Electricity without Greenhous Gases:

Essential to meeting the challenge of climate change

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It is particularly fitting…

…that I am speaking to you today from Pittsburgh, PA.

Rachel Carson graduated in biology from the Pennsylvania College for Women, now Chatham University, which is located just up the street from my CMU office.

As you can see from the image below, the Pittsburgh region proudly counts her as one of its own.

Image sources: Wikipedia and positivelypittsburgh.com

Today I will talk about three things:

1. Some basic background on:
   - Climate science
   - The electricity system
2. Why electric power is critical to climate change:
   - As a leading source of CO_2 and other GHG emissions and how to reduce those emissions
   - As the most viable option to replace fossil fuels
3. The need to expand electric power transmission capacity and some efforts we are undertaking to address the problem.

To be an informed participant…

…in public discourse about climate change people need to know three simple facts:

1. Burning coal, oil, and natural gas produces carbon dioxide that enters the atmosphere.
2. Carbon dioxide in the atmosphere warms the earth, and that warming changes the climate.
3. Once carbon dioxide gets into the atmosphere, much of it remains there for many hundreds of years.

My social science colleagues and I first studied what people know 30 years ago

Risk Analysis, Vol. 14, No. 6, 1994

What Do People Know About Global Climate Change? 1. Mental Models

Ann Bostrom,[1] M. Granger Morgan,[2] Baruch Fischhoff,[2] and Daniel Read[2]

Received August 16, 1993; revised February 7, 1994

A set of exploratory studies and mental model interviews was conducted in order to characterize public understanding of climate change. In general, respondents regarded global warming as both bad and highly likely. Many believed that warming has already occurred. They tended to confuse stratospheric ozone depletion with the greenhouse effect and weather with climate. Automobile use, heat and emissions from industrial processes, aerosol spray cans, and pollution in general were frequently perceived as primary causes of global warming. Additionally, the "greenhouse effect" was often interpreted literally as the cause of a hot and steamy climate. The effects attributed to climate change often included increased skin cancer and changed agricultural yields. The mitigation and control strategies proposed by interviewees typically focused on general pollution control, with few specific links to carbon dioxide and energy use. Respondents appeared to be relatively unfamiliar with such regulatory developments as the ban on CFCs for nonessential uses. These beliefs must be considered by those designing risk communications or presenting climate-related policies to the public.

KEY WORDS: Climate change; global warming; mental model; risk communication; decision making.

1. INTRODUCTION

The last decade has been marked by growing public concern and widespread media coverage surrounding the possibility of global warming due to an increased greenhouse effect.(1,2) To a significant degree, the effectiveness with which society responds to this possibility depends on how well it is understood by individual citizens. As voters, citizens must decide which policies and politicians to support. As consumers, they must decide whether and how to consider environmental effects when making choices such as whether our resources are most efficiently deployed by using paper or polystyrene foam cups.(3) Despite the crucial implications of their knowledge and opinions for public policy, little is known regarding the public's literacy about global climate change.

The United States spends approximately $1.5 billion annually researching global environmental change, including climate change. For that research to have any practical value, its results must find their way to decision makers, including individual citizens and policy makers. In order to educate the citizenry, we must start by educating ourselves about what they already know and believe and how it differs from what they need to know in order to make effective decisions. We cannot trust technical experts' intuitions about public beliefs.(4,5) Indeed, many controversies in risk communication arise when experts either underestimate or overestimate the public's knowledge. Consequently, the provision of information should begin with an empirical assessment of what people already know, along with a scientific determination of what missing information is most critical to their decisions.(6,7)

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1994

Risk Analysis, Vol. 14, No. 6, 1994

What Do People Know About Global Climate Change? 2. Survey Studies of Educated Laypeople

Daniel Read,[1] Ann Bostrom,[2] M. Granger Morgan,[1] Baruch Fischhoff,[1] and Tom Smuts[1]

Received August 16, 1993; accepted February 7, 1994

Drawing on results from earlier studies that used open-ended interviews, a questionnaire was developed to examine laypeople's knowledge about the possible causes and effects of global warming, as well as the likely efficacy of possible interventions. It was administered to two well-educated opportunity samples of laypeople. Subjects had a poor appreciation of the facts that (1) if significant global warming occurs, it will be primarily the result of an increase in the concentration of carbon dioxide in the earth's atmosphere, and (2) the single most important source of additional carbon dioxide is the combustion of fossil fuels, most notably coal and oil. In addition, their understanding of the climate issue was encumbered with secondary, irrelevant, and incorrect beliefs. Of these, the two most critical are confusion with the problems of stratospheric ozone and difficulty in differentiating between causes and actions specific to climate and more general good environmental practice.

KEY WORDS: Climate change; global warming; risk communication; public understanding.

1. INTRODUCTION

In the preceding paper,(1) we used open-ended interview methods to study how well several convenience samples of well-educated laypeople understand the issues surrounding climate change. We discovered a mixture of correct and incorrect beliefs (e.g., viewing the ozone hole as the principle cause of climate change, not realizing the role of carbon dioxide and fossil fuel consumption). We hypothesized that some of these misunderstandings could misdirect the public's support for proposed policies, as well as leave it vulnerable to manipulation by interest groups.

Open-ended elicitation procedures allow people to express their beliefs naturally, with a minimum of constraints imposed by the investigator's perspective. Unfortunately, they are very labor intensive and, thus, tend to have small samples. We used results from our previous interviews, and from related studies by Kempton,(2) to construct a structured questionnaire which can be administered to large numbers of subjects. In this paper we give a more precise indication of the frequency with which beliefs observed by Bostrom *et al.* and by Kempton are encountered among well-educated laypeople. We reasoned that the beliefs and opinions of such well-educated people are of particular importance because they may be opinion leaders in their communities and are likely to take on activist and leadership roles—indeed, one of our samples comprised a group aspiring to leadership positions in the city of Pittsburgh. Moreover, the beliefs about technical issues held by well-educated people will probably constitute an "upper boundary" of sophistication; if our sample makes an error, it is unlikely that the error will be less common in a less educated sample.

Our work is designed to direct the content of risk communications as well as assess the level of public understanding. Risk communication will be most suc-

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1994

Risk Analysis, Vol. 30, No. 10, 2010

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Now What Do People Know About Global Climate Change? Survey Studies of Educated Laypeople

Travis William Reynolds,[1,*] Ann Bostrom,[1] Daniel Read,[2] and M. Granger Morgan[3]

In 1992, a mental-models-based survey in Pittsburgh, Pennsylvania, revealed that educated laypeople often conflated global climate change and stratospheric ozone depletion, and appeared relatively unaware of the role of anthropogenic carbon dioxide emissions in global warming. This study compares those survey results with 2009 data from a sample of similarly well-educated laypeople responding to the same survey instrument. Not surprisingly, following a decade of explosive attention to climate change in politics and in the mainstream media, survey respondents in 2009 showed higher awareness and comprehension of some climate change causes. Most notably, unlike those in 1992, 2009 respondents rarely mentioned ozone depletion as a cause of global warming. They were also far more likely to correctly volunteer energy use as a major cause of climate change; many in 2009 also cited natural processes and historical climatic cycles as key causes. When asked how to address the problem of climate change, while respondents in 1992 were unable to differentiate between general "good environmental practices" and actions specific to addressing climate change, respondents in 2009 have begun to appreciate the differences. Despite this, many individuals in 2009 still had incorrect beliefs about climate change, and still did not appear to fully appreciate key facts such as that global warming is primarily due to increased concentrations of carbon dioxide in the atmosphere, and the single most important source of this carbon dioxide is the combustion of fossil fuels.

KEY WORDS: Climate change; global warming; laypeople; mental models; risk communication; United States

1. INTRODUCTION

In 1992 we conducted a survey of beliefs and attitudes in the United States concerning global climate change.(1) Since that time both the public discourse and media coverage of the issue have changed almost beyond recognition. By 2008 climate change was at the forefront of popular media. Al Gore had starred in an Academy Award winning movie on climate change; rock stars like David Gilmour and U2 offered "carbon neutral" CDs; and marketers, auto manufacturers, and even airlines were beginning to promote their products based on their reduced effects on climate change.[4] Whereas in 1992 there was little official acknowledgment of global warming, in 2008 both U.S. presidential candidates proposed explicit policies designed to reduce or slow climate change.

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[4] For an example, see http://www.easyjet.com/en/Environment/index.html. Accessed April 15, 2010.

2010

Today most American's …

…now know these first two facts.

1. Burning coal, oil, and natural gas produces carbon dioxide that enters the atmosphere.
2. Carbon dioxide in the atmosphere warms the earth, and that warming changes the climate.

BUT, most do not know this third fact.

3. Once carbon dioxide gets into the atmosphere, much of it remains there for many hundreds of years.

When we add…

…carbon dioxide (CO_2) to the atmosphere some of it is absorbed in the ocean or taken up by plants.

HOWEVER, most of the balance stays in the atmosphere **for hundreds of years**.

That means that some of the CO_2 you are breathing as you listen to me was emitted in Britain several hundred years ago during the industrial revolution!

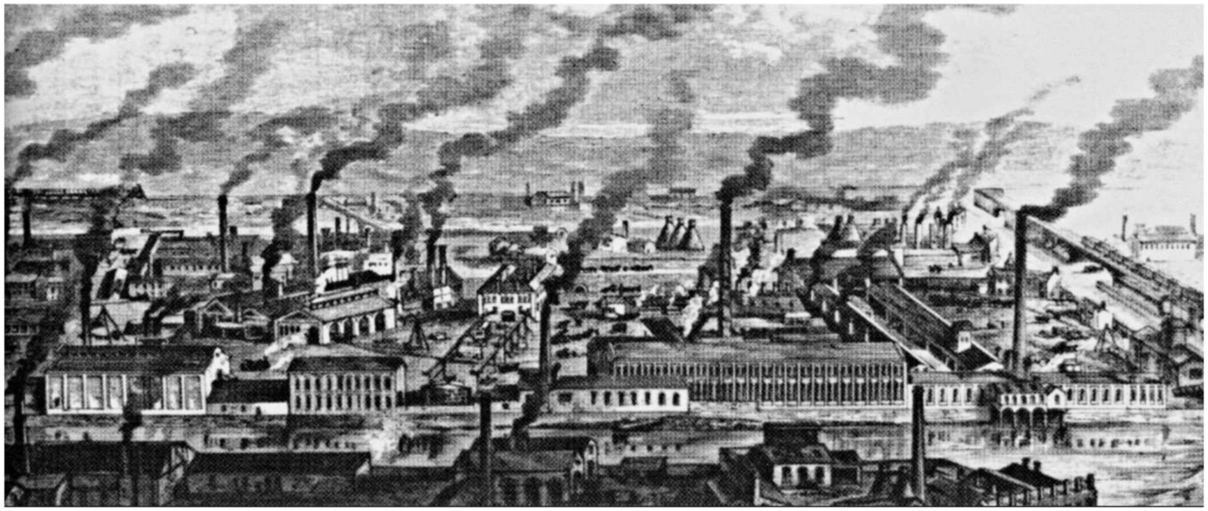
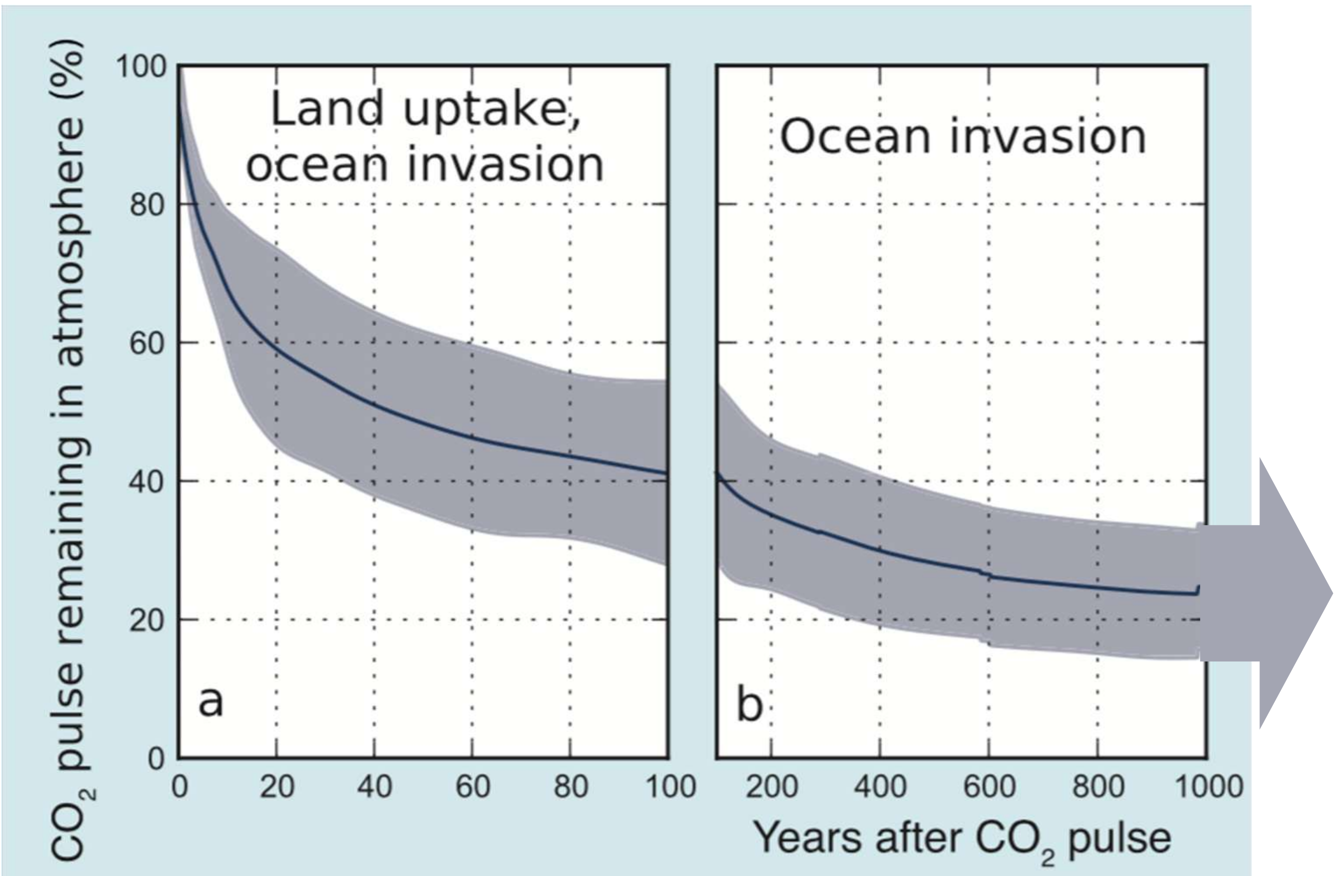


Image from: top5resources.blogspot.com/2014/05/industrial-revolution.html

There is no *single* residence time for CO_2.

Here is how a pulse of CO_2 added today decays over time:

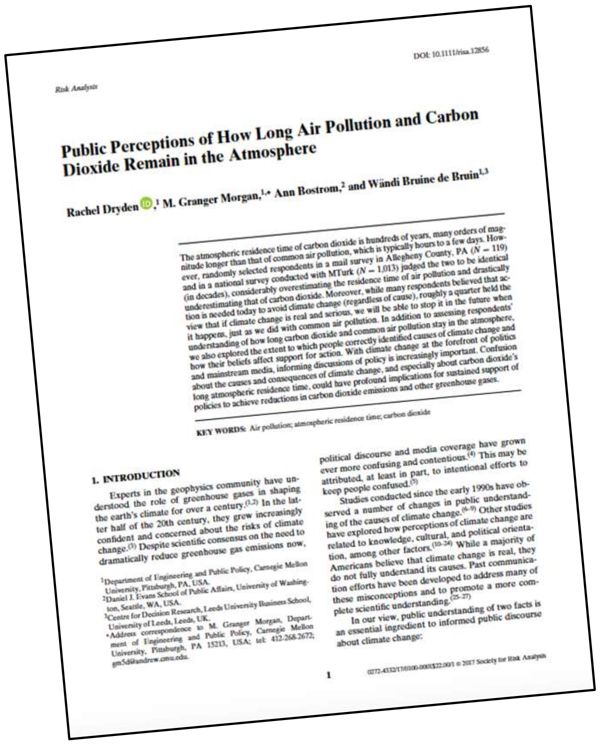


Then, on time scales of thousands of years, it mineralizes.

Image source: IPCC AR5 WG1

Most people...

...think CO_2 stays in the atmosphere about as long as conventional air pollution.



DOI: 10.1111/risa.12856

Risk Analysis

Public Perceptions of How Long Air Pollution and Carbon Dioxide Remain in the Atmosphere

Rachel Dryden,[1] M. Granger Morgan,[1,*] Ann Bostrom,[2] and Wändi Bruine de Bruin[1,3]

The atmospheric residence time of carbon dioxide is hundreds of years, many orders of magnitude longer than that of common air pollution, which is typically hours to a few days. However, randomly selected respondents in a mail survey in Allegheny County, PA ($N = 119$) and in a national survey conducted with MTurk ($N = 1,013$) judged the two to be identical (in decades), considerably overestimating the residence time of air pollution and drastically underestimating that of carbon dioxide. Moreover, while many respondents believed that action is needed today to avoid climate change (regardless of cause), roughly a quarter held the view that if climate change is real and serious, we will be able to stop it in the future when it happens, just as we did with common air pollution. In addition to assessing respondents' understanding of how long carbon dioxide and common air pollution stay in the atmosphere, we also explored the extent to which people correctly identified causes of climate change and how their beliefs affect support for action. With climate change at the forefront of politics and mainstream media, informing discussions of policy is increasingly important. Confusion about the causes and consequences of climate change, and especially about carbon dioxide's long atmospheric residence time, could have profound implications for sustained support of policies to achieve reductions in carbon dioxide emissions and other greenhouse gases.

KEY WORDS: Air pollution; atmospheric residence time; carbon dioxide

1. INTRODUCTION

Experts in the geophysics community have understood the role of greenhouse gases in shaping the earth's climate for over a century.(1,2) In the latter half of the 20th century, they grew increasingly confident and concerned about the risks of climate change.(3) Despite scientific consensus on the need to dramatically reduce greenhouse gas emissions now, political discourse and media coverage have grown ever more confusing and contentious.(4) This may be attributed, at least in part, to intentional efforts to keep people confused.(5)

Studies conducted since the early 1990s have observed a number of changes in public understanding of the causes of climate change.(6-9) Other studies have explored how perceptions of climate change are related to knowledge, cultural, and political orientation, among other factors.(10-24) While a majority of Americans believe that climate change is real, they do not fully understand its causes. Past communication efforts have been developed to address many of these misconceptions and to promote a more complete scientific understanding.(25-27)

In our view, public understanding of two facts is an essential ingredient to informed public discourse about climate change:

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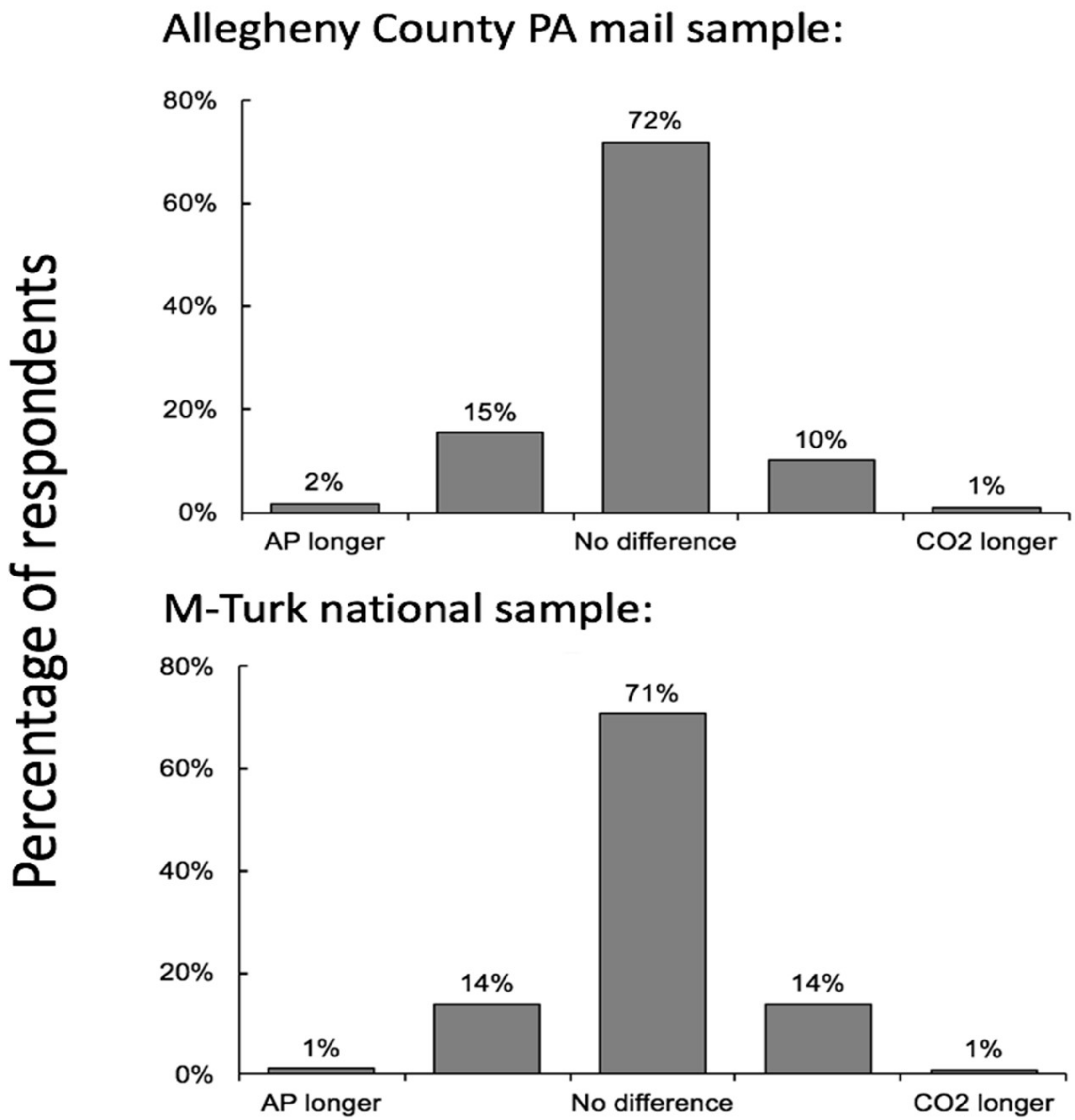
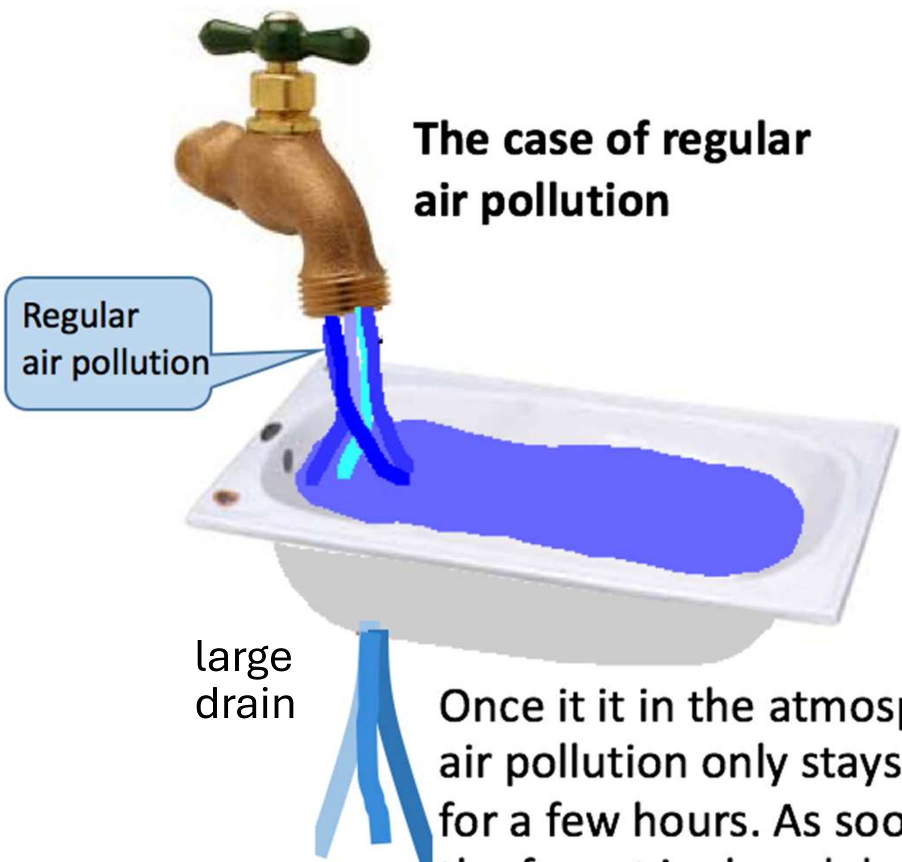
Image from: Dryden, R., Morgan, M. G., Bostrom, A., & Bruine de Bruin, W. (2018). Public perceptions of how long air pollution and carbon dioxide remain in the atmosphere. *Risk Analysis*, *38*(3), 525-534.



Difference in people's estimates of how long air pollution (AP) and CO_2 stay in the atmosphere

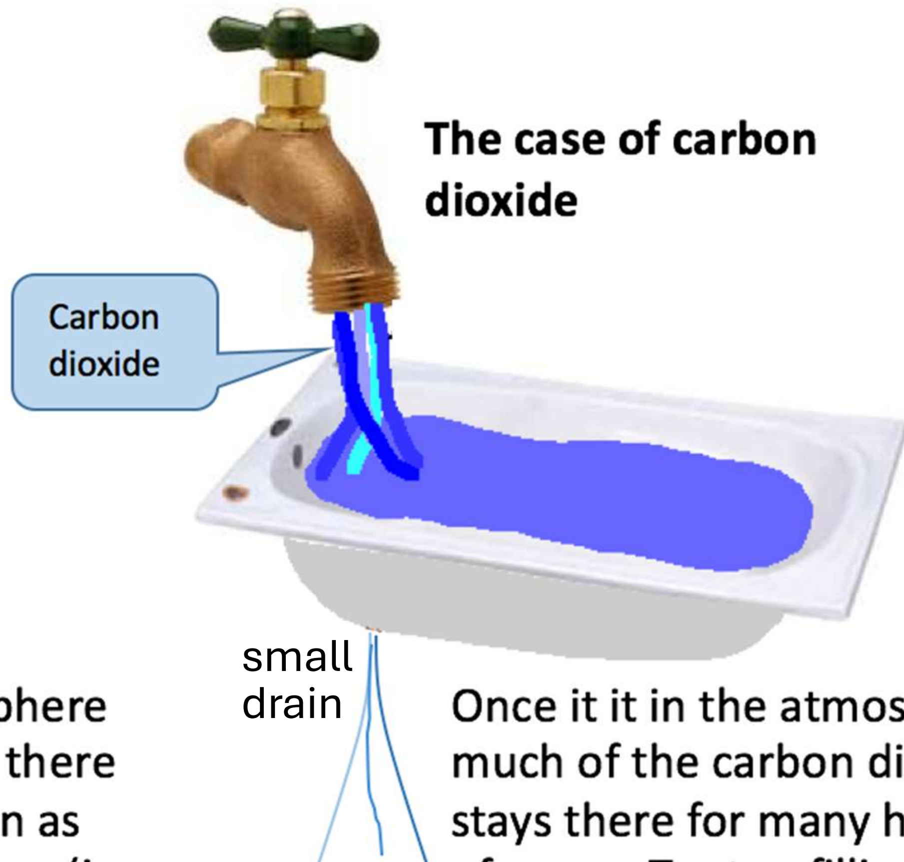
Here is a bathtub model that helps explain

The case of regular air pollution



Once it it in the atmosphere air pollution only stays there for a few hours. As soon as the faucet is closed down (i.e. emissions are reduced) the tub starts to drain.

The case of carbon dioxide



Once it it in the atmosphere much of the carbon dioxide stays there for many hundreds of years. To stop filling the tub the faucet has to be *almost completely shut off*.

The bottom line

We can argue about how fast we should reduce our emissions of carbon dioxide and other greenhouse gases – how best to make the tradeoff between incurring inconvenience and costs today *versus* leaving a habitable world for our children tomorrow.

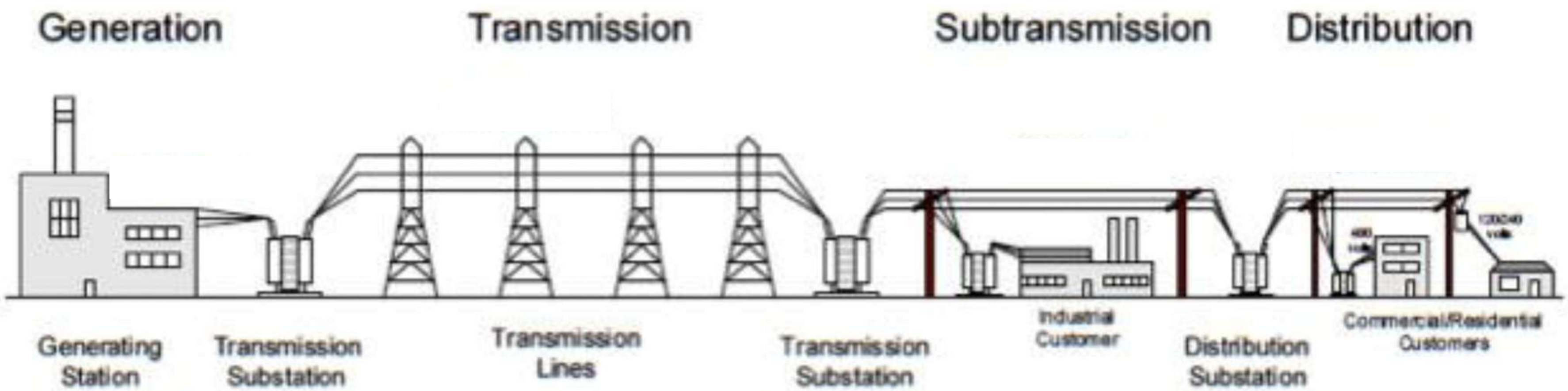
But neither proceeding full steam ahead pretending the problem of climate change doesn't exist - which appears to be the new policy of the U.S. government - nor going along with that policy because folks figure that in a few years when things get bad enough, we'll just fix the problem – is simply not going to work.

Much of carbon dioxide we add to the atmosphere today will still be there, warming the planet and changing the climate for our grandchildren.

Today I will talk about three things:

1. Some basic background on:
   - Climate science
   - The electricity system
2. Why electric power is critical to climate change:
   - As a leading source of CO_2 and other GHG emissions and how to reduce those emissions
   - As the most viable option to replace fossil fuels
3. The need to expand electric power transmission capacity and some efforts we are undertaking to address the problem.

The traditional structure of the electricity system



A few things to notice:

- Three conductors because using three phase alternating current (AC) is more efficient for long transmission and for many heavy loads like big motors.
- High voltage (V) is used for transmission since power is the product VxI, but losses go as I^2R, so moving a given amount of power using a higher voltage means lower current (I) and lower losses.
- While many large customers take three phase power at thousands of volts, most residential customers take single phase power typically at 240/120 volts

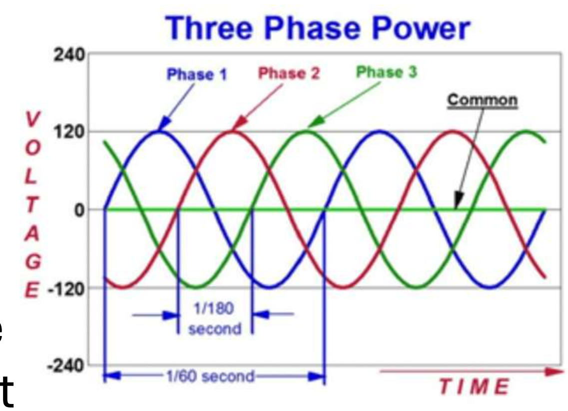


Image sources:researchgate.net; pocketsparky

Today that simple traditional system is getting more and more complicated

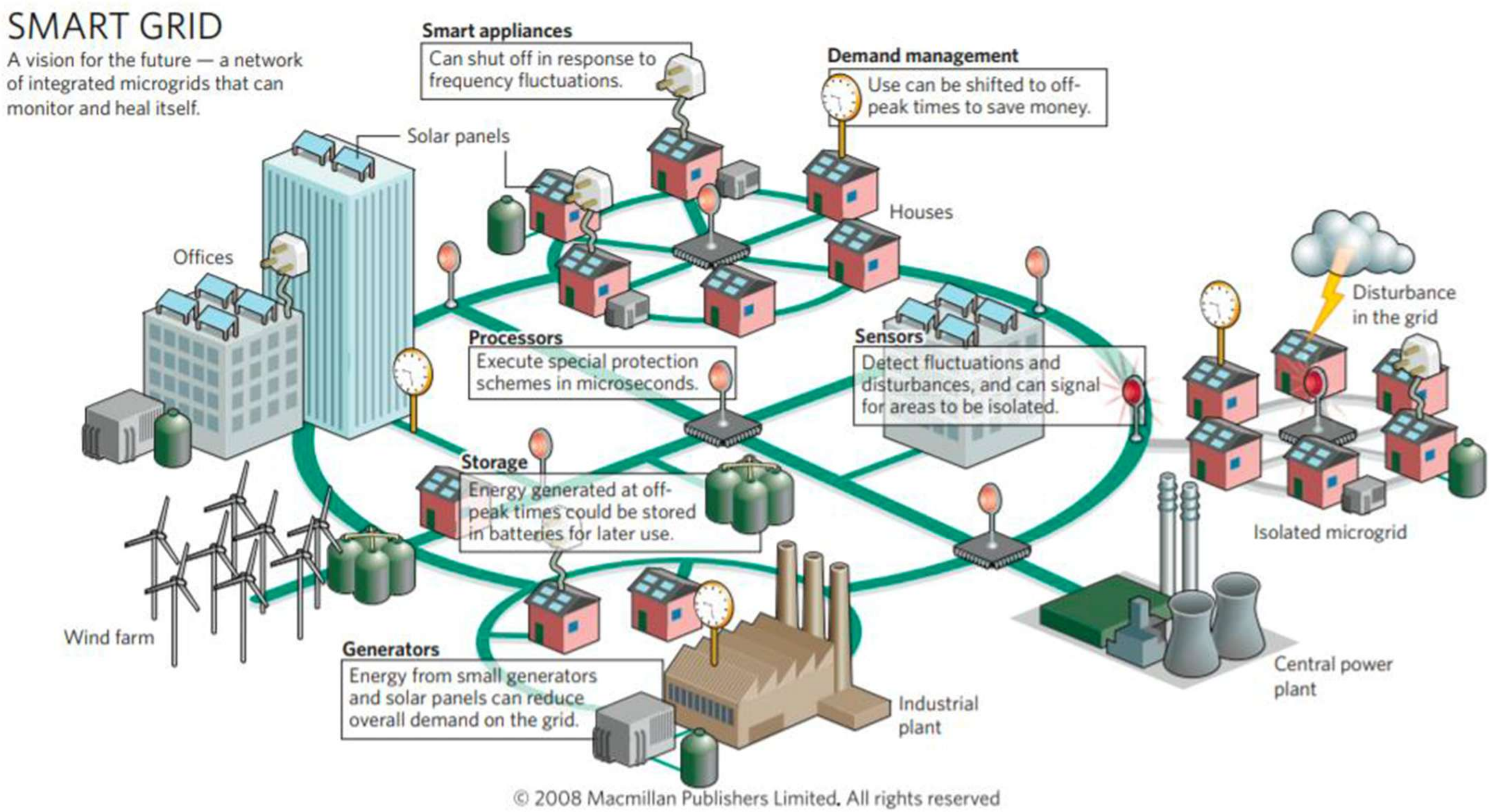
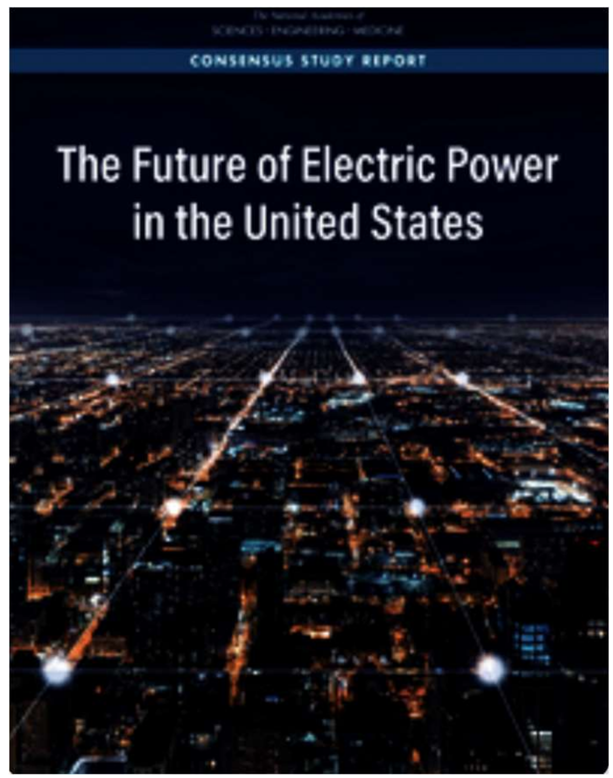


Image from NASEM The future of electric power in the United States, 2021

These two National Academy Consensus studies…

…that I chaired provide background on the U.S. electricity system. They can be downloaded for free from the web site of the National Academy Press

2017



2021

Today I will talk about three things:

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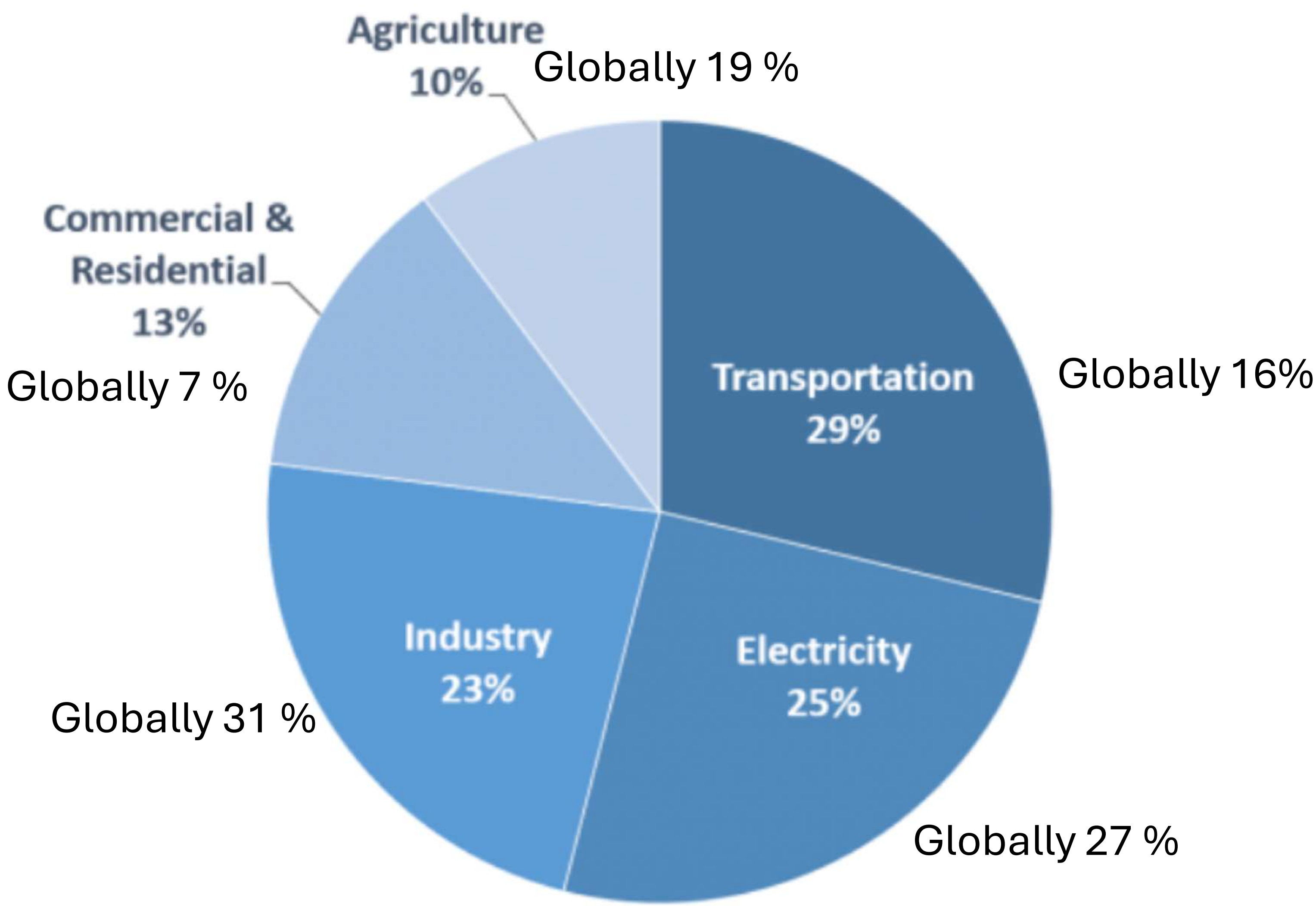
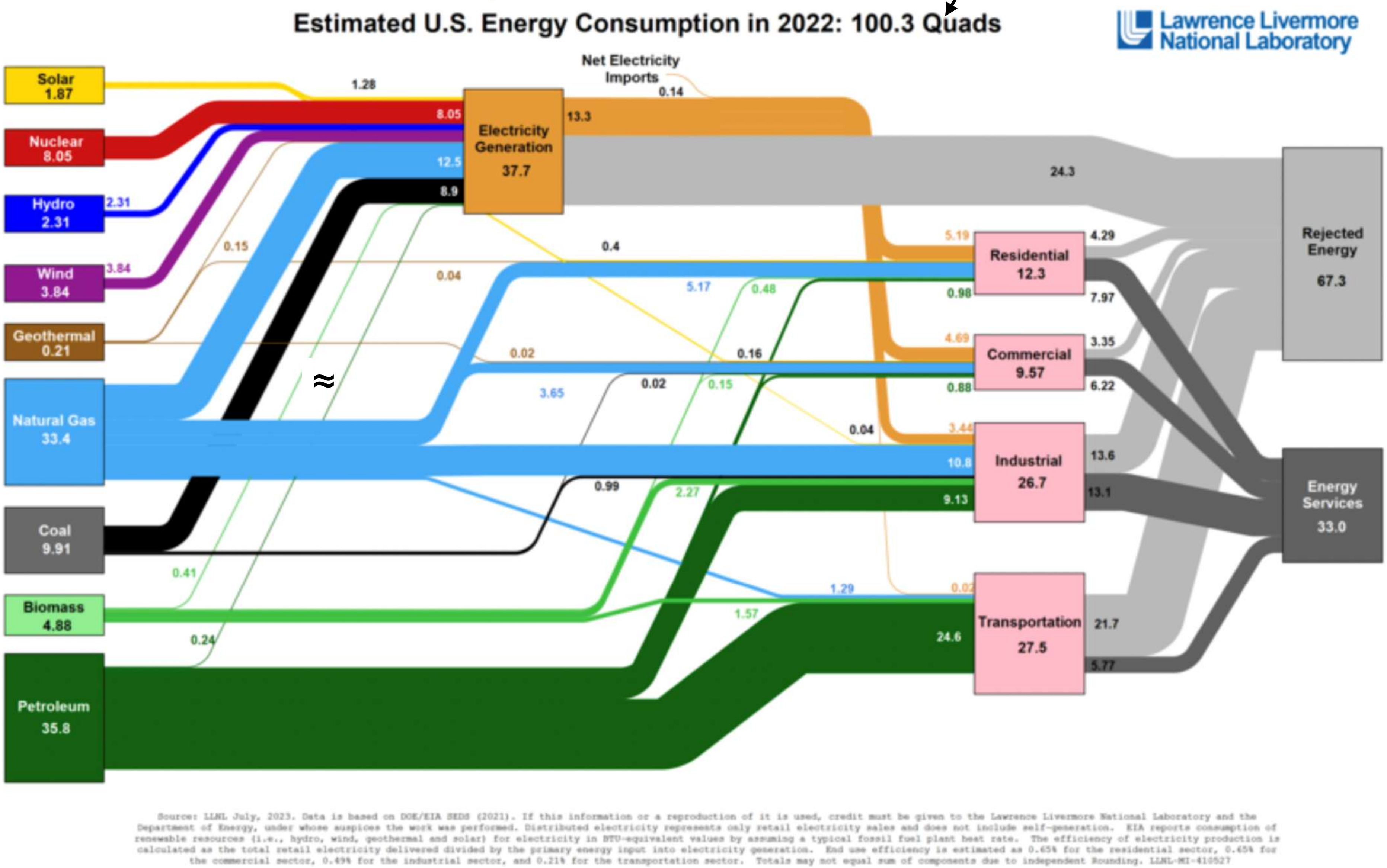
Where CO2 comes from, in the U.S. and globally:



Sources: US EPA and Gates

1 quad is 10^{15} BTU or $\approx 0.3\times10^{12}$ kW-hr

The US energy system:

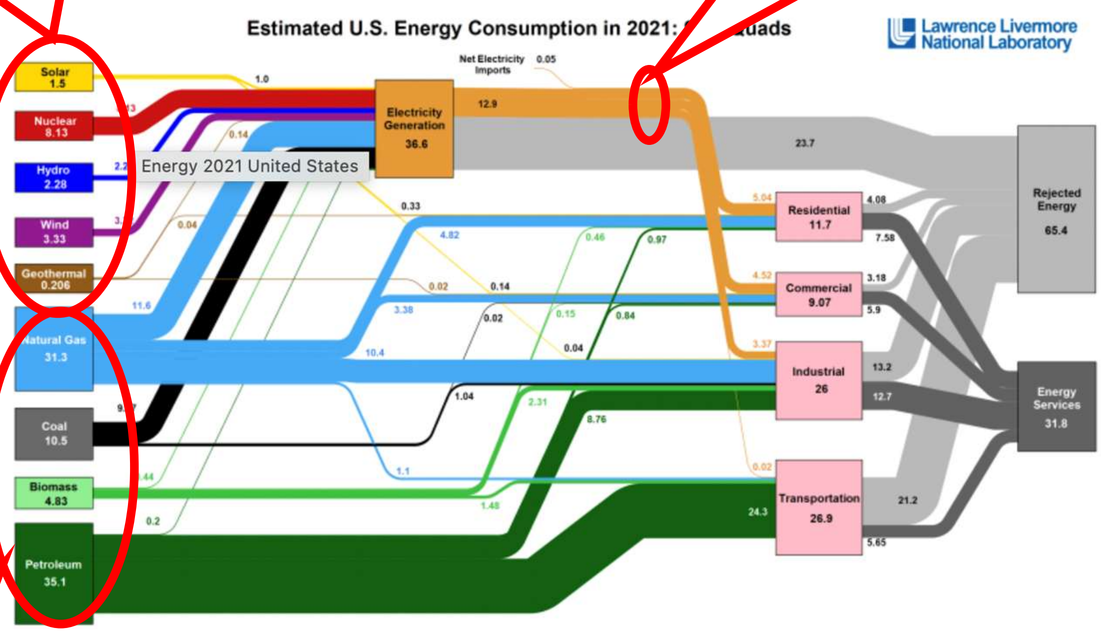


Source: https://flowcharts.llnl.gov

Basically, three strategies:

Use more generation that does not produce CO_2

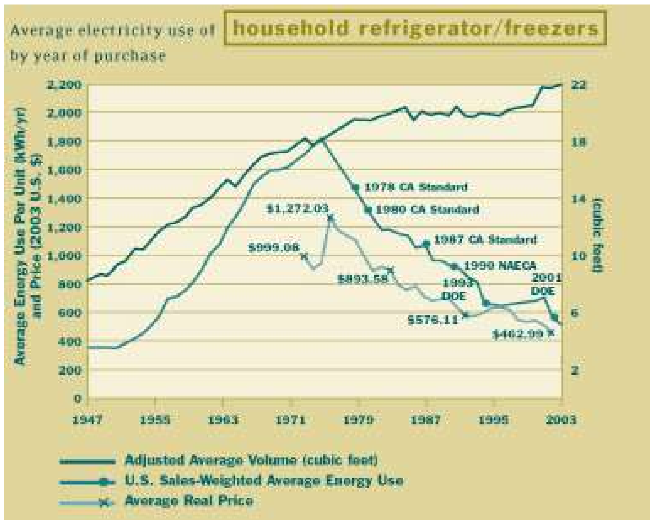
Use the electricity we generate more efficiently so we don't need to make as much.



Don't let the CO_2 enter the atmosphere.

There is an enormous potential to reduce CO_2 emissions through more efficient use of electricity. Here are four examples:

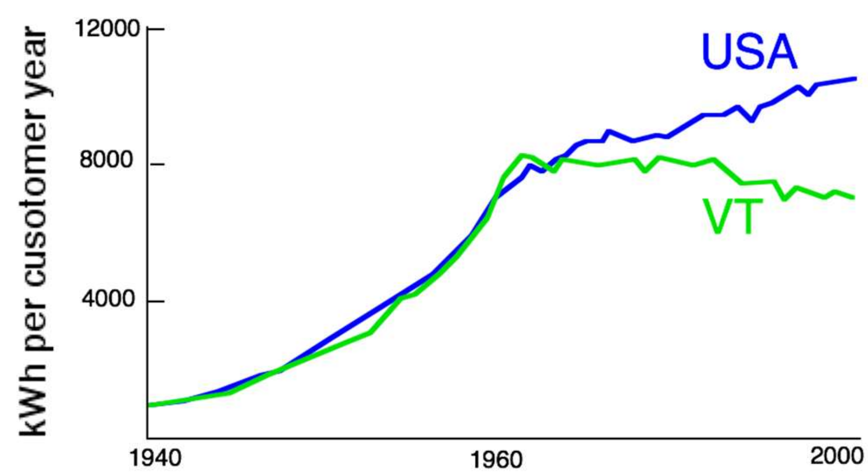
Refrigerators:



Heat pumps:

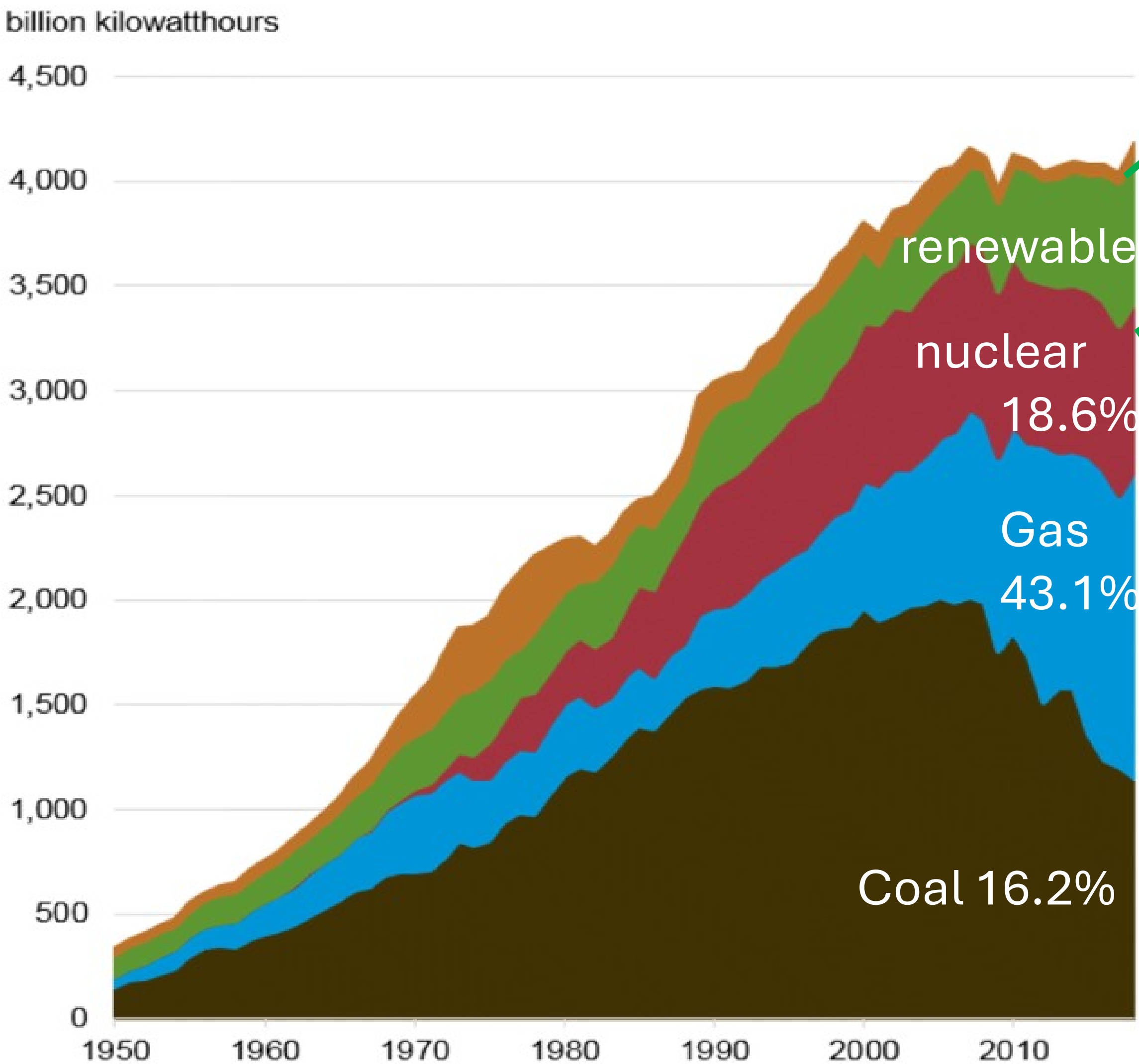
Solid state lighting:

Efficiency VT:



Sources: Marilyn Brown et al.; Phillips; Bosch; Kensa; M. Dworkin

How the US generates electricity



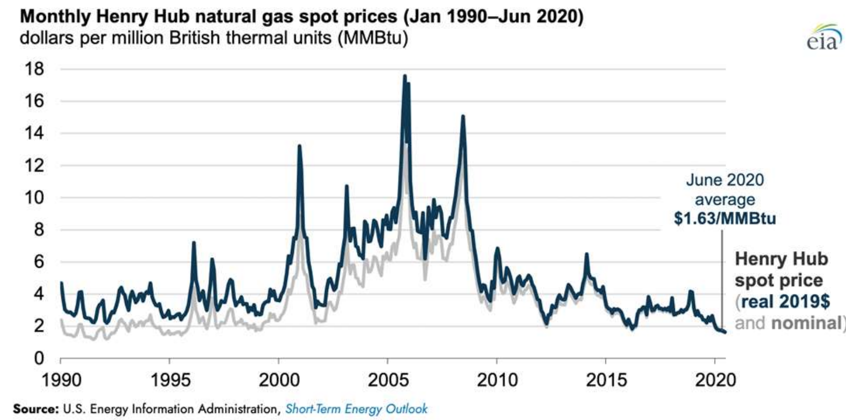
Fraction of total from renewables in 2023

Wind	10.2%
Hydro	5.7%
Solar	3.9%
Other	1.6%

Note: Electricity generation from utility-scale facilities.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 7.2a, March 2019

The switch to natural gas

In the early 2000s the shale gas revolution took off, and gas prices fell dramatically. Because producing electricity with gas produces only half as much CO_2 as using coal, some describe the switch to gas as a "bridge to decarbonizing electricity."



BUT… a bridge needs an abutment at the far end and, so far not much has been done to build that!

Image sources: G.Morgan, EIA, http://mydrivingseat.com

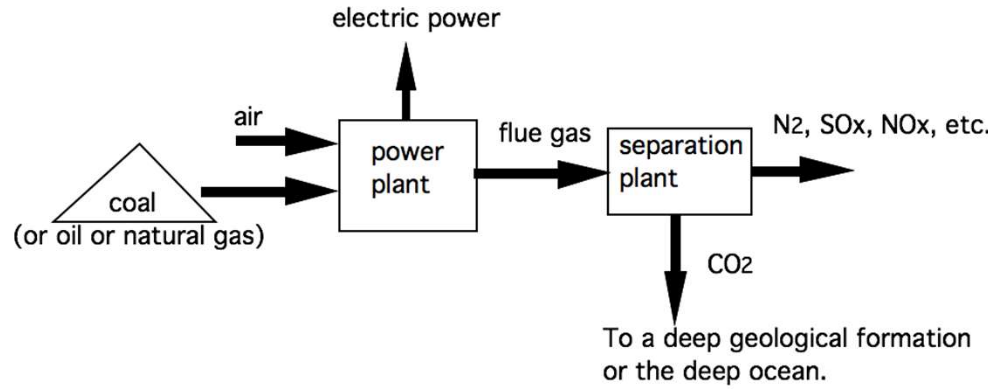
We’ve got lots of coal and gas…

…and, while wind and solar should play a *much* bigger role, we are not likely to be able to completely decarbonize just using renewables.

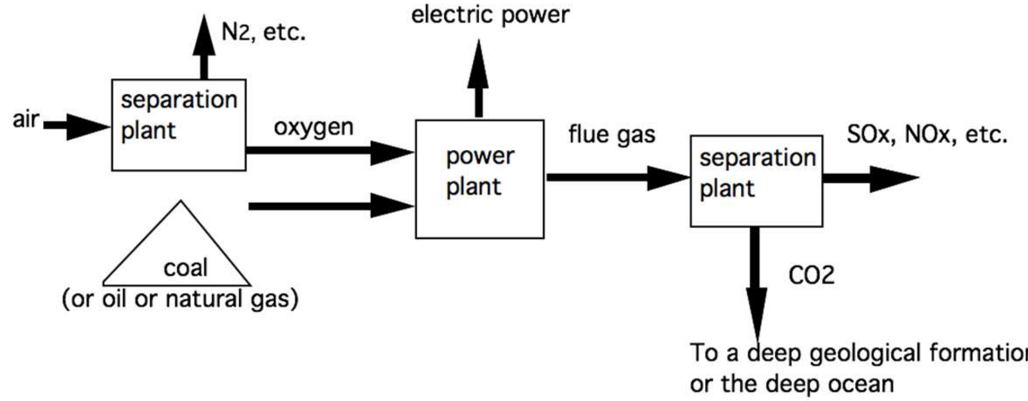
That means we need to find ways to use gas (and perhaps some coal) while *not* releasing CO_2 to the atmosphere.

Capturing CO_2 from coal or gas plants

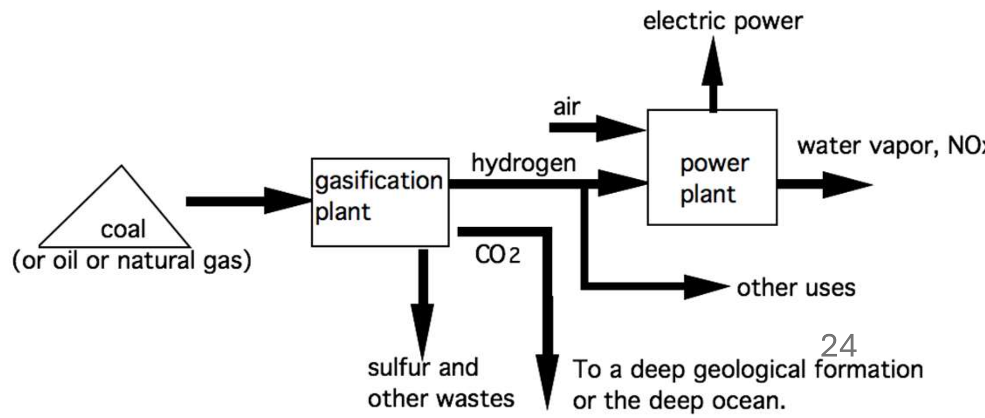
1. Burn it in the normal way and then scrub the carbon dioxide out of the “flue gas” (which is mainly made up of nitrogen since that is what makes up most of air).



2. Separate oxygen from the air and burn the coal or gas in oxygen. That way there the flue gas is mostly carbon dioxide so its easy to capture.



3. Extract the hydrogen run the plant on hydrogen. When hydrogen burns it combines with oxygen to make H_2O, which of course is just water.

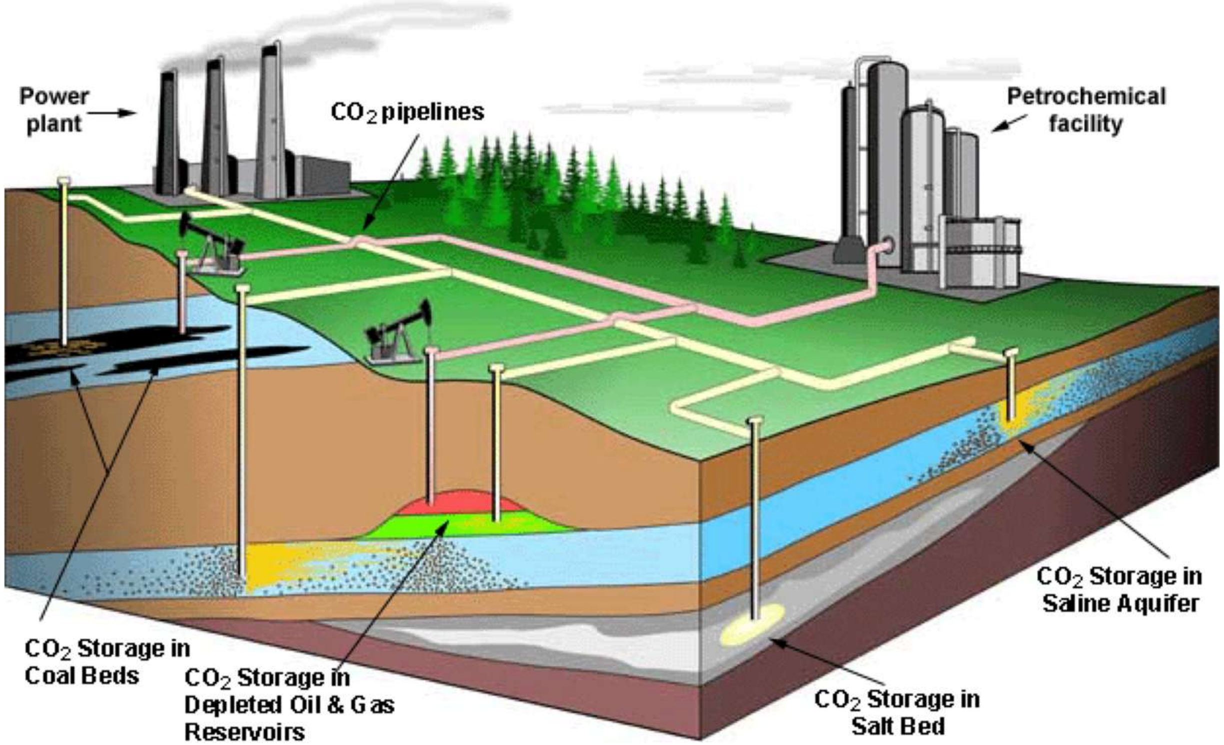



This is not just pie in the sky
Sources: www.free-pictures-photos.com and movementbuilding.org

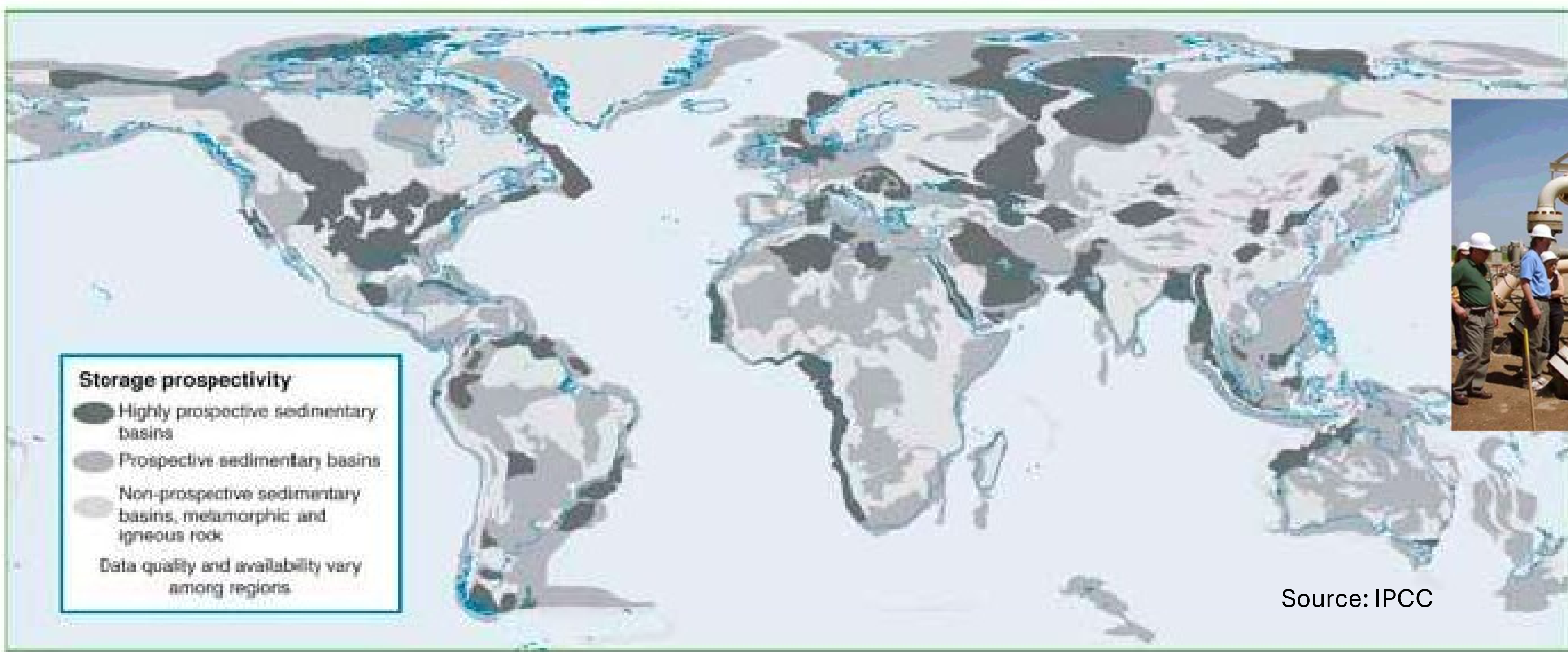
W.A. Parish Plant

Once the CO_2 has been captured…

…it must be compressed and injected into suitable geological structures deep under ground (>1km).



Source: www.nrcan.gc.ca



Source: IPCC

http://gsc.nrcan.gc.ca

Statoil

Sleipner Field

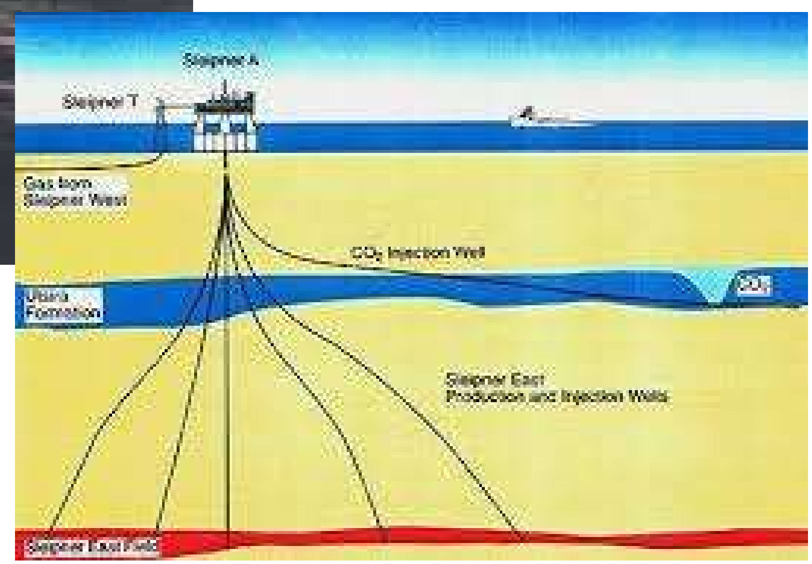
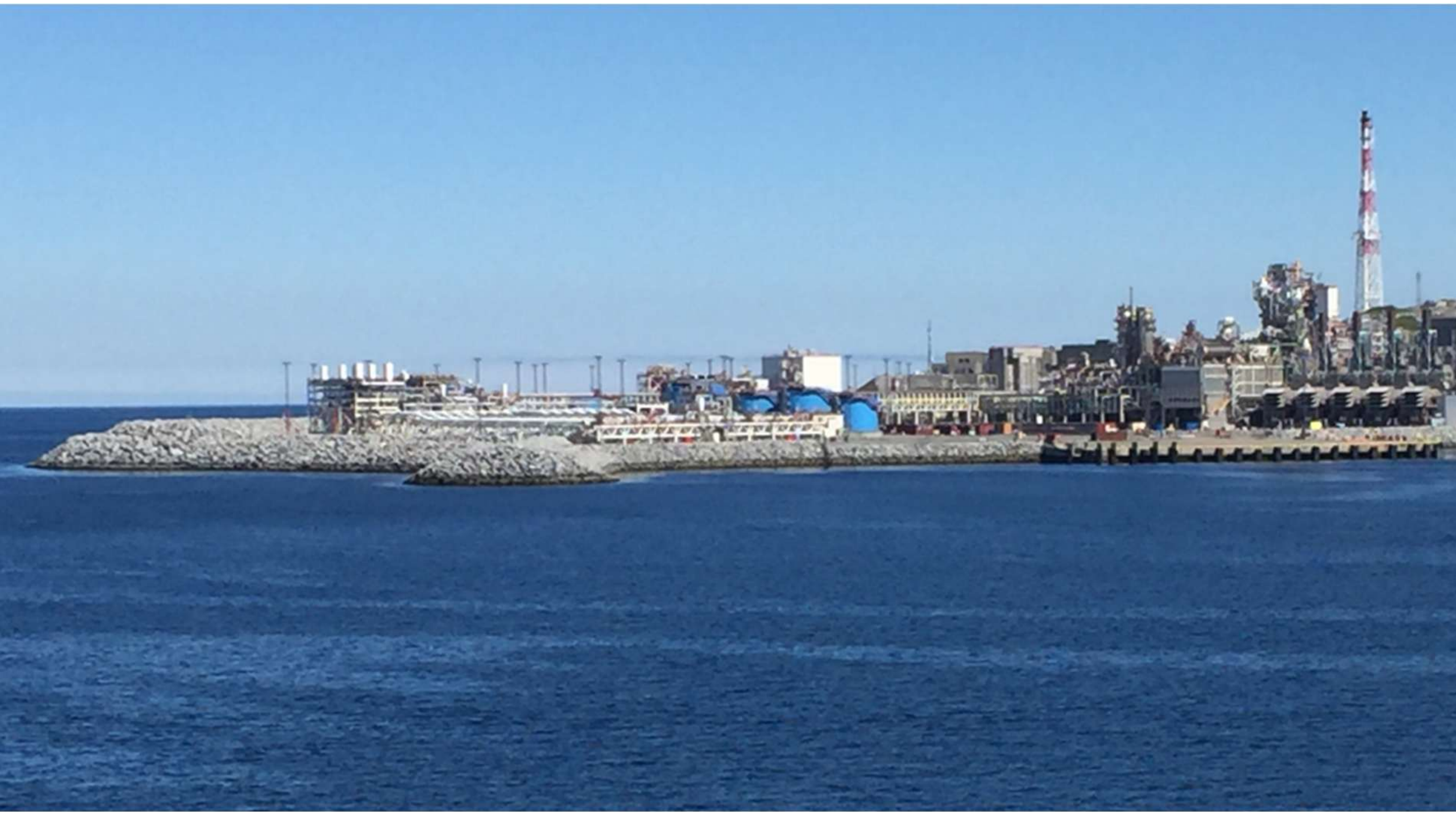


Image sources: USGS and 21stcentech.com

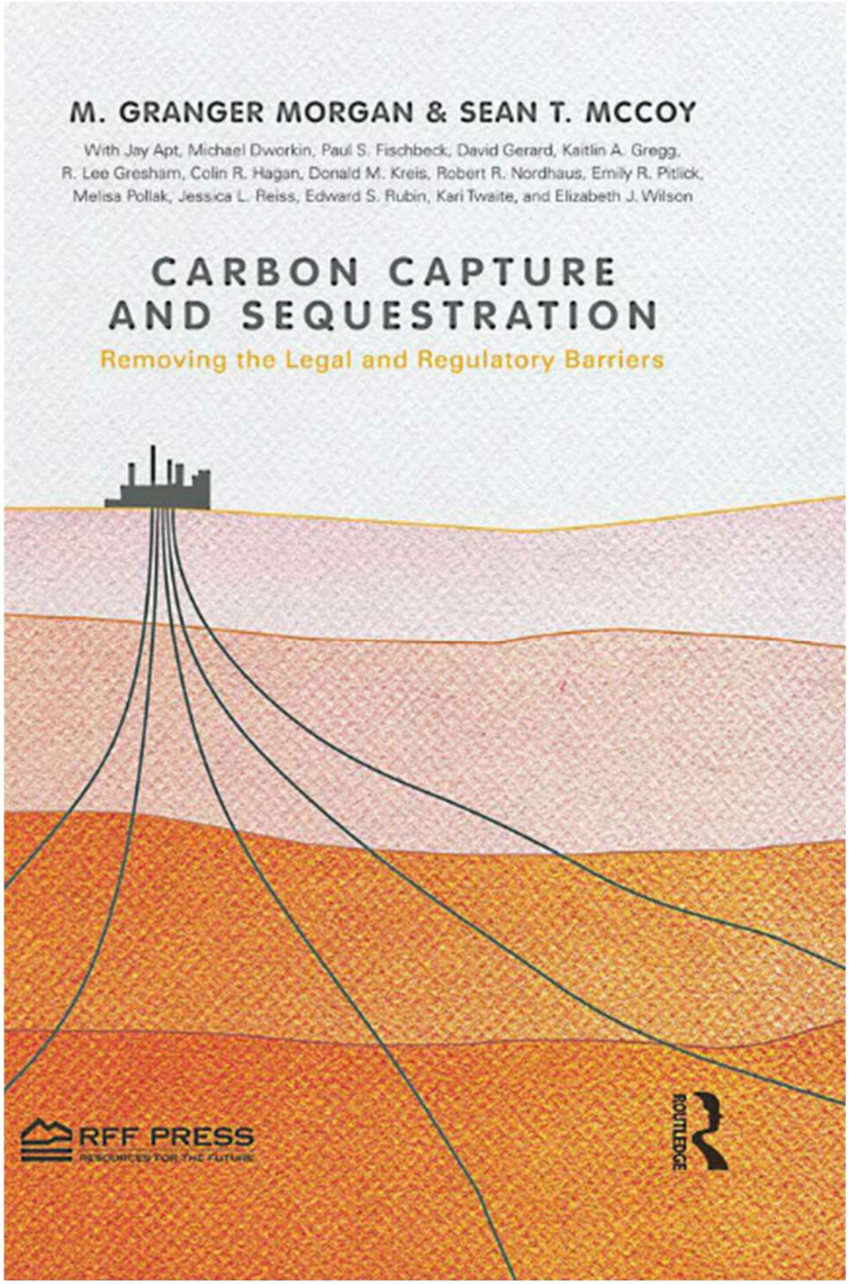
Melkøya near Hammerfest



This facility (at 70.6 °N) receives and processes natural gas from the Snøhvit field in the Barents Sea. The gas is conveyed in a 160 km gas pipeline to the facility, which became operational in the autumn of 2007

We ran a big project on CCS …

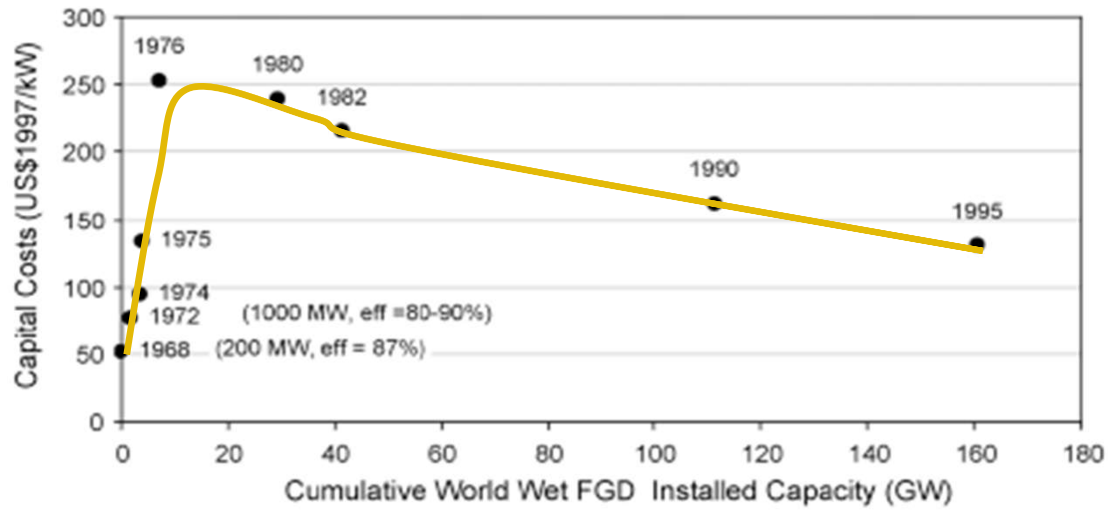
…and published a book through RFF Press.

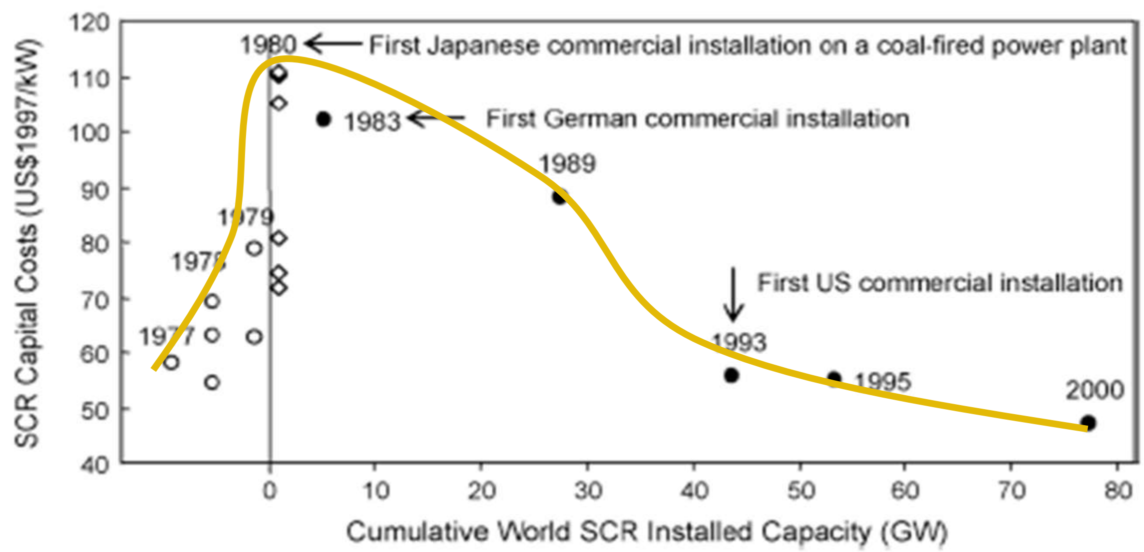


Contents

Learning takes time

In the case of both SO_2 scrubber technology and in the case of NOx control technology, Ed Rubin has found that costs rose significantly after problems were encountered with the design and performance of the first few plants.





There is every reason to believe that the same is true for CCS.

Source: Rubin et al., IJGGC, 2007

The US and the world are moving *MUCH* too slowly on CCS!

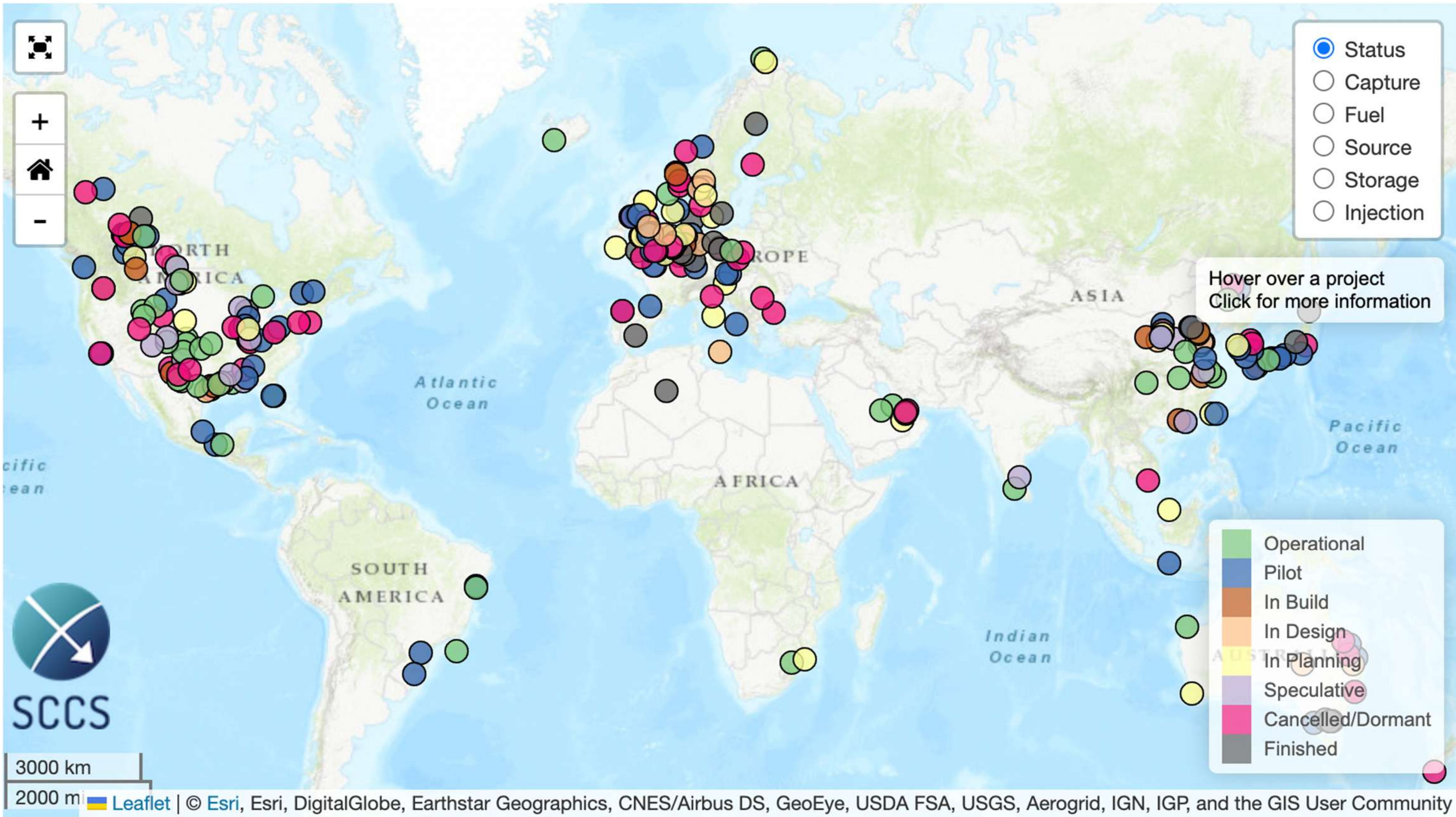


Image source: https://www.sccs.org.uk/resources/global-ccs-map

Today about 40% of US electricity is carbon free

Today in the US we make about:

5.7 % from hydropower

18.6 % from nuclear

10.2 % from wind

3.9 % from solar

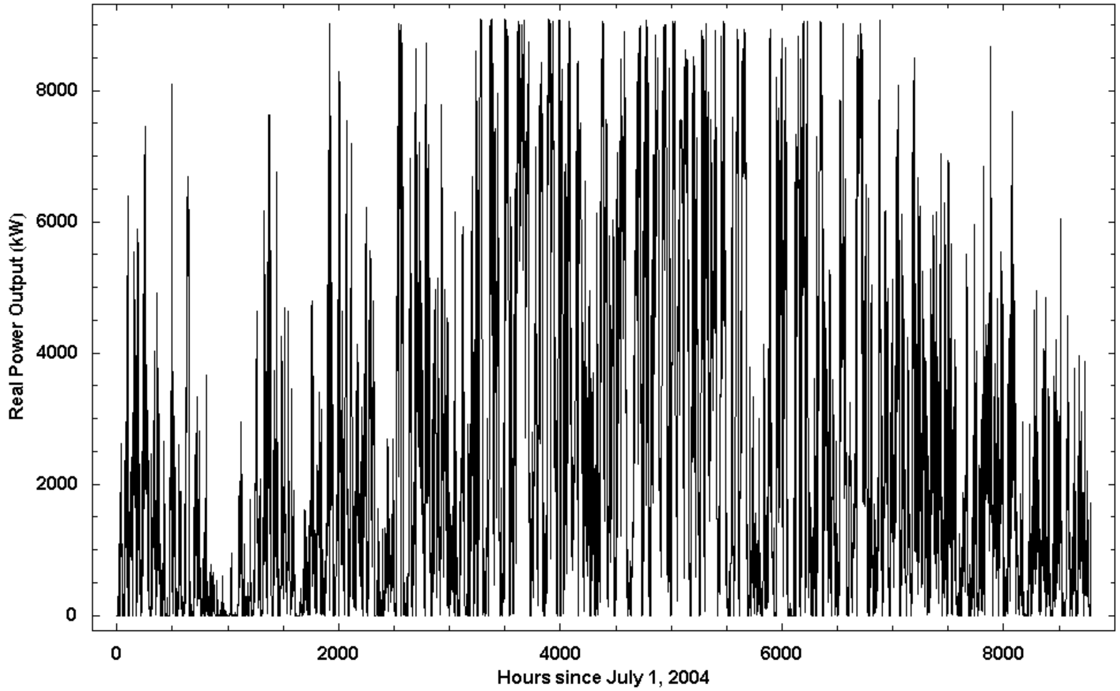
1.1 % from biomass & geothermal

To fully decarbonize by 2035, we'll need to build ≥55 GW new carbon free electricity *per year*. Although the U.S. built 60 GW of natural gas generators per year in 1999 and 2000, it has not built more than 15 GW of renewables in a single year. We can do it – but it will take a BIG push.

Source: U.S. EIA

Wind can play a bigger role

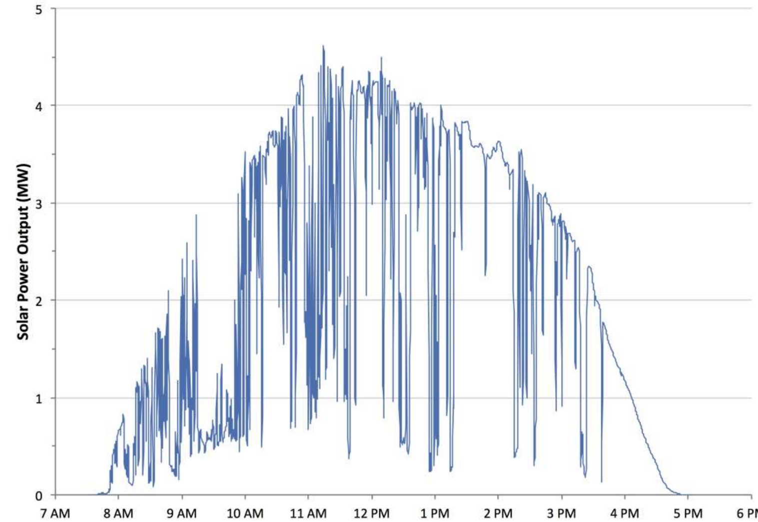
But, as the fraction of installed capacity grows, dealing with intermittency becomes a major problem.

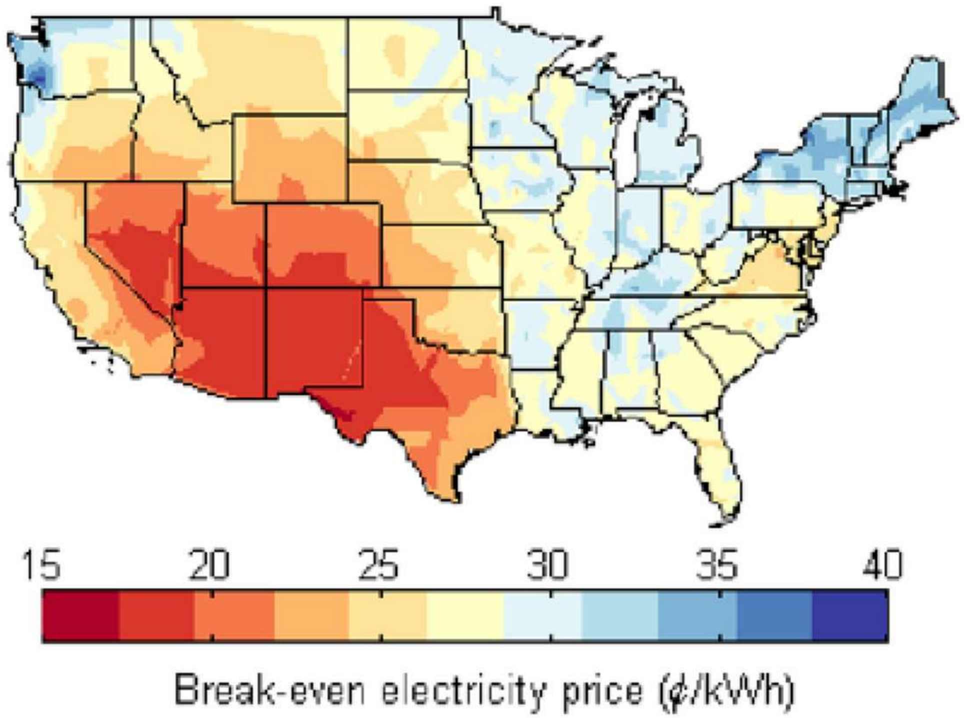


In places with lots of hydro power, like the U.S. Pacific Northwest and Scandinavia, this can be handled. Elsewhere it is a serious problem

Sources: GE, Jay Apt, USBoR

Solar PV





SunShot
U.S. Department of Energy

The U.S. Department of Energy SunShot Initiative is a national effort to drive down the cost of solar electricity and support solar adoption. SunShot aims to make solar energy a low cost electricity source for all Americans through research and development efforts in collaboration with public and private partners.

Shelly Hagerman, Paulina Jaramillo and M. Granger Morgan, "Is Rooftop Solar PV at Socket Parity Without Subsidies?," *Energy Policy*, *89*, 84-94, 2016.

Photo from energynext.in

35

Nuclear

As the French have clearly shown, despite its various issues, nuclear power is capable of serving a nation's electricity needs without CO_2 emissions. In years past about 88% of EDF's electricity has been generated in 58 nuclear power plants at 19 different sites.

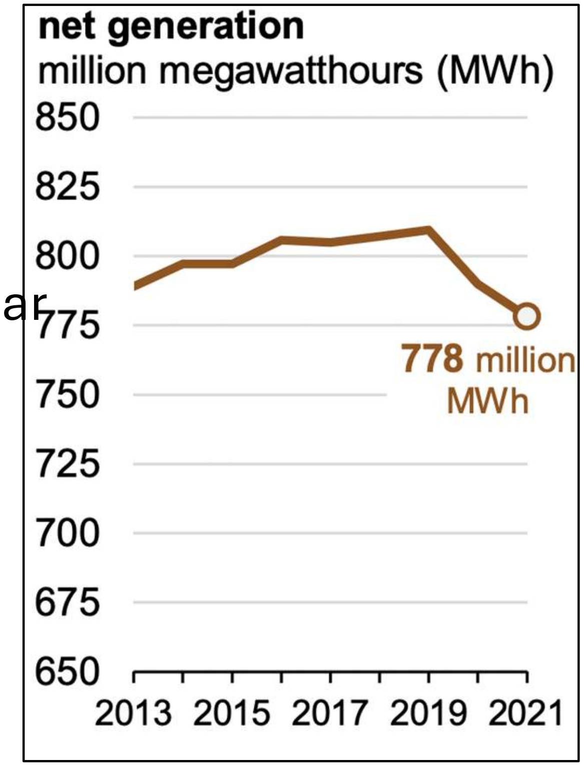
In the US ~20% of our electricity has been coming from nuclear power. That is carbon free electricity. These plants are getting old so there are major efforts underway to engage in "life extension".

Issues include **cost**, public acceptance, safety, risk of nuclear proliferation, and waste management

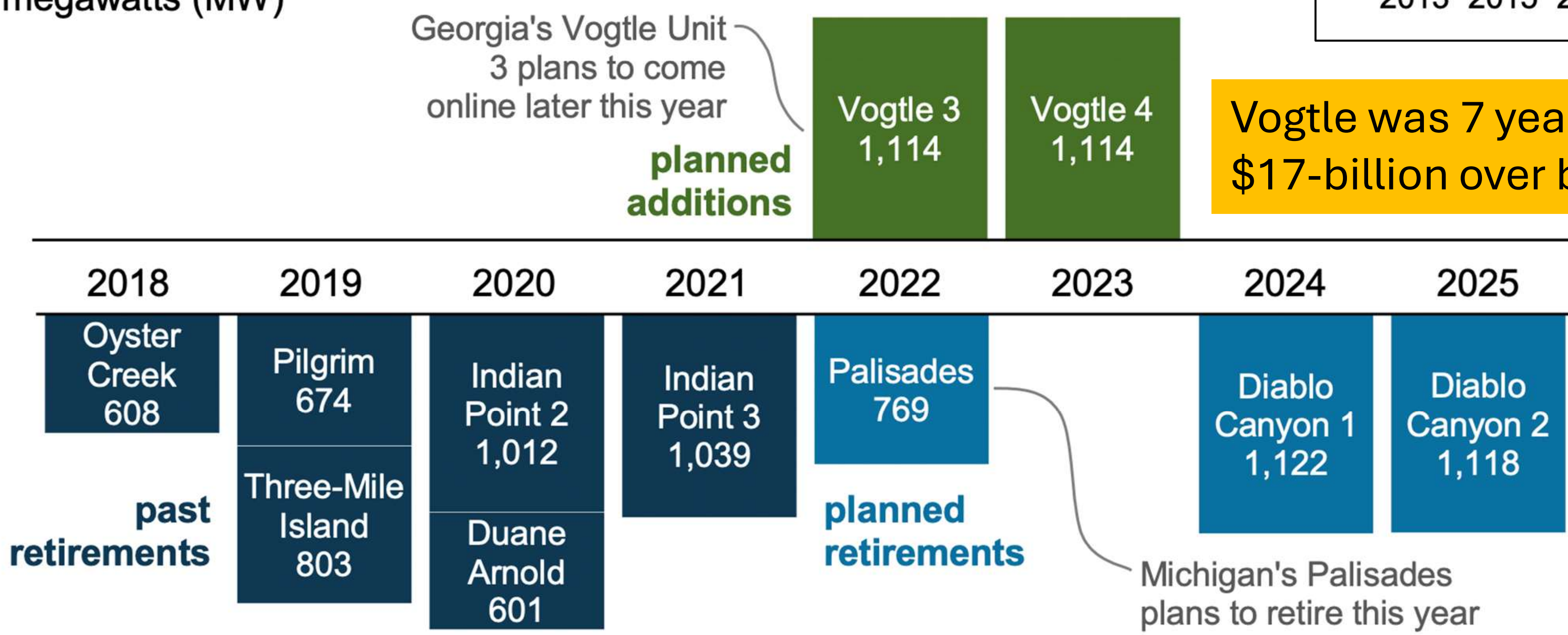
Source: www.edf.fr/12025m/txt/Homefr/EDFEnergies/Nuclearpower.html; en.wikipedia.org/wiki/Électricité_de_France

U.S. Nuclear over time

In 2023 18.6% of U.S. electricity generation came from nuclear



U.S. nuclear power plant capacity additions and retirements (2018–2025)
megawatts (MW)



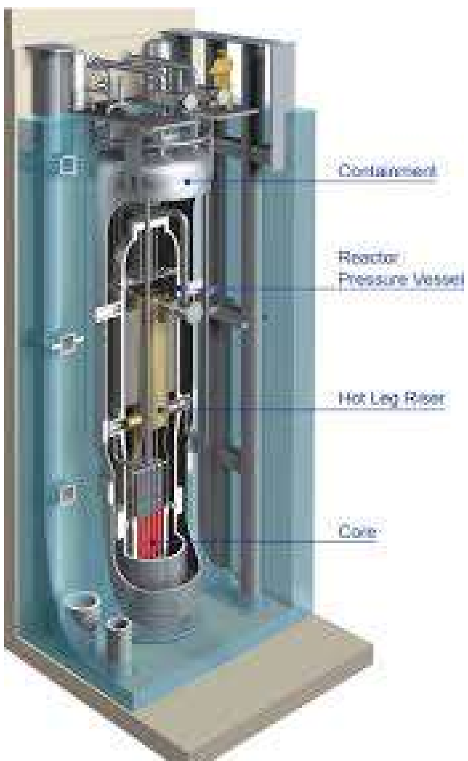
Vogtle was 7 years late and $17-billion over budget

Source U.S. Energy Information Administration, *Preliminary Monthly Electric Generator Inventory*

Imaged from EIA

SMR and micro reactors

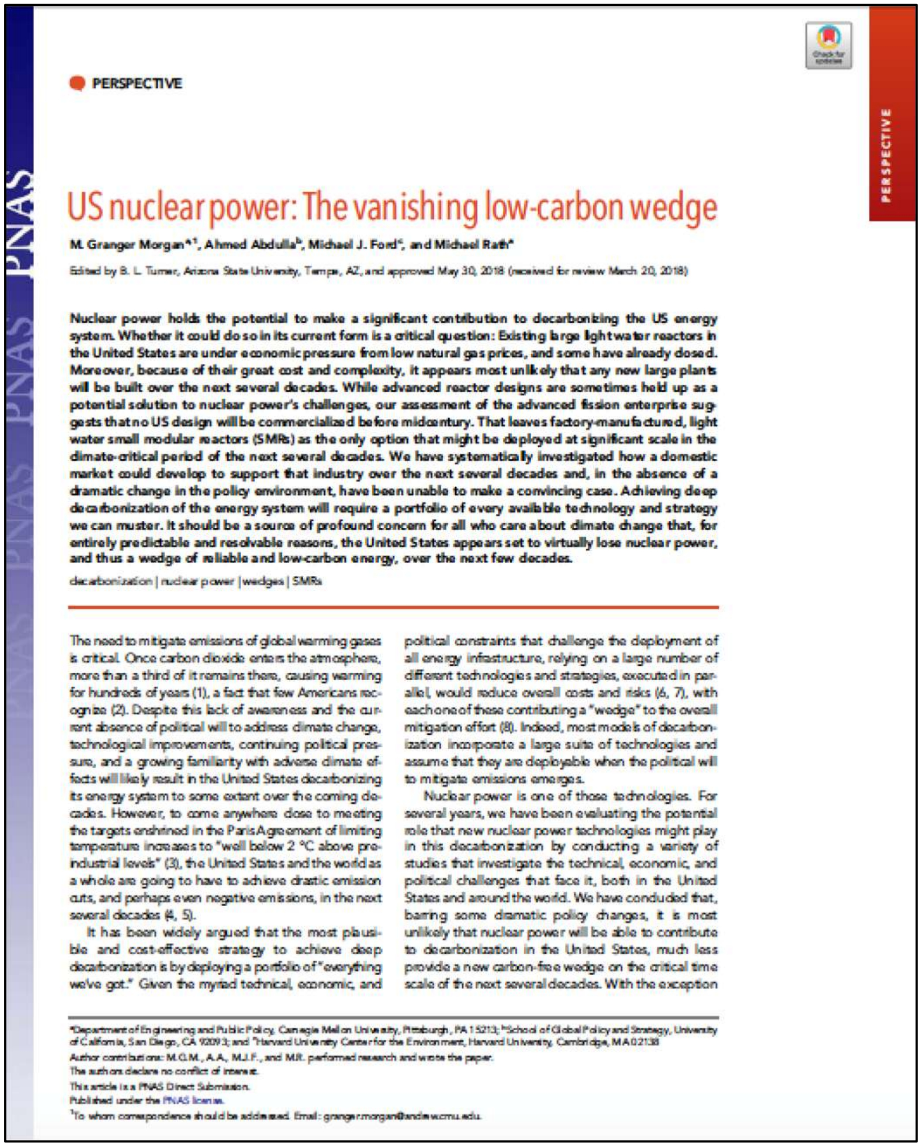
Many argue that if new nuclear plants are going to play a role in decarbonizing the US energy system over the next 3-4 decades, it will be via factory mass-produced light water small modular reactors (SMRs) and even smaller micro- reactors.



While SMR's could be used to produce electricity, they could also be used for process heat for many industrial processes.

Images from NuScale

While there is lots of talk, I think for the next several decades we'll not see significant new nuclear



PERSPECTIVE

US nuclear power: The vanishing low-carbon wedge

M. Granger Morgan[a,1], Ahmed Abdulla[b], Michael J. Ford[a], and Michael Rath[a]

Edited by B. L. Turner, Arizona State University, Tempe, AZ, and approved May 30, 2018 (received for review March 20, 2018)

Nuclear power holds the potential to make a significant contribution to decarbonizing the US energy system. Whether it could do so in its current form is a critical question: Existing large light water reactors in the United States are under economic pressure from low natural gas prices, and some have already closed. Moreover, because of their great cost and complexity, it appears most unlikely that any new large plants will be built over the next several decades. While advanced reactor designs are sometimes held up as a potential solution to nuclear power's challenges, our assessment of the advanced fission enterprise suggests that no US design will be commercialized before midcentury. That leaves factory-manufactured, light water small modular reactors (SMRs) as the only option that might be deployed at significant scale in the climate-critical period of the next several decades. We have systematically investigated how a domestic market could develop to support that industry over the next several decades and, in the absence of a dramatic change in the policy environment, have been unable to make a convincing case. Achieving deep decarbonization of the energy system will require a portfolio of every available technology and strategy we can muster. It should be a source of profound concern for all who care about climate change that, for entirely predictable and resolvable reasons, the United States appears set to virtually lose nuclear power, and thus a wedge of reliable and low-carbon energy, over the next few decades.

decarbonization | nuclear power | wedges | SMRs

The need to mitigate emissions of global warming gases is critical. Once carbon dioxide enters the atmosphere, more than a third of it remains there, causing warming for hundreds of years (1), a fact that few Americans recognize (2). Despite this lack of awareness and the current absence of political will to address climate change, technological improvements, continuing political pressure, and a growing familiarity with adverse climate effects will likely result in the United States decarbonizing its energy system to some extent over the coming decades. However, to come anywhere close to meeting the targets enshrined in the Paris Agreement of limiting temperature increases to "well below 2 °C above preindustrial levels" (3), the United States and the world as a whole are going to have to achieve drastic emission cuts, and perhaps even negative emissions, in the next several decades (4, 5).

It has been widely argued that the most plausible and cost-effective strategy to achieve deep decarbonization is by deploying a portfolio of "everything we've got." Given the myriad technical, economic, and political constraints that challenge the deployment of all energy infrastructure, relying on a large number of different technologies and strategies, executed in parallel, would reduce overall costs and risks (6, 7), with each one of these contributing a "wedge" to the overall mitigation effort (8). Indeed, most models of decarbonization incorporate a large suite of technologies and assume that they are deployable when the political will to mitigate emissions emerges.

Nuclear power is one of those technologies. For several years, we have been evaluating the potential role that new nuclear power technologies might play in this decarbonization by conducting a variety of studies that investigate the technical, economic, and political challenges that face it, both in the United States and around the world. We have concluded that, barring some dramatic policy changes, it is most unlikely that nuclear power will be able to contribute to decarbonization in the United States, much less provide a new carbon-free wedge on the critical time scale of the next several decades. With the exception

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Author contributions: M.G.M., A.A., M.J.F., and M.R. performed research and wrote the paper.

The authors declare no conflict of interest.

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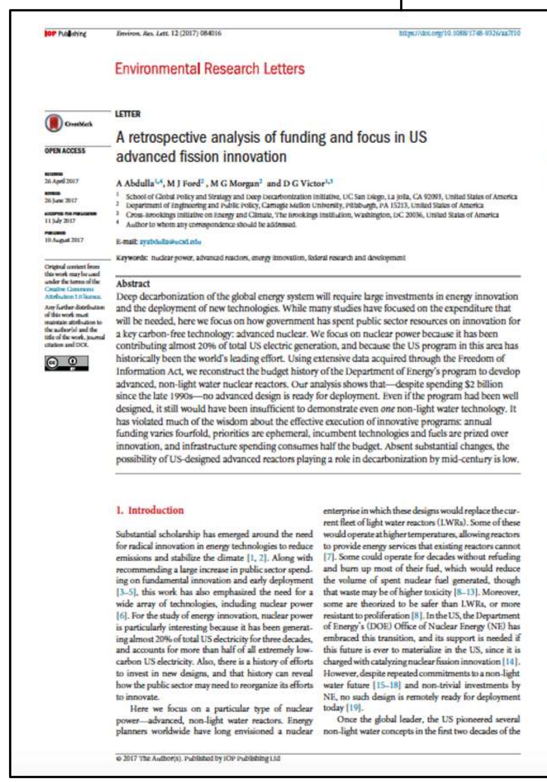

Environmental Research Letters

LETTER

A retrospective analysis of funding and focus in US advanced fission innovation

A Abdulla[1,4], M J Ford[2], M G Morgan[2] and D G Victor[1,3]

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2 Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA 15213, United States of America
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Keywords: nuclear power, advanced reactors, energy innovation, federal research and development

Abstract

Deep decarbonization of the global energy system will require large investments in energy innovation and the deployment of new technologies. While many studies have focused on the expenditure that will be needed, here we focus on how government has spent public sector resources on innovation for a key carbon-free technology: advanced nuclear. We focus on nuclear power because it has been contributing almost 20% of total US electric generation, and because the US program in this area has historically been the world's leading effort. Using extensive data acquired through the Freedom of Information Act, we reconstruct the budget history of the Department of Energy's program to develop advanced, non-light water nuclear reactors. Our analysis shows that—despite spending $2 billion since the late 1990s—no advanced design is ready for deployment. Even if the program had been well designed, it still would have been insufficient to demonstrate even *one* non-light water technology. It has violated much of the wisdom about the effective execution of innovative programs: annual funding varies fourfold, priorities are ephemeral, incumbent technologies and fuels are prized over innovation, and infrastructure spending consumes half the budget. Absent substantial changes, the possibility of US-designed advanced reactors playing a role in decarbonization by mid-century is low.

1. Introduction

Energy Policy

Expert assessments of the state of U.S. advanced fission innovation

Michael J. Ford[a,*], Ahmed Abdulla[b], M. Granger Morgan[a], David G. Victor[b,c]

ARTICLE INFO

ABSTRACT

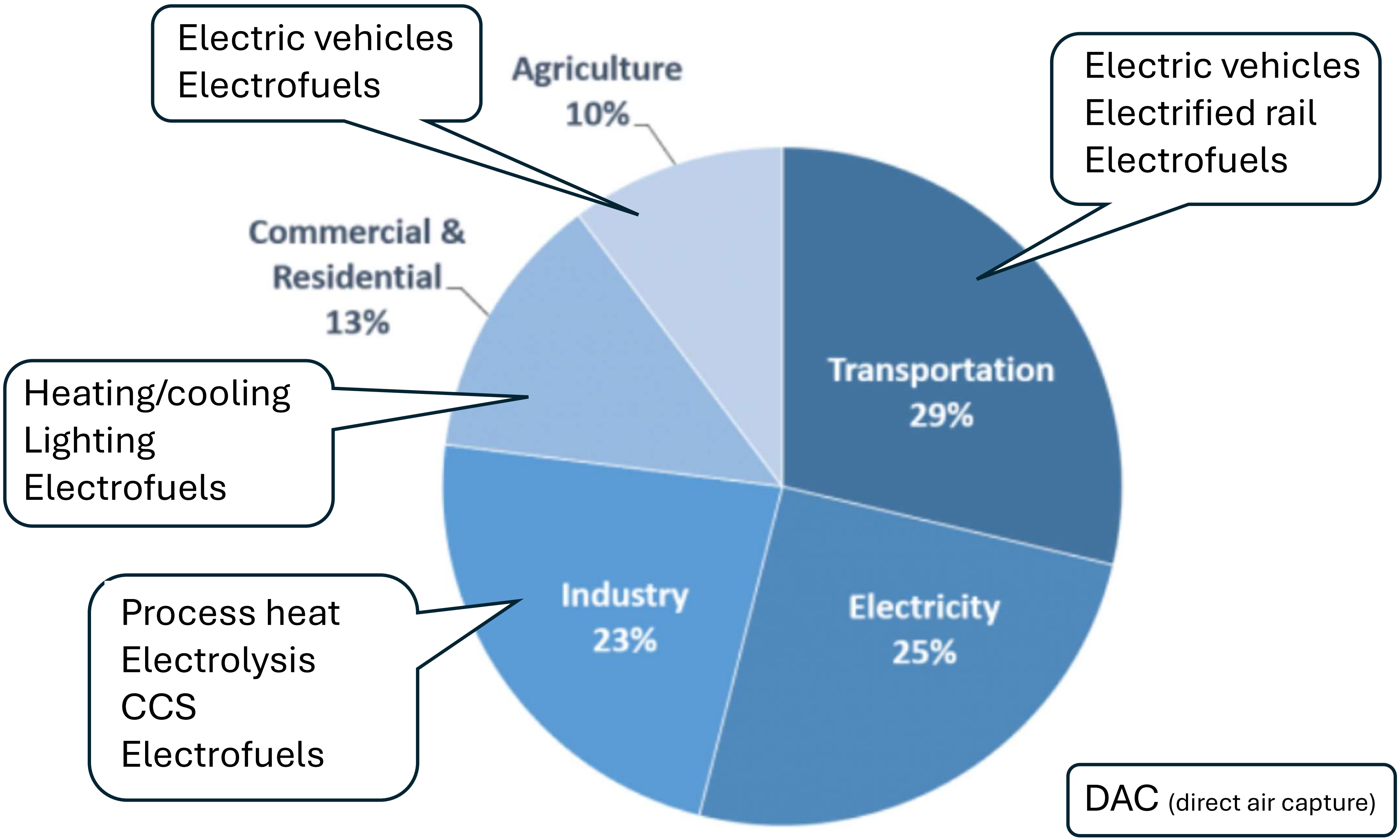
Deep decarbonization in the U.S. will require a shift to an electrified society dominated by low-carbon generation. Many studies assume a role for nuclear power in the new energy economy, and the nuclear industry anticipates an eventual transition from light water reactors to advanced, non-light water designs. The development of these advanced reactors is emblematic of the type of dramatic change that is needed to transition from fossil fuels and deeply decarbonize the energy system. The Office of Nuclear Energy (NE) in the U.S. is entrusted with the allocation of public sector expenditures for this transition, but there is little to show for its efforts; no advanced design is remotely ready for deployment.

Here, we report results from structured interviews we conducted with 30 nuclear energy veterans to elicit their impressions of the state of U.S. fission innovation. Most experts assessed NE as having been largely unsuccessful in enabling the development of advanced designs. The interview results highlight the importance of leadership and programmatic discipline, and how their absence leads to poor performance in driving change. Responses point to the likely demise of nuclear power and nuclear science in the U.S. without significant improvements in leadership, focus and political support.

Today I will talk about three things:

1. Some basic background on:
   - Climate science
   - The electricity system
2. Why electric power is critical to climate change:
   - As a leading source of CO_2 and other GHG emissions and how to reduce those emissions
   - As the most viable option to replace fossil fuels
3. The need to expand electric power transmission capacity and some efforts we are undertaking to address the problem.

Options to use electricity to decarbonize the other sectors:



Electrofuels

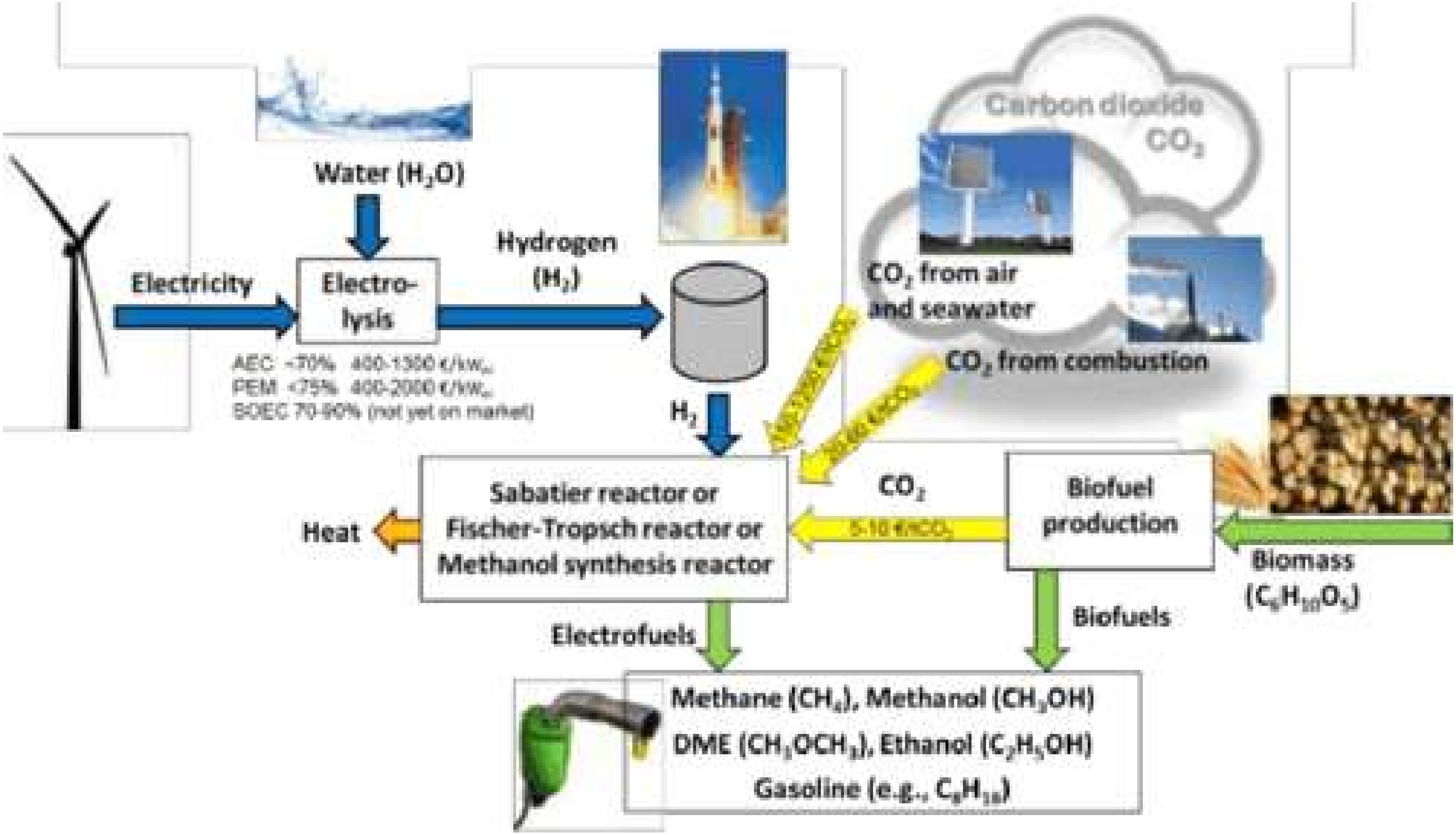


Image from M. Grahnet al, 2016.

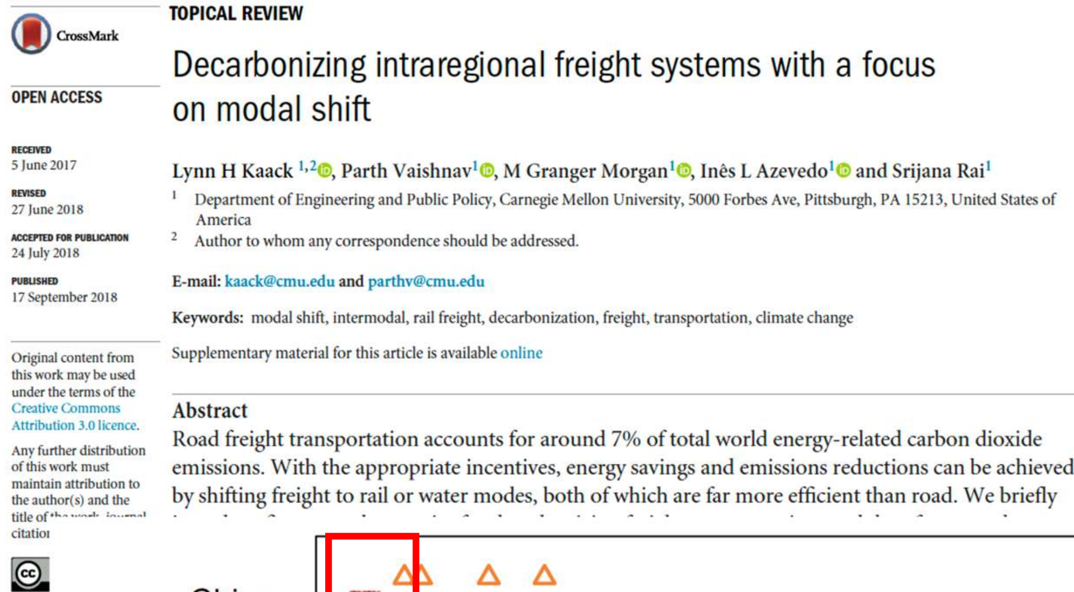
Electric vehicles

All electric

Hybrid electric

Images from: Toyota, Mercedes, Volvo, Hurtigruten

Electrified Rail



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TOPICAL REVIEW

Decarbonizing intraregional freight systems with a focus on modal shift

Lynn H Kaack [1,2], Parth Vaishnav[1], M Granger Morgan[1], Inês L Azevedo[1] and Srijana Rai[1]

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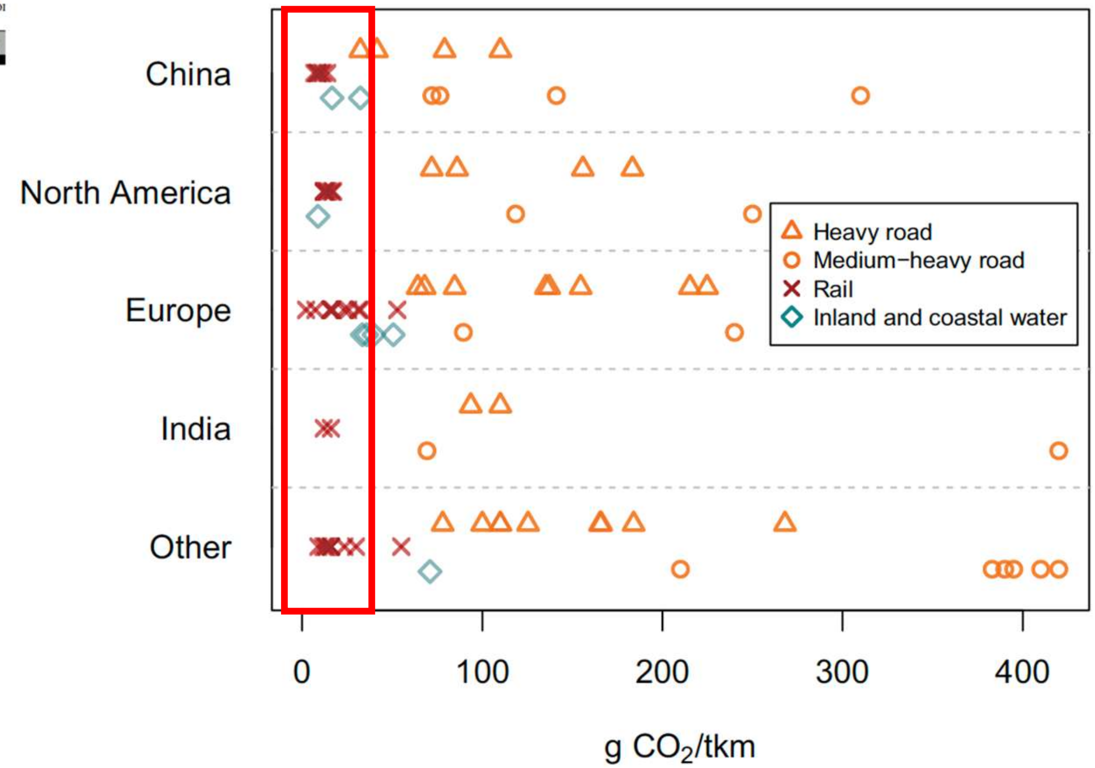
Keywords: modal shift, intermodal, rail freight, decarbonization, freight, transportation, climate change

Supplementary material for this article is available online

Abstract

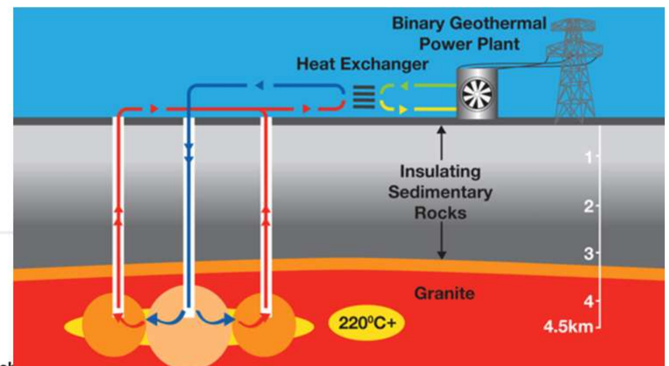
Road freight transportation accounts for around 7% of total world energy-related carbon dioxide emissions. With the appropriate incentives, energy savings and emissions reductions can be achieved by shifting freight to rail or water modes, both of which are far more efficient than road. We briefly

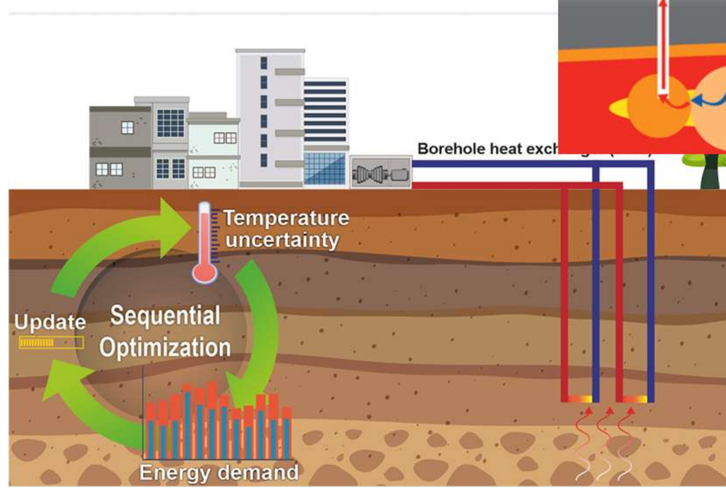


Images from: Virginiamercury; railmagazine

Heating, cooling and lighting

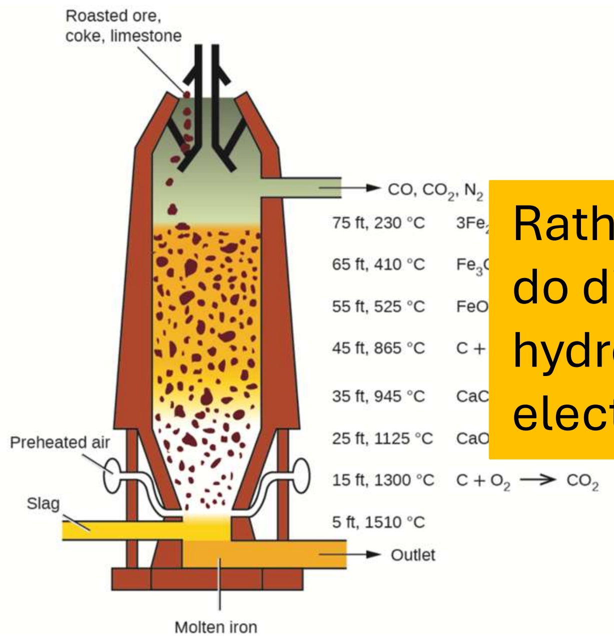
Solid state lighting:





Images from: DOE, apolarbearair.com, ars.els-cdn.com, geologyin.com, Phillips

Heavy industry…I'll make simple comments on two examples



Rather than use coke do direct reduction with hydrogen made with electricity.

CO_2 is generated … several …ces.

Process Step	Direct CO_2 emission (tCO_2/t)
Coke plant	0.794
Sinter plant	0.200
Pellet plant	0.057
Blast furnace	1.219
BOS plant	0.181

…: https://www.steelonthenet.com/kb/co2-emissions.html#:~:text=The%20main%20process%20steps%20that,produce%20large%20volume%20of%20CO2.

Use CCS and/or a different feed stock and electrofuel.

CO_2 is generated from three independent sources:

- …de-carbonation of limestone in the kiln (about 525 kg CO_2 per tonne of clinker),
- …combustion of fuel in the kiln (about 335 kg CO_2 per tonne of cement) and
- use of electricity (about 50 kg CO_2 per tonne of cement).

Source: https://www.ctc-n.org/technologies/clinker-replacement

Images from Wikipedia

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   - As the most viable option to replace fossil fuels
3. The need to expand electric power transmission capacity and some efforts we are undertaking to address the problem.

Do we really need more transmission?

Won't distributed generation (DG) like rooftop solar and moving large loads such as data centers to where electricity is generated make it unnecessary to expand transmission capacity?

The answer is no. Those things will help but we still need to move power to where loads are from:

- wind power in the Midwest and offshore platforms,
- solar in the Southwest
- hydro from Canada and other remote locations

And we also need it to assure continued system resilience (e.g. with more inverter-based power etc.)

But we face a logjam…

… arising from public opposition and legal, regulatory and other constraints including the incentives faced by utilities, that makes it difficult, often even impossible, to move clean energy from the locations where it is produced to the locations where it is needed, while assuring that the power system remains resilient.

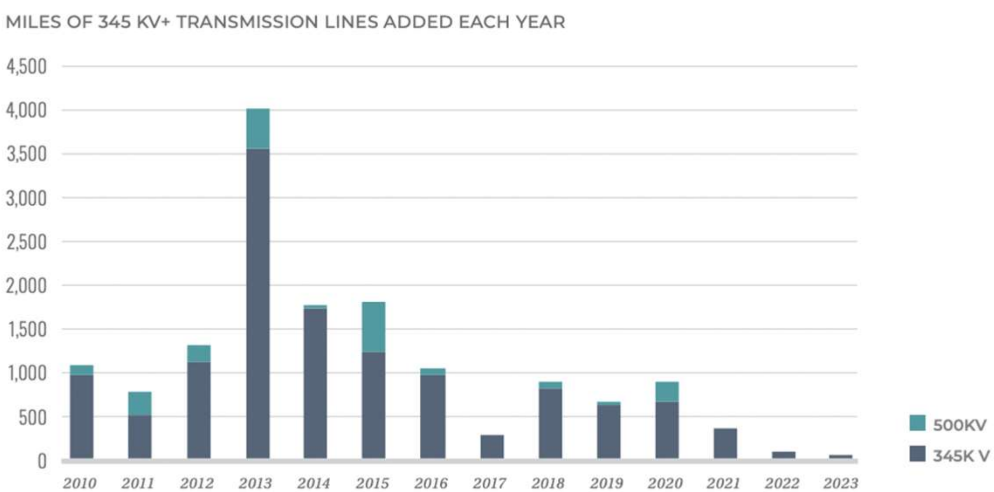


Figure from Shreve et al. (2024)

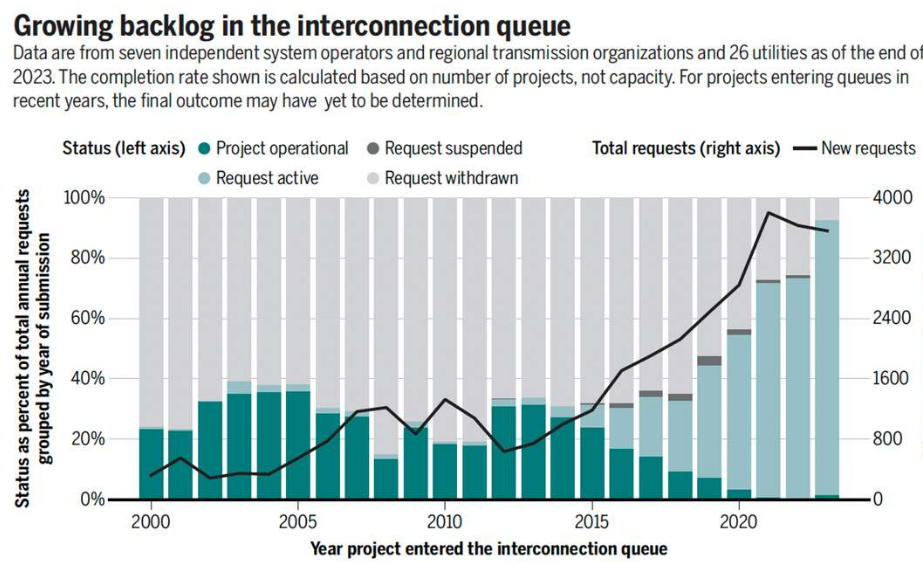


Figure from Armstrong et al. (2024).

The Federal Energy Regulatory Commission (FERC)…

…several DoE labs, and others are working on this issue, *but most of what they are doing is **very incremental*** and typically does not contemplate possible fundamental institutional, legal or regulatory changes, nor does it address public understanding and resistance.

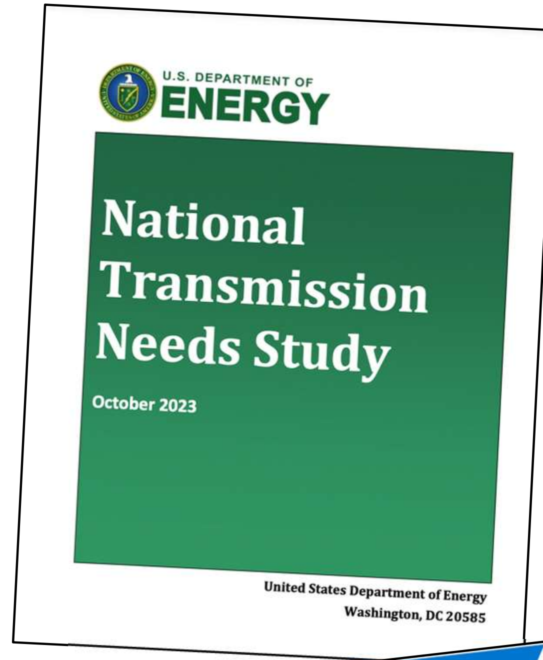
It therefore fails to address and develop solutions for a number of key issues.

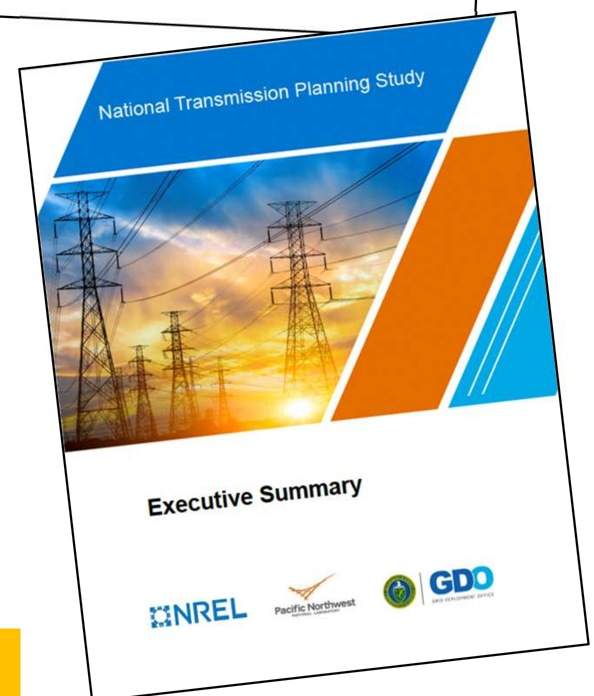
In two recent studies…

…DOE has argued that if the economy is going to stay strong, and the nation is going to make good progress in reducing CO_2 emissions, by 2050 the U.S. will need to ***more than double*** the capacity of our high-voltage transmission system. DOE has also laid out a set of optimal ways in which to expand the transmission system.

However, what neither of these DOE studies does is address the issue of *how to actually get this new transmission built.*

As I'll explain





That is what a team we've assembled proposes to do

With several colleagues, we are working to create…

…a multi-disciplinary multi-institutional (CMU, UCSD, USC, UCB, Penn State, PNNL) consortium that will identify and facilitate solutions to the problem of expanding U.S. transmission capacity.

While a solid technical and economic underpinning will be essential, we see the key challenges as:

- studying public perceptions and improving public understanding of the need for expanded transmission;
- assessing legal, regulatory, institutional, and political obstacles and those arising from interest groups.

And then:

- *proposing and actively promoting* needed fundamental structural, legal, regulatory, public communication, policy and other changes.

Public perceptions and improving public understanding

While there have been a few recent studies conducted in Europe, there do not appear to be any modern US-focused studies that use good modern social science research methods.

We are now designing such studies.

While it is important to…

…continue to work on facilitating the construction of new conventional overhead HVAC transmission lines and making incremental changes to existing legal and regulatory environments.

It is also important to complement that work by:

1. Developing ways to expand the amount of power that can be moved through existing high voltage transmission corridors.
2. Using HVDC cables embedded in both traditional and non-traditional right-of-ways (ROWs).

1. More power through existing ROWs

Three strategies hold potential to move more power through existing transmission ROWs.

1. Make greater and better use of the large amounts of data now being collected on modern transmission systems in order to operate those systems more efficiently.
2. Upgrade the capacity of existing HVAC lines. Because the amount of power that can be moved through a line is proportional to the product of the voltage and the current (P=VI), increasing either or both allows one to move more power. Doing this often requires reconductoring, new insulator strings, and/or wider ROWs. Anytime one does anything to a transmission line, issues of regulatory approval and public concerns and possible opposition become significant.
3. Convert existing HVAC lines to HVDC. Previous work we have done suggests that this may allow three times as much power to be moved through the same corridor. While the U.S. has not yet employed such a strategy, it is being done in Germany. Even to a greater extent than for reconductoring, issues of regulatory approval and public concerns are likely to play important roles in this case.

Three papers on these strategies for those who'd like to learn more:


The Electricity Journal 33 (2020) 106770

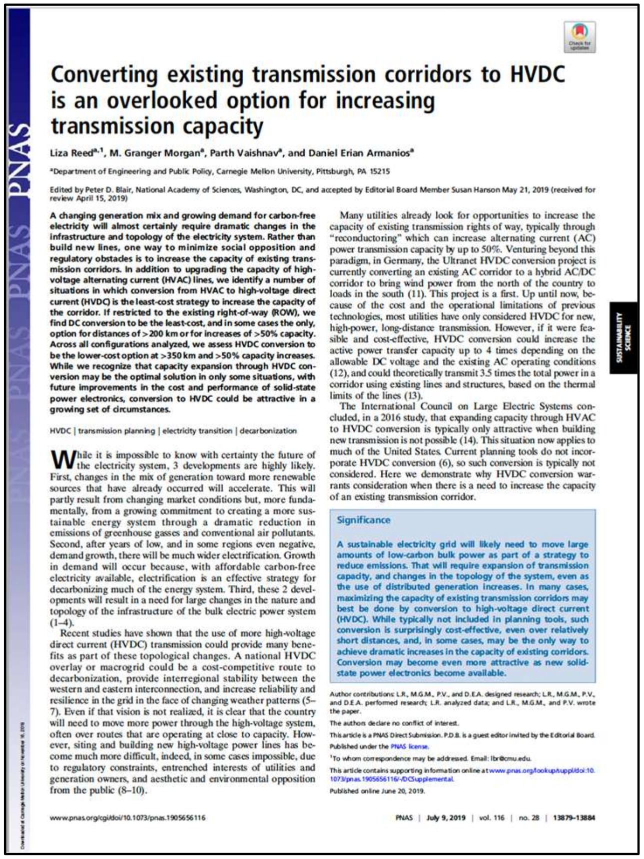
Contents lists available at ScienceDirect

The Electricity Journal

journal homepage: www.elsevier.com/locate/tej

Expanding Transmission Capacity: Examples of Regulatory Paths for Five Alternative Strategies

Liza Reed[a,*], Michael Dworkin[b], Parth Vaishnav[a], M. Granger Morgan[a]


Converting existing transmission corridors to HVDC is an overlooked option for increasing transmission capacity

Liza Reed[a,1], M. Granger Morgan[a], Parth Vaishnav[a], and Daniel Erian Armanios[a]


PNAS

Accelerating transmission capacity expansion by using advanced conductors in existing right-of-way

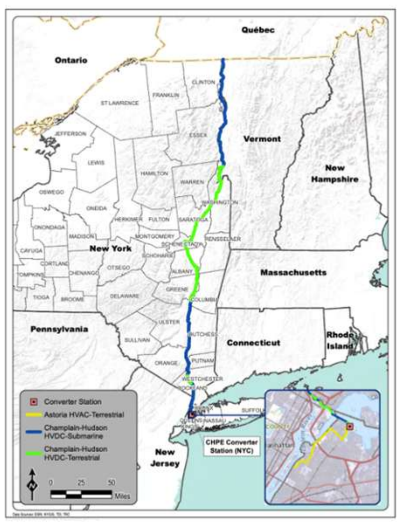
Emilia Chojkiewicz, Umed Paliwal, Nikit Abhyankar, Casey Baker, Ric O'Connell, Duncan Callaway, and Amol Phadke

2. More power via HVDC cables in traditional and non-traditional ROWs

- Existing lower-voltage transmission corridors
- Existing state and federal highways
- Existing rail corridors
- Waterways (lakes, rivers, canals)
- Abandoned and repurposed rail corridors
- Existing pipeline corridors

Champlain Hudson Power Express

This >300-mile transmission line now under construction will deliver >1GW of low-carbon power from Quebec to New York City.



Soo Green

Four strands of our planned research

1. Improve understanding of public knowledge and perceptions	2. Lay key foundations and background	3. Analysis of expanded capacity using traditional ROWs	4. Analysis of expanded capacity using non-traditional ROWs
• Perform mental model studies of public beliefs about the role about transmission and need for capacity expansion. • Develop, evaluate, refine and disseminate communication materials to improve public understanding.	• Identify and analyze past siting & upgrade failures and successes. • Develop engineering/ economic models of capacity expansion strategies. • Use power system models to assess expansion options.	• Identify obstacles to the use of: o reconductoring o HVAC to HVDC conversion o others • Develop and promote legal, regulatory and other strategies to align incentives to overcome obstacles.	• Identify obstacles to the use of: o highway ROWs o rail ROWs o lake/river/canal ROWs o others • Develop and promote legal, regulatory and other strategies to align incentives to overcome obstacles.

By the end of the project…

…we plan to:

- Have created material to improve public understanding of the need for expanded transmission capacity and together with the pros and cons of different ways of doing that.
- Have systematically identified legal regulatory and other barriers to expanding transmission capacity through both traditional and nontraditional ROWs and developed recommendations for how they might best be overcome.

That concludes my talk…
thanks very much for your attention

Acknowledgments

Much of our work has been supported by the U.S. National Science Foundation through a series of center grants on climate and energy decision-making, as well as by EPRI, the US DOE and several others.

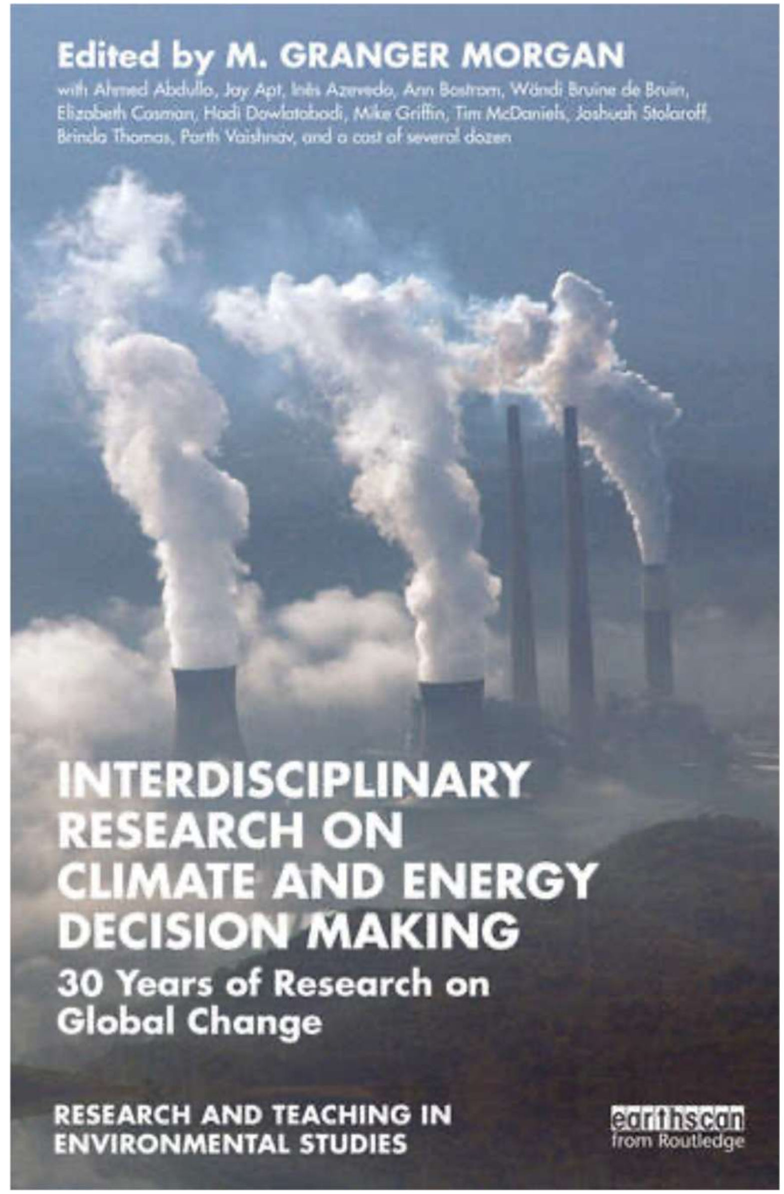
More recent work on power electronics, and the expansion of the transmission system is being supported by the Alfred P. Sloan Foundation

PS

We recently published a book that summarizes 30 years of work we did in three large NSF-supported distributed centers on climate and energy decision making.

It contains first person accounts in lay language. At the end of each chapter are a set of citations (often with abstracts) to some of the work we have discussed.

Then in an appendix we provide citations to more than 650 journal publications and scores of book chapters and PhD theses that have resulted from our work.



Routledge, 2023, 336pp.

Here are many of our collaborators whose work is summarized in that book.