A Million Solar Roofs for Colorado

A Big, Bold Plan to Protect Our Environment and Grow Our Economy

Environment Colorado Research & Policy Center

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Cover photo: Denver Housing Authority homes with rooftop solar photovoltaic (PV) panels installed by Namaste Solar Electric of Boulder, Colorado. Courtesy of Namaste Solar Electric and Vantage Point Imagery.

Graphic Design: Harriet Eckstein Graphic Design, harrieteckstein@cox.net

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Executive Summary

As one of the sunniest states in the country, Colorado has great potential for solar energy. By 2030, Colorado could install solar energy capacity equivalent to that of a million solar rooftops—reducing our dependence on fossil fuels, addressing global warming and boosting our economy.

Colorado can install a million solar roofs—or at least 3,000 MW of solar energy capacity—by 2030.*

- Denver has sunny skies 245 days of the year, and Colorado as a whole has a better solar resource than many places in California, the nation's solar leader.

- Colorado has a lot of empty rooftop space. Installing solar photovoltaic (PV) panels on every available and appropriate rooftop space in Colorado would yield more than 16,000 MW of solar capacity by 2030. With the right policies in place, Colorado can develop at least 3,000 MW of this capacity—the equivalent of installing one million rooftop solar energy systems.

- Community solar projects and utility-scale solar energy can further expand solar capacity in Colorado, providing hundreds of additional megawatts of capacity in the near term and thousands of megawatts over time.

By 2030, solar power can help Colorado avoid 3.6 million metric tons of global warming pollution annually—equivalent to taking 760,000 of today's passenger vehicles off the road.

- Preventing global warming pollution is critical to protecting our treasured ecosystems and way of life. Global warming could increase average global surface temperatures by as much as 11°F by 2100. Temperature increases on this scale would reduce winter snowpack, threaten urban and rural water supplies, interfere with agriculture, threaten the state's forests with more frequent and intense wildfires and insect infestations, and shrink wildlife habitat.

**For the purposes of this report, we assume rooftop solar energy systems to be 3 kW (DC) in size.*

Increasing solar power would help protect public health by reducing harmful air pollution from the state's fossil fuel-fired power plants.

- Colorado's coal- and natural gas-fired power plants harm public health by emitting smog-forming pollution. In 2013, Fort Collins and Denver received "F" grades from the American Lung Association for high levels of ground-level ozone, a key element of smog; Colorado Springs received a "C" grade.

- In 2030, a million solar roofs (or at least 3,000 MW of solar energy capacity) would help the state avoid 11.8 million pounds of smog-forming nitrogen oxide pollution from power plants annually—a reduction of 9 percent below 2012 power plant emission levels.

Solar power can help speed Colorado's transition to a clean energy economy.

- There are already 266 solar energy companies employing 3,600 people in Colorado—placing Colorado sixth in national rankings for total number of jobs in the solar industry and seventh in jobs per capita.

- The largest area of solar employment in Colorado is in system installation, according to the Solar Energy Industries Association (SEIA). These jobs cannot be outsourced, and as the solar industry grows, so will local employment.

- Altogether, the solar industry contributed more than $1 billion to Colorado's economy over the past three and half years, according to a report by the *Denver Post*.

State leaders should set a goal of installing one million solar rooftops—or at least 3,000 MW of solar energy capacity—by 2030. At least half of this capacity should come from distributed, small-scale solar PV systems to ensure a robust, self-sustaining solar energy market for the long term. The state should also establish a goal of installing 250,000 residential and commercial rooftop solar water-heating systems by 2030.

Reaching this goal will require ambitious policies to promote both small-scale and large-scale solar energy systems, as well as a sustained commitment to strengthening these policies in the long term.

To promote development of Colorado's solar energy market, policymakers should:

1. **Strengthen the state's renewable energy standard:** The state should strengthen its renewable energy standard (RES) for all utilities by requiring them to get 50 percent of their electricity from renewable sources by 2030. Included in the standard should be a requirement that 10 percent come from distributed renewable energy sources, which will boost development of small-scale and onsite renewable projects such as rooftop solar energy systems.

2. **Strengthen net metering policies:** The state's net metering policies require investor-owned utilities to credit customers who produce electricity through rooftop solar panels at the retail rate for every kilowatt-hour they supply to the grid. Colorado should require that customers of municipal and cooperative utilities be reimbursed at the retail rate, as well.

3. **Make solar energy an attractive investment for all customers:**

Colorado should require utilities to work with solar developers to create long-term contracts to purchase solar power from local providers at a fixed rate, which helps eliminate the financial uncertainty caused by fluctuations in electricity prices and guarantees solar energy producers a reasonable return on their investments. The state should also offer more financing options that make solar energy cost-competitive with traditional fossil fuels.

4. **Develop Colorado's potential for solar water heating:** Solar water-heating systems have the potential to reduce household energy use for water heating by about 60 percent, but they are not widely used because they have higher up-front costs than natural gas water-heating systems. The state should create an incentive program to bring down the cost of installing solar and other renewable energy water-heating systems and include renewable water-heating technologies in residential and commercial natural gas efficiency programs.

5. **Renew tax exemption programs:** Colorado exempts renewable energy products—such as solar panels, mounting equipment and wiring—from sales and use taxes. The state should extend these exemptions beyond their 2017 expiration date, guaranteeing the incentives for at least 10 years.

6. **Support community solar projects:** Community solar gardens allow residents to pool their resources to establish community solar arrays, and to offset their electricity use through group net metering. By fall 2013, Xcel Energy's community solar program is expected to bring online 9 MW of solar capacity in 13 solar gardens across the state. Xcel should continue approving solar gardens at this pace, and other utilities should follow suit.

7. **Eliminate regulatory barriers to the expansion of solar energy:** State and local leaders should work to standardize procedures, minimize fees, and streamline the process of installing a new solar energy system and integrating it into the electricity grid to make it as easy and affordable as possible for Coloradans to participate in the solar market.

8. **Create a net-zero energy building code:** A net-zero energy building code requirement would increase the use of solar and other local clean energy systems in new construction. Colorado should require all new homes to include solar power or other on-site renewable electricity generation by no later than 2020, and all non-residential buildings by no later than 2030, through a net-zero energy building code requirement.

Introduction

Colorado has some of the sunniest weather in the country. Strong, frequent sunshine even during winter months can melt a week's worth of snow in a matter of hours. Whether climbing the Rockies in summer or skiing on sun-splashed slopes in winter, Coloradans enjoy cloudless blue skies for about 245 days out of the year.[1]

This sunlight shines on millions of square feet of empty rooftop space in the state. If outfitted with solar panels, these rooftops would help provide Colorado with an abundant supply of zero-emission energy—all while creating jobs and boosting the economy.

Colorado is well-poised to take advantage of its full potential for solar power. Thanks to the state's 2004 adoption of a renewable energy standard—the nation's first to be passed by popular vote—Colorado's clean energy industry is now drawing millions of dollars in capital investment annually, mostly in green building and wind energy technologies.[2] In recent years, solar energy has emerged as a robust part of the state's clean energy economy, as well. The industry is already supported by thousands of workers who develop, manufacture, sell and install solar energy systems and their component parts. In 2012, investments in solar installations for homes and businesses topped $187 million.[3]

Still, the state gets less than 1 percent of its electricity from solar energy. With the right policies in place, clean, renewable solar power can become a significant part of Colorado's energy mix, helping the state expand its clean energy economy and protect its environment from the impacts of global warming. This report explores this potential for expanding solar energy in Colorado and charts a path forward for widespread adoption of solar energy in the state.

Colorado Can Install Solar Capacity Equivalent to a Million Solar Roofs

Colorado's abundant solar resources and rooftop space make it an ideal place to launch a market for rooftop solar power. Given the amount of rooftop solar power currently installed in Colorado, even modest growth—much slower than the growth of other leading states such as California and New Jersey—would result in about 3,000 megawatts (MW) of solar power by 2030.[4] That amount of solar capacity would be enough to supply 8 percent of the state's electricity needs in 2030.[5] Much of Colorado's rooftop space that is appropriate for solar PV could also support solar water-heating systems, and achieving an equivalent market penetration for solar water-heating systems as solar PV would reduce the state's water-heating needs by 11 percent in 2030.[6]

The state can also tap into its potential for large-scale, non-rooftop solar power, such as along highways, over landfills or on military bases. Non-rooftop solar arrays can be ground-mounted in community solar "gardens" or span dozens of acres of barren land. These community and utility-scale solar energy projects can help Colorado replace much more dirty electricity in the short term.

Photo courtesy of GE Solar

The Sun Shines on Colorado

Coloradans are blessed with sunny weather. The sun can shine for weeks in a row in any season, and a day that begins as overcast can end with blue skies. Denver has sunny skies 245 days of the year, and Colorado as a whole has a better solar resource than many places in California.[7] (See Figures 1 and 2.)

Solar resource quality at a given location can be measured by the average output of a solar photovoltaic (PV) panel over the course of a year. The output—or amount of solar power generated—depends on the intensity of the sunlight reaching the panel, which varies from hour to hour with the weather and the passing of day and night, and from season to season with the angle of the sun and length of the day.

In Denver and other Colorado population centers, a one kilowatt (kW) solar energy system using today's technology will capture enough sunlight to generate around 1,460 kWh of electricity over the course of a year.[8] Colorado's solar resource rivals that of California, which, like Colorado, has a strong solar energy market, and far outstrips that of Germany, the world's most developed solar energy market.[9] For example, in Sacramento a one kilowatt solar energy system will generate about 1,400 kWh per year; in Germany, it would produce only 754 kWh per year.[j] (See Figure 1.)

Colorado also has great potential to capture heat from the sun to reduce energy consumed for water heating. Rooftop solar water-heating systems are more effective in Colorado that in many other parts for the country, according to the National Renewable Energy Laboratory.[12] (See Figure 3.)

Figure 1. Solar Energy Resources by Location[11]

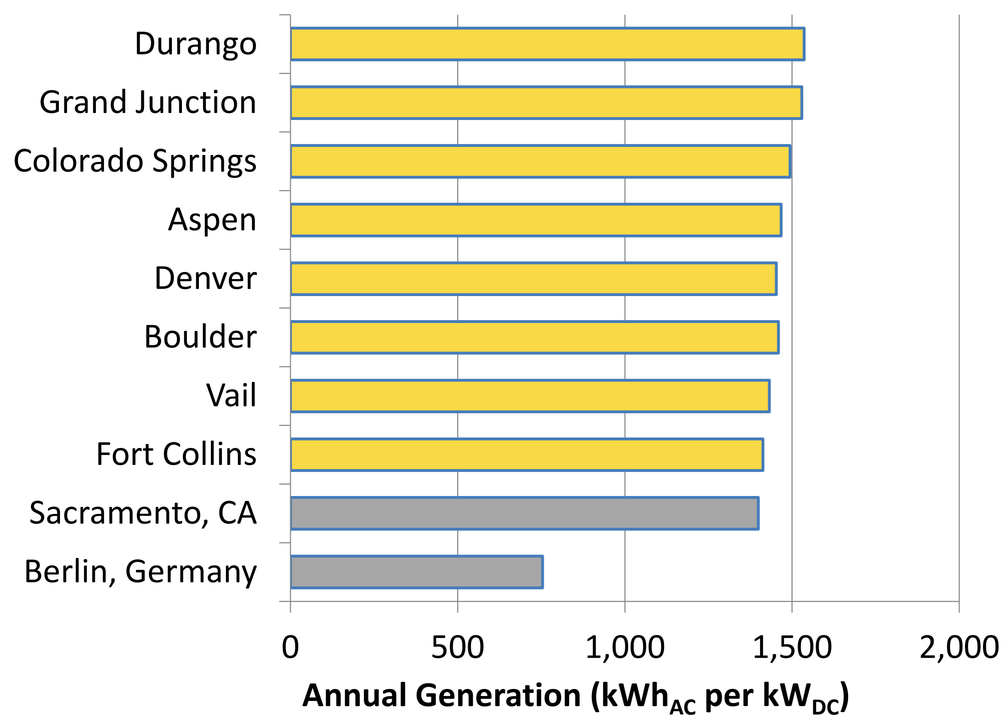
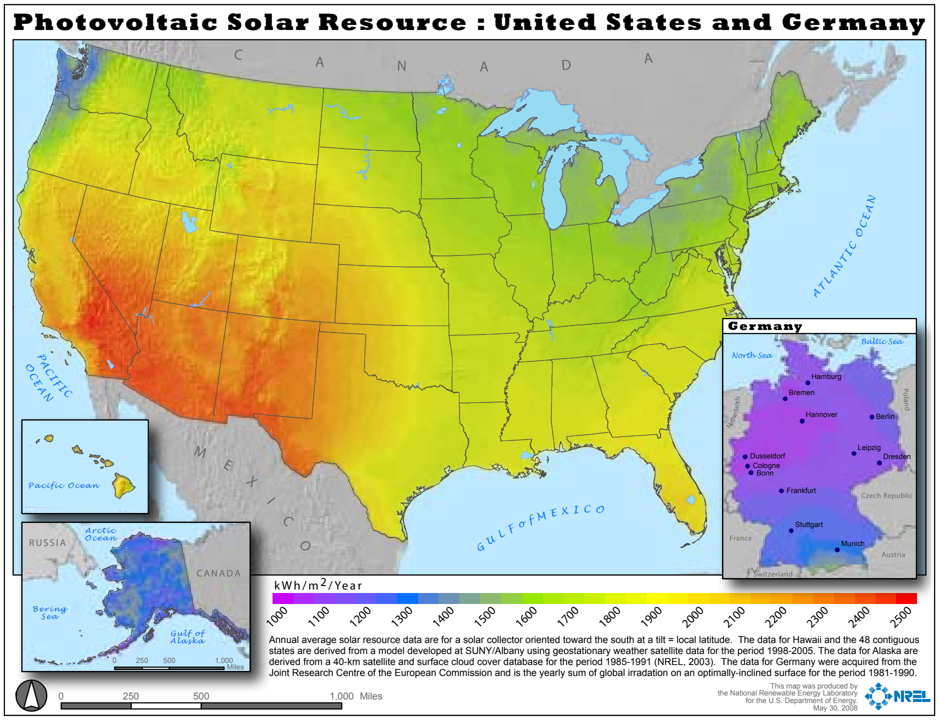


Figure 2. Solar Energy Resources in Colorado far Exceed Those in Germany, the World's Largest Solar Market



National Renewable Energy Laboratory

Figure 3. Solar Water-Heating Systems Work Well in Colorado[13]

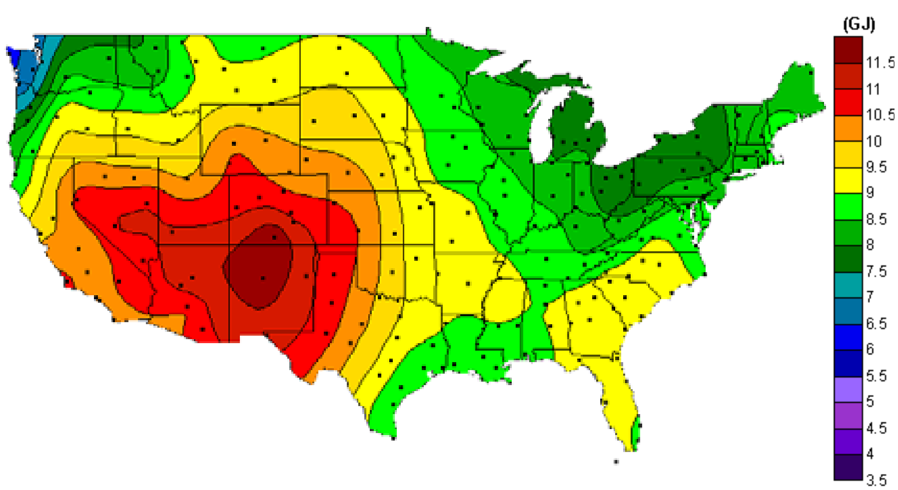


Figure shows annual energy savings in gigajoules (GJ)

Courtesy of Piper Foster

Rooftop solar water-heating system above the Grand Hyatt resort in Aspen.

Rooftop Solar Energy Systems Work

Solar photovoltaic (PV) panels capture the energy in sunlight and turn it into electricity. Buildings with rooftop solar PV systems are typically connected to the electric grid. The grid provides supplemental power during cloudy weather or at night. During sunny weather it distributes the extra electricity produced by the panels for use elsewhere. Since rooftop solar panels generate electricity close to where it will be used—and often at times of the day when demand for electricity is high and the cost of supplying the electricity is also high—solar technology can reduce the need to invest in cross-country power lines and help increase the reliability of electricity service.

Solar water-heating systems use simple technology to capture solar energy and heat water for a home, commercial building or factory. Tens of millions of households worldwide—particularly in Israel and China, but also increasingly in the United States—use solar water heating.[14] Solar water-heating systems work by preheating water before storing it in an insulated tank, reducing the amount of electricity or natural gas required to further heat the water to a useable temperature. In Denver, solar water-heating systems can cut the energy use of a standard water heater by about 60 percent.[15]

The Benefits of Solar Power to Colorado

Solar power can make an important contribution to a stable, sustainable and affordable regional electricity system. By 2020, Colorado's population is expected to reach nearly 6 million—up from 5.2 million in 2012.[16] Colorado will need more energy options to meet the needs of this growing population. Solar power can help meet this additional demand and reduce the state's reliance on dirty forms of energy.

Solar panels generate the greatest amount of electricity at the times when it is most needed—particularly on hot, sunny summer days, when more residents run their air conditioners. During these periods of peak consumption, electricity providers must bring peaking power plants, which are expensive to operate, on line to ensure reliability of service. Most power providers use natural gas-fired power plants to meet peak electricity demand, which makes it the fuel most commonly replaced by solar power—also a peaking resource.[17] Solar power also has the potential to replace baseload electricity fuel sources, such as coal, as overall capacity expands and energy storage technology improves, according to the Department of Energy.[18]

Solar power's unique characteristics as a clean, distributed energy source would reduce the need to run these peaking power plants or to build more of them in the future. A significant increase in solar energy deployment would also reduce energy prices in the long term.[19]

Solar energy has many other advantages, as well, including:

- Rooftop solar energy is generated near where it is used. It therefore reduces the need to invest in new high-voltage transmission lines and reduces the electricity losses that result from long-distance transmission of power from large, centralized power plants.[20]

- Solar panels provide energy for decades at a fixed cost, because sunlight is free. Fossil fuels often experience wild price swings. Solar PV can act as an effective hedge against these price fluctuations, helping to maintain stable electricity prices.[21]

- Rooftop solar energy requires no additional land beyond that already occupied by buildings, parking lots or other developed areas, and consumes practically no water.

- Solar energy benefits society at large by reducing global warming pollution.[22]

Solar Energy Protects Colorado's Environment and Strengthens the Economy

Solar energy prevents emissions of carbon dioxide, a leading contributor to global warming, and helps protect Colorado's environment and economy for current and future generations. Increasing the market for solar power will also benefit the state's economy by creating jobs in solar energy system installation and manufacturing.

Solar Energy Helps Prevent Global Warming Pollution

Increased deployment of solar PV panels and solar water-heating systems can reduce Colorado's dependence on fossil fuels and lessen its contribution to global warming. Solar energy can replace fossil fuel combustion—especially natural gas—reducing the state's emissions of carbon dioxide, which is the leading pollutant driving global warming.[23]

Like the rest of the country, Colorado's environment and economy are vulnerable to the impacts of global warming.[24] From 1977 to 2006, temperatures in Colorado increased approximately 2°F.[25] Climate models predict global average surface temperatures could increase by 2.5°F by 2025 and up to 11°F by 2100.[26] Climate experts warn that higher temperatures will impact many aspects of Colorado's environment and economy, including:

- **Declines in snowpack:** Higher winter temperatures will cause more precipitation to fall as rain rather than snow, reducing winter snowpack. By the middle of the 21st century, models predict that snowpack will decline by 10 to 20 percent in elevations higher than 8,200 feet.[27] In addition, higher spring temperatures will melt winter snowpack at a faster pace. From 1978 to 2004, snowpack that melts to feed streams began melting two weeks earlier.[28] These disruptions to Colorado's water cycle reduce the runoff feeding into the headwaters of Colorado rivers. Projections indicate that runoff from the Upper Colorado River Basin into the Colorado River will decrease 6 to 20 percent by 2050 compared to the 20th century average.[29]

- **Insect infestations:** Rising temperatures may also lead to destructive impacts from invasive species and insect pests, such as mountain pine beetles. Rising temperatures have allowed these beetles to survive in once-inhospitable areas and caused changes in their life cycle, even, in some cases, allowing two generations of beetles to exist per year rather than one.[30] In Colorado and Wyoming, pine beetle populations have surged, resulting in 1.5 million acres of damaged lodgepole pine trees between 1996 and 2008.[31] As temperatures increase, insects from regions south of Colorado—historically unable to survive in cold, high-altitude areas—will migrate north, causing unknown effects to the state's forests.[32]

- **Wildfires:** A study by the University of Arizona found that wildfires in the Western United States burned seven times more forested federal land between 1987 and 2003 than between 1970 and 1986.[33] The study cited higher temperatures in spring and summer months, especially in mid-elevation areas in the northern Rocky Mountains, as the primary factor behind the increased fires.[34] Thirty of Colorado's 35 largest recorded fires have occurred since 2000.[35] In 2012, Colorado experienced the most destructive and second-most destructive fires in state history.[36]

- **Shrinking alpine forests:** As temperatures rise, dense alpine forests become unable to survive at current elevations. According to U.S. Environmental Protection Agency, for each degree increase in temperature, alpine forests could shift upwards by 350 feet.[37]

- **Wildlife habitat destruction:** Rising temperatures threaten Colorado's wildlife. The state is currently home to 74 threatened and endangered species, including the lynx, the whooping crane and the river otter.[38] Changes in precipitation will also affect stream flows and water temperatures, putting fish that cannot adapt to higher water temperatures at risk. Rising temperatures could cause Western trout populations—which reside in cold water bodies—to decline by more than 60 percent across the region.[39]

In the Rocky Mountain Power Area (RMPA), the regional electricity grid that includes Colorado and parts of Wyoming and South Dakota, energy sources used to meet daily peak electricity needs emit over 1,750 pounds of carbon dioxide pollution for every megawatt-hour of electricity generated. In comparison, solar panels emit zero carbon dioxide pollution.[40]

With a million solar roofs—or 3,000 MW of solar PV capacity—Colorado could significantly reduce the state's contribution to global warming. By 2030, this much solar energy would annually prevent 3.6 million metric tons of carbon dioxide pollution per year—equivalent to the annual emissions of 760,000 of today's passenger vehicles.[41]

Reducing Colorado's energy use for water heating by 11 percent through the use of solar hot water systems would additionally prevent 347,000 metric tons of global warming pollution.[42] Solar energy can make a strong contribution to meeting Colorado's goals of reducing global warming pollution to 20 percent below 2005 levels by 2020 and 80 percent below 2005 levels by 2050.[43]

Solar Energy Helps Prevent Health Threatening Air Pollution

Colorado's coal- and natural gas-fired power plants harm public health by emitting a variety of pollutants, including pollution that contributes to ground-level ozone, or "smog." When inhaled, ozone quickly reacts with airway tissues and produces inflammation similar to sunburn on the inside of the lungs. This inflammation makes lung tissues less elastic, more sensitive to allergens, and less able to ward off infections.[44] Minor exposure to ozone can cause coughing, wheezing and throat irritation. Constant exposure to ozone over time can permanently damage lung tissues, decrease the ability to breathe normally, and exacerbate or potentially even cause chronic diseases like asthma.[45]

The American Lung Association's 2013 *State of the Air* report awarded "F" grades to Fort Collins and Denver, and awarded a "C" grade to Colorado Springs for air quality because of high levels of ground-level ozone, a key element of smog.[46] The severity of Denver's air pollution problem is especially apparent during the winter, when an inversion layer traps health-endangering pollutants from power plants, fires and automobiles close to the ground, forming a "brown cloud" that hovers over the city.

However, with a million solar roofs—or

3,000 MW of solar energy capacity—Colorado could replace 8 percent of its fossil fuel-generated electricity by 2030, which would help the state avoid 11.8 million pounds of smog-forming nitrogen oxide pollution from power plants annually—a reduction of 9 percent below 2012 power plant emission levels.[47]

Solar Energy Creates Jobs and Strengthens Colorado's Economy

Increasing the market for solar power in Colorado would create jobs in manufacturing of solar panels and other parts of solar energy systems, sales and installation, and would boost the state's economy.

Colorado's clean energy industry already has significant momentum. More venture capital for "advanced energy companies"—which include solar firms—is invested in Colorado than any other state except California and Massachusetts.[48] In 2012, more than 3,600 Coloradans were employed by 266 firms in the solar industry—placing Colorado sixth in national rankings for total number of jobs in the solar industry and seventh in jobs per capita, according to the Solar Energy Industries Association (SEIA).[49] In Colorado, the top creator of jobs in the solar industry is system installation, and these jobs cannot be outsourced.[50] As Colorado's solar market grows, so will local employment.

According to SEIA, the second-largest sector of the solar energy industry in Colorado is manufacturing.[51] Companies such as SunPower, Enphase Energy and Amatis Controls support local communities by purchasing local fuel or supplies, and by paying property taxes that help support schools, fire services, roads and hospitals. Company employees also purchase food from local restaurants and grocery stores and support local entertainment and hospitality industries. Altogether, the solar industry contributed over $1 billion to Colorado's economy over the past three and a half years.[52]

Expanding demand for solar energy systems could create thousands of additional

Dennis Schroeder / National Renewable Energy Laboratory

Two installers with Lighthouse Solar put microcrystalline PV modules on top of a townhome in Golden in December 2011.

jobs throughout Colorado's economy. Workers would be needed to design and manufacture solar energy technology, and to install and periodically inspect and maintain those systems. A 2009 study from the University of California, Berkeley, concludes that every MW of solar capacity installed results in 25 job-years of employment in manufacturing, installation and maintenance of solar energy systems—although only the installation and maintenance labor is guaranteed to be local.[53]

Colorado Has Great Solar Potential

Millions of Buildings Are Suitable for Solar Development

Empty rooftops represent a prime location for solar energy systems. In Colorado, there are nearly 600,000 multi-unit apartment buildings, about 1.7 million single-family homes, and about 120,000 commercial buildings with hundreds of millions of square feet of empty rooftop space.[54] Many of these buildings have the proper orientation and exposure to the sun to support solar panels, and as more buildings are constructed, the state's solar energy potential increases even further.

The amount of solar PV or solar water-heating capacity that can be installed if every square inch of appropriate, available rooftop space is used is known as "technical potential." Technical potential does not consider economic factors or new policies to drive market development. It is therefore not a projection of how the market will develop; it is merely an accounting of how much rooftop space can support either solar PV or solar water-heating systems. In this chapter, we have calculated Colorado's "technical potential" for each of these technologies in 2030. In the next chapter, "Launching a Market for Solar Power," we estimate how much of that technical potential Colorado could feasibly develop, with the right policies in place and given historical precedent elsewhere.

Rooftop Solar Photovoltaic Panels

Solar photovoltaic panels produce the most power when they are placed on a roof with optimal sun exposure. Appropriate locations face south or southwest and are not shaded by trees or other objects for most of the day. A typical home solar installation ranges from 3 to 8 kilowatts (kW) in capacity, taking up 300 to 800 square feet of rooftop area.[55] Solar PV systems on commercial buildings can exceed 100 kW in size, especially on large warehouses.[56]

In 2008, Navigant Consulting estimated how much residential and commercial rooftop area in each state was appropriate for solar power development for the U.S. National Renewable Energy Laboratory.[57] Navigant's estimate took into account shading, building orientation, roof structural soundness, and anticipated

Namaste Solar Electric / National Renewable Energy Laboratory

Namaste Solar Electric installs a 300 kw PV rooftop installation on top of the Colorado Convention Center in Denver in March 2012.

improvement in solar PV technology. The organization calculated that there is enough properly oriented and available rooftop space in Colorado to accommodate 11,644 megawatts (MW) of solar capacity in the year 2013.[58]

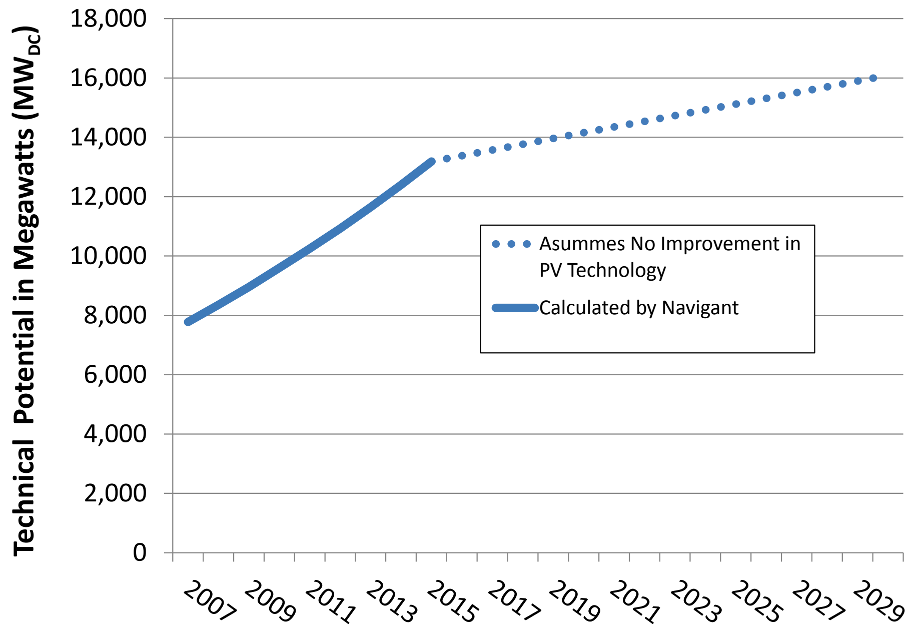
Based on pre-2008 trends in construction of new homes, warehouses and other buildings, and ignoring any potential for solar technology to improve beyond the year 2015 (a conservative assumption), Colorado has the technical potential to support 16,000 MW of solar PV capacity on rooftops by 2030.[59] (See Figure 4.) That much solar photovoltaic capacity could generate nearly 23.6 million MWh of electricity—the equivalent of about 40 percent of Colorado's estimated annual electricity needs in that year.[60]

Rooftop Solar Water-Heating Systems

Virtually any building with a roof exposed to the sun can take advantage of solar water heating. The U.S. Department of Energy's National Renewable Energy Laboratory estimates that 55 percent of homes and 65 percent of commercial buildings in the U.S. Mountain region have appropriate characteristics to support a solar water-heating system.[61] These characteristics include factors such as proper roof orientation, minimum roof size, shading and load-bearing capability, and local building codes and ordinances.[62]

Moreover, solar water-heating systems take up very little space. Solar water-heating technology is simple and compact. A

Figure 4. Technical Potential for Rooftop Solar PV in Colorado Through 2030



dark surface and liquid-filled tubes are enough to effectively capture the heat energy in sunlight.[63] In fact, reaching Colorado's full potential for rooftop solar water-heating systems would only reduce the rooftop space available for solar PV systems in 2030 by about 8 percent.[64]

At full technical potential in 2030, Colorado could host nearly 1.2 million residential solar hot water systems and 117,000 commercial-scale solar hot water systems. Those systems could save 783,000 MWh of electricity and 22 billion cubic feet of natural gas.[65]

Community Solar and Utility-scale Solar Power

There are also many non-rooftop locations in Colorado that could support solar arrays. Ground-mounted solar panels can be installed along highways or on land with minimal ecological or economic value, such as landfills or brownfields. They can also be installed in creative locations such as on top of parking structures or utility poles. These solar arrays can take the form of small community solar gardens or vast, utility-scale solar arrays that can span dozens of acres. Colorado has great potential for both types of large-scale solar power.

Utility-scale solar arrays can be virtually any size, but most are at least 1 MW. As of early 2013, Colorado had 109 MW of utility-scale solar projects that were at least 1 MW in size—representing about 40 percent of total installed solar PV capacity in Colorado in 2012.[66] The Air Force Academy in Colorado Springs installed a 6 MW, ground-mounted solar power system that became operational in 2011.[67] Fort Carson, just south of the city, has also installed a 2 MW solar array on top of a former landfill near the base that will supply 2.3 percent of Fort Carson's energy consumption.[68] Denver International Airport has 8 MW of solar capacity, which supplies about 6 percent of the airport's electricity use.[69]

Because these systems are large, they can displace a significant amount of dirty

Tom Stoffel / National Renewable Energy Laboratory

The 82-acre Alamosa Photovoltaic Plant near the New Mexico border is one of the largest photovoltaic power plants in the country. It generates about 8.2 megawatts of power, which is purchased by Xcel Energy.

electricity in the short term. In addition to the 109 MW of utility-scale solar energy projects currently operating in the state, Colorado has 267 MW of utility-scale solar energy projects under development.[70] Combined, these systems will generate enough clean electricity to prevent about 440,000 metric tons of carbon dioxide pollution—equivalent to that emitted by 84,000 of today's passenger vehicles.[71]

The technical potential for utility-scale solar energy in Colorado is limited only by the availability of appropriate locations and transmission lines to carry the electricity to market. The National Renewable Energy Laboratory estimated in 2012 that Colorado's urban areas could technically support 19,000 MW of utility-scale solar projects, while rural areas could support 4.5 million MW.[72] Most utility-scale solar projects not located at facilities using the electricity directly are connected to the power grid via a local substation, and the electricity is distributed in the same way as from a traditional power plant.

Utility-scale solar power is also one of the most affordable ways to install large amounts of solar power. These systems generally have lower overhead costs than rooftop solar PV systems because they benefit from economies of scale and standardized, ground-mounted system designs, according to NREL.[73] With solar module costs decreasing as well, some of these projects—such as SunPower's 579 MW Antelope Valley Solar Projects being constructed in California—have become cost-competitive with peaking natural gas power plants.[74]

Colorado can also take advantage

of utility-scale solar thermal power technologies. Solar thermal power stations use mirrors to concentrate the heat of the sun to generate electricity.[75]

Other large-scale solar installations in Colorado take the form of community solar projects. These installations are usually smaller than utility-scale solar installations and can be installed by community groups, non-profit organizations or local governments. Community solar projects allow residents who would not normally be able to benefit from solar power—either because they are renters or don't have homes that are appropriate for solar power—to pool their resources to establish these solar arrays. Some of these projects, known as solar "gardens," have net metering, allowing community members who buy into the system to offset their electricity use. United Power near Brighton opened the first community solar array in the state.[76] Clean Energy Collective opened the first of eight new community projects approved in Xcel territory, in Boulder County.[77] Community solar projects are also cropping up in far western Colorado, in the San Miguel Power territory, and in northern Colorado, in the Poudre Valley Rural Electric territory.[78]

Solar Photovoltaic Technology Is Becoming Increasingly Cost Effective

Solar energy has great benefits for Colorado and is becoming increasingly attractive as the price of solar PV systems plummets. As the market for solar energy technology has expanded and matured, economies of scale have drive down costs for raw materials and for manufacturing solar panels.

In 2012, the installed cost of solar photovoltaic panels declined by 27 percent from installed costs in 2011, according to Greentech Media and SEIA's annual *U.S. Solar Market Insight Report*.[79] These declining prices are partially a result of increasing economies of scale in solar panel production and falling prices for solar modules.[80] The price of solar PV modules dropped precipitously in 2012, falling 41 percent from an average sales price of $1.15/W in the fourth quarter of 2011 to $0.68/W at the end of 2012.[81] No other type of major power generation technology is achieving cost reductions at such a rapid pace.[82]

The price drop in solar panels mirrors the consumer experience with cell phones, digital cameras, flat-screen televisions and other modular electronic technologies, which have all rapidly improved and become cheaper as manufacturers produce more devices. As the market for solar PV grows in Colorado, the industry is likely to develop economies of scale in manufacturing and installation, which will also reduce so-called "soft costs," or non-hardware costs associated with installing solar PV systems. These costs, which include permitting, inspection and interconnection, can account for up to 40 percent of the installed cost of a standard rooftop PV system, according to Colorado Solar Energy Industries Association (COSEIA).[83] Growing the solar market and streamlining the permitting and interconnection process can significantly reduce these costs. Germany, for example, has the world's most developed solar market, with an established supply chain, a large network of skilled installers, and a streamlined permitting process; as a result, Germany's non-hardware costs are lower than in the United States, making the overall cost of installed solar PV much cheaper. Germany's average installed costs for solar PV in the third quarter of 2011—not including incentives or rebates—were 50 percent less than in the United States.[84]

In 2012, COSEIA launched a Solar Friendly Communities program, designed to bring down soft costs in Colorado.[85] It is a voluntary program that offers local governments an easy-to-follow roadmap and certifies them as Solar Friendly Communities once they make significant progress. In November 2012, COSEIA recognized Denver as a solar friendly-community because of its progressive policies to promote solar power; including posting permitting requirements online; offering low-cost, same-day permits; streamlining inspections; and providing educational materials to residents.[86]

Launching a Market for Rooftop Solar Power

At the end of 2011, Colorado had about 197 megawatts (MW) of solar photovoltaic capacity installed in total, or about 39 watts per resident.[87] This placed the state sixth in national rankings for per capita solar PV installations, right behind California, which had 42 watts per resident.[88] New Jersey, which receives far less sun than Colorado, has 64 watts per resident.[89]

Strong energy policies have accelerated solar markets in Colorado and other leading states, such as New Jersey. The main hurdle preventing even greater solar energy deployment is the same hurdle facing any new energy technology—developing the experience and economies of scale needed to make it cost-competitive with established forms of energy generation, many of which have benefited from decades of consumer investment and government support. In 2011, total worldwide subsidies for fossil fuels were about $588 billion—six times more than subsidies for renewable energy technologies, according to the International Energy Agency.[90] Clean energy policies can level the playing field for solar power. In Germany, strong policy support helped its solar market grow from 2 MW to more than 32,000 MW—a 16,000-fold increase—in just 22 years.[91]

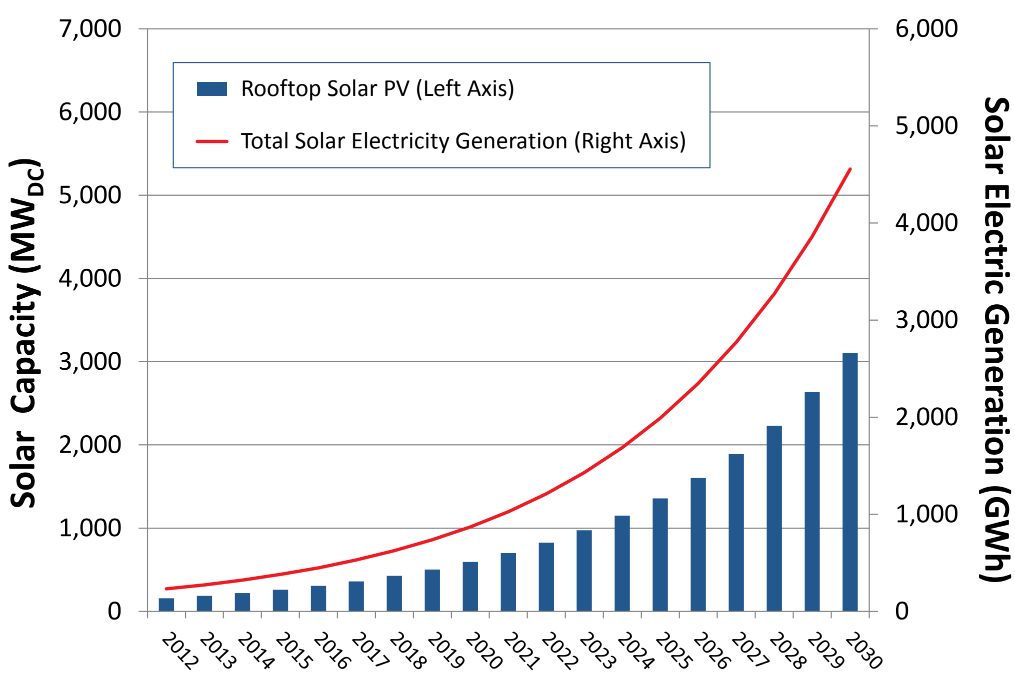
With a sustained commitment to progress, renewable energy can grow quickly in Colorado, too. The state's renewable energy standard helped the state's wind industry grow from 231 MW at the end of 2004 to 2,301 MW at the end of 2012.[92] With the right policies in place to promote rooftop solar power, Colorado can install a million solar roofs—or 3,000 MW of solar energy capacity—and nearly 250,000 commercial and residential solar water-heating systems by 2030.[93] Colorado can achieve this amount of solar capacity even with modest market growth of 18 percent per year—far slower than the growth of recent years in Colorado (66 percent per year on average from 2009 to 2012), as well as in California (52 percent per year on average from 2001 to 2012) and New Jersey (87 percent per year on average from 2005 to 2012), where strong clean energy policies have driven solar PV development.[94]

In Colorado, reaching 3,000 MW of solar capacity would generate the equivalent of 8 percent of Colorado's anticipated annual electricity needs in 2030, or 4.6 million MWh.[95] That is enough electricity to power nearly 490,000 typical Colorado homes—or nearly three times the number of households in Colorado Springs.[96] (See Figure 5.)

With additional policies to drive adoption of solar water-heating systems, Colorado could achieve an equivalent market penetration to solar PV systems, yielding 226,000 residential-scale and nearly 23,000 commercial-scale solar water-heating systems by 2030.[97] Incentive programs or stronger energy efficiency building codes can help put solar water-heating systems on a level playing field with traditional natural gas systems. Natural gas systems have lower up-front costs than solar water-heating systems, but solar water-heating systems are less expensive over time because sunlight—in contrast to fossil fuels—is free. With 249,000 commercial and residential systems, solar water-heating technology would reduce Colorado's water heating energy use by 11 percent, saving 150,000 MWh of electricity and 4.2 billion cubic feet of natural gas per year.[98] That much energy could meet the water-heating needs of 300,000 Colorado households.[99]

In total, this much solar energy capacity would use only 19 percent of the state's available rooftop area suitable for solar development, leaving a great deal of room to continue expanding the rooftop solar energy market in the years beyond 2030.[100] Additionally, this level of solar energy development does not consider Colorado's large potential for utility-scale solar power, which if deployed aggressively, would likely put Colorado on track to achieving 3,000 MW of solar capacity well before 2030.

Figure 5. Electricity Generation from Rooftop Solar Power in Colorado in 2030



Policy Recommendations

With all the sun that shines on Colorado, the state can significantly reduce its dependence on gas and coal for much of its energy needs. Solar energy is clean, renewable and becoming cheaper over time. Solar energy is ready to take off in Colorado. **The state should set a goal of installing one million solar rooftops—or at least 3,000 MW of solar energy capacity—by 2030**.[101] At least half of this capacity should come from distributed, small-scale solar PV systems to ensure a robust, self-sustaining solar energy market for the long term. Additionally, the state should set a parallel goal of installing at least 250,000 residential and commercial solar water-heating systems by 2030.

Reaching this goal will require ambitious policies to promote both small-scale and large-scale solar energy systems, as well as a sustained commitment to strengthening these policies in the long term.

To promote development of Colorado's solar energy market, policymakers should:

1. **Strengthen the state's renewable energy standard:** To drive development of solar power in Colorado, the state should strengthen its renewable energy standard (RES) for all utilities in the state, including investor-owned utilities, municipal utilities and rural electric co-ops. Specifically, the state should set an ambitious standard requiring that 50 percent of our electricity come from renewable sources by 2030. Included in the standard should be a requirement that 10 percent come from distributed renewable energy sources, which will boost development of small-scale and onsite renewable projects such as rooftop solar systems.

2. **Maintain and strengthen net metering policies:** The state's net metering policies require investor-owned utilities to credit customers who produce electricity through rooftop solar panels at the retail rate for every kilowatt-hour they supply to the grid. Colorado should strengthen its net metering laws by mandating that customers of municipal and cooperative utilities, who are currently compensated at a rate determined by the utility, be reimbursed at the retail rate.[102]

3. **Make solar energy an attractive investment for all customers:** Colorado should require that utilities work with solar developers to create long-term contracts for producing clean, local solar power. Requiring utilities to purchase all of the electricity fed into the grid from a solar energy system at a set rate over several years would help eliminate the financial uncertainty caused by fluctuations in electricity prices and guarantee solar energy producers a reasonable return on their investments. Germany's feed-in-tariff is one example of this type of arrangement. The state should also offer more financing options that make solar energy cost-competitive with fossil fuels. Encouraging banks to offer low-interest loans to citizens interested in financing solar energy systems or working with local governments to get Property Assessed Clean Energy (PACE) projects up and running are two of many examples of ways to help make solar energy more accessible.

4. **Develop Colorado's potential for solar water heating:** Solar water-heating systems have the potential to reduce household energy use for water heating by about 60 percent. However, these systems have not gained widespread use in Colorado because they have higher up-front costs than traditional natural gas water-heating systems. To level the playing field, the state should create an incentive program to bring down the cost of installing solar and other renewable energy water-heating systems. The state should also include renewable water-heating technologies in residential and commercial natural gas efficiency programs.

5. **Renew tax exemption programs:** Colorado exempts renewable energy products—such as solar panels, mounting equipment and wiring—from sales and use taxes. The state should extend these exemptions beyond their 2017 expiration date, guaranteeing the incentives for at least 10 years.[103]

6. **Support community solar projects:** Community solar gardens allow residents who are unable to take advantage of rooftop solar PV systems to pool their resources to establish community solar arrays, which help offset electricity use through grouped net metering. By fall 2013, Xcel Energy's community solar program is expected to bring online 9 MW of solar capacity in 13 solar gardens across the state.[104] Xcel should continue approving solar gardens at least at this pace, and other utilities should follow the lead of progressive municipal and rural co-op utilities in encouraging community solar projects as well.

7. **Eliminate regulatory barriers to the expansion of solar energy:** Colorado policymakers at all levels of government should simplify and standardize permitting and interconnection rules to make it as easy and affordable as possible for Coloradans to participate in the solar market. Different jurisdictions across the state have varying permitting and interconnection procedures and fees, which can add unnecessary friction to the process of installing solar energy systems. State and local leaders should work to standardize procedures, minimize fees, and streamline the process of installing a new solar energy system and integrating it into the electricity grid.

8. **Create a net-zero energy building code:** A net-zero energy building code requirement would increase the use of solar and other local clean

energy systems in new construction. Incorporating solar energy technology into new buildings at the time of construction represents an enormous opportunity to grow Colorado's solar market. Colorado should require all new homes to include solar power or other on-site renewable electricity generation by no later than 2020, and all non-residential buildings by no later than 2030, through a net-zero energy building code requirement.

Methodology

This analysis focuses on the potential for solar power and water heating on the rooftops of Colorado buildings and on other large structures. Electricity and hot water generated on top of buildings can be used locally, reducing the need for cross-country transmission lines and increasing grid efficiency and reliability.

Solar PV Potential

Technical

To estimate the total technical potential for rooftop solar PV in Colorado, we relied upon *Rooftop Photovoltaics Market Penetration Scenarios*, a report carried out by Navigant Consulting for the National Renewable Energy Laboratory.[105] Taking into account factors such as trees and other shading, roof tilt and orientation, and the room taken up by other objects such as chimneys and fan systems, Navigant estimated that 22 percent of residential roof space and 65 percent of commercial roof space in states with cool climates (such as Colorado) could be used for solar panels, on average.[106]

Navigant found that installing solar panels on all suitable residential and commercial rooftop space in Colorado in 2008 would result in 8,350 MW of solar power. Navigant also estimated total technical rooftop solar potential through 2015, based on a forecast for increasing rooftop space as new buildings are constructed.[107] Navigant also assumed that solar PV technology would increase in average efficiency from 13.5 percent in 2007 to 18.5 percent in 2015—meaning that the same amount of rooftop area could host solar panels capable of producing more electricity.[108]

To estimate total solar PV potential in 2030, we extrapolated Navigant's trend of Colorado technical PV potential from 2007-2015, ignoring any possible further improvements in solar technology. We found that in 2030, Colorado could technically install 16,000 MW of rooftop solar capacity.

We next calculated how large an area this would cover. We calculated that at 18.5 percent conversion efficiency, installing the full 16,000 MW of Colorado's technical PV potential in 2030 would require approximately 842 million square feet of rooftop area.[109] Subtracting out the area required by solar water-heating systems at full penetration (see below) would reduce the area available for PV by 8 percent, yielding a total net technical potential in 2030 of 14,700 MW.

We did not attempt to make an estimate of the technical potential for non-rooftop solar installations, which would be limited only by the availability of appropriate open land area (i.e. having minimal ecological or economic value) with adequate sun exposure and transmission capacity to bring the electricity to market. According to the National Renewable Energy Laboratory, Colorado's technical potential for utility-scale solar installations in urban and rural areas may exceed 4,519 gigawatts.[110]

2030 Vision

To lay out a vision for a future course of rooftop solar PV development for Colorado to pursue, we first needed to determine how much rooftop solar power capacity Colorado had installed at the end of 2012. To do this, we subtracted Colorado's operational utility-scale solar capacity from total capacity, and used the non-utility-scale solar capacity numbers as a proxy for "rooftop" solar capacity in the state. We referred to the Interstate Renewable Energy Council *Solar Market Trends 2010 and 2011* reports for cumulative solar capacity installed in each year in Colorado.[111] To obtain a 2012 value for installed solar capacity, we referred to SEIA *2012 Top 10 Solar States*, which reported 69.9 MW installed in 2012.[112] The resulting cumulative statewide capacity numbers (which include utility-scale solar installations) are shown in Table A-1.

Table A-1. Annual Solar Market Growth and Cumulative Solar PV Capacity Installed in Colorado, 2008-2012

Year	Cumulative Capacity (MW)	Percent Market Growth
2008	36	
2009	60	65%
2010	122	104%
2011	197	62%
2012	267	35%

To isolate installed rooftop solar capacity from these cumulative estimates, we referred to a SEIA fact sheet that reported 109 MW of operating utility-scale solar capacity in Colorado as of March 2013.[113] We subtracted 109 MW from the 2012 cumulative capacity of 267 MW, resulting in a rough estimate of 158 MW distributed rooftop solar in Colorado in 2012. (See Table A-2.)

Table A-2: Potential Rooftop Solar PV Market Growth in Colorado[114]

Year	Growth Rate	Percent Cumulative Capacity (MW)
2012	35%*	158
2013	18%	186
2014	18%	220
2015	18%	259
2016	18%	306
2017	18%	361
2018	18%	426
2019	18%	503
2020	18%	594
2021	18%	700
2022	18%	826
2023	18%	975
2024	18%	1,151
2025	18%	1,358
2026	18%	1,602
2027	18%	1,891
2028	18%	2,231
2029	18%	2,633
2030	18%	3,106

*Colorado's solar market growth between the end of 2011 and the end of 2012 was 35 percent. See Table A-1.

We created a development scenario in which the market for distributed solar power in Colorado increases at 18 percent per year through 2030. This development scenario would get Colorado to the goal of 3,000 MW of rooftop solar capacity by 2030; however, this scenario represents only one of several possible pathways for solar market development in Colorado. In our scenario, the average annual growth of the solar market is considerably slower than that experienced in Colorado from 2008 to 2012 (See Table A-1), in California (52 percent on average from 2001 to 2012) and New Jersey (87 percent on average from 2005 to 2012).[115] With the right policies in place, Colorado's market could grow much faster than in our development scenario.

In Colorado, 3,000 MW of solar PV will generate about 4.6 million MWh of electricity per year.[116] (See Figure 5 on page 21.) That's about 8 percent of Colorado's projected electricity supply in 2030. (See "Estimating Colorado's Future Electricity and Hot Water Energy Needs" below.)

Energy Output

We calculated the energy output of solar PV panels in Colorado using a population-weighted state average annual electricity generation estimate of 1,466 kWh per kW, per the National Renewable Energy Laboratory's *PVWatts* tool.[117]

Solar Water Heating Potential

Technical

To calculate the maximum market penetration for solar hot water systems, we first needed an estimate of the number of residential and commercial buildings that will exist in Colorado in 2030. We estimated the number of housing units in Colorado in 2030 using data from the U.S. Census Bureau. Using 2010 estimates of population and housing units, we calculated a ratio of residents to housing unit.[118] Holding this ratio constant, we then applied population projections to obtain an estimate of total housing units in 2030.[119]

We calculated the current number of commercial buildings in Colorado using estimates of the number of commercial buildings and the number of establishments per building in the Mountain census region, per the U.S. Department of Energy's *Commercial Building Energy Consumption Survey*.[120] Given that the Census reports that there were 144,000 commercial establishments in Colorado in 2003—the year of the most recent available data on commercial building energy consumption—we calculated that there were 119,000 commercial buildings in the state in that year.[121] (The number of establishments per commercial building was listed as ranges in the *Commercial Buildings Energy Consumption Survey*—for example, two to five establishments per building. In order to be conservative in estimating the number of buildings, the highest number in the range was assumed when converting number of establishments to number of buildings.)

To project the number of commercial buildings in Colorado in 2030, we first calculated growth in commercial building space. We began with a 2004 Brookings Institution Metropolitan Policy Program report called *Toward a New Metropolis: The Opportunity to Rebuild America*. This report estimates and projects the number of commercial workers by state in 2000 and 2030, and the building space that they require.[122] To interpolate those figures for intervening years, we assumed that the percentage of the population engaged in commercial work (determined using the Brookings Institution commercial workers data and population projections from the U.S. Census) would change at a steady rate between

2000 and 2030.[123] Then we calculated the total square footage of building space that those commercial workers would require using the Brookings Institution estimates of space requirements per worker. We found that Colorado commercial building area is likely to increase 52 percent by 2030 relative to 2003.[124] Assuming that average space per commercial building remains constant, in 2030, Colorado would have 180,000 commercial buildings.[125]

We assumed that 55 percent of residential buildings and 65 percent of commercial buildings in the Mountain region could technically support solar hot water systems, per the National Renewable Energy Laboratory.[126] This yielded a maximum of nearly 1.2 million residential solar hot water systems and 117,000 commercial-scale solar hot water systems in 2030. We calculated that Colorado would require 71 million square feet of rooftop area to deliver the energy savings described, assuming solar water-heating systems have an average heat-capture efficiency of 55 percent (very conservative) and using population-weighted solar resources per our PVWatts estimate described above.

2030 Vision

We assumed that solar water-heating systems could be installed in Colorado such that the state would achieve 19 percent of total technical potential for solar water heating by 2030—achieving the same percentage of technical potential achieved by solar PV, as described above. This yielded 226,000 residential and 23,000 commercial solar water-heating systems—249,000 systems altogether.

Energy Output

To determine how much energy could be saved by solar hot water systems in 2030, we first had to determine how much energy the buildings with solar water-heating systems installed would otherwise consume to heat water.

To determine the amount of energy that would otherwise be consumed to heat water by buildings with solar water-heating systems in 2030, we first we used the *Residential Energy Consumption Survey* and *Commercial Building Energy Consumption Survey* to determine what percentage of residential and commercial buildings in Colorado use electricity to heat water, and what percentage use natural gas.[127] We assumed these percentages hold constant through 2030 and used them to determine how many of the solar water-heating systems installed in 2030 would be on buildings that heat water with natural gas, and how many would be on buildings that use electricity for water heating.

We then multiplied the number of solar water-heating systems by the average Mountain region electricity or gas consumption per household and per commercial building for water heating, which yielded the total amount natural gas and electricity that the buildings with solar water-heating systems in 2030 would normally consume.[128] Then, we assumed that a typical solar hot water system in Colorado could replace 50 percent of the energy used to heat water, per the National Renewable Energy Laboratory report.[129]

Estimating Colorado's Future Electricity and Hot Water Energy Needs

Calculations for the equivalent percent of Colorado's future energy needs that solar output would represent were based on the following.

We derived an estimated value for 2030 electricity consumption in Colorado using the actual and forecasted annual growth rates for electricity demand 2010-2030 in the service territory of Public Service

Company of Colorado.[130] Public Service Company (a subsidiary of Xcel Energy) is one of two investor-owned utilities in the state, which together supplied almost 63 percent of all electrical power sold to customers in the state in 2009.[131] Of the 3.1 million electricity customers served by the two utilities, Public Service Company serves 87 percent.[132] We assumed that the projected power needs of the state's largest electricity provider would be representative of the state's electricity needs as a whole. Therefore, beginning with actual statewide electricity consumption in 2010, per Energy Information Administration *State Electricity Profiles*, we applied Public Service Company's actual and projected annual rates of growth in electricity consumption to project what statewide electricity consumption would be in 2030.[133]

Colorado's anticipated water heating energy needs in 2030 were derived by multiplying the housing and commercial space increase forecast described above by the average electricity and natural gas consumption for water heating per residence or square foot of commercial building space, per the U.S. Census Bureau's *Residential Energy Consumption Survey* and *Commercial Building Energy Consumption Survey*.[134]

To be conservative, this calculation assumes that there are no improvements in the energy efficiency of residential and commercial buildings in Colorado before 2030.

Reducing Global Warming Pollution

We translated energy generation figures into global warming pollution as follows.

We assumed that energy generated by solar PV would primarily replace non-baseload electricity generation. In the Rocky Mountain Power Area (RMPA), non-baseload electricity sources produce an average of 1,757 lbs of carbon dioxide per MWh.[135]

We assumed that electricity saved by solar water-heating systems would not necessarily be timed to coincide with peak electricity demand, and therefore assumed that solar water heating would displace electricity at the total RMPA subregion pollution rate of 1,825 lbs of carbon dioxide per MWh.[136]

For natural gas, we assumed that every million British thermal units (BTU) of avoided natural gas use would prevent 53 kilograms of carbon dioxide pollution, per emission coefficients from the U.S. Department of Energy.[137]

Notes

1 NBC Channel 9 News, *Weather Resources—FAQs*, downloaded from www.9news.com/weather/resources/faq, 19 April 2013. A day with sunny skies is one with less than 80 percent cloud cover.

2 Green building and wind: Clean Edge, Inc., *2012 State Clean Energy Index—Executive Summary*, May 2012, available at www.cleanedge.com/sites/default/files/SCEI2012execsum_0.pdf.

3 Solar Energy Industries Association, *Colorado Solar*, downloaded from www.seia.org/state-solar-policy/colorado on 31 May 2013.

4 Our development scenario assumes that by 2030 Colorado could reach 3,100 MW of solar PV capacity through "rooftop" solar installations, which for the purposes of this report we have defined as non-utility-scale installations smaller than 1 megawatt. Developing utility-scale solar energy in addition to rooftop solar energy would likely help Colorado achieve 3,000 MW of solar PV capacity before 2030. All capacity numbers are in direct current (DC), unless otherwise noted.

5 See methodology.

6 Ibid.

7 See note 1.

8 The population-weighted average electricity production for a one kilowatt solar energy system installed in Aspen, Boulder, Colorado Springs, Denver, Durango, Fort Collins, Grand Junction and Vail is 1,466 kWh_{AC} per kW_{DC} per year. Annual generation figures obtained from U.S. Department of Energy, National Renewable Energy Laboratory, *PVWatts Viewer (Version 2)*, downloaded from gisatnrel.nrel.gov/PVWatts_Viewer/index.html on 19 April 2013. Population estimates obtained from U.S. Census Bureau, *State and County Quickfacts*, revised 10 January 2013, available at quickfacts.census.gov/qfd/index.html.

9 Solar energy generation for Germany: U.S. Department of Energy, see note 8;

Germany is the world's largest solar energy market: See "Solar Reaches 100 GW Threshold Worldwide, Wind Grows 20 Percent," *Sustainablebusiness.com*, 12 February 2013.

10 U.S. Department of Energy, National Renewable Energy Laboratory, *PVWatts Viewer (Version 2)*, downloaded from gisatnrel.nrel.gov/PVWatts_Viewer/index.html on 19 April 2013

11 See note 10.

12 J. Burch, T. Hillman and J. Salasovich, National Renewable Energy Laboratory, *Cold-Climate Solar Domestic Hot Water Systems: Cost/Benefit Analysis and Opportunities for Improvement*, January 2005.

13 Figure shows annual energy savings using a glycol solar water heating system with a selective surface collector. See note 12.

14 Bernadette del Chiaro, Environment California Research & Policy Center, and Timothy Telleen-Lawton, Frontier Group, *Solar Water Heating: How California Can Reduce Its Dependence on Natural Gas*, April 2007.

15 P. Denholm, U.S. Department of Energy, National Renewable Energy Laboratory, *The Technical Potential of Solar Water Heating to Reduce Fossil Fuel Use and Greenhouse Gas Emissions in the United States*, March 2007.

16 2020 population: Colorado Demography Office, Colorado Department of Local Affairs, *2012 Population Overview*, downloaded from www.colorado.gov/cs/Satellite/DOLA-Main/CBON/1251593240528 on 13 May 2013; 2012 population: U.S. Census Bureau, see note 8.

17 U.S. Department of Energy SunShot Initiative, *Sunshot Vision Study*, February 2013.

18 Ibid.

19 The U.S. Department of Energy estimates that increased deployment of solar power could save consumers on the order of $30 billion by 2030, or about $6 per month for the average homeowner. See note 17.

20 Richard Perez and T. Hoff, New York Solar Energy Industry Association and the Solar Alliance, *Energy and Capacity Valuation of Photovoltaic Power Generation in New York*, 2008.

21 T. Hoff, et al., Clean Power Research LLC, *The Value of Distributed Photovoltaics to Austin Energy and the City of Austin*, 2006.

22 Richard Perez, State University of New York at Albany, et al., *New Solar Power Generation in the US: Too Expensive, or a Bargain?*, April 2011.

23 Leading pollutant: Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007;* National Research Council, *Advancing the Science of Climate Change*, 2010.

24 Colorado Water Conservation Board, *Climate Change*, downloaded from cwcb.state.co.us/environment/climate-change/Pages/main.aspx on 16 April 2013.

25 Based on a 10-year moving average of annual mean temperatures. See Andrea Ray, et al., *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation*, prepared by

the Western Water Assessment for the Colorado Water Conservation Board, 2008.

26 See note 24 and National Research Council, note 23.

27 See note 25.

28 Ibid.

29 Ibid.

30 Jeffrey B. Mitton and Scott M. Ferrenberg, "Mountain Pine Beetle Develops an Unprecedented Second Generation in Response to Climate Warming," *The American Naturalist* 179(5): E163-E171, May 2012, doi: 10.1086/665007.

31 Todd Hartman, "Deaths of Trees 'Catastrophic'," *Rocky Mountain News*, 15 January 2008.

32 Center for Integrative Environmental Research, University of Maryland, and the National Conference of State Legislatures, *Climate Change and the Economy; Colorado; Assessing the Costs of Climate Change*, 2008.

33 A. L. Westerling et al, "Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity," *Science* 18: 940-943, August 2006.

34 Ibid.

35 Vickie Makings, "Colorado's Largest Wildfires, Ranked by Acres Burned," *Denver Post*, 11 June 2012.

36 Erin Udell, "Smoke Rises in Waldo Canyon Burn Area as Officials Warn of Flood Risk," *The Denver Post*, 21 July 2012; National Interagency Coordination Center, *Wildland Fire Summary and Statistics Annual Report 2012*, downloaded from www.predictiveservices.nifc.gov/ on 25 February 2013; Doyle Rice, "U.S. Endures Near Record Wildfire Season," *USA Today*, 12 November 2012.

37 United States Environmental Protection Agency, *Climate Change and Colorado*, September 1997.

38 Colorado Parks & Wildlife, *Threatened & Endangered List*, downloaded from wildlife.state.co.us on 3 May 2013. Note: 74 species includes those that are federally endangered, federally threatened, state endangered, state threatened and determined by the state to be of special concern.

39 C.J. Keleher and F.J. Rahel, "Thermal Limits to Salmonid Distribution in the Rocky Mountain Region and Potential Habitat Loss Due to Global Warming: A Geographic Information System (GIS) Approach," *Transactions of the American Fisheries Society* 125(1): 1-13, 1997; F.J. Rahel, "Using Current Biogeographical Limits to Predict Fish Distributions Following Climate Change," *Fisheries in a Changing Climate*, American Fisheries Society Symposium 32: 99-110, 2002.

40 U.S. Environmental Protection Agency, *eGRID2012 Version 1.0*, downloaded from www.epa.gov/cleanenergy/energy-resources/egrid/index.html, 18 April 2013.

41 For carbon pollution avoided, see methodology. Passenger vehicles emit about 5.2 metric tons of carbon dioxide annually, per U.S. Environmental Protection Agency, *Emission Facts: Greenhouse Gas Emissions from a Typical Passenger Vehicle*, February 2005.

42 Calculation includes energy savings from natural gas and electric water heating systems. We did not attempt

to calculate savings from propane systems. See methodology.

43 Governor Bill Ritter, Jr., Governor of Colorado, *Executive Order D 004 008; Reducing Greenhouse Gas Emissions in Colorado*, 22 April 2008.

44 M. Lippman, "Health Effects of Ozone: A Critical Review," *Journal of the Air Pollution Control Association* 39: 672-695, 1989; I. Mudway and F. Kelley, "Ozone and the Lung: A Sensitive Issue," *Molecular Aspects of Medicine* 21: 1-48, 2000; M. Gilmour, et al., "Ozone-Enhanced Pulmonary Infection with Streptococcus Zooepidemicus in Mice: The Role of Alveolar Macrophage Function and Capsular Virulence Factors," *American Review of Respiratory* Disease 147: 753-760, March 1993.

45 Kendall Powell, "Ozone Exposure Throws Monkey Wrench into Infant Lungs," *Nature Medicine*, 9(5), May 2003; R. McConnell, et al., "Asthma in Exercising Children Exposed to Ozone: A Cohort Study," *The Lancet* 359: 386-391, 2002; N. Kunzli, et al., "Association Between Lifetime Ambient Ozone Exposure and Pulmonary Function in College Freshmen—Results of a Pilot Study," *Environmental Research* 72: 8-16, 1997; I.B. Tager, et al., "Chronic Exposure to Ambient Ozone and Lung Function in Young Adults," *Epidemiology* 16: 751-9, November 2005.

46 American Lung Association, *State of the Air 2013; Compare Your Air*, downloaded from www.stateoftheair.org/2013/city-rankings/compare-your-air.html on 2 May 2013.

47 Calculation assumes 2012 electricity consumption of 49,565,124 MWh (down from 52,917,786 MWh in 2010, per U.S. Energy Information Administration, *2010 Colorado Electricity Profile*, released 30 January 2012). See "Estimating Colorado's Future Electricity and Hot Water Needs" in methodology. Rocky Mountain Power Area eGRID subregion non-baseload NOx annual emission rate is 2.5904 lbs/MWh. See note 40.

48 Tom Plant, "Is Colorado's 'New Energy Economy' Still Viable in Light of Recent Setbacks in the Industry? Yes," *Denver Post*, 11 November 2011.

49 The Solar Foundation, *State Solar Jobs: Colorado*, downloaded from thesolarfoundation.org/solarstates/Colorado on 3 May 2012.

50 Ibid.

51 Ibid.

52 See note 48.

53 Max Wei, et. al., *Putting Renewables and Energy Efficiency to Work: How Many Jobs Can the Clean Energy Industry Generate in the U.S.?*, 19 October 2009.

54 Number of homes: U.S. Census Bureau, see note 8; number of commercial buildings: see methodology.

55 Size based on data from the California Solar Initiative: California Energy Commission & California Public Utilities Commission, *California Solar Initiative Working Data Set*, 7 September 2011, available at www.californiasolarstatistics.ca.gov/current_data_files; Systems take approximately 100 square feet of roof area per kW: Solaris Blackstone, *Frequently Asked Questions*, downloaded from www.solarisblackstone.com/faq.html on 20 January 2012.

56 California Energy Commission & California Public Utilities Commission, see note 55.

57 J. Paidpipati, L. Frantzis, H. Sawyer, and A. Kurrasch, Navigant Consulting, Inc. for National Renewable Energy Laboratory, *Rooftop Photovoltaics Market Penetration Scenarios*, February 2008.

58 Ibid. Taking into account factors such as tree and other shading, roof tilt and orientation, and the room needed on roofs between solar panels and other objects such as chimneys and fan systems, Navigant estimated that 22 percent of residential roof space and 65 percent of commercial roof space in states with cool climates (such as Colorado) could be used for solar panels, on average.

59 See methodology.

60 Ibid.

61 See note 15. The United States' Mountain region includes Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah and Wyoming.

62 Ibid.

63 Find Solar, *Solar Heating (Solar Thermal) Systems*, downloaded from www.findsolar.com/content/solarthermal.aspx, 7 August 2009.

64 See methodology.

65 Ibid.

66 Solar Energy Industries Association, *Utility Scale Solar Projects in the U.S. Operating, Under Construction, or Under Development* (fact sheet), updated 29 March 2013.

67 U.S. Air Force Academy, *Academy Hits Switch on 6-MW Solar Array* (press release), 13 June 2011.

68 U.S. Environmental Protection Agency, *Re-Powering America's Land: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites: Fort Carson, Colorado, Success Story*, February 2009.

69 Denver International Airport, *Denver International Airport to Celebrate Earth Day 2013* (press release), 18 April 2013.

70 See note 66.

71 For average solar radiation in Colorado, see note 8; non-baseload electricity generation sources emit 1,757 lbs of CO2 per MWh in Colorado, per U.S. Environmental Protection Agency, see note 40; Passenger vehicles emit about 5.2 metric tons of carbon dioxide annually, per U.S. Environmental Protection Agency, see note 41.

72 Anthony Lopez, et al., National Renewable Energy Laboratory, *U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis*, July 2012.

73 Alan Goodrich, Ted James and Michael Woodhouse, National Renewable Energy Laboratory, *Residential, Commercial, and Utility-Scale Photovoltaic (PV) System Prices in the United States: Current Drivers and Cost-Reduction Opportunities*, February 2012.

74 James Montgomery, "Mega-Solar Matchmaking in California: How MidAmerican and SunPower Sealed the Deal for a Nearly 600-MW AVSP Project in the US — And What's Next for Both Sides," *Renewableenergyworld.com*, 8 January 2013.

75 For more details about solar thermal power and its potential, see Bernadette Del Chiaro, Environment America Research & Policy Center, and Tony Dutzik and Sarah Payne, Frontier Group,

On the Rise: Solar Thermal Power and the Fight Against Global Warming, Spring 2008.

76 Greg Pahl, *Power from the People: How to Organize, Finance and Launch Local Energy Projects*, 2012.

77 Clean Energy Collective, *Clean Energy Collective Breaks Ground on First Community Solar Array with Xcel Energy* (press release), 21 February 2012.

78 San Miguel Power Association, Inc., *SMPA Community Solar Groundbreaking July 31* (press release), 13 July 2012; Poudre Valley Rural Electric Association, *Second Community Solar Farm Announced!* (press release), 4 April 2013.

79 GreenTech Media, Inc., and Solar Energy Industries Association, *U.S. Solar Market Insight Report: 2012 Year in Review — Executive Summary*, 2013.

80 Galen Barbose, Naïm Darghouth, and Ryan Wiser, Lawrence Berkeley National Laboratory, *Tracking the Sun V: An Historical Summary of the Installed Cost of Photovoltaics in the United States from 1998 to 2011*, November 2012; Allen Chen, Lawrence Berkeley National Laboratory, *The Installed Price of Solar Photovoltaic Systems in the U.S. Continues to Decline at a Rapid Pace* (press release), 27 November 2012.

81 See note 79.

82 See comparison between the forecast cost of electricity from different technologies in: Joel Klein, California Energy Commission, *Comparative Costs of California Central Station Electricity Generation Technologies*, CEC-200-2009-017-SD, Draft Staff Report, August 2009.

83 U.S. Department of Energy, *Finding Solutions to Solar's Soft Cost Dilemma*, 8 January 2013, available at energy.gov/articles/finding-solutions-solars-soft-cost-dilemma.

84 Steven Lacey, "Germany Installed 3 GW of Solar PV in December—The U.S. Installed 1.7 GW in All of 2011," *Climate Progress*, 10 January 2012.

85 Colorado Solar Energy Industries Association, *Solar-Friendly Communities Program*, downloaded from solarcommunities.org on 23 May 2013.

86 Colorado Solar Energy Industries Association, *Denver Recognized as First Solar Community* (press release), 27 November 2012.

87 Larry Sherwood, Interstate Renewable Energy Council, *U.S. Solar Market Trends 2010* and *U.S. Solar Market Trends 2011*, June 2011 and August 2012, respectively.

88 Ibid.

89 Ibid.

90 Ben Sills, "Fossil Fuel Subsidies Six Times More Than Renewable Energy," *Bloomberg.com*, 9 November 2011.

91 Installed solar PV in Germany, 1990: *Renewable Energy Sources Act Progress Report 2007*, submitted by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), downloaded from www.erneuerbare-energien.de/fileadmin/eeimport/files/english/pdf/application/pdf/erfahrungsbericht_eeg_2007_zf_en.pdf on 13 March 2013; 2013: "Solar Reaches 100 GW Threshold Worldwide, Wind Grows 20 Percent," *Sustainablebusiness.com*, 12 February 2013.

92 U.S. Department of Energy, *Wind Powering America*, downloaded from

www.windpoweringamerica.gov/wind_installed_capacity.asp on 31 May 2013.

93 See methodology.

94 For market growth rates in Colorado, see note 87, compiling statistics from the versions of this report published from 2008 through 2012, covering the years 2006 through 2011, and Solar Energy Industries Association, *2012 Top 10 Solar States*, 2013, available at www.seia.org/research-resources/2012-top-10-solar-states; for California, see: Travis Madsen, Frontier Group, and Michelle Kinman and Bernadette Del Chiaro, Environment California Research & Policy Center, *Building a Brighter Future: California's Progress Toward a Million Solar Roofs*, November 2011, with updated with statistics for 2011 and 2012, per Go Solar California, *California Solar Statistics*, downloaded from www.californiasolarstatistics.ca.gov/ on 20 January 2012 and 15 January 2013; for New Jersey market growth rates, see note 87, compiling statistics from the versions of this report published from 2008 through 2012, covering the years 2006 through 2011; for 2012 installed capacity in New Jersey, see Solar Energy Industries Association, *New Jersey Solar*, downloaded from www.seia.org/state-solar-policy/New-Jersey on 13 May 2013.

95 See methodology.

96 Typical Colorado residences consume 9,325 kWh of electricity annually. Calculated assuming Colorado annual residential electricity consumption of 18,102,000 MWh, per U.S. Energy Information Administration, *2010 Colorado Electricity Profile—Table 8. Retail Sales, Revenue, and Average Retail Price by Sector, 1990 Through 2010*, released 30 January 2012. Number of households in Colorado and in Colorado Springs, see U.S. Census Bureau, note 8.

97 See methodology.

98 Ibid.

99 Ibid.

100 Ibid.

101 For the purpose of this report, we assume one rooftop solar energy system to be 3 kW (DC) in size.

102 U.S. Department of Energy, *DSIRE; Database of State Incentives for Renewables & Efficiency; Colorado; Net Metering*, downloaded from www.dsireusa.org on 23 April 2013.

103 U.S. Department of Energy, *DSIRE; Database of State Incentives for Renewables & Efficiency; Colorado; Sales and Use Tax Exemption for Renewable Energy Equipment*, downloaded from www.dsireusa.org on 24 April 2013.

104 Xcel Energy, *Solar Rewards Community: Grow a Solar Garden in Your Community*, downloaded from www.xcelenergy.com on 6 June 2013.

105 See note 57.

106 Ibid.

107 Ibid. Note: All capacity numbers in this report are in direct current (DC), except where otherwise noted.

108 In 2012, several manufacturers introduced solar panels with conversion efficiencies exceeding 18 percent. See First Solar Inc., *First Solar Sets New World Record for CdTe Solar Cell Efficiency* (press release), 26 February 2013; and James Montgomery, "SunPower Tops in Mono C-Si Solar Cell Efficiency: Cell Efficiency Ranges from 18-22 Percent — But Module and System Performance May Vary," *RenewbaleEnergyWorld.com*, 29 March 2012.

109 Based on converting annual solar output to BTU by multiplying by 3,412 BTU per kWh, then calculating how much surface area would be required to capture that much sunlight in a year given a population-weighted average solar resource in Colorado of 6 kWh/m^2/day (per U.S. Department of Energy, see note 8) at 18.5 percent conversion efficiency and adding an additional 25 percent to account for space required by ancillary equipment, per note 57.

110 See note 72.

111 See note 87.

112 Solar Energy Industries Association, *2012 Top 10 Solar States*, 2013, see note 94.

113 See note 66.

114 Ibid.

115 See note 94.

116 U.S. Department of Energy, see note 8.

117 See note 8.

118 Population and housing units: U.S. Census Bureau, see note 8.

119 U.S. Census Bureau, Population Division, *Interim State Population Projections*, 21 April 2005.

120 Current number of commercial establishments: U.S. Census Bureau, *2010 County Business Patterns, NAICS*, downloaded from censtats.census.gov on 13 May 2013; Number of establishments per building: Energy Information Administration, *2003 Commercial Buildings Energy Consumption Survey—Table A3. Census Region and Division, Number of Buildings for All Buildings (Including Malls), 2003*, June 2006.

121 Ibid.

122 Brookings Institution, Metropolitan Policy Program, *Toward a New Metropolis: The Opportunity to Rebuild America*, 2004. Note: To the extent that the recession of 2008 may have slowed down the expansion of commercial space in Colorado projected in the Brookings Institution report, our estimate of the total technical potential for rooftop solar power in the state in 2030 may be slightly overstated.

123 See note 119.

124 We used 2003 as a point of reference because it is the year of the most recent available data on commercial building energy consumption from Energy Information Administration, *2003 Commercial Buildings Energy Consumption Survey*, June 2006.

125 Calculated by multiplying 119,000 commercial buildings in 2003 by 52 percent, the expected growth in commercial building space between 2003 and 2030, per Brookings Institution, see note 122.

126 See note 15.

127 Among households in Colorado's census region, 68 percent use natural gas for water heating, and 16 percent use electricity, per Energy Information Administration, *2009 Residential Energy Consumption Survey—Table HC.1.11 Fuels Used and End Uses in Homes in West Region, Divisions, and States*, downloaded from www.eia.gov on 11 January 2012. Of the commercial buildings that have water heating, 55 percent use natural gas for that purpose, and 43 percent use electricity, Energy Information

Administration, *2003 Commercial Buildings Energy Consumption Survey*, June 2006. Note: About 300,000 households in the West region use propane for water heating, but we did not attempt to include propane savings in our analysis.

128 Average household energy consumption for water heating is 2,890 kWh of electricity or 22,000 cubic feet of natural gas in the Mountain region, per Energy Information Administration, *2005 Residential Energy Consumption Survey—Table WH6: 2005 Physical Units per Household*, *Mountain Region*, January 2009. Average commercial building energy consumption for water heating is about 244,000 cubic feet (cf) of natural gas or 13,400 kWh of electricity. We obtained these values using Energy Information Administration, *2003 Commercial Buildings Energy Consumption Survey*, June 2006 and the following methodology: We multiplied total electricity and natural gas used for water heating in commercial buildings in the Mountain Region by the percentage of commercial buildings in the Mountain Region that are in Colorado (see "See Solar Water Heating Potential" in methodology), and then divided those numbers by the number of commercial buildings in Colorado that use electricity or natural gas for water heating, respectively (See note 127).

129 See note 57.

130 Public Service Company of Colorado *2011 Electric Resource Plan: Volume II Technical Appendix*, 31 October 2011.

131 Navigant Consulting, Inc., *2010 Colorado Utilities Report*, prepared for the Governor's Energy Office, August 2010.

132 Ibid.

133 U.S. Energy Information Administration, *Colorado Electricity Profile 2010*, released 30 January 2013.

134 Number of households in Colorado: U.S. Census Bureau, *2010 U.S. Census*, May 2010; Average energy used to heat water per household: Energy Information Administration, *2005 Residential Energy Consumption Survey—Table US14. Average Consumption by Energy End Uses*, January 2009; Number of households that use electricity and natural gas for water heating: See note 127; Energy Information Administration, *2003 Commercial Buildings Energy Consumption Survey*, June 2006.

135 U.S. Environmental Protection Agency, see note 40.

136 Ibid.

137 U.S. Department of Energy, Energy Information Administration, *Voluntary Reporting of Greenhouse Gases Program Fuel Emission Coefficients*, 31 January 2011.