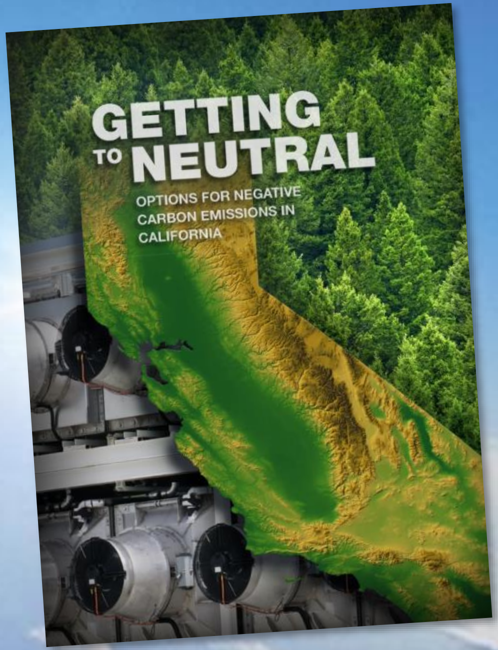
THE LLNL CARBON INITIATIVE

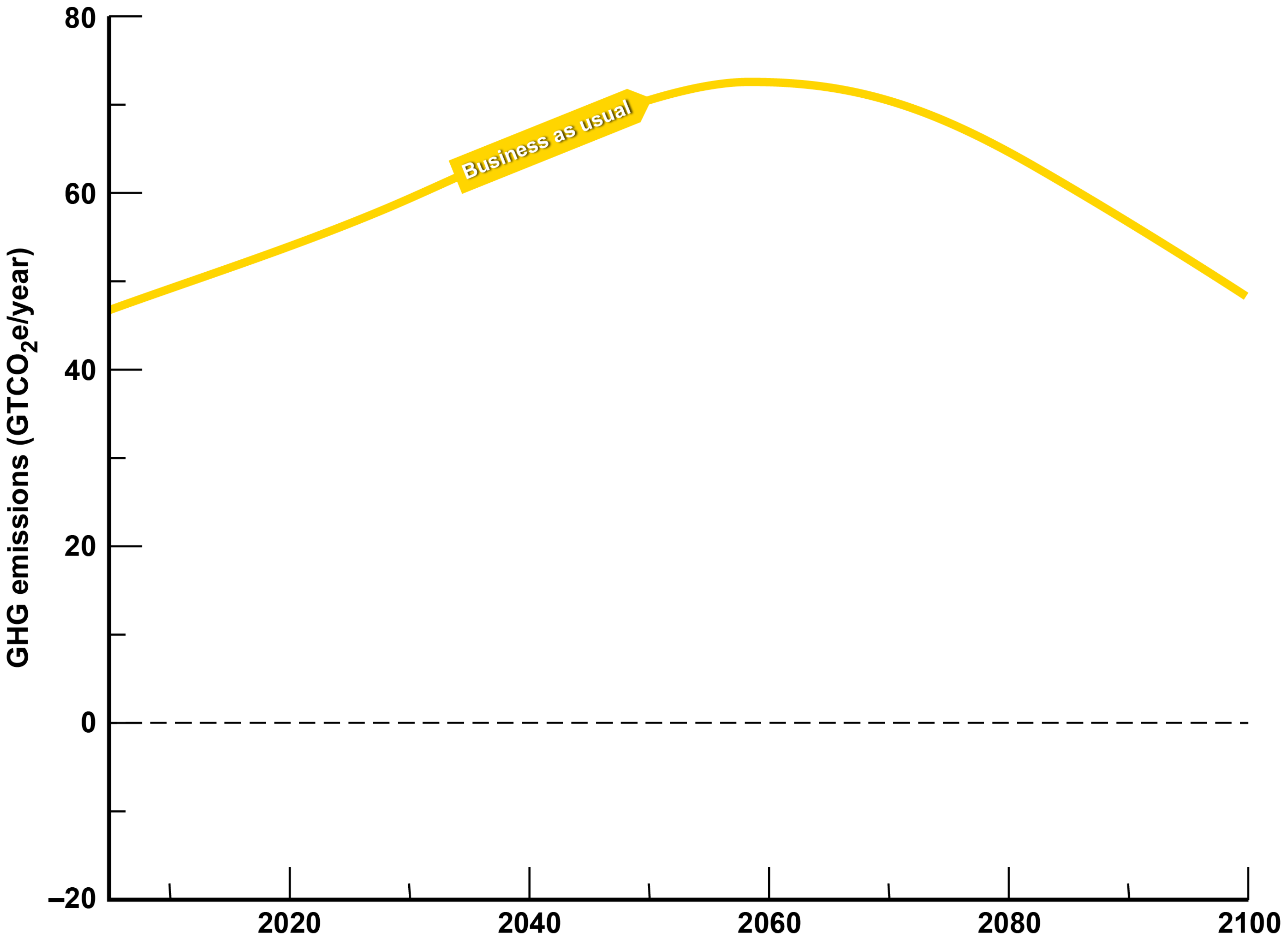
Options for Removing CO_2 from California's Air



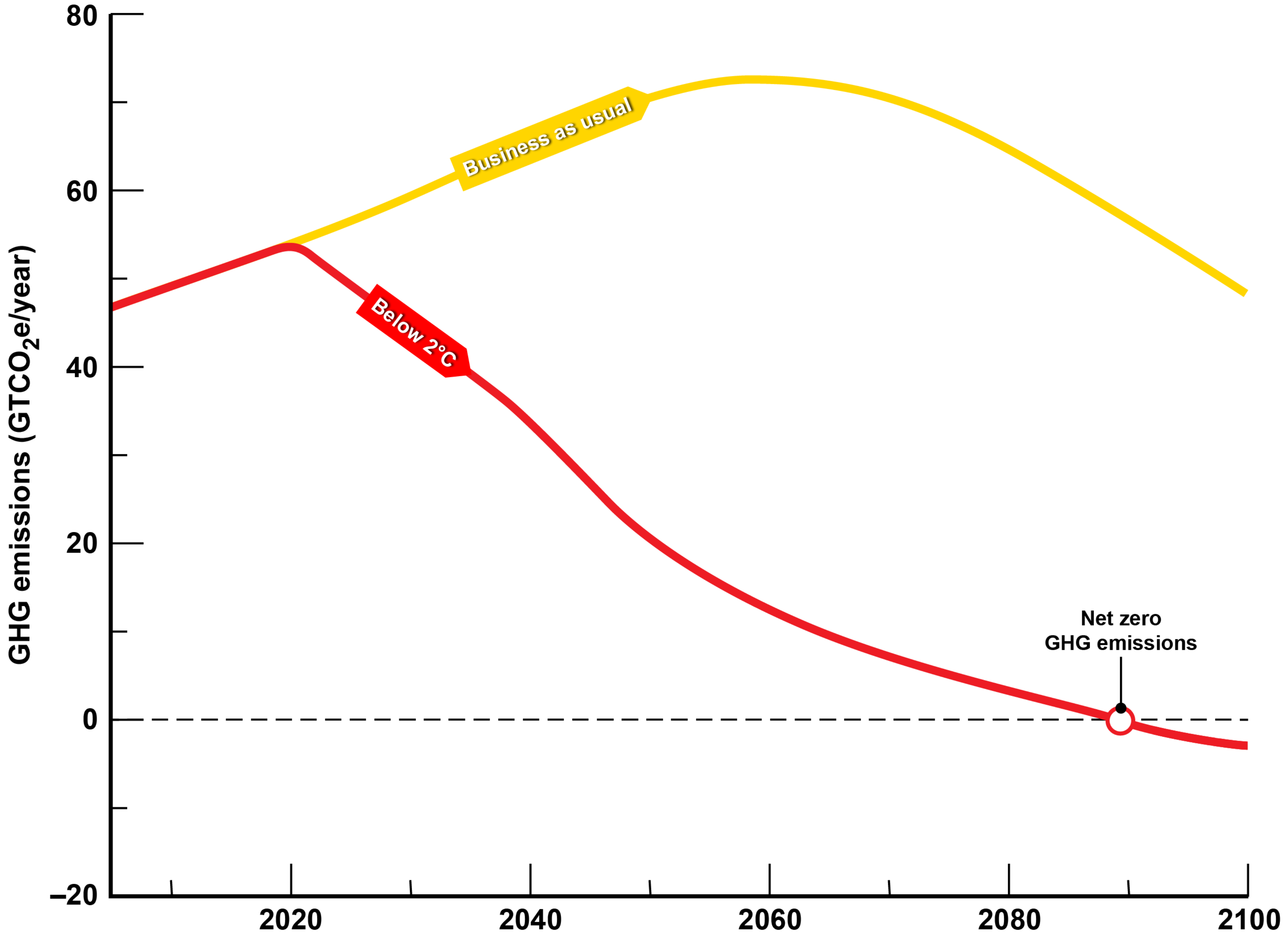
Roger Aines
Energy Program Chief Scientist
Lawrence Livermore National Laboratory

LLNL-PRES-825083

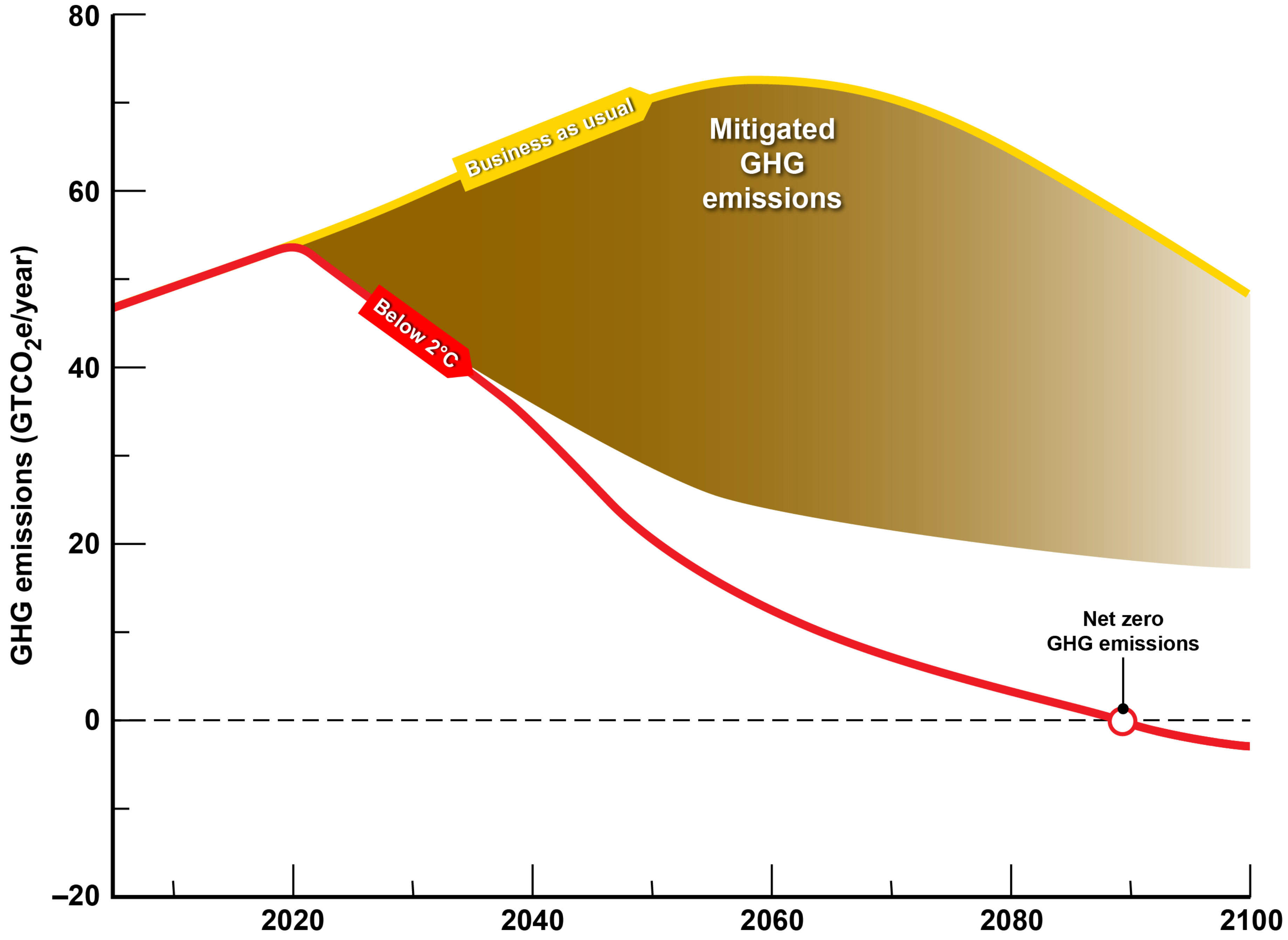
Perspectives



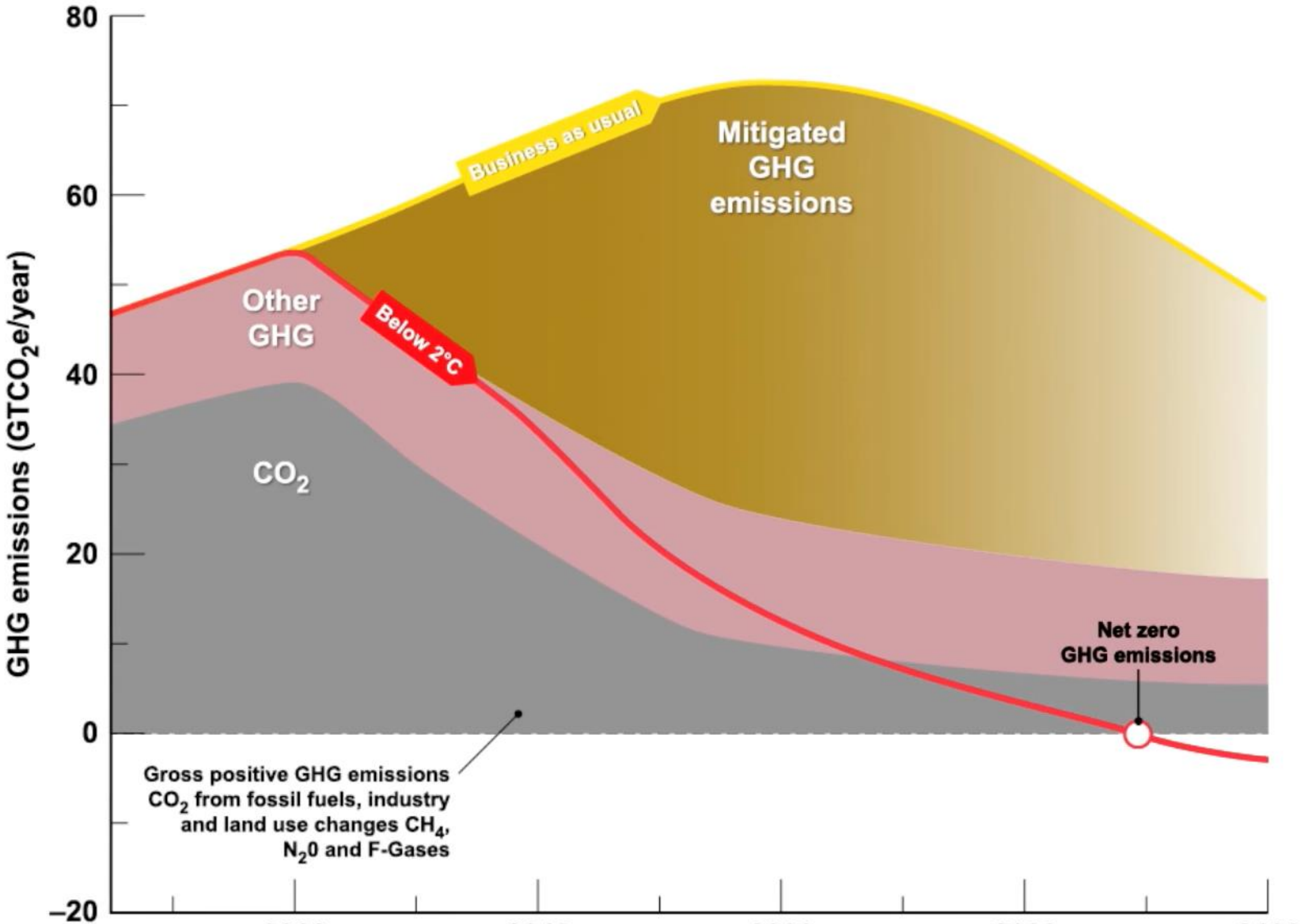
Source: Jérôme Hilaire Mercator Institute



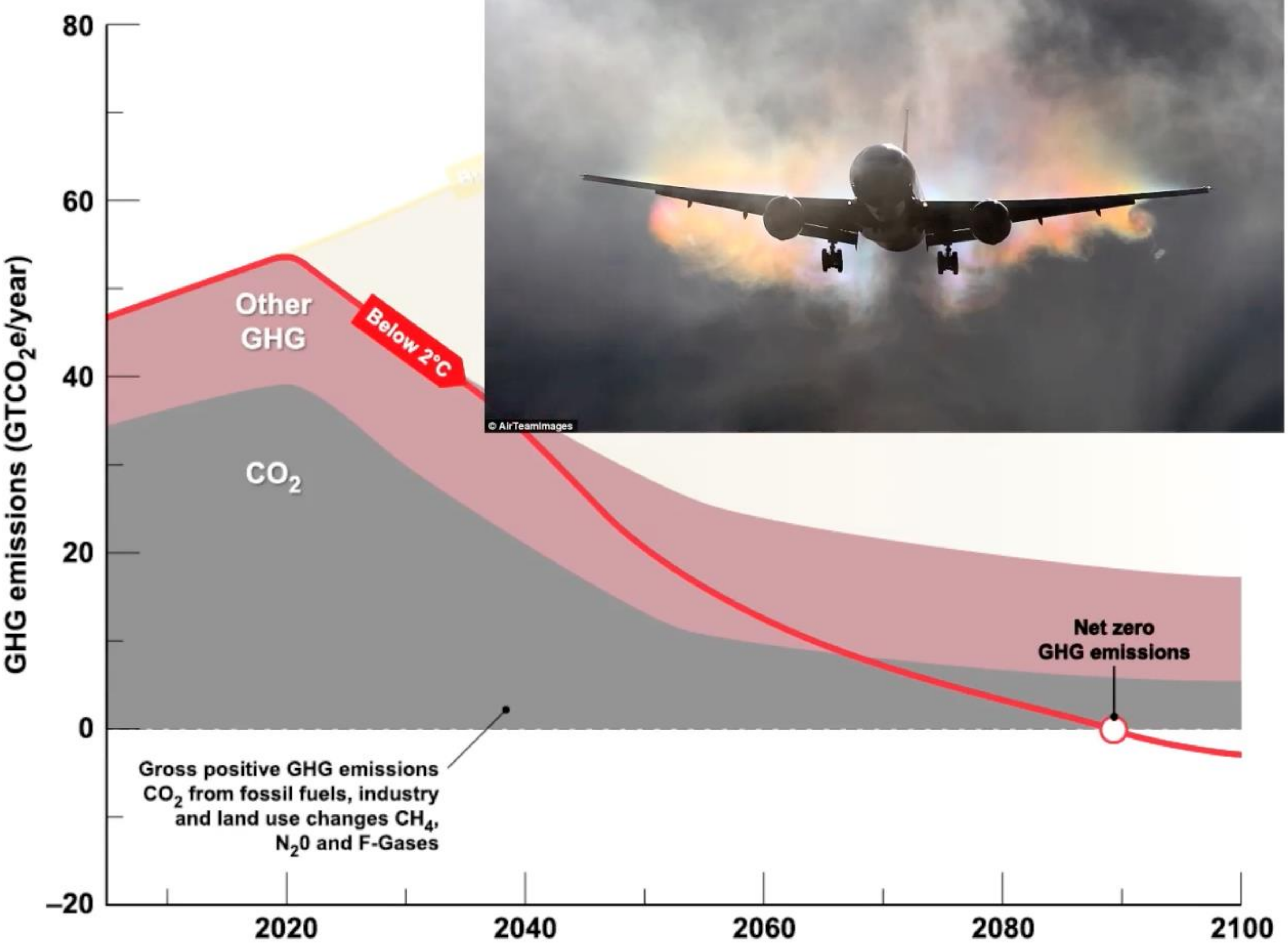
Source: Jérôme Hilaire Mercator Institute



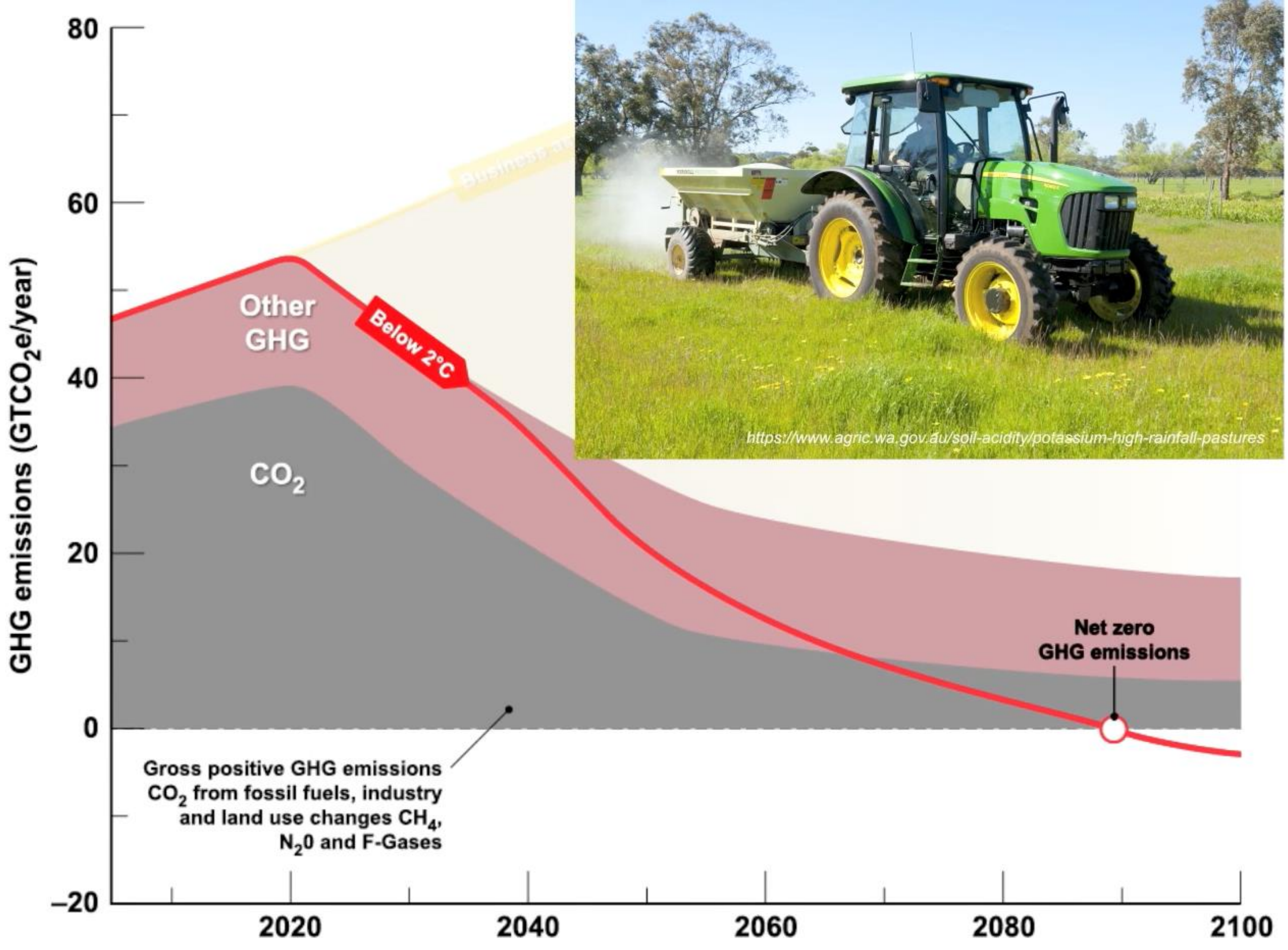
Source: Jérôme Hilaire Mercator Institute



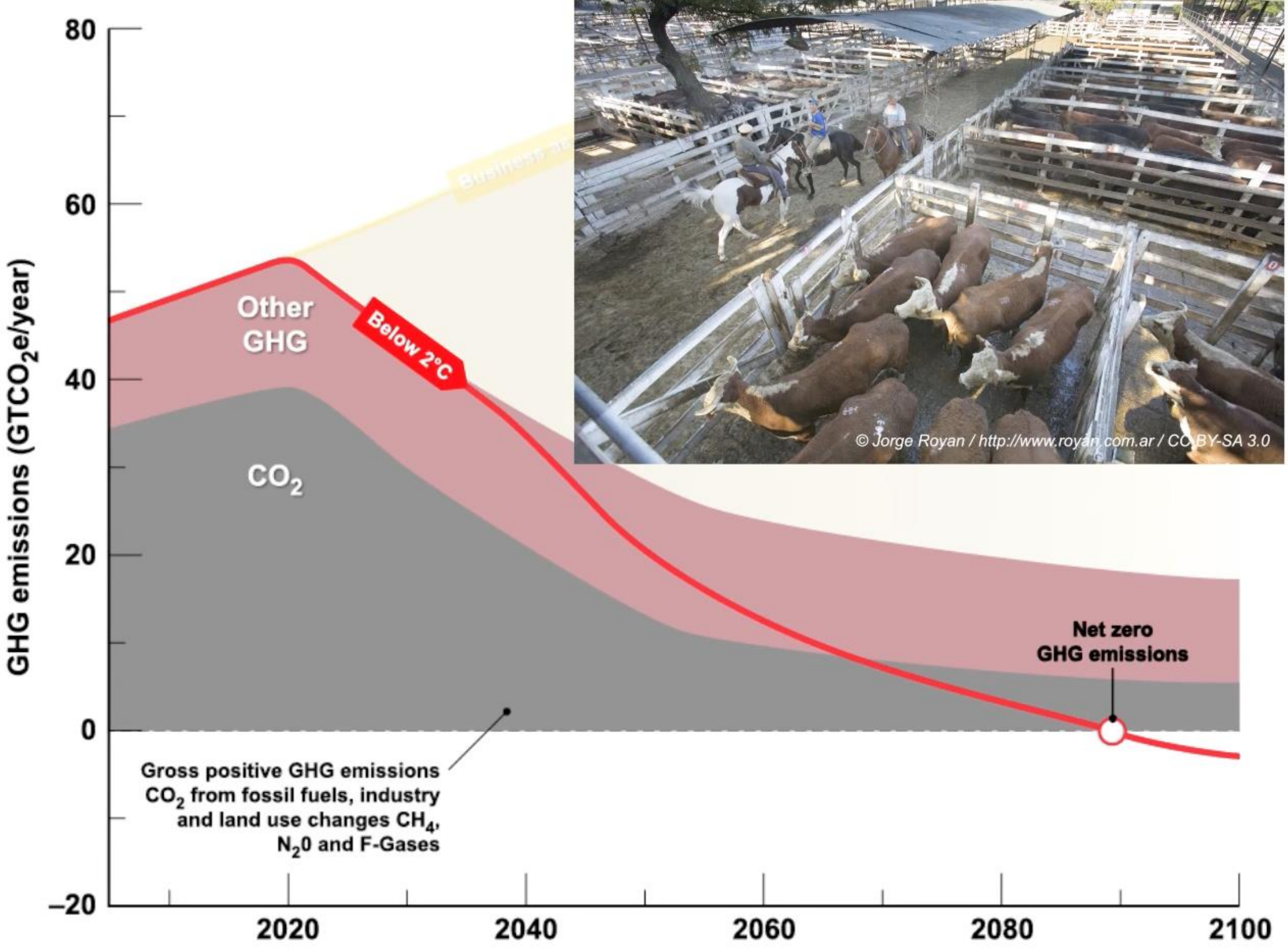
Source: *Jérôme Hilaire Mercator Institute*



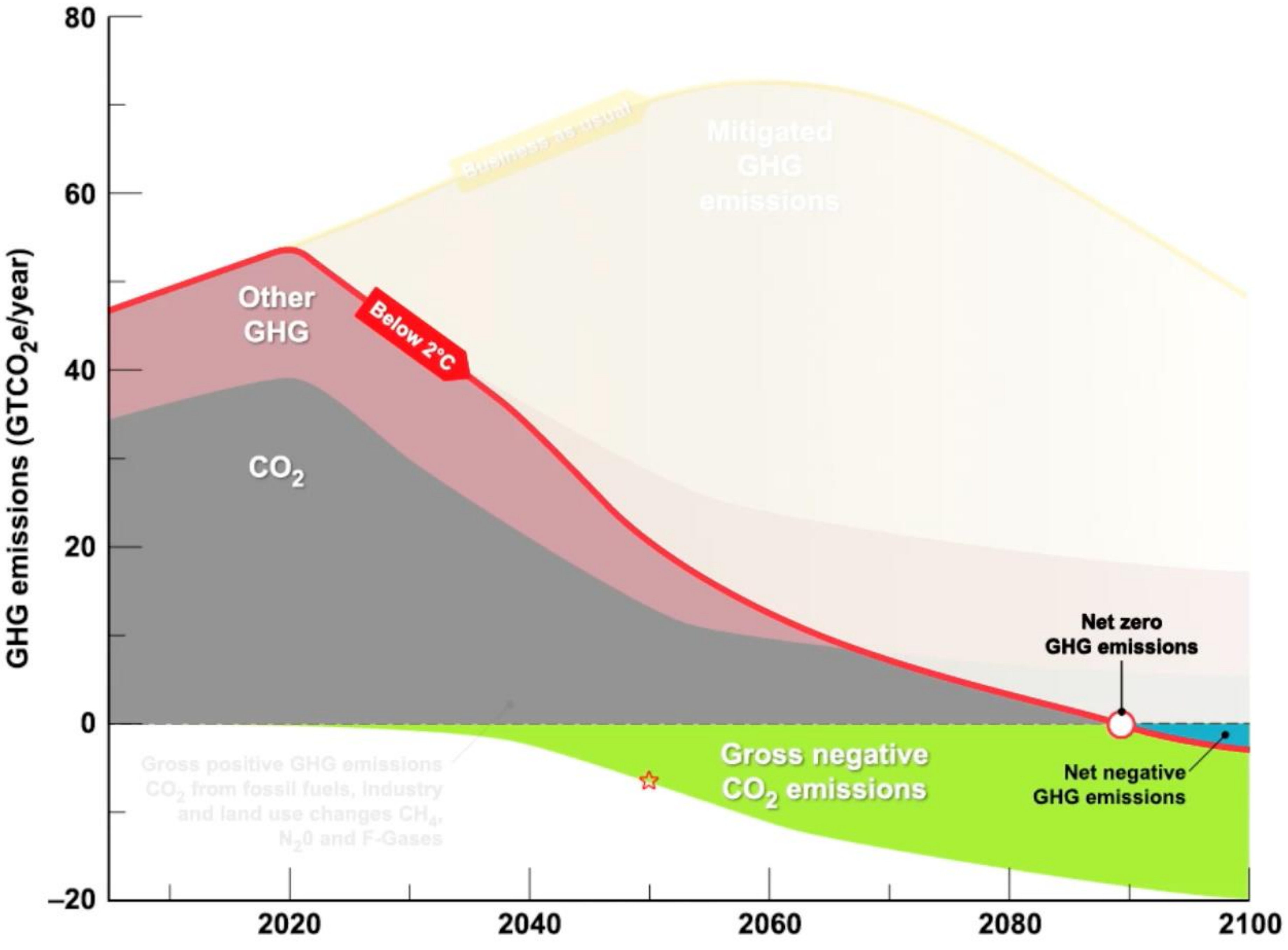
Source: Jérôme Hilaire Mercator Institute



Source: Jérôme Hilaire Mercator Institute



Source: Jérôme Hilaire Mercator Institute



Source: Jérôme Hilaire Mercator Institute

Reductions
In Emissions

Removals
From the Air

We love to think globally, but most actions will be local

Overall economy or region

Academics love this perspective "optimal"

Carbon tax is the preferred tool from this view

Business

Net zero is the common goal

Must deal with your own emissions, your suppliers, and customers

Need specific pathways

Sector (like transportation)

Mixture of the first two – easier to make clear policy

Microsoft

CALIFORNIA
AIR RESOURCES BOARD

We love to think globally, but most actions will be local

Overall economy or region

- Academics love this perspective "optimal"
- Carbon tax is the preferred tool from this view

Business

- Net zero is the common goal
- Must deal with your own emissions, your suppliers, and customers
- Need specific pathways

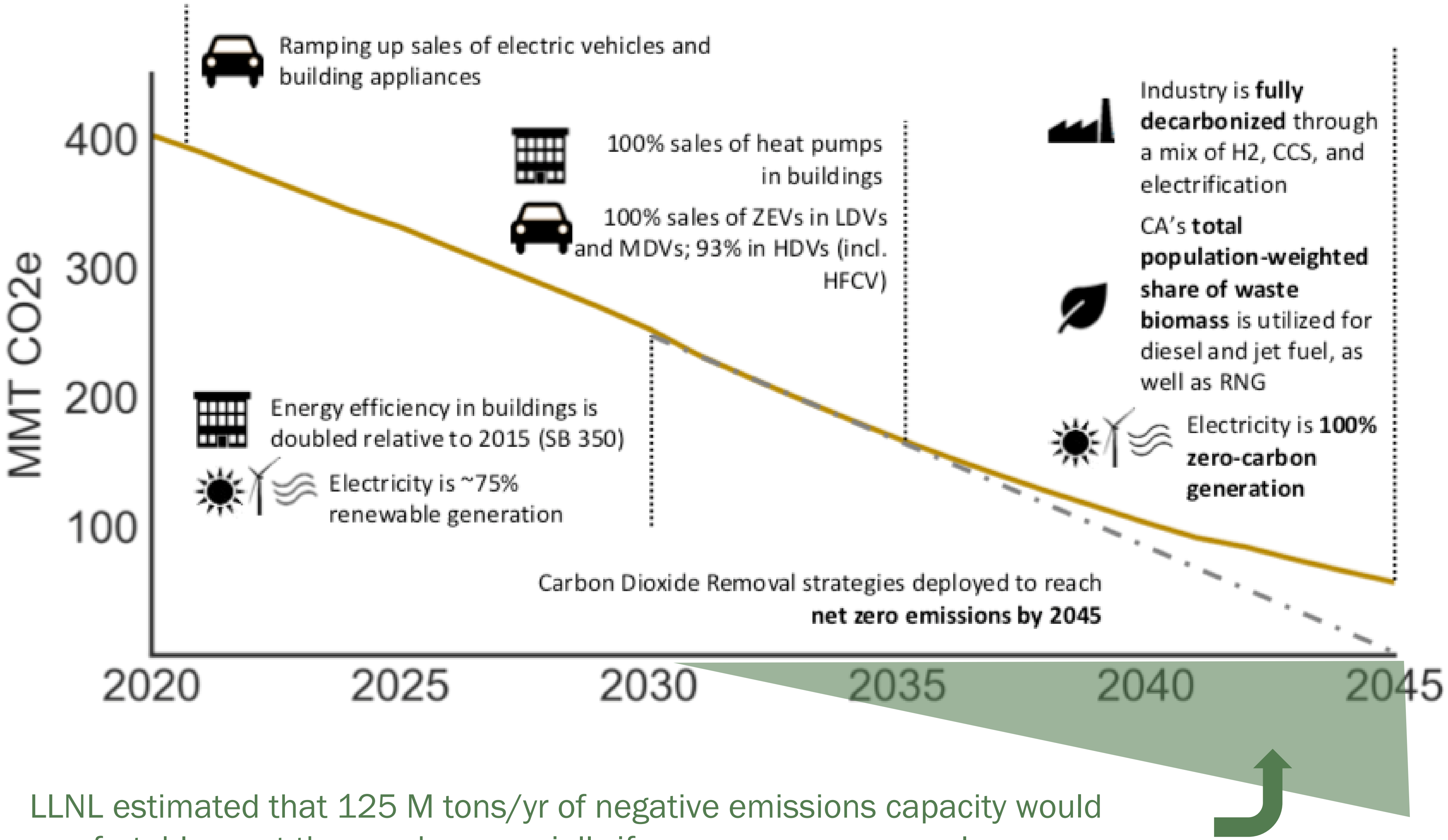
Sector (like transportation)

- Mixture of the first two – easier to make clear policy

Microsoft

CALIFORNIA
AIR RESOURCES BOARD

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?

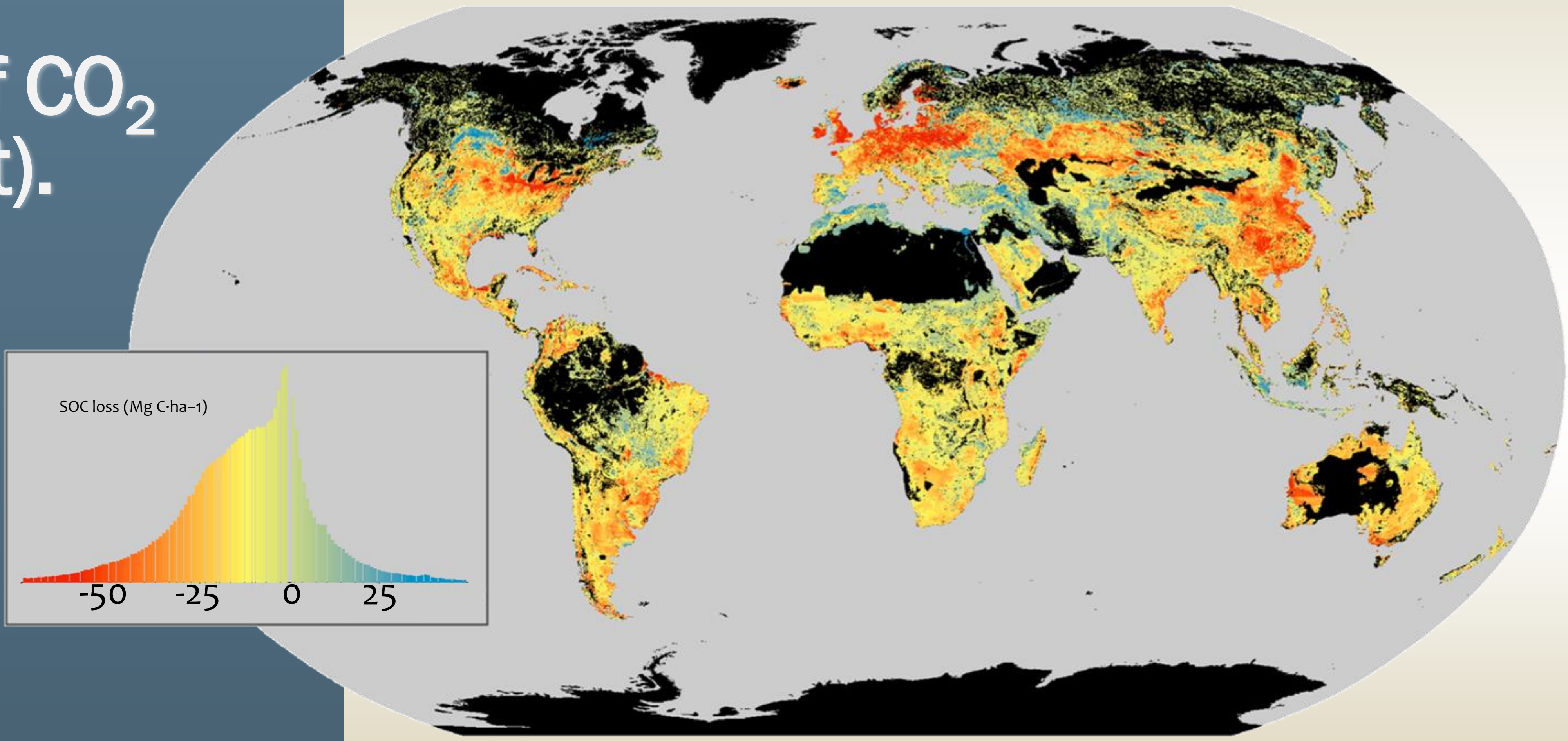
1. **Natural Solutions** (trees and soil)
2. **Biomass Solutions** (permanently store carbon from plants)
3. **Direct air capture** (machines and chemical systems to filter CO_2 from the air)

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

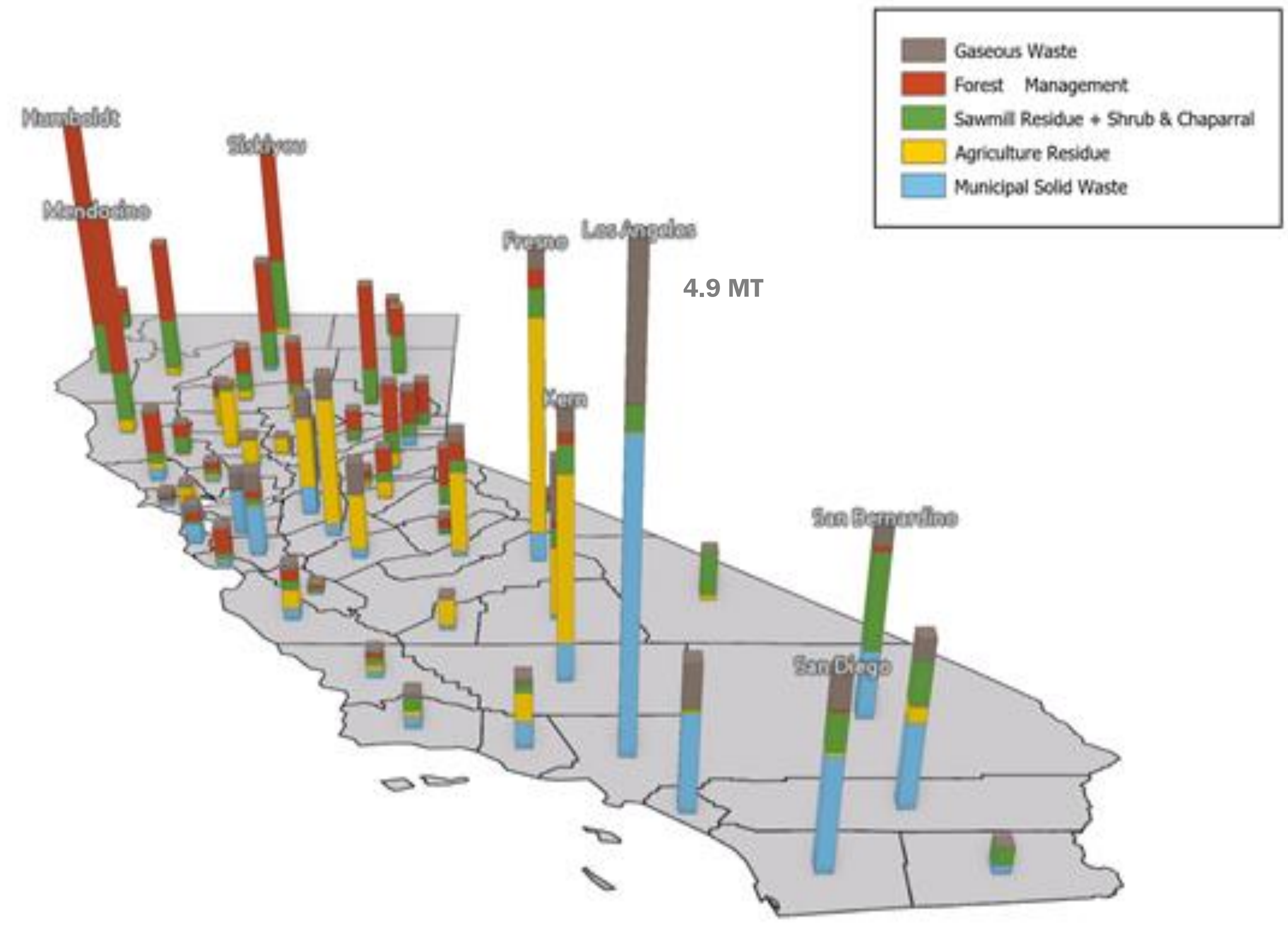
2 Capture biomass carbon while producing products like hydrogen

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

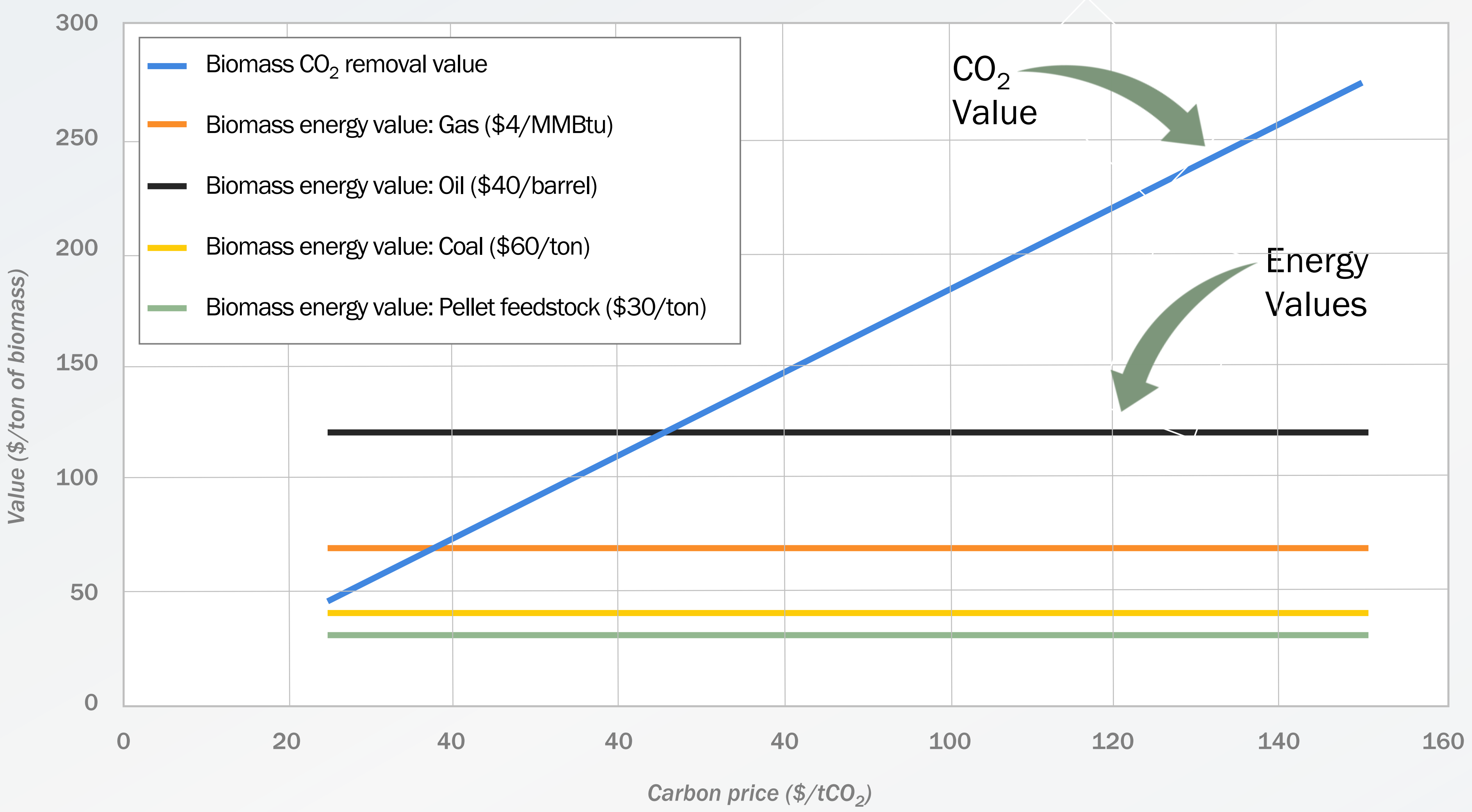

Using forest waste is
a great place to start
Link-Belt
Todd Nishikawa, Placer County Air Pollution Control District

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



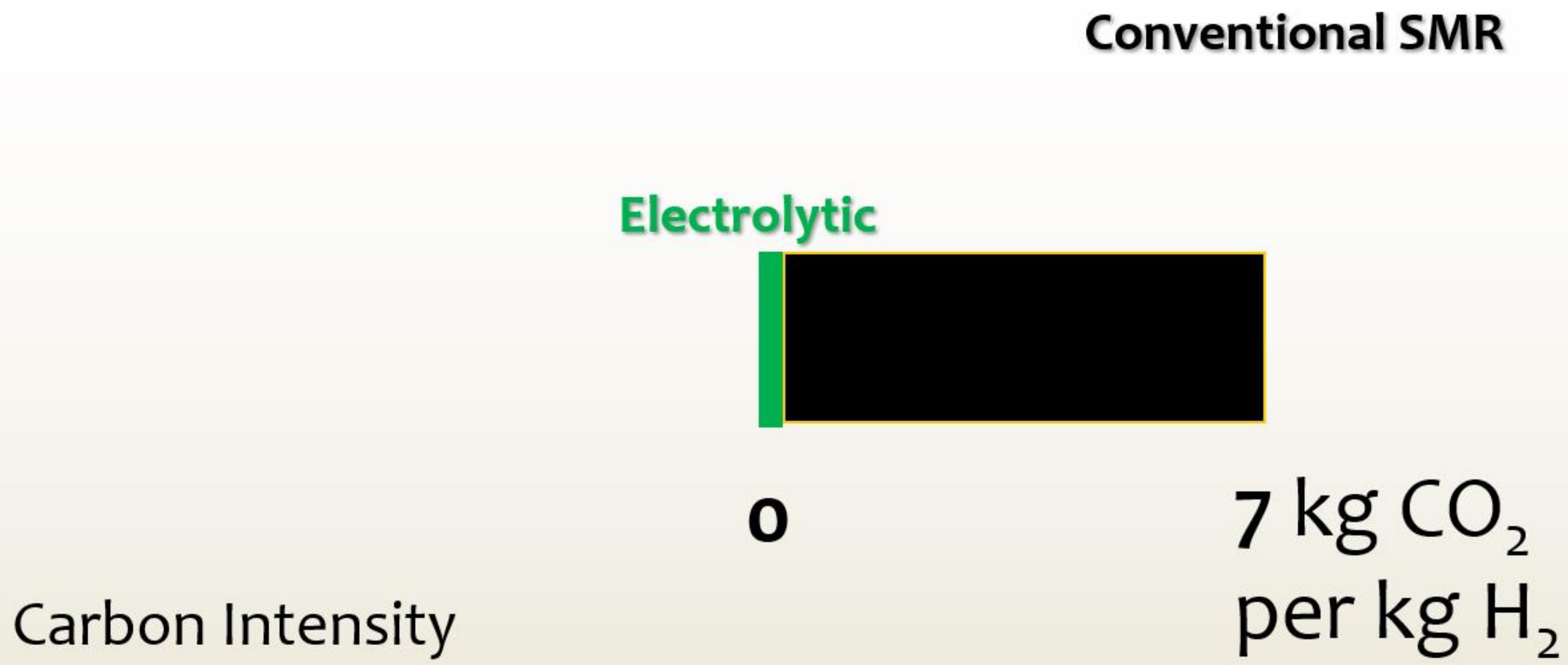
Carbon Intensity of Hydrogen: +7 to – 20 kg CO_2/kg H_2

Electrolytic

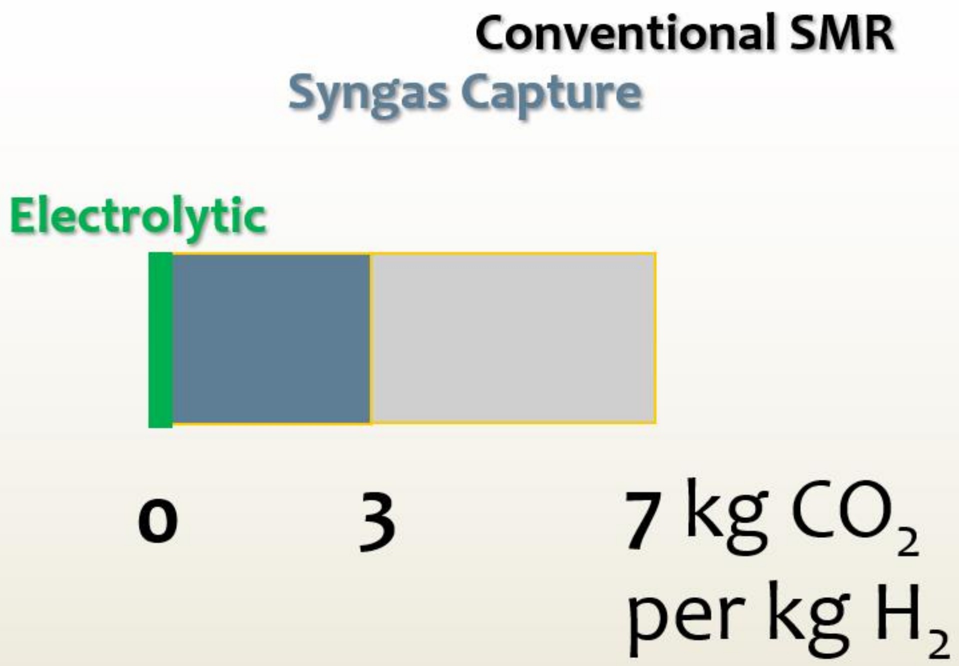
0

Carbon Intensity

Carbon Intensity of Hydrogen: +7 to – 20 kg CO_2/kg H_2

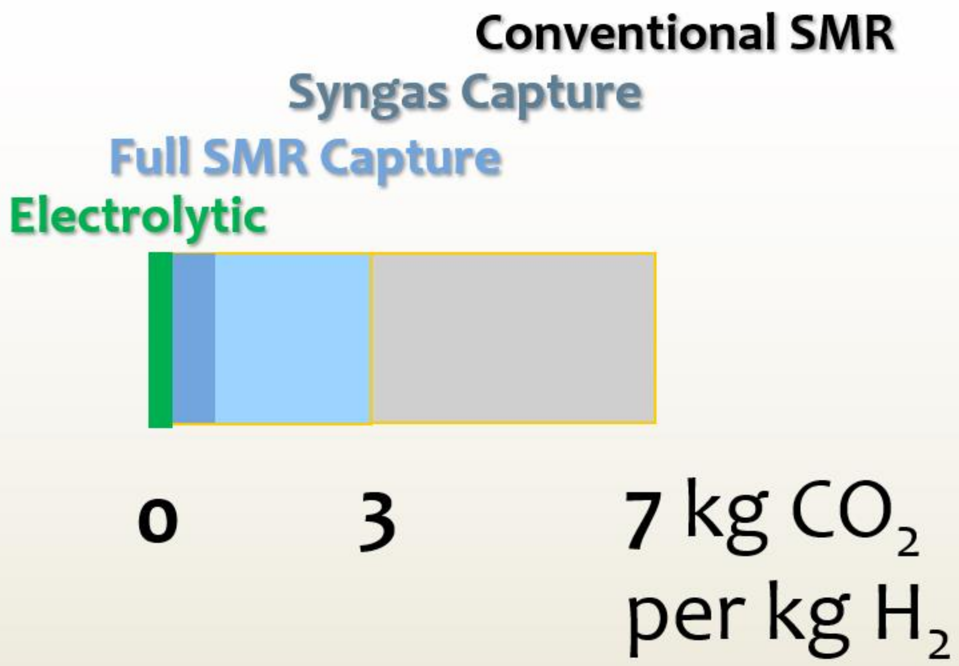


Carbon Intensity of Hydrogen: +7 to – 20 kg CO_2/kg H_2



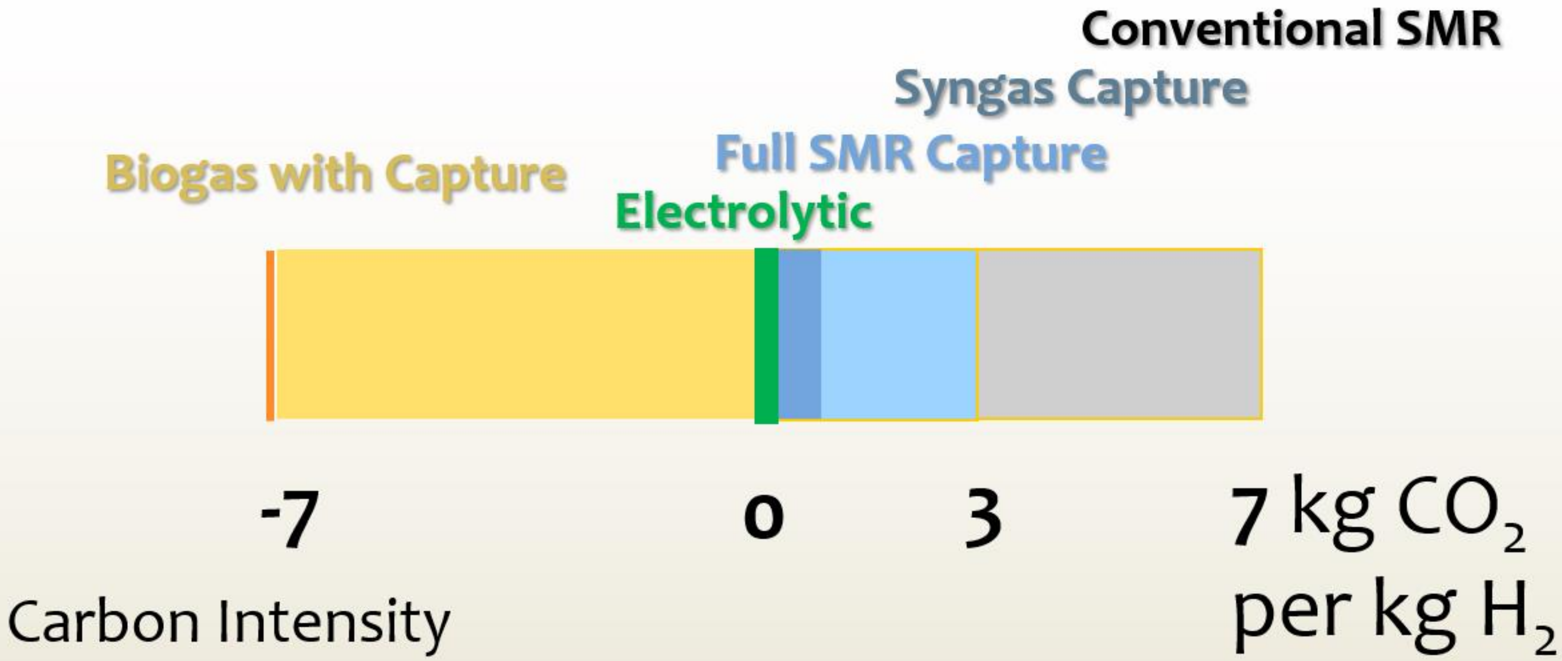
Carbon Intensity

Carbon Intensity of Hydrogen: +7 to – 20 kg CO_2/kg H_2

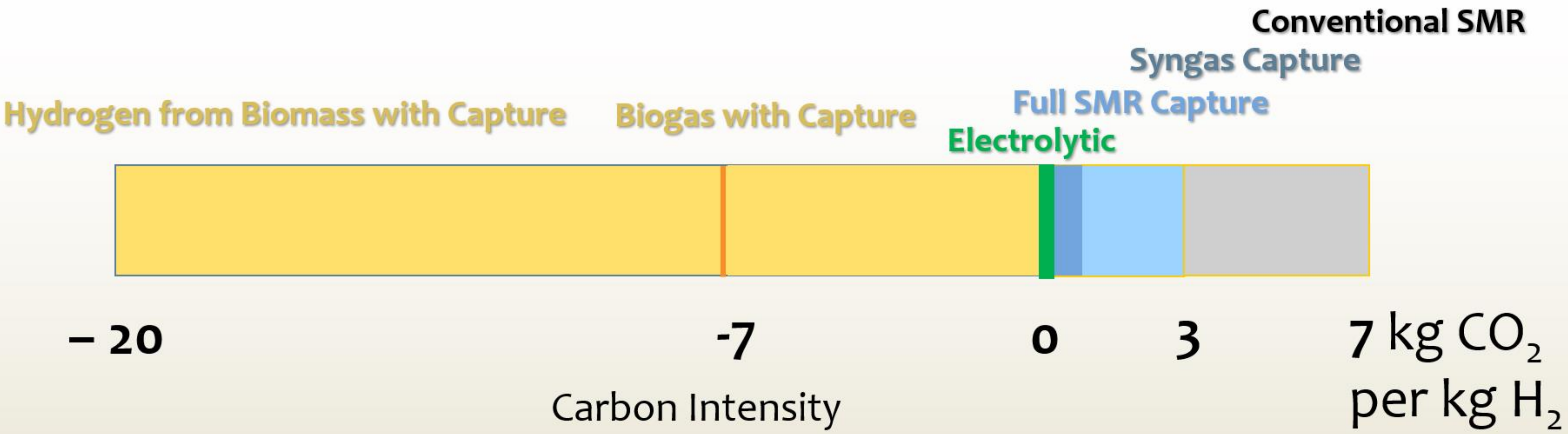


Carbon Intensity

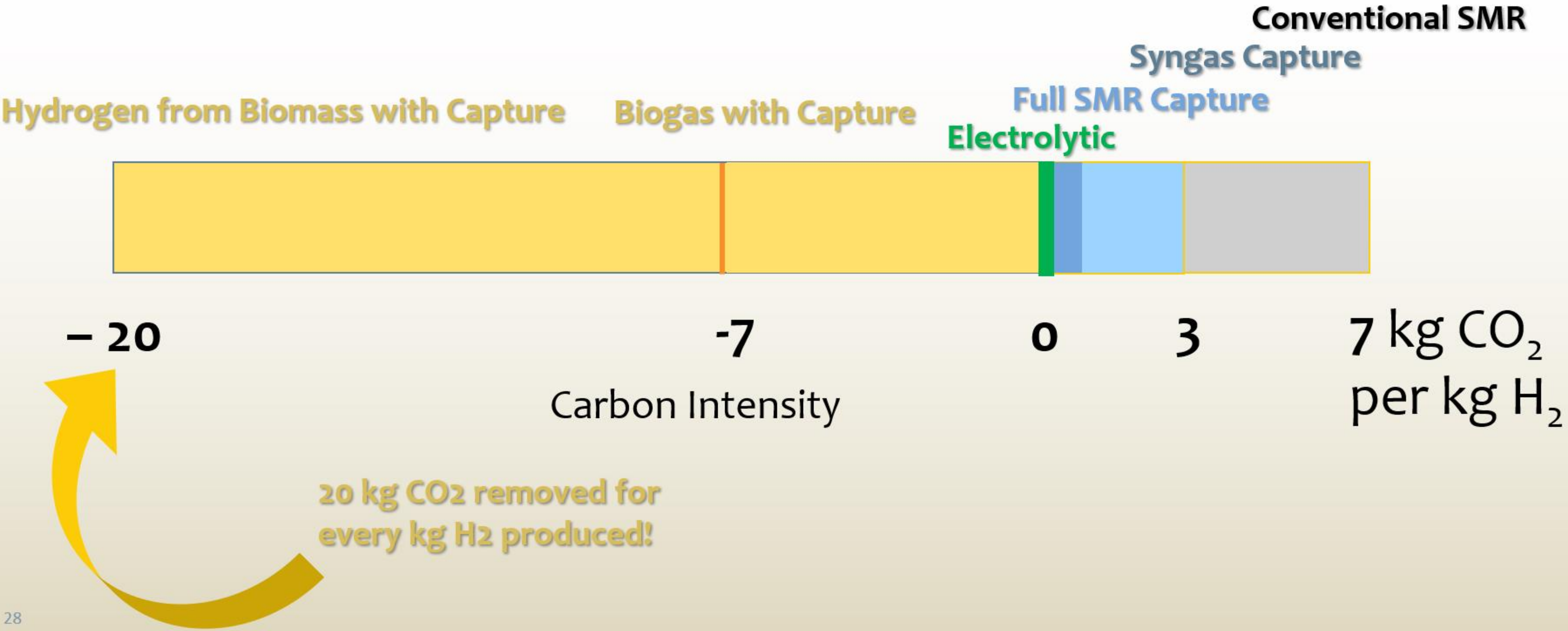
Carbon Intensity of Hydrogen: +7 to – 20 kg CO_2/kg H_2



Carbon Intensity of Hydrogen: +7 to – 20 kg CO_2/kg H_2



Carbon Intensity of Hydrogen:
+7 to – 20 kg CO_2/kg H_2



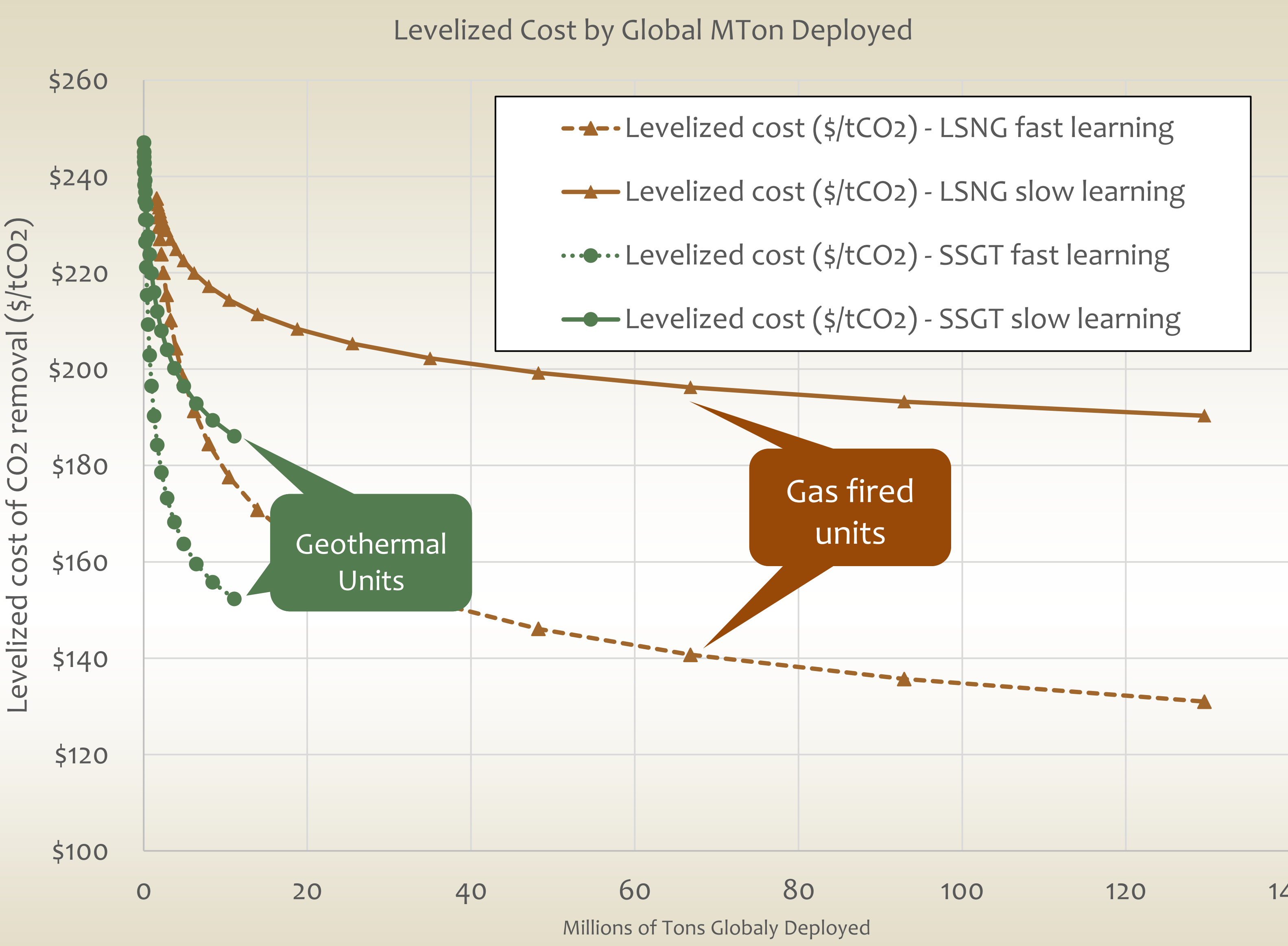
3 Build machines to clean the air

Chemical filters, solvents, and minerals that absorb CO_2

1000 ton per year capture facility, Zurich

Learning curves for natural gas and geothermal-powered DAC systems

- Does not depend on the rate of construction.
- Both count total global units built.
- Geothermal units limited to California heat supply.
- Gas units learn more slowly because they are bigger.



Bottom Line

The three major options can provide 125 M tons of removals with net benefits

1. Natural and Working Lands

25 MT/year

2. Waste Biomass Conversion to Fuels with CO_2 Storage

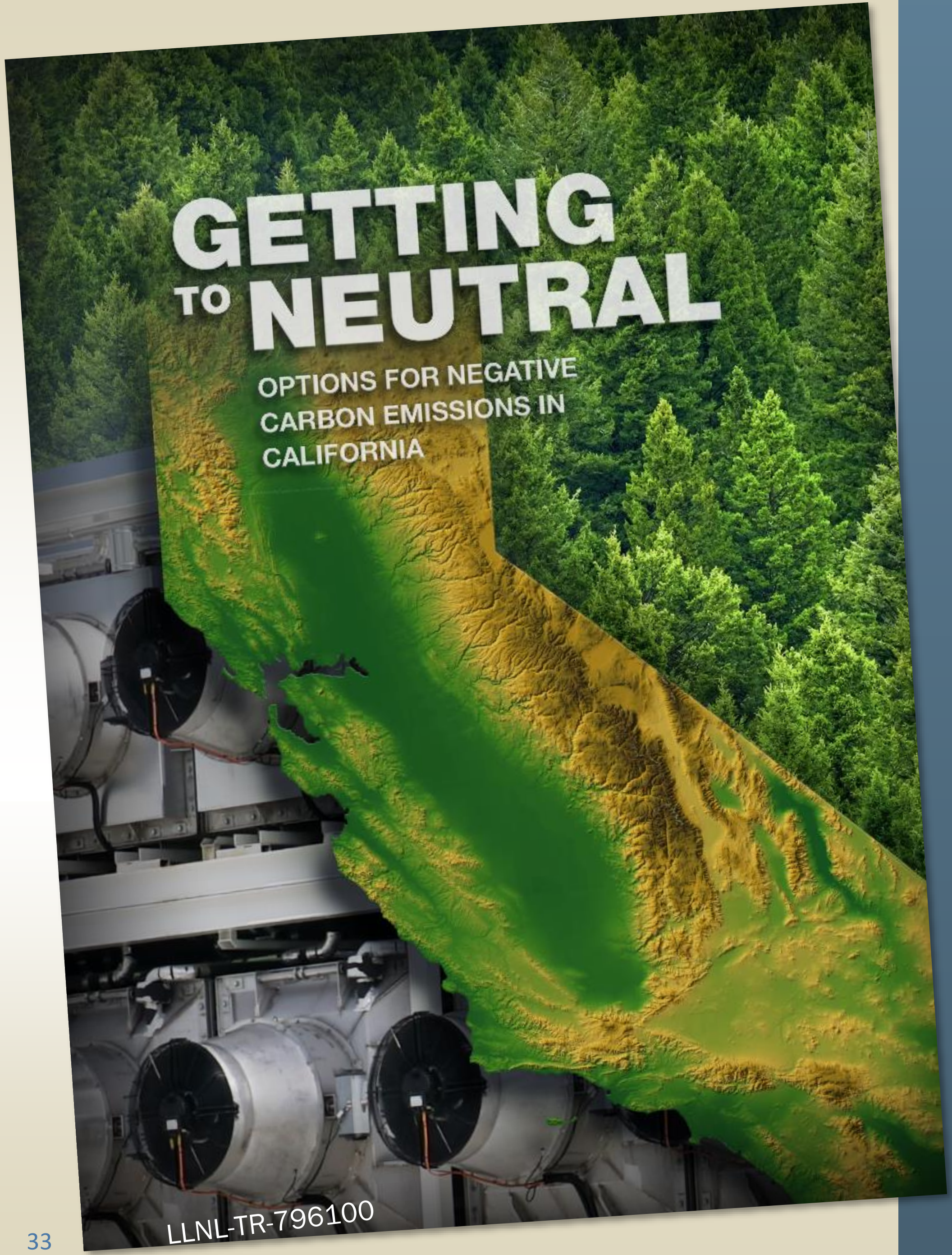
Todd Nishikawa, Placer Cty Air Pollution Control District

83 MT/year

3. Direct Air Capture with CO_2 Storage

>17 MT/year

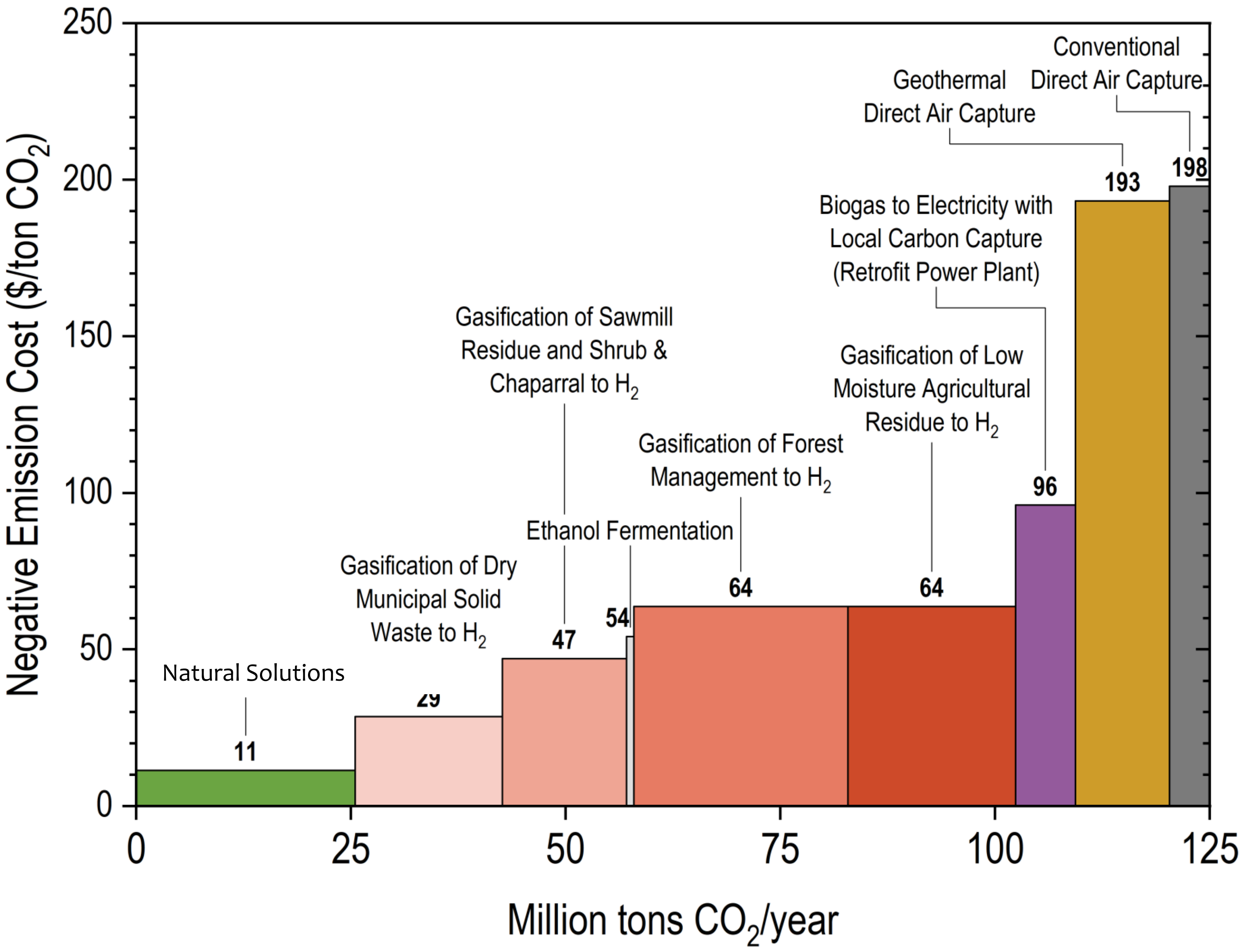
Technological readiness: mid-to-high — no new breakthroughs required



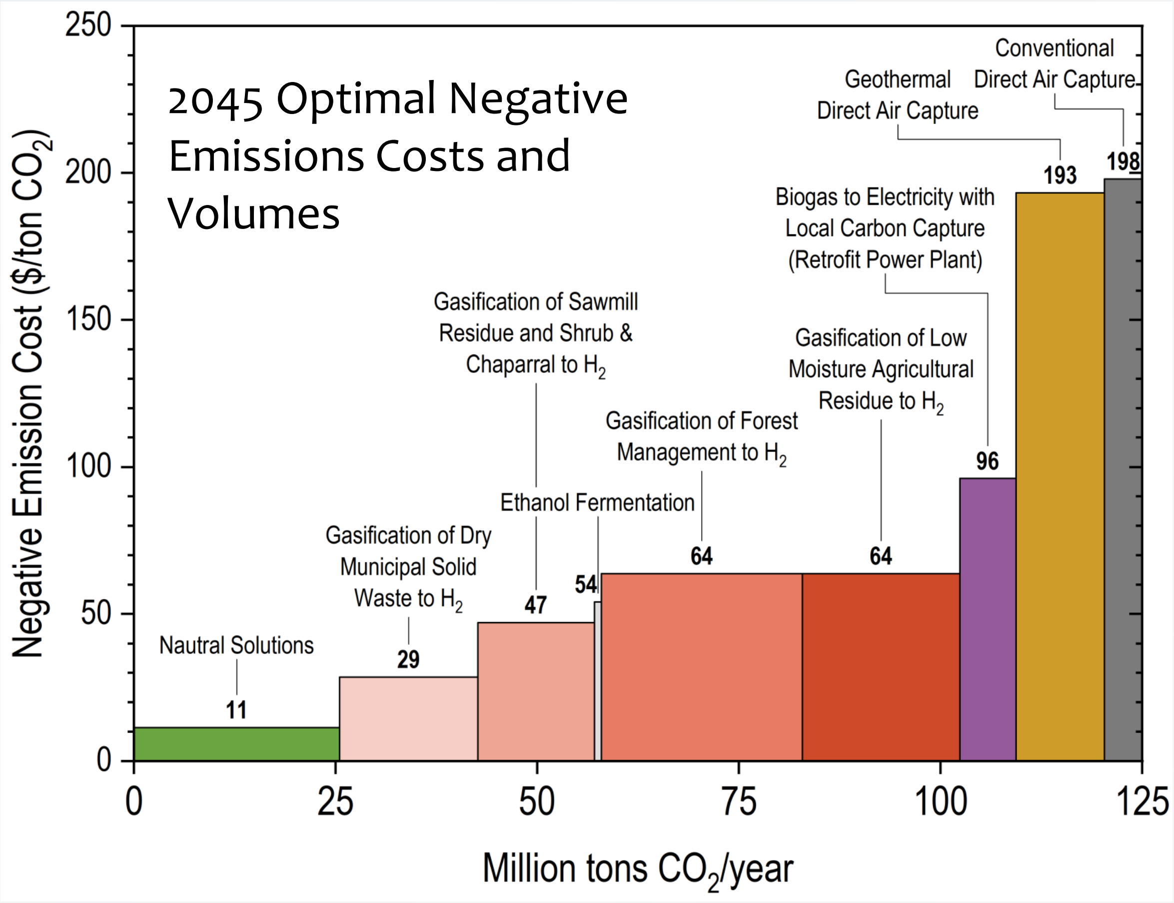
We evaluated the potential in tons per year, and estimated 2045 costs

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

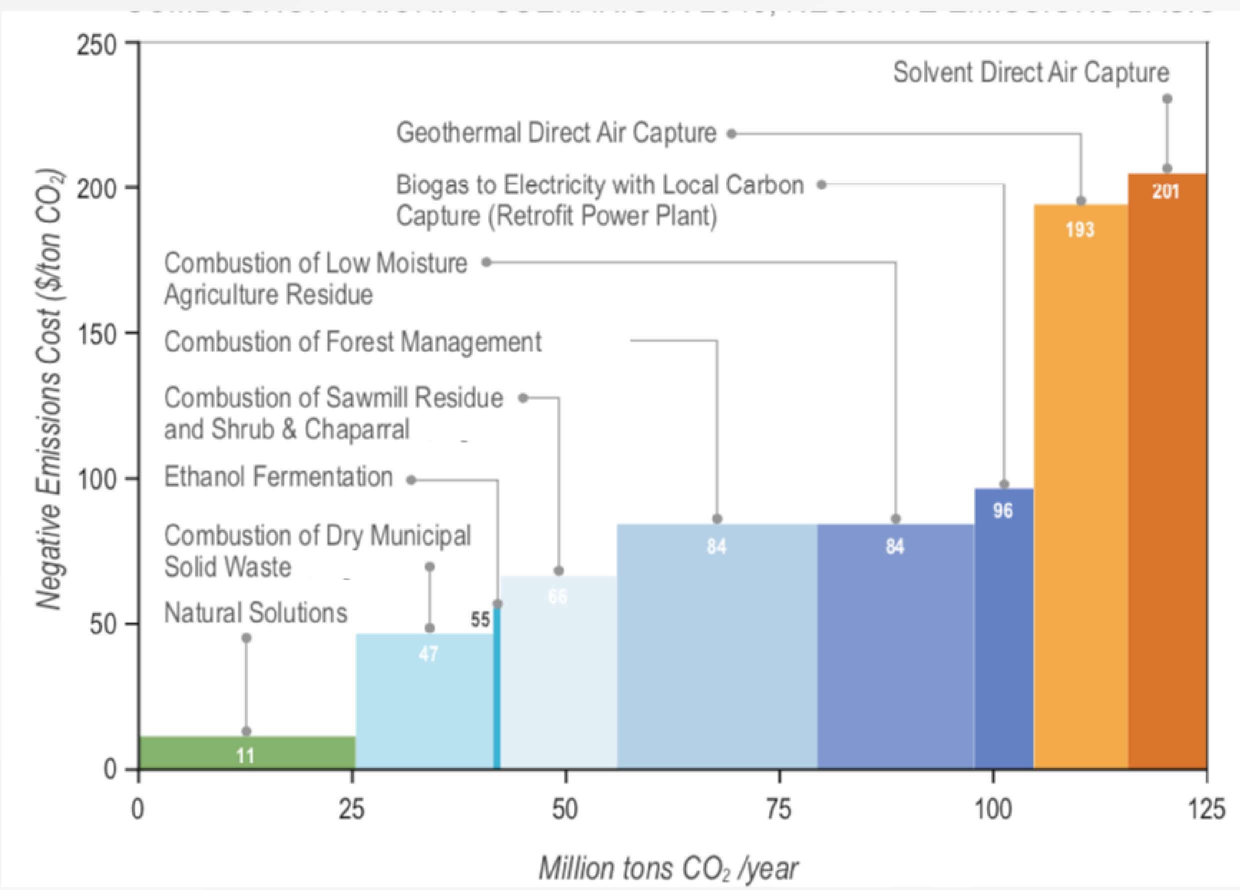
California's 2045 least-cost path to 125 MT/year of carbon removal and permanent storage would average about $65/ton



The least-cost path to 125 MT/year uses natural solutions, gasification of biomass to H_2, and some direct air capture – but pure combustion (BECCS) is close.



H_2 Production \$8.1 B System Cost



Combustion \$10 B System Cost

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.

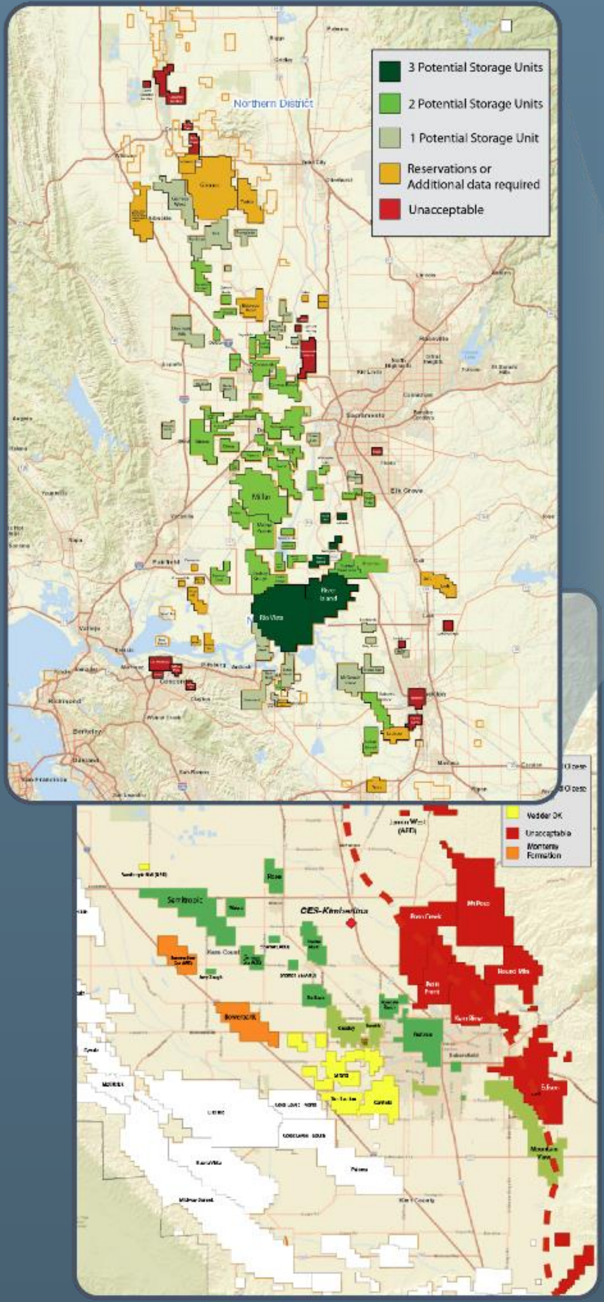
The technology, people, and jobs are the same for both.

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

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.

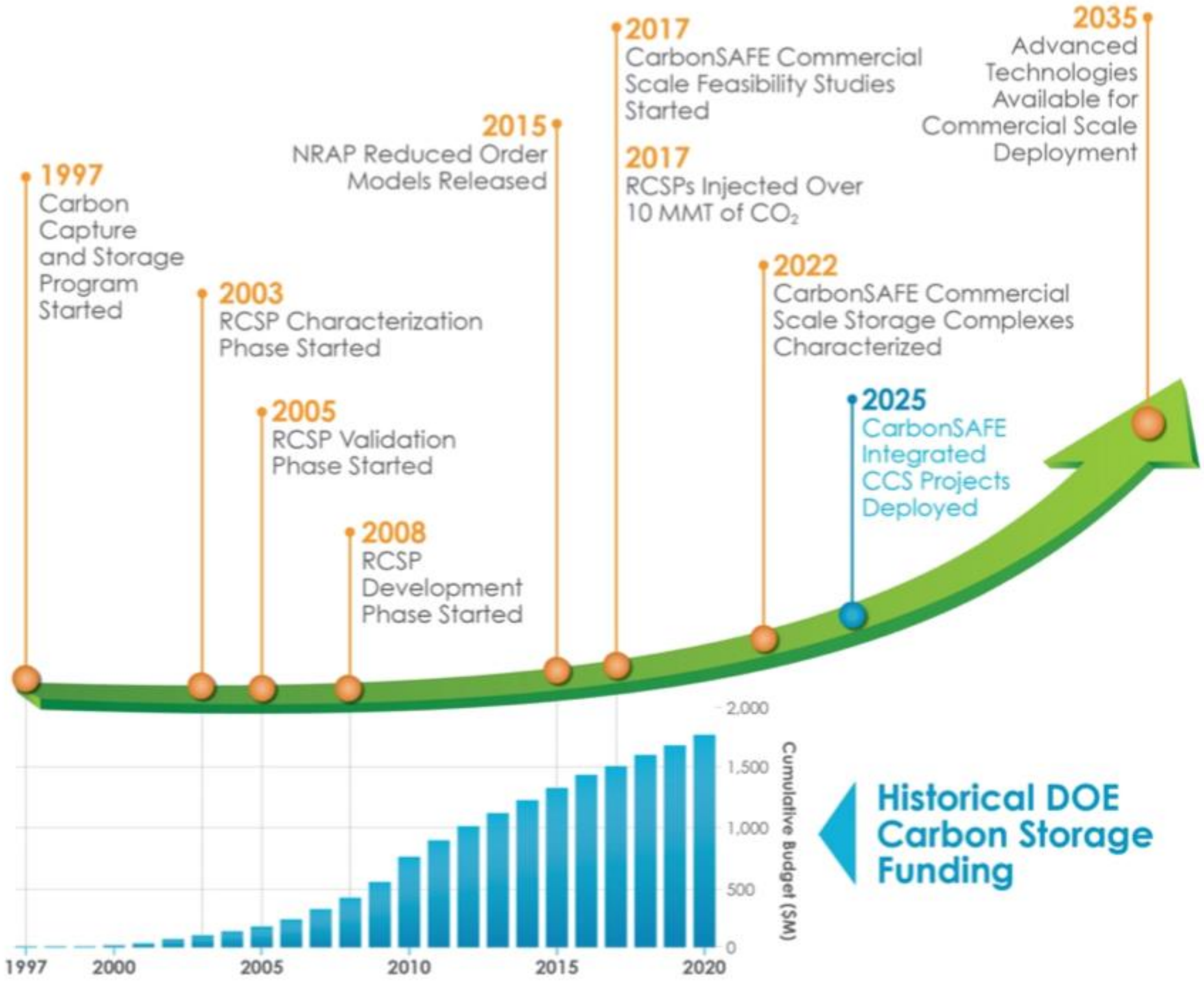
LLNL has identified **17 billion tons** of safe storage in **just 2 areas** of the Central Valley. As much as **200 billion tons** may be available.

Permanent geologic storage is available



We need to be stronger in our messaging that storge is safe

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



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 CO_2 retained in the subsurface over 10,000 years**."

"Large-scale CO_2 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 CO_2 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

Getting to Neutral Takeaways

Mother nature can't do it on her own

– *Key outcome for State Legislators*

Biomass should be used to draw down CO_2 first, rather than emphasize energy

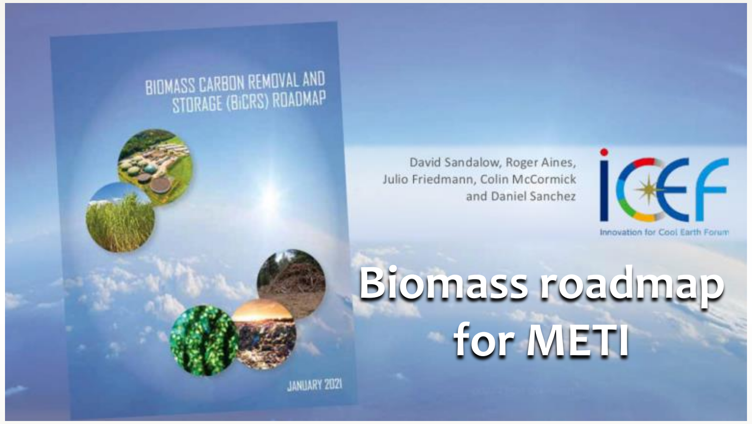
– *Guides international standards*

H_2 from biomass with CO_2 storage is a leading technology for California

– *Double win of drawdown and clean H_2*

Google 'Getting to Neutral' to see the full report.

Natural solutions are about 20% of what we need



Biomass-H2-CO2 demo in Swindon, UK


Keep a Big Tent
Learn to like lots of approaches.
Embrace all the technologies and approaches necessary to fully decarbonize the economy.