350 PPM Pathways for the United States
Frequently Asked Questions with Answers from the Research Team

Q: Why is this report groundbreaking? What does it mean?

A: This report provides a detailed roadmap to transition the U.S. off of fossil fuels quickly. It is the first of its kind to illustrate several low carbon energy pathways consistent with returning atmospheric CO2 to 350 ppm by 2100.

Q: How does this research relate to the Juliana v. United States legal case?

A: The report is co-authored by Ben Haley, Ryan Jones, and Jim Williams. Williams is one of the nearly two-dozen pro bono experts supporting the 21 young Americans who brought the landmark constitutional climate lawsuit Juliana v. United States. This study illustrates several feasible and economical decarbonization pathways that are consistent with a 350 ppm CO2 target by 2100 being sought by the plaintiffs in Juliana.

Q: **Are there other deep decarbonization studies that come to similar conclusions?**

A: Our study supports many of the conclusions of other decarbonization studies, even though we use a unique analytical approach that gives us additional insight into electricity system operations and the role that some new technologies might play on the system.

Q: **Why do you use the energy forecast provided by the U.S. Energy Information Agency (EIA) as your baseline? Are EIA's forecasts and data reliable or do they overproject energy demand?**

A: We use the underlying energy services demand forecast (space heating, industrial production, vehicle miles traveled, etc.) to support the idea that we can decarbonize the economy, the same economy that is predicted to run primarily on fossil fuels by the US government, without necessitating changes in lifestyle or a reduction in economic output. The EIA's forecasts suffer from the same limitations as all forecasting exercises and will inevitably deviate from actual future service demands but they represent an apples to apples comparison.

Q: **Why don't you assume more people will walk or bike or take public transit?**

A: We wanted to support the hypothesis that we could support the same level and type of energy services that the US government predicts we'll need to satisfy to 2050. Lifestyle changes, however, will make the transition, easier, cheaper, and necessitate less additional infrastructure and so should continue to be encouraged for those and other reasons, even if they're not a requirement for decarbonization.

Q: **If we conserve more energy and consume less, can we meet our energy demand with 100% renewables by 2050?**

A: Meeting our energy demand with 100% renewables (wind, water, solar, hydro, biomass + storage) by 2050 is possible even under the projections of steady energy demand provided by the U.S. Energy Information Administration. Meeting all energy demand with renewables would just be more costly, under our assumptions, than to continue to deploy small amounts of fossil fuels in some areas of the economy.

Q: **Can I access the data sets you used for this research?**

A: We plan on making the data sets more broadly available through the process of the forthcoming academic publication.

Q: **Can I access the detailed results you used for this research?**

A: We plan on making more results available through the process of the forthcoming academic publication, but specific results may be furnished upon request.

Q: **Has an energy transition of this speed and magnitude ever happened in the U.S. or elsewhere?**

A: Significant energy and economic transitions have happened in the U.S. (rural electrification, nuclear deployment, WWII mobilization), sometimes at even greater rates of change, but there are no perfect analogs domestically or internationally for this transition.

Q: **What would need to happen for this transition to be done in a way that is just and equitable?**

A: This transition offers two key inherent opportunities for making our energy system more equitable than it is today. With nearly complete reliance on fossil fuels, the current energy system disproportionately impacts lower income households who pay a larger share of their income for energy. Without alternatives to fossil fuels, when energy prices spike those same low income households get squeezed financially. In this way, the current energy system is extremely regressive.

In contrast, in a low-carbon energy system:

1. Electricity becomes the centerpiece of energy service delivery, and the regulation of electricity rates gives policymakers the ability to support equity with different rate structures (i.e. low-income rates) and cost allocation mechanisms. Fossil fuels like oil are obviously not subject to regulated rates, eliminating this opportunity to improve equity.

2. Air quality, which disproportionately impacts the poor, will be improved dramatically from reduced combustion in power plants, vehicles, and petroleum refineries.

In terms of managing the transition effectively, it will be necessary to focus on policymaking for industries that may decline or change significantly. In our scenarios, for example, there are some very obvious transition paths: while petroleum refining declines, we have an entire new advanced biofuels, ccs, and power-to-fuels industry that requires much of the same skillset.

Policymakers will need an understanding of how to manage the changing nature of energy system costs from one that is primarily operating costs (i.e. gasoline, natural gas, etc.) to one that is capital intensive (discussed in more detail below).

Q: **How does this type of energy transition get paid for? How much does the government need to spend on this transition?**

A: As shown in our net cost results, the key to this transition is that the shift in energy system spending is large, but the overall net cost is relatively modest. That means that much of our spending is supported by savings in fossil fuels. The example of electric vehicles (EVs) is indicative here, with lifecycle costs of owning an EV becoming lower in the long-run because the incremental cost of the EV is paid back through fuel savings.

However, the nature of these costs changes substantially. While fuel costs are saved over the vehicle's lifetime, the initial upfront cost is incurred over a shorter period (i.e. length of the car loan).

Q: **Fossil fuel jobs will be lost in this transition. Will this energy transition create more jobs than the number lost?**

A: That isn't a number that we calculate nor is it a number that is possible to calculate with the types of modeling tools traditionally employed. Macroeconomic models are intended to represent small changes to the current economy, which is precisely calibrated. Huge shifts like the ones we model aren't well-suited for these types of analyses. We can say that the opportunity exists in a low-carbon economy for a vast number of infrastructure jobs and an increasing domestic share of overall energy production.

Q: **Have you modeled the macroeconomic impacts of this transition?**

A: We haven't, and we do not currently have plans to investigate the macroeconomic impacts part of this study.

ICF International completed a study of macroeconomic impacts of decarbonization based on the results of our 80x50 decarbonization study completed in 2014. The results would be illustrative of the types of results we might expect from this 350 PPM Pathways research.

Those results are available here: https://nextgenpolicy.org/wp-content/uploads/2015/11/ICF-Study-Summary-of-Findings-Decarb-Econ-Analysis-Nov-5-2015.pdf

Q: **What are your assumptions about passenger and freight rail?**

A: We don't assume significant changes in passenger and freight rail due to the uncertainty around costs/viability of alternative technologies like direct electrification.

Q: **Are there technologies that are not yet developed that would be needed to implement one of the pathways modeled?**

A: No technologies that are in the research phase are employed in this study, though some are employed that have only been piloted or not deployed at commercial scale.

Q: **What is the hardest part about deep decarbonization at this scale?**

A: Multiple challenges come to mind, the three we would highlight are: coordinating change across all sectors of the economy; siting large amounts of new infrastructure in short periods of time; and accelerating industrial production of key technologies (wind, solar, batteries) to support the timelines of the transition. A comprehensive national plan would greatly assist with the coordination of the decarbonization and help overcome these hurdles.

Q: **What is the benefit of deep decarbonization at this scale?**

A: The most significant benefit is reducing greenhouse gas emissions commensurate with what science says we need to achieve to avoid the worst impacts from climate change (e.g., multi-meter sea level rise). Co-benefits include huge reductions in air pollution, potential domestication of 100% of energy production, and reduced environmental degradation from fossil fuel extraction.

Q: **How will this energy transition most impact an ordinary person? What will our lives look like if this happens?**

A: Most of the change will be in the way that you pay for energy services. Instead of oil bills, gas bills, and paying at the pump, much of your household expenses will be concentrated into one electricity bill. These scenarios don't necessitate significant lifestyle changes, so your life won't be significantly different. Many of the changes occur "under the hood" of the energy system, or well before a consumer interacts with it. For example, operations of the electricity system will need to change drastically, but the (LED) lights will still come on when you turn on a switch and you will still be able to drive your (electric) car.

Q: **Can market-based mechanisms achieve this deep decarbonization transition? How important is government policy and leadership?**

A: Coordinated policy and leadership from the federal government is critical. A broad portfolio of policy changes are likely to be required in order to compel a transition of this scale this quickly. Smart application of market-based mechanisms would help this transition, as well as targeted approaches that set standards and allow markets to develop to meet them. We don't imagine an economy-wide carbon tax as a silver bullet. While it is not the focus of our report, others are examining the specific policies that will help effectuate such a transition.

Q: **How much harder does it get to stay within the targets and the carbon budget with each year of delay?**

A: Each year of stasis in the energy system is hugely detrimental to meeting the targets simply because today's emissions represent such a huge portion of the remaining emissions budget. In our base scenario, we have 15 years of current emissions left before exceeding our budget through 2050. In our Low Land NETS scenario, we have less than 10. If we continue to burn fossil fuels at the current rate, even for a few years, the descent will have to be that much steeper and deeper over the rest of the first half of this century.

Q: **What are the most important things that need to happen in the next 5 years? The next 10 years?**

A: In the report we identify key actions by decade. For the 2020s we state the following as the most important actions both for near-term reductions and setting us up for a transition to a longer-term low emissions economy:

- Begin large-scale electrification in transportation and buildings
- Switch from coal to gas in electricity system dispatch
- Ramp up construction of renewable generation and reinforce transmission
- Allow new natural gas power plants to be built to replace retiring plants
- Start electricity market reforms to prepare for a changing load and resource mix
- Maintain existing nuclear fleet
- Pilot new technologies that will need to be deployed at scale after 2030
- Stop developing new infrastructure to transport petroleum fuels
- Begin building carbon capture for large industrial facilities

Q: **What kinds of government policies would be required to make this kind of change happen?**

A: A recently published book, Legal Pathways to Deep Decarbonization in the United States, lists a host of local, state, and federal policy tools that could be used to achieve an 80% reduction in GHGs by 2050 in the United States. Similar tools would need to be applied more aggressively in order to achieve the reductions demonstrated in this study.

Q: **How is Direct Air Capture different from Carbon Capture and Storage (CCS)?**

A: Direct air capture is a technology that captures CO_2 from the air, at atmospheric concentrations. Traditional carbon capture technologies rely on capturing a more concentrated stream of CO_2 from a combustion source. Direct air capture technologies are considered “negative” emissions technologies because they extract CO2 from the atmosphere where carbon capture, when applied to sources of fossil fuel combustion, only avoids additional CO_2 emissions.

Q: **Why is Direct Air Capture an important component of deep decarbonization?**

A: Direct Air Capture can be an important backstop technology if other strategies that we intend to rely on (zero-carbon biomass, electrification, etc.) don't materialize at their expected scale. When powered by zero-carbon electricity, direct air capture can remove CO_2 from the atmosphere and either sequester it (resulting in negative emissions) or utilize it with hydrogen to produce a carbon-neutral alternative to fossil fuels (gas, diesel, gasoline, etc.).

Q: **Has Direct Air Capture of carbon dioxide been proven at scale? How do you know it will work?**

A: Direct Air Capture hasn't been proven at scale but has been demonstrated in pilot projects. It is not deployed in all scenarios and is only deployed at any volume in later years of the analysis to offset certain hard-to-decarbonize corners of the economy if other mitigation pathways fail to materialize. In this way, it's an important "backstop" technology.

Q: **What are the risks or downsides of Direct Air Capture technology?**

A: Capturing CO_2 from the atmosphere is an energy intensive process. Therefore, these direct air capture plants are most cost effective if they operate on excess low-carbon electricity – solar or wind, for example, when they are producing more than is needed. This electricity that would otherwise be "curtailed" is inexpensive from a system perspective. If there is not excess electricity available, the operation of Direct Air Capture facilities will require the construction of new renewables to support their energy needs. It isn't possible to run these economically on the grid as it looks today because the emissions associated with fossil-fueled electricity would offset much of the benefit of the capture process. It only "fits" on a low-carbon grid. Like other new infrastructure, there will be land use and siting challenges, though there is no imperative to locate them near to human habitation.

Q: **Why do the 350 ppm deep decarbonization pathways call for building more gas power generation capacity?**

A: In the near-term, the priority is displacing electricity generation from the existing coal fleet. We assume real world limitations on the speed of renewable energy deployment in the near-term, which means while much of the displacement can be renewables, gas still plays a role in the rapid drawdown of coal generation. If planned well, in the longer-term these aren't wasted investments, as gas-fired electricity generation, running very rarely to provide capacity, is the most cost-efficient way to maintain electric reliability, even as we transition to a system where most of the energy is being provided by renewable sources. With load growth from electrification, in the longer term, the need for capacity is growing, even with higher energy efficiency, flexible load, and the deployment of significant renewables.

Q: Will the transition to low carbon require construction of new natural gas transmission pipelines?

A: New pipelines that transport biogas, synthetic gas from renewables, hydrogen, or CO_2 will be required. This is because the locations where these future sources of energy or carbon are sourced are not the same locations where we source natural gas today; and therefore, will require some new pipeline to connect them with loads or with carbon sequestration locations. As a general rule, new pipelines to transport natural gas are not needed in this transition, though exceptions may exist. As stated before, the priority is creating a switch from coal to gas as fast as possible and new pipelines, where they can make this transition happen faster, may be a part of the lowest cost strategy to reach 350 ppm.

Q: **How often would gas powered plants be used in the low-carbon scenarios?**

A: By the year 2050, gas generators operate less than 15% of the hours of the year. This is approximately a quarter of the time they operate today on a grid that delivers ~2x more electricity. This gas does not need to be fossil, either. It can burn electrically-derived or bio-based fuels.

Q: **Why do most scenarios call for Carbon Capture and Storage (CCS) and Carbon Capture and Utilization (CCU)? Why can't we transition off of fossil fuels quickly enough to avoid the need for carbon capture?**

A: Carbon capture does not mean we are always capturing emissions from fossil energy. Most of our carbon capture is done in conjunction with biofuels production or accomplished through direct air capture, which is not a function of fossil emissions.

These both contribute negative emissions without requiring fossil consumption so the use of carbon capture in these scenarios does not necessarily support continued use of fossil fuels.

When fuels (aviation, for example) or the chemical components of fuels (cement, petrochemicals) are required for an application, the use of carbon capture is critical. This can be used either in the production of fuels (CCS on biomass production, power-to-x using direct air capture) and/or at the point of use (CCS on cement and petrochemicals). This can result in zero or negative emissions fuels pathways, which contribute to overall emissions reductions in the economy.

Q: Are **CCS and CCU already being used in the U.S.? How much more use would be needed?**

A: CCS and CCU in the applications we're describing is not common in the U.S. The only significant use for captured carbon, currently, is enhance oil recovery, which is not an application we analyze in any great detail and is not the purpose of CCS and CCU in our scenarios. This would therefore be an almost entirely new industry, but one in which the technical implementation is already understood.

Q: **How are synthetic liquid fuels made? Are there facilities making synthetic liquid fuels? Can they be used the same as petroleum products?**

A: Synthetic liquid fuels are made by synthesizing a mixture of CO2 (produced through carbon capture) and hydrogen (produced primarily through electrolysis). This is synthesized into liquid hydrocarbons through the Fischer-Tropsch process in our modeling, though there are other synthesis routes as well.

Q: **How does making synthetic gas by methanation work? Are there facilities making synthetic gas?**

A: Synthetic gas is made by methanating a mixture of CO_2 (produced through carbon capture) and hydrogen (produced primarily through electrolysis). There are dozens of projects in Europe but only one demonstration project in the U.S. as of 2019.

Q: **Can existing fossil fuel infrastructure be used with synthetic fuels and gases?**

A: Yes, these are what we refer to as "drop-in fuels" meaning all the components of the existing delivery (pipelines, storage facilities, etc.) and end-use consumption infrastructure (trucks, boilers, etc.) can use these fuels as if they were fossil-based.

Q: **How are jet fuels made? Are there facilities producing low carbon jet fuels at scale?**

A: In our modeling, jet fuel is made through Fischer-Tropsch processes, like the processes employed to make power-to-liquids. In this case, biomass is gasified to produce the mixture of CO2 and H2 (syngas) needed to then be synthesized into liquid fuels using Fischer-Tropsch.

Q: **Can bio-based aviation fuels be produced at the quantity required without impinging on land needed for crop production?**

A: Based on previous analysis we conducted, the level of biomass we employ is consistent with a level that would not impinge on food production domestically or internationally. Partly this is due to the fact that much of the biomass is waste or woody biomass, but also there is significant land that could be repurposed from corn ethanol production in our analysis. This corn ethanol production declines commensurate with the decline in gasoline demand as we electrify light duty vehicle travel.

Q: **How much more biofuel production would be needed over the amount produced today?**

A: Current biofuel production is approximately 1600 TBtu with the vast majority being corn ethanol. The most biofuel we see in any of our scenarios is 8400 TBtu. This would represent an approximately 5x increase in overall biofuel production. The low-biomass scenario uses 4,200 TBtu.

Q: **How is hydrogen made from electricity? Are there large scale hydrogen production facilities in use in the United States?**

A: Hydrogen is made from electricity through the process of electrolysis, which splits water molecules into H_2 (hydrogen) and O_2 (oxygen) molecules with an electric current. This is a well understood process that is used in some industrial applications. There are not currently large-scale electrolysis facilities in the U.S. because the economics currently support hydrogen production through natural gas reformation. With higher levels of renewables on the systems and an imperative to reduce carbon, economics would dictate the deployment of electrolysis or the employment of carbon capture on natural gas reformation.

Q: **How does this study compare to a 100% renewable electricity study? Why is looking at electricity supply in isolation from other energy sectors counter-productive to stopping climate change?**

A: 100% renewable electricity studies focus only on reducing emissions in the electric sector. This is important, but too limited when trying to understand how to reduce an entire economy’s emission to near-zero. The electric sector requires significant sectoral integration (production of electric fuels, direct electrification of transportation) both to meet its own targets and support the transition to zero-emissions economies for all sectors. Narrowly focusing on an electric sector without considering its interaction with other sectors or its role in supporting the emissions reductions from other sectors (e.g. transportation) is likely to lead to poor decision-making. For example, rather than forecasting declining electricity demand in the future, we need to be planning for a 2-fold increase in electricity demand. Even though we don't directly model 100% renewable systems, we are modeling very high renewables and there are two key lessons to learn in terms of the economic operations of these types of systems in an economy-wide low carbon context:

1. The use of electric fuels as a balancing resource in order to address seasonal balancing challenges is critical to avoiding large amounts of overgeneration of electricity that would result in temporarily shutting down renewable generators, a practice known as "curtailment".
2. Allowing new gas-burning electricity generators to be constructed, even if requiring them to be fueled with biogas or power-to-gas when they run, is essential for operating a high renewables system reliably and economically.

Q: **Do you have state-specific results? Which states are looking at their energy systems holistically? Can the EER results be tailored for state planning purposes?**

A: This analysis did not produce state-specific results, but the underlying model, data, and analytical framework can and has been leveraged for statewide analyses. An increasing number of states have or are beginning to look at their energy systems holistically using studies similar to this one.

Q: **Does this plan rely on offsets to meet the emissions reduction and carbon budget targets?**

A: No, this does not rely on offsets to meet the targets. As explained by climate scientists like Dr. James Hansen, being on the 350 ppm by 2100 trajectory requires rapid emission reduction and carbon sequestration through improved forestry and agriculture.

Q: **How does your study address natural carbon sequestration from forestry and agriculture?**

A: This study did not model or evaluate sequestration potential. We stipulated a certain amount of carbon sequestration from forestry and agriculture based on recent research of what is feasible and based on the quantities necessary to return to 350 ppm in the atmosphere by 2100. These amounts provided a constraint that informed the energy system decarbonization scenarios.

Q: **What would happen if we decommissioned nuclear power plants that are currently operating?**

A: Decommissioning nuclear without the time to replace them with renewable energy would result in higher operating levels for other online thermal plants (coal and gas). In the longer-term, they can be technically replaced with renewables, but in many cases, this would increase the cost of achieving emissions targets. Still, this would not affect our conclusion of the scenario being technically possible.

Q: **Do we need new nuclear to meet the emissions reduction and carbon budget targets?**

A: No, we do not. We see that in our "No New Nuclear" sensitivity where we prohibit the construction of new nuclear facilities. Achieving the target requires more renewables, but this can be accomplished with little impact to overall compliance costs.

Q: **Has this study been peer reviewed?**

A: No, this study has not been peer reviewed. This analysis, however, is in the process of being prepared for submission to the academic literature for peer review.