# 14 TIMELINE AND POLICIES NEEDED TO TRANSITION

The solution to global warming, air pollution, and energy security requires not only a technical and economic roadmap but also popular support, political will, and a rapid rollout of the solution. In fact, the main barriers to transitioning to 100 percent clean, renewable energy are neither technical nor economic; instead, they are social and political. People need to be confident that a solution is possible, to understand what changes they can make in their own lives to solve the problems, to make such changes, and to support policymakers who pass laws speeding a transition. Policymakers, themselves, need to understand the urgency and thus take bold steps. One of the most important factors leading to a change is education about what is needed and how fast it is needed. This chapter discusses the necessary timeline for a transition, obstacles in the way of meeting the timeline, actions that individuals can take, and policies that are needed to overcome the obstacles to meet the 100 percent goal on time.

## 14.1 Transition Timeline

A critical step in implementing a transition to 100 percent WWS is to develop a transition timeline. The perfect timeline is one in which a 100 percent transition occurs in all energy sectors immediately. That won't happen. Jacobson and Delucchi[272] postulated that

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transitioning all world energy by 2030 is technically and economically feasible but noted that, for social and political reasons, a completion date two decades later, such as 2050, may be more practical. Since then, most 100 percent WWS roadmaps developed[136,144,278] have proposed an 80 percent transition by 2030 and 100 percent by no later than 2050. Because technologies are advancing and WWS costs are dropping more quickly than previously thought, newer studies[5,251] propose an 80 percent transition by 2030 and 100 percent ideally by 2035 but certainly no later than 2050. For electricity and buildings, a transition by 2030 is possible. For industry and transportation, a transition by 2035 is more feasible. This is particularly the case because some technologies, such as long-distance hydrogen fuel-cell aircraft, may not be commercially available until near 2030.

Although new WWS infrastructure will be installed upon the natural retirement of the current infrastructure, policies are needed to force the remaining existing infrastructure to retire early to allow the conversion to WWS at the rapid pace necessary to solve air pollution, climate, and energy security problems.

### 14.1.1 Transition Timelines for Individual Technologies

Some technologies can transition faster than others. Below is a proposed timeline for transitioning technologies in different sectors, either naturally or through aggressive policies.

**Development of super grids and smart grids:** As soon as possible, countries should expand the transmission-and-distribution systems to supply geographically dispersed WWS energy to demand centers. The grid should be managed with modern **smart grid** digital communication technology that detects and reacts to local changes in supply and use by invoking storage, demand response, geographically dispersed generation, and backup WWS power generation.

**Power plants:** by 2022, no more construction of new coal, nuclear, natural gas, oil, or biomass fired power plants should occur; all new power plants built should be WWS.

**Heating, drying, and cooking in the residential and commercial sectors:** by 2022, all new devices, machines, and equipment for heating, drying, and cooking should be powered by electricity, direct heat, and/or district heating.

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**Marine vessels:** by 2022 to 2030, all new boats (speed boats, yachts, barges, dredgers, towing vessels, fishing boats, patrol vessels, ferries, military boats, etc.) and ships (container ships, cruise ships, military ships, etc.) should be electrified and/or use electrolytic hydrogen, and all new and existing port operations should be electrified. This should be feasible for ports and ships because ports are centralized, and few ships are built each year. Policies are needed to incentivize the early retirement of fossil-fuel-powered ships that do not naturally retire before 2030.

**Industrial heat:** by 2023, all new high-, mid- and low-temperature industrial process technologies should be electric technologies, such as arc furnaces, induction furnaces, resistance furnaces, dielectric heaters, electron beam heaters, and heat pumps.

**Rail and bus transport:** by 2023, all new buses should be electric and new trains should be electric or hydrogen fuel-cell.

**Nonroad vehicles:** by 2023, all new nonroad land-based vehicles (agricultural machines, construction vehicles, military vehicles) should be electric.

**Heavy-duty truck transport:** by 2022 to 2030, all new heavy-duty trucks and buses should be battery-electric or hydrogen fuel-cell.

**Light-duty on-road transport:** by 2023, all new light-duty on-road vehicles should be battery-electric.

**Short-haul aircraft:** by 2024, all new small, short-range aircraft should be battery-electric.

**Long-haul aircraft:** by 2027 to 2035, all remaining new aircraft should be hydrogen fuel-cell or battery-electric.

Although much new WWS infrastructure can be installed upon the natural retirement of conventional infrastructure, new policies are needed to force remaining existing infrastructure to retire early in order to allow the complete conversion to WWS to occur on time.

Some suggest that retiring fossil plants early will create **stranded assets**, incurring a large cost. However, averaged worldwide, the annual social cost of a WWS energy system is less than 10 percent that of a fossil system. As such, replacing a fossil plant before the end of its life saves substantial damage and money. Transitioning also increases the number of jobs available. Society thus benefits from stopping the operation of existing fossil-fuel plants and replacing them with new WWS plants as soon as possible.

During the transition, fossil fuels, bioenergy, and existing WWS technologies are needed to produce the new WWS infrastructure. However, if no WWS infrastructure or machines were produced, much of the conventional energy would still be used to produce new business-as-usual infrastructure and machines. Further, as the fraction of WWS energy increases, conventional energy generation used to produce WWS infrastructure decreases, ultimately to zero. At that point, all new WWS infrastructure will be produced with WWS energy. In sum, the time-dependent transition to WWS infrastructure may result in a temporary increase in emissions before such emissions are eliminated.

### 14.1.2 How the Proposed Timeline May Impact Carbon Dioxide Levels and Temperatures

The WWS strategy proposed here is to transition the world to 80 percent WWS by 2030 and 100 percent by no later than 2050, but ideally by 2035, while eliminating non-energy emissions at the same pace.

An important question then is, how long will carbon dioxide levels take to recover once carbon dioxide emissions have been halted? Carbon dioxide levels in the air in 1750, before the Industrial Revolution, were about 276 parts per million. In 2021, they were up to a peak of almost 420 parts per million. Global computer simulations suggest that eliminating 80 percent of all human-created carbon dioxide emissions by 2030 and 100 percent by 2050 may reduce carbon dioxide levels in the air down to about 350 parts per million by 2100,[8] which is a reasonably safe level, albeit higher than the 1750 level. On the other hand, holding constant or increasing carbon dioxide emissions going forward will increase carbon dioxide levels in the air substantially compared with today.

How would globally averaged near-surface air temperatures respond if we eliminate emissions as proposed? Global air temperature rise is roughly proportional to cumulative carbon dioxide emissions, regardless of the timing of those emissions. As such, the more the cumulative emissions, the greater the temperature rise. The less the cumulative emissions, the lower the rise.

Between 1850 and 2019, the world emitted an estimated 2,390 billion tonnes of carbon dioxide from fossil-fuel combustion, cement manufacturing, and land use change.[7] This has resulted in the average global surface temperature between 2011 and 2020 being about 1.09 degrees Celsius warmer than between 1850 and 1900.

To limit global warming to no more than 1.5 degrees Celsius above the 1850 to 1900 mean temperature (with a 50 percent probability), we can allow no more than another 500 billion tonnes of carbon dioxide emissions from all human sources after 2020. To limit warming to no more than 2 degrees Celsius, we can allow no more than 850 billion tonnes of carbon dioxide emissions.[7]

In 2020, global carbon dioxide emissions from fossil-fuel burning and cement production were about 34.1 billion tonnes per year and those from land use change were about 5.9 billion tonnes per year, for a total of 40 billion tonnes per year. 2020 was a pandemic year, and total emissions were about 7 percent lower than in 2019.

If carbon dioxide emissions stay constant at 2020 levels going forward, enough carbon dioxide will accumulate in the air for the Earth to warm by 1.5 degrees Celsius relative to 1850 to 1900 levels by 2032 and 2 degrees Celsius by 2041.

On the other hand, if emissions of carbon dioxide from all energy and non-energy sources decrease 80 percent from 2020 levels by 2030 and 100 percent by 2050, additional cumulative emissions of only 340 billion tonnes of carbon dioxide will go into the air by 2050. This will avoid 1.5 degrees Celsius global warming since 1850. This is the strategy proposed here: to transition the world to 80 percent WWS by 2030 and to 100 percent by no later than 2050, but ideally by 2035, and eliminate non-energy emissions at the same pace. To accomplish this goal, aggressive policies are needed.

## 14.2 Obstacles to Overcome for a Transition

While technically and economically feasible, a transition of the entire world's energy infrastructure to clean, renewable energy in all sectors is a daunting task that faces significant social and political hurdles. Below, several of these challenges are discussed.

### 14.2.1 Vested Interests in the Current Energy Infrastructure

Possibly the greatest challenge to overcome in transitioning the world to 100 percent clean, renewable energy is the challenge of repelling vested interests. Fossil-fuel companies have accumulated enormous wealth and political influence since the start of the Industrial Revolution. As a result, they have been able to implement legislation that has given them an entrenched financial benefit in many countries through tax code breaks, direct grants, and subsidies. In addition, most of the existing energy infrastructure is a fossil-fuel infrastructure, and most people's day-to-day lives depend on that infrastructure (through transportation; building heating, cooling, and refrigeration; lighting, etc.). Further, over 25 million jobs worldwide depend on the fossil-fuel infrastructure.

Given the great financial resources available to the fossil-fuel industry and the dependency of many people's jobs and livelihoods on the current infrastructure, great care is needed to ensure that a transition to WWS brings along the same or a better standard of living, the same or more jobs, and the same or better comfort to as many people as possible. This means encouraging shareholders of fossil-fuel companies to move their investments to clean, renewable energy and storage, setting policies to retrain workers, and setting policies to ensure that WWS electricity supply is at least as reliable as the current supply of electricity on the grid.

Movement is already occurring in all three areas. Investors are moving capital resources into WWS. The WWS infrastructure is creating more jobs per unit energy than is the fossil infrastructure. The WWS system is also proving to be even more reliable and less expensive than was the preceding fossil system in the few places that WWS has completely replaced conventional fuels.

**Transition highlight**

For example, after 1 year of construction, a large (100 megawatt, 129 megawatt-hour) battery system that was installed in South Australia to fill in gaps in electric power supply for a 317-megawatt wind farm saved $40 million (Australian dollars) in grid stabilization costs. This was due to the rapid speed (100 milliseconds) at which batteries can react to shortages.[332] In another example, during July 2019, NextEra energy determined that investing in a combined wind (250 megawatt), solar PV (250 megawatt), and battery storage (200 megawatt, 800 megawatt-hour) system was less expensive than investing in a natural gas peaker plant.[333]

### 14.2.2 Zoning Issues (NIMBYism)

The second obstacle that needs to be overcome to implement a 100 percent WWS system is the **not-in-my-backyard** syndrome (**NIMBYism**). NIMBYism is an objection to the siting of something that a person thinks is unpleasant or dangerous in their neighborhood while not objecting to the development of the same thing somewhere else. Classic examples of NIMBYism are the siting of a landfill or a hazardous waste site near a neighborhood. However, NIMBYism extends to most every type of infrastructure development. People generally do not want to see additional buildings or facilities, including energy facilities, near them.

Although the installation of onshore and offshore wind and solar farms and transmission lines will face opposition in many locations, they will likely face less opposition than the building of more coal and natural gas plants, nuclear plants, oil and gas wells, refineries, and pipelines. The reason is that most people realize that WWS technologies do not bring air pollution or catastrophic risk along with them, whereas the fossil technologies bring both, and nuclear plants bring the risk of catastrophic failure and exposure to radiation above background levels. A second reason is that, although no one wants to add anything to the landscape, the addition of WWS often reduces land use relative to a fossil-fuel infrastructure. Similarly, whereas land used for a coal or nuclear plant cannot be used for another purpose at the same time, land occupied by a wind farm can be used for multiple purposes simultaneously: agriculture, animal grazing, open space, or even housing solar PV and batteries.

In addition, many people are becoming accustomed to rooftop solar panels, so they object to them less than in the past. Some types of solar panels are also integrated into building design, so it is difficult to tell whether the panels are even there. Most wind farms are located away from buildings because winds are fastest where no obstacles exist on the ground. With the advent of floating offshore wind turbines, visual objections to siting offshore wind are virtually eliminated because people cannot see such turbines.

Probably the most difficult WWS infrastructure to site is aboveground transmission. Siting transmission lines and pipelines today already results in NIMBYism, for good reason. Aboveground transmission lines and pipelines are not pretty. In addition, sparks from aboveground transmission lines can trigger wildfires. Wildfires around the world caused by transmission-line malfunctions have resulted in enormous damage, including loss of life.

Wildfires triggered by transmission-line sparks were a problem long before WWS, but the issue still needs to be addressed. The best solution is to bury the lines underground. To that end, in 2021, the northern California utility Pacific Gas & Electric announced that it will bury, over several years, 16,000 kilometers of existing transmission lines to reduce fire hazard. Although underground transmission lines are more expensive upfront than are overhead lines, burying lines may cost less over the long term because it eliminates devastating fire damage due to transmission lines. Burying transmission lines also solves their view problem.

Another partial solution to reducing reliance on transmission lines is to install more rooftop solar PV and batteries in fire-prone regions and to use more storage in general instead of transmission. A third partial solution is to improve safety measures by clearing more brush, and by learning from the causes of previous fires.

Adding new overhead or underground transmission lines due to 100 percent WWS will enable the elimination of all oil and natural gas pipelines. Such pipelines leak and/or rupture, sometimes causing explosions that result in damage and death. Particularly dangerous are leaky natural gas distribution pipes, which exist almost everywhere in densely populated cities.

Finally, many new transmission lines will be built on the same pathways as existing transmission lines, reducing the need for new land.

Because of the delays caused by zoning requirements, the installation of many new transmission pathways for a 100 percent WWS system may be limited in some countries and states. Fortunately, though, an alternative to transmission is more energy storage. Because storage costs are declining rapidly, the future WWS system may be dominated by storage over transmission.

### 14.2.3 Countries Engaged in Conflict

A third potential obstacle to a large-scale WWS buildout is the difficulty in building new energy infrastructure in countries suffering from conflict, such as civil war, terrorism, or war with another country. In 2022, five countries or regions of the world had conflicts with more than 10,000 deaths per year (Afghanistan, Yemen, Myanmar, Ukraine, and Eritrea–Ethiopia–Sudan). Another 14 had conflicts with between 1,000 and 10,000 deaths per year (Somalia, Azerbaijan, Iraq, Mexico, Colombia–Venezuela, the Democratic Republic of the Congo, Syria, Libya, Sudan, South Sudan, Mali, Algeria–Morocco–Tunisia–Libya–Mali–Niger–Chad, Nigeria–Cameroon–Niger–Chad, and Mozambique–Tanzania). Dozens of additional countries suffered less than 1,000 casualties during the year from conflict.

Because millions of people live in countries of ongoing conflict, it is even more essential to bring distributed, clean renewable energy to these countries. Oil pipelines and transmission lines are often targets for destruction or theft, so local microgrids may be the best way to provide energy safely to communities in countries engaged in conflict until the conflict is resolved. A **microgrid** is a grid isolated from or disconnected from outside sources of electricity. It may consist, in its simplest form, of solar panels plus batteries. The next step may be to add heat storage in a water tank. The electricity may be combined with a water filtration or desalinization system to provide clean water from wastewater or salt water, respectively. It may also be combined with a greenhouse or a food-growing container to provide food year-round.[18] In locations with suitable terrain, the microgrid may be combined with a small pumped-hydropower storage facility and small wind turbines.

Major problems in a war-torn country are famine and poverty. Microgrids, if set up and maintained properly, can help produce food, water, and energy together, mitigating both problems. One way to help alleviate some of the difficulty in setting up a microgrid in a war-torn country is for safer countries to provide aid in the form of clean, renewable WWS microgrid technology.

Some conflicts between countries arise over energy. For example, one country that provides natural gas to another may withhold the gas to extract concessions or use money from the sale of the gas to fund a war against another country. Alternatively, one country may need more energy and so invade a neighbor to take control of its oil and natural gas wells or coal mines. Transitioning a country entirely to clean, renewable energy, where most or all of the raw WWS resources are obtained from within the country, will make the country more energy-independent, reducing the reasons for conflict. However, many countries, even if they produce most of their own energy in the annual average, will benefit from trading energy with their neighbors to reduce the cost of matching power demand with supply over time. The reason is that, whereas the wind may not blow in one country at a given time, it is more likely to blow somewhere among several countries. The same applies to solar.

### 14.2.4 Countries with Substantial Poverty

Countries with a large segment of their population in poverty will benefit from transitioning to 100 percent clean, renewable energy as soon as possible. Millions of people die from indoor plus outdoor air pollution each year. Of these about 20 percent are children under the age of five. Almost all of the indoor air pollution deaths (about 2.6 million per year in 2016) are due to the burning of biomass and coal in developing countries for home heating and cooking.

The main step in eliminating indoor air pollution death is to eliminate indoor burning of fuel for cooking and heating. This can be accomplished most readily with the use of electric induction burners and electric heat pumps. For remote communities, the electricity would be obtained from a microgrid that combines solar PV or wind with batteries or pumped hydropower. Such an infrastructure costs money, and impoverished communities usually do not have access to such funds. However, costs of WWS generation and storage continue to decline. In addition, national governments may help financially. International aid will help with this solution too.

Impoverished countries will also benefit from a large-scale transition to WWS. Their end-use energy requirements will go down by an average of 56.4 percent; their annual cost of energy will consequently drop by over 60 percent. Their annual social costs of energy will decrease by near 90 percent.

However, the main barrier these countries face is the capital cost of their investment. WWS generators have no fuel cost, but they have an upfront capital cost. Although that capital cost pays for itself relatively quickly, raising upfront capital is not a trivial matter. To that end, wealthier countries need to work with more impoverished countries to help finance the upfront cost of a transition.

### 14.2.5 Transitioning Long-Distance Aircraft and Long-Distance Ships

Whereas 95 percent of the technologies needed for a transition to 100 percent WWS are currently commercialized, the rest are not yet available. The two most obvious technologies not yet commercialized are long-distance aircraft and long-distance ships. About 15 percent of worldwide commercial aircraft flights by number and 46 percent

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of such flights by distance are mid-haul flights (3 to 6 hours) or long-haul flights (longer than 6 hours).[61] The best WWS solution for such flights may be the development of hydrogen fuel-cell planes. However, for such aircraft to work cost-effectively, fuel-cell sizes and efficiencies need to improve. A transition to long-distance WWS aircraft may not occur until 2027 to 2035 because of the improvements and testing needed to commercialize hydrogen fuel-cell aircraft for mid- and long-distance travel. For short-haul flights (less than 3 hours), aircraft will be primarily battery-electric.

Long-distance ships have a similar issue to aircraft and are also proposed to be mostly hydrogen fuel-cell although some may be battery-electric. Long-distance ships can stop during their journey to refuel (if they are hydrogen fuel-cell) or recharge (if they are battery-electric). In addition, ships have less constraint on mass than aircraft, so ships are easier to design. As such, a transition of ships may be implemented between 2022 and 2030.

### 14.2.6 Competition among Solutions

One more obstacle facing a rapid transition is the competition among proposed solutions to the problems of air pollution, global warming, and energy security. Given the severity of the problems facing the world and the short time to fix them, competition among energy plans can result in poor technologies being implemented, thereby slowing down the solution. The main competitors for solutions to date have been a WWS solution and an **all-of-the-above** solution. An all-of-the-above solution includes WWS but also includes nuclear, fossil fuels with carbon capture, biofuels with or without carbon capture, direct air capture, and hydrogen from natural gas with or without carbon capture, among other technologies. However, those non-WWS technologies are opportunity costs. They result in more air pollution, more greenhouse gas emissions, more energy security risk, more land use risk, higher costs, or longer planning-to-operation times, or all of these, relative to WWS. As such, spending money on non-WWS technologies results in less benefit and a longer delay before enough WWS can be implemented to eliminate air pollution, global warming, and energy insecurity. The best way to overcome this obstacle is to educate the public and policymakers about it and guide them to the WWS solution.

## 14.3 What Can Individuals Do?

The solution to air pollution, global warming, and energy insecurity requires actions by individuals, businesses, nonprofits, and policymakers. This section discusses some of the actions that individuals can take to reduce energy use and to change the types and sources of the energy that they consume.

Most individuals consume energy that results in carbon dioxide and air pollution emissions in all of the main energy sectors (electricity, transportation, building heating and cooling, and industry). We consume electricity for lights, computers, refrigerators, and food production. We drive to work or for leisure. We desire buildings of a certain temperature for comfort. We consume products and food created by industry. Because we consume, we can control our emissions both by changing our habits and choices and by changing the type and sources of energy we use.

Because each person is in a different situation in terms of both the energy they consume and their financial and practical ability to transition their energy, each recommendation given here may apply to some people but not others.

### 14.3.1 New Home Construction

Those building a new home from scratch can plan their home not only to minimize energy use but also to produce their own WWS energy. The first step in planning such a home is to ensure that it uses only one energy source, electricity, rather than both electricity and natural gas. There is no reason to have two sources of energy in a building since every appliance that runs on natural gas has an electrical equivalent that is the same or better in quality. To the contrary, adding natural gas to a home or another building adds unnecessary costs, including for a gas hookup fee charged by the utility, for ditches to bury natural gas pipes, for natural gas pipes themselves, for a natural gas meter, for vents to provide air and ventilation for natural gas combustion, for carbon monoxide monitors, and for inspection of all of the above. These items sum to tens of thousands of dollars of unnecessary cost per home. Natural gas use in buildings also releases health-affecting air pollutants. Health problems from natural gas fumes and combustion products are eliminated by eliminating natural gas use.

The appliances in a building that run on natural gas often include an air heater, a water heater, a cooktop, a dryer, and a pool heater. In locations on district heating, air heating and water heating (and rarely, air cooling) are supplied from centralized boilers and chillers, so in-house appliances are not needed for these tasks.

For locations not on district heating loops, a natural gas air heater, water heater, dryer, and pool heater can be avoided by using an electric heat pump version of each. A natural gas cooktop can be avoided by using an electric induction cooktop. Because heat pump air heaters all automatically run in reverse as air conditioners, the use of a heat pump for air heating and air conditioning eliminates the need for a separate air conditioner, saving additional money. Because heat pumps consume one-quarter the energy of natural gas heaters, the installation of a heat pump saves a lot of money each year. Finally, the use of a heat pump air heater/air conditioner that has an indoor unit in each room of the house, and an outdoor unit to exchange air between the inside and outside, eliminates the need for ducts throughout the house, saving more money.

The third step in new home planning is to minimize energy use by maximizing energy efficiency. The first way to make a building energy efficient is to install thick insulation within walls, below the bottom floor, between floors, above the ceiling, around water pipes, and in and around windows. Concrete, which helps to keep the temperature relatively stable inside a building, can also be used as floor or wall material. Triple-paned windows minimize heat transfer through the windows. The greater the insulation, the less the energy needed to heat or cool a home, reducing energy consumption and extending heat pump life.

Similarly, smart glass windows reduce cooling and heating needs. They are translucent during summer, thereby blocking incoming heat from the outside, and transparent during winter, maximizing sunlight into your home during that time. The second way to minimize energy use is to install LED lights everywhere. The third way is to use only energy-efficient electric appliances (refrigerator, dishwasher, washing machine, television, vacuum, etc.).

The fourth step in new home planning is to install rooftop solar PV panels, garage batteries, an inverter to control both, and an electric car charging port. In some windy locations, a backyard wind turbine may be possible instead of solar PV. The solar PV or wind system should be sized, at a minimum, to meet 100 percent of your annual average electricity demand for your home, including for any electric vehicles you might use. Ideally, the PV system will be sized larger than this to account for any future growth in demand and to help the grid when the grid is not producing enough electricity to meet everyone's demand. One or two batteries are helpful to store electricity during times of low demand, such as during the morning, and to discharge electricity during times of peak demand, such as just after sunset. Such batteries help to relieve stress on the grid and save you money.

The fifth step is to use sustainable building materials for construction. One option is to use prefabricated, recycled steel for the structure.[97] Since the steel is produced precisely in a factory and is from recycled material, it minimizes waste. Wood homes typically result in wood waste during construction. Concrete can also be recycled and used as aggregate, either as a sub-base material or mixed as an aggregate with new concrete. Some sustainable building materials include composite roofing shingles and bamboo. Composite roofing materials require much less repair and replacement than do asphalt shingles, tile, and wood shake. Bamboo re-grows in 3 years versus 25 years for most trees.

### 14.3.2 Home Retrofits

Hundreds of millions of buildings already exist worldwide, and the turnover is only 1 percent per year. Given the substantial energy use in existing buildings, retrofitting such buildings to become all electric is essential for solving the air pollution, climate, and energy security problems we face.

Solutions for existing buildings are usually not technically challenging. However, unlike for new buildings, where one can save a lot of money by going to 100 percent WWS, retrofitting existing buildings usually saves less.

One of the lowest-cost ways to reduce energy use in your home, thus reduce energy cost, is to weatherize your home by sealing cracks in windows and doors and adding insulation around water pipes. Adding or changing the insulation below the floor or in the attic also helps. Even insulating an attached garage can minimize heat loss from the house to the garage.

A second step is to change lights to efficient LED lights and to change appliances to electric, energy-efficient appliances. Certainly, if

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a natural gas water heater needs replacing, it should be replaced with a heat pump water heater. Most natural gas air heaters in buildings are centralized units that provide heat that is sent through ducts to the rest of the building. When or before the heater breaks down, it should be replaced with a centralized heat pump air heater and air conditioner that also uses ducts. Similarly, a natural gas dryer should be replaced with a heat pump dryer. A natural gas cooktop should be replaced with an induction cooktop. Gradually, all appliances in a building can be changed from natural gas to electric.

A third step is to install rooftop PV or backyard wind, one or two batteries, an inverter, and a car charging port, just like with a new building.

Although some of these measures are low cost and others can be done when an existing appliance breaks down, the rest require new investments. Although some people can afford such investments, many others cannot. As such, policies are needed to encourage and help finance retrofits. Otherwise, only a small fraction of the needed retrofits will be performed.

### 14.3.3 Renting

Many people rent apartments, condominiums, or town houses, so they have little control over either their source of electricity or the appliances that they use. However, renters do have some control. First, renters pay electricity bills to a utility. Many utilities today, particularly community choice aggregation utilities, but also many others, offer to sell customers 100 percent WWS electricity. Second, even if an apartment has a natural gas cooktop, it is possible to purchase an individual induction cooktop burner for $40 to $100. These just plug into the wall and replace the natural gas cooktop. Third, weatherizing doors and windows in the rental can save a lot of money, as can changing lights to LED lights. If the building is on district heating, then natural gas is not used for any other purpose in the rental, and you are done. If your rental has a natural gas air or water heater, then it would be up to the landlord to change these. The first step in doing this is to request the landlord to invest in electric heat pump air and water heating, especially when existing units break down. The second step is to ask your local policymaker to incentivize or require such changes.

### 14.3.4 Transportation

People travel primarily by foot, bicycle, car, streetcar, bus, train, ship, or airplane. Many people own or lease cars. If a new car is needed, the next one should be electric. A variety of electric cars are currently available. Whereas only expensive electric cars were available until a few years ago, lower-cost models are now available most everywhere. Traveling by bus, train, ship, or plane usually results in less energy consumed per unit distance traveled than traveling by car.

### 14.3.5 Consumer Choices

Individuals make conscious or unconscious choices every day about how much energy they consume and, therefore, how much pollution they emit. Consumers decide what to eat, where to travel, whether to use a computer or television, and what goods to buy. Based on today's fossil-fuel use worldwide, each product purchased or action taken results in certain **carbon footprint**, which is the lifecycle $CO_2$-equivalent emissions of the product or action. However, as we go to 100 percent WWS and address non-energy emissions too, the carbon footprint of actions and products will go to zero, which is good news. In the meantime, though, certain actions can definitely reduce air pollution and carbon emissions.

Such actions include telecommuting for work instead of driving to and from work; holding more meetings virtually instead of in person; minimizing travel; using more public transportation; biking or walking instead of driving; shutting off lights when they are not needed; dimming the screen on a computer or phone slightly; reducing meat consumption; and purchasing fewer nonessential goods.

**Transition highlight**

In an extreme example of how consumer choices can affect energy use, on July 11, 2021, Richard Branson and three others flew into space 85.3 kilometers above the surface of the Earth as the world's first space tourists. However, the 1.5-hour, 11,260-kilometer flight resulted in 135,000 kilograms of carbon dioxide emissions per person along with other rocket fuel exhaust emissions.[334] The average person in the United States emits 3.4 kilograms of carbon dioxide per 1.5 hours. So, the emissions per person for that 1.5-hour flight were 40,000 times those of the average person. A better solution is not to travel to space for tourism, thereby avoiding wasteful energy use.

## 14.4 Policies

The policies necessary to transform to 100 percent WWS differ by country, depending largely on the willingness of the government and people in each country to effect a rapid change. This section first defines several types of policy options that each country can consider implementing. Policy options for different energy sectors are then discussed in more detail.

### 14.4.1 Policy Options for a Transition

Below are some policy options that have been used in the past. The list is by no means complete.

**Renewable portfolio standards**, also called renewable electricity standards, are policy mechanisms requiring a certain fraction of electric power generation to come from specified renewable energy sources by a certain date. Thus, for example, a mandate of 80 percent WWS by 2030, and 100 percent no later than 2035, is a renewable portfolio standard. 100 percent renewable portfolio standards have been enacted in many countries, states, cities, and towns to date.

**Financial incentives and laws for increasing energy efficiency and reducing energy use** are policy methods to reduce the demand for energy. For example, a law requiring the substitution of low-energy-consuming LED light bulbs for high-energy-consuming incandescent ones reduces energy demand. Demand reduction reduces the pressure on energy supply, which makes it easier for WWS supply to match demand.

**Laws requiring demand response** are helpful because they force utilities to incentivize customers to shift the time of their electricity use from a time of peak electricity demand to a time of lower demand during the day or night. Demand response is usually accomplished in one of two ways. The first way is for utilities to increase the price of electricity during times of peak electricity use. The higher cost of electricity incentivizes customers to use less electricity during those times of day. The second way is for utilities to pay customers to use less electricity during times of high electricity demand. In both cases, the customer can react manually to the change in rate or payment by reducing or stopping energy consumption during times of peak demand. Alternatively, the customer can agree to

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have internet- or radio-controlled switches installed on air conditioners or other devices to automatically reduce energy use during times of peak demand.

**Feed-in tariffs** are subsidies to cover the difference between electricity generation cost (ideally including grid connection cost) and wholesale electricity prices. Feed-in tariffs have been an effective policy tool for stimulating the market for renewable energy. To encourage innovation and the large-scale implementation of WWS, which will itself lower costs, feed-in-tariffs should be reduced gradually. Otherwise, technology developers have little incentive to improve.

**Output subsidies** are payments by governments to energy producers per unit energy produced. For clean, renewable energy producers, the justification of such subsidies is to correct the market because fossil-fuel and bioenergy energy producers are not paying for the pollution they emit, which has health and climate costs to society. In other words, the subsidies attempt to address the tragedy of the commons, which arises because the air is not privately owned. As such, the air historically has been polluted without polluters paying the health, climate, and environmental costs of the pollution.

**Investment subsidies** are direct or indirect payments by governments to energy producers for research and development. Historically, such subsides have been given mostly to conventional fuel producers through legislation and clauses in the tax code, such as deductions and credits for specified activities. Conventional generators have benefited historically from such subsidies by not paying externality costs of the pollution that their energy creates. Investment subsidies are now available to WWS energy sources in many countries.

One type of investment subsidy is a **loan guarantee**, whereby the government guarantees a loan to a company for constructing a facility. Without such guarantees, many large energy projects would not be approved for a construction loan. Such loan guarantees have been historically provided to the conventional fuels industry. Guarantees will benefit the WWS industry as well.

On a smaller scale, **municipal financing** of residential energy efficiency retrofits and solar installations help to overcome the financial barrier of the high upfront cost to individual homeowners. **Purchase incentives and rebates** can also help stimulate the market for electric vehicles.

A potential policy tool that has not been used widely to date is a **revenue-neutral carbon tax or pollution tax**. This is a tax on polluting energy sources, with the revenue transferred directly to nonpolluting energy sources. In this way, no net tax is collected, so the cost to the public is zero in theory. If the tax is a revenue-neutral carbon tax, it may not address air pollution. For example, a biomass or coal-with-carbon-capture electricity plant can claim it is low carbon (which itself is not accurate), thus avoid much of the tax, yet still emit substantial health-affecting air pollutants along with carbon. A second problem is that heavy polluters can choose to pay the tax and withstand a lower profit margin or raise their prices, yet still emit.

A related tool is straight **pollution tax**, such as a **carbon tax**. Such a tax is not so popular since it is perceived as a cost to the public, because the money collected from the tax does not necessarily go back to reducing energy prices. Instead, polluting companies merely increase their prices charged to customers to pay the tax.

Another noneconomic policy is **mandatory emission limits** (usually tailpipe or stack exhaust emission limits) for technologies. This is a **command-and-control** policy option implemented widely under the U.S. Clean Air Act Amendments and in many countries to reduce vehicle emissions. By tightening emission standards, including for carbon dioxide, policymakers can force the adoption of cleaner vehicles. Such emission limits can and have also been set for other pollution sources. A disadvantage of emission limits (unless they are zero) is that they allow the fossil-fuel industry and their upstream mining to persist while the industry pursues incremental reductions in tailpipe or stack emissions. However, a mandate of absolutely zero tailpipe pollution emissions would mean that only electric and hydrogen fuel-cell cars could meet these limits. That would lead to the phase out of internal combustion engine vehicles.

Related to mandatory emission limits is **cap and trade**. Under this policy mechanism, mandatory emission limits lower than current emissions levels are set for an entire industry, and pollution permits are issued corresponding to the total pollution emissions allowed. Polluters in the industry can then buy and sell pollution permits. The net result is lower overall emissions and a payment by the polluters for the remaining emissions. The problem with this mechanism is similar to that with emission limits. Unless the cap is zero, pollution will persist long into the future.

### 14.4.2 Policy Options by Sector

Current energy markets, institutions, and policies have been developed to support the production and use of fossil fuels, bioenergy, nuclear power, and clean renewable energy. New policies are needed to ensure that a 100 percent clean, renewable energy system develops quickly and broadly in each country, and that dirtier energy systems are not promoted. Below, several policy mechanisms are proposed for each energy sector to accomplish these goals. For each sector, the policy options are listed roughly in order of proposed priority.

#### 14.4.2.1 Energy Efficiency and Building Energy Measures

- Expand energy efficiency standards.
- Incentivize the conversion from natural gas water and air heaters to electric heat pump heaters.
- Promote, through incentives, rebates, and municipal financing, energy efficiency measures in buildings.
- Revise building codes to incorporate "green building standards" based on best practices for building design, construction, and energy use.
- Incentivize landlord investment in energy efficiency. Allow owners of multi-family buildings to take a property tax exemption for energy efficiency improvements in buildings.
- Create energy performance rating systems with minimum performance requirements to assess energy efficiency levels and pinpoint areas of improvement.
- Create a green building tax credit program for the corporate sector.

#### 14.4.2.2 Energy Supply Measures

- Increase the percentage of WWS energy supply required under renewable portfolio standards.
- Extend or create WWS production tax credits (a tax credit for every kilowatt-hour of electricity produced).
- Invest in job retraining from business-as-usual energy to WWS energy.
- Incentivize the expansion of building-scale electricity storage.
- Streamline the permit approval process for large-scale WWS power generators.

- Streamline the permit approval process for high-capacity transmission lines. In the United States, for example, 750 gigawatts of WWS electricity generation projects were sitting in an "interconnection queue" in 2021, waiting to connect to the transmission grid.[335] Once at the front of the queue, project owners are often charged high fees to cover the cost of transmission upgrades to support their project. One solution to this problem is to identify and pre-approve regions where large generation and transmission can be added simultaneously, reducing the cost of additional transmission.
- Work with local and regional governments to streamline zoning and permitting for new electricity generation and storage within existing planning efforts to reduce the cost and uncertainty of projects and to expedite their build-out.
- Streamline the small-scale solar and wind installation permitting process. Create common codes, fee structures, and filing procedures across a country.
- Lock in fossil-fuel and nuclear power plants to retire under enforceable commitments. Implement taxes on air pollution and carbon emissions by current utilities to encourage their phase-out.
- Incentivize home or community battery storage (through garage electric battery systems, for example) that accompanies rooftop solar.

#### 14.4.2.3 Utility Planning and Incentive Structures

- Incentivize district heating and community seasonal heat and cold storage.
- Incentive the development of utility-scale grid electric power storage in CSP, pumped hydropower, more efficient large hydropower, and large battery systems.
- Require utilities to use demand response grid management to reduce the need for short-term energy backup on the grid.
- Incentivize the use of excess WWS electricity to produce and store hydrogen, heat, and cold to help manage the grid.
- Develop programs to use electric-vehicle batteries, after the end of their useful life in vehicles, for stationary storage.
- Implement **net metering**, whereby rooftop solar owners can sell electricity back to the grid to offset a part or all of the cost of the electricity that they buy from the grid.

#### 14.4.2.4 Transportation Measures

- Mandate battery-electric vehicles for government transportation (mail delivery, service vehicles, military base vehicles) and use incentives and rebates to encourage the transition of commercial and personal vehicles to battery-electric and hydrogen fuel-cell vehicles.
- Promote more public transport by increasing its availability.
- Increase safe biking and walking infrastructure, such as dedicated bike lanes, sidewalks, crosswalks, and timed walk signals.
- Set up time-of-use electricity rates to encourage vehicle charging during off-peak hours.
- Use incentives or mandates to stimulate the growth of private fleets of electric and/or hydrogen fuel-cell buses.
- Incentivize battery-electric and hydrogen fuel-cell ferries, riverboats, tugboats, speed boats, dredgers, and other local watercraft.
- Adopt zero-emission standards for all new on-road and off-road vehicles for all purposes, with 100 percent of new production required to be zero-emission of every air pollutant by 2030. Incentivize the transition by gasoline and diesel superusers the fastest, since the top 10 percent of gasoline users, for example, consume more gasoline than the bottom 60 percent.[336]
- Ease permitting for installing electric charging stations in public parking lots, hotels, suburban metro stations, on streets, and in residential and commercial garages.
- Incentivize the electrification of freight rail and shift freight from trucks to rail.

#### 14.4.2.5 Industrial Sector Measures

- Provide financial incentives for industry to convert to electricity for high-temperature manufacturing processes.
- Provide financial incentives to encourage industry to use WWS electric power generation.
- Encourage industry to take part in demand response measures to help match power demand with supply and storage on the grid.
- Encourage steel, concrete, and silicon manufacturing plants to shift to processes producing those products without releasing carbon dioxide chemically.

The measures listed above are a limited list. Yet, many are necessary to speed a transition, which would otherwise drag on long past 2050. Each town, city, state, province, or country must select its own policies based on what works best in their region. Yet, the reduction in cost that has already occurred combined with economies of scale due to further WWS expansion are a cause for optimism. If effective policies are put in place, an all-sector transition to 100 percent WWS, ideally by 2035, but no later than 2050, is possible.