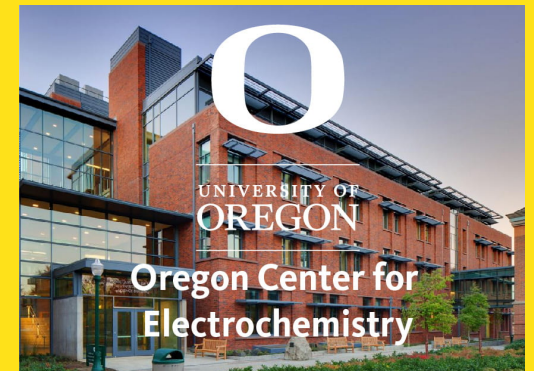
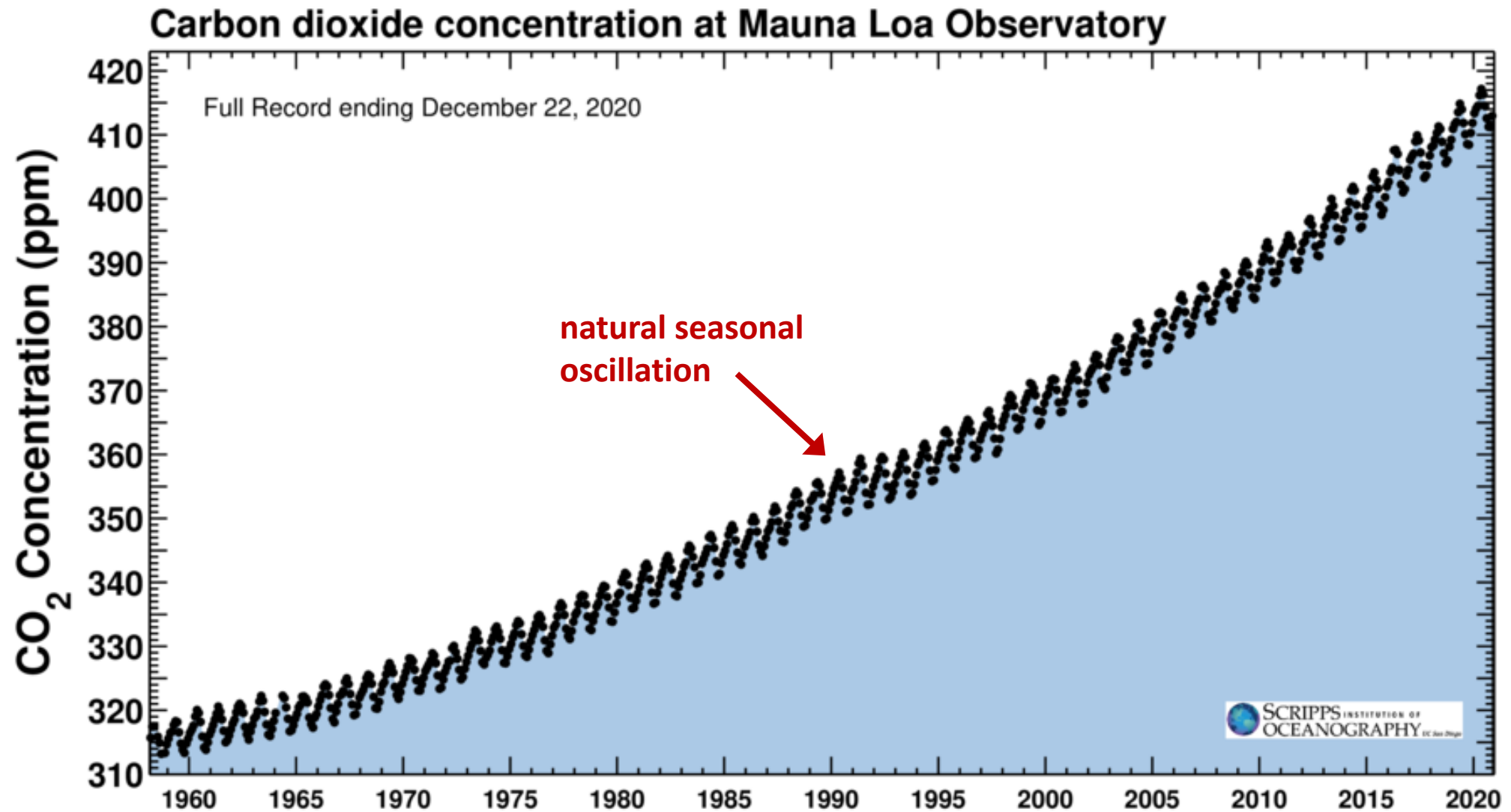




Technical challenges (and solutions) to an inevitable clean-energy future: how fast will we get there?

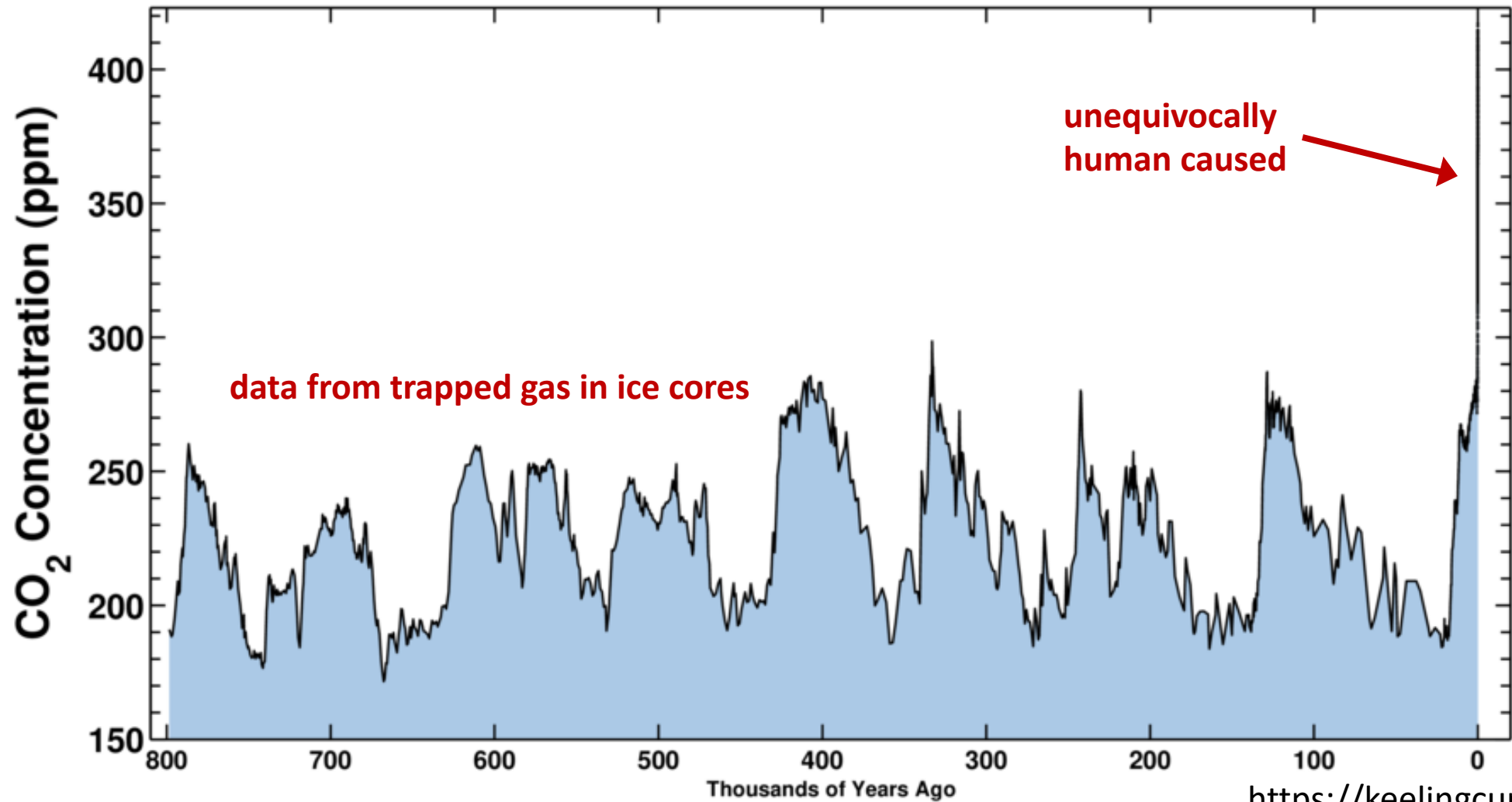
Prof. Shannon Boettcher
Director, Oregon Center for Electrochemistry
email: swb@uoregon.edu





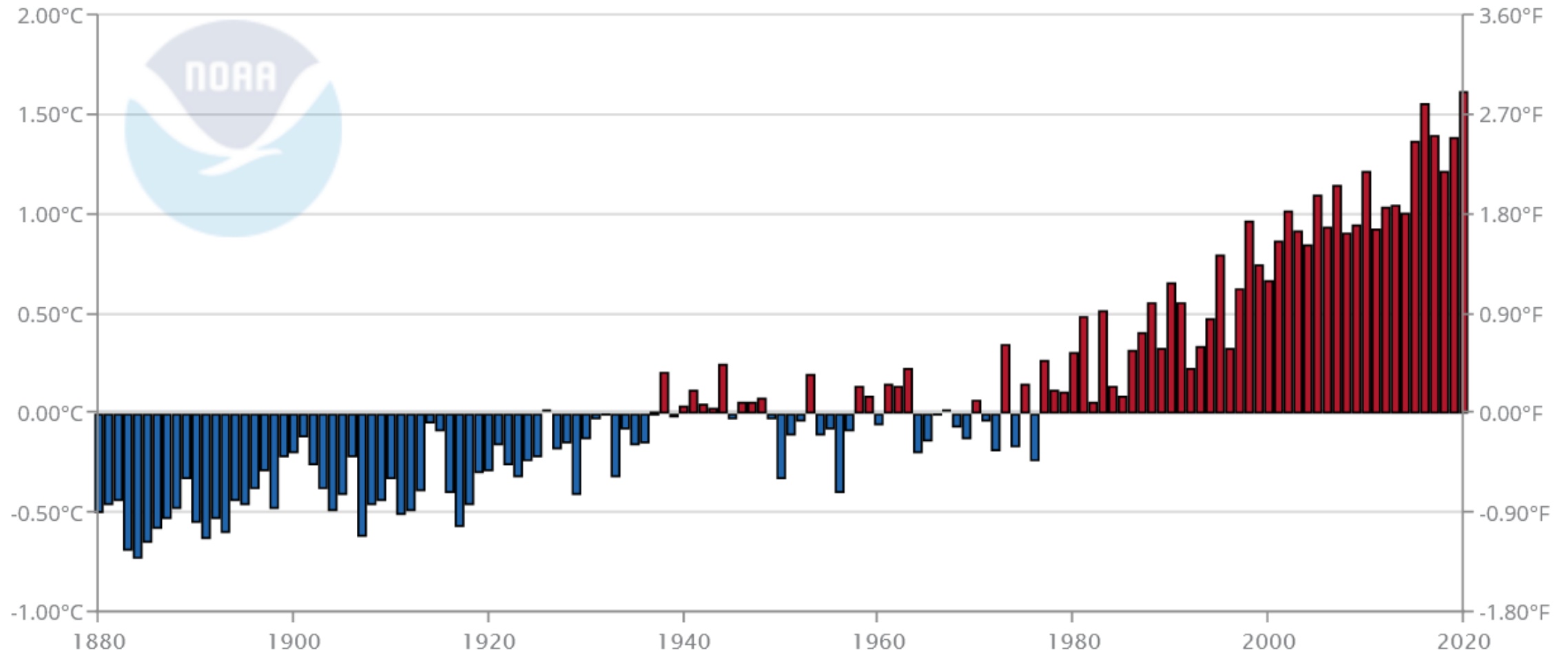
<https://keelingcurve.ucsd.edu/>

Nearly one million years of data show current CO₂ unprecedented



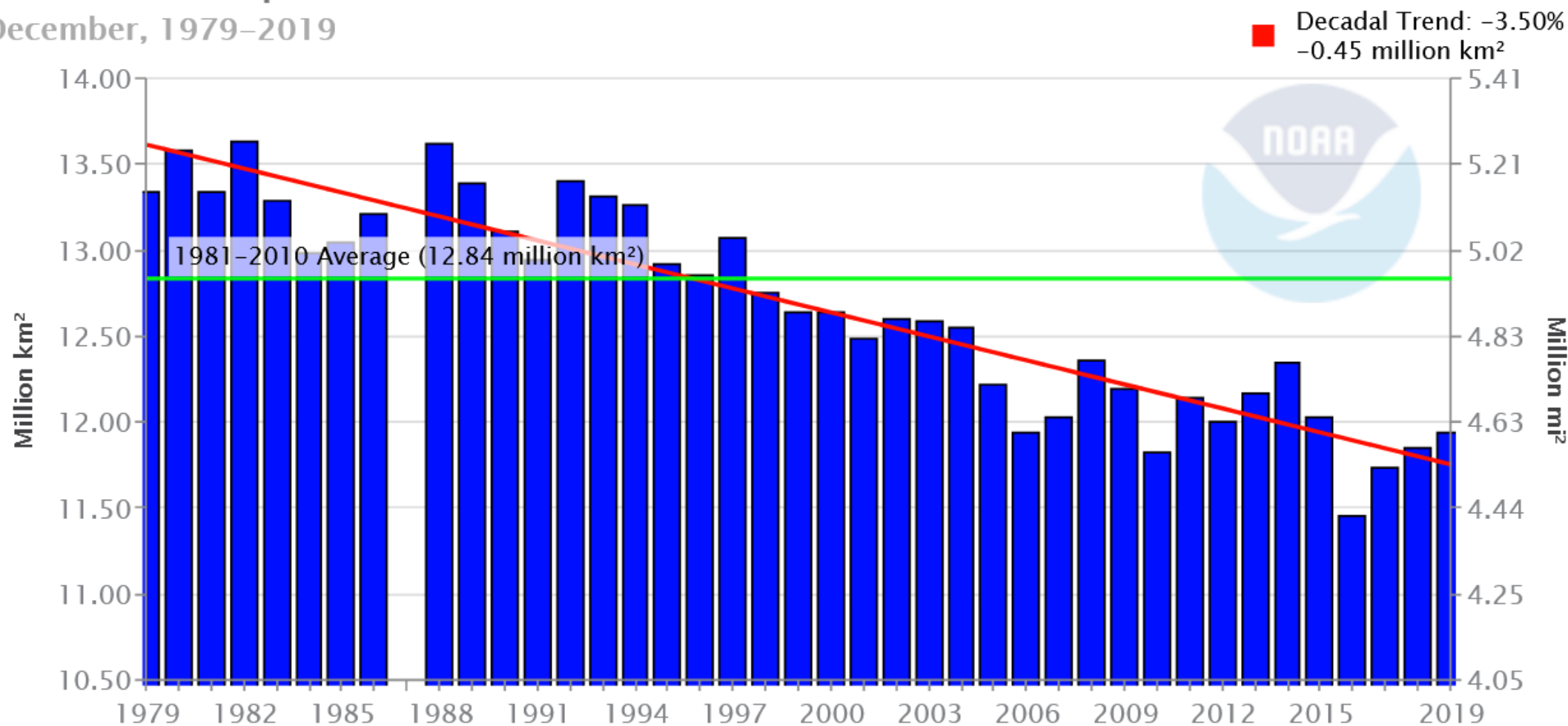
<https://keelingcurve.ucsd.edu/>

Global-Average Land-Based Temperature Measurements



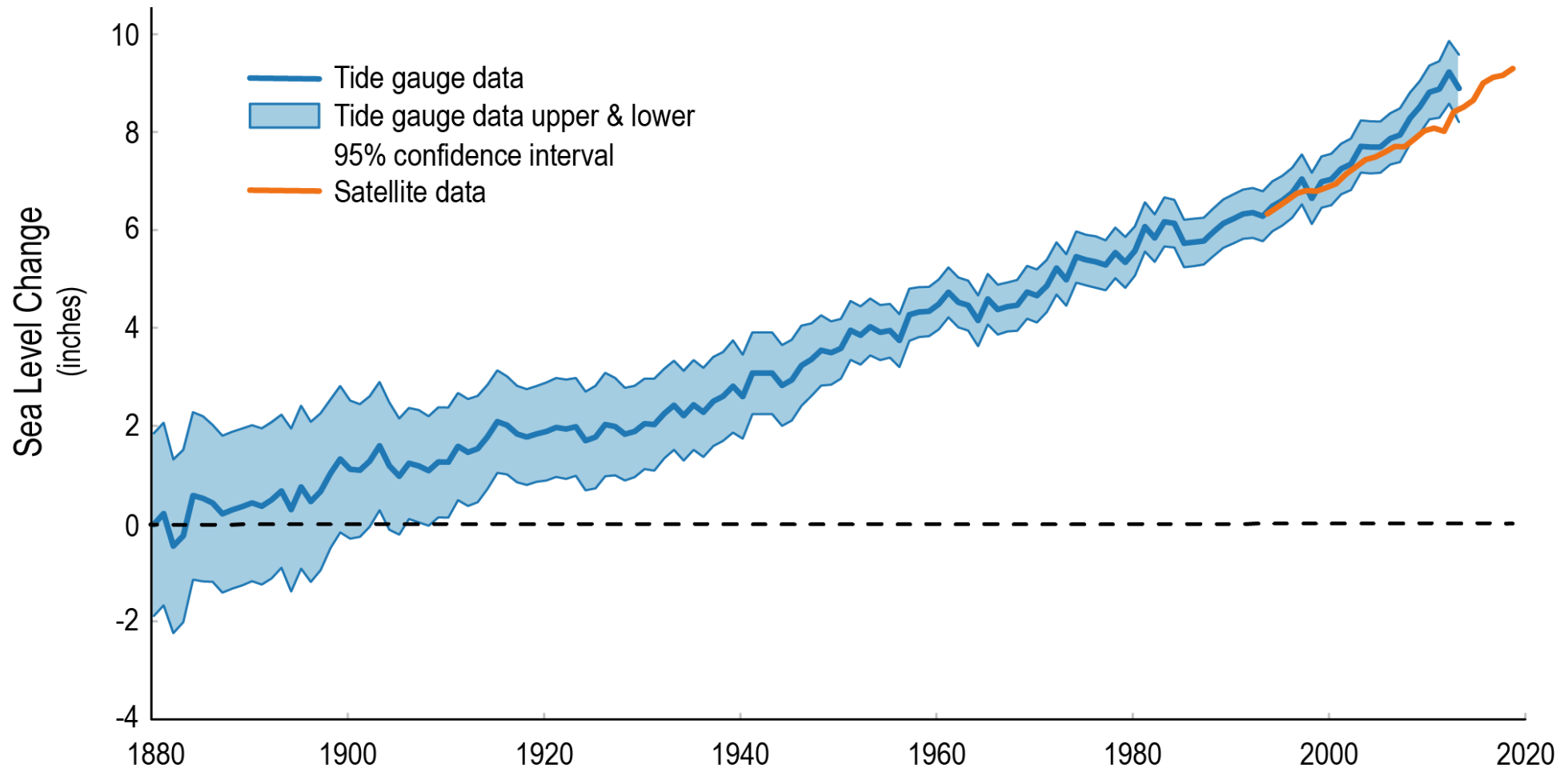
NOAA National Centers for Environmental information, Climate at a Glance: Global Time Series, published December 2020, retrieved on December 28, 2020 from <https://www.ncdc.noaa.gov/cag/>

Northern Hemisphere Sea Ice December, 1979–2019

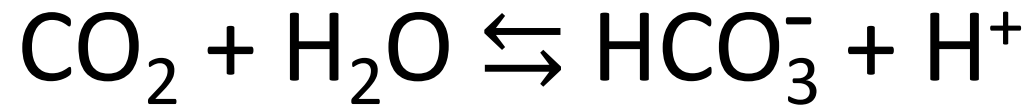
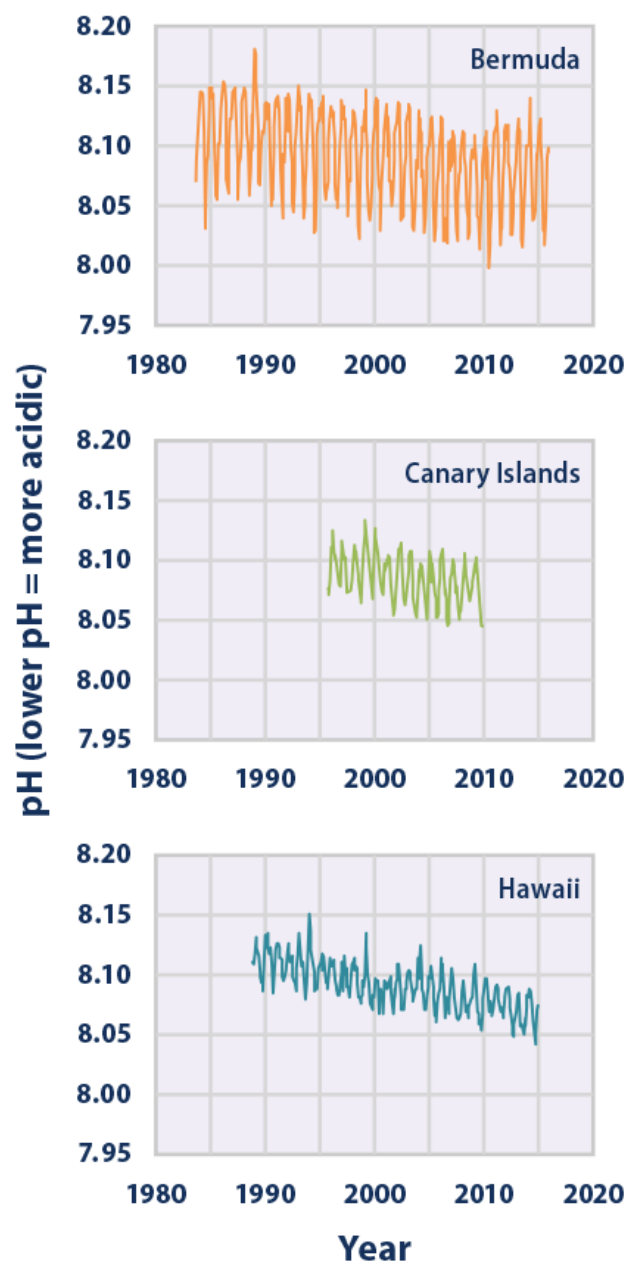


NOAA National Centers for Environmental information, Climate at a Glance: Global Time Series, published December 2020, retrieved on December 28, 2020 from <https://www.ncdc.noaa.gov/cag/>

Global Average Sea Level Change Relative to 1880



<https://www.globalchange.gov/browse/indicators/global-sea-level-rise>



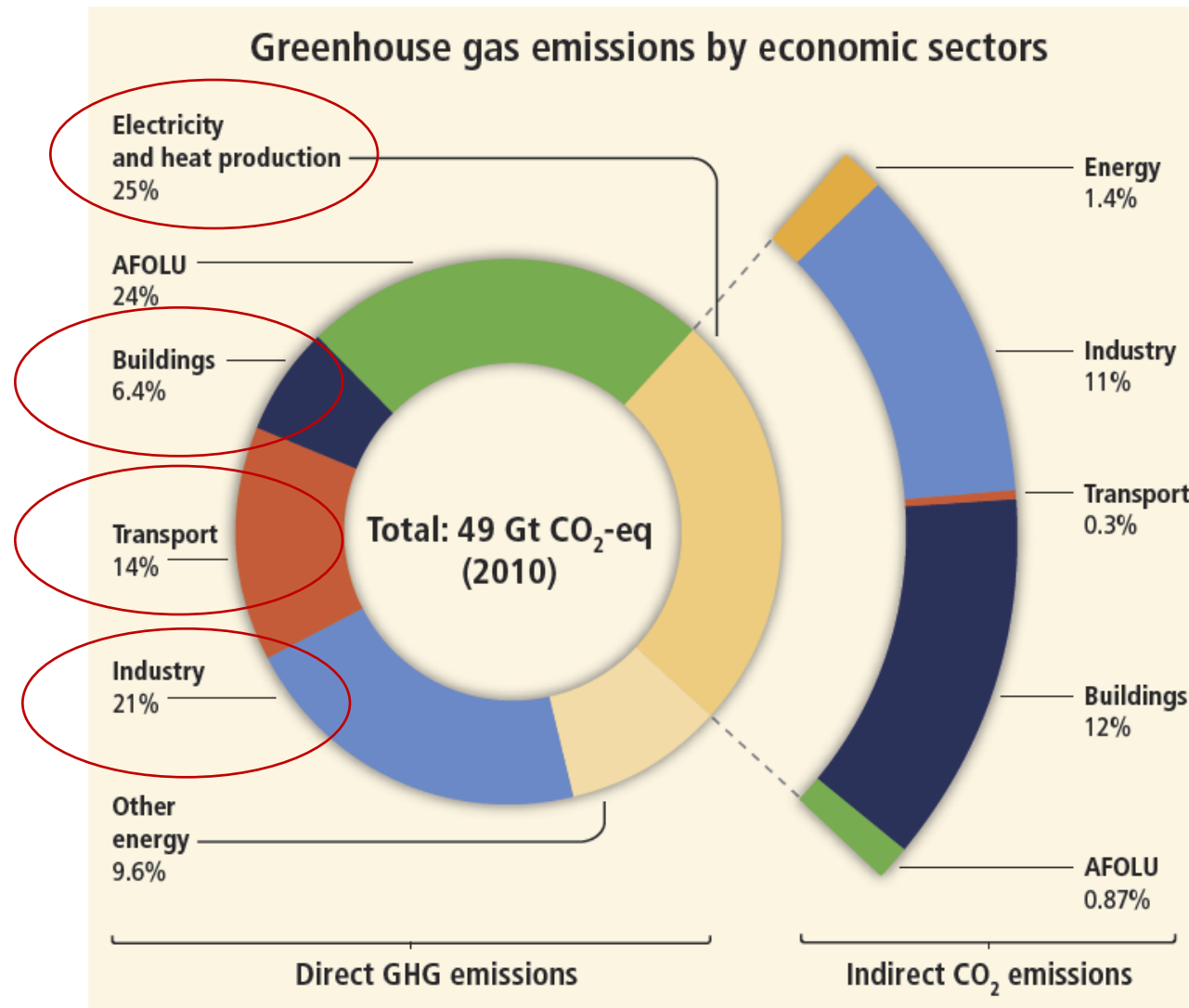
Of the 1300 Gt CO₂ emitted from human activity over the last 200 years, ~38% of that has gone into the oceans.

This has led to a 30% increase in acidity.

Calcifiers (coral, shellfish, etc.) risk extinction.



<https://www.epa.gov/climate-indicators/climate-change-indicators-ocean-acidity>; Rackley, Stephen A. (2010), "[Ocean Storage](#)", *Carbon Capture and Storage*, Elsevier, pp. 267–286,

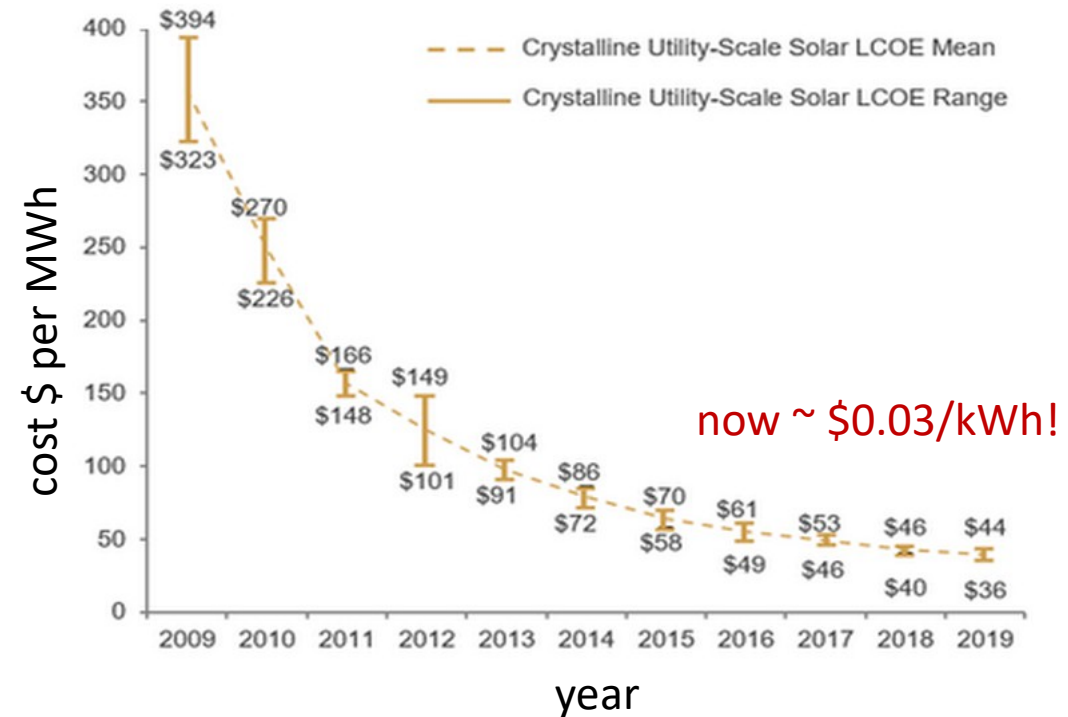
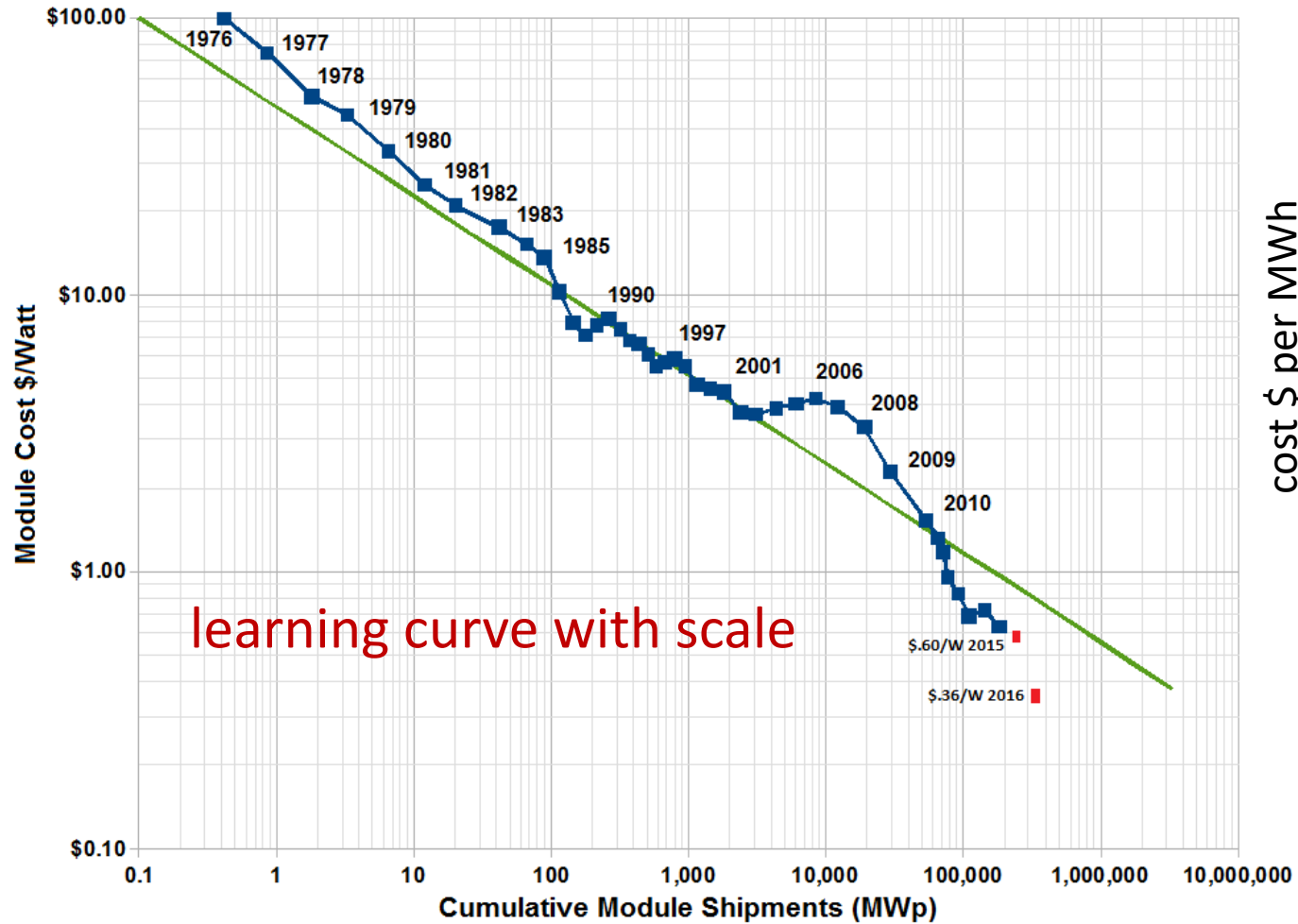


To prevent (likely catastrophic) human induced climate change CO₂ emissions must go to 0 – or even negative.

AFOLU = Agriculture, Forestry, and Other Land Uses

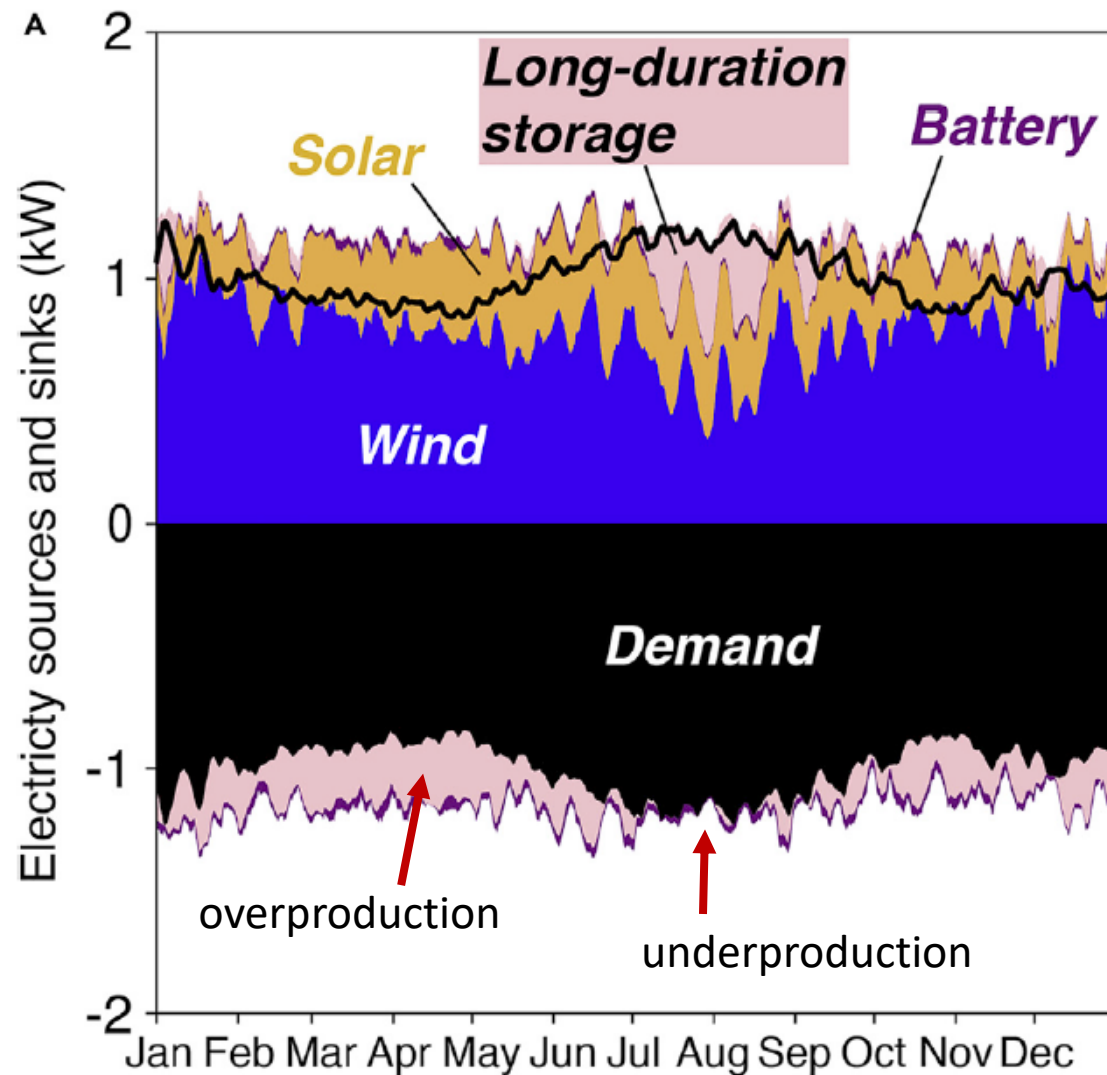
IPCC, 2014: Climate Change 2014: Synthesis Report.

Technology innovation plus scaling: *renewables now provide the lowest cost electricity*



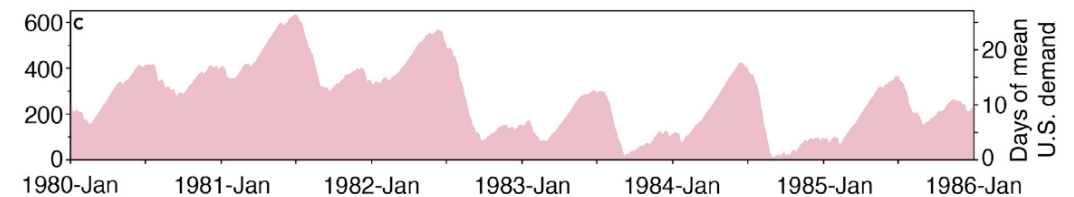
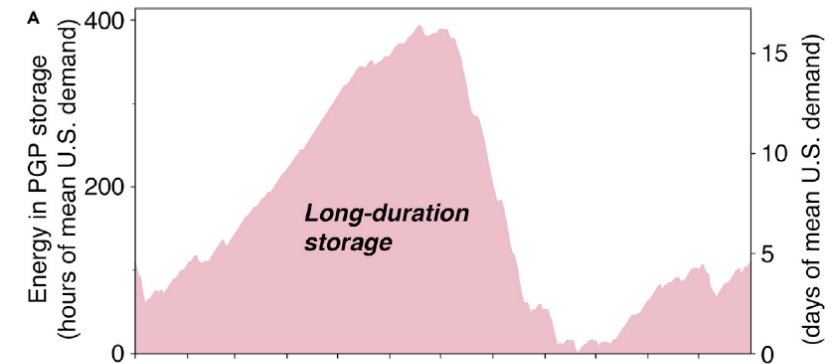
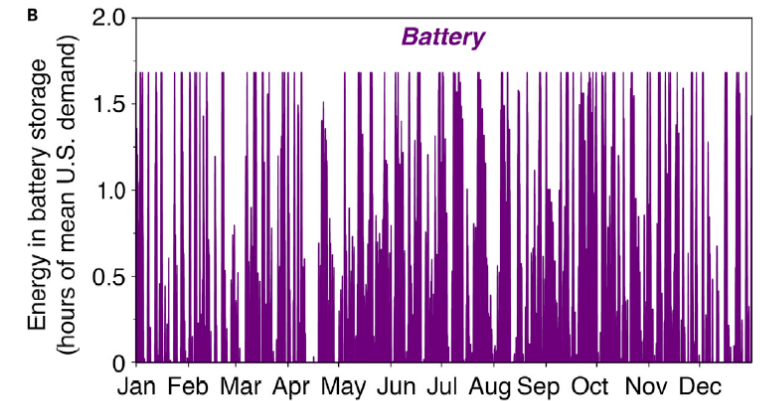
20 years ago this was thought impossible
10 years ago it was thought very unlikely

https://en.wikipedia.org/wiki/Swanson's_law



Need (cheap) short duration daily variation

Need (cheap) long-duration storage for season and decadal variation



Lewis, Caldeira, et. al., Role of Long-Duration Energy Storage in Variable Renewable Electricity Systems. *Joule* **2020**, 4, 1907-1928.

Chemistry is the Solution: Lithium ion battery

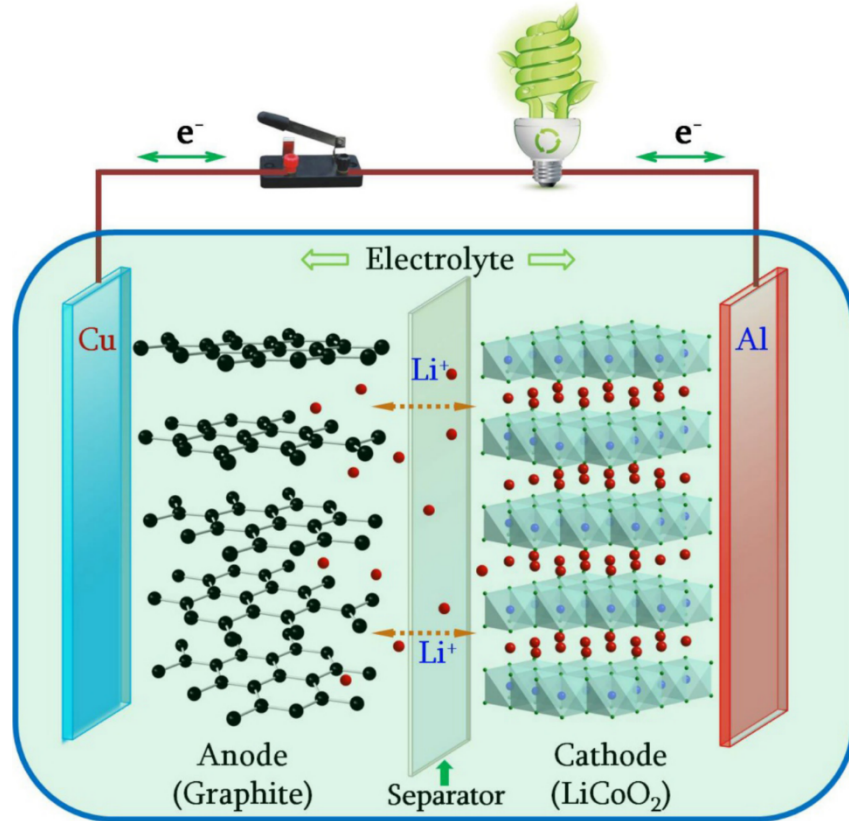
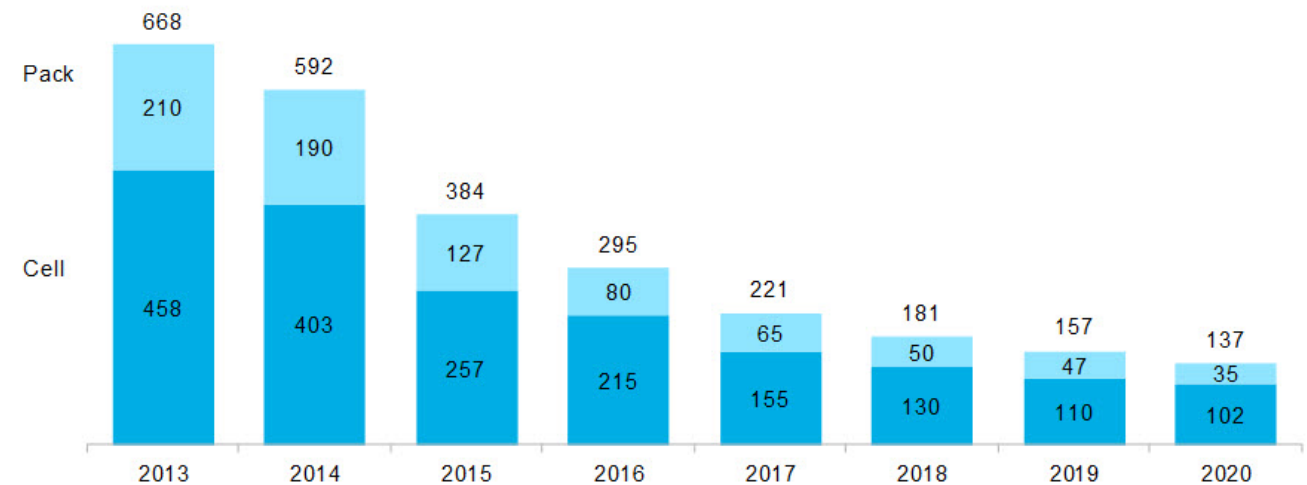


Figure 1: Volume-weighted average pack and cell price split

real 2020 \$/kWh



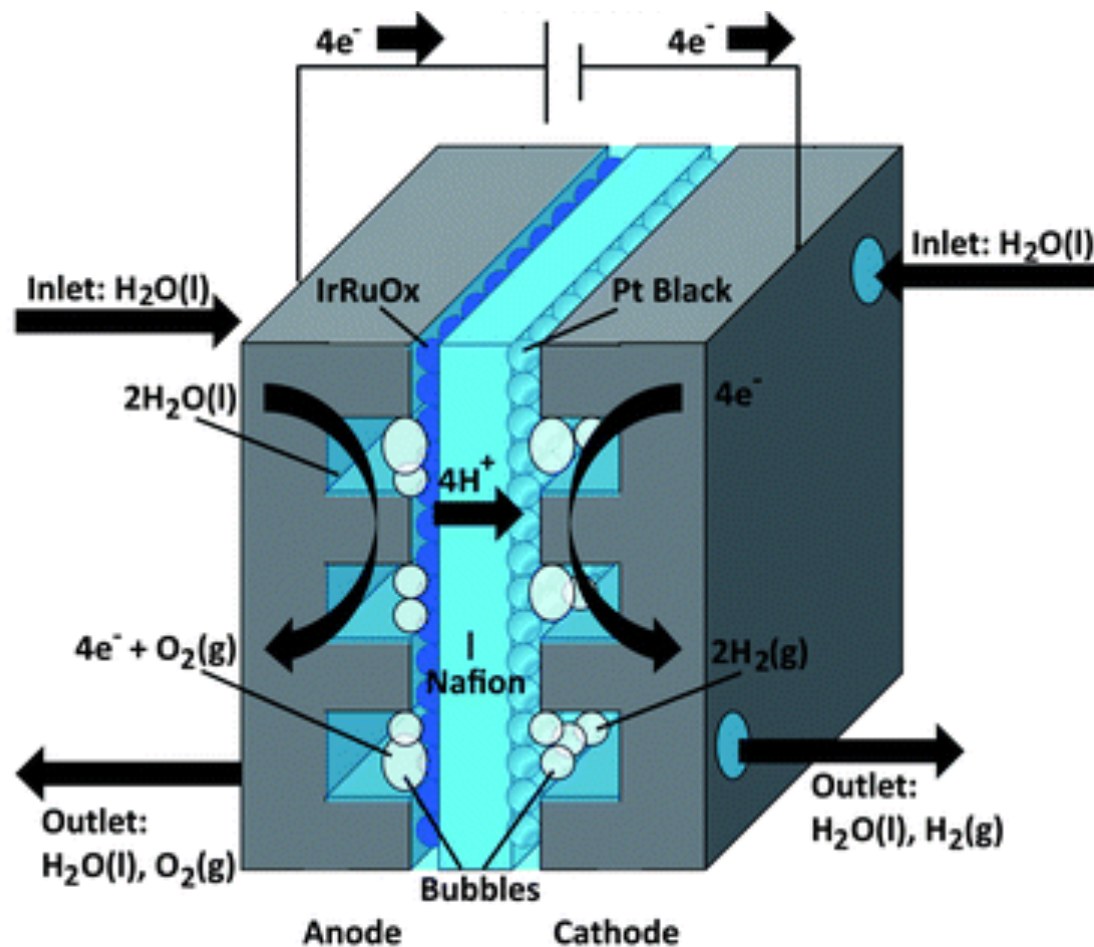
Source: BloombergNEF

2019 Nobel Prize in Chemistry

< \$100/kWh as the target for “true” price parity with ICE vehicles (2-3 y)
< \$20/kWh for long-duration storage (uncertain timeline)



Electrolysis forms hydrogen fuel

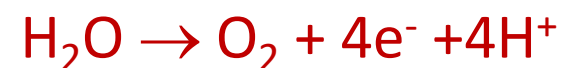


Half reactions:

Cathode (reduction):



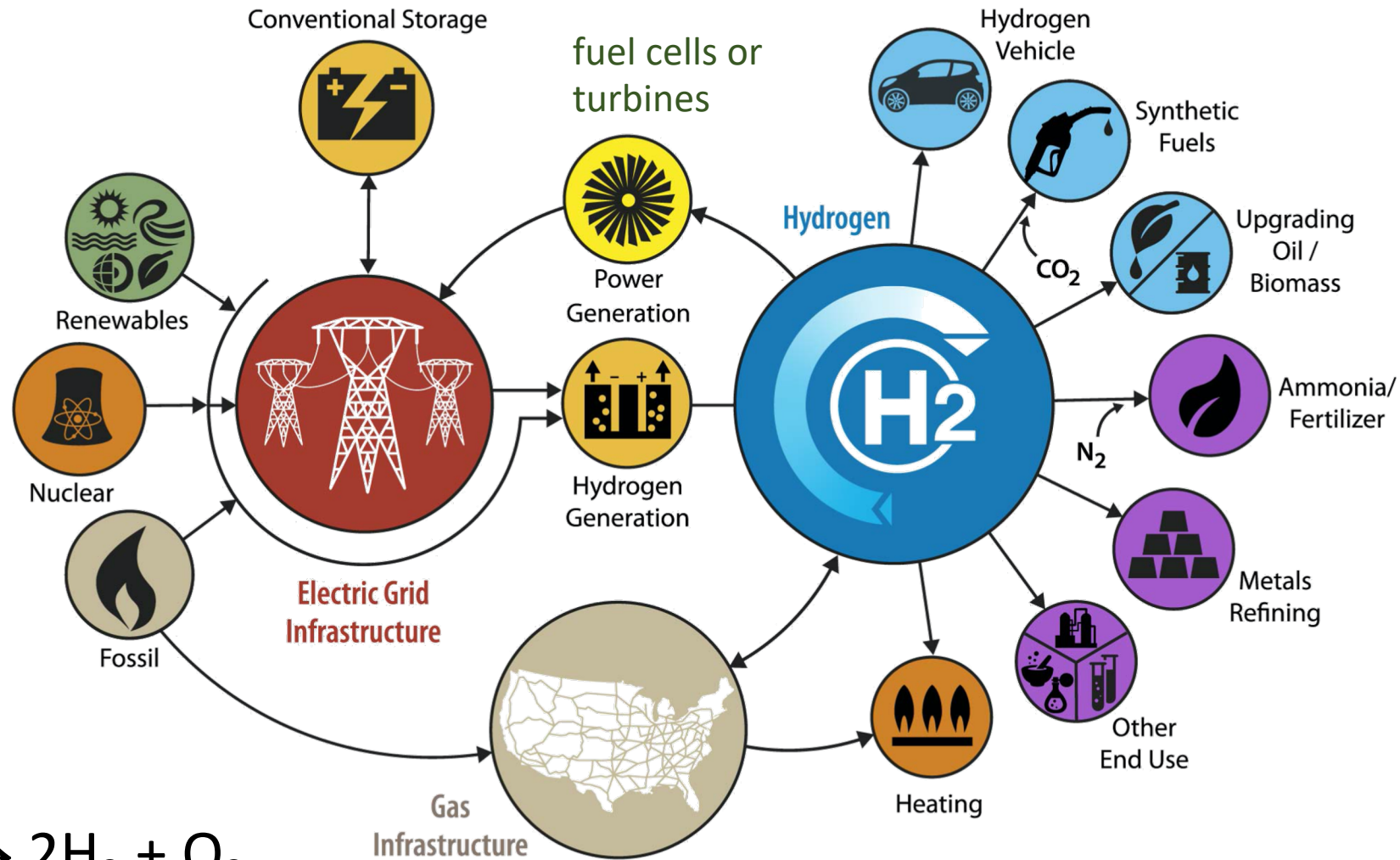
Anode (oxidation):



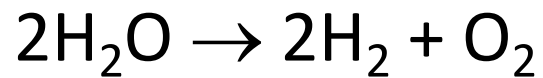
Science and Technology Challenges:

- Cheap, earth-abundant, and stable catalysts
- Lower-cost cell designs for mass production
- Improved processes and materials for durable ionic membranes

Hydrogen enables long-duration storage... and more



Predication:
natural gas
companies will
become hydrogen
companies over
the next 20 years.



National Renewable Energy Laboratory, NREL 54313.

World's First Hydrogen-Electric Flight of a Commercial Airplane Uses Fuel Cell System from PowerCell Sweden

By FuelCellsWorks | September 27, 2020 | 3 min read (415 words)

0 Comments

16



power

AIR TRANSPORT

Airbus Eyes Hydrogen Power for Airliner in Next Decade

by Kerry Lynch - July 21, 2020, 4:59 PM



Airbus hopes to bring a zero-emissions commercial airliner to market in the early 2030s and says key technology decisions must be made in the next five years. (Photo: Airbus)



Airbus sees hydrogen as the pathway toward its goal of bringing a zero-emissions commercial airliner to market in the next decade, a key executive said Tuesday.

Budweiser brewer makes first beer delivery with Nikola semi truck

And a BYD electric truck took the beer to its final destination.



Sean Szymkowski Nov. 22, 2019 10:04 a.m. PT



▶ LISTEN - 01:43



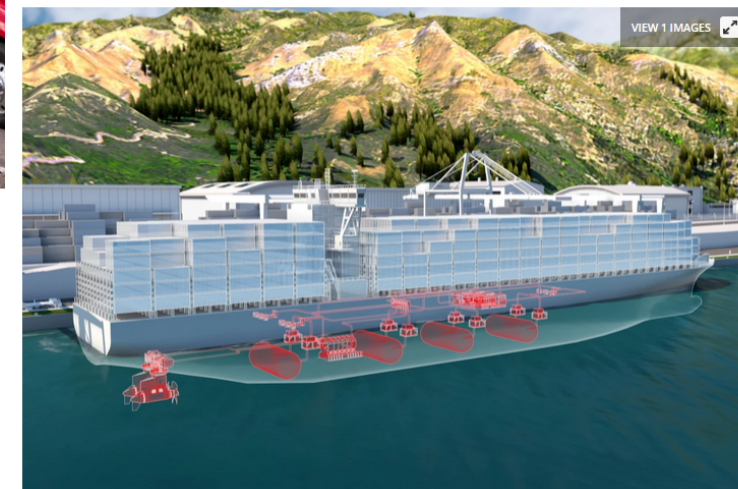
beer coming through.

MARINE

ABB plans "megawatt-scale" hydrogen powertrains for container ships

By Loz Blain
April 14, 2020

▶ Listen To This Article

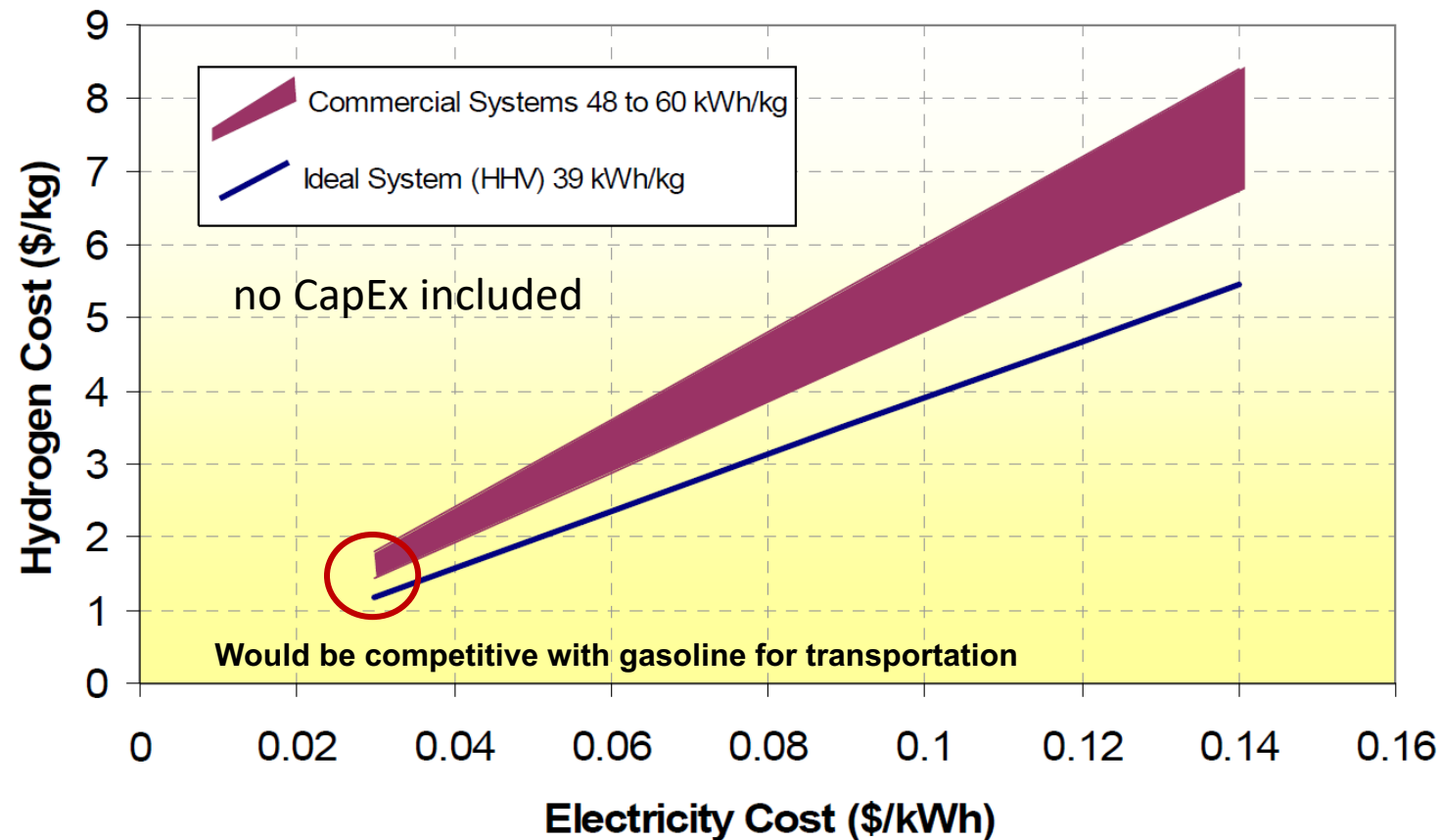


VIEW 1 IMAGES

ABB and Hydrogene de France are teaming up to build enormous hydrogen fuel cell powertrains for large marine vessels ABB

One round-trip flight from New York to Europe or to San Francisco creates a warming effect equivalent to 2 or 3 tons of carbon dioxide per person.

Cost of Electrolysis-Derived Hydrogen Gas



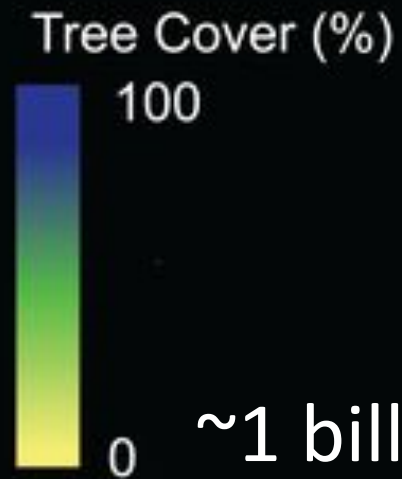
Massive, very-low-cost electrolyzer and fuel-cell technology is coming in the next 5-10 y as the sector scales and learns.

1 kg of hydrogen gas has about the same energy content of 1 gallon of gasoline.
Hydrogen from natural gas reforming costs 1.5 - 3 \$/kg

2009 Report NREL/BK-6A1-46676

Want negative
emissions?
Use Nature.

Massive investment in
reforestation and **forest
management** in rural areas
critical.



~1 billion hectares “available” = ~200 GtC = 2/3 of human emissions



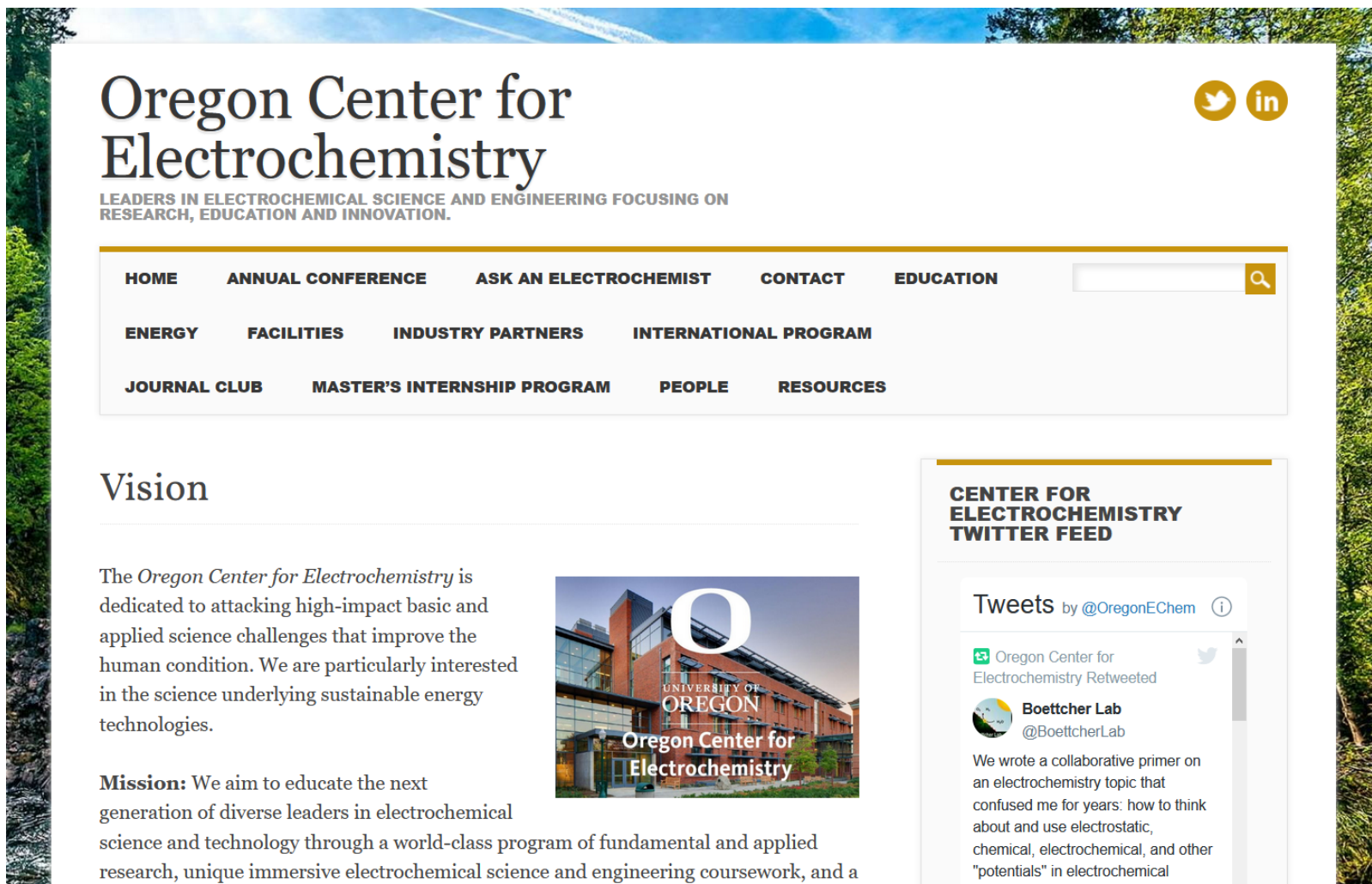
UNIVERSITY OF
OREGON

Office of the Provost
Environment Initiative

Crowther and coworkers, The global tree restoration potential.
Science **2019**, 365, 76-79.

- The cost of renewable electricity generation has **dropped dramatically** and due to science, engineering, and production scaling
- Cost of solar/wind electricity is lower per kWh than any other source
- Daily, seasonal, and decadal variation in renewables a solvable challenge with existing technology whose costs will continue a dramatic decline
- Clear, ambitious, policy is needed to enable private investment in new technology still seen as risky
- Over the next two decades, solar/wind energy + storage will be the cheapest form of energy.
- Investments/policy that continue legacy fossil-fuel technology is not only bad for the environment, it is ultimately bad for Oregon business.

electrochemistry.uoregon.edu



The screenshot shows the homepage of the Oregon Center for Electrochemistry. The header features the center's name in a large serif font, with a tagline below it: "LEADERS IN ELECTROCHEMICAL SCIENCE AND ENGINEERING FOCUSING ON RESEARCH, EDUCATION AND INNOVATION." Social media icons for Twitter and LinkedIn are in the top right. A navigation menu includes links for HOME, ANNUAL CONFERENCE, ASK AN ELECTROCHEMIST, CONTACT, EDUCATION, ENERGY, FACILITIES, INDUSTRY PARTNERS, INTERNATIONAL PROGRAM, JOURNAL CLUB, MASTER'S INTERNSHIP PROGRAM, PEOPLE, and RESOURCES. A search bar is located on the right side of the menu. The main content area is titled "Vision" and contains a paragraph about the center's dedication to high-impact science. To the right of this text is a photo of the center's building. Below the vision text is a "Mission" statement. On the far right, there is a "CENTER FOR ELECTROCHEMISTRY TWITTER FEED" section showing a tweet from the Boettcher Lab.

Oregon Center for Electrochemistry

LEADERS IN ELECTROCHEMICAL SCIENCE AND ENGINEERING FOCUSING ON RESEARCH, EDUCATION AND INNOVATION.


HOME ANNUAL CONFERENCE ASK AN ELECTROCHEMIST CONTACT EDUCATION

ENERGY FACILITIES INDUSTRY PARTNERS INTERNATIONAL PROGRAM

JOURNAL CLUB MASTER'S INTERNSHIP PROGRAM PEOPLE RESOURCES

Vision

The *Oregon Center for Electrochemistry* is dedicated to attacking high-impact basic and applied science challenges that improve the human condition. We are particularly interested in the science underlying sustainable energy technologies.



Mission: We aim to educate the next generation of diverse leaders in electrochemical science and technology through a world-class program of fundamental and applied research, unique immersive electrochemical science and engineering coursework, and a

CENTER FOR ELECTROCHEMISTRY TWITTER FEED

Tweets by @OregonEChem

Oregon Center for Electrochemistry Retweeted

Boettcher Lab
@BoettcherLab

We wrote a collaborative primer on an electrochemistry topic that confused me for years: how to think about and use electrostatic, chemical, electrochemical, and other "potentials" in electrochemical



UNIVERSITY OF
OREGON

Office of the Provost
Environment Initiative