Meeting the Climate Challenge: Cheap but Not Easy

Jay Coggins

Department of Applied Economics
University of Minnesota

Canadian Association of the Club of Rome
April 22, 2026

My message on the economics of climate change

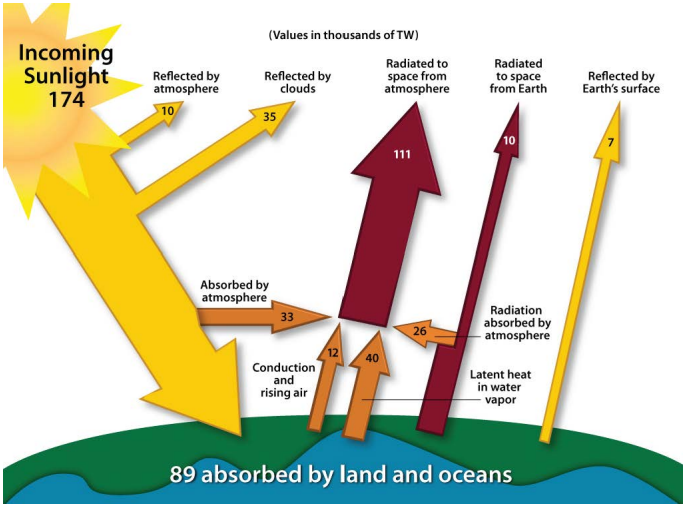
- A rapid transition away from fossil energy will be expensive, but . . .
- Doing nothing is even more expensive

My message on the economics of climate change

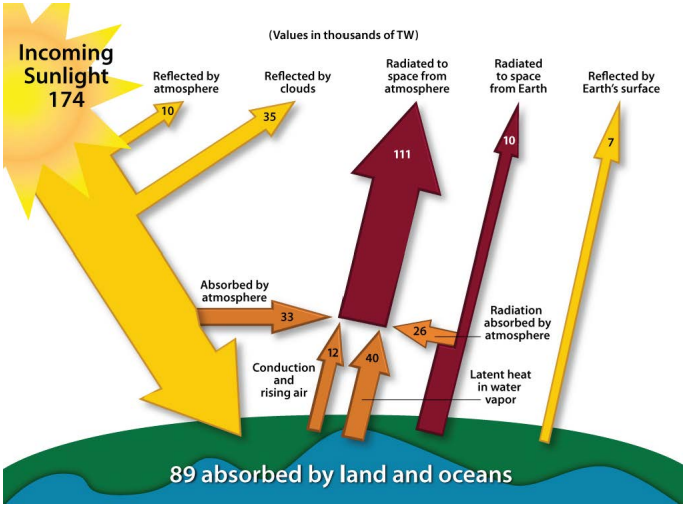
- A rapid transition away from fossil energy will be expensive, but . . .
- Doing nothing is even more expensive
- Cheaper does not mean easy. This will be really hard

How does warming depend on CO_2?

The sun powers Earth's energy system

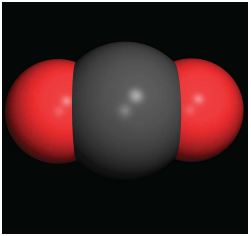


The sun powers Earth's energy system



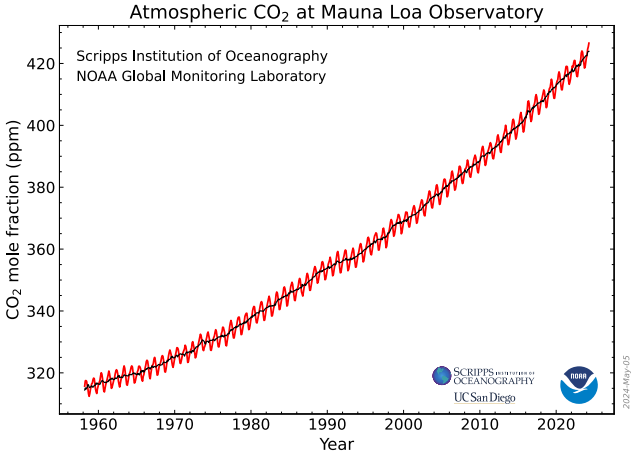
Human activity consumes $\sim$12.5 TW of energy continuously

Carbon dioxide is essential to life on Earth



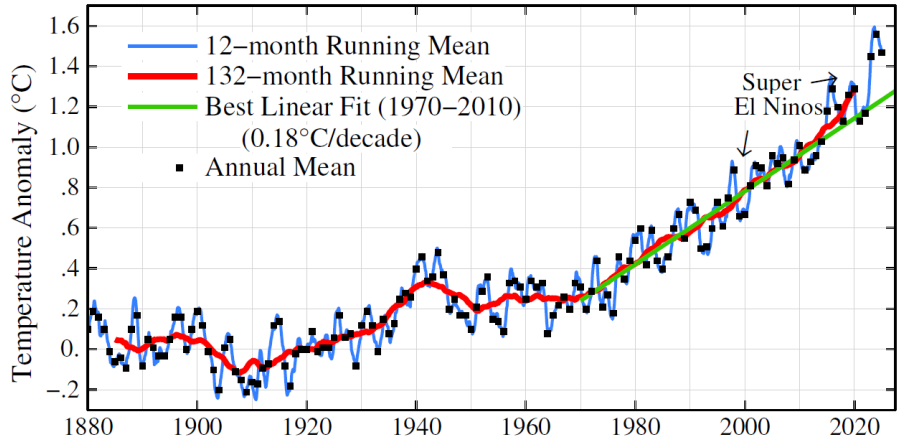
- Without CO_2, the Earth's temperature would be around $-21^{\circ}C$

There can be too much of a good thing



https://gml.noaa.gov/ccgg/trends/

Temperature since thermometers were available, 1880–1920 base



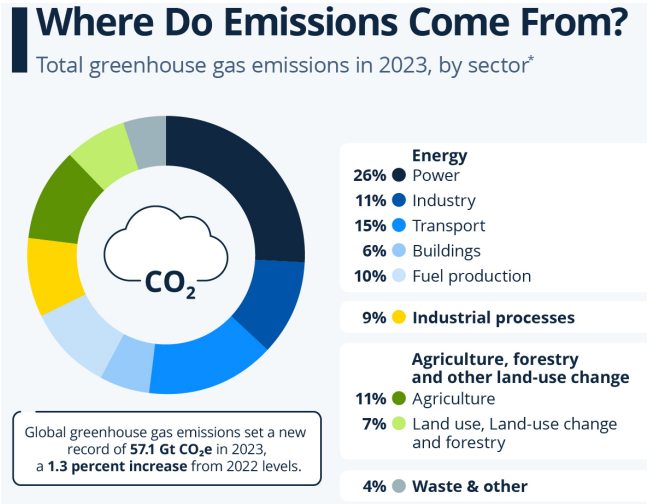
Source: www.columbia.edu/~mhs119/Temperature/

This is important to understand

4°C warming is very bad

And also totally unnecessary!

2023 CO_2 emissions by sector



Source: www.statista.com/chart/33334/total-greenhouse-gas-emissions-by-sector/

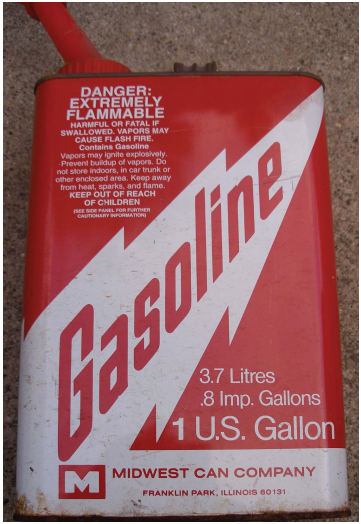
Fossil energy and agriculture do a lot of good

- Enough food for 8.3 billion people
- Modern society: economic growth, convenient living
- Fossil fuels are a brilliant source of energy

Family travel then: 15 miles/day

Family travel now: 30 miles in 23 minutes

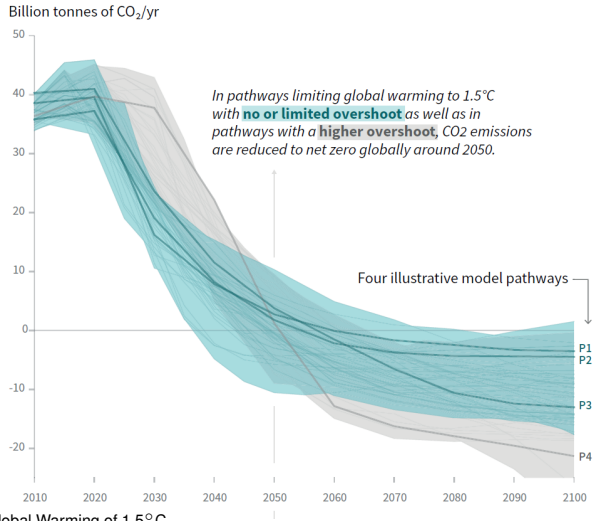
Using only this much fossil fuel



The challenge is daunting

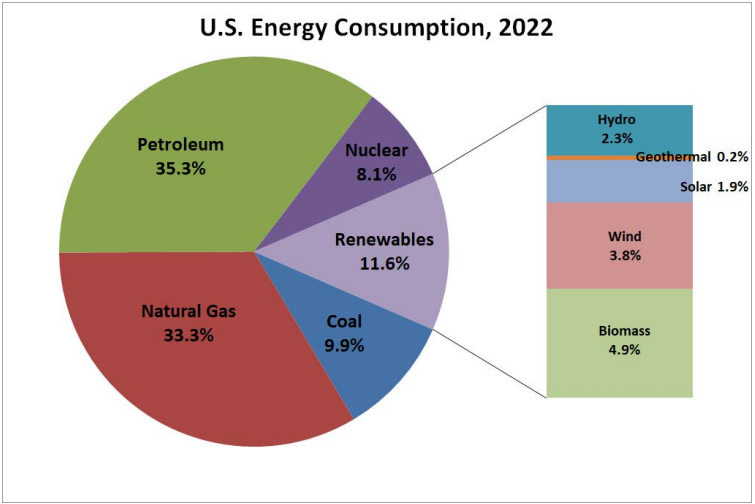
- 2015 Paris climate agreement aspirational goal: 1.5° warming
- Paris hard goal: 2° warming
- I won't dwell on frightening climate mayhem, except to say I regard the problem as urgent
- We need solutions that meet the scale of the challenge

Emissions must fall to zero by 2050 to stay below 1.5°C



Source: IPCC Special Report, Global Warming of 1.5°C

The 2022 U.S. energy mix



Source: www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf

What it means to solve the climate problem

Electrify everything, using renewable energy

The future will be amazing

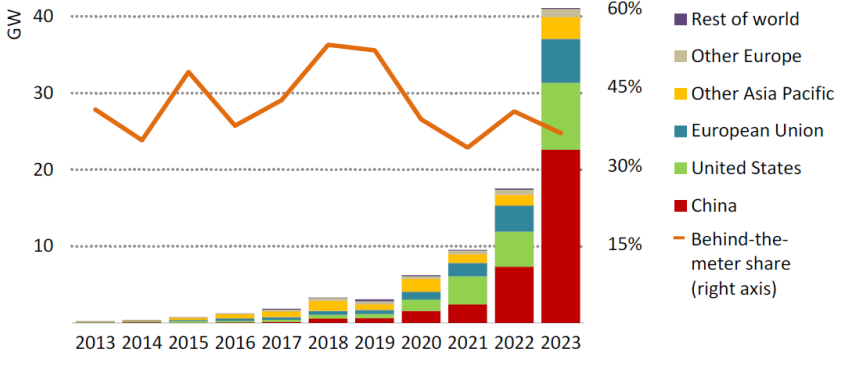
Taking carbon out: electrify everything

Taking carbon out: renewables

corporate.target.com/article/2017/04/solar-power-update

Taking carbon out: utility-scale storage

Figure 1.8 ▷ Battery storage capacity additions worldwide, 2013-2023



Capacity additions doubled in 2023, led by China, the United States and the European Union

IEA: Batteries and Secure Energy Transitions, 2024

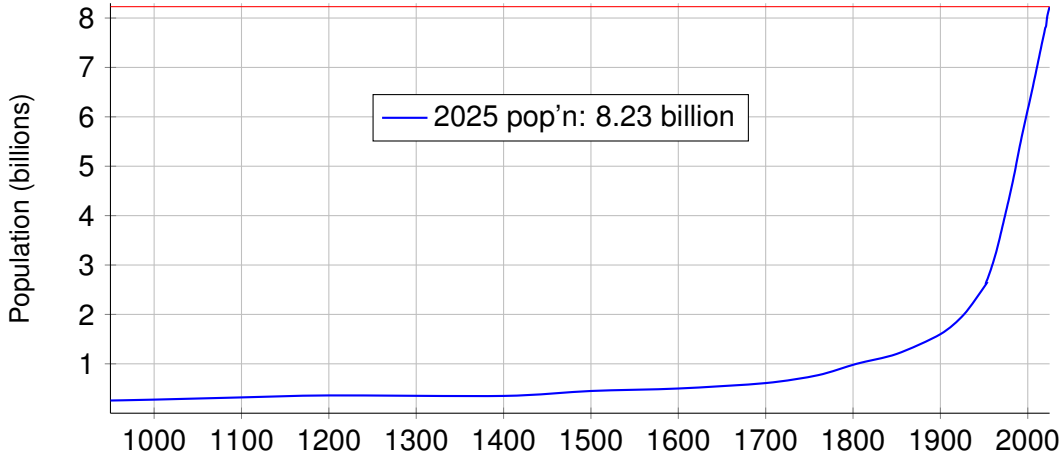
Taking carbon out: transmission capacity

Taking carbon out: efficiency

Really expensive: hundreds of trillions

Doing nothing: more fossil fuels

The global population keeps growing



Source: www.worldometers.info/world-population/world-population-by-year/

More people will have electricity

Really expensive: hundreds of trillions

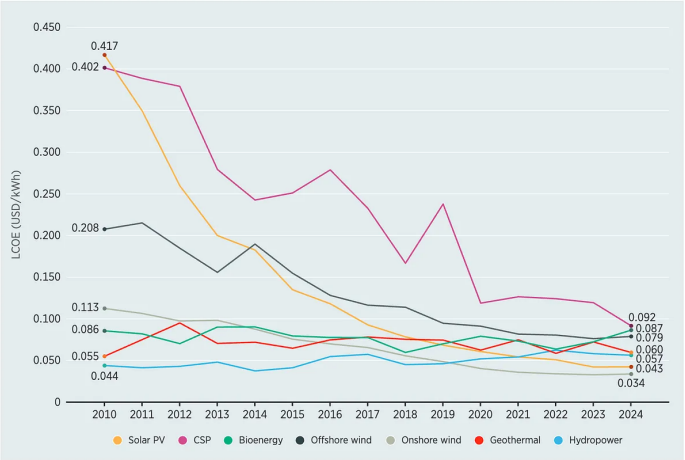
Really expensive: hundreds of trillions

Before digging into the data

Let’s consider a broad perspective

Renewable costs are plunging. . .

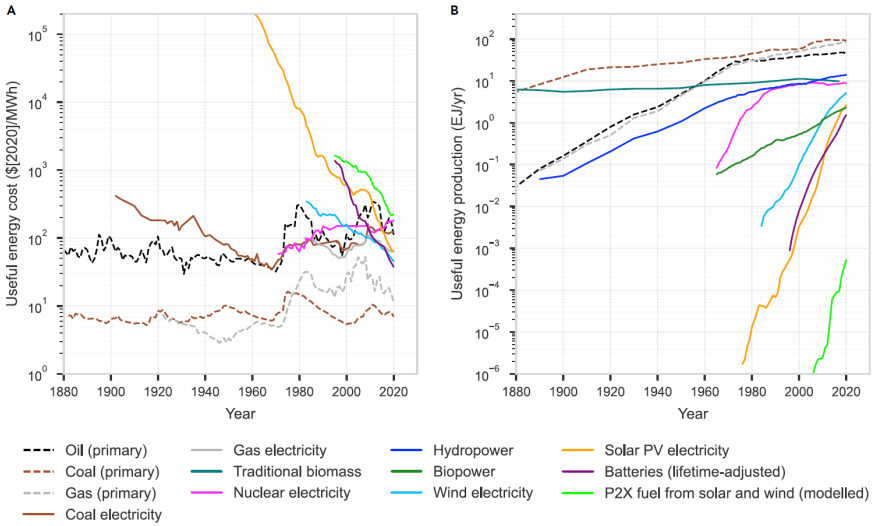
Figure S1 Renewable energy LCOE decline, 2010-2024



Notes: CSP = concentrated solar power; kWh = kilowatt hour; LCOE = levelised cost of electricity; PV = photovoltaic; USD = United States dollar.

Source: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Jul/

. . . fossil costs aren't

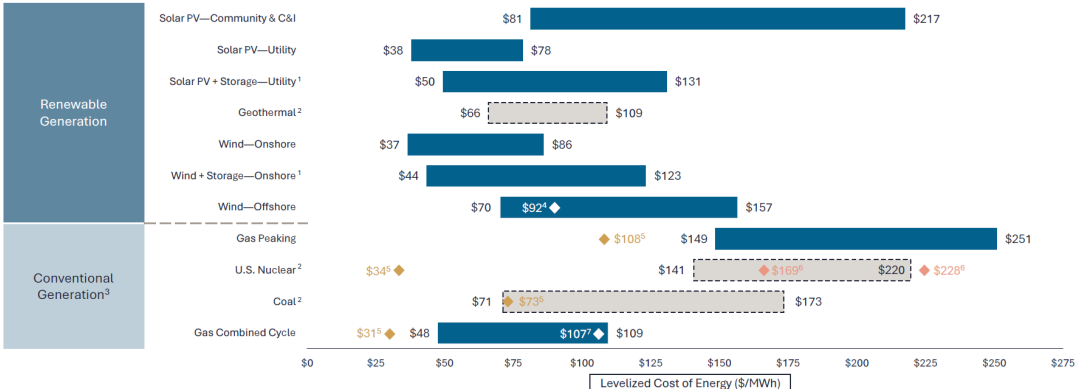


Source: Way *et al.*, *Joule*, 2022

Renewables + storages beat fossil electricity now

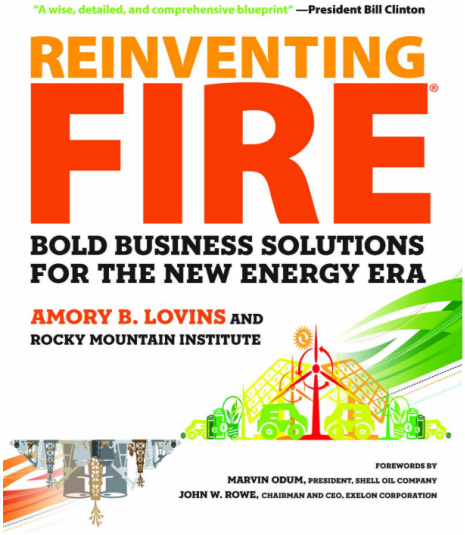
Levelized Cost of Energy Comparison—Version 18.0

Selected renewable energy generation technologies remain cost-competitive with conventional generation technologies under certain circumstances



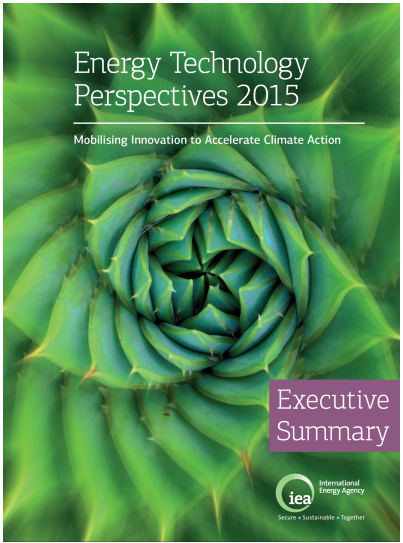
Source: www.lazard.com/research-insights/levelized-cost-of-energyplus-lcoeplus/

Solving climate is cheaper than doing nothing: 2011



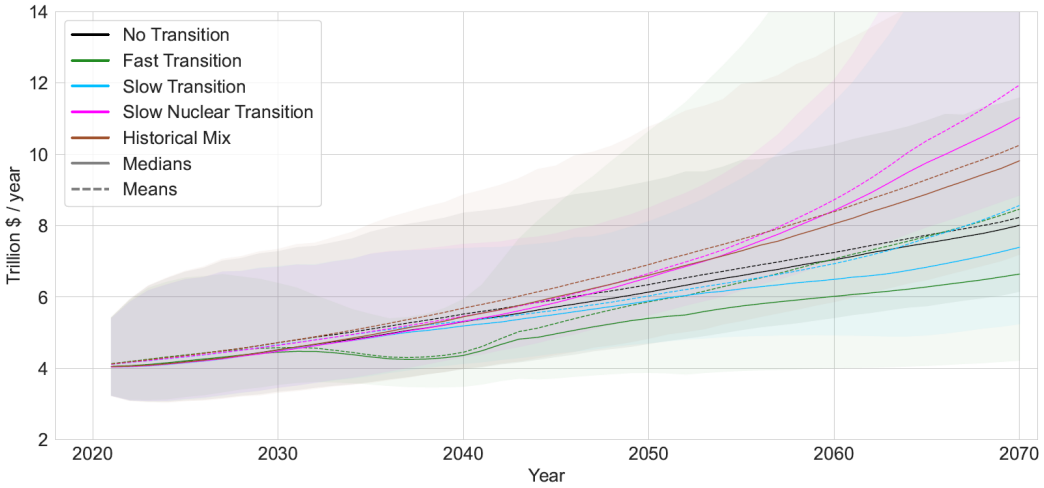
- Amory Lovins wrote this book 15 years ago
- "[T]hat long-awaited energy tipping point—where alternatives work better than oil and coal and compete purely on cost—is no longer decades in the future. It is here and it is now."

Solving climate is cheaper than doing nothing: 2015



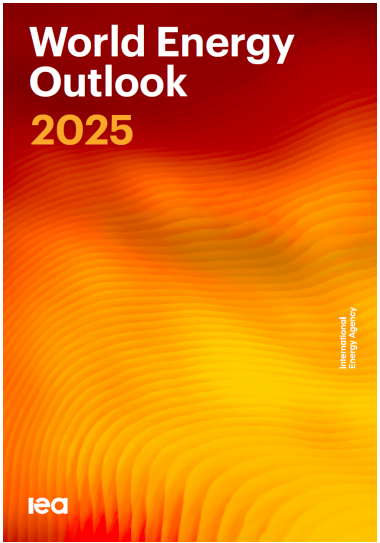
- Global energy cost, 35-year horizon, to 2050
- Cost of 2DS future: $243 trn ($6.9 trn/year)
- Under BAU, save $40 trn in capital investment
- But also spend $115 trn more in fuel
- Cost of BAU future: $318 trn ($9.1 trn/year)

Solving climate is cheaper than doing nothing: 2022



Source: Way *et al.*, *Joule*, 2022

Solving climate is cheaper than doing nothing: 2025



- Net Zero Emissions by 2050 scenario
- Energy investment rises from $3.3 trillion today to $4.8 trillion per year over the next decade
- “As these upfront investments are made, savings from lower fuel prices together with efficiency gains mean that households face costs for energy services comparable to those of today through to 2035, and lower still in the longer term.”

Is a 100% renewables energy system feasible? Yes

On the History and Future of 100% Renewable Energy Systems Research

CHRISTIAN BREYER[1], SIAVASH KHALILI[1], DMITRII BOGDANOV[1], MANISH RAM[1], AYOBAMI SOLOMON OYEWO[1], ARMAN AGHAHOSSEINI[1], ASHISH GULAGI[1], A. A. SOLOMON[1], DOMINIK KEINER[1], GABRIEL LOPEZ[1], POUL ALBERG ØSTERGAARD[2], HENRIK LUND[2], BRIAN V. MATHIESEN[3], MARK Z. JACOBSON[4], MARTA VICTORIA[5], SVEN TESKE[6], THOMAS PREGGER[7], VASILIS FTHENAKIS[8], (Fellow, IEEE), MARCO RAUGEI[8,9], HANNELE HOLTTINEN[10,11], (Senior Member, IEEE), UGO BARDI[12], AUKE HOEKSTRA[13], AND BENJAMIN K. SOVACOOL[14,15,16]

The main conclusion of the vast majority of 100% renewable energy systems studies is that such systems can power all energy in all regions of the world at low cost. As such, we do not need to rely on fossil fuels in the future. In the early 2020s, the consensus has increasingly become that solar PV and wind power will dominate the future energy system and new research increasingly shows that 100% renewable energy systems are not only feasible but also cost effective. This gives us the key to a sustainable civilization and the long-lasting prosperity of humankind.

If it's so cheap, why would climate action be hard?

Three main challenges

1. The required scale is eye-watering. And it has to happen *fast*
2. Powerful fossil interests fight hard to preserve their business model
3. We have to get utility regulation right too

Challenge #1

The required scale of the change, and the required speed

Renewables are cheap, but think how much is needed

- Largest solar array in the U.S. is 585MW
- Meeting mid-level U.S. targets requires building two 400MW arrays *per week* for the next 30 years

Renewables are cheap, but think how much is needed

- Largest solar array in the U.S. is 585MW
- Meeting mid-level U.S. targets requires building two 400MW arrays *per week* for the next 30 years
- The E.U. has 5,400 offshore wind turbines, the U.S. has 19
- The Biden Administration proposed 2,000 by 2030

Renewables are cheap, but think how much is needed

- Largest solar array in the U.S. is 585MW
- Meeting mid-level U.S. targets requires building two 400MW arrays *per week* for the next 30 years
- The E.U. has 5,400 offshore wind turbines, the U.S. has 19
- The Biden Administration proposed 2,000 by 2030
- NREL say transmission capacity must grow by 1.3–2.9$\times$ current level

  Source: Ruhl and Salzman, 2023, *Emory Law Journal*

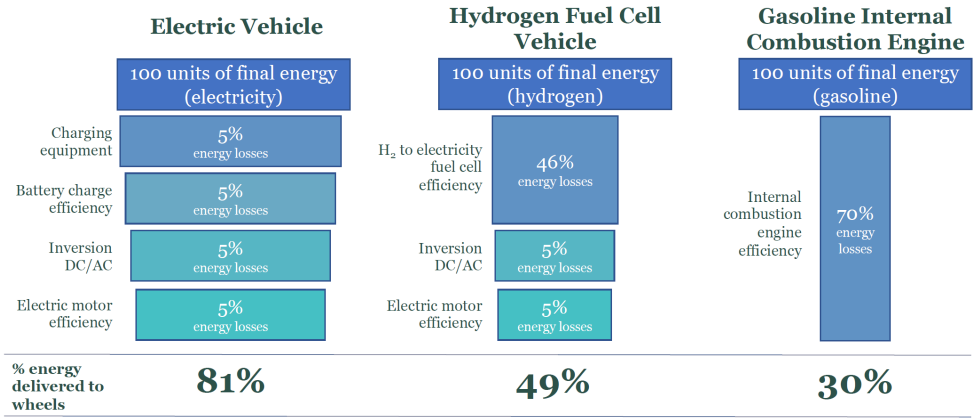
- This all costs trillions, but remember the fuel savings!

EVs are getting cheap too, but think how many are needed

- There are 1.45 million EVs on the road today
- That number must grow to 210–330 million by 2050

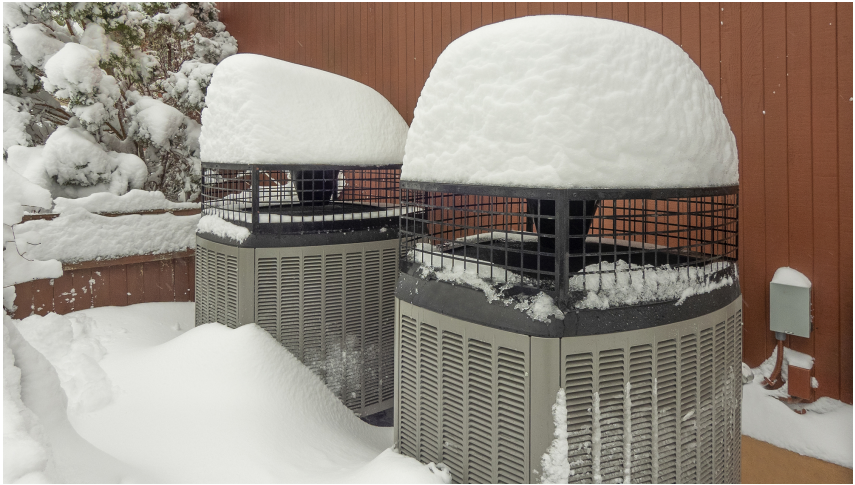
Source: Ruhl and Salzman, 2023, *Emory Law Journal*

Electricity is far more efficient than combustion . . .



Source: netzeroamerica.princeton.edu/the-report

Heat pumps can heat a home to -22°F



energysense.uillinois.edu/cold-climate-heat-pumps-work/

Scale is hard here too

- About 50% of U.S. homes heat with natural gas
- About 100 million homes must be electrified with heat pumps

Source: Ruhl and Salzman, 2023, *Emory Law Journal*

This is easy: electric short-haul trucks are everywhere

Heavy trucks are harder

www.drive.com.au/caradvice/four-minute-battery-swaps-is-this-the-future-of-evs/

Heavy equipment might be hydrogen fuel-cells

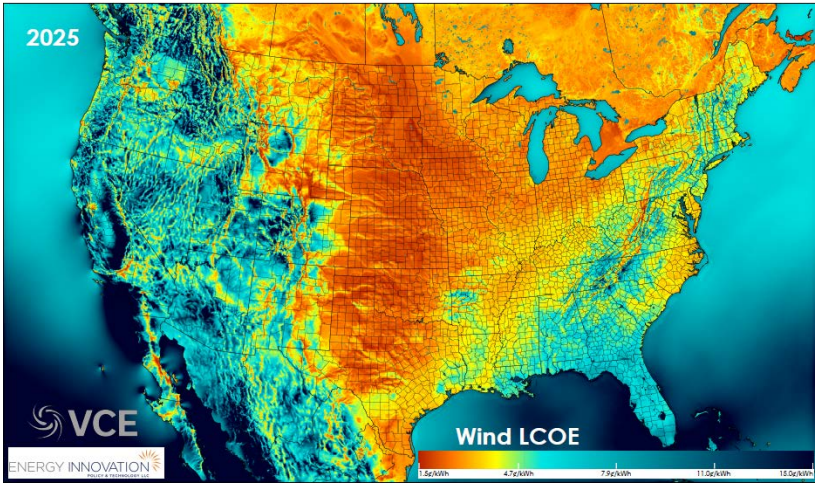
www.treehugger.com/cars/new-holland-unveils-farm-ready-hydrogen-fuel-cell-tractor.html

Aviation is likely to be hardest

Keeping the lights on: Connexus Energy solar + storage

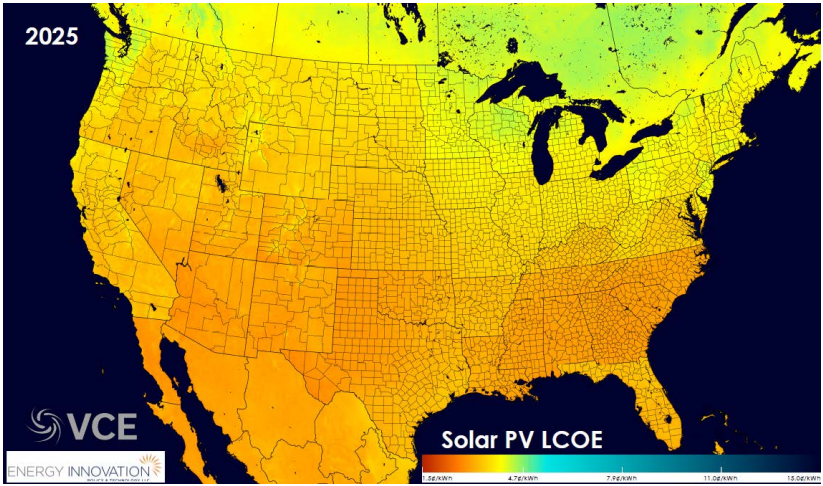
www.connexusenergy.com/save-money-and-energy/programs-rebates/solar-energy/solar-storage

It’s windy in some places . . .



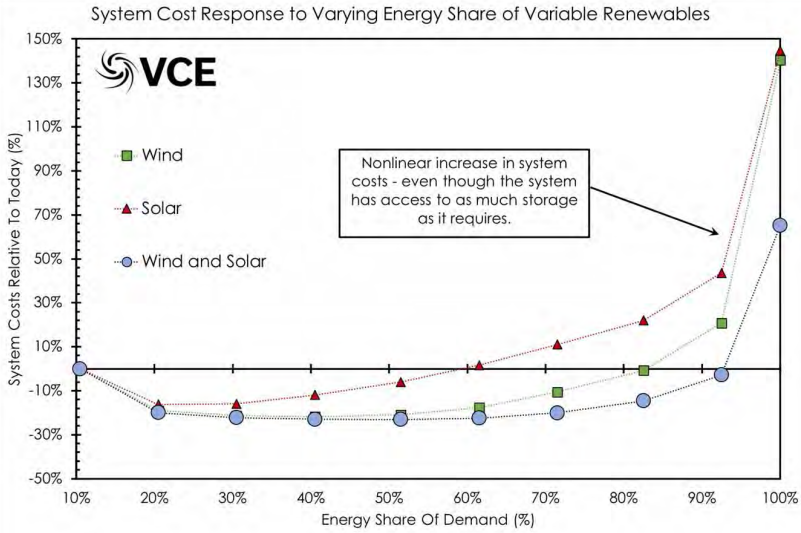
energyinnovation.org/publication/the-coal-cost-crossover/

. . . and it's sunny everywhere else



energyinnovation.org/publication/the-coal-cost-crossover/

Xcel 2018 IRP. Avoided savings are like a tax



www.xcelenergy.com/company/rates_and_regulations/resource_plans

Challenge #2

Powerful fossil interests will fight to preserve their business model

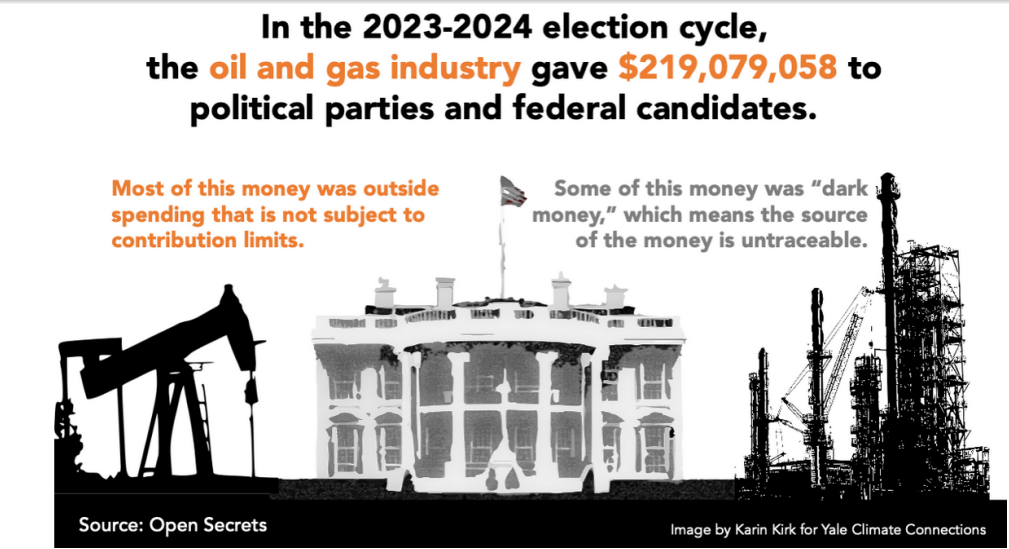
Trillions in coal, oil, and gas must be left in the ground

- Who gains when we keep burning oil, coal, and gas?
  - Gross profits of Exxon Mobil in 2025: $143.15 billion

Trillions in coal, oil, and gas must be left in the ground

- Who gains when we keep burning oil, coal, and gas?
  - Gross profits of Exxon Mobil in 2025: $143.15 billion
- Who gains when we switch to renewables? Electric utilities, among others
  - Gross profits of top five U.S. electric utilities in 2025: $21.9 billion
  - Nextera, Duke, Berkshire Hathaway, AEP, Edison International
  - Much of this is based on fossil fuel generation
- Actual renewables industries are much less profitable—now

2024 U.S. political contributions by fossil fuel industry

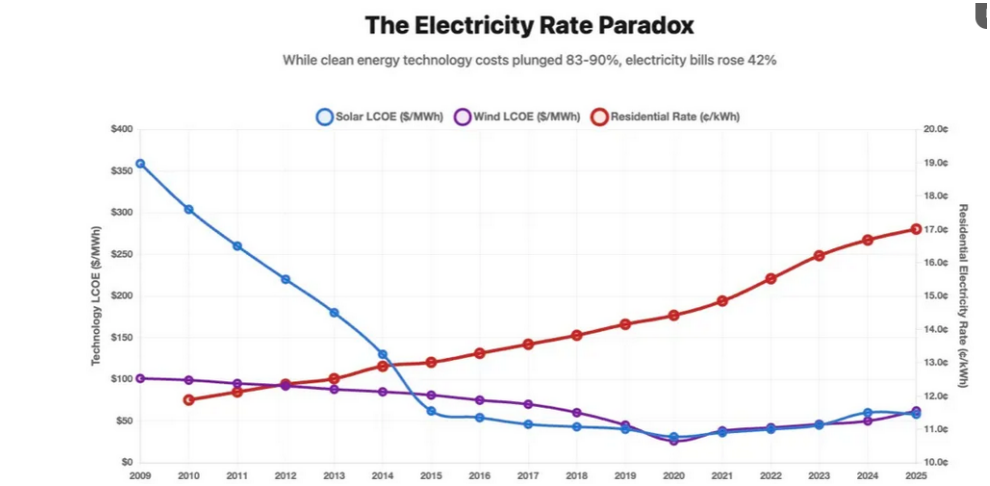


yaleclimateconnections.org/2025/01/the-fossil-fuel-industry-spent-219-million-to-elect-the-new-u-s-government/

Challenge #3

Electric utility regulation is not designed for our future

Cost of renewables plunges while electric bills rise



Chris Johnson, substack.com/inbox/post/179791790

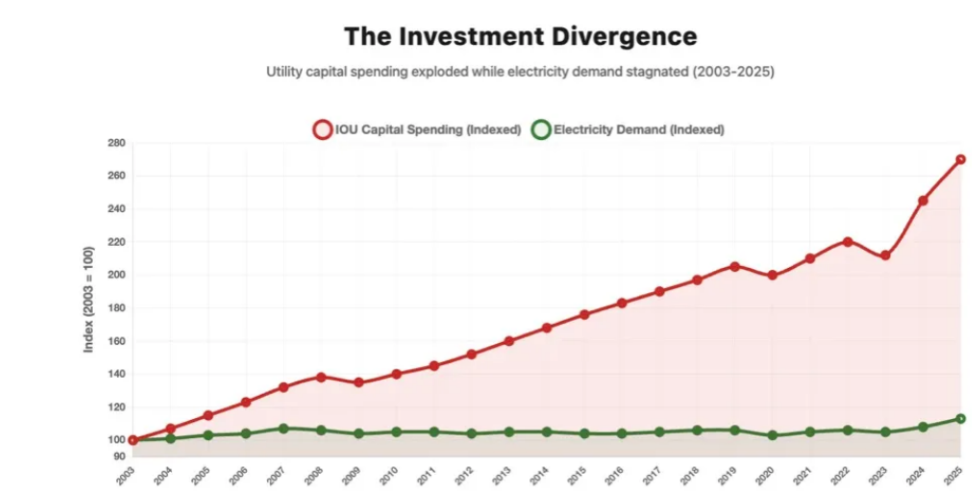
Why would this happen?

- 96% of U.S. retail electricity sales is by rate-regulated utilities
- Utilities are allowed to earn above-normal rates of return
- But only on capital investment, not operating expenses (fuel, maintenance)

Why would this happen?

- 96% of U.S. retail electricity sales is by rate-regulated utilities
- Utilities are allowed to earn above-normal rates of return
- But only on capital investment, not operating expenses (fuel, maintenance)
- Profits come from building stuff, not from reducing costs
- Maintaining equipment: no profit
- Replacing failed equipment: outsized profit

Spending on capital rose, while demand was flat



Chris Johnson, substack.com/inbox/post/179791790

Compare Sacramento MUD to PG&E

- SMUD is publicly owned, with no shareholders, governed by an elected board
- SMUD's 2024 average residential rate was 17 cents per kWh

Compare Sacramento MUD to PG&E

- SMUD is publicly owned, with no shareholders, governed by an elected board
- SMUD's 2024 average residential rate was 17 cents per kWh
- PG&E is investor owned, with rate-of-return regulation
- PG&E's baseline residential rate 42 cents per kWh
- SMUD customers save about $855 annually compared to neighboring PG&E

What policies should we pursue?

- Economists tend to favor carbon taxes
- But there's a problem: they're unpopular, and too incremental

What policies should we pursue?

- Economists tend to favor carbon taxes
- But there's a problem: they're unpopular, and too incremental
- My view now is that we need to aim bigger
- Including mandates against some things and subsidies for others
- Nudging people to weatherize their home doesn't work

Some ideas I now favor: mandates

- We need solutions on the scale of the challenge
- Compel a switch from gas to heat pumps for home heating

Some ideas I now favor: mandates

- We need solutions on the scale of the challenge
- Compel a switch from gas to heat pumps for home heating
- Stop banks from lending for oil exploration
- Set a date certain after which gasoline cars cannot be sold
- My craziest idea: buy all oil reserves and wind the industry down in 10 years

Bank lending to fossil companies continues

Banks have given almost $7tn to fossil fuel firms since Paris deal, report reveals

Among world's top 60 banks those in US are biggest fossil fuel financiers, while Barclays leads way in Europe

A pump jack over an oil well near Dacono, Colorado. US banks contributed 30% of the total $705bn provided in 2023, the report found. Photograph: David Zalubowski/AP

www.theguardian.com/environment/article/2024/may/13/banks-almost-7tn-fossil-fuel-firms-paris-deal-report

A new conception of utility regulation

- First, ROE is systematically too high across the U.S.
- Alternative schemes are being used: Total Expenditure Regulation

A new conception of utility regulation

- First, ROE is systematically too high across the U.S.
- Alternative schemes are being used: Total Expenditure Regulation
- Guide transmission expansion, with an eye to faster renewables expansion
- Maybe reconsider the entire framework of investor-owned utilities 10 years

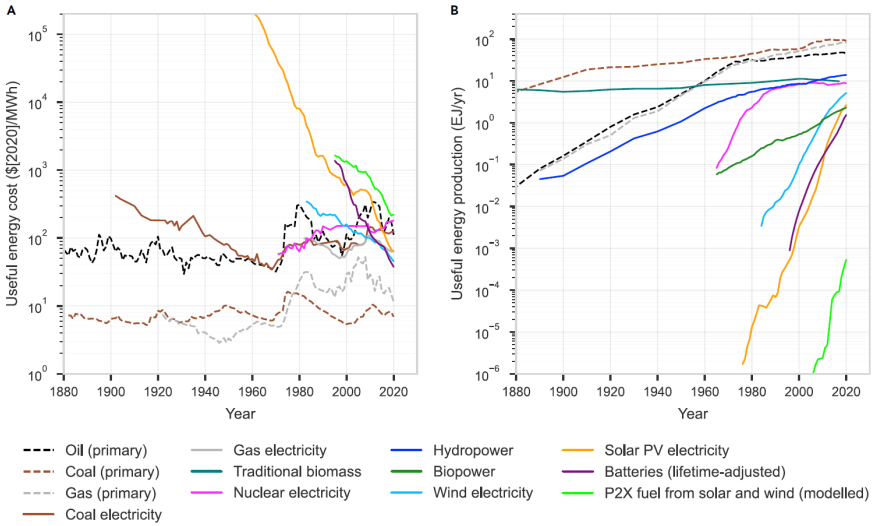
Contact information

Jay Coggins
University of Minnesota
Ph: 651-308-1874
email: jcoggins1@umn.edu

Changing gears a little

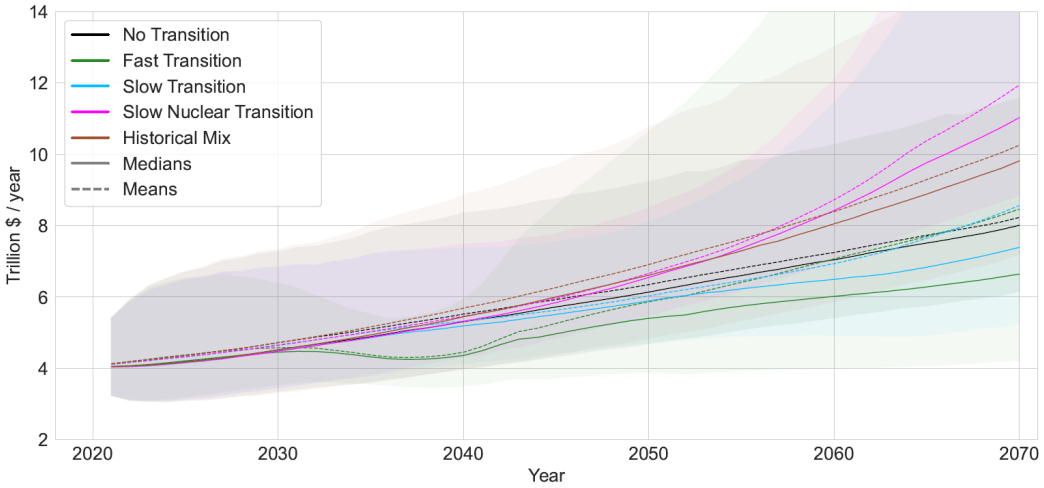
What about nuclear power as a solution?

Nuclear costs are not falling, and production is flat



Source: Way *et al.*, *Joule*, 2022

A nuclear-heavy energy future is the most expensive

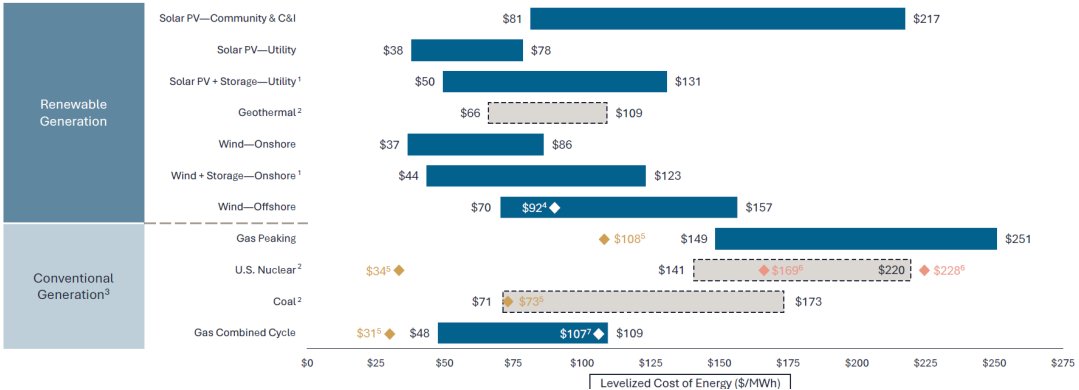


Source: Way *et al.*, *Joule*, 2022

Nuclear is the most expensive electricity source

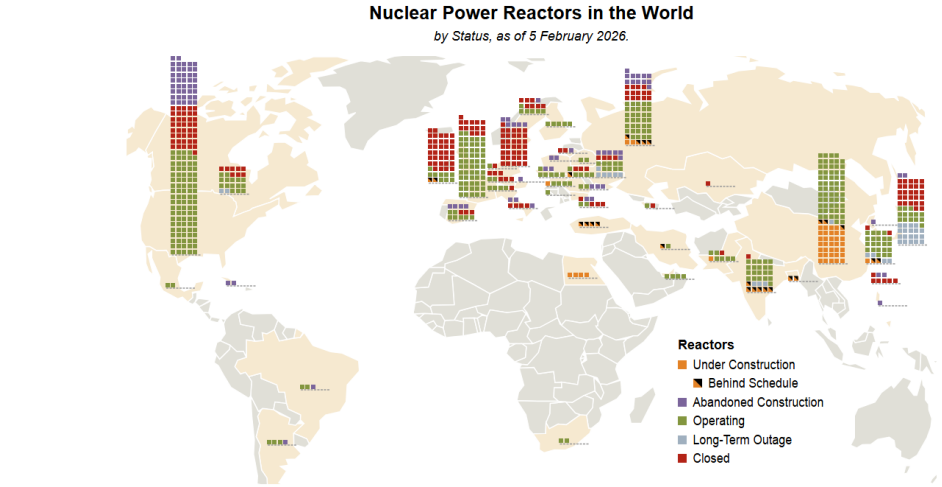
Levelized Cost of Energy Comparison—Version 18.0

Selected renewable energy generation technologies remain cost-competitive with conventional generation technologies under certain circumstances



Source: www.lazard.com/research-insights/levelized-cost-of-energyplus-lcoeplus/

Where are nuclear reactors around the world?



Source: www.worldnuclearreport.org/reactors.html

We have recent experience with new nuclear in the U.S.

Source: apnews.com/article/georgia-nuclear-power-plant-vogtle-rates-costs

Some facts about Plant Vogtle

- It was approved in 2010, planned to open in 2016
- Projected cost was around $16 billion
- Capacity of the two units is 2.2 GW
- Units began operating in 2023 and 2024

Some facts about Plant Vogtle

- It was approved in 2010, planned to open in 2016
- Projected cost was around $16 billion
- Capacity of the two units is 2.2 GW
- Units began operating in 2023 and 2024
- Final cost was $36 billion
- Westinghouse, the main contractor, declared bankruptcy in 2017
- Georgia Power customers will pay an extra $35/month to cover costs

Is resistance to nuclear power rational?

- Fossil generation is far more deadly, due to air pollution
- But the worst-case scenario for nuclear is cataclysmic
- Even if it's very unlikely to happen, this is scary in expected terms

Is resistance to nuclear power rational?

- Fossil generation is far more deadly, due to air pollution
- But the worst-case scenario for nuclear is cataclysmic
- Even if it's very unlikely to happen, this is scary in expected terms
- Nuclear advocates should address the Price-Anderson Act
- Max private insurance coverage for a nuclear plant is $450 million
- Price-Anderson money covers up to $15 billion, funded by the industry
- The Federal Government backs up nuclear liability above $15 billion
- No other generation source has this benefit

Maybe Small Modular Nuclear will work better?

E&E NEWS By POLITICO

Publications ▾ Subscription ▾ About ▾ FREE TRIAL › LOGIN

Full access to essential energy & environment news for professionals. Learn more

7-DAY UNLIMITED ACCESS | FREE TRIAL

ENERGYWIRE

NuScale cancels first-of-a-kind nuclear project as costs surge

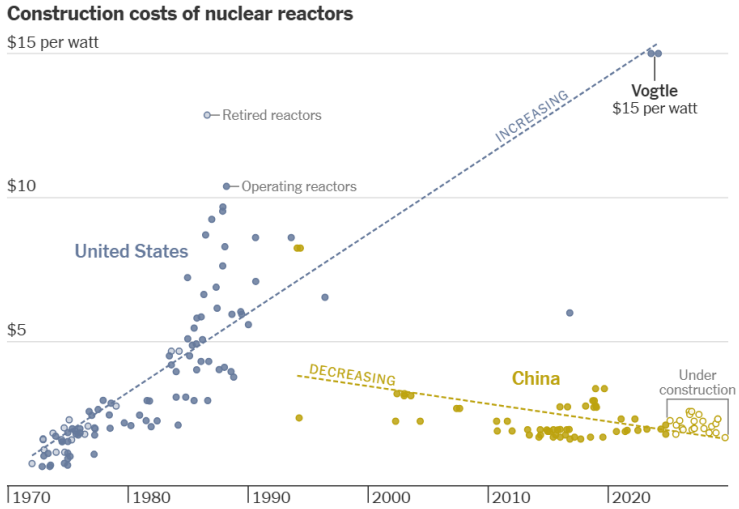
By ZACH BRIGHT | 11/09/2023 06:48 AM EST

The Oregon-based company and the Utah Associated Municipal Power Systems terminated an agreement for six small modular reactors.

This artist's rendering shows a prospective NuScale Power small modular nuclear reactor site. Business Wire/AP

Source: www.eenews.net/articles/nuscale-cancels-first-of-a-kind-nuclear-project-as-costs-surge/

Nuclear costs *are* falling in China



NYTimes: How China Raced Ahead of the U.S. on Nuclear Power

Two final thoughts

- Don't listen to the siren of the individual carbon footprint. That's a way the oil industry makes us think it's our fault. The system has to change
- If you want to make a difference, help elect different political leaders