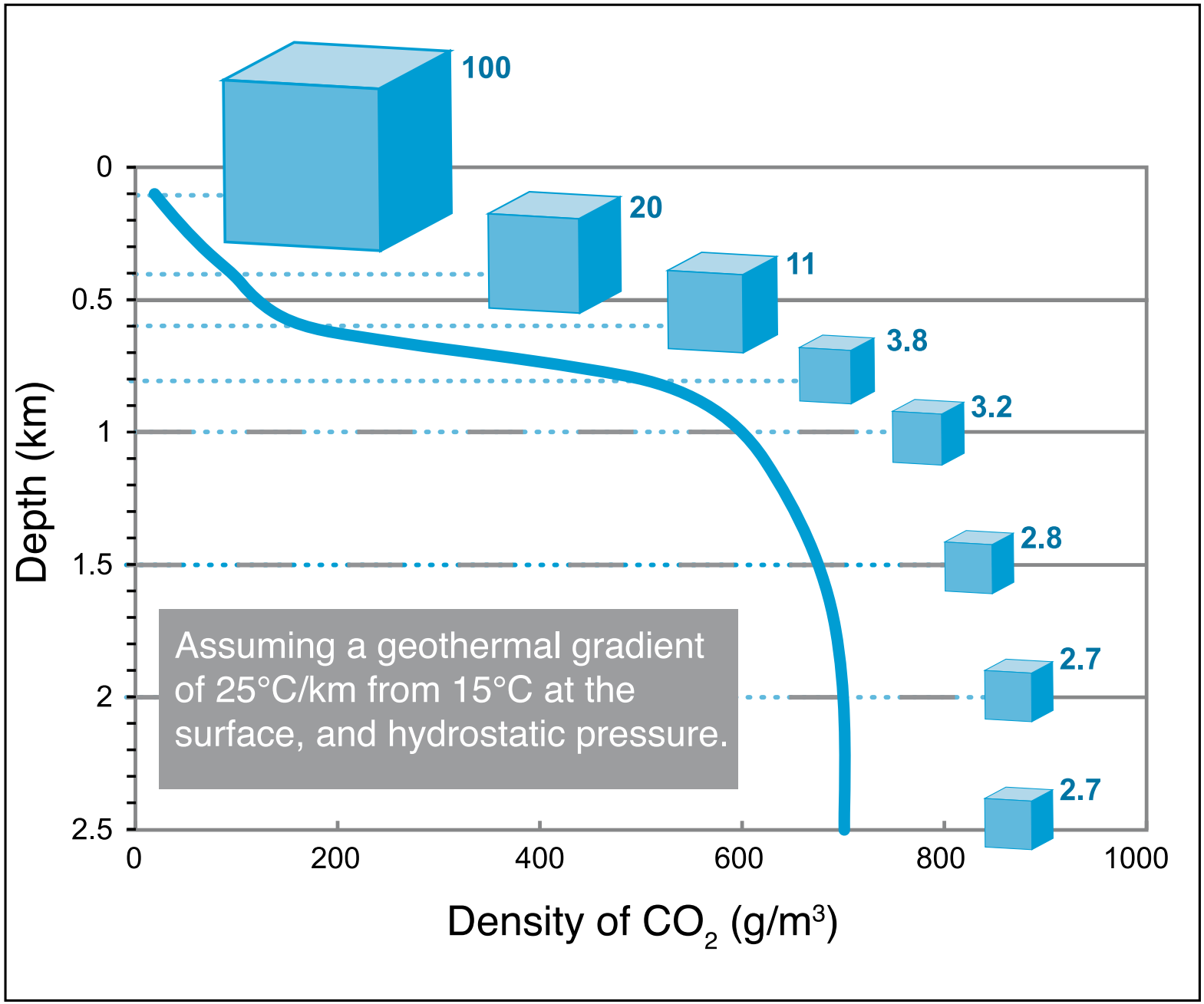



**Figure 5.2** Variation of $CO_2$ density with depth, assuming hydrostatic pressure and a geothermal gradient of 25°C $km^{-1}$ from 15°C at the

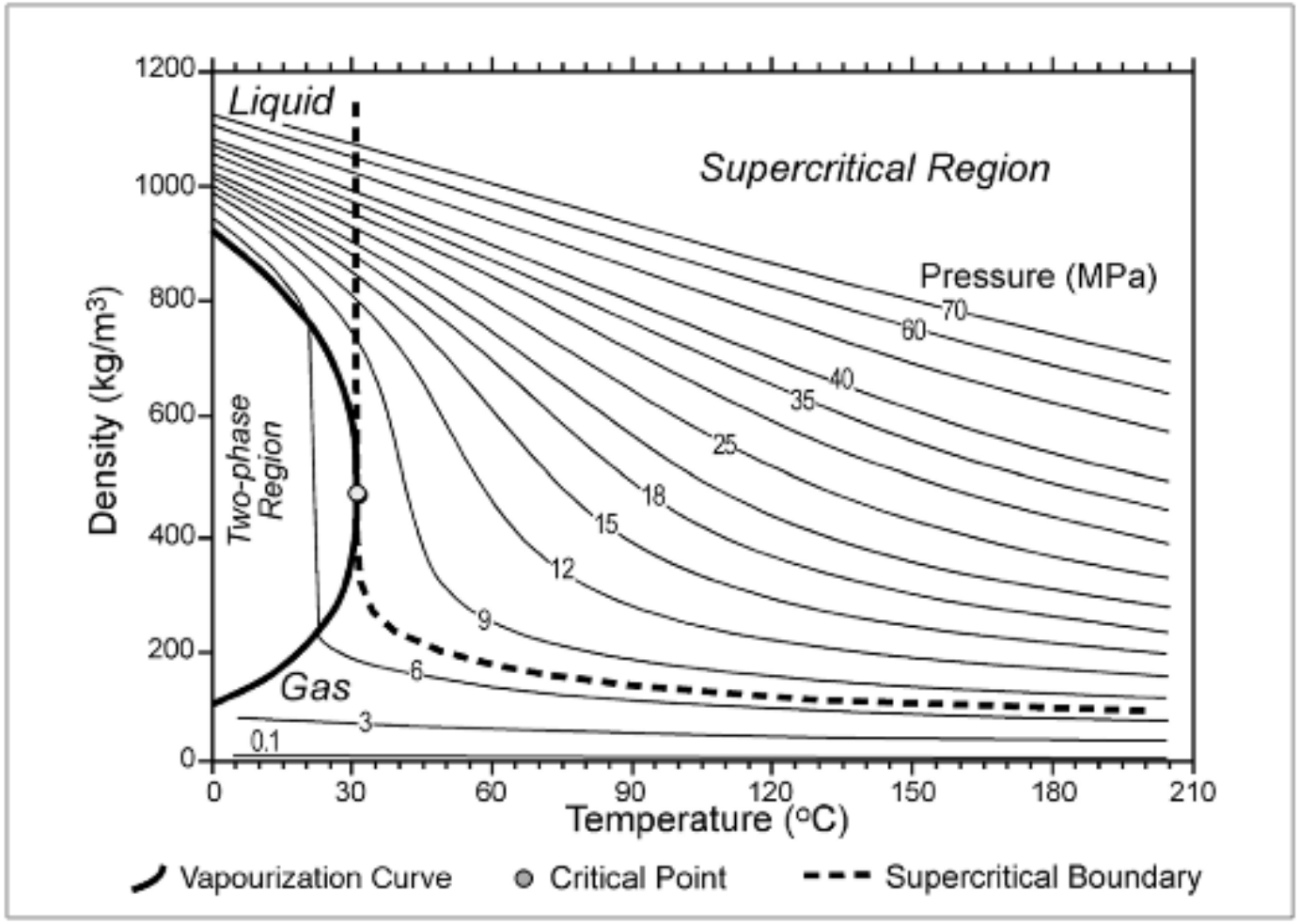
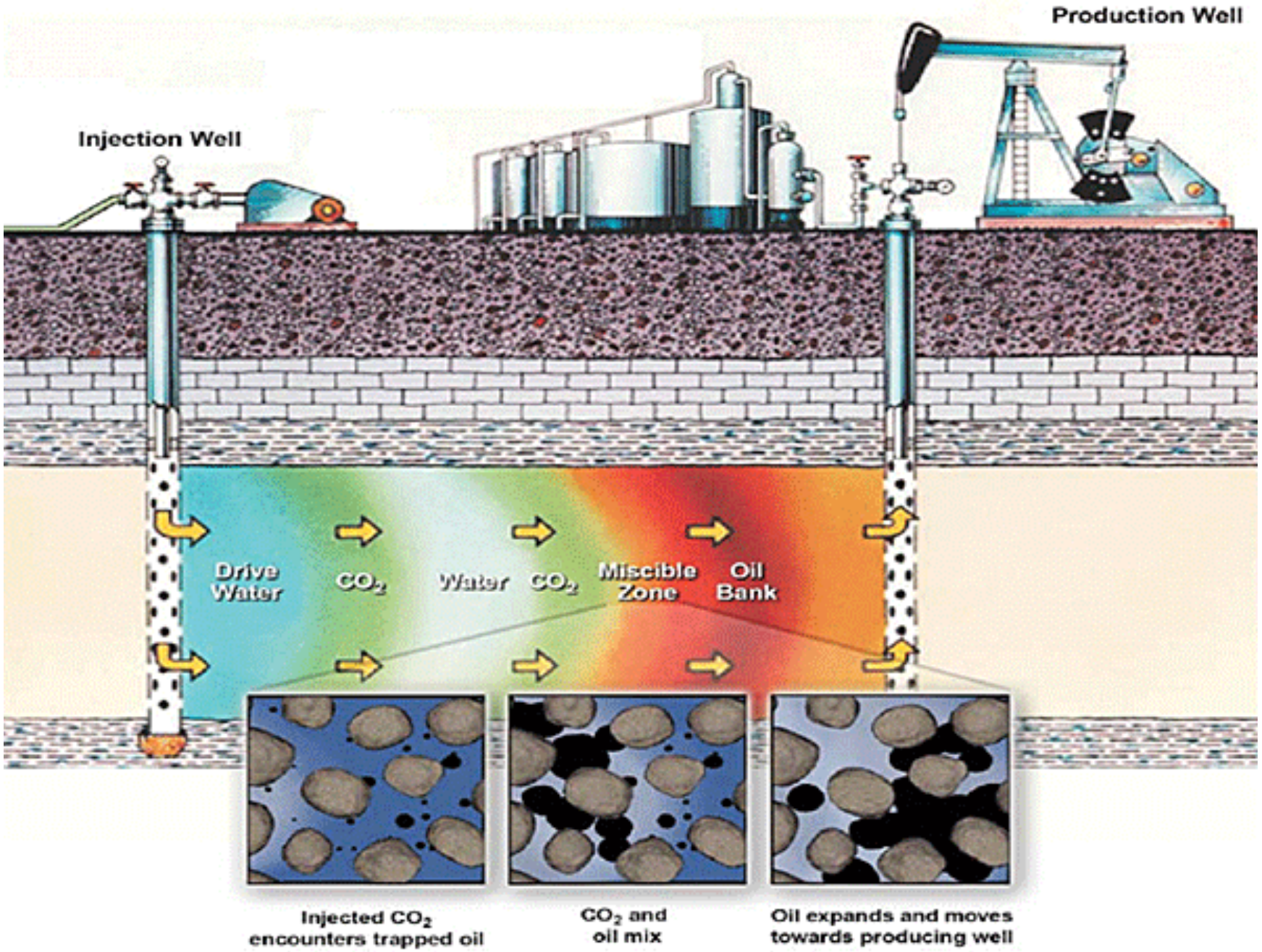
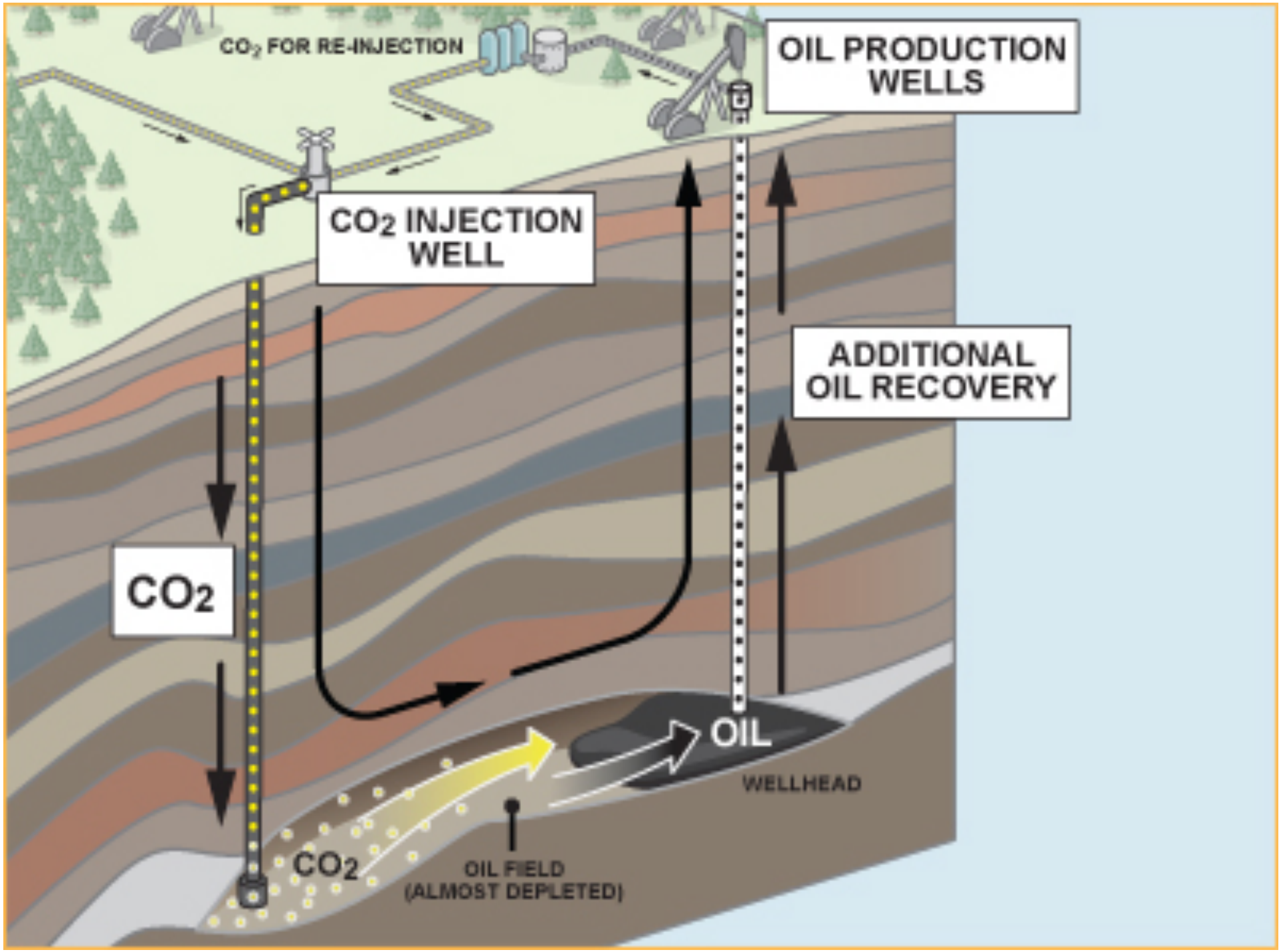


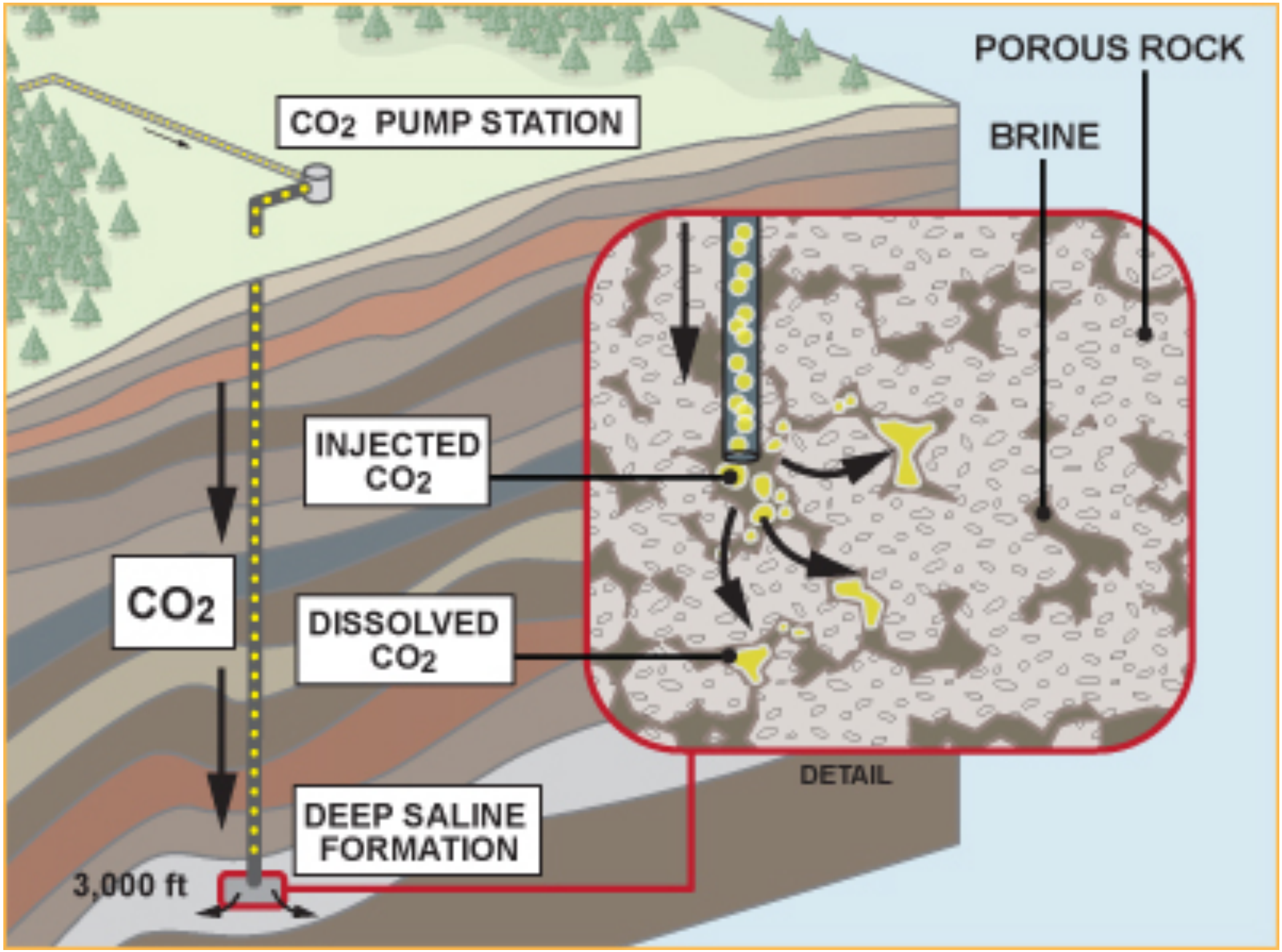

**Figure AI.2** Variation of $CO_2$ density as a function of temperature and pressure (Bachu, 2003).

$0.1302838 \cdot 10^{-2} \cdot S^2 - 0.1871199 \cdot 10^{-4} \cdot S^3)$ (1)




2012 California CCS Coalition


$CO_2$ FOR RE-INJECTION
OIL PRODUCTION WELLS
$CO_2$ INJECTION WELL
ADDITIONAL OIL RECOVERY
$CO_2$
OIL
WELLHEAD
$CO_2$
OIL FIELD (ALMOST DEPLETED)


POROUS ROCK
BRINE
$CO_2$ PUMP STATION
INJECTED $CO_2$
$CO_2$
DISSOLVED $CO_2$
DETAIL
DEEP SALINE FORMATION
3,000 ft

After injection, carbon dioxide is remarkably immobile, trapped in the geological formation by three mechanisms:

1) Structural trapping – confinement by impermeable layers (usually shale)

2) Residual trapping (capillary trapping) – immobility caused by interactions with the walls of the pore spaces

3) Solubility trapping – dissolution of $CO_2$ in the brine, creating a $CO_2$-saturated solution that is denser than either supercritical $CO_2$ or the original bring.

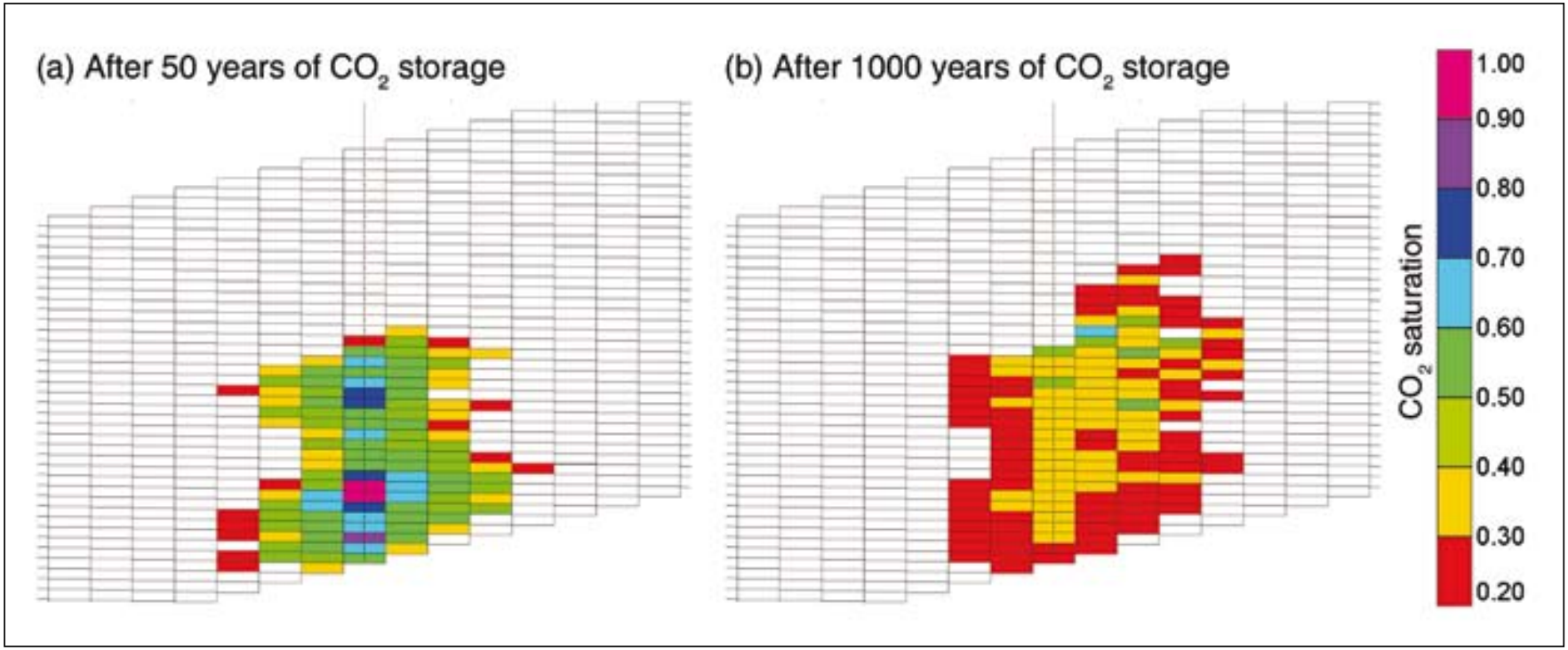
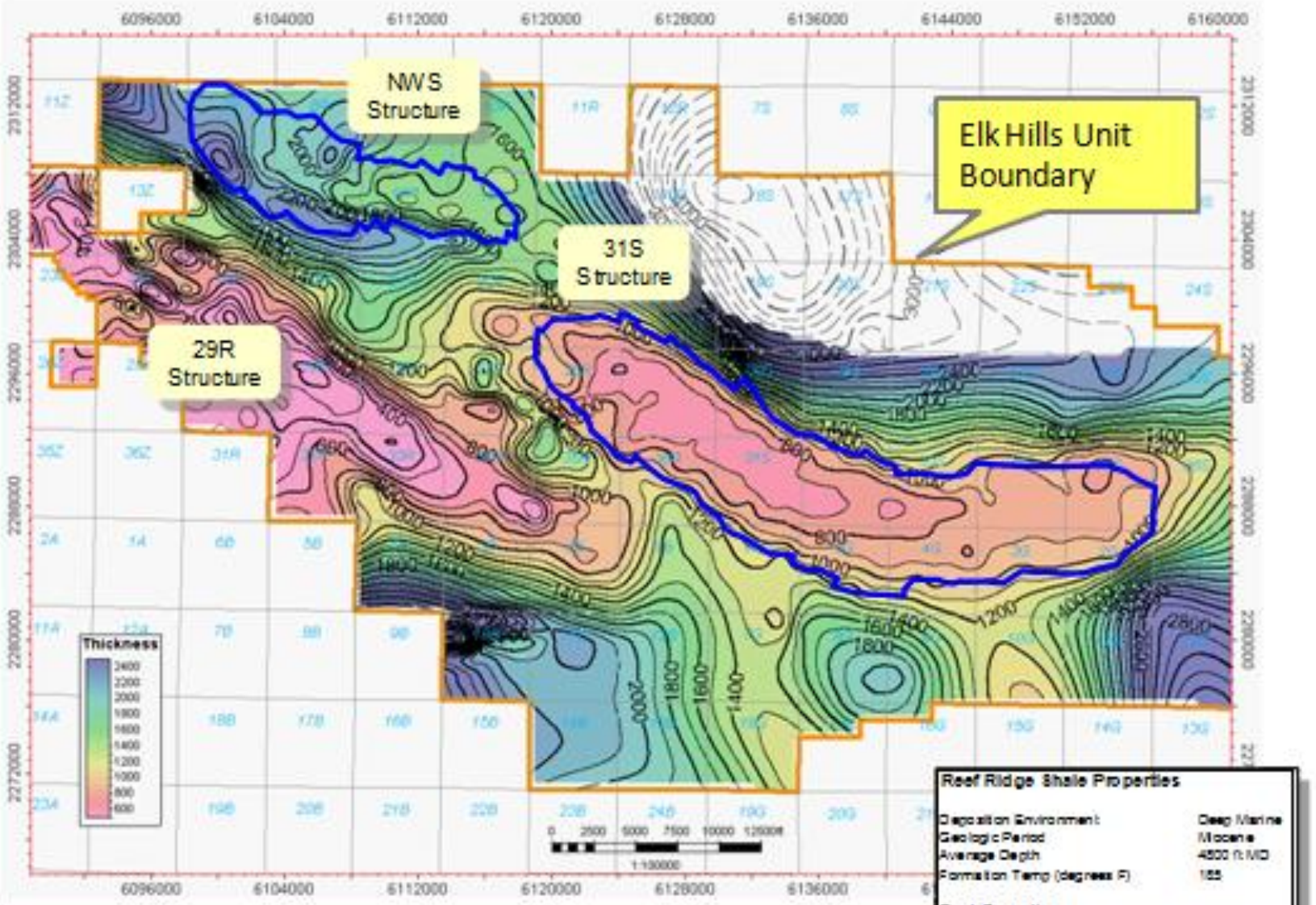


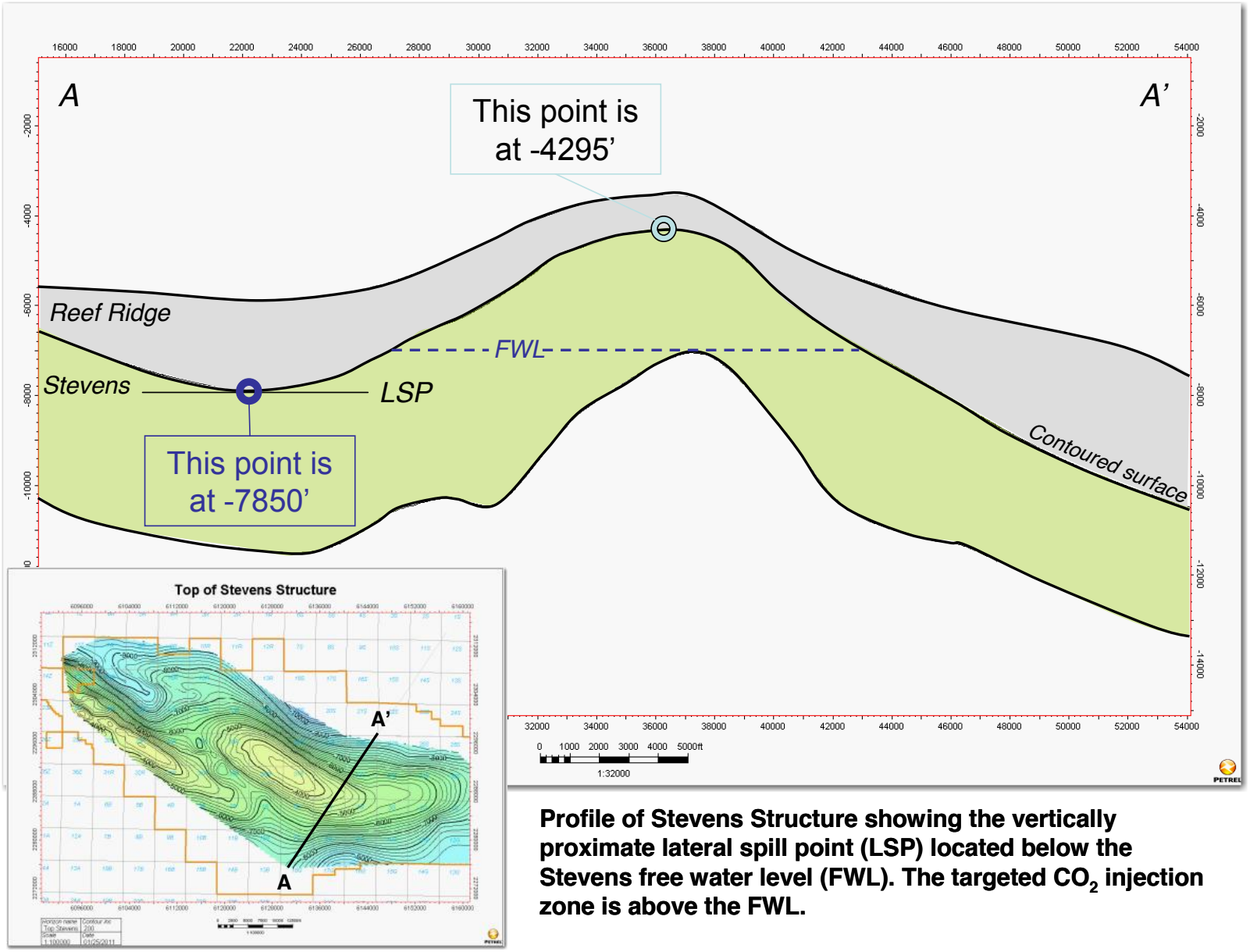

**Figure 5.8** Simulation of 50 years of injection of $CO_2$ into the base of a saline formation. Capillary forces trap $CO_2$ in the pore spaces of sedimentary rocks. (a) After the 50-year injection period, most $CO_2$ is still mobile, driven upwards by buoyancy forces. (b) After 1000 years, buoyancy-driven flow has expanded the volume affected by $CO_2$ and much is trapped as residual $CO_2$ saturation or dissolved in brine (not shown). Little $CO_2$ is mobile and all $CO_2$ is contained within the aquifer (after Kumar et al., 2005).




Note:

*Contour interval = 100'*

*Dashed contours denote areas of limited control points.*




**Profile of Stevens Structure showing the vertically proximate lateral spill point (LSP) located below the Stevens free water level (FWL). The targeted $CO_2$ injection zone is above the FWL.**

**Figure 19 - View of Stevens Cross Section Showing Spill Point and Free Water Level**

What about old wells that puncture the Ridge Reef shale?

1) Old wells have all been sealed.

2) Data collected during oil extraction above and below the Reef Ridge shale demonstrates that these old wells do not provide pathways for significant leakage of $CO_2$.

3) The presence of large quantities of methane (natural gas) below the Reef Ridge Shale is also very strong evidence that leakage cannot occur.

# CONCLUSIONS

Enhanced oil recovery (EOR) is an excellent way to provide long-term geologic storage of $CO_2$ at low cost, in advance of an economic or regulatory incentive that makes non-EOR $CO_2$ injection feasible.

The $CO_2$ injected into a geologic formation is usually in a supercritical state, behaving more like oil than like gas.

The specific geology in the Elk Hills oil field is ideally suited for long-term (permanent) storage of $CO_2$ as the injection target is relatively deep, with an excellent seal (Reef Ridge shale), and with extensive knowledge of the subsurface geology.