Transformer – How U.S. Clean Energy Happens

By John Benson

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1. Introduction

This paper will answer an important question: how does the U.S. Government make major decisions about our energy future? A major part of the answer comes from an unlikely source: an Assistant Professor of Mechanical and Aerospace Engineering from the Andlinger Center for Energy and the Environment at Princeton University. I just read an article about above subject in IEEE Spectrum, and felt that this was important enough that my readers would also want to know about it.

2. The Policy Mill

In the past two years, the U.S. Congress has provided hundreds of billions of dollars to speed the deployment of clean-energy technologies. These investments are one reason why the International Energy Agency (IEA) in September insisted that there's still hope to hold global temperature rise to 1.5 °C in this century. [1]

Thousands of Washington insiders and climate activists have had a hand in these legislative breakthroughs. Among the most articulate and almost certainly the wonkiest is Jesse Jenkins, a professor of engineering at Princeton University, where he heads the ZERO Lab–the Zero-carbon Energy systems Research and Optimization Laboratory, that is.

In 2021 and 2022, during the high-stakes negotiations over what became the Infrastructure Investment and Jobs Act and the Inflation Reduction Act, the ZERO Lab and the San Francisco-based consultancy Evolved Energy Research[2] *operated a climate-modeling war room that provided rapid-fire analyses of the likely effects of shifting investments among a smorgasbord of clean-energy technologies. As legislation worked its way through Congress, Jenkins's team provided elected officials, staffers, and stakeholders with a running tally of the possible trade-offs and payoffs in emissions, jobs, and economic growth.*

Author's comment: The reference at the end of this comment has a link to a good presentation from ZERO Lab about some of its work on the Inflation Reduction Act.[3]

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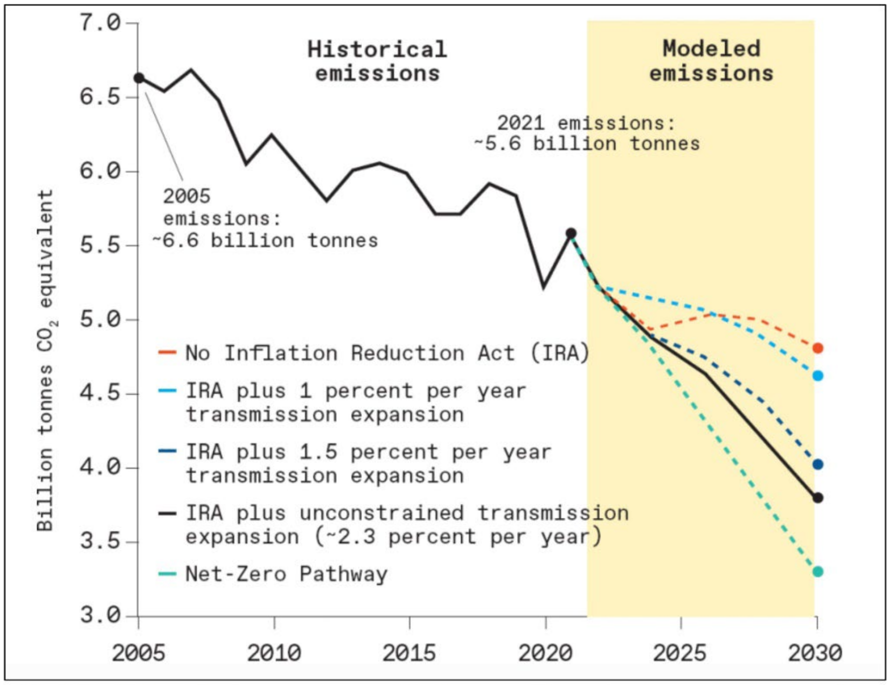
[1] Peter Fairley, IEEE Xplore and IEEE Spectrum, "The Transformer: How energy modeler Jesse Jenkins helped Congress get serious about the power grid," Dec 8, 2023, https://ieeexplore.ieee.org/abstract/document/10352408 Note that full access is limited to IEEE Members.

[2] See https://www.linkedin.com/company/evolved-energy-research I tried calling up their web-site and my Microsoft Bing Search Engine wasn't comfortable bringing it up ("www.evolved.energy uses an unsupported protocol"), and I'm OK with that.

[3] Jesse D. Jenkins, Princeton ZERO LAB, "The Inflation Reduction Act and the Path to a Net-Zero America," Sep 12, 2022, https://cpree.princeton.edu/sites/g/files/toruqf651/files/documents/2022-09-12%20-%20Inflation%20Reduction%20Act%20and%20Path%20to%20Net-Zero.pdf

Jenkins has also helped push Congress to think more seriously about the power grid, releasing a report last year that showed that much of the 43 percent emissions reduction expected by 2030 would be squandered if the United States doesn't double the pace of transmission upgrades.

See the figure below, which relates to the above paragraph.



Modelled CO_2 reduction scenarios with IRA plus 3 transmission expansion levels from Princeton ZERO LAB

Author's comment: I was curious as to what the "Net-Zero Pathway" in the above chart was. I assumed it was a scenario put forward by ZERO Lab, and spent some time digging on their site. They have a "Net -Zero America: Potential Pathways, Infrastructure, and Impacts" Report (link below).

https://netzeroamerica.princeton.edu/the-report

Within that report is the text below:

We define and model five different net-zero energy system scenarios (or pathways), each with different assumptions about energy-demand and energy-supply technology options available in the future. The pathways help highlight the role of three key elements in energy system transitions: 1) extent of end-use electrification in transport & buildings, 2) extent of solar & wind electricity generation, and 3) extent of biomass utilization for energy. Each of the 5 scenarios has its own short-hand label used in presenting results:

E+ Assumes aggressive end-use electrification, but energy-supply options are relatively unconstrained for minimizing total energy-system cost to meet the goal of net-zero emissions in 2050

E- Less aggressive end-use electrification, but same supply-side options as E+

E- B+ Electrification level of E-; Higher biomass supply allowed to enable possible greater biomass-based liquid fuels production to help meet liquid fuel demands of non-electrified transport

E+ RE- Electrification level of E+; On supply-side, RE (wind and solar) rate of increase constrained to 35 GW/y (~30% greater than historical maximum single-year total).Higher CO_2 storage allowed to enable the option of more fossil fuel use than in E+

E+ RE+ Electrification level of E+; Supply-side constrained to be 100% renewable by 2050, with no new nuclear plants or underground carbon storage allowed, and fossil fuel use eliminated by 2050.

So, I suppose there are five pathways. Back to Reference 1.

As The Wall Street Journal noted in a July 2023 profile, Jenkins has played an "outsized role" in determining where federal cash can have the biggest impact, and politicos like White House clean-energy advisor John Podesta name-drop the professor and his numbers to sell their ideas.

IEEE Spectrum contributing editor Peter Fairley recently spoke with Jenkins via Zoom about where the U.S. energy system needs to go and how the latest energy models can help.

The Rapid Energy Policy Evaluation and Analysis Toolkit–REPEAT –which you developed at Princeton with Evolved Energy Research, influenced Congress to create massive incentives for clean-energy tech. How did REPEAT come together?

Jesse Jenkins: *In early 2021, given the results of the U.S. presidential election, it seemed that we were entering one of those rare windows where you might see substantial policy action on climate and clean energy. The U.S. government was going to try a whole bunch of different government interventions-incentive programs, tax credits, grants, infra-structure investments-to bend the trajectory of our energy transition. We realized that as the policy was coming into shape, it was going to be difficult to understand its aggregate impact.*

So, we decided to launch REPEAT in the spring of 2021, with funding from the Hewlett Foundation. We threw in real policies as they were being proposed and debated in Congress, to provide as close to real-time analysis as possible as to the likely impact of the legislation. We did that throughout the debate on the bipartisan infrastructure bill and the Inflation Reduction Act.

I think that, along with similar efforts by consultancies like the Rhodium Group and Energy Innovation, we provided important real-time information for stakeholders inside and outside the negotiations as to what its likely impact would be and whether it was strong enough. It's similar to how the Congressional Budget Office tries to score the budgetary impact of legislation as it's being debated. Those estimates are always wrong, but they're better than having no estimate. And we were much more transparent than CBO is. They don't tell you how they come up with their numbers.

How has energy-system modeling evolved to make the detailed simulations and projections like REPEAT's possible?

Jenkins: *Energy systems became globalized in the middle of the 20th century and then encountered global supply shocks, like the oil embargoes of the '70s. These are complex systems, so it's hard to predict exactly how an intervention at one point is going to affect everything else. Energy-system models that marry engineering, physics, economics, and policy constraints and concerns allow us to test assumptions, explore actions, and build intuitions about how those systems work…*

I entered the field in the mid-2000s, motivated by climate concerns, and I encountered a whole range of questions about the role of emerging technologies, potential policies to reshape our energy systems, and the implications of energy transitions. The tools built in the '70s and' 80s were not cut out for that, so there's been quite a flurry of activity from the 2010s on to build a new generation of modeling tools, fit for the energy challenges that we face now.

When I entered the field, commercial wind was starting to scale up and the questions were about engineering feasibility. What was the maximum share of wind that we could have in the system without blowing it up–5 percent or 20 percent or 30 percent? How fast can you ramp power plants up and down to mitigate variability from wind and solar?

Now the questions are much more about implementation, about the pace of the energy transition that's feasible, and the distribution of the benefits and impacts. That's demanding that the models go beyond stylized representations of how and where stuff gets built, so that those considerations get embedded right into the modeling practice.

Until recently, energy modeling by the U.S. Energy Information Administration (EIA) and IEA vastly under-projected wind and solar deployments. What about the pitfalls with energy modeling?

Jenkins: *These are decision-support tools, not decision-making tools. They cannot give you the answer. In fact, we shouldn't even think of these models as predictive. We say that the IEA makes projections. Well, they're really making a scenario that's internally consistent with a set of assumptions. That "prediction" is only as good as the assumptions that go into it, and those assumptions are challenging. We're not talking about a physical phenomenon that I can repeatedly observe in an experiment and derive the equations for and know will hold forever, like gravity or the strong nuclear force. We're trying to project a dynamically changing system involving deep uncertainties where you cannot resolve the probability distribution or even the range of possible outcomes.*

We face deep uncertainties because we're talking about policies that will shape capital investments that will live for 20 or 30 years or longer. If you ask a bunch of experts to predict the cost of a technology 10 years from now, they're all over the map-9 out of 10 are wrong, and you don't know which one is right. There's just so much that is contingent and unknowable. The best we can do is to build tools that allow us to explore possible futures, to build intuition about the consequences of different actions under different assumptions, and to hope that that helps us make better decisions than if we were simply ignorant.

I think the models do succeed and are helping us understand, on a broad scale, the potential implications of energy-system decision making. There may be 30 things that we care about, but maybe five of them are the most important and the other ones we can sort of disregard as second- or third-order concerns. I can't tell you exactly what the outcome will be for those five parameters. But I can tell you, “These are the ones you want to watch out for, and you want to plan a strategy that is hedged against those five key indicators.”

Earlier this year, you raised a red flag when Congress ordered up a 2.5-year grid study from the U.S. Department of Energy, which you said would delay crucial action to upgrade the power grid. Why is grid expansion so important?

Jenkins: *One reason is that we're going to need more electricity. Electricity demand is likely to start growing at a pretty sustained rate due to the growth of electric vehicles, AI and data centers, heat pumps, electrification of industry, hydrogen production. You need a bigger grid to supply that electricity.*

The second reason is that the grid we have is built out to places where there were coal mines and hydro-power dams, not where there's the best wind and sun. So we need to expand the grid in ways that can tap into the best American resources, particularly wind power. Solar panels convert solar radiation to power linearly, in proportion to the amount of sunlight. But wind turbines convert wind to power at the wind speed cubed. If you double the wind speed, you get 8 times as much wind power output, so a good wind site is way better than a bad wind site.

Jesse Jenkins and his collaborators used the REPEAT energy model to project the greenhouse-gas reductions resulting from recent U.S. clean-tech legislation. The target of reducing U.S. emissions by 50 percent by 2030 was established through an executive order in 2021.

“The models are helping us understand, on a broad scale, the potential implications of energy-system decision making.”

How would expanding the grid prevent climate-driven disasters like Winter Storm Uri, the ice storm that devastated Texas in February 2021?

Jenkins: *Expanding the grid means that when one part of the grid is struggling with an extreme event, it can rely on its neighbors. Expansion also enables wider electricity markets, which tend to lower electricity costs. We've seen a steady expansion of regional transmission organizations, and that trend is now spreading into the Western Interconnection [one of North America's two large AC grids], as several Western utilities are joining the Southwest Power Pool [SPP, a regional grid operator].*

Texas, unfortunately, is its own little grid island. The [Electric Reliability Council of Texas] system is not interconnected with the Western and Eastern Interconnections. It can only exchange a few hundreds of megawatts of power with each. So, when Texas got hit by Uri, it couldn't pull power from New Mexico or Colorado or further away in the Eastern Interconnection. They're on their own, and that's a much more brittle system. A bigger grid is just better, even if we weren't facing the need to tap a lot of wind power and to meet electrification needs.

Does anything happening inside or outside of Congress give you hope that the grid will meet the challenge of the climate emergency?

Jenkins: *There's the Big Wires Act[4] that's been introduced in Congress to set minimum standards for interregional transfer capacity. That's similar to what Europe has done-basically every country has interties so they can trade energy more effectively and lower costs for consumers.*

What makes me optimistic is how quickly transmission expansion has gone from off the radar–aside from the wonky proceedings of regional planning boards-–to the top of congressional concern. A year ago, we weren't even having this conversation.

And we had a role in that, helping to elevate the importance of transmission expansion to the overall energy transition. The longer you have your sights on a big problem like this, the more likely you're going to see creative solutions that make progress, whether it's more serious efforts by regional transmission organizations or state-level policies or the Federal Energy Regulatory Commission [FERC, which regulates the U.S. transmission grid] taking action or Congress finally getting its act together.

High-voltage DC (HVDC) transmission technology is playing a big role in China and Europe. Does HVDC have a role to play in the U.S. grid?

Jenkins: *There is a growing effort to create stronger interties between the Eastern and Western Inter-connections. SPP in particular is starting to operate markets on both sides of that divide. And we've seen private developers like Grid United working on proposals that would cross that seam.*

Another example is the Champlain-Hudson Power Express line under construction from Quebec into New York City. It runs underneath Lake Champlain and the Hudson River for most of its route, and it's HVDC because DC works much better underground and underwater than AC. There was also a need to keep the project out of sight in order to get the permits. Competing projects with over-head lines were rejected. As we see more challenges in siting long-distance lines, we are likely to see more underground transmission…

There's a company that's trying to run HVDC transmission under rail lines, where you already have disturbed ground and it's easier to secure a right of way. Generally, underground lines are something like 10 times more expensive than overhead lines. But if you can't build the overhead line at all, underground may be the only way to move forward.

The reason Texas is on its own is because they don't want their power market to be subject to federal regulations. But they could add 10 gigawatts of DC interties to their neighbors without sacrificing that independence. Just the interstate interties would be regulated by FERC. Alas, the Texas legislature is not taking this as seriously as I would have hoped. There have been basically no serious reforms implemented since Uri. They're just as vulnerable today as they were then.

Besides boosting grid capacity and building out wind and solar, what's the most important thing that needs to happen to meet our emissions goals and start slowing climate change?

Jenkins: *We have to shut down coal plants as fast as is feasible because they're by far the most environ-mentally damaging. We have the ability to substitute for them very quickly and affordably.*

[4] H.R.5551 - BIG WIRES Act, Rep. Peters, Scott H. [D-CA-50] (Introduced 09/18/2023), https://www.congress.gov/bill/118th-congress/house-bill/5551, Go through this link and click on Text (1) tab to see the current bill, but it is very early in this bill's journey.

We probably have to maintain all of our existing natural gas capacity. In some parts of the country, we may need to build some new gas plants to maintain reliability alongside a growing share of wind and solar, but we will use their energy less and less. All the things we don't like about natural gas, whether it's methane leaks or fracking or air pollution or CO_2 emissions, scale with how much gas we burn. So keep the capacity around, but reduce the amount we burn. We will maintain the existing nuclear fleet, so that we're not shutting down low-carbon reactors while we're trying to displace fossil fuels.

Doing all that will get us to about an 80 percent reduction in emissions from current levels at a very affordable cost. It doesn't get us to a hundred. The last piece is deploying the full set of what I call "clean firm" technologies that can ultimately replace our reliance on natural gas plants-advanced nuclear, advanced geothermal, carbon capture, biomass, hydrogen, biomethane, and all the other zero-carbon gases that we could use. Those technologies are starting to see their first commercial deployments. We need to be deploying almost all of them at commercial scale this decade, so that they're ready for large-scale deployment in the 2030s and 2040s, the way we scaled up wind in the 2000s and solar since 2010…

Final author's comment: For further reading on what Dr. Jenkins calls "clean firm" technologies in the above paragraph, note that I have written earlier papers or series of papers on most of these. These are summarized and linked below.

Nukes, part 7: I've mentioned before that when I worked for Landis & Gyr Systems, PacifiCorp was one of our best customers. Thus, when a came across an article about how they are considering converting their coal-fired power plants to nukes, I had to write a short paper on this.

https://energycentral.com/c/gn/nukes-part-7-0

Hot Rocks Part 3 – Widespread Geothermal Power: The title of this post indicated it's the third part in this series. The first part was posted a little over a year ago, and the second this spring. This post is about Enhanced Geothermal Systems (EGS).

The principal elements of heat, water, and permeability—when found together and in sufficient amounts—can support cost-competitive rates of geothermal energy extraction. Independent of water and permeability, thermal energy (heat) exists everywhere on Earth and increases with depth. At the most basic level, EGS are manmade geothermal reservoirs. Where the subsurface is hot but contains little permeability and/or fluid, pumping water into wells could stimulate the formation of a geothermal reservoir capable of supporting commercial rates of energy extraction.

https://energycentral.com/c/gn/hot-rocks-part-3-%E2%80%93-widespread-geothermal-power

Zero-Emissions Combined Cycle and Beyond: This paper has a proposal that will keep combined cycle power plants running by converting them to (nearly) zero greenhouse gas (GHG) emission operation via carbon dioxide capture and storage…

https://www.energycentral.com/c/cp/zero-emissions-combined-cycle-and-beyond

Small Steps to Mitigate Climate Change – Biomass: I started thinking about another future post on Bioenergy, in general, and started researching this. I discovered a very rich vein of information about all of activity currently in progress about this renewable energy source…

"Bioenergy Technology" actually covers many technologies. Thus, what I will do in this paper is to start with a description of the value of these technologies, and then cover this technology.

https://energycentral.com/c/cp/small-steps-mitigate-climate-change-%E2%80%93-biomass

A Solution for the Rest of Our Economy: The most important two major projects we can undertake to fight climate are (1) move all electric generation to renewable technologies, and (2) electrify all energy usage by our (the world's) economies, starting with non-electric segments that are easiest to electrify.

However, the above linked projects bring up an important question: what about those segments that are very difficult to electrify, "…the Rest of Our Economy." The solution for many of these applications is hydrogen.

https://energycentral.com/c/cp/solution-rest-our-economy

Reasonable Transition: There is a debate in Europe regarding what constitutes a renewable electricity source, and specifically whether natural-gas fired plants should be considered "renewable" under reasonable conditions. Natural Gas is labeled as a "transition fuel", and investments in a natural gas plant will count as "green power" if:

- The plant emits no more than 270 grams of CO_2 equivalent greenhouse gas (GHG) per kWh of electricity produced
- The natural gas plant must replace a plant with higher GHG emissions per kWh

The key point here is this discussion regarding natural gas seems to be an "either or" discussion. In fact, a modern combined cycle plant fueled with geologically sourced natural gas can evolve to very low GHG emissions in the future. The quick method is to use biomethane – the plant will require few, if any, modifications, and (at least in my home state, California) the biomethane can be transmitted through the natural gas pipelines. The not-so-quick method is to retrofit existing combined-cycle power plants to be fired with partial-to-100% hydrogen, and then use green hydrogen to fire it.

https://energycentral.com/c/gn/reasonable-transition