Re-engineering a sustainable world

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The Front Row Lecture Series

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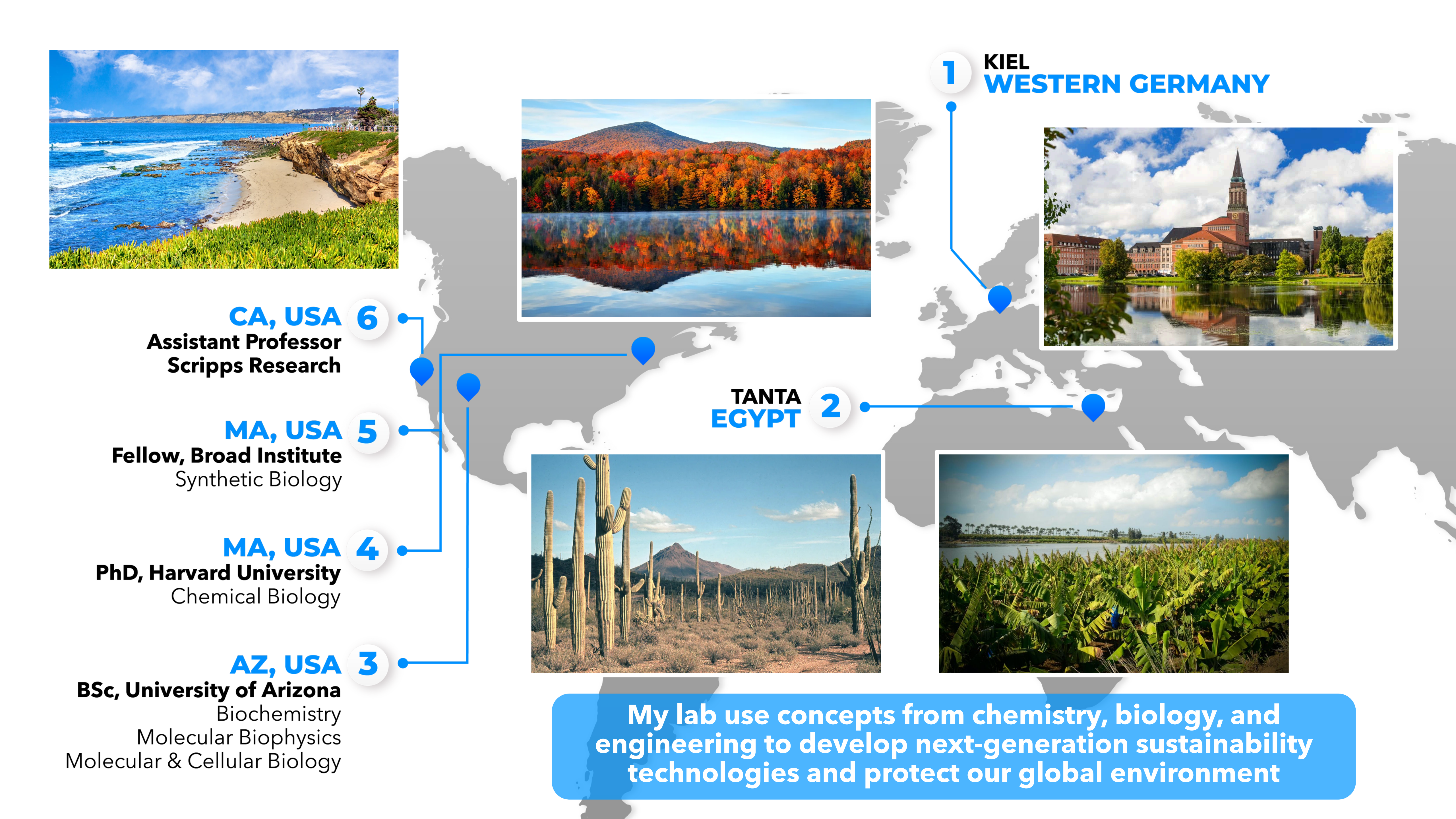

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Assistant Professor
Scripps Research
MA, USA 5
Fellow, Broad Institute
Synthetic Biology
MA, USA 4
PhD, Harvard University
Chemical Biology
AZ, USA 3
BSc, University of Arizona
Biochemistry
Molecular Biophysics
Molecular & Cellular Biology
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WESTERN GERMANY
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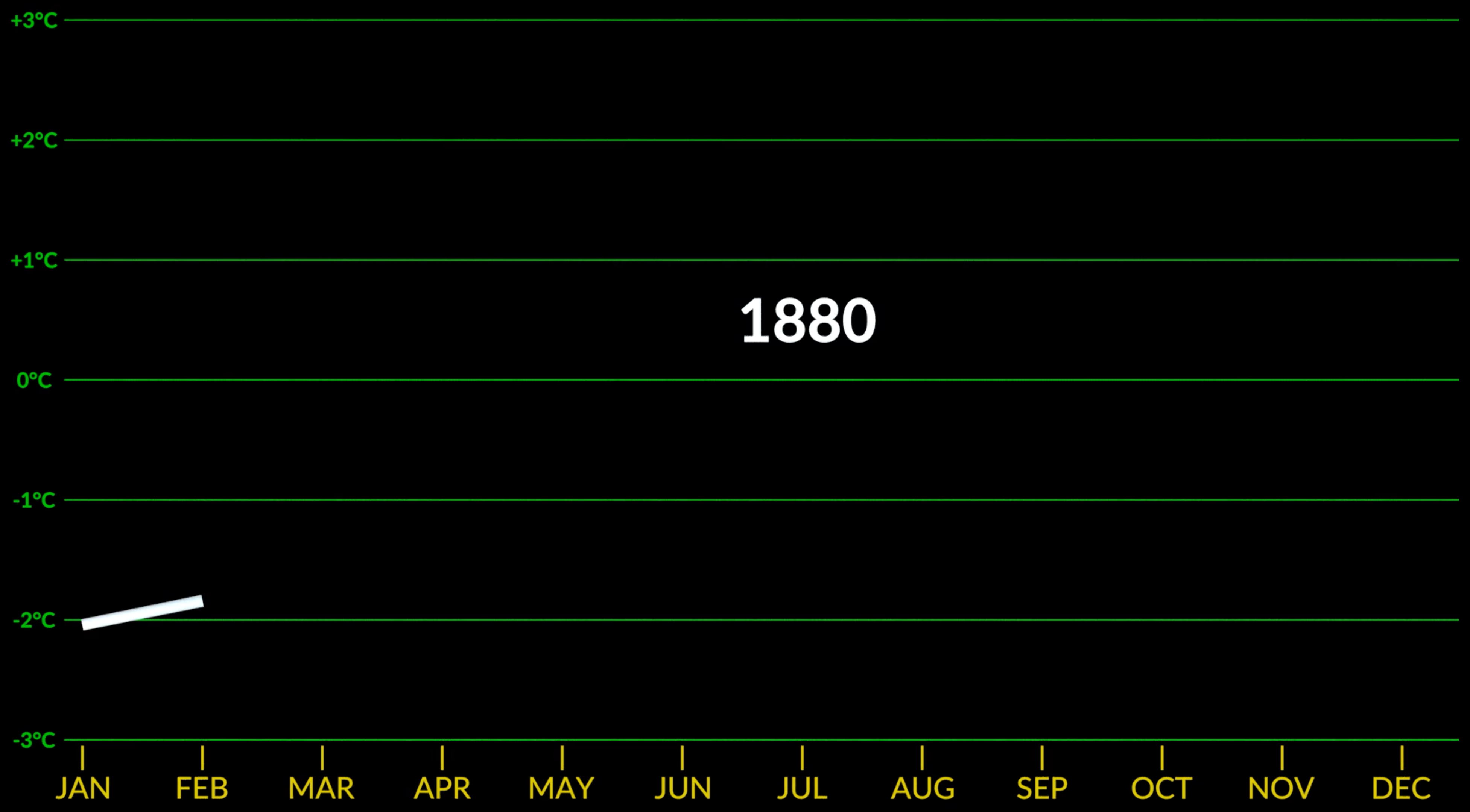
EGYPT 2
My lab use concepts from chemistry, biology, and engineering to develop next-generation sustainability technologies and protect our global environment

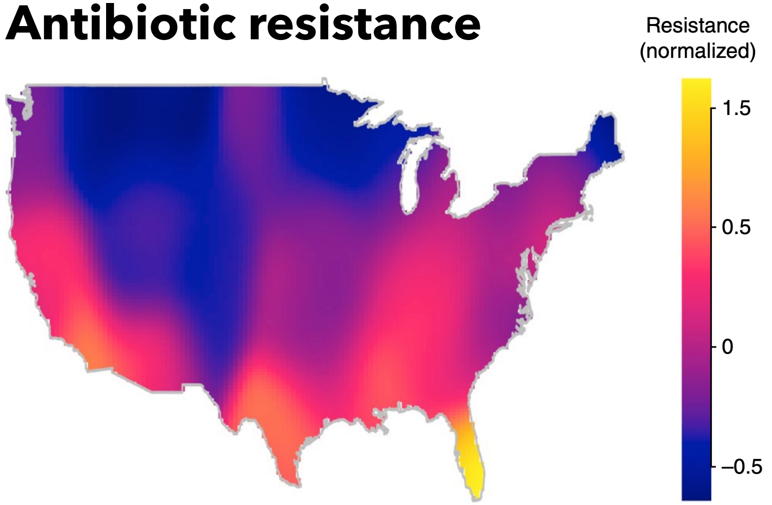
Our Planet Is Heating Up!



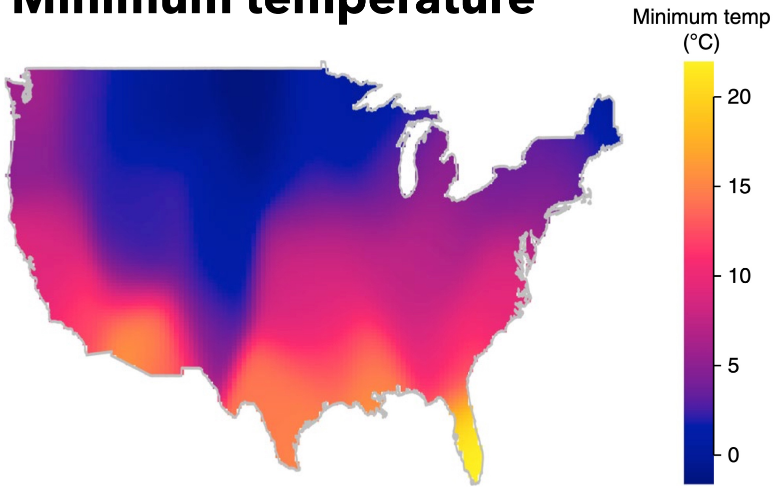
NASA

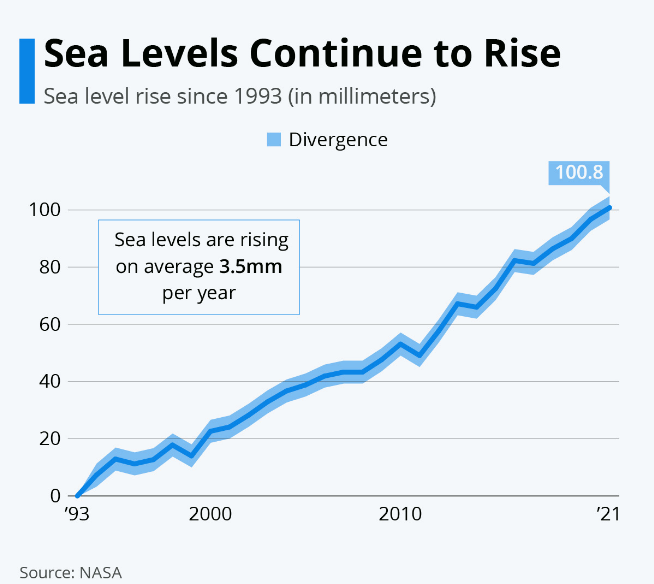
The Impact of Climate Change

Antibiotic resistance



Minimum temperature



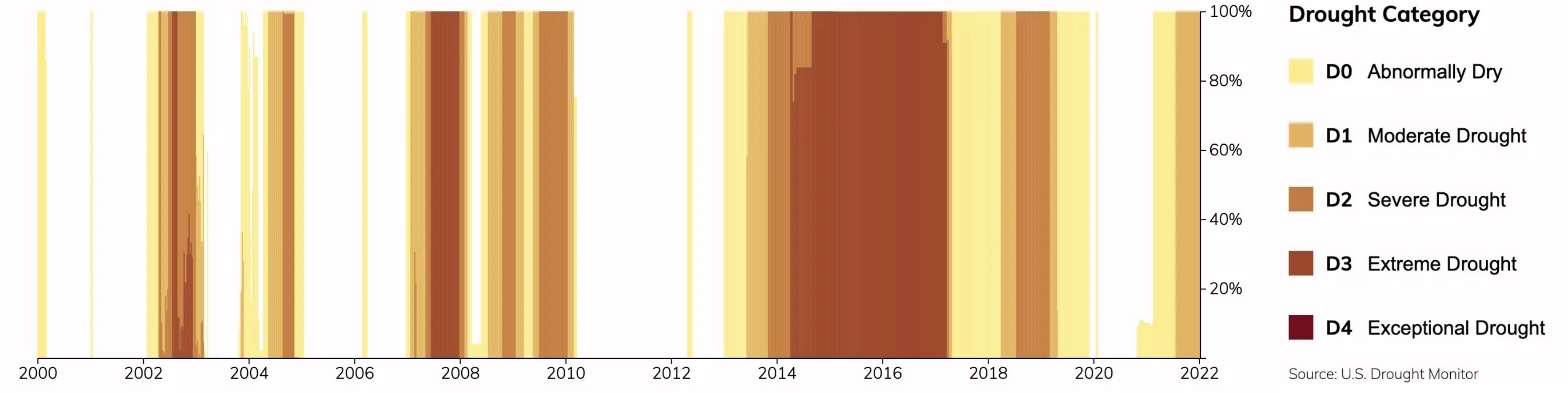


La Jolla Cove, CA

The UN estimates that by 2030 the world will need 30% more fresh water and 50% more energy; by 2050 we will need 70% more food.

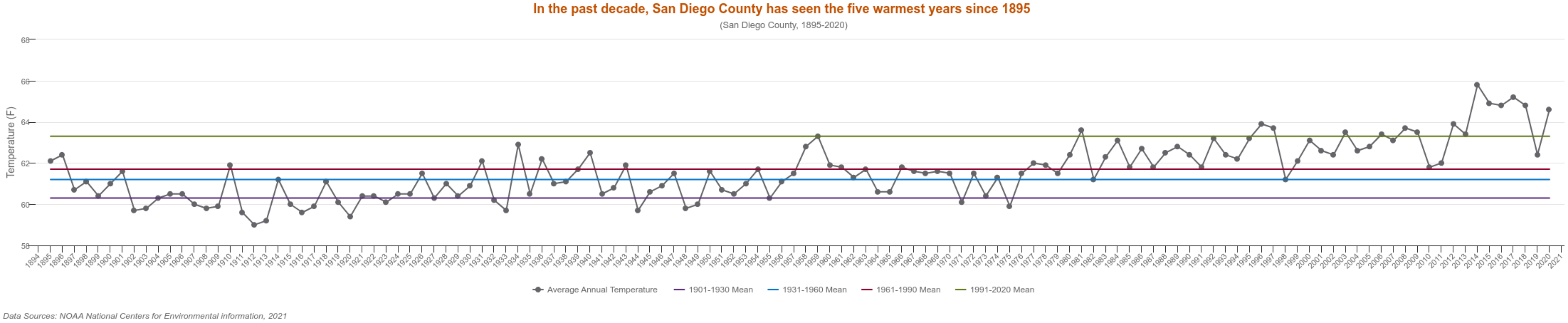
MacFadden et al. ***Nature Climate Change*** *(2018)*

The Impact of Climate Change **in San Diego**



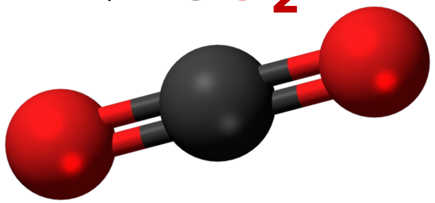
More frequent droughts

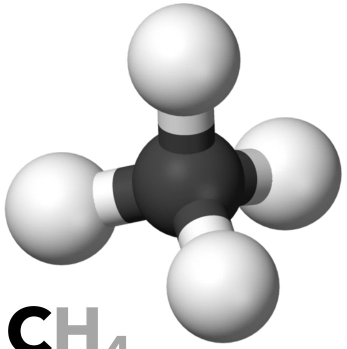
ClimateCheck



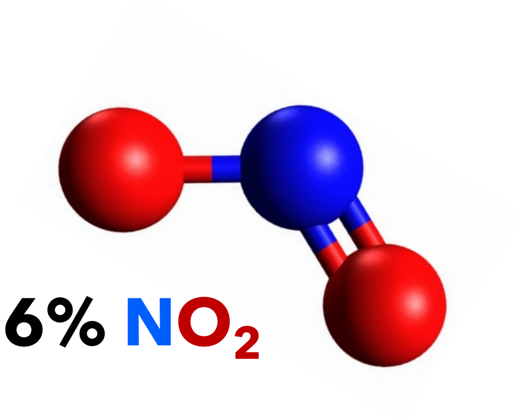
Greenhouse gases and our planet's atmosphere

79% CO_2





12% CH_4



6% NO_2

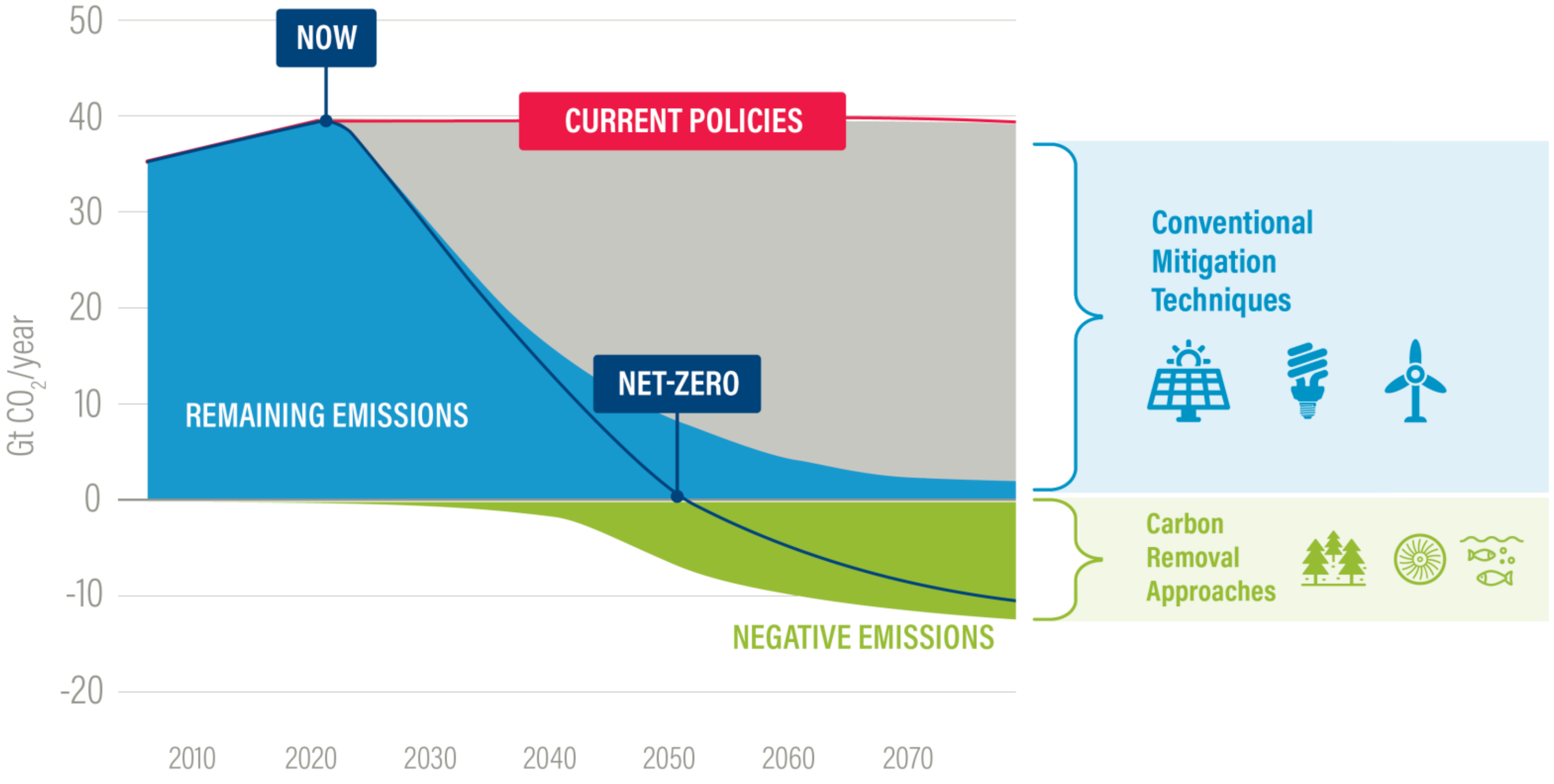
Where do greenhouse gases come from?

Burning fossil fuels will continue to ***increase the Earth's temperature, resulting in a runaway greenhouse effect***

We need ***strategies to purify CO_2 from air*** to fix the climate of our planet

United States Environmental Protection Agency (EPA)

How do we get rid of greenhouse gases?



Greenhouse gas (GHG) levels are projected to increase 2.5 – 2.9 °C globally by 2100.

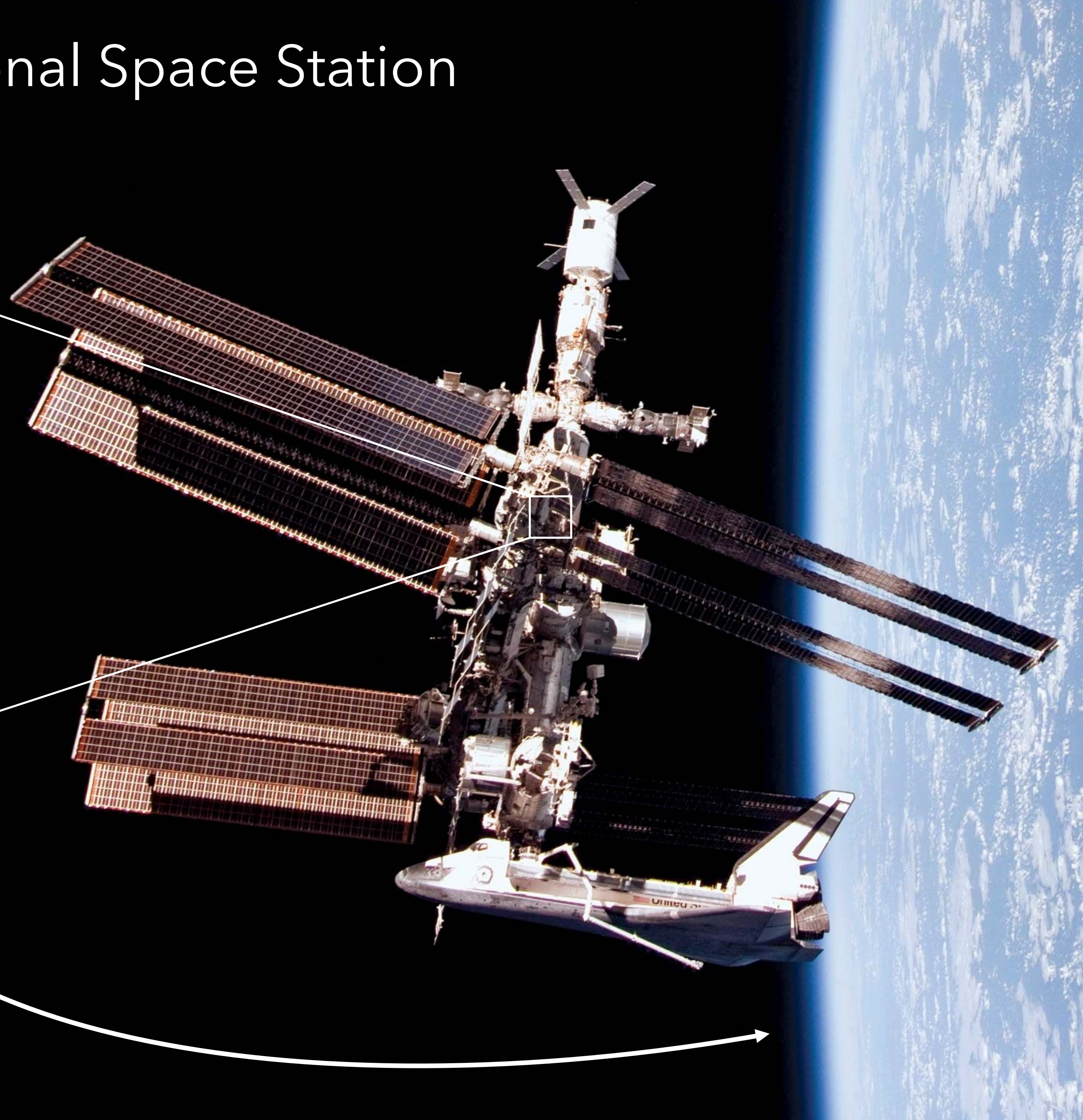
New ***negative emission technologies*** are needed to correct the Earth's deteriorating climate.

How can we effectively remove **CO_2 (the most abundant GHG)** from air?

World Resources Institute

Air Purification on the International Space Station

Carbon Dioxide Removal Assembly

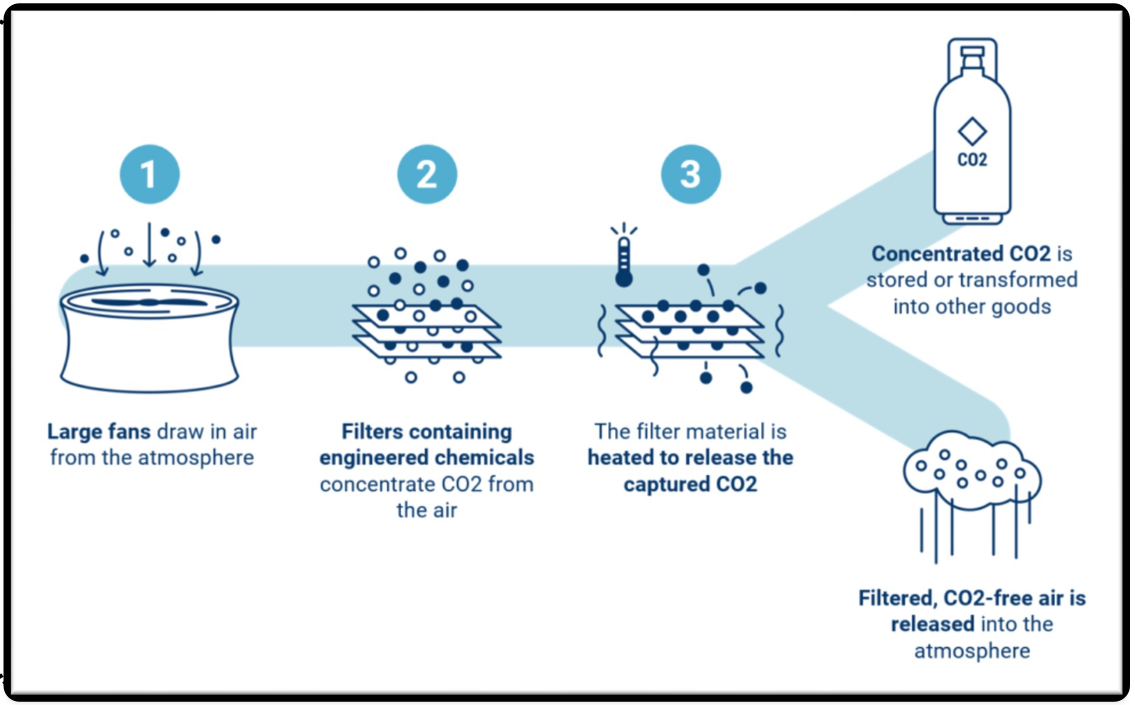


Maybe this CO_2 removal strategy can be used on Earth?

NASA, Britannica

Direct Air Capture (DAC) on Earth

CBInsights



Drawbacks of DAC technologies:

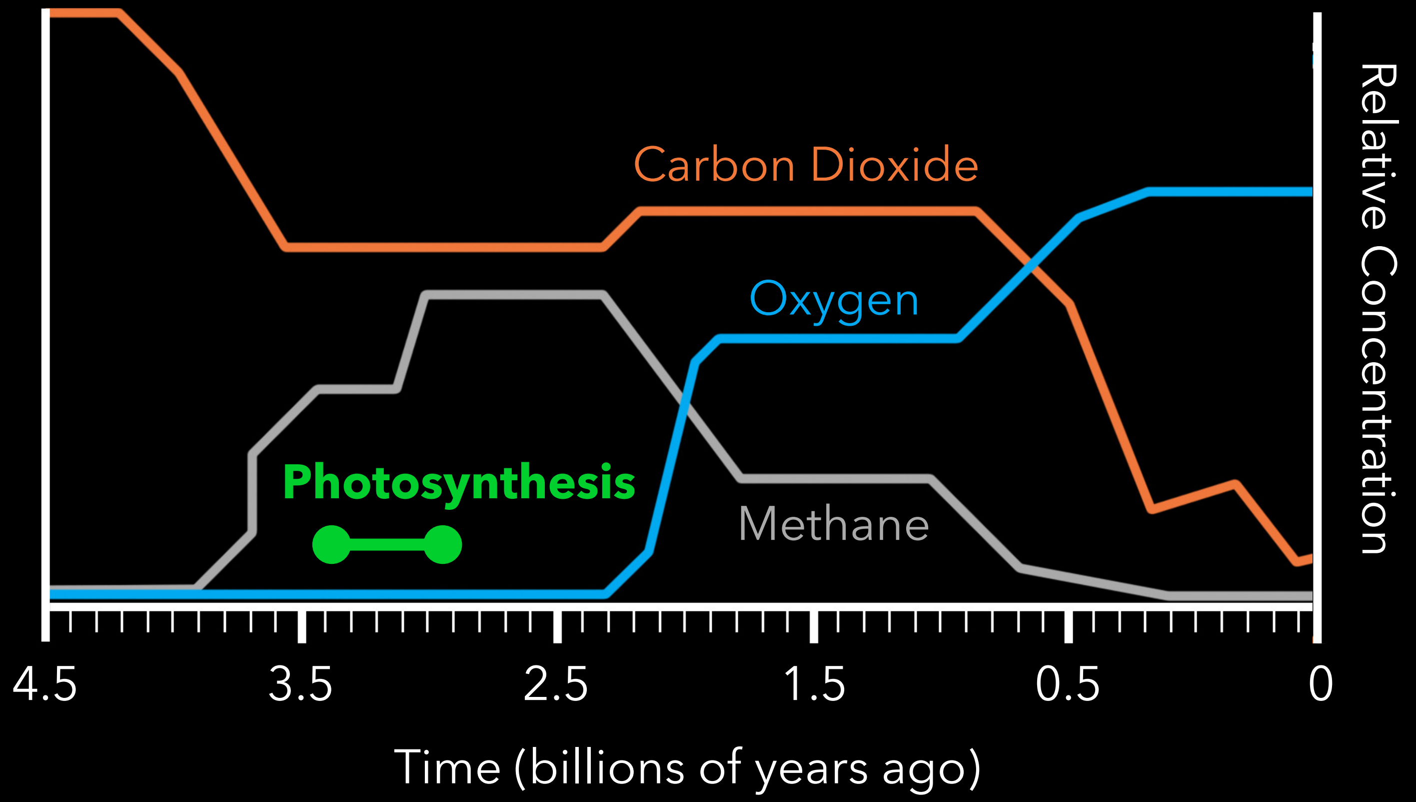
- Huge energy expenditures
- Finite filter lifetime before replacement
- Captured CO_2 is stored underground

An idealized strategy:

- **Cheap** to build and operate
- Can be easily **regenerated**
- Converts CO_2 to **useful molecules**

Can we use biology to engineer next generation climate solutions?

Biology's Solution to Capture Atmospheric CO_2



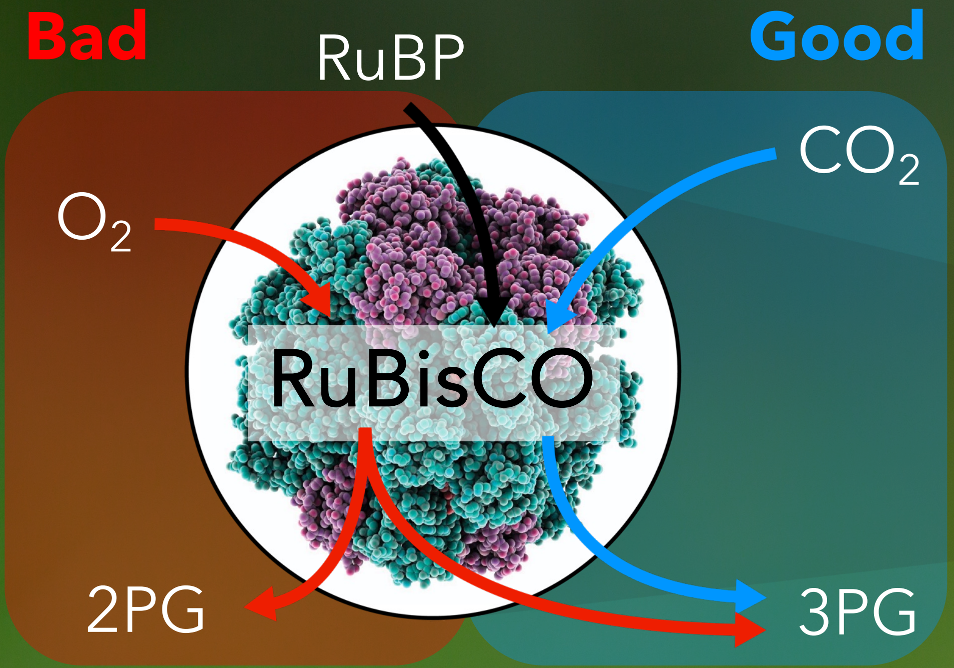
Earth's atmosphere:
78% Nitrogen
21% Oxygen
0.04% Carbon Dioxide
0.00015% Methane

Biological systems already discovered ***a general strategy to capture and use CO_2 called photosynthesis!***

Photosynthesis: a biological solution to slow climate change

United States Environmental Protection Agency (EPA)

Climate Correction Using Nature's Solution, **RuBisCO**

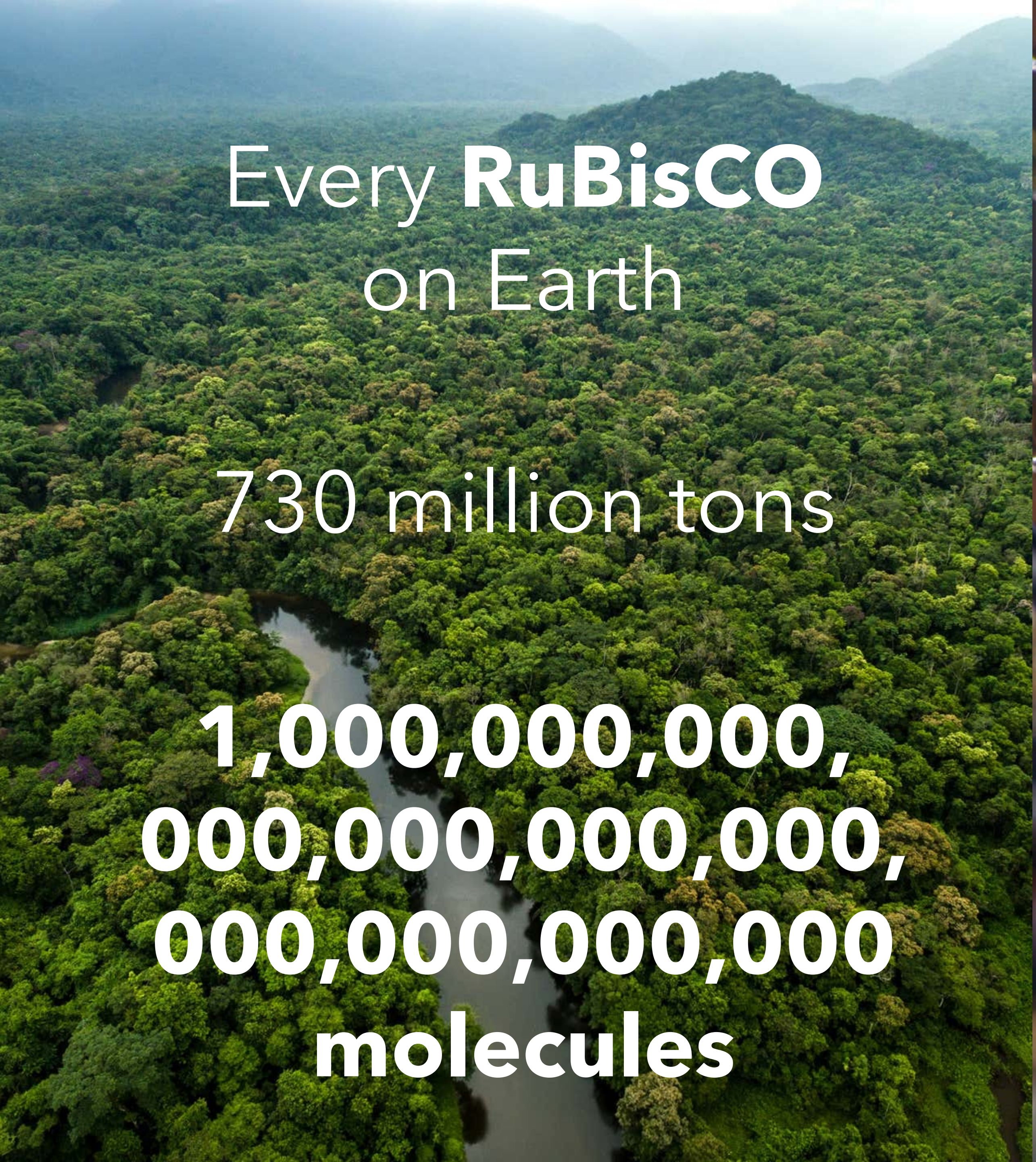


RuBisCO is the most effective CO_2 capturing mechanism on Earth (~120,000,000 tons CO_2 per year)

But has issues that made it a key engineering target:

- RuBisCO is ***slow*** (~1-22 CO_2 molecules per sec)
- RuBisCO makes ***mistakes*** (uses O_2 ~25% of the time)
- RuBisCO is ***burdensome*** (up to 50% leaf dry weight)

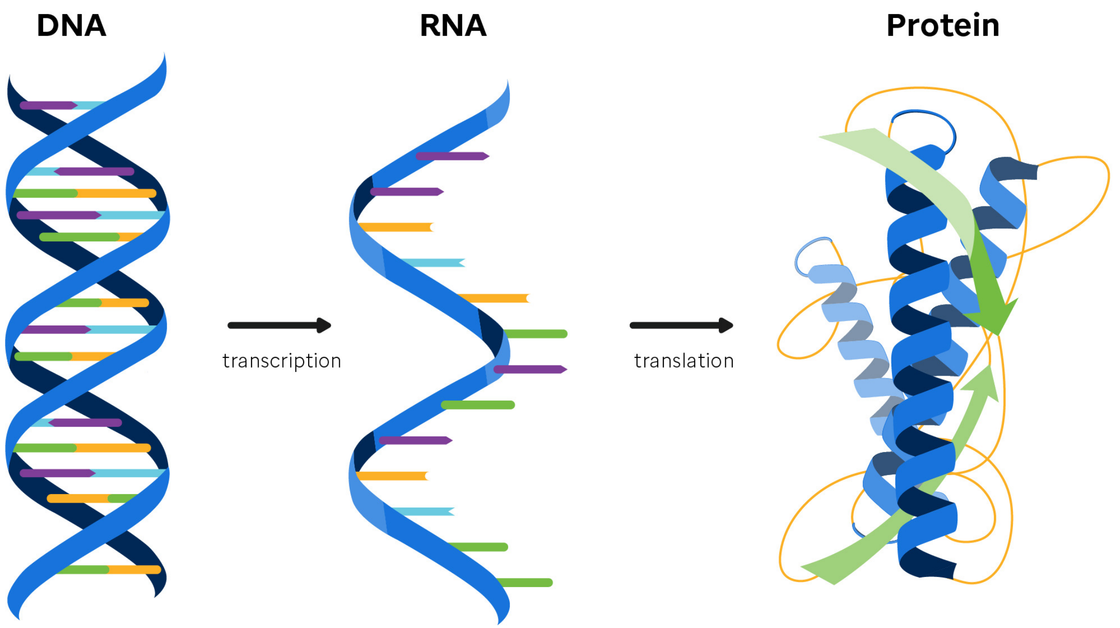
Can we make RuBisCO ***better at capturing CO_2?***


Every **RuBisCO** on Earth
730 million tons
1,000,000,000,000,000,000,000,000,000,000,000,000 molecules

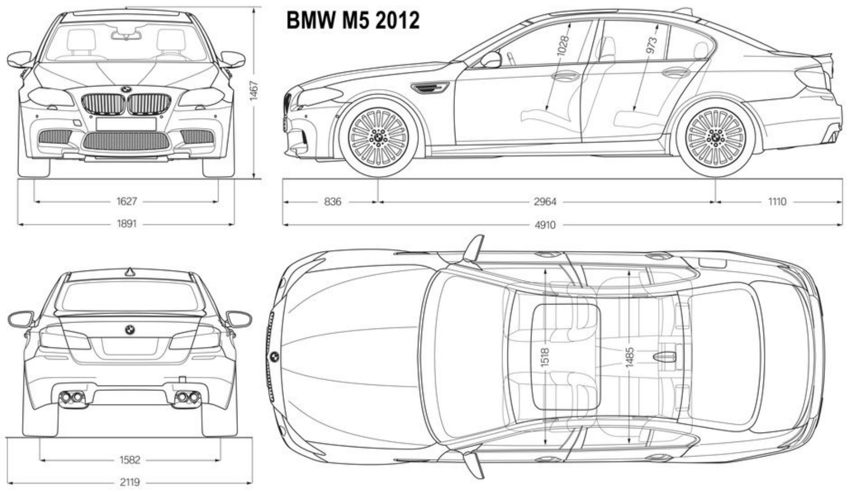

Every **human** on Earth
390 million tons
8,045,311,447 people

RuBisCO is a Genetically Encoded Molecular Machine

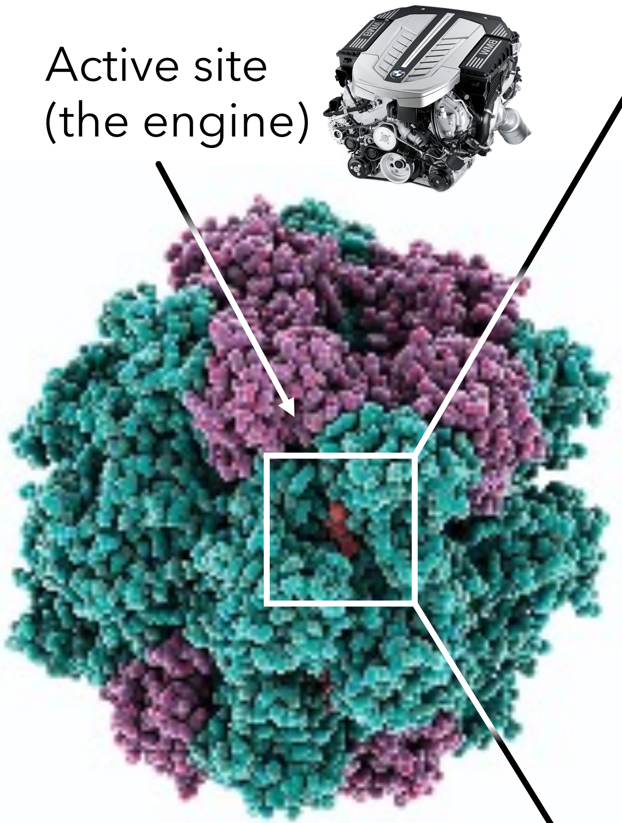
Blueprint of life:
Encodes all the components and molecular machines that make up a cell



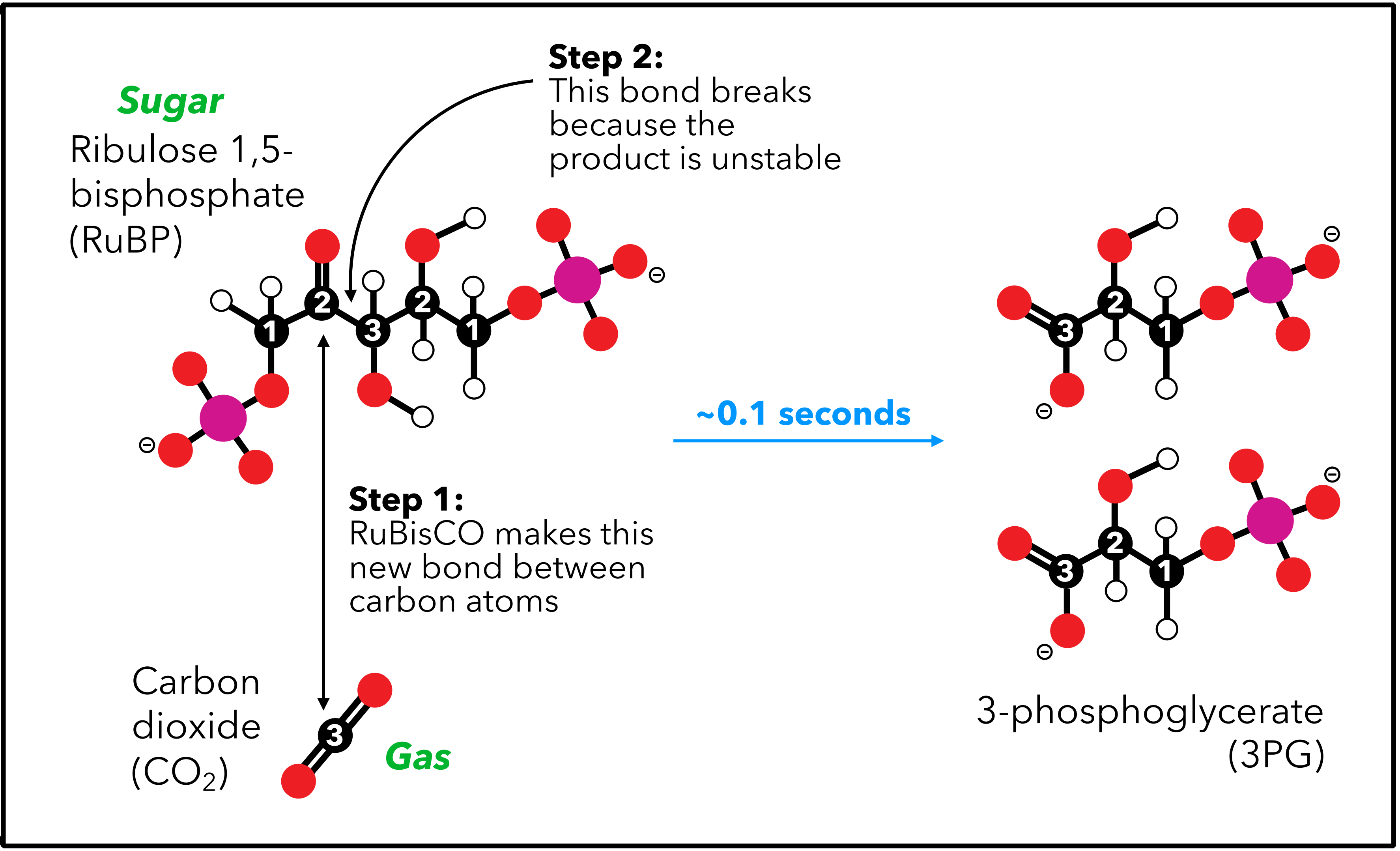
Workhorses of cells:
Carry out all the biochemical functions needed to maintain a healthy, living cell



How Does RuBisCO (a ***Biological*** Machine) Catalyze ***Chemistry***?

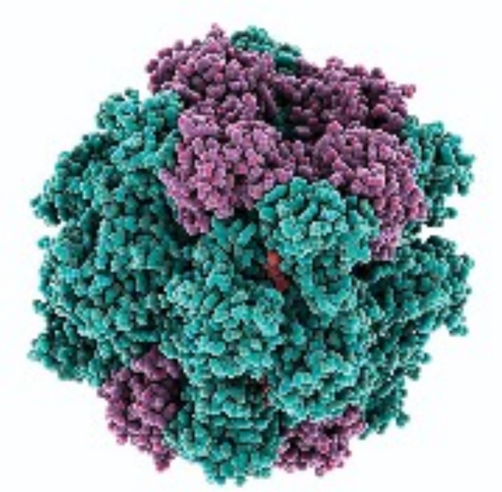


RuBisCO is a protein that catalyzes a reaction = ***Enzyme***



3PG generated by RuBisCO is used to ***build nearly everything*** in the plant: tissue, leaf, stalk, proteins, DNA…etc.

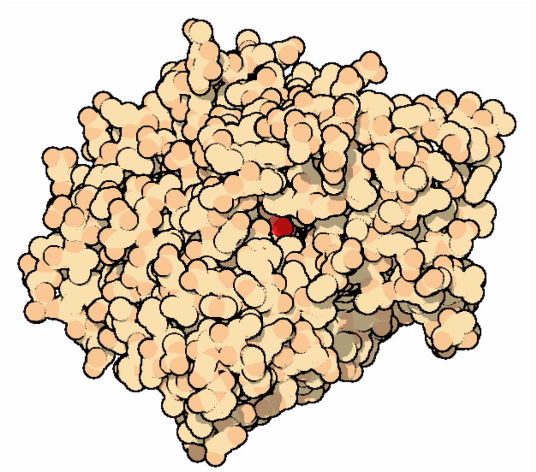
How Slow is RuBisCO (Really)?



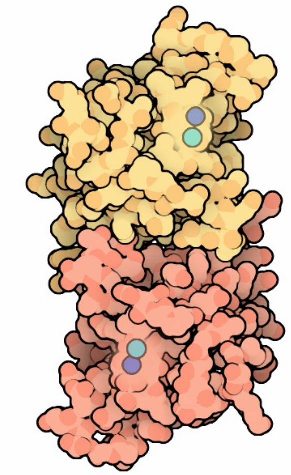
RuBisCO:
1 – 22 per second

Car engine:
10 – 70 per second

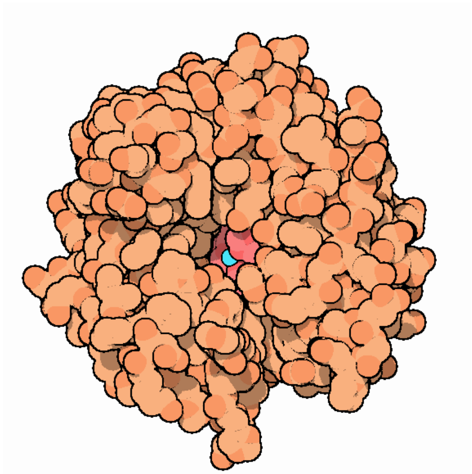
The average enzyme is ***~79 per second***
But there are much faster enzymes than this…



Acetylcholine esterase:
~1000 per second



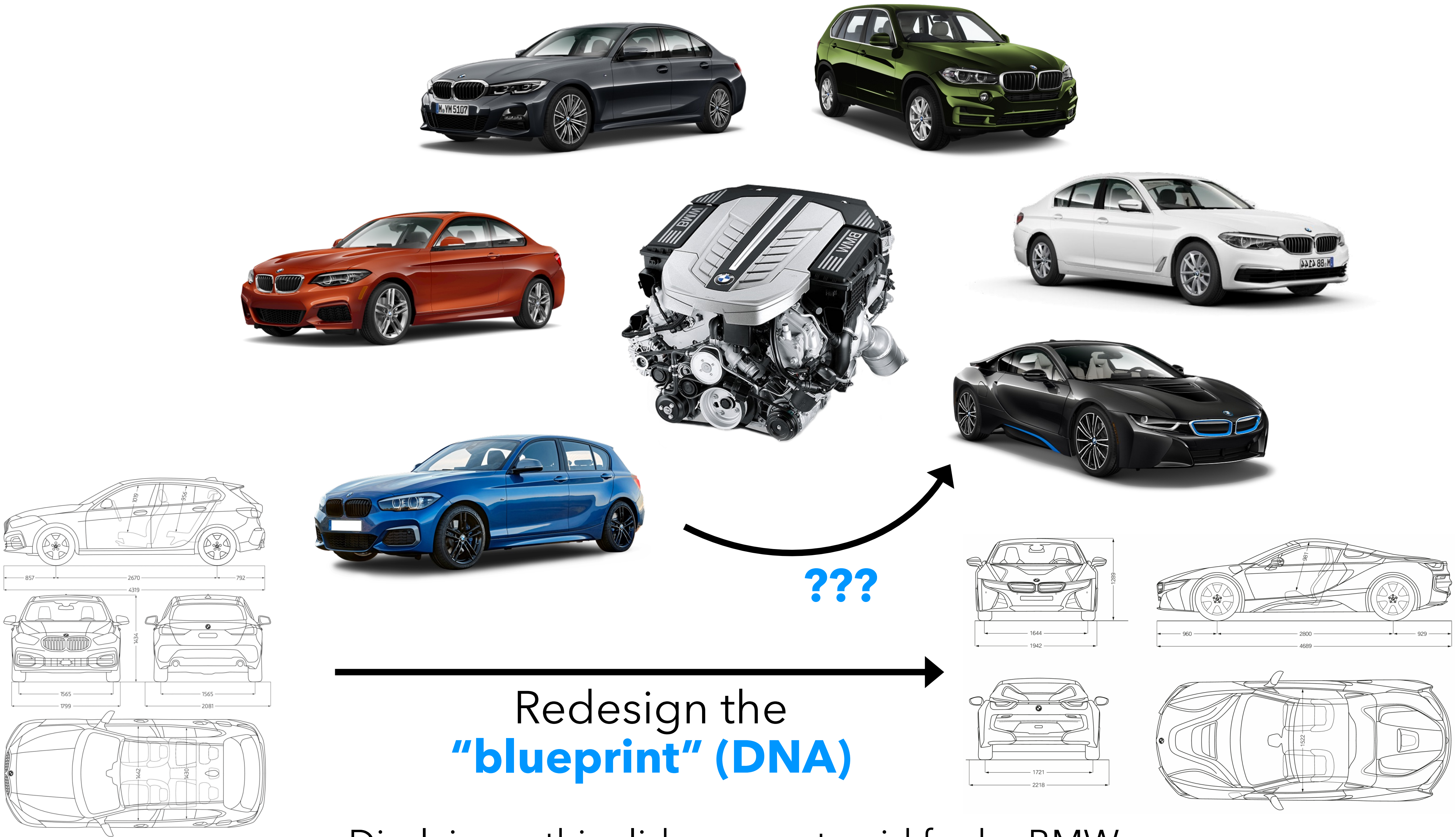
Superoxide dismutase:
~100,000 per second



Carbonic anhydrase:
>4,000,000 per second

Using idealized physical parameters, we know that enzymes ***cannot catalyze reactions at speeds faster than ~10,000,000 per second***

How Do We Make Enzymes Better?

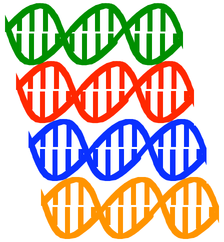


Disclaimer: this slide was not paid for by BMW

Key Stages of Improving RuBisCO

Diversification

DNA sequences
(***billions***)



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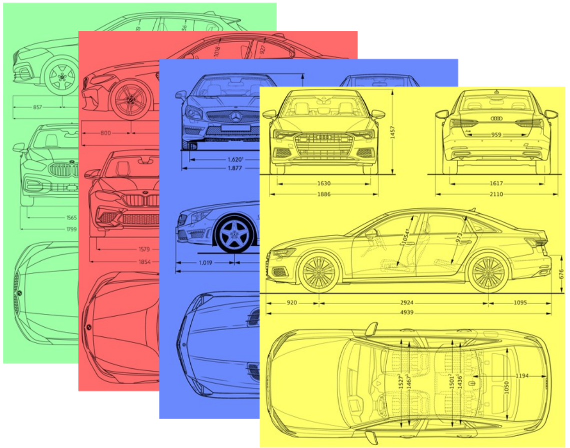
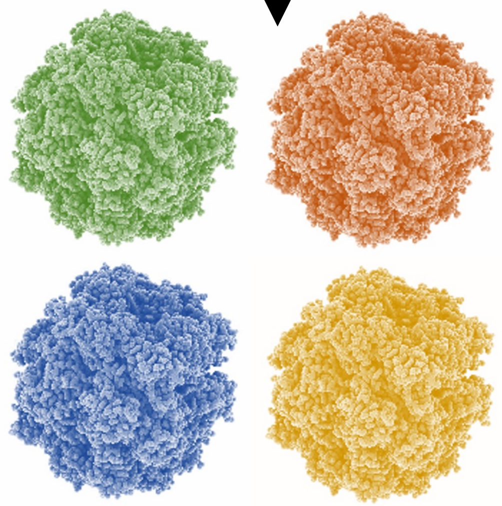


"A library"

Central Dogma

Factory

Selection



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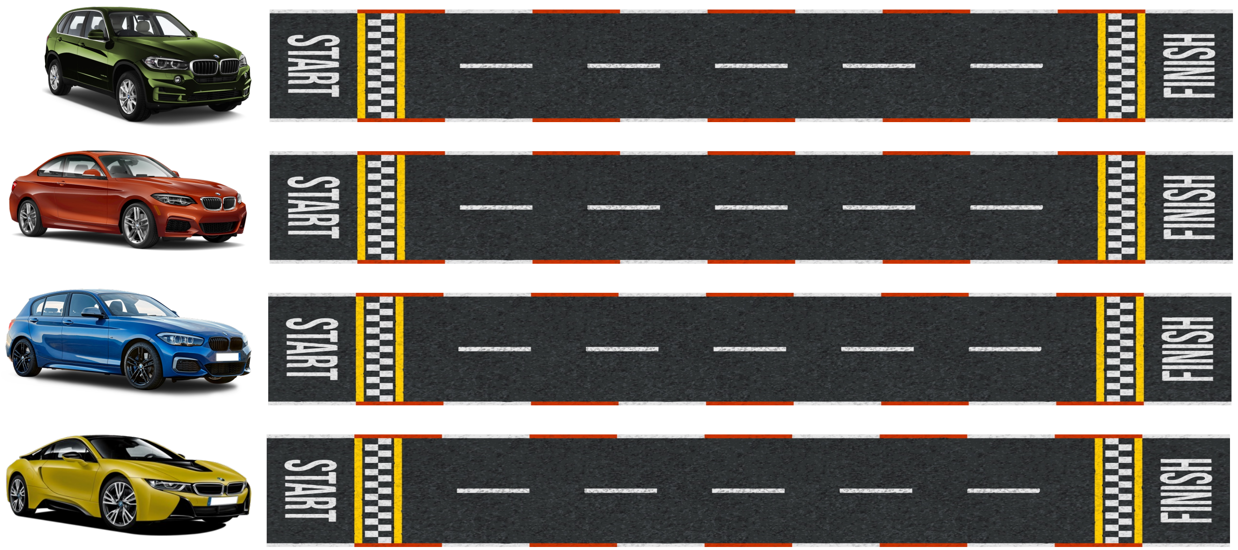
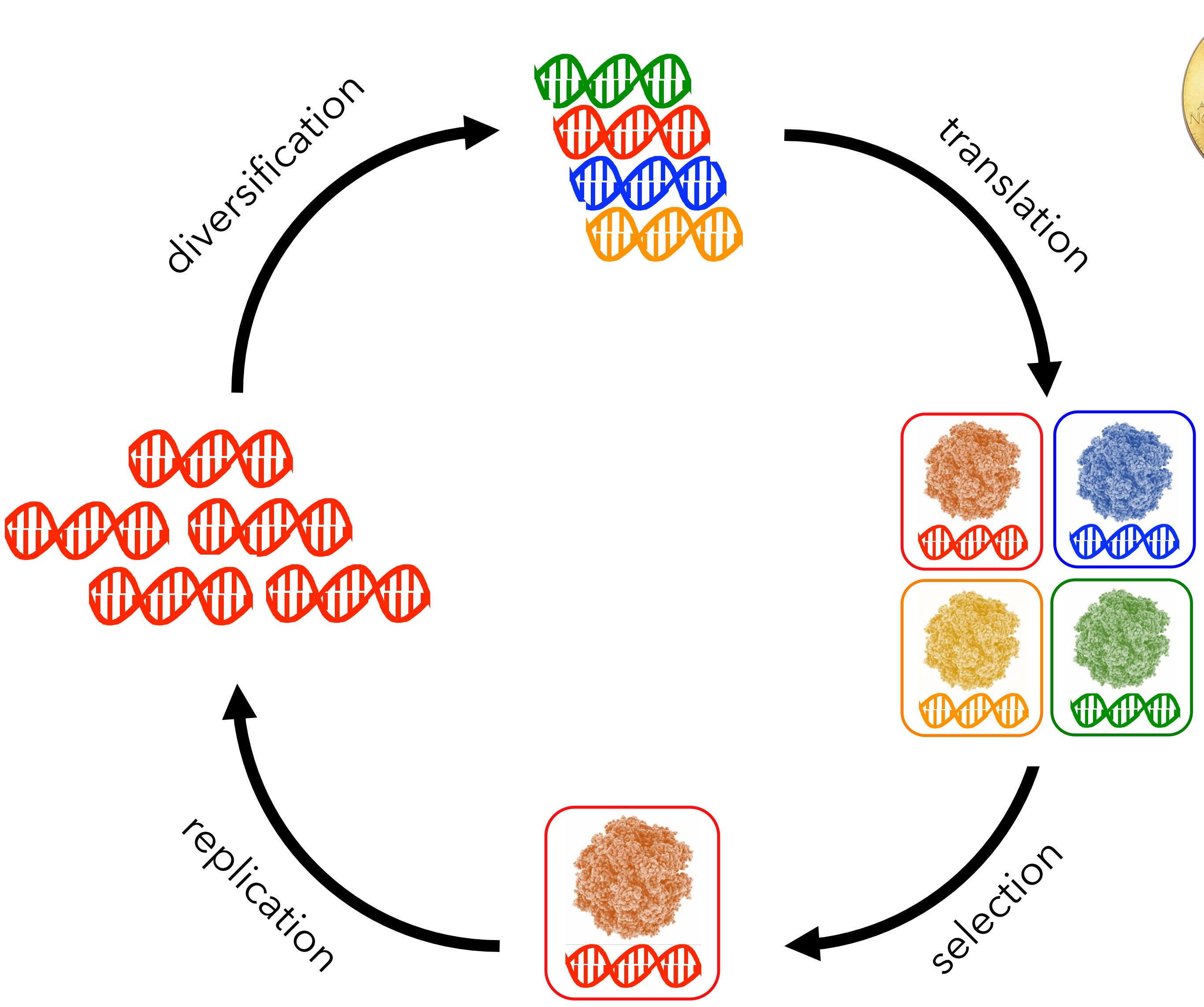


Improving RuBisCO in the Laboratory



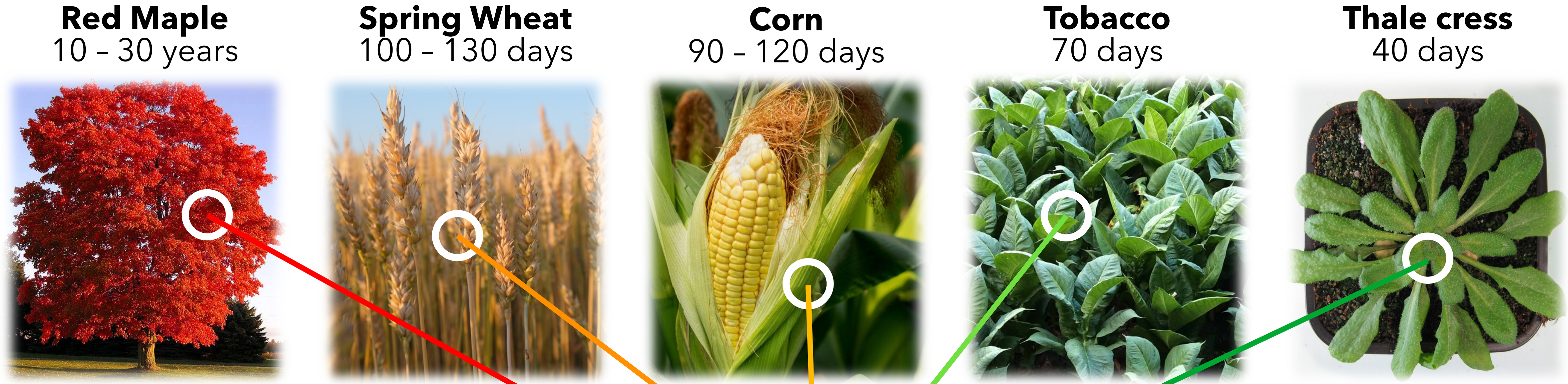
Directed Evolution
2018 Nobel Prize (Chemistry)

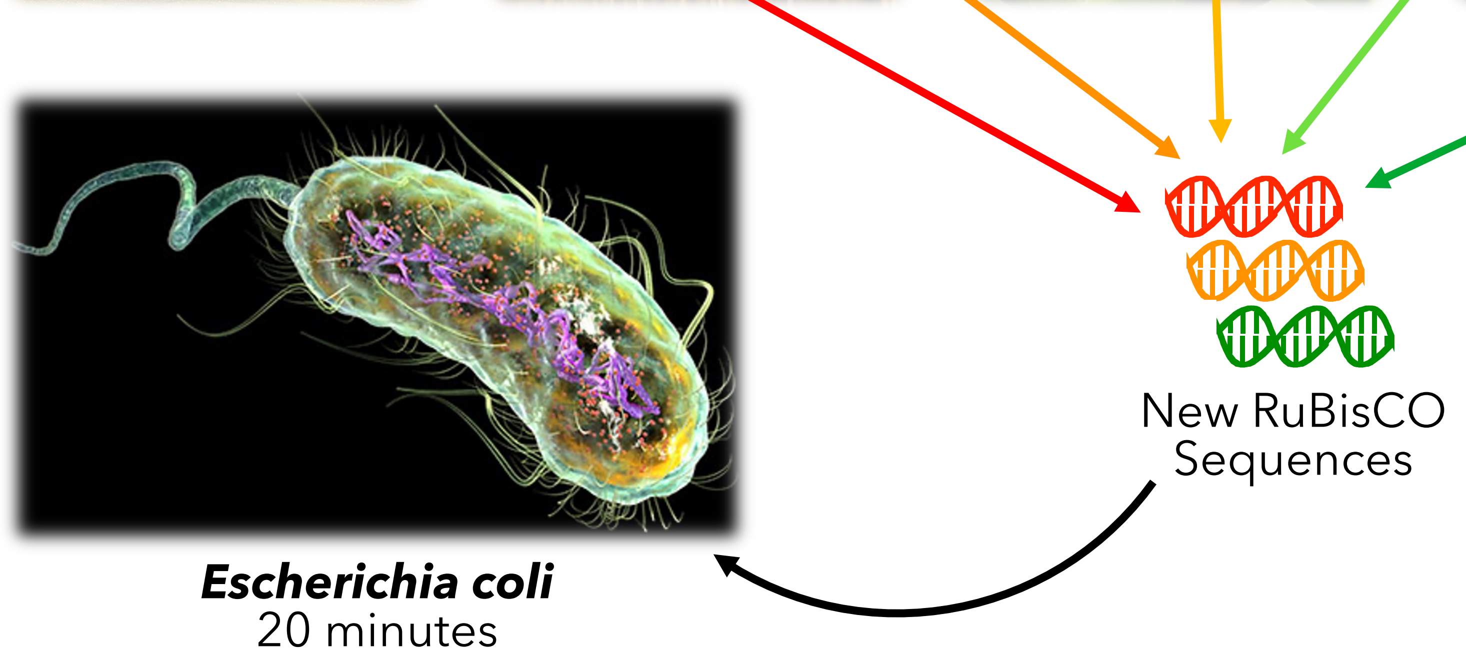
Traditional methods can require ***days to weeks*** to complete a single round of directed evolution…

My lab uses **modern, high-throughput approaches** that require ***only 20 minutes*** to complete one round of directed evolution (~300-fold improvement)

How does this compare to evolution in Nature?

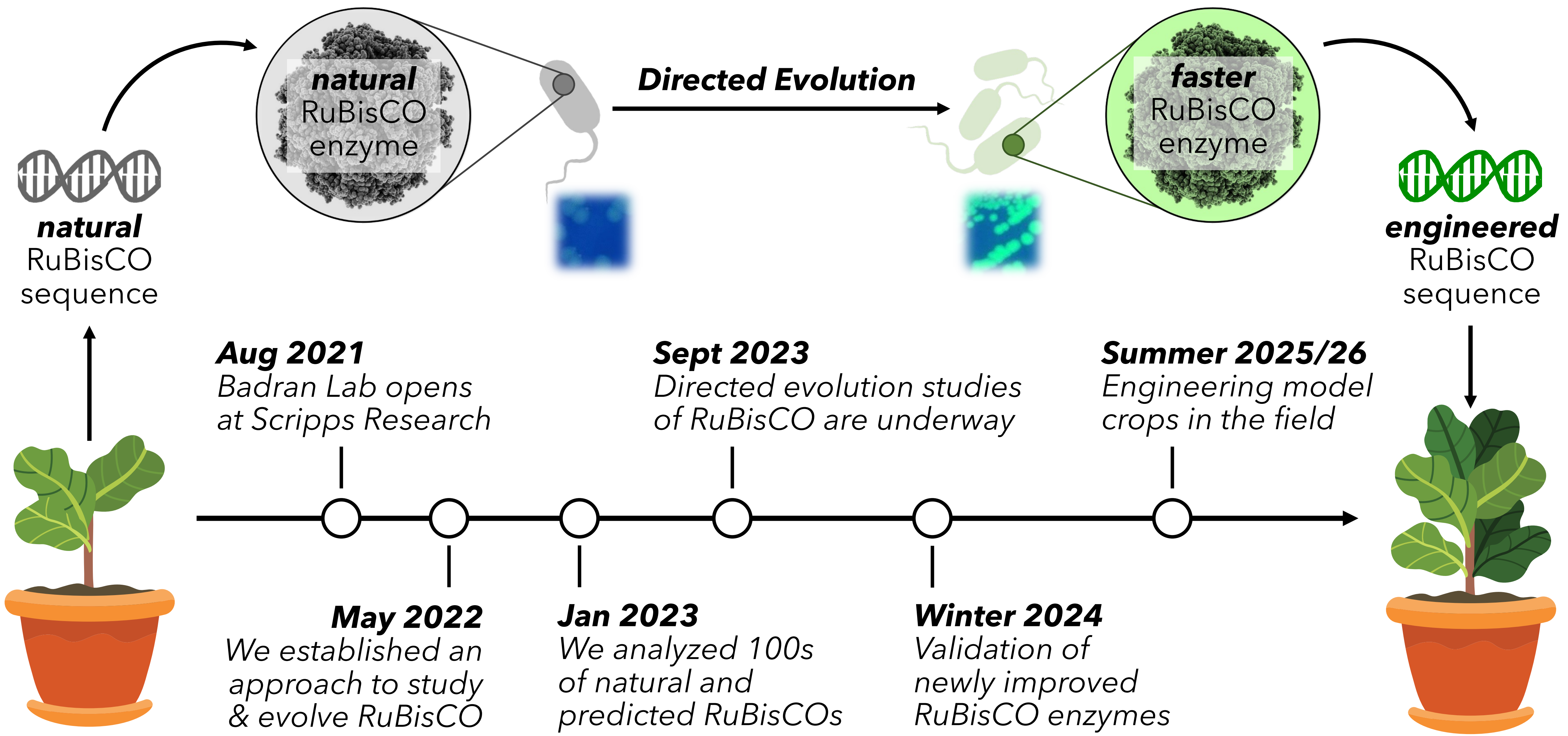
Directed Evolution vs. Nature





By capitalizing on the quick growth of *E. coli* and modern synthetic biology techniques, we can evolve RuBisCO in the lab ***~1,000,000 times faster than Nature***

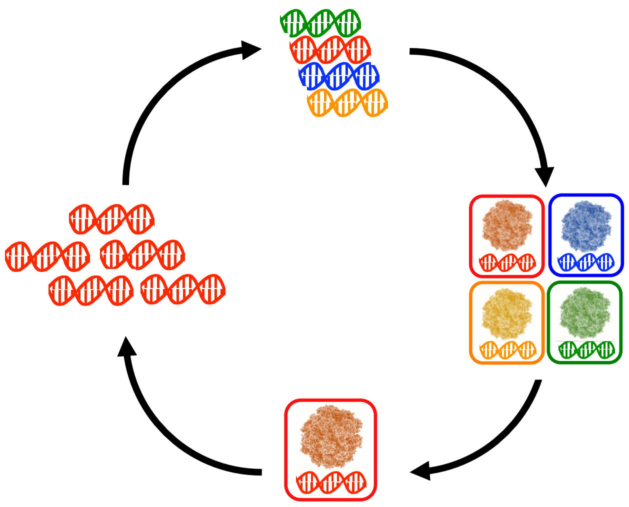
Roadmap for Evolving a Better RuBisCO



Why hasn’t anyone done this before?

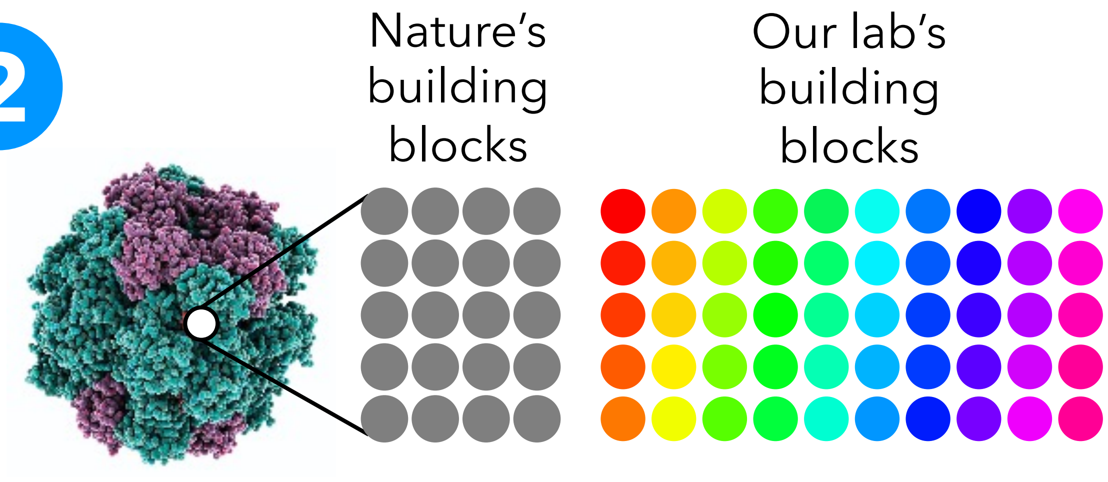
Our Technological Breakthroughs at Scripps Research

1



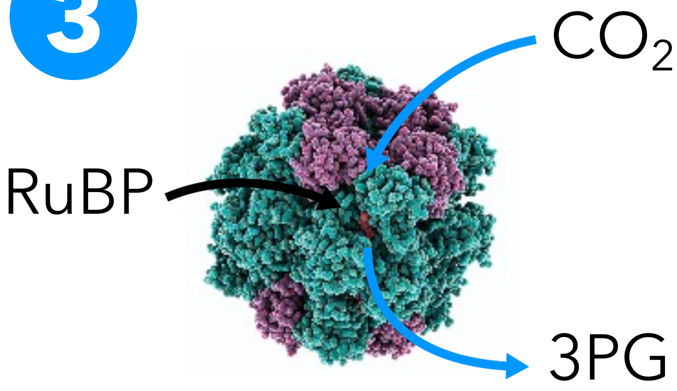
Fast Laboratory Evolution:
mimics natural evolution with ~1,000,000-fold greater speed to improve RuBisCO efficiency

2



New Chemical Parts:
makes RuBisCOs that cannot be made by Nature, expanding the limits of chemistry

3



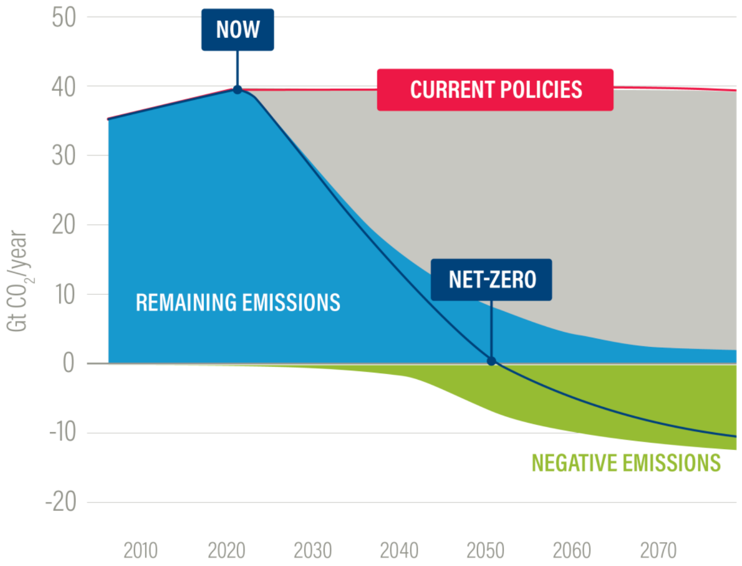
climate change

biodegradable plastics

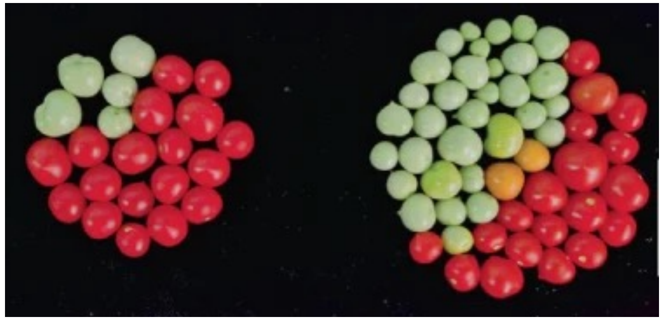
next-gen medicines

Defined Conversion Pathways:
converts captured CO_2 to key industrial products, greatly amplifying our impact

Outcomes of a Better RuBisCO



More fruit production



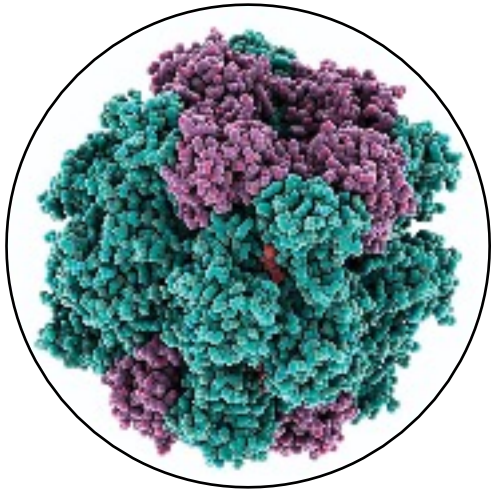
Greater drought tolerance

Sustainable
climate correction

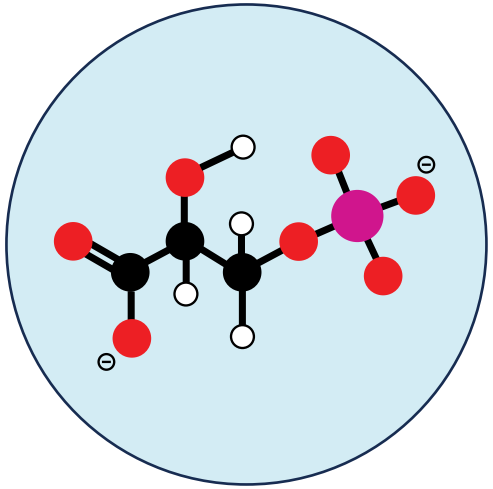
Faster growing plants

Summary

Climate change will irreparably change our planet unless we act now



RuBisCO could be a sustainable strategy to undo this damage



Re-engineering the chemistry of plants and CO_2 capture is the key

Climate repair could be as easy as planting a seed in the near future

Check out our lab website to learn more about our work: https://badranlab.com

We're working on:
- Improving RuBisCO for climate correction
- Using bacteria to degrade plastics
- Discovering next-generation antibiotics
- Making new-to-Nature catalysts

...and much more!

Scripps Research

J-WAFS Abdul Latif Jameel Water & Food Systems Lab

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