Options for Removing CO_2 from California's Air

THE LLNL CARBON INITIATIVE

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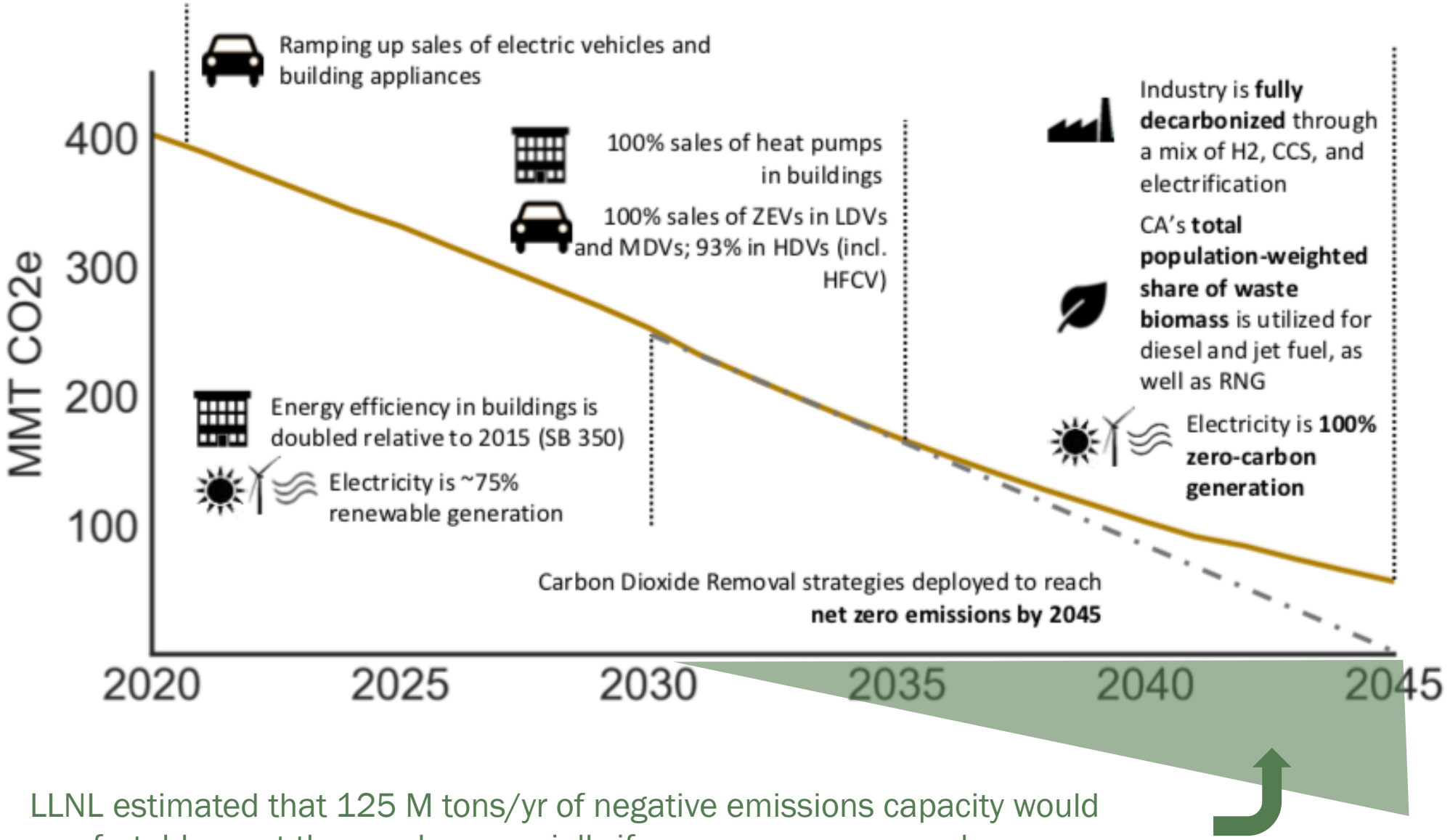
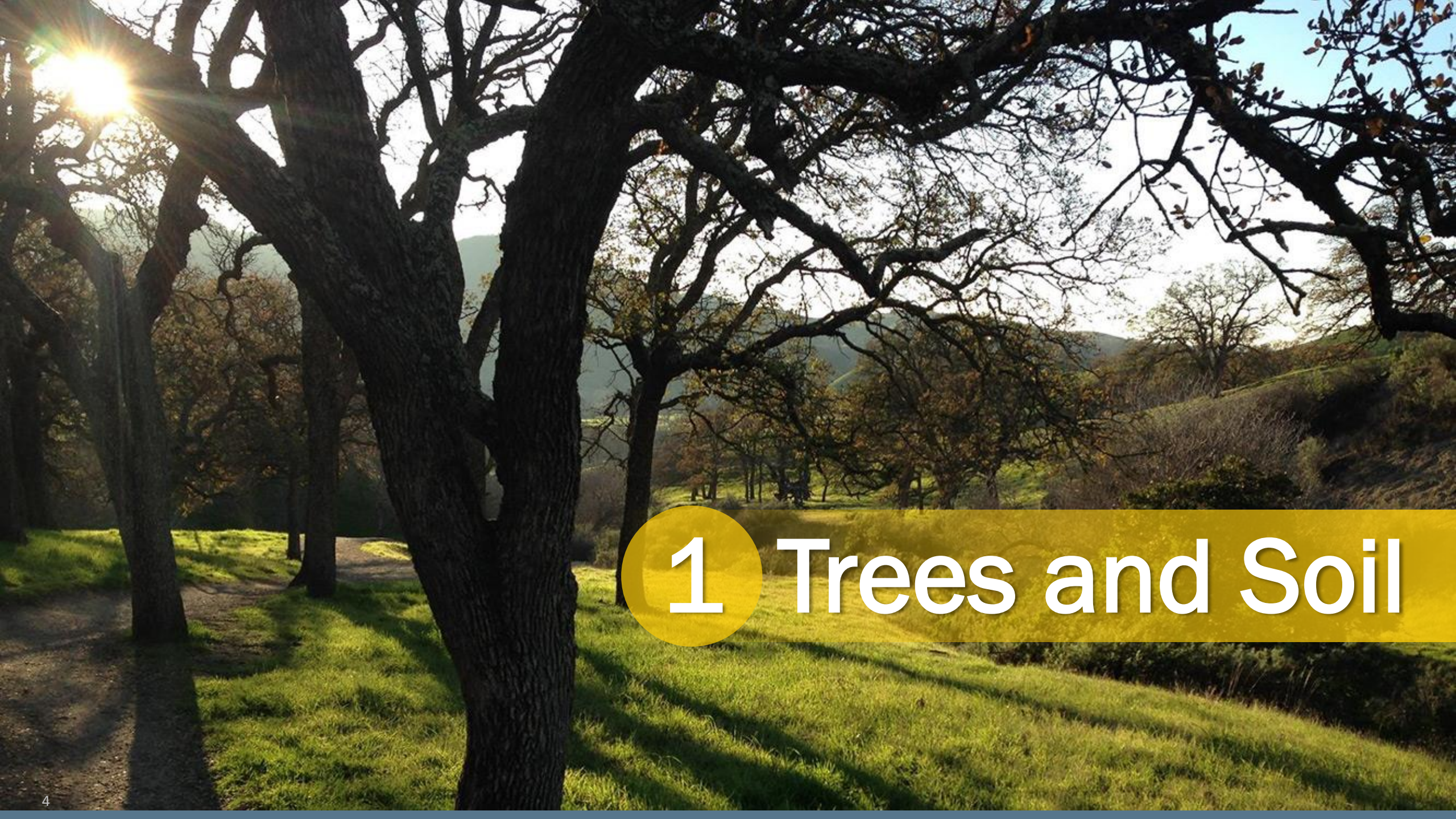
California's Path to Zero Requires Carbon Removal



LLNL estimated that 125 M tons/yr of negative emissions capacity would comfortably meet the need – especially if some measures are slow

How can we remove CO_2 from the air?

1. **Natural Solutions** (trees and soil)
2. **Biomass Solutions** (permanently store carbon from plants)
3. **Direct air capture** (machines and chemical systems to filter CO_2 from the air)

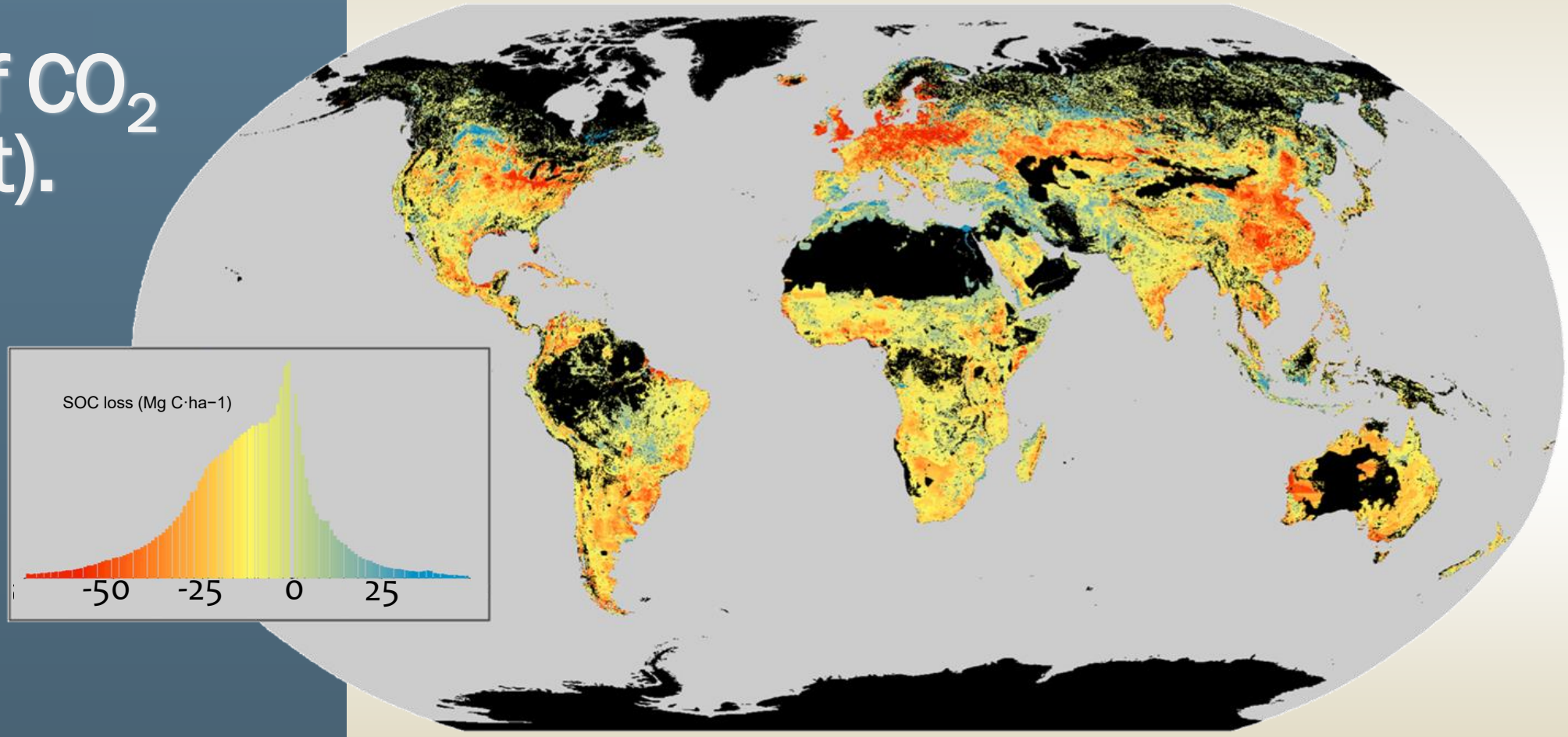


1 Trees and Soil

The world's farm soils have lost at least 487 gigatons of CO_2 (equivalent).

Can we put it back?

How fast?



Sanderman et al. 2017

2 Capture biomass carbon while producing products like hydrogen

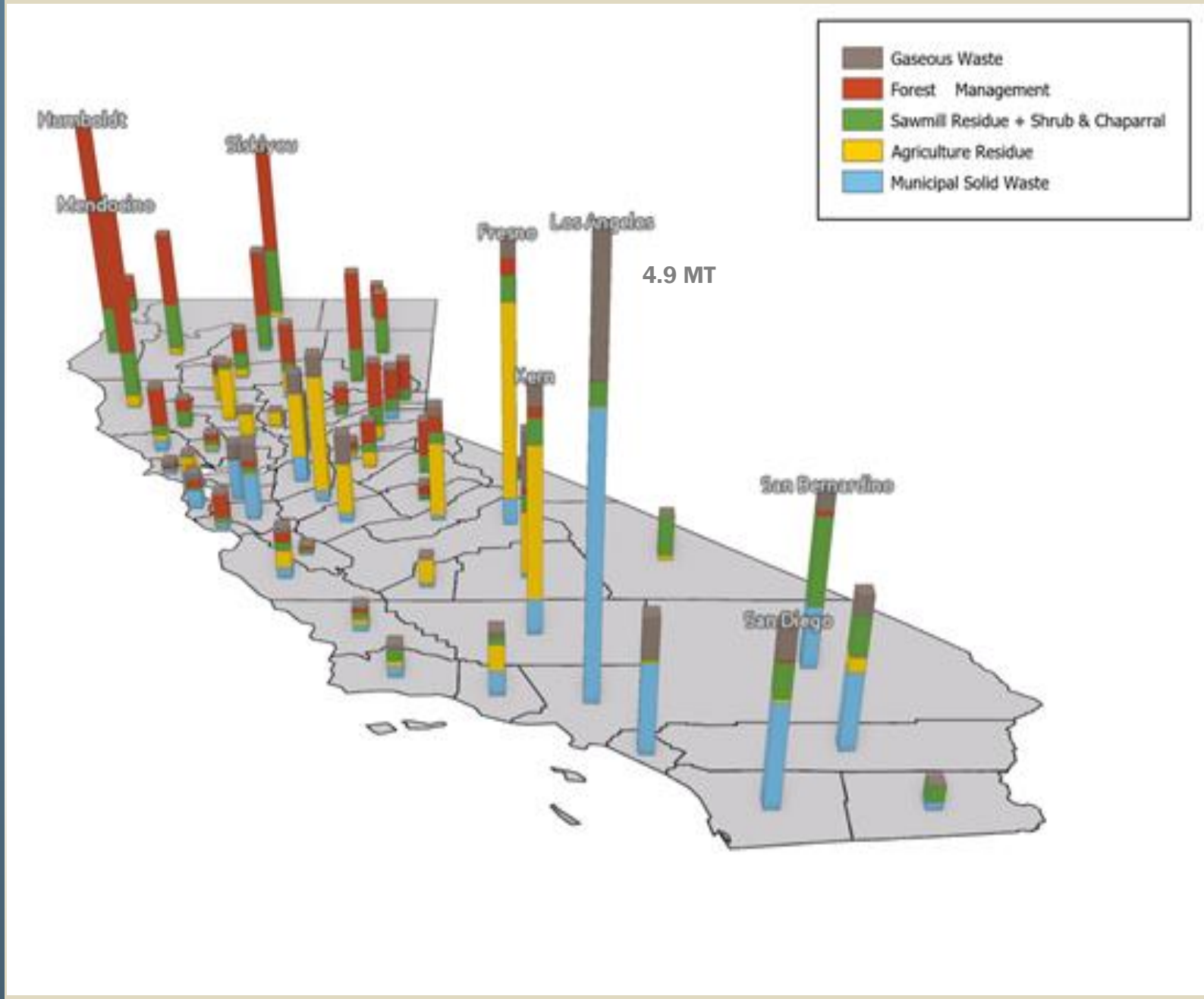
Using biomass must be restricted to true waste – but there is a lot of that

Using forest *waste* is a great place to start

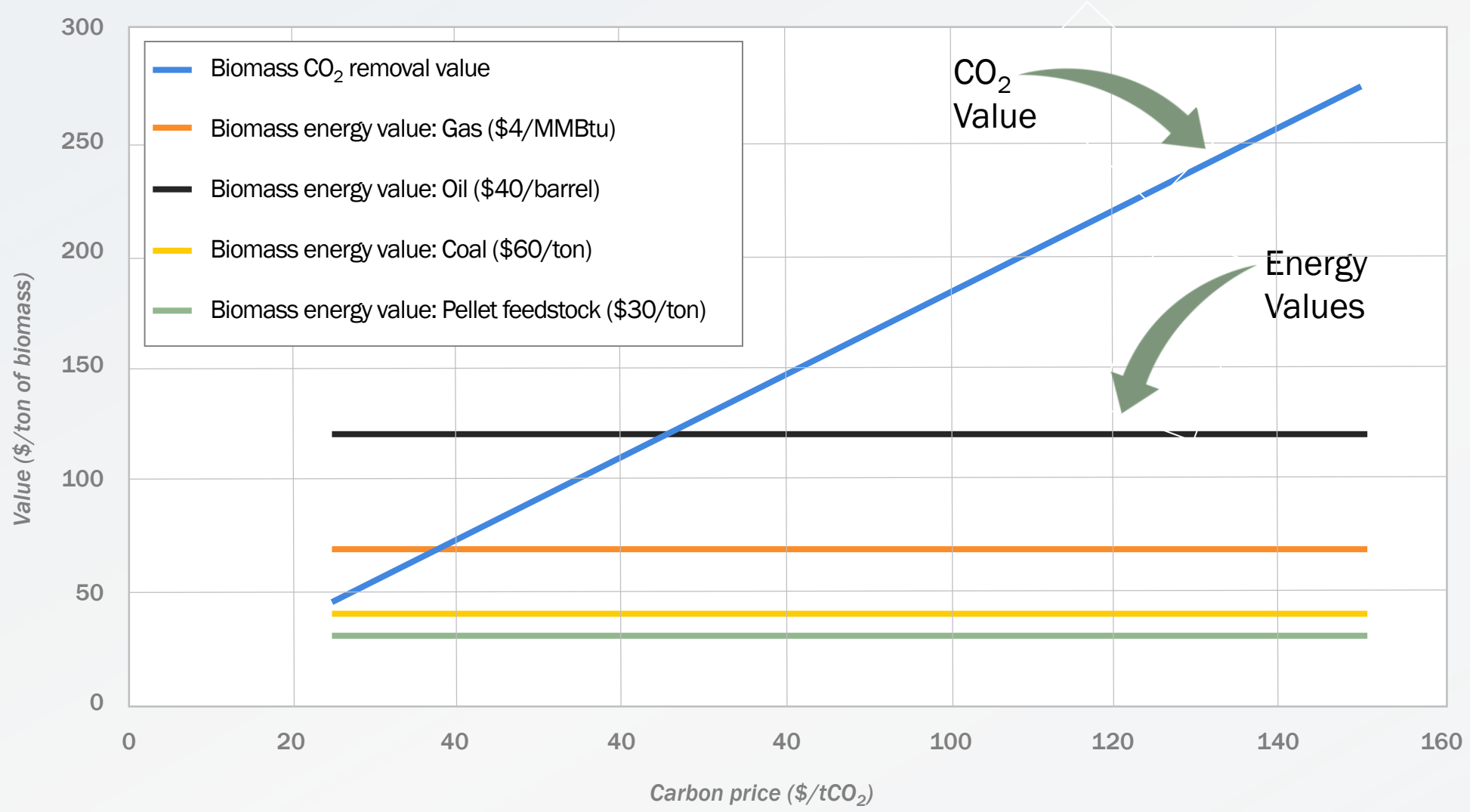
Todd Nishikawa, Placer County Air Pollution Control District

58 million tons of biomass waste is available

- We estimate that 58 million bone-dry tons will be available from waste sources in 2045
- 100% conversion to CO_2 would yield 106 MT CO_2
- Only waste biomass considered — no energy crops
- Much of this is burned or allowed to decay today



The carbon removal value of biomass greatly exceeds its energy value at realistic carbon prices



3 Build machines to clean the air

Chemical filters, solvents, and minerals that absorb CO_2

1000 ton per year capture facility, Zurich

Livermore National Lab evaluated the maximum amount of CO_2 the three major approaches could annually remove from California's air

1. Natural and Working Lands

25 MT/year

2. Waste Biomass Conversion to Fuels with CO_2 Storage

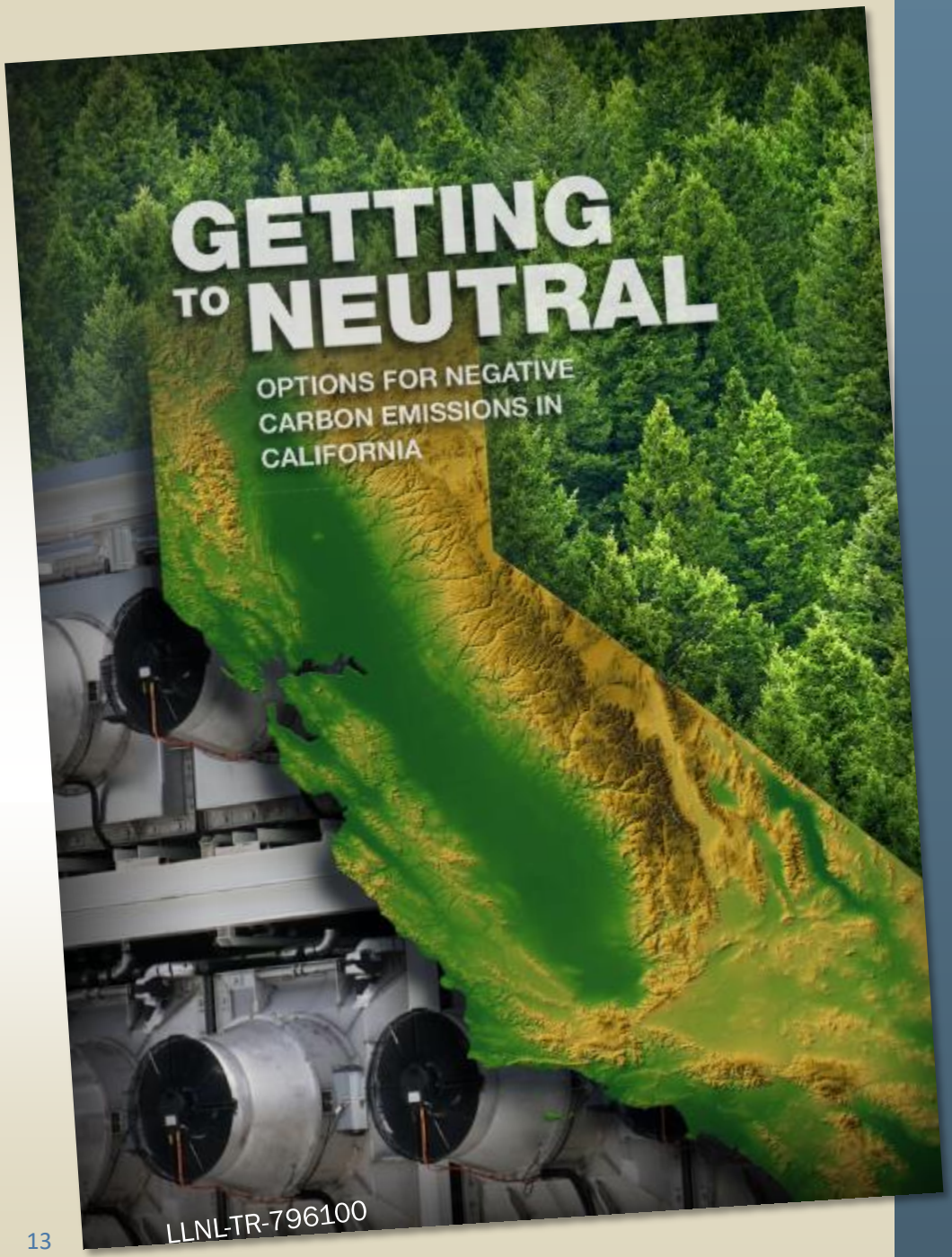
Todd Nishikawa, Placer Cty Air Pollution Control District

83 MT/year

3. Direct Air Capture with CO_2 Storage

>17 MT/year

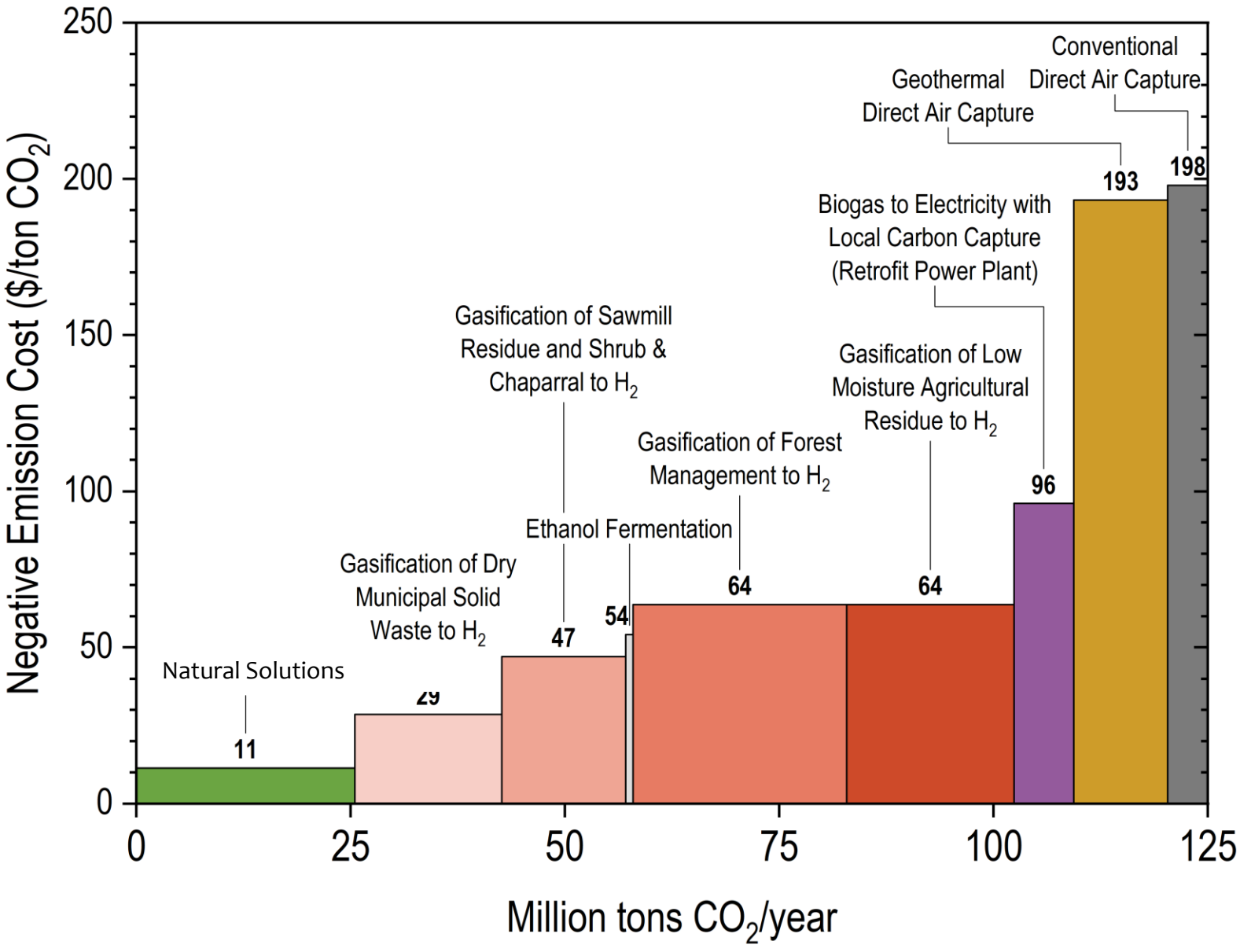
Technological readiness: mid-to-high — no new breakthroughs required



LLNL's report on California's options for carbon removal and storage evaluated the potential in tons per year, and estimated 2045 costs

https://www-gs.llnl.gov/content/assets/docs/energy/Getting_to_Neutral.pdf

California's 2045 least-cost path to 125 MT/year of carbon removal and permanent storage would average about $65/ton



Much of the removed CO_2 will have to go back underground.

CO_2's properties are very similar to oil.

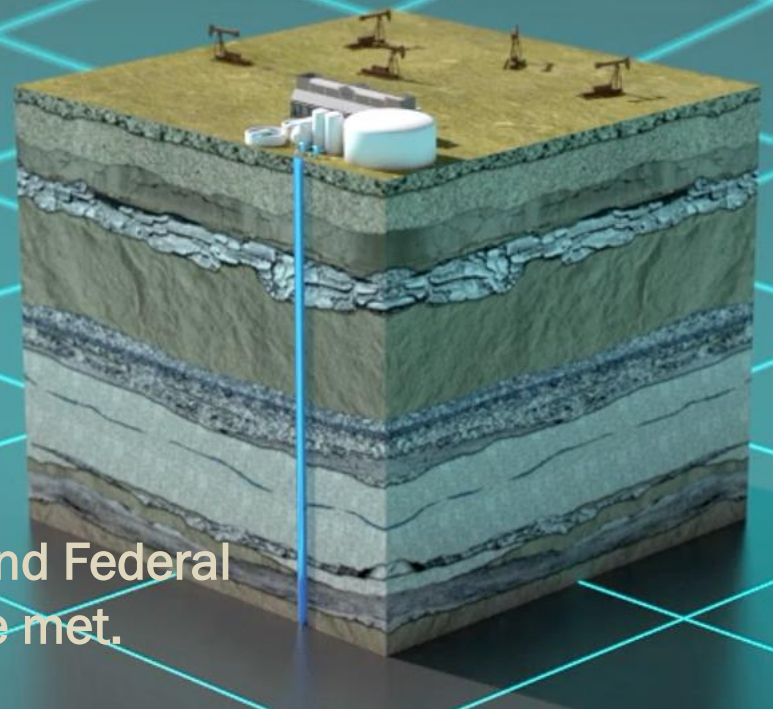
It can be stored in the same places.

The technology, people, and jobs are the same for both.

The sunset of the oil age can also be the rise of the storage age.

But is geologic storage safe?

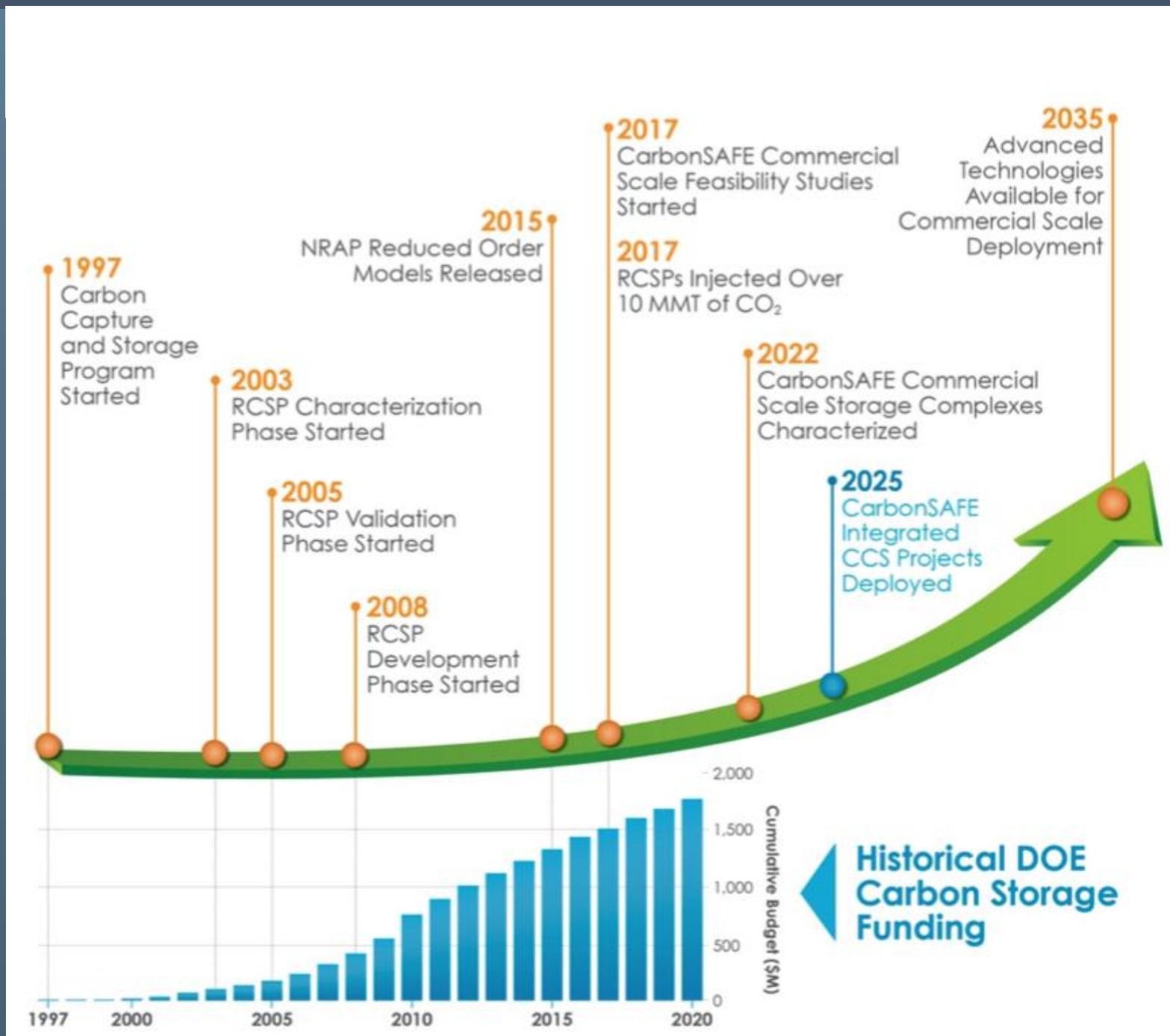
Geologic Storage is Highly Regulated and Safely Places Liquid CO_2 at Great Depth



Strict State and Federal rules must be met.

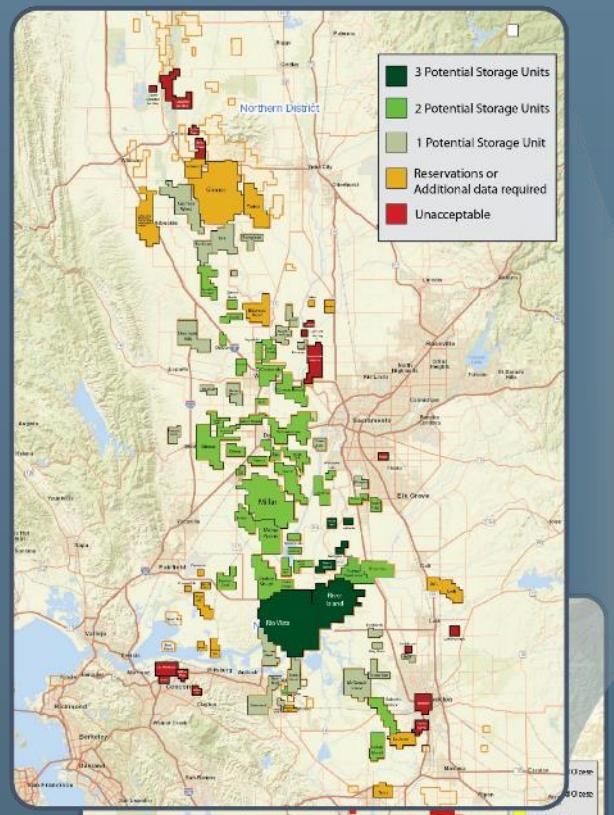
California has the most stringent CO_2 storage regulations in the world.

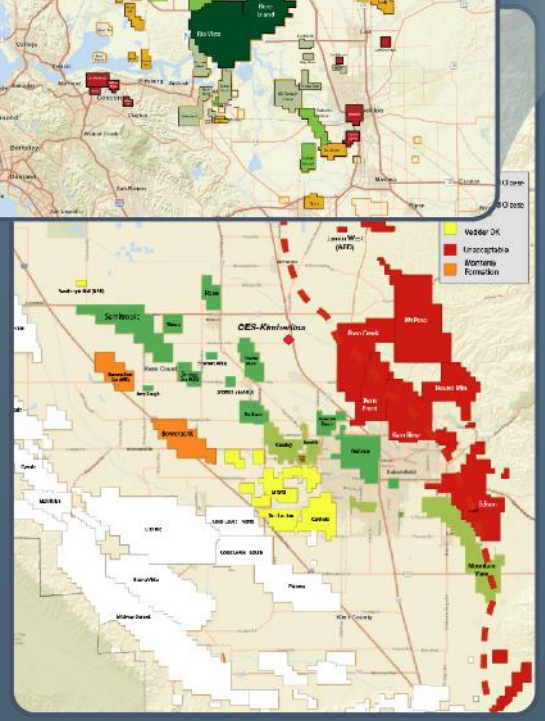
Cumulative Department of Energy investment in carbon capture and storge development currently exceeds $1.7 Billion



There is **plenty of safe space in California** to store CO_2 underground—in the same rocks that have held oil and gas for millions of years.

LLNL has identified **17 billion tons** of safe storage in **just 2 areas** of the Central Valley. As much as **200 billion tons** may be available.





Permanent geologic storage is available

20 years of CCS testing show it is safe and reliable

"We calculate that realistically well-regulated storage in regions with moderate well densities has a 50% probability that leakage remains below 0.0008% per year, with over **98% of the injected CO2 retained in the subsurface over 10,000 years**."

"Large-scale CO2 storage research projects are being conducted by the U.S. Department of Energy (DOE) in various geologic settings across the United States …To date, **more than 14 million metric tons (MMT) of CO2 have been successfully injected**"

A total of five Best Practices Manuals were revised in 2017.

nature COMMUNICATIONS

DOI: 10.1038/s41467-018-04423-1 OPEN

Estimating geological CO_2 storage security to deliver on climate mitigation

Juan Alcalde, Stephanie Flude, Mark Wilkinson, Gareth Johnson, Katriona Edlmann, Clare E. Bond1, Vivian Scott, Stuart M.V. Gilfillan, Xènia Ogaya & R. Stuart Haszeldine

PERMANENCE AND SAFETY OF CCS

NATIONAL ENERGY TECHNOLOGY LABORATORY

https://netl.doe.gov/coal/carbon-storage/faqs/permanence-safety

The National Academy of Science found that carbon removal is ready to deploy

"Four negative emissions technologies are ready for large-scale deployment: afforestation/reforestation, changes in forest management, uptake and storage by agricultural soils, **and bioenergy with carbon capture and storage (BECCS).** These NETs have low to medium costs ($100/t CO_2 or less) and substantial potential for safe scale-up from current deployment. They also provide co-benefits"

"Direct air capture and carbon mineralization have high potential capacity for removing carbon, but direct air capture is currently limited by high cost and carbon mineralization by a lack of fundamental understanding."

The National Academies of | SCIENCES ENGINEERING MEDICINE THE NATIONAL ACADEMIES PRESS

This PDF is available at http://nap.edu/25259

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Both natural and engineered methods will be needed for removing carbon dioxide from the air, and permanently storing it.

Methods using waste biomass as the carbon source are low cost and can also produce valuable hydrogen.

Permanent geologic storage is widely available in California and has been shown to be safe and effective in 20 years of U.S. testing.