Climate Change:
Simple, Serious, Solvable

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Atmospheric Science, CSU

1. Simple

2. Serious

3. Solvable

1. Simple

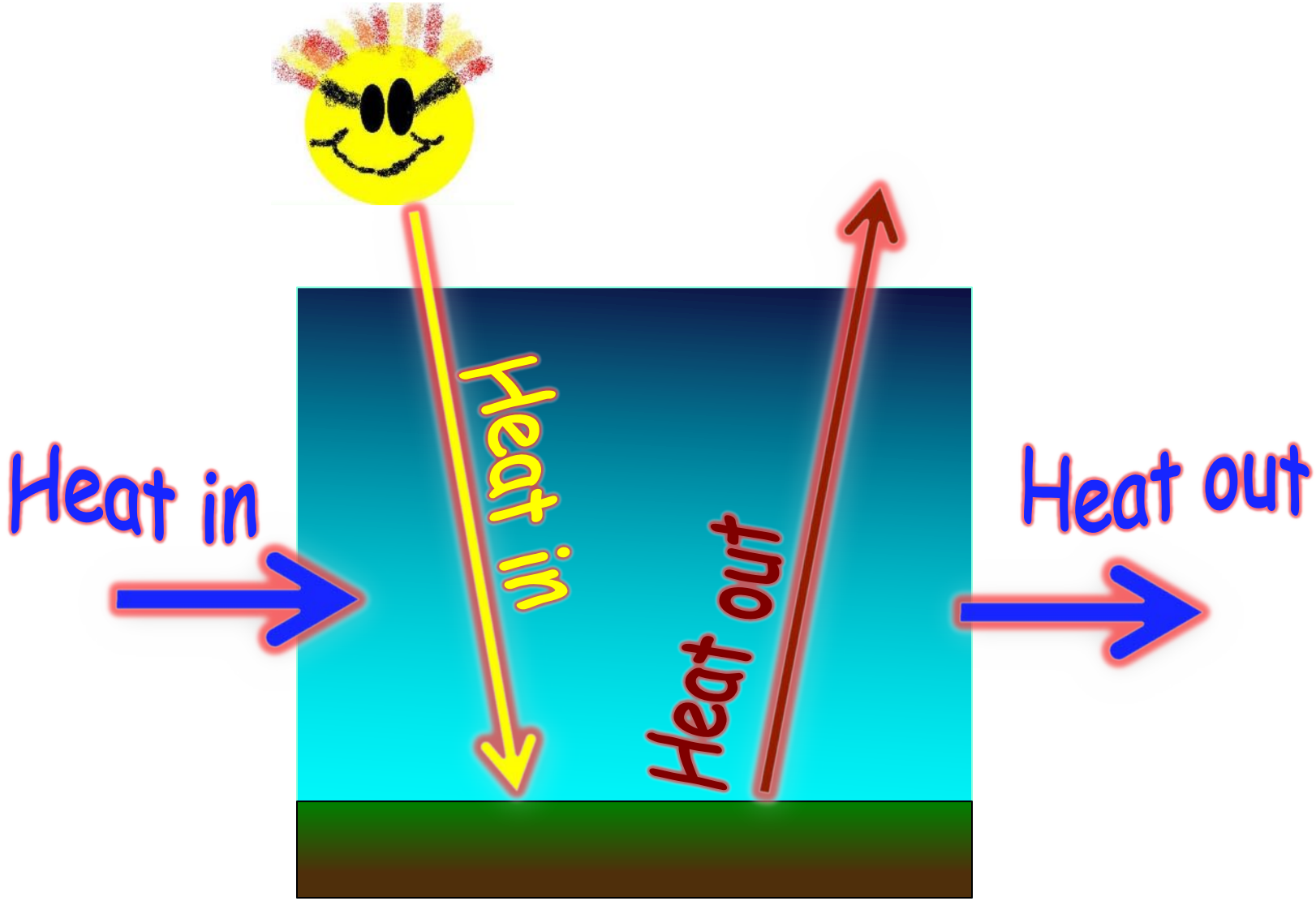
2. Serious

3. Solvable

Ever Wonder Why?

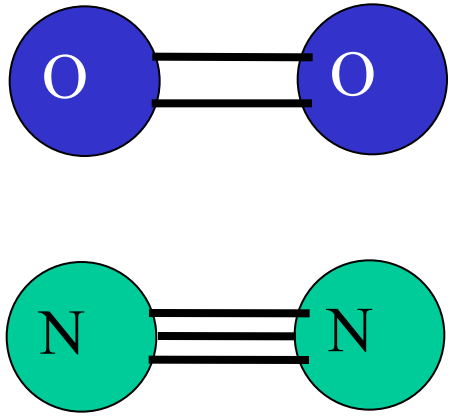
- **Day** is warmer than **night**
- **Summer** is warmer than **winter**
- **Phoenix** is warmer than **Fargo**

Heat Budgets



Dancing Molecules and Heat Rays!

- Nearly all of the air is made of oxygen (O_2) and nitrogen (N_2) in which two atoms of the same element share electrons



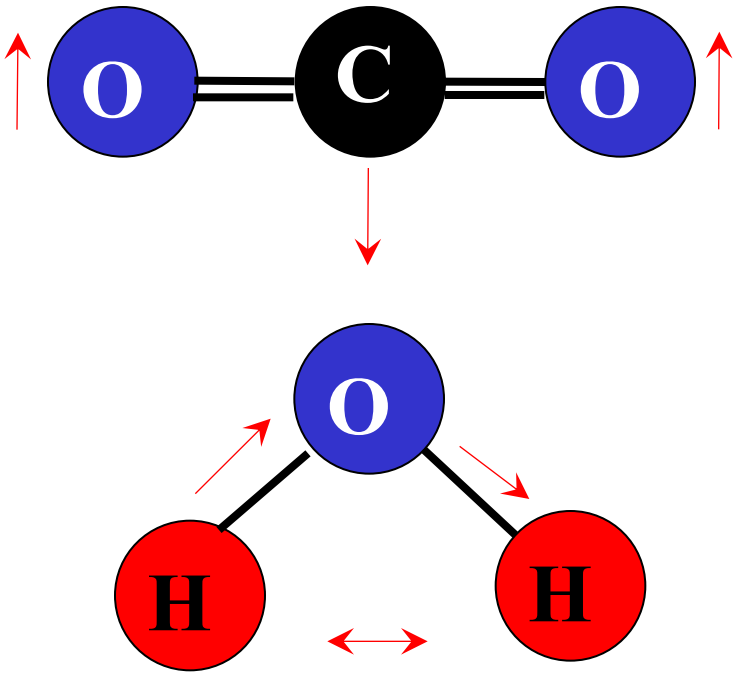
- Infrared (heat) energy radiated up from the surface can be absorbed by these molecules, but not very well

Diatomic molecules can vibrate back and forth like balls on a spring, but the ends are identical

Dancing Molecules and Heat Rays!

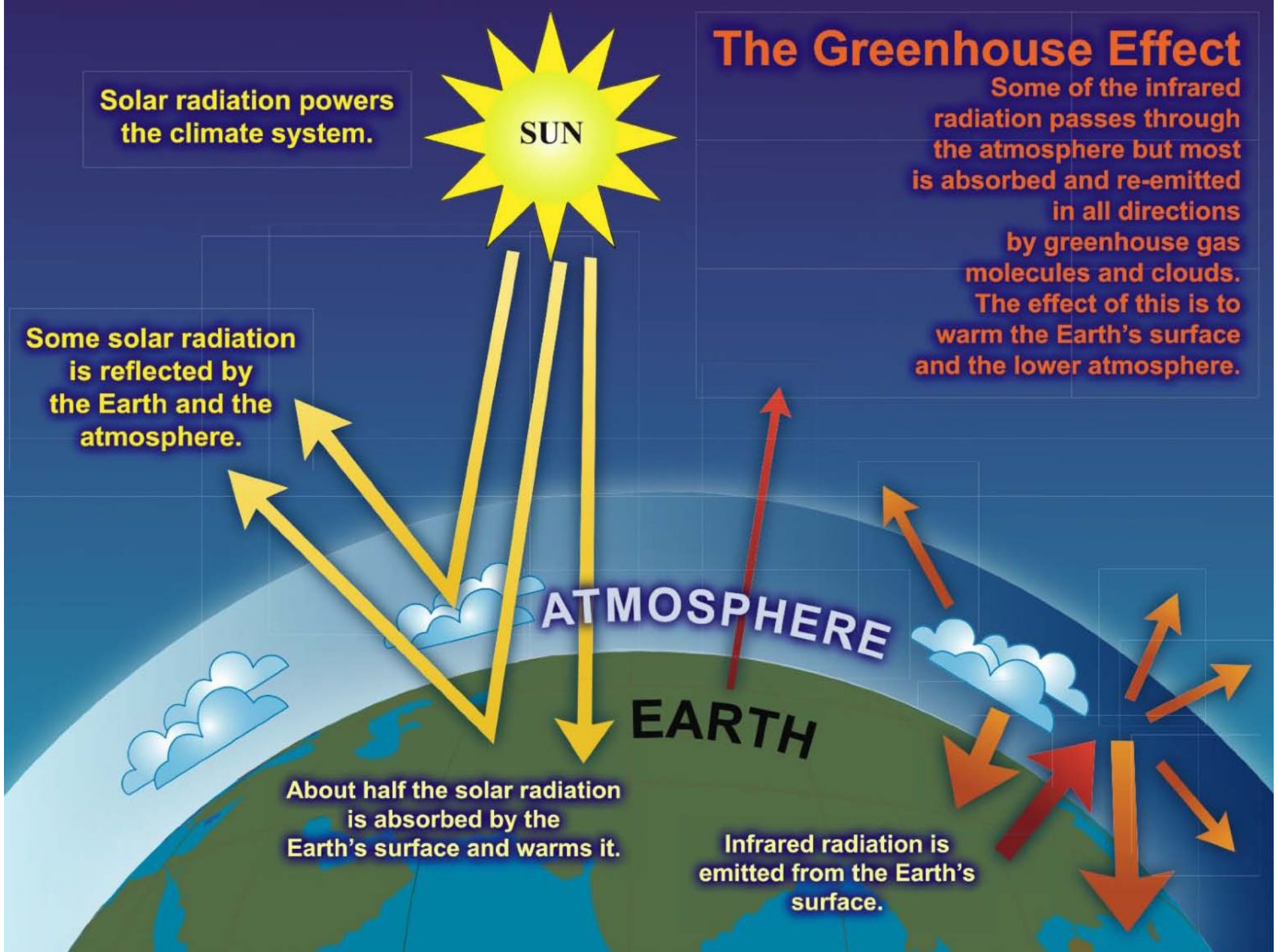
- Carbon dioxide (CO_2) and water vapor (H_2O) are different!

- They have **many more ways to vibrate** and rotate, so they are very good at absorbing and emitting infrared (heat) radiation



Molecules that have many ways to wiggle are called "Greenhouse" molecules

Absorption spectrum of CO2 was measured by John Tyndall in 1863


The Greenhouse Effect
Some of the infrared radiation passes through the atmosphere but most is absorbed and re-emitted in all directions by greenhouse gas molecules and clouds. The effect of this is to warm the Earth's surface and the lower atmosphere.
Solar radiation powers the climate system.
SUN
Some solar radiation is reflected by the Earth and the atmosphere.
ATMOSPHERE
EARTH
About half the solar radiation is absorbed by the Earth's surface and warms it.
Infrared radiation is emitted from the Earth's surface.

1856 – Eunice Foote

Our Roll of Honor

Containing all the

Signatures to the "Declaration of Sentiments"

Set Forth by the First

Woman's Rights Convention,

held at

Seneca Falls, New York

July 19-20, 1848

LADIES:

Lucretia Mott
Harriet Cady Eaton
Margaret Pryor
Elizabeth Cady Stanton
Eunice Newton Foote
Mary Ann M'Clintock
Margaret Schooley
Martha C. Wright
Jane C. Hunt
Amy Post
Catherine F. Stebbins
Mary Ann Frink
Lydia Mount
Delia Mathews
Catherine C. Paine
Elizabeth W. M'Clintock
Malvina Seymour
Phebe Mosher
Catherine Shaw
Deborah Scott
Sarah Hallowell
Mary M'Clintock
Mary Gilbert

Sophronia Taylor
Cynthia Davis
Hannah Plant
Lucy Jones
Sarah Whitney
Mary H. Hallowell
Elizabeth Conklin
Sally Pitcher
Mary Conklin
Susan Quinn
Mary S. Mirror
Phebe King
Julia Ann Drake
Charlotte Woodward
Martha Underhill
Dorothy Mathews
Eunice Barker
Sarah R. Woods
Lydia Gild
Sarah Hoffman
Elizabeth Leslie
Martha Ridley

Rachel D. Bonnel
Betsey Tewksbury
Rhoda Palmer
Margaret Jenkins
Cynthia
Mary M.
P. A. C
Susan R
Rebecca
Sarah A
Mary E.
Lucy Sp
Lovina
Sarah S
Eliza Ma
Maria E
Elizabet
Caroline
Ann Por
Experien
Antoinet
Hannah
Sarah S

GENTLEMEN:

Richard P. Hunt
Samuel D. Tillman
Justin Williams
Elisha Foote
Frederick Douglass
Henry W. Seymour
Henry Seymour
David Spalding
William G. Barker
Elias J. Doty
John Jones

William S. Dell
James Mott
William Burroughs
Robert Smallbridge
Jacob Mathews
Charles L. Hoskins
Thomas M'Clintock
Saron Phillips
Jacob P. Chamberlain
Jonathan Metcalf

Nathan
S. E. W
Edward
George
Joel Bur
Isaac Va
Thomas
E. W. C
Stephen
Henry F
Azaliah

CIRCUMSTANCES

Affecting the Heat of the Sun's Rays.

BY MRS. EUNICE FOOTE.

Read before the American Association for the Advancement of Science,

AUGUST 23, 1856.

Thirdly. The highest effect of the sun's rays I have found to be in carbonic acid gas.

One of the receivers was filled with it, the other with common air, and the result was as follows:

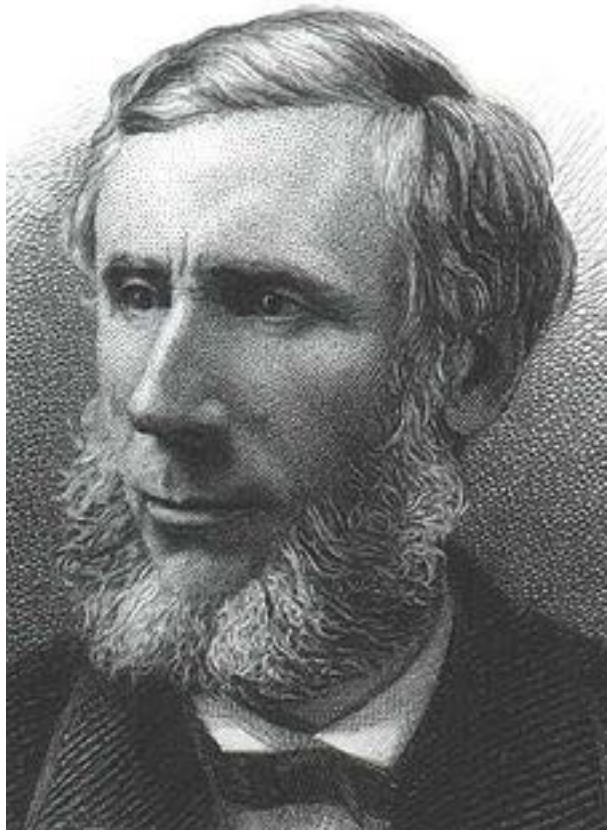
In Common Air.		In Carbonic Acid Gas.	
In shade.	In sun.	In shade.	In sun.
80	90	80	90
81	94	84	100
80	99	84	110
81	100	85	120

The receiver containing the gas became itself much heated—very sensibly more so than the other—and on being removed, it was many times as long in cooling.

An atmosphere of that gas would give to our earth a high temperature; and if as some suppose, at one period of its history the air had mixed with it a larger proportion than at present, an increased temperature from its own action as well as from increased weight must have necessarily resulted.

On comparing the sun's heat in different gases, I found it to be in hydrogen gas, 104°; in common air, 106°; in oxygen gas, 108°; and in carbonic acid gas, 125°.

Common Sense

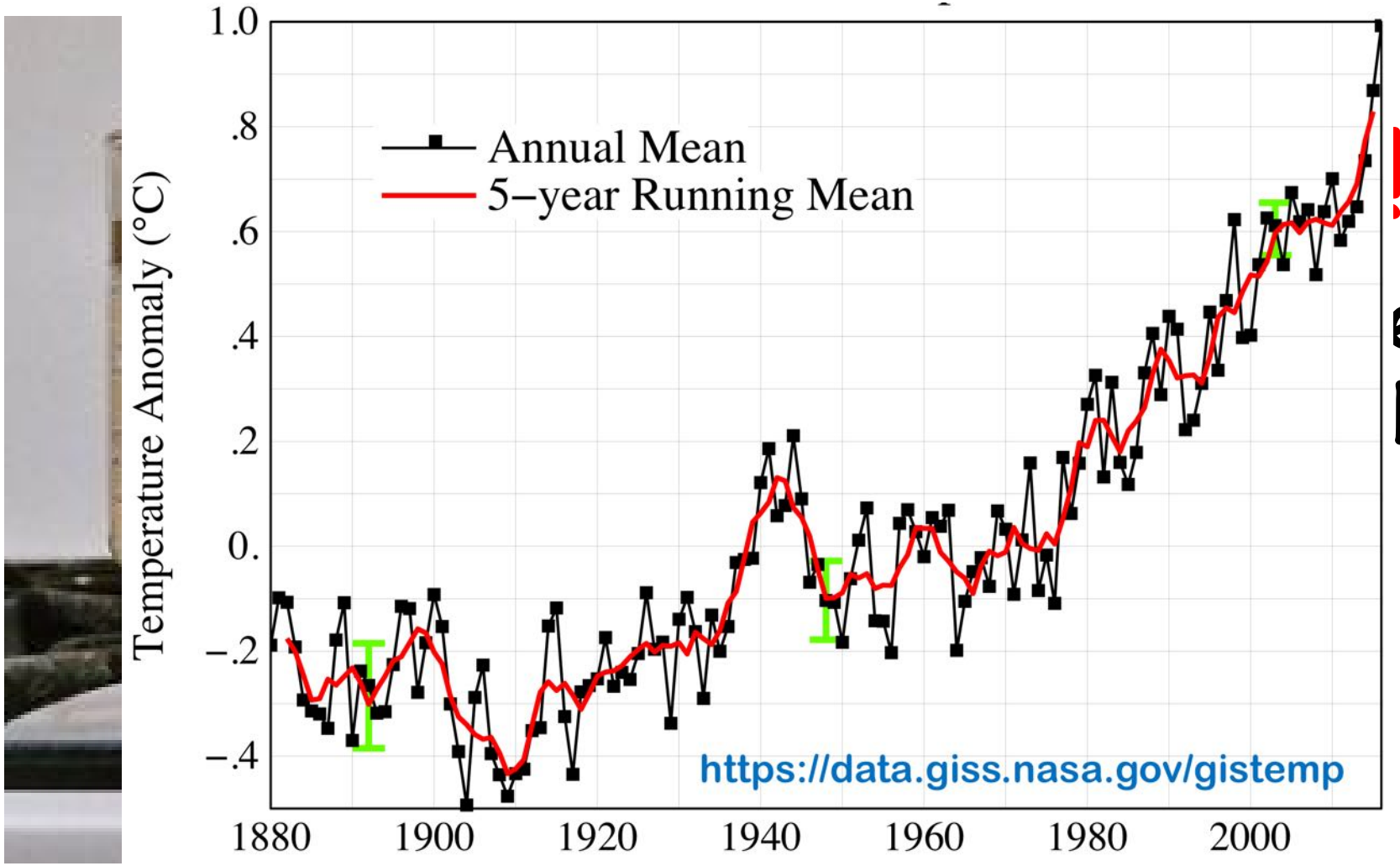


John Tyndall, January 1863

- Doubling CO_2 would add 4 watts to every square meter of the Earth, 24/7/365
- Doing that would make the surface warmer
- This was known before light bulbs were invented!

Common Myth #1

"Scientists expect a warmer future
because it's been warming up recently"



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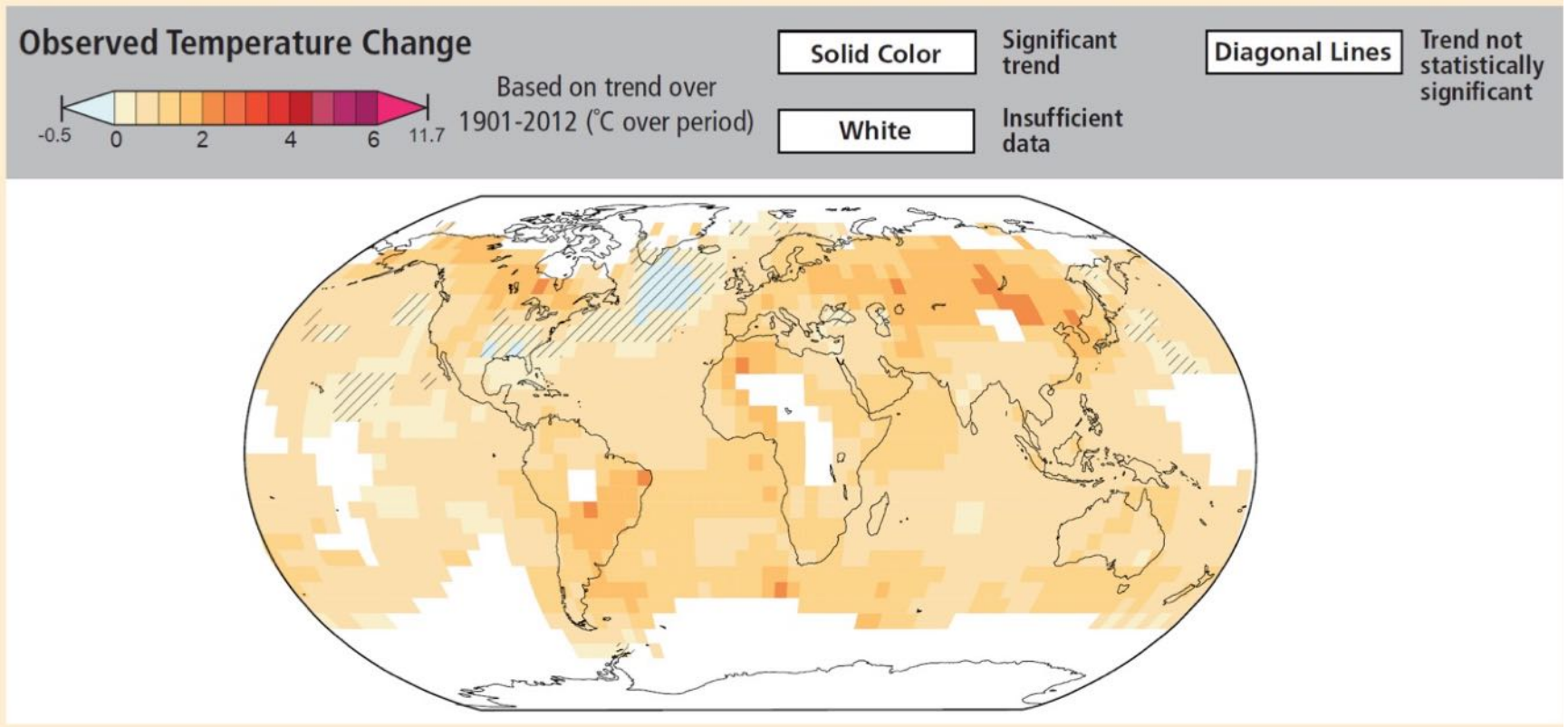
to

1. Simple

2. Serious

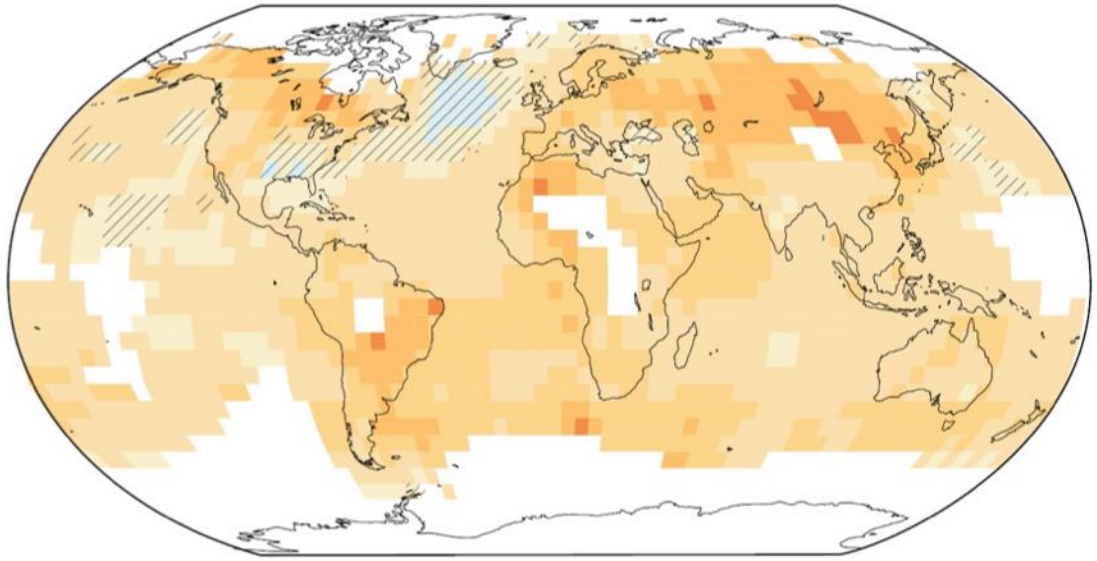
3. Solvable

Recent Changes

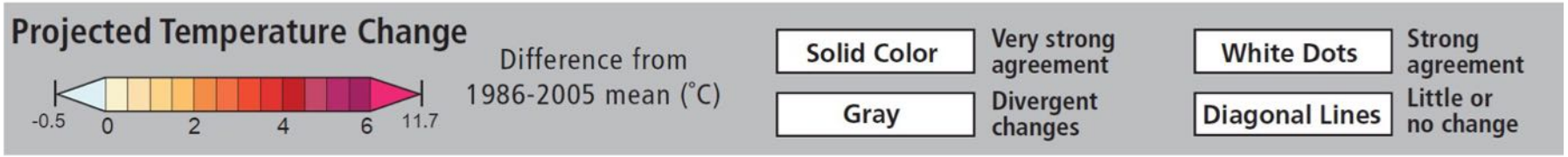


- More warming on land than ocean
- Warming since 1900 less than 1 C over ocean
- Warming since 1900 around 1 C over land

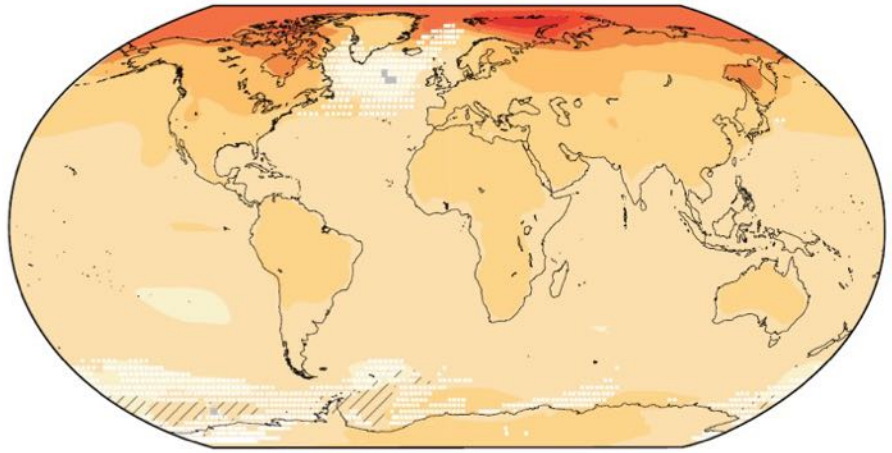
Observed Change 1901-2012



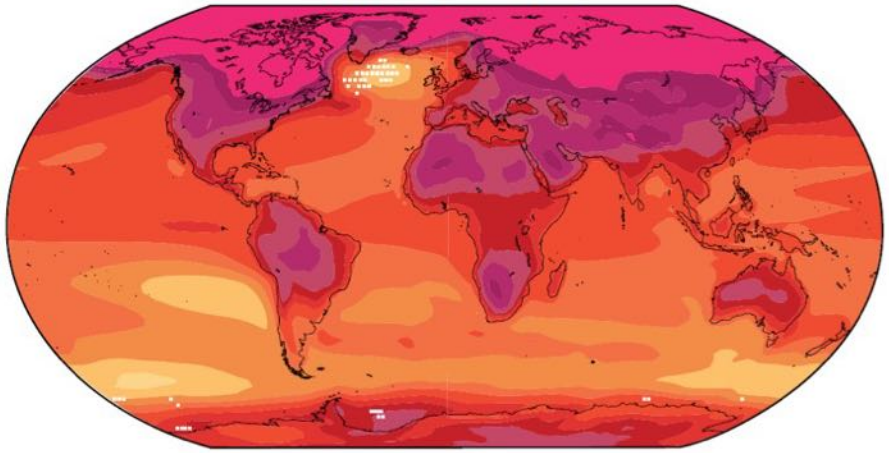
Big Choices



RCP2.6 2081 - 2100

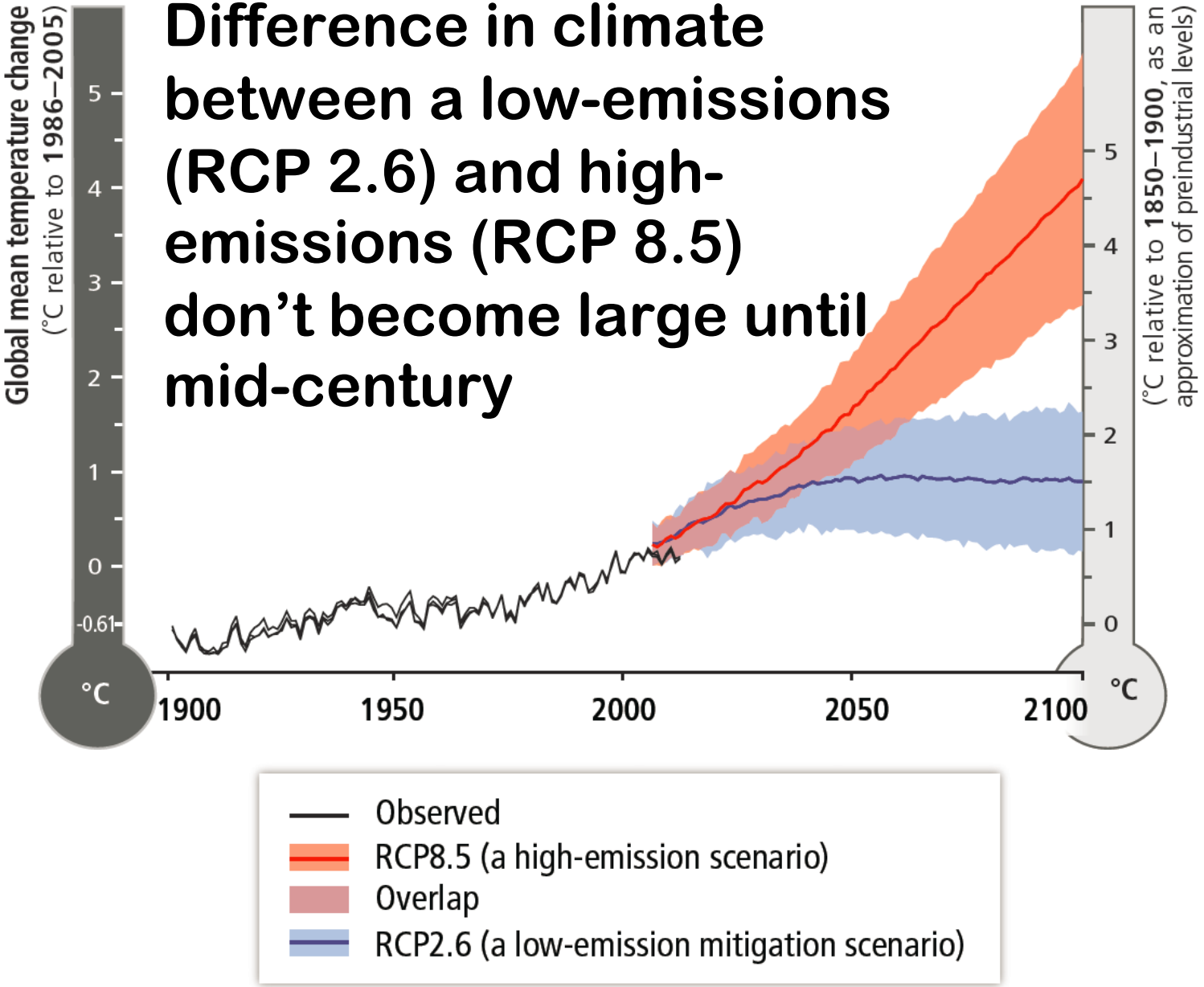


RCP8.5 2081 - 2100



Past and Future

Difference in climate between a low-emissions (RCP 2.6) and high-emissions (RCP 8.5) don't become large until mid-century



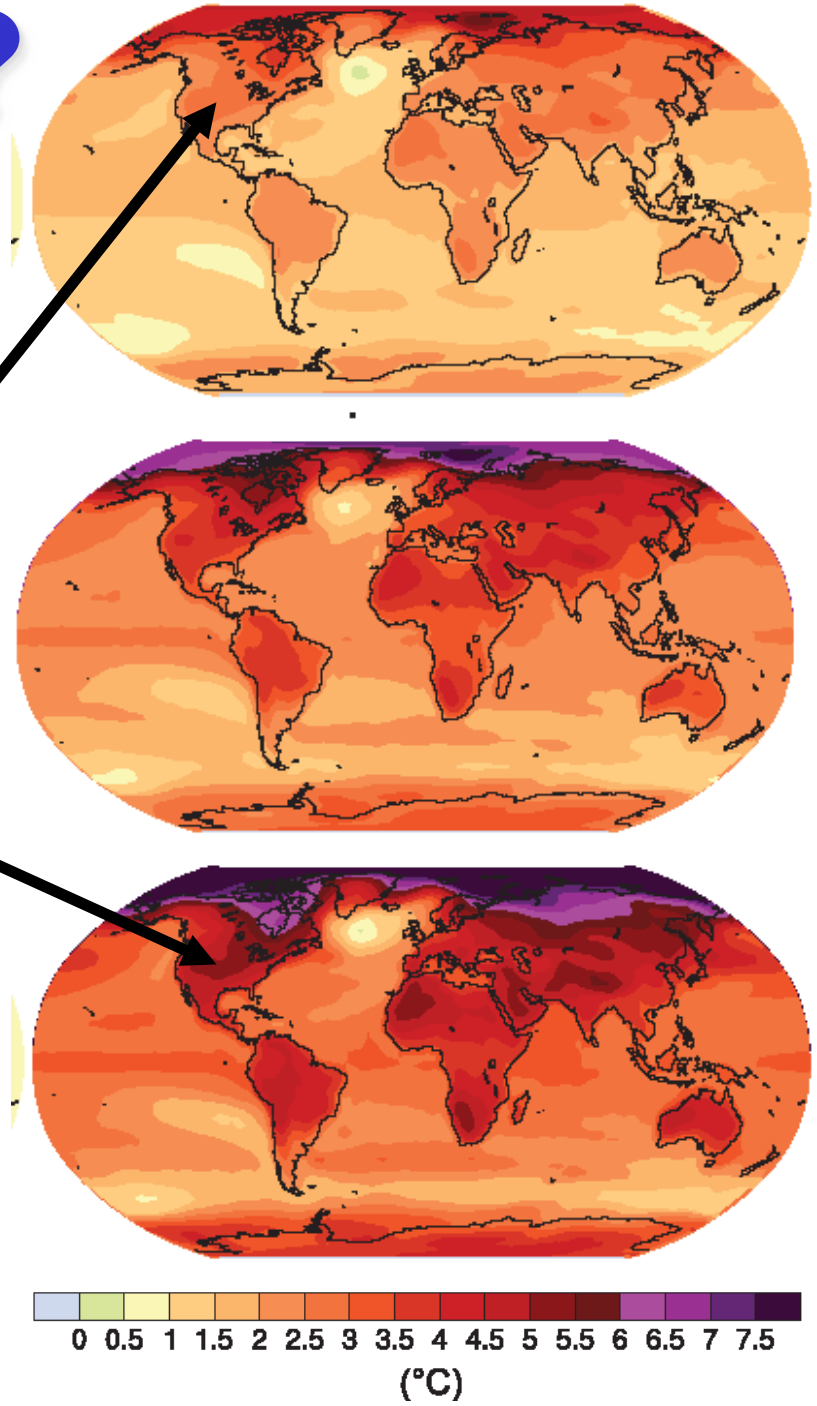
How much warmer?

- Land vs Oceans !
- North vs South
- Snowy vs not

- We warm up more
- 3 °C to 6 °C
- 5 °F to 10 °F

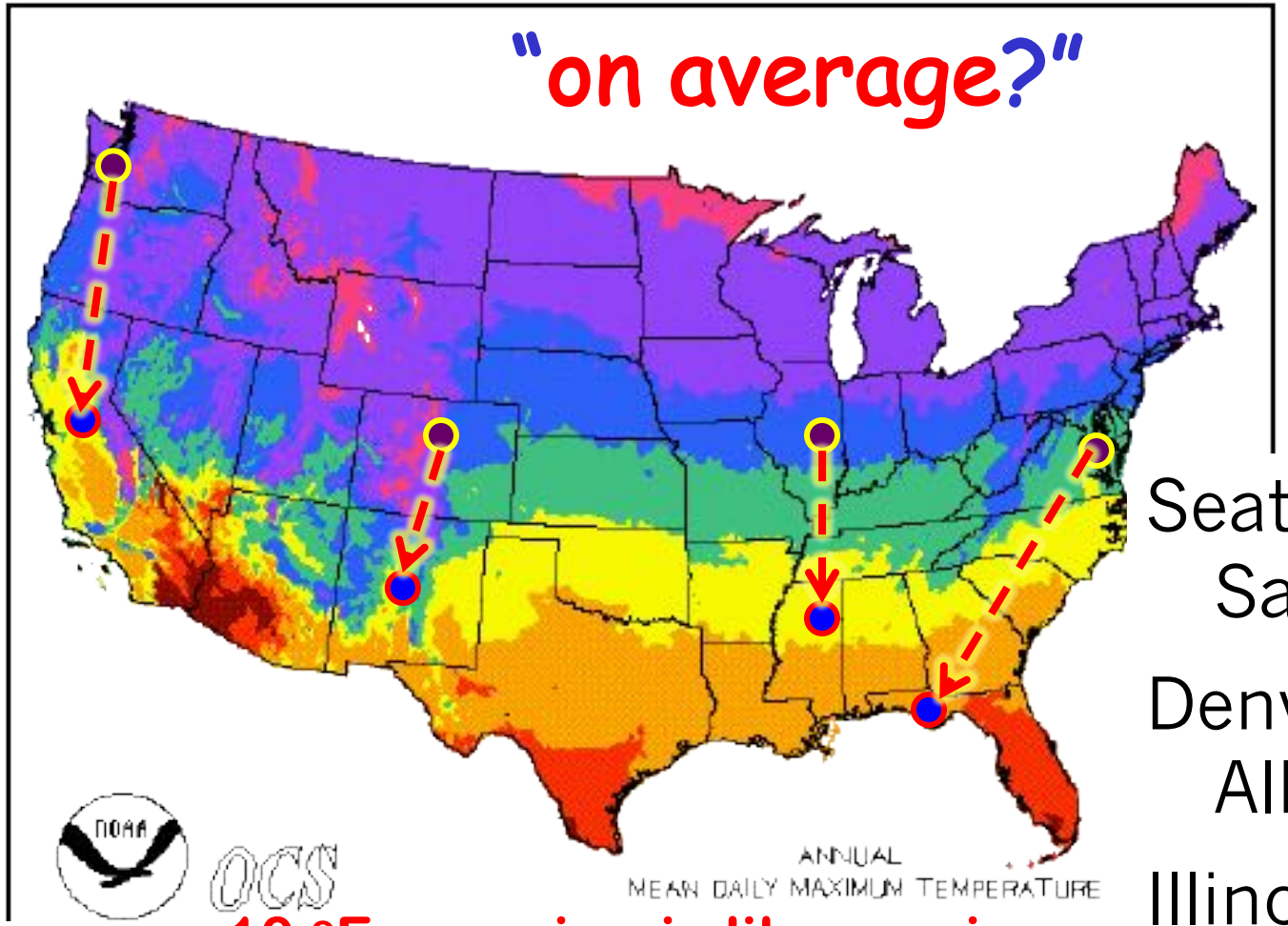
5 °F

10 °F



Where is it 10º F Warmer

"on average?"



10 ºF warming is like moving 600 – 800 miles South!

Water? *Crops?*

Real Estate? *Health?*

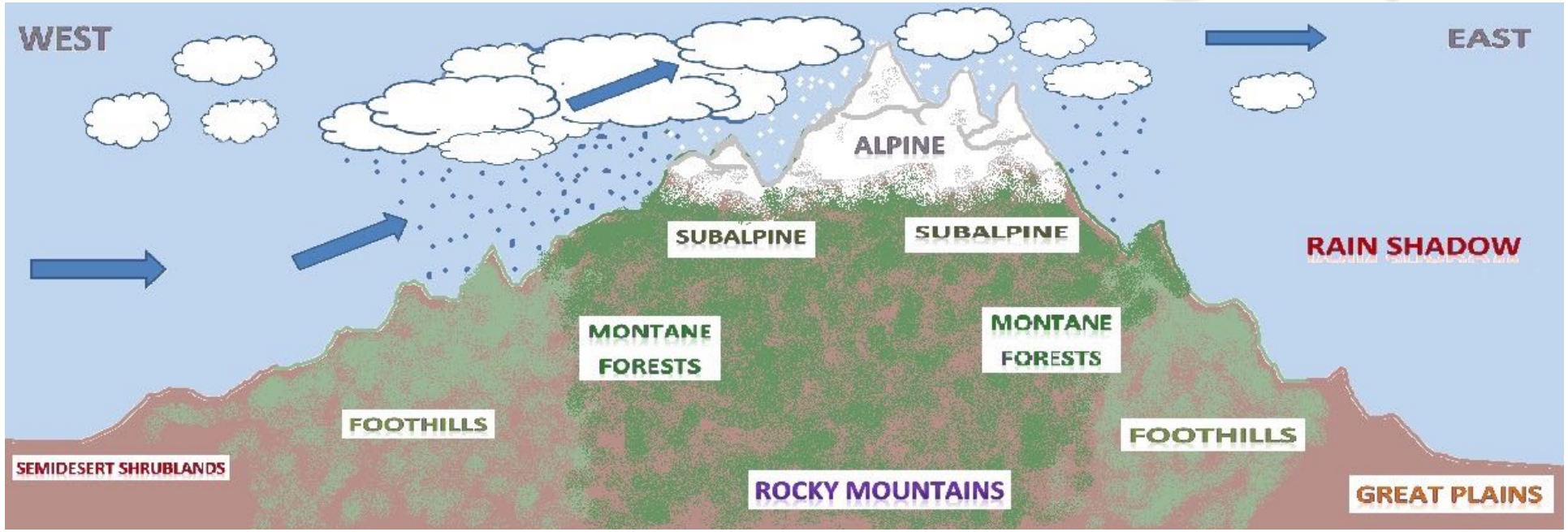
Seattle ➔ Sacramento

Denver ➔ Albuquerque

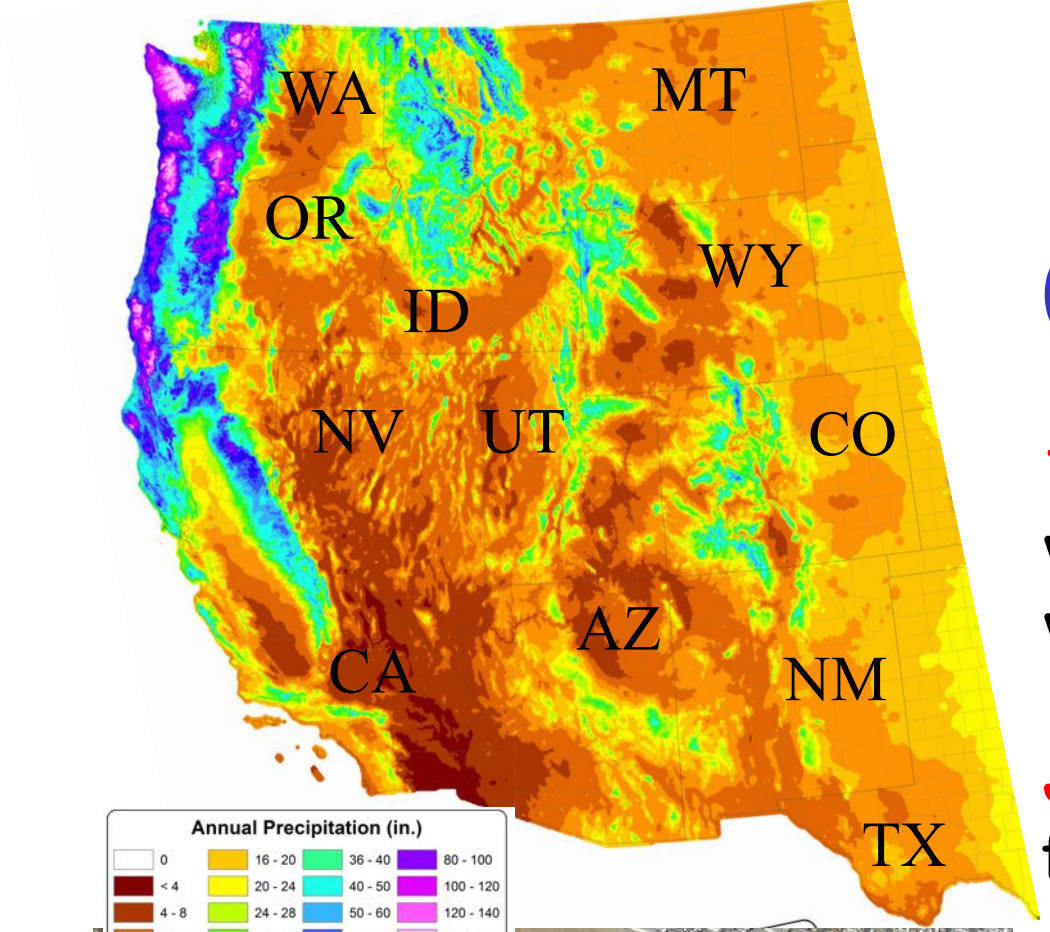
Illinois ➔ Mississippi

Washington DC ➔ Tallahassee

Zones Marching Up



- In Colorado, temps drop about 10 F for each 3000 feet of elevation
  - Denver -> Estes Park
  - Estes Park -> Trail Ridge Road
- But in 100 years instead of 100 centuries!



A Region On the Edge

75 million people in the western US live in a region with **marginal precipitation**

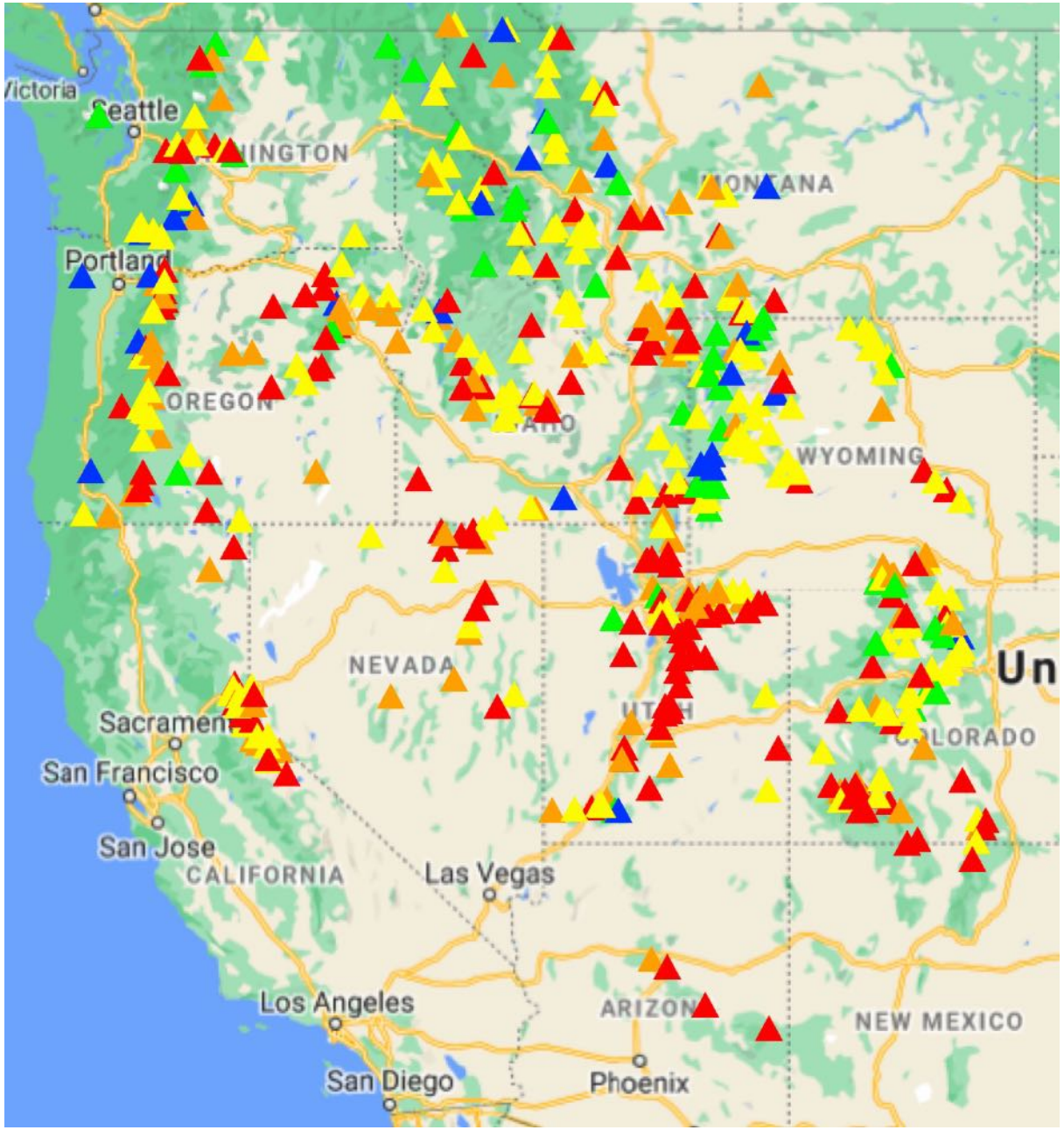
Just enough snow to support forests and reservoirs

Just enough irrigation water to support farming

Just enough **water for cities and towns**

Our Water Supply

Loss of Mountain Spring Snowpack



Declining Snowpack

40 years of daily snow records from 549 stations across the western USA

Station Color Key:

Red: Decline of more than 50%

Orange: Decline between 20% & 50%

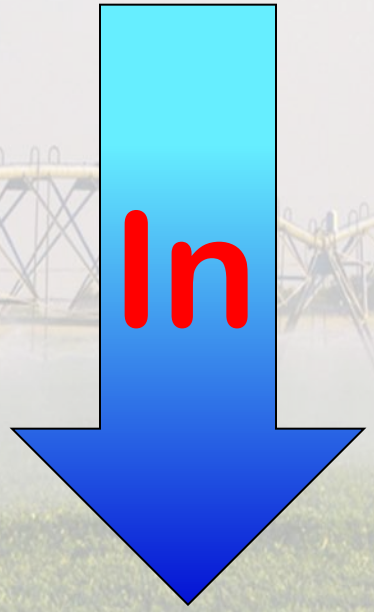
Yellow: Nearly steady over 40 years

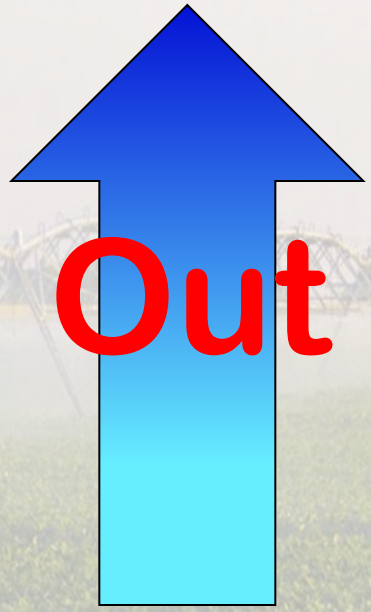
Green: Increase between 20% & 50%

Blue: Increase more than 50%

Water Budgets

Evaporative demand increases w/ temperature





Drought is the *running sum* of water out minus water in

Droughts Past & Future

Medieval Megadroughts

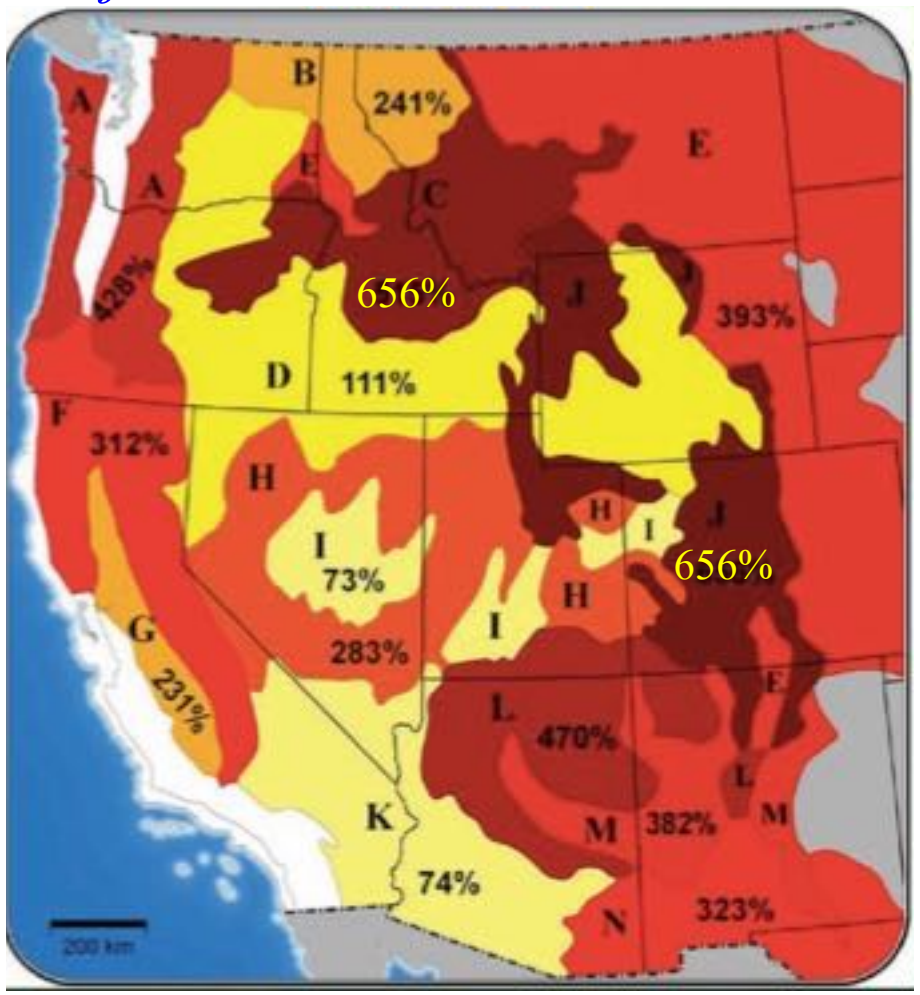
Climate models

Coming droughts *much* worse than any in past 1000 years

Warming Promotes Wildfire

1. Warmer air increases **evaporative demand** on forests
2. Longer **warm season** depletes soil moisture
3. More frequent extremely **hot, dry, windy days** when fires are uncontrollable

Projected Increase in Area Burned

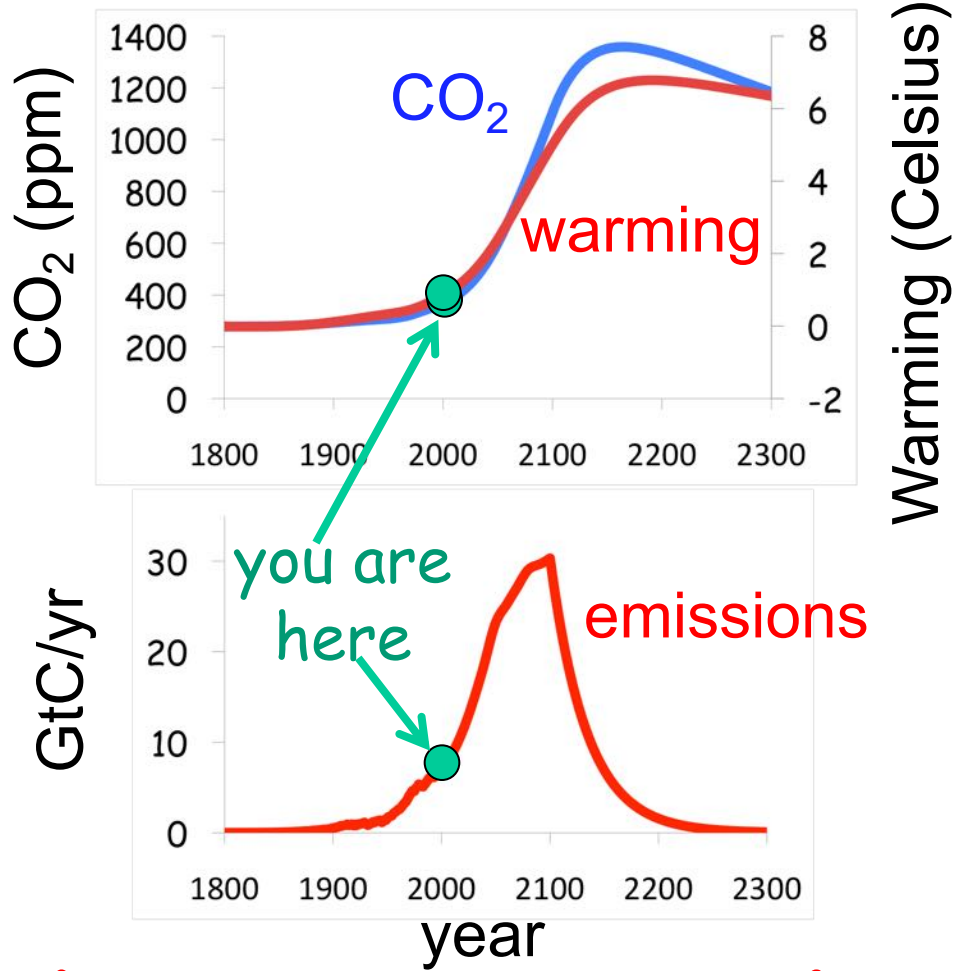


NRC 2011

Common Myth #2

"When we reduce or stop burning fossil fuel, CO_2 will go away and things will go back to normal"

- If China, India, & Africa industrialize with coal, CO_2 will rise to **4x preindustrial**
- Extra CO_2 will last for **thousands of years after coal is gone**



Thermostat only turns one way!

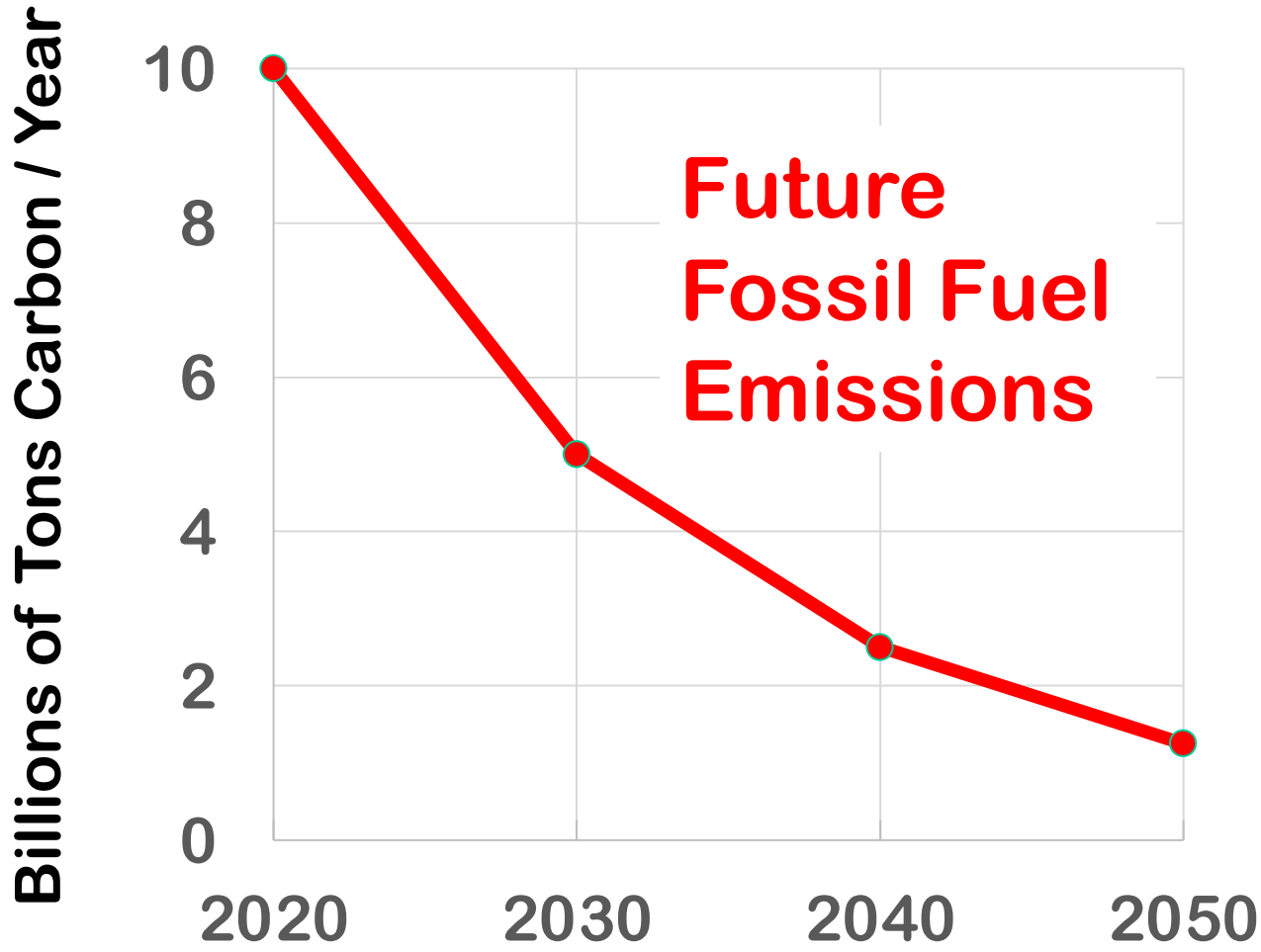
1. Simple

2. Serious

3. Solvable


Stop setting
stuff on fire!

Like Moore's Law



- To limit warming to 2 C, emissions have to fall 50% each decade starting now!
- This will be really hard!

Rockstrom et al (2017)
A roadmap for rapid decarbonization
Science 24 Mar 2017:
355, 1269-1271
DOI: 10.1126/science.aah3443

How Much Will We Burn?

$$CO_2 \text{ Emitted} = P \times \frac{\$}{P} \times \frac{E}{\$} \times \frac{CO_2}{E}$$

Population $\quad$ $/person $\quad$ energy/$ $\quad$ CO_2 / energy

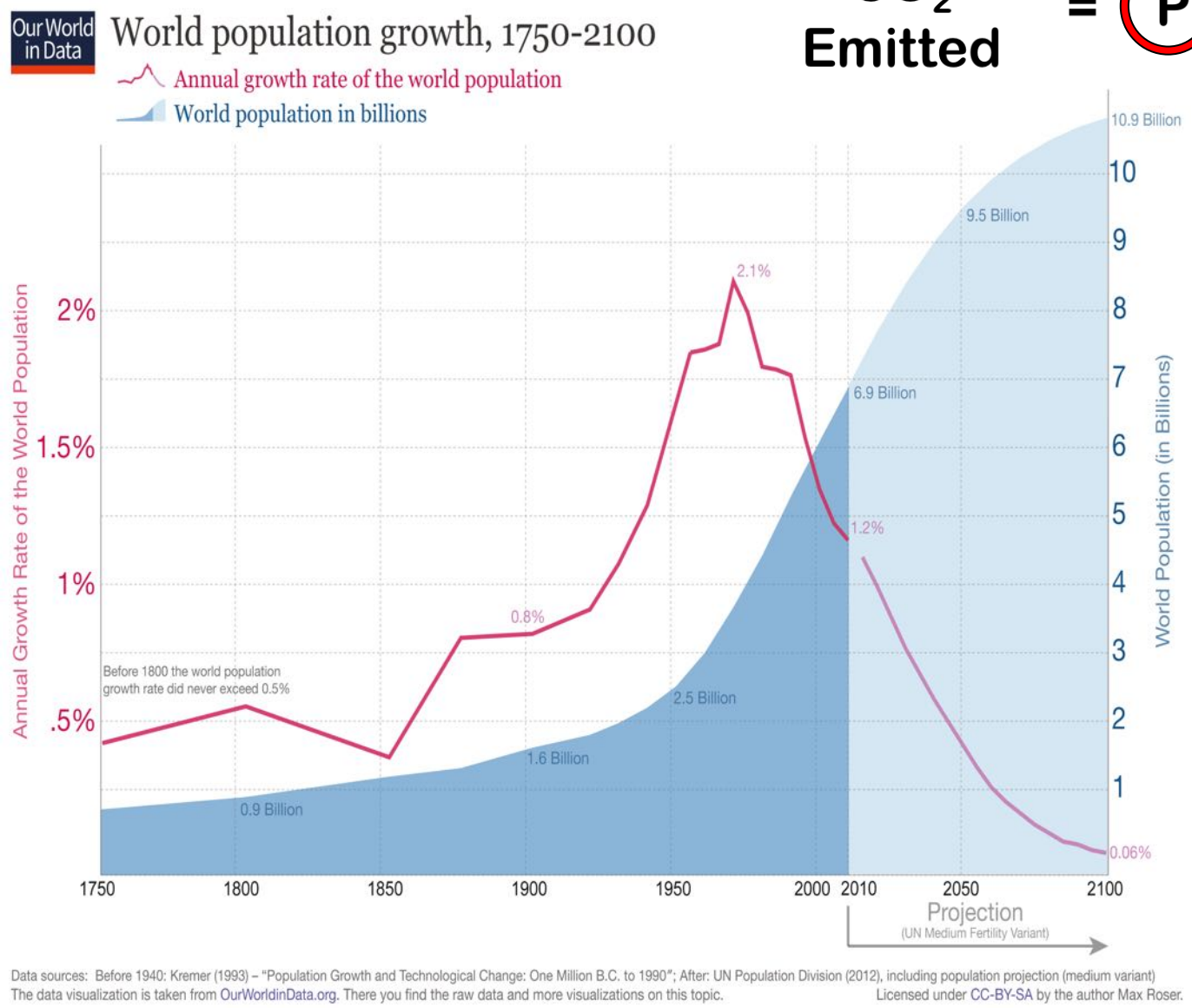
Kaya Identity

Four factors determine fossil fuel emissions:

- Population
- Economic activity
- Energy efficiency of economy
- Carbon efficiency of energy

World Population

$$CO_2 \text{ Emitted} = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{CO_2}{E}$$

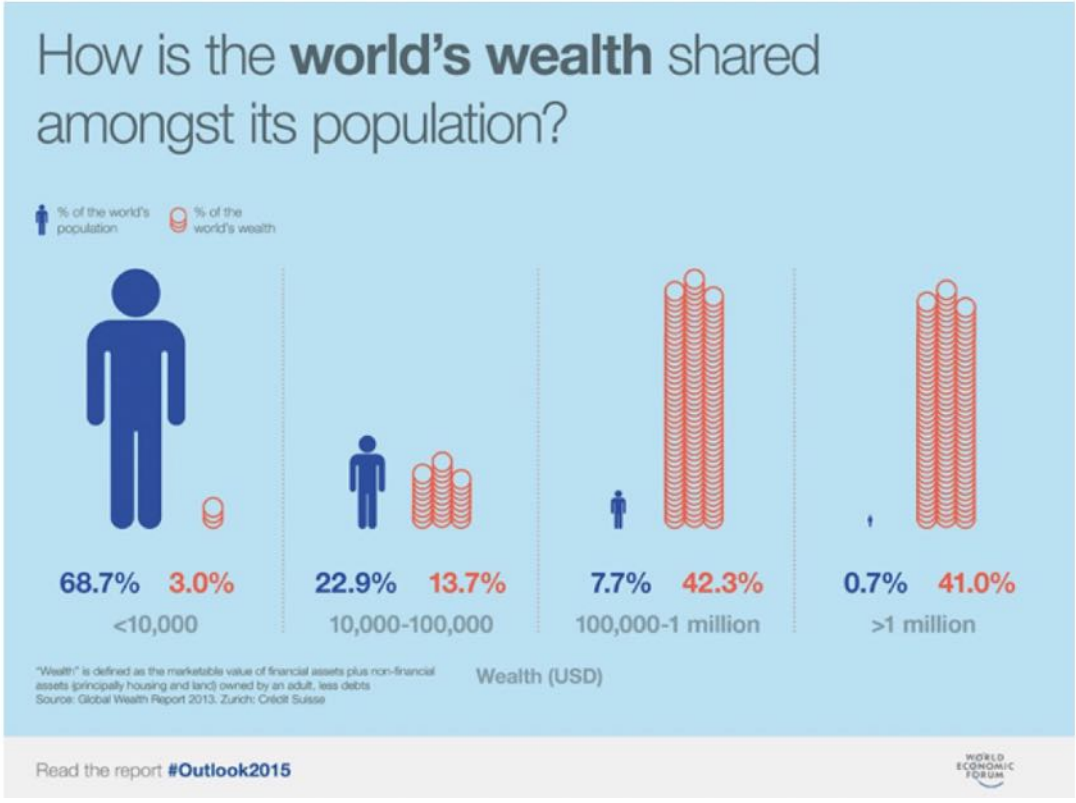


Remember
"*The Population Bomb*"?

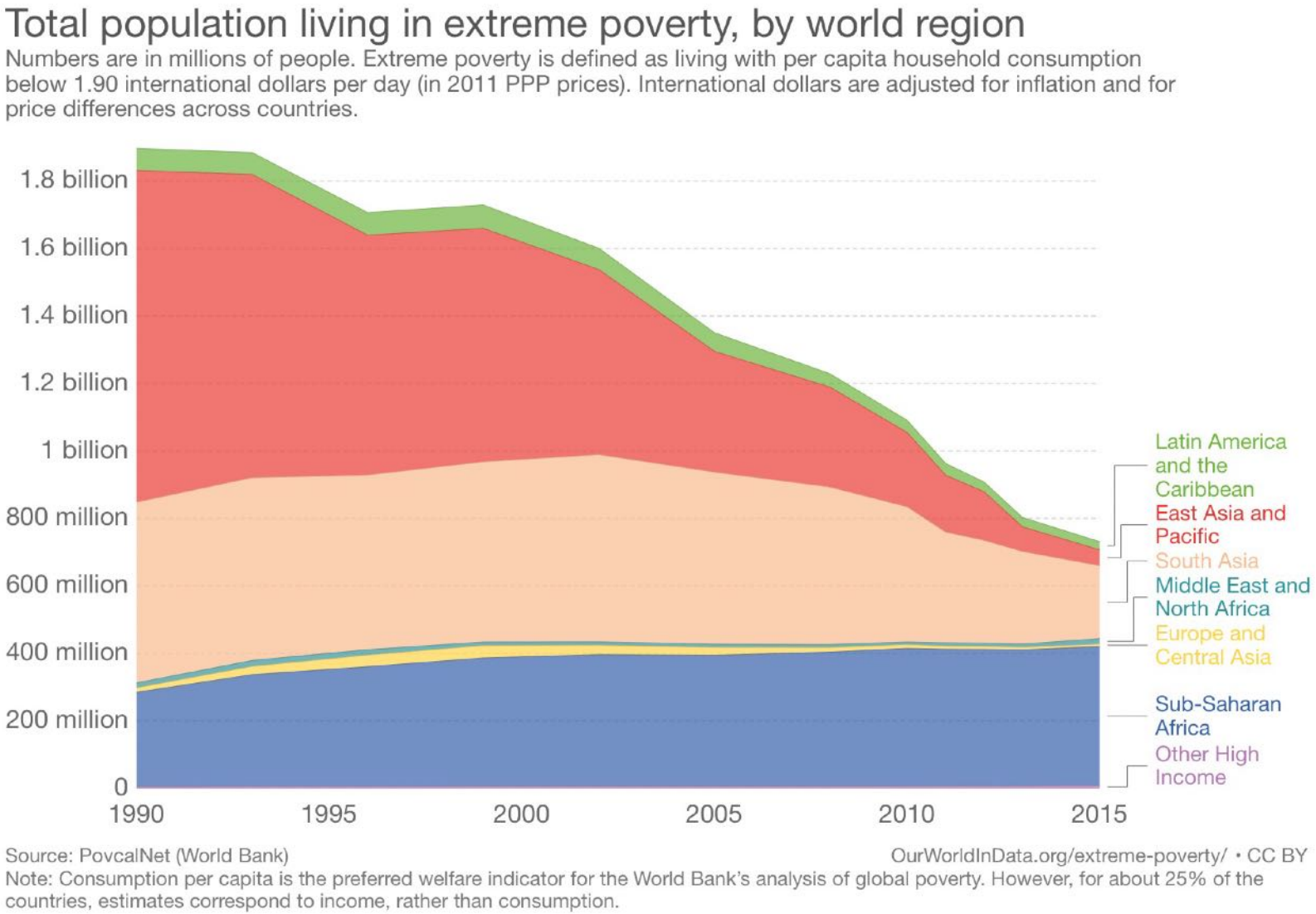
- **World population has more than doubled in my lifetime**
- **It will never double again**
- **Population growth rate is half what it was when I was a teenager**
- **Expected to reach zero population growth by 2100**

UN Sustainable Development Goals

1. Eliminate Extreme Poverty
2. Improve Equality of Opportunity
3. *Don't Destroy the World*



SDG 1: End Extreme Poverty



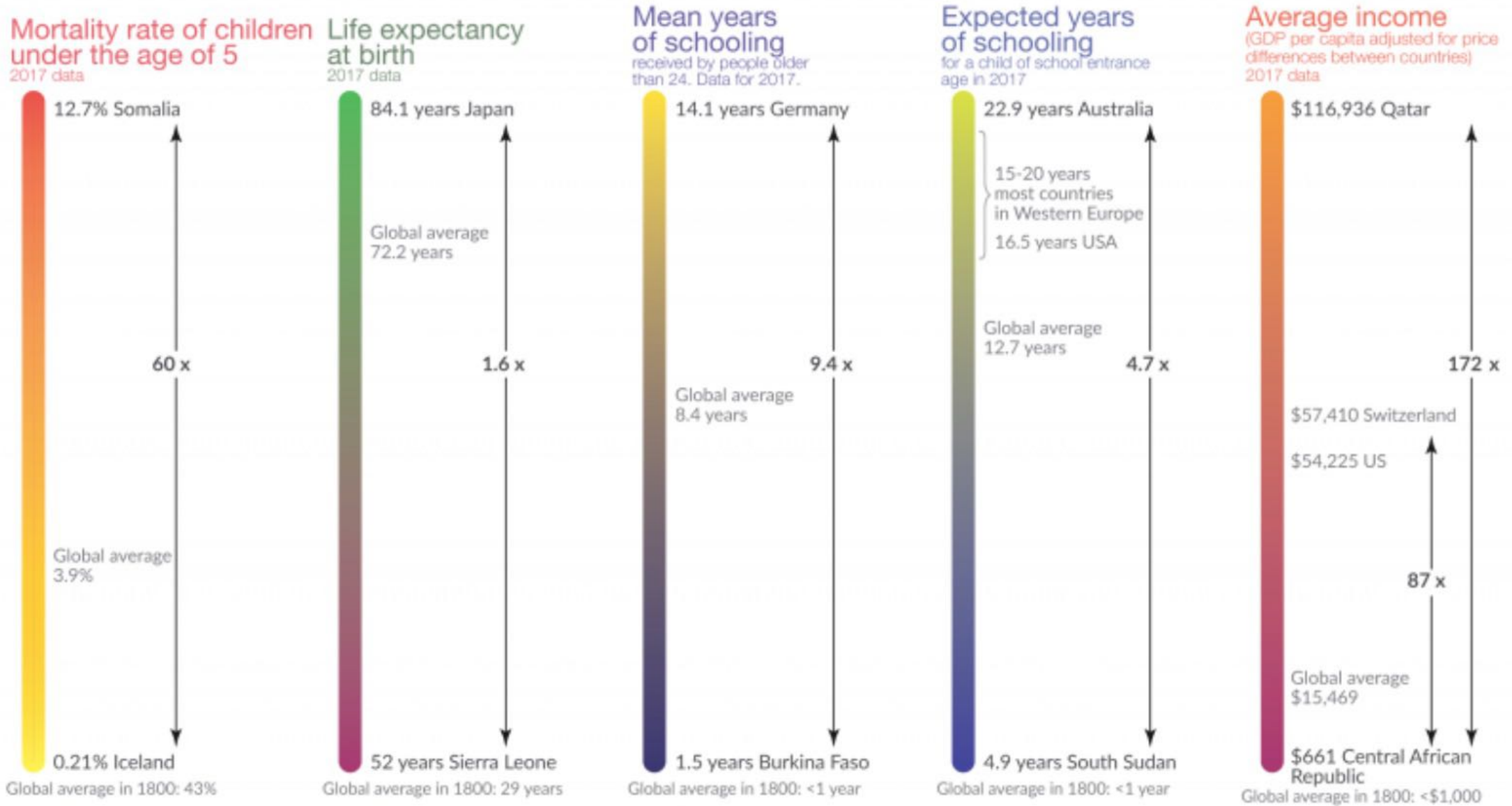
- < $1.90 / day
- 0.9 billion people worldwide
- Cut in half since 1990!
- Almost all in South Asia & Tropical Africa

SDG2

Global inequality in living conditions

between the world's worst-off and best-off countries

Our World in Data



Data source: all data for 2017 is taken from various UN publications. Historical estimates for 1800 are from OECD – How was life? and Our World in Data
This is a visualization from OurWorldinData.org, where you find data and research on the world's largest problems.

Energy Use in Buildings

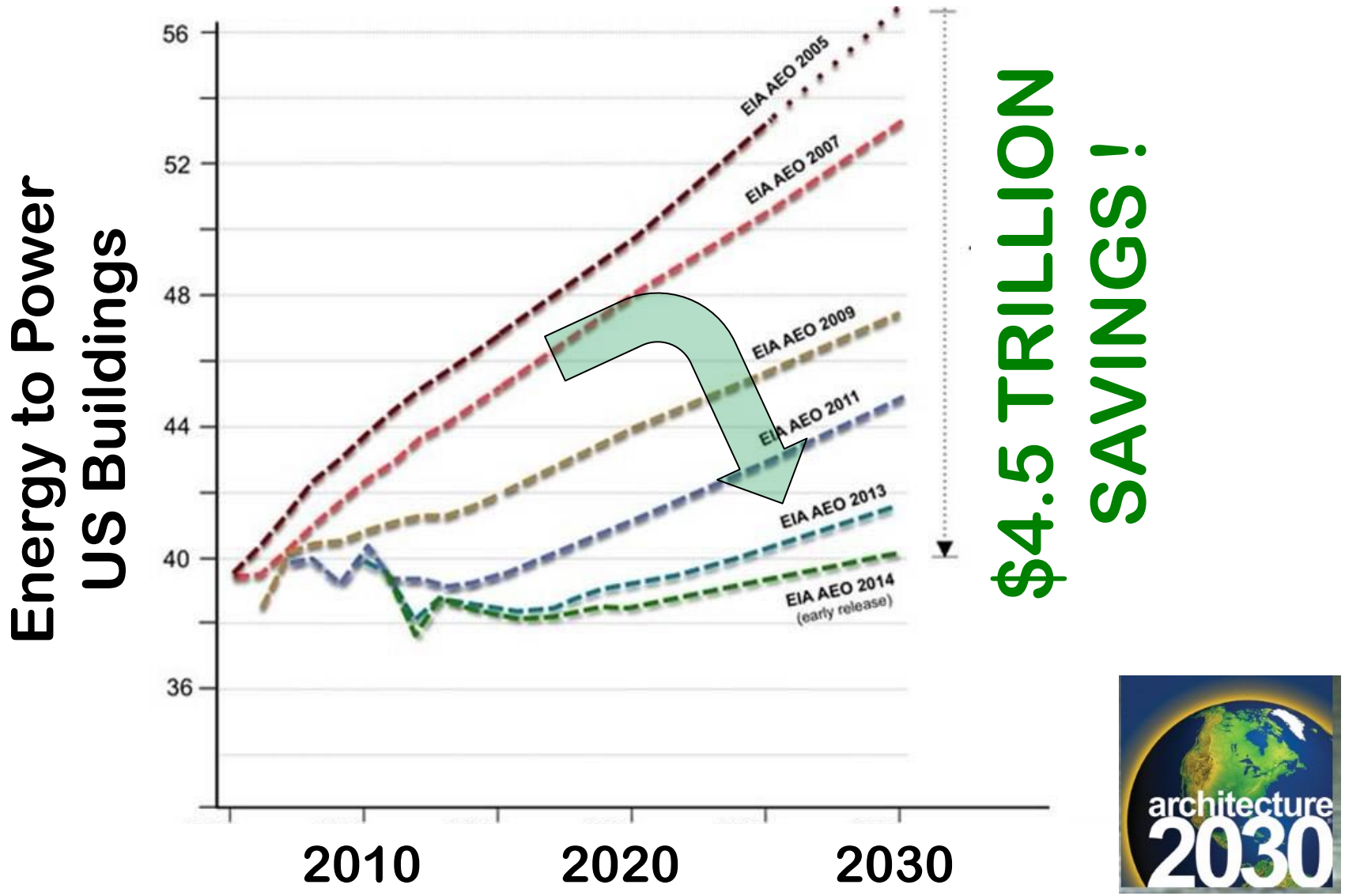
In the developed world, our biggest energy need is constructing and operating buildings!

Almost twice as much as transport or industry!

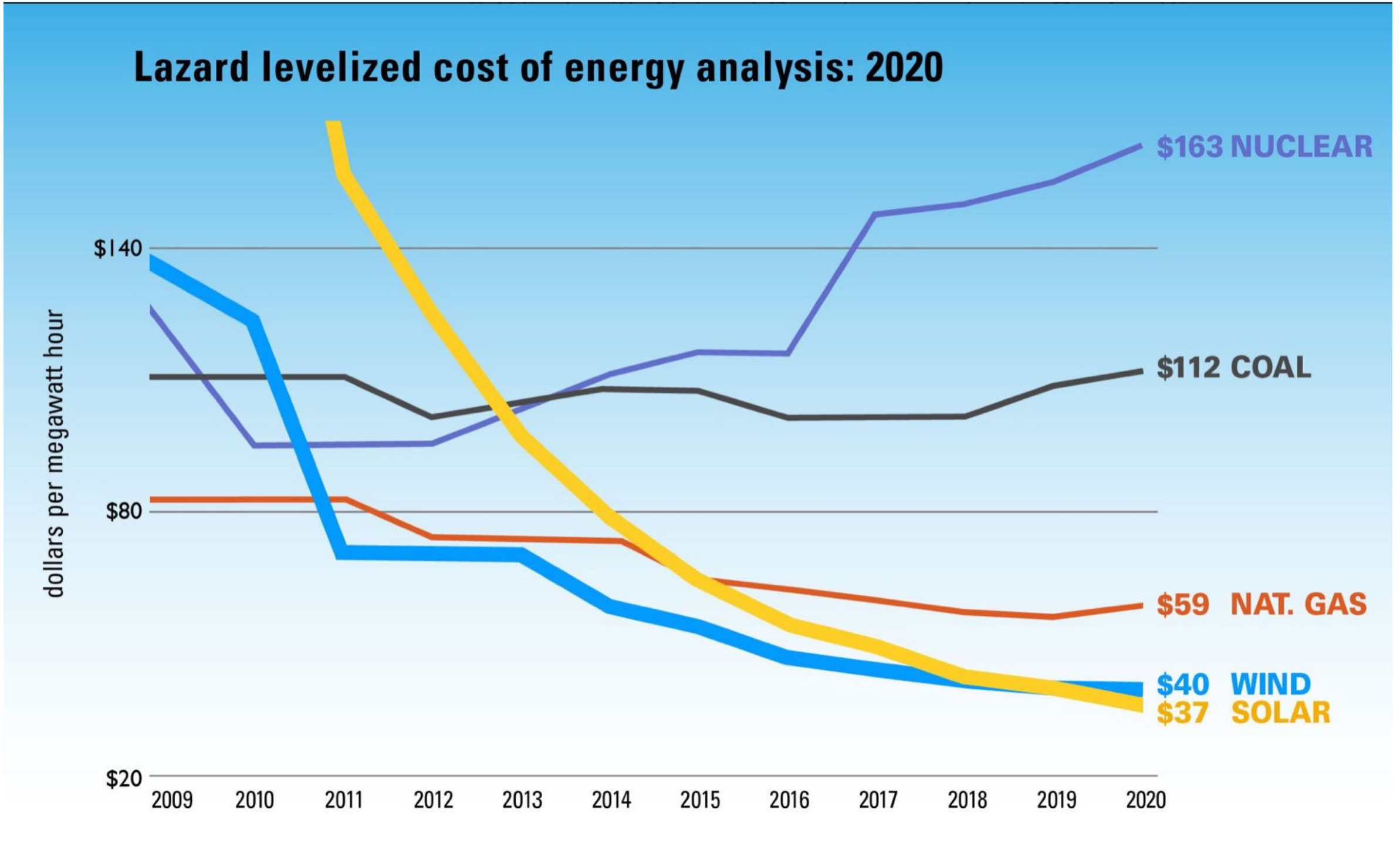
LOTS of room for improvement!

energy / $

Efficient Architects!



architecture 2030


Lazard levelized cost of energy analysis: 2020
dollars per megawatt hour
$140
$80
$20
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
$163 NUCLEAR
$112 COAL
$59 NAT. GAS
$40 WIND
$37 SOLAR

Simple Plan for Deep Decarbonization

1. Clean up electricity
2. Electrify everything

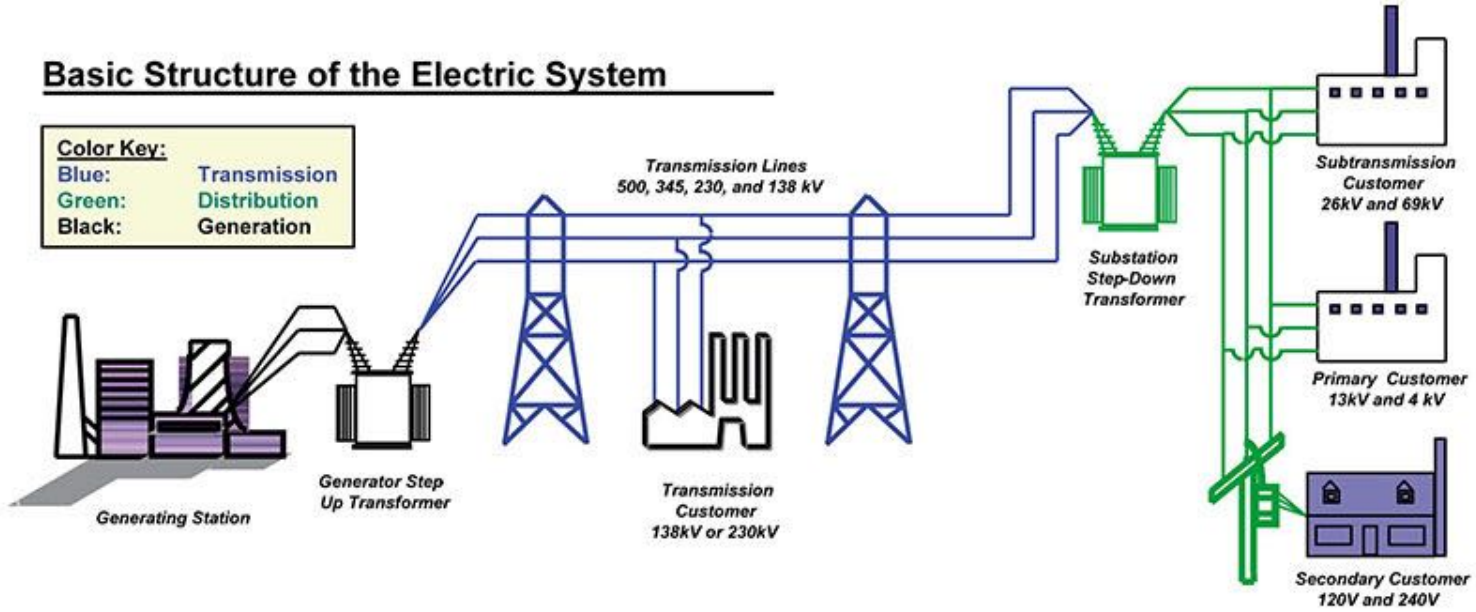
Simple.

See reading

https://www.vox.com/2016/9/19/12938086/electrify-everything

Variable Supply & Demand

- Clean energy is already cheaper than old-fashioned energy



- The real challenge is getting it from where it's made to where and when it's used

Transmission

nature climate change

ARTICLES

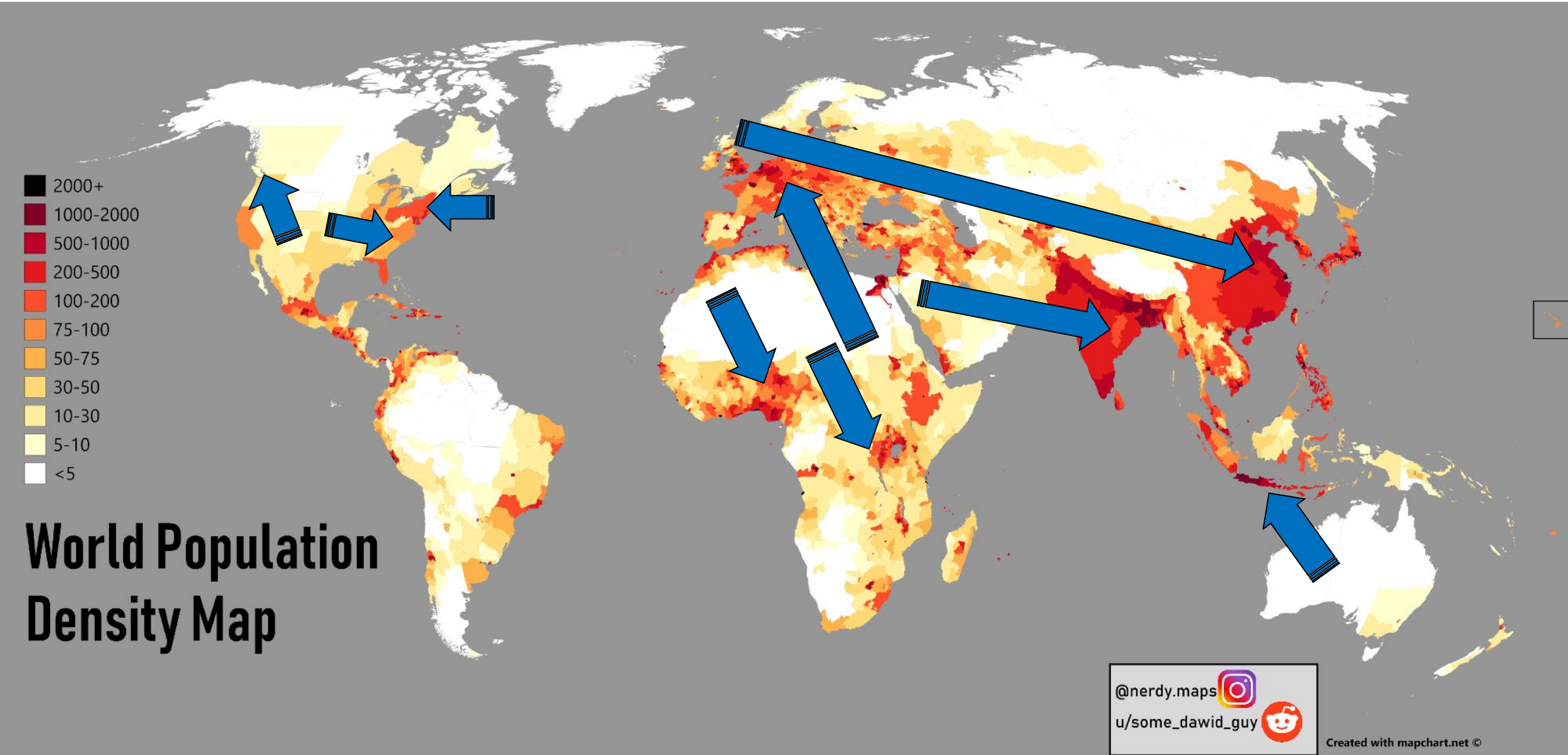
PUBLISHED ONLINE: 25 JANUARY 2016 | DOI: 10.1038/NCLIMATE2921

Future cost-competitive electricity systems and their impact on US CO_2 emissions

Alexander E. MacDonald[1*†], Christopher T. M. Clack[1,2*†], Anneliese Alexander[1,2], Adam Dunbar[1], James Wilczak[1] and Yuanfu Xie[1]

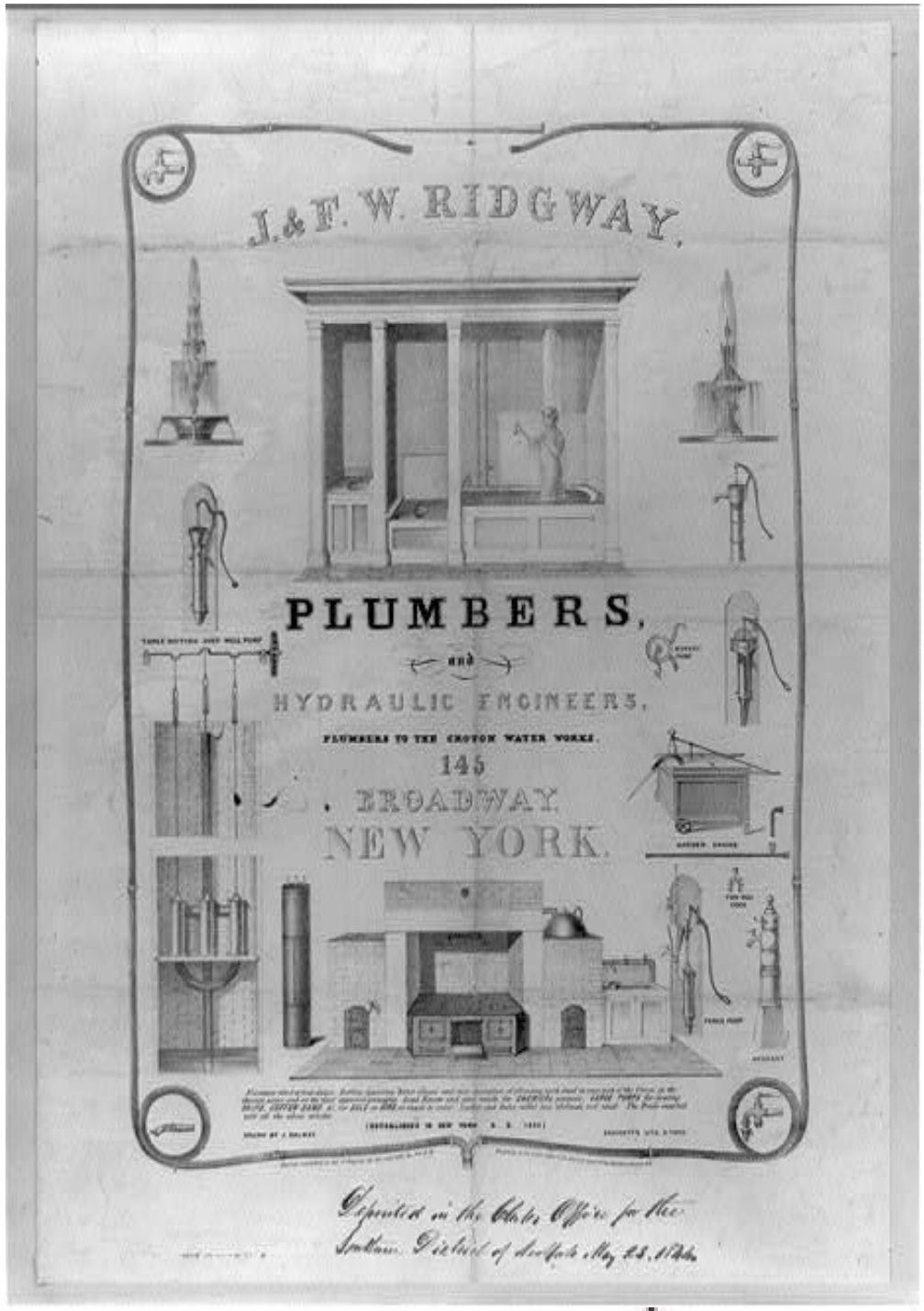
- For the US, build out new generation sources that are cheaper than just OPERATING existing sources
- Connect them across regions w/a new HVDC grid
- Meet 100% of demand 100% of the time
- 80% CO2 emissions reduction in 10 years
- Nobody's electric bills go up

HVDC Transmission!



Global Citizens

- Deep decarbonization is harder than building clean energy in the first place
- Nobody is going to spend $100T building land lines across Africa
- The best & cheapest new energy will be in places without existing stuff



Costs

- Conversion to 100% noncarbon energy will cost about 1% of GDP
- That's about what it cost to retrofit all the world's cities with indoor plumbing a century ago …
- It was *SO* worth it!

Costs in Context

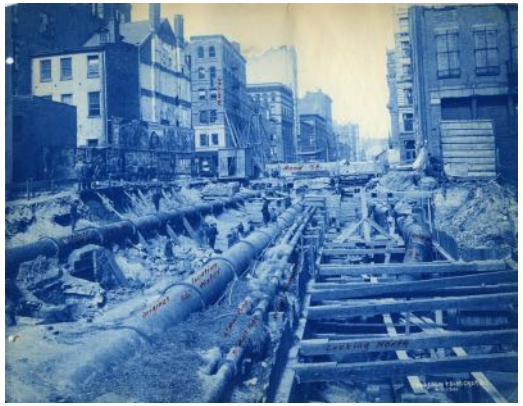
Item	Cost
1% of global GDP	$850 billion per year
New mobile phones (handsets only)	$600 billion per year
US Military (DOD only)	$665 billion per year
New cars & light trucks (90 million/year @ $25,000)	$2,250 billion per year
Roads (64 million miles @ $5M/mile)	$ 320 *TRILLION* total

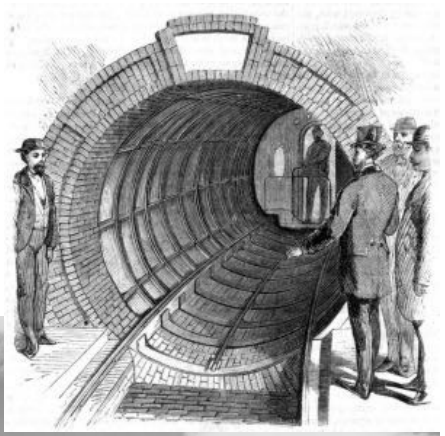
Rescuing civilization will cost a lot of money.

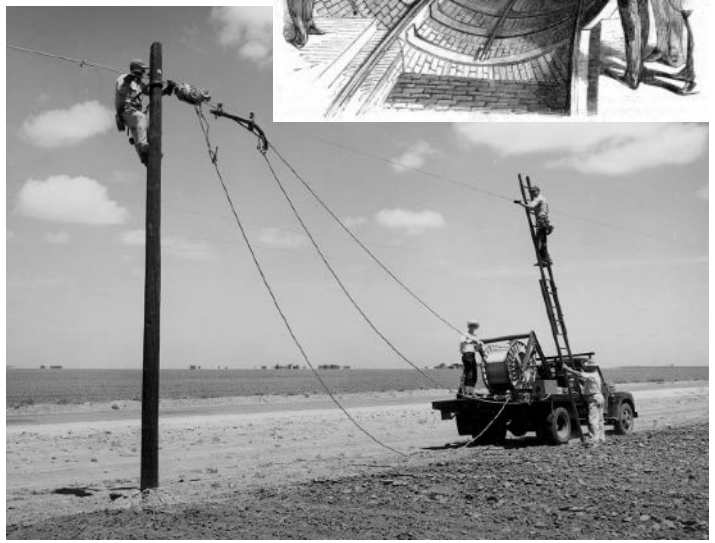
- Probably in the neighborhood of what we spend on brand new phones or the military
- Maybe 1/3 of what we spend on new cars
- *Vastly less* than we have spent on roads!


My Grandparents

My Grandparents' Generation

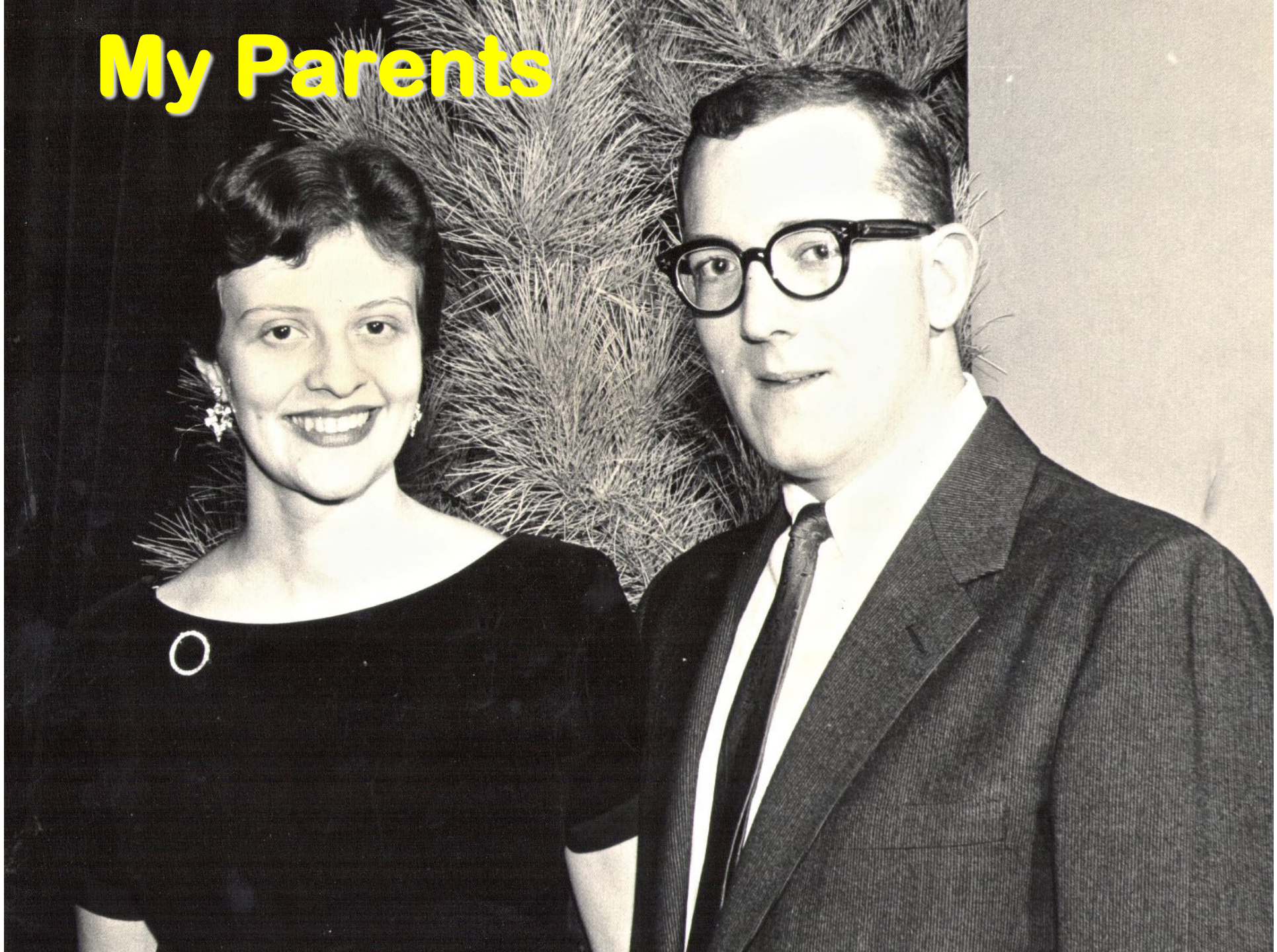






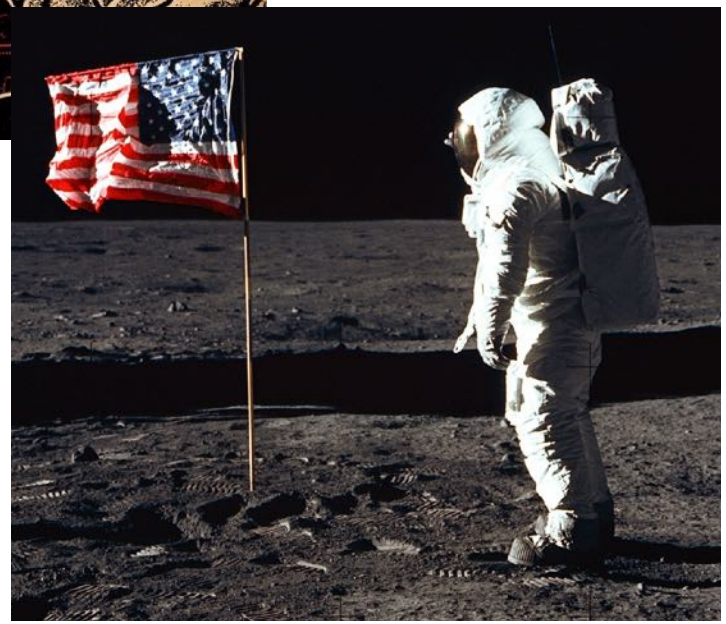
Built subways, sewers,
the electrical grid, defeated the Nazis

My Parents



My Parents' Generation

Ribbon-cutting ceremony along the first portion of Interstate highway to be completed in Wisconsin on September 4, 1958—I-94 in the Waukesha area. (Photo courtesy Wisconsin Historical Society Archives.)



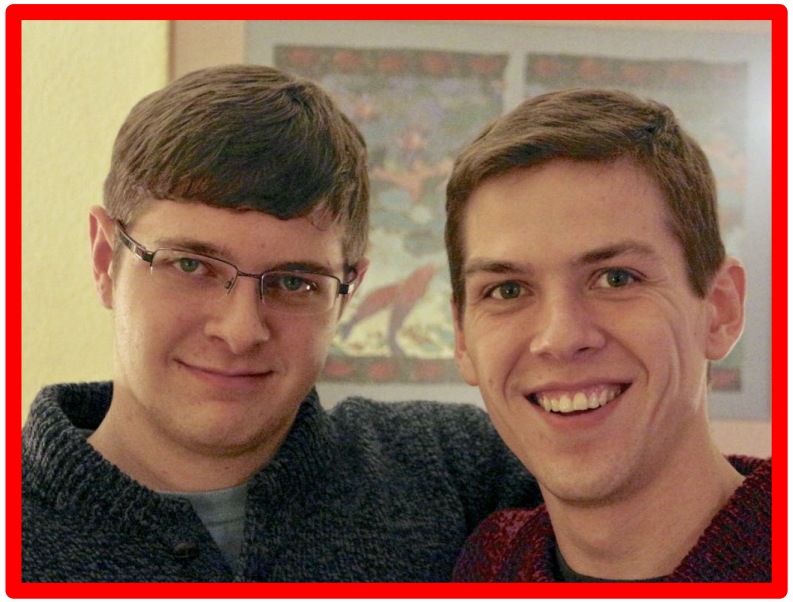
Built the Interstate Highways,
fought the cold war, landed on the Moon!


Jennifer & Me

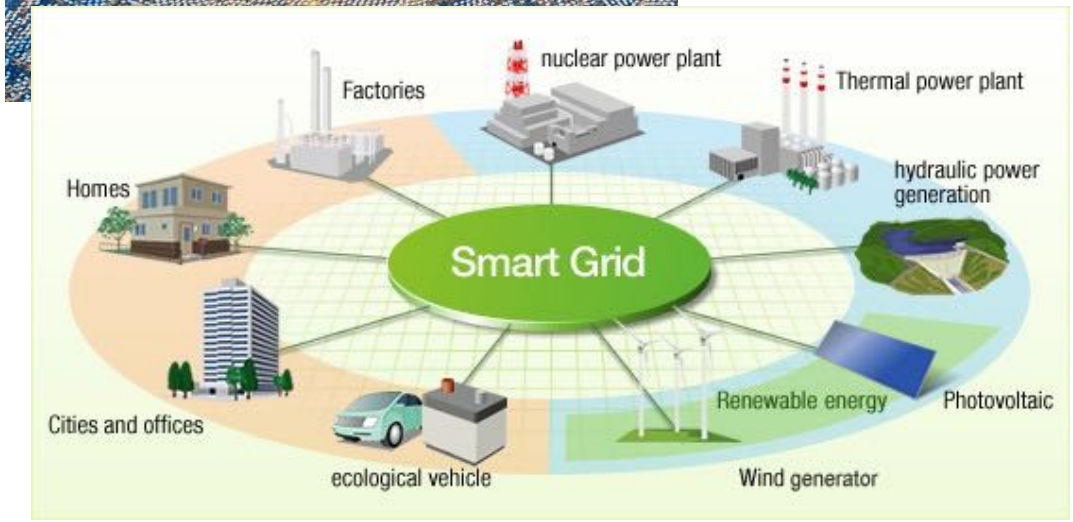
My Generation

Invented the PC, Built the internet,
replaced billions of land-lines with cell phones

My Kids



My Kids' Generation



Will replace the world's energy system *again!*

Choose Your Future

Many people think:

"Our well-being is based on stuff we extract from the ground"

When we stop burning coal, will our descendants shiver in the dark?

Choose Your Future

I prefer:

"We create our well-being through creativity, ingenuity, and hard work"

The future is bright!