Keeping Snow and Ice Frozen with Renewable Energy Solutions to Halt Climate Change

PATRICK GONZALEZ

On the edge of a rock valley wall, I looked down 160 m at the surface of Haupapa/Tasman Glacier in Aoraki/Mount Cook National Park, Aotearoa New Zealand. Next to me, scratches in the rock marked where the glacier had scraped by that location a century earlier. Scientific research shows that human-caused climate change has dominated other factors in melting glaciers around the world, including Haupapa/Tasman Glacier (Kirkbride 1995; Marzeion et al. 2014; IPCC 2021), which, since 1890, has lost a thickness of ice equivalent to the height of the Washington Monument.

The increased heat of human-caused climate change has reduced snowfall and melted snowpack, glaciers, and sea ice around the world (IPCC 2021). Reductions of snow and ice decrease downstream water supplies, diminish the cool conditions that maintain moist ecosystems, and raise sea levels (IPCC 2022). Eliminating fossil fuel burning and replacing it with solar, wind, and other renewable energy is an essential solution to halt human-caused climate change (IPCC 2023). Recent progress, including a quadrupling of global renewable energy capacity (IRENA 2023), a 17% cut of carbon pollution in the United States (US EPA 2023), and a 30% cut in Europe (EU EEA 2023), offers hope for the future.

Polar and high-elevation regions are the coldest places on Earth due to, respectively, long periods of low sunlight and diminished heat retention of a thinner atmosphere. So, these regions naturally contain the most snow and ice in the world. At the same time, human-caused climate change has

▲ Aoraki/Mount Cook and Haupapa/Tasman Glacier in Aoraki/Mount Cook National Park, Aotearoa New Zealand. Gravel from the receding glacier covers the lower-elevation ice. Haupapa/Tasman Glacier melted 160 m in depth from 1890 to 1986 (Kirkbride 1995), caused primarily by anthropogenic climate change (Marzeion et al. 2014; IPCC 2021). PATRICK GONZALEZ increased temperatures in polar and high-elevation regions more than other areas of the world, due primarily to a self-reinforcing feedback between loss of reflective white surface cover and increased absorption of sunlight by darker ground and sea surfaces (MRI 2015; Clem et al. 2020; Rantanen et al. 2022; Davy and Griewank 2023).

Consequently, climate change increased temperature 3.1°C in the Arctic from 1979 to 2021, quadruple the global rate (Rantanen et al. 2022), and 1.8°C in Antarctica from 1989 to 2018, triple the global rate (Clem et al. 2020). Temperatures have also increased in many mountain areas around the world at higher rates than in adjacent lowlands (MRI 2015), although the global average difference is not statistically significant (Pepin et al. 2022).

In Denali National Park, Alaska, location of the highest mountain in North America and a US national park closer to the North Pole than most other parks, average annual temperature increased at a rate of 1.7°C per century from 1901 to 2009, faster than temperature increases in any other national park in the 49 continental US states (Gonzalez et al. 2018). This rate is nearly double the global average rate of 0.9°C per century from 1900 to 2020 (IPCC 2021).

Since snow and ice require temperatures below the freezing point of water, they show particular sensitivity to the increased heat of climate change. Sea ice is doubly sensitive, to heating above, of the air, and below, of the ocean water.

Intergovernmental Panel on Climate Change (IPCC) assessments and other scientific research use detection and attribution analyses to estimate the relative weights of human-caused climate change and other factors in causing measured changes. Detection and attribution analyses show that human-caused climate change has reduced Northern Hemisphere snow cover 9% since 1922 (Rupp et al. 2013; Najafi et al. 2016); spring snowpack in the Sierra Nevada, California, 20% since 1950 (Pierce et al. 2008; Mote et al. 2018); snowpack in the Italian Alps to its lowest level in 600 years (Carrer et al. 2023); and spring snowpack across the western US to its lowest level in 800 years (Pederson et al. 2011). Globally, 20% of glacier ice melted from 1901 to 2019, with human-caused climate change causing half of that loss (Marzeion et al. 2014; Hugonnet et al. 2021; IPCC 2021). These global results derive from measurements of 270,000 glaciers around the world (Pfeffer et al. 2014; RGI Consortium 2023), including Muir Glacier in Glacier Bay National Park, Alaska, which melted up to 640 meters in depth from 1948 to 2000, equivalent to the height of One World Trade Center in New York City (Larsen et al. 2007). The sample also included Agassiz Glacier, in Glacier National Park, Montana, which melted 1.5 km in length from 1926 to 1979 (Pederson et al. 2004), and four glaciers that completely melted away in North Cascades National Park, Washington, by 2004 (Pelto 2006).

Human-caused climate change shortened global average lake ice duration nine days from 1981 to 2019 (Magnuson et al. 2000; Grant et al. 2021); melted the Greenland ice sheet enough to raise global sea level 1.4 cm, one-seventh of total sea level rise, from 1972 to 2018 (IPCC 2019; Mouginot et al. 2019; IMBIE Team 2020); cut summer Arctic ice extent in half from 1979 to 2018, the most severe loss in 1,000 years (IPCC 2019); and has melted Antarctic sea ice, which declined in February 2023 to its smallest extent since the beginning of systematic monitoring in 1979 (Purich and Doddridge 2023).

If we do not cut carbon pollution to net zero by 2050, climate change under a worst-case scenario could increase global temperature up to 4°C above the pre-industrial level (IPCC 2021). Climate change at 4°C could eliminate snowfall from the mid-Atlantic US and reduce snowfall up to half in the western US (Notaro et al. 2014; Lute et al. 2015; Ning and Bradley 2015), reduce winter snow 28% in Denali National Park (Littell et al. 2018); eliminate snow from the Andes Mountains, South America (Rhoades et al. 2022); possibly eliminate glaciers from Glacier National Park, Montana (Hall and Fagre 2003; Brown et al. 2010); and reduce global glacier extent 40% (Rounce et al. 2023).

Most gravely, climate change of 4°C could collapse the West Antarctic Ice Sheet (Bell and Seroussi 2020;

Muir Glacier, Glacier Bay National Park, Alaska, melted up to 640 m in depth from 1948 to 2000 (Larsen et al. 2007), caused primarily by anthropogenic climate change (Marzeion et al. 2014; IPCC 2021). Photos aligned by Patrick Gonzalez. Top: August 13, 1941. WILLIAM O. FIELD, US GEOLOGICAL SURVEY Bottom: August 31, 2004. BRUCE F. MOLNIA, US GEOLOGICAL SURVEY

Lai et al. 2020; Armstrong McKay et al. 2022; Pattyn and Morlighem 2020; Naughten et al. 2023), raising global sea level 2 m or more, though over several centuries (IPCC 2021), and completely melt all Arctic sea ice (IPCC 2021; Kim et al. 2023). Because of a time lag between emissions of greenhouse gases from human activities and increased temperatures in the atmosphere and oceans, past emissions commit the world to some loss of snow and ice (Abrams et al. 2023; Kim et al. 2023; Naughten et al. 2023).

Cutting greenhouse gas emissions to meet the UN Framework Convention on Climate Change Paris Agreement upper goal of a global temperature increase of less than 2°C above the pre-industrial level could limit projected snow losses in the US to less than half of the 4°C scenario (Lute et al. 2015; Ning and Bradley 2015; Littell et al. 2018) and limit global glacier area loss to less than 30% (Rounce et al. 2023).

Decreases of snowpack and glacial ice reduce spring meltwater that supplies water for billions of people globally (Immerzeel et al. 2020). Ice melt from land areas runs eventually into the oceans and raises sea level (Frederikse et al. 2020), inundating coastal lands where millions of people live (IPCC 2022).

In addition to increasing risks to people, losses of snow and ice threaten biodiversity (Cauvy-Fraunié and Dangles 2019). High-elevation snow provides cooler, moister local conditions that create alpine habitats, while snow, glaciers, and sea ice sustain unique plants and animals. Decreased runoff from reduced snow and ice lowers water flows that support many aquatic ecosystems. Many plant species, including red fir trees (*Abies magnifica*) and numerous alpine and tundra plants, depend on snow cover. Consequently, reductions of snow can increase mortality of these species at the warm edges of their ranges and cause upslope or poleward biome shifts of vegetation from adjacent warmer areas (Gonzalez et al. 2010).

The US Endangered Species Act lists several animal species as threatened due to climate change because they depend on snow, glaciers, or sea ice. These include Canada lynx

Iceberg and sea ice, McMurdo Sound, Antarctica, January 29, 2015. PETER REJCEK, NATIONAL SCIENCE FOUNDATION

Snow at Upper Young Lake, Yosemite National Park, California, USA, August 31, 2023. PATRICK GONZALEZ

(*Lynx canadensis*), emperor penguin (*Aptenodytes forsteri*), meltwater lednian stonefly (*Lednia tumana*), polar bear (*Ursus maritimus*), and western glacier stonefly (*Zapada glacier*) (US FWS 2023).

Burning coal, oil, and other fossil fuels caused 89% of global carbon pollution in 2022 (Friedlingstein et al. 2023). Fossil fuel-fired electricity plants generated one-third of those emissions (IEA 2023).

Renewable energy, including solar, wind, hydroelectric, biomass, and geothermal, generates as little as 1% of the greenhouse gas emissions of fossil fuels per unit of electricity over the entire life cycle, including mining, construction, operation, maintenance, and waste (IPCC 2011). Therefore, elimination of fossil fuels and replacement with renewable energy is an essential solution to halt climate change.

Moreover, solar, wind, and other renewable energy now cost less per unit of electricity generation capacity than coal, oil, other fossil fuel systems, and nuclear energy (Lazard 2023). So, renewable energy is more cost-effective.

Globally, renewable energy provided 12% of total energy supply in 2022 (IEA 2023) and powered 40% of electricity generation capacity in 2022, with renewable electricity capacity rated at 3.4 Terawatts (TW; trillion watts of power) (IRENA 2023). Renewable electricity capacity quadrupled globally from 2000 to 2022, with the increases displacing the equivalent of 6,500 coal-fired plants (IRENA 2023).

In the US, renewable energy provided 8% of total energy supply in 2022 (US EIA 2023). Investments from legislation advanced by President Obama (American Recovery and Reinvestment Act of 2009) and President Biden (Infrastructure Investment and Jobs Act of 2021, Inflation Reduction Act of 2022) more than doubled the fraction of electricity generation capacity by renewable sources, from 14% in 2008 (US EIA 2011) to 31% in 2022 (US EIA 2023). In California, renewable energy produces an even higher fraction: 44% of in-state electricity in 2022 (CEC 2023).

Replacement of fossil fuels with renewable energy, energy efficiency and conservation, public transit, and other measures have enabled the US to cut greenhouse gas emissions 17% from 2005 to 2021 (US EPA 2023) and the European Union to cut emissions 30% from 1990 to 2021 (EU EEA 2023).

At current rates of fossil fuel burning, global temperature could increase 1.5°C above the pre-industrial level by 2032 and 2°C by 2050 (IPCC 2021). To meet the 1.5°C goal, the world can only emit 75 billion more tons of carbon (Friedlingstein et al. 2023). This is our remaining carbon budget. It requires us to cut carbon pollution 43% from 2022 to 2030 and to net zero by 2050 (UNEP 2023; UNFCCC 2023). Every gram of carbon pushes us closer to the limit.

You can take meaningful action to help eliminate fossil fuels and halt climate change by installing or purchasing renewable energy for your electricity use. If your household or your workplace has sufficient funds, you can purchase solar photovoltaic panels to install on rooftops.

Rooftop solar is a form of decentralized renewable energy with environmental and energy advantages over centralized industrial solar plants. Rooftop solar does not require any new land and is located at the site of the energy user, substantially decreasing transmission infrastructure needs and the electricity losses during transmission that are a function of wire length. Another form of decentralized solar is parking lot solar, which uses land that has already been urbanized and which provides shade for the lot. In contrast, centralized solar is often constructed on extensive areas of natural land far from electricity users. Those facilities can destroy or fragment natural habitat and often require new transmission lines.

Rooftop solar panels could power one-third of US electricity use (Gagnon et al. 2018). Globally, the maximum potential of all rooftop solar is 30.5 TW (Yeligeti et al. 2023), more than triple the 8.4 TW global installed electricity generation capacity from all sources in 2022 (IRENA 2023).

In the US, the Residential Clean Energy Credit currently covers 30% of the cost of new renewable energy devices installed at a home (https://www.irs.gov/credits-deductions/home-energy-tax-credits). This tax credit covers solar electric panels, solar water heaters,

Rooftop solar panels, Lassen Volcanic National Park, California, USA. PATRICK GONZALEZ

wind turbines, geothermal heat pumps, fuel cells, and battery storage technology. Many state and local governments provide additional tax incentives. Also, many states have authorized net energy metering, through which a user can sell excess electricity to the electric grid.

While operating costs of renewable energy are relatively low, purchasing and installing renewable energy systems can be expensive. An option for users in certain areas is purchasing renewable energy from an electric utility or a community organization that operates a program that adheres to the principle of additionality—a condition in which a new activity is additional to previously funded or required actions (UNFCCC 1997). Additionality aims to ensure that an activity reduces greenhouse gas emissions. For utility programs that offer renewable electricity for users to purchase, the renewable electricity capacity needs to be new, additional to previously funded or required renewable electricity generation.

For my home in Berkeley, California, I have enrolled in the Pacific Gas and Electric Company (PG&E) Solar Choice program. This scientifically sound program ensures additionality by accumulating enrollee funds until they amount to the cost of new solar arrays that the utility adds to the existing generation pool. The new solar electricity capacity is also additional to the capacity that California state law requires PG&E to install under the state renewable energy portfolio standard, which mandates California utilities to generate a specified fraction of their electricity from renewable sources. The renewable energy portfolio standard, set most recently by the California 100 Percent Clean Energy Act of 2018, started at 20% in 2017 and increases to 40% in 2024, 60% in 2030, and 100% in 2045.

Not all utilities have established programs that ensure additionality. Some sell a financial instrument called a renewable energy certificate (REC) that attempts to simulate renewable electricity generation by representing a fraction of the electricity generated in a regional electric grid. In the continental US and Canada, five electric grids cover vast regions: eastern states and provinces, western states and provinces, Québec, Texas, and Alaska. Once the electricity from a generator, whether fossil fuel or renewable, enters a grid, the electrons are mixed and no longer distinguishable by their generation sources. A REC claims that the electricity for an individual customer comes from a certain fraction of the electrons from renewable generators. Because the electricity was already generated, however, funds paid for a REC do not necessarily contribute to new additional renewable capacity. Scientific research shows that, in practice, a REC does not reduce greenhouse gas emissions (Brander et al. 2018; Bjorn et al. 2022).

Another potential option in some areas is community solar, in which subscribers pay into the costs of a local solar array.

If any of the renewable energy options described here are not currently possible for your home, you can concentrate on cutting your carbon pollution with other actions that I practice personally and have described in previous editions of this column: living car-free (Gonzalez 2023a), eating plant-rich and meat-free (Gonzalez 2023b), and traveling by public transit when visiting national parks (Gonzalez 2023c). Scientific analyses by the IPCC (2023) have shown that concerted action by governments, corporations, and individuals together can cut carbon pollution enough to avert the most drastic risks of climate change to people and nature.

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