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A GREEN GROWTH PROGRAM FOR COLORADO

Climate Stabilization, Good Jobs, and Just Transition

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Highlights of Main Findings

This study examines the prospects for a transformative green growth program for Colorado. The centerpiece of the program is clean energy investments, undertaken in combination by the public and private sectors throughout the state. This program can advance two fundamental goals:

- Promoting global climate stabilization by reducing carbon dioxide (CO_2) emissions in Colorado without increasing emissions outside of the state.
- Expanding good job opportunities throughout the state.

Reducing CO_2 Emissions

- The first goal for clean energy investments will be to achieve, by 2030, a 50 percent reduction in CO_2 emissions in Colorado relative to the 2005 level of emissions.
  - Emissions in Colorado as of 2005 were at 95.2 million metric tons. The emissions level as of 2030 will therefore need to be no more than 48 million tons.[1]

Major Areas of Clean Energy Investments

- **Energy Efficiency.** Dramatically improving energy efficiency standards in Colorado's stock of buildings, automobiles and public transportation systems, and industrial production processes.
- **Clean Renewable Energy.** Dramatically expanding the supply of clean renewable energy sources—primarily wind, solar, and geothermal power—available at competitive prices to all sectors of Colorado's economy.
- **Total Investment Expenditures.** The level of investment needed to achieve Colorado's energy goals will be roughly $14.5 billion per year between 2021 – 2030.
  - This estimate assumes that Colorado's economic growth proceeds at an average rate of 2.4 percent per year.
  - Clean energy investments will need to equal about 3.5 percent of Colorado's annual GDP.
  - The average annual clean energy investment level of 3.5 percent of GDP means that about 96 percent of Colorado's economic activity will be directly engaged in activities *other than* clean energy investments.

Clean Energy Investments Will Deliver Lower Energy Costs

- Raising efficiency standards enable consumers to spend less for a given amount of energy services.
- The costs of wind, solar, geothermal, and hydro power are presently roughly equal to or lower than those for fossil fuels and nuclear energy.

- The average Colorado household should be able to save about 36 percent on their overall annual energy bill, reducing spending from $4,600 to $2,900. This would be after they have paid off their initial up-front efficiency investments over five years.

Job Creation through Clean Energy Investments

- Investing $14.5 billion per year in clean energy projects in Colorado will generate about 100,000 jobs per year in the state.
- New job opportunities will be created in a wide range of areas, including construction, sales, management, production, engineering, and office support.
- Current average total compensation in these occupations ranges between about $60,000 and $100,000.
- Employment growth in these areas should create increased opportunities for women and minority workers to be employed and to raise unionization rates.
- Higher unionization rates should promote gains in compensation and better working conditions in the affected industries.
- Good-quality worker training programs will be needed to ensure that a wide range of workers will have access to the jobs created by clean energy investments and that the newly-employed workers can perform their jobs at high productivity levels.

Just Transition for Fossil Fuel Industry Dependent Workers and Communities

- About 88 percent of all energy consumption in Colorado comes from burning oil, coal and natural gas. Consumption of oil and gas will need to fall by about 40 percent as of 2030 while coal consumption will need to fall by 70 percent.
- About 34,000 workers in Colorado are presently employed in 10 industries that will be heavily affected by these cuts in statewide fossil fuel consumption.
- We estimate that total job losses will average 688 per year, 585 of which are non-managerial.
  - This is after allowing that an average of 745 workers per year will voluntarily retire.
- A Just Transition program for all 585 non-managerial workers presently employed in Colorado's fossil fuel related industries should include five components:
  - Pension guarantees for retired workers who are covered by employer-financed pensions;
  - Retraining to assist displaced workers to obtain the skills needed for a new job and 100 percent wage replacement while training;
  - Re-employment for displaced workers through an employment guarantee, with 100 percent wage insurance.
  - Relocation support for all workers who require this support; and
  - Full Just Transition support for older workers who choose to continue working past the age of 65 rather than retiring.

- The average costs of supporting these workers will amount to about $234,000 per worker, or about $78,000 per year over three years. Overall costs will amount to about $114 million per year over the duration of the Just Transition program.

A Clean Energy and Sustainable Communities Investment Policy Agenda

- Our policy framework builds from the existing *Colorado Climate Plan*. The main recommended policy measures include:
- A carbon tax.
  - We estimate revenues from a carbon tax at varying tax rates.
  - A flat tax rate of $15 per ton of carbon will generate about $1 billion in revenues per year.
  - A tax rate that rises from $25 to $75 per ton of carbon over 2021 – 2030 will generate about $3 billion per year.
  - The revenues can be used to both rebate lower-income households and finance Colorado's clean energy investment programs.
- Strengthening existing energy efficiency and renewable energy portfolio standards.
- Strengthening existing procurement programs to support an expanding market for electric vehicles.
- Expanding subsidized financing policies currently available through the Colorado Climate Plan.
  - These include Property Assessed Clean Energy (PACE) financing, along with loan guarantees and tax incentives.
- Greatly expanding Colorado's current and recent worker training programs for clean energy employment opportunities.
- Channeling new investment funds into communities that are significantly dependent on the state's fossil fuel related industries.
  - These include Moffat, Weld, Cheyenne, Los Animas, Mesa, Gunnison and Yuma Counties.
  - Support could be developed through expanding Colorado's "Rural Response, Recovery and Resilience program (R4)."
- Pueblo Colorado is already actively engaged in a green community transition.
  - Pueblo's experiences underscore both the opportunities and challenges with green transition programs.

Achieving a 90 percent Emissions Reduction by 2050

- Colorado can reduce its CO_2 emissions by 90 percent relative to its 2005 level, to 9 million tons, by 2050 through continuing its clean energy investment program.
- Average clean energy investments would need to equal about 1.2 percent of state GDP per year over 2031 – 2050.

- Average job creation through these clean energy investments will range between 40,000 – 50,000 jobs per year.
- Just Transition support for displaced workers over 2031 – 2050 will amount to about $54 million per year.
- Colorado will be able to achieve the goal of a 100 percent renewable electricity supply as of 2040 within this 2031 – 2050 clean energy investment framework.

Summary of Study

This study examines the prospects for a transformative green growth program for Colorado. Clean energy investments are the centerpieces of the program, undertaken in combination by the public and private sectors throughout the state. These investments should be supported by a combination of public investments and incentives for private investors. This investment project should be understood as a major initiative within the state to advance the fundamental goal of global climate stabilization.

The first specific aim of this project is to achieve, by 2030, a 50 percent reduction of carbon dioxide (CO_2) emissions in Colorado relative to the state's 2005 emissions level. The second, equally important, goal is to achieve this 2030 emissions reduction goal while also expanding job opportunities and raising average living standards throughout Colorado.

The expansion of both public and private clean energy investments will need to focus on 1) dramatically improving energy efficiency standards in Colorado's stock of buildings, automobiles and public transportation systems, and industrial production processes; and 2) equally dramatically expanding the supply of clean renewable energy sources—primarily wind, solar, and geothermal power—available at competitive prices to all sectors of Colorado's economy.

In addition to these goals for 2030, this study also explores the prospects for achieving the longer-term aim of bringing down CO_2 emissions in Colorado by 90 percent as of 2050 relative to the 2005 emissions level, while concurrently expanding job opportunities and raising average living standards throughout the state. We also integrate, as a component of this 2050 emissions reduction trajectory, the proposal of Colorado Governor Jared Polis for the state to obtain 100 percent of its electricity supply from clean renewable sources as of 2040. This overall framework is also well aligned with the commitment announced last December by Xcel Energy, the state's largest power utility, to operate with 80 percent carbon-free energy as of 2030 and carbon-free electricity as of 2050.

Over the course of this study, we show that all these goals are achievable. We also document how clean energy investments will provide the state with a major new engine of job creation. Critically, we further show how Colorado's clean energy transition will deliver *lower energy costs for all state consumers*. This would result because raising energy efficiency standards means that, by definition, consumers will spend less for a given amount of energy services, such as being able to travel 50 miles on a gallon of gasoline with a high-efficiency automobile as opposed to 30 miles with a less efficient vehicle. Moreover, the costs of supplying energy through wind, solar, geothermal and hydro power are now, on average, roughly equal to or lower than those for fossil fuels and nuclear energy.

As of 2016, average household energy consumption in Colorado was about $4,600, equal to 5.0 percent of average household income of about $88,000. We estimate that energy efficiency investments in Colorado between 2021 – 2030 can generate efficiency gains of 36 percent between 2021 – 2030. This would mean that, by 2030, average household energy costs could decline to $2,900, a $1,700 savings. To realize these savings, households would need to invest in purchasing a more fuel efficient-vehicle, such as a hybrid car as opposed to a gasoline car, and to raise the efficiency standards in their residences. We can assume roughly that to pay off those investments with interest would absorb the $1,700 annual energy savings for an initial 5-year period. But after the 5-year payback period, the household would be spending $1,700 less to purchase a given level of energy services—e.g. driving a given number of miles per year in one's car; or heating, cooling and lighting one's house by a given amount.

This study examines measures to reduce that portion of total greenhouse gas emissions produced by burning fossil fuels—oil, coal and natural gas—to generate energy. Climate change cannot be entirely blamed on we humans consuming oil, coal, and natural gas to generate energy. But people consuming fossil fuels for energy can be blamed for about 74 percent of the problem. CO_2 emissions from burning coal, oil and natural gas alone produce about 63 percent of all greenhouse gas emissions, while another 11 percent is caused mainly by methane leakages during extraction. Agricultural production is the other major source of greenhouse gas emissions, accounting for about 13 percent in total, in about equal shares of methane and nitrous oxide. Controlling methane and nitrous oxide emissions from agricultural as well as other, smaller sources of emissions will of course be necessary to advance a successful global climate stabilization project. But this study will focus on the roughly 75 percent of the problem that we can solve by burning less oil, coal and natural gas, as well as, to a lesser extent, high-emissions renewables, such as corn ethanol.

Colorado's current climate initiatives, as summarized in the *2018 Climate Plan*, are certainly worthy. But they are not adequate to enable Colorado to advance a sufficiently robust program in support of global climate stabilization. Still, the *Climate Plan* is a valuable starting point from which the state can advance a climate stabilization program that is adequate to the challenges we face. That is why this study builds from the *Climate Plan* in proposing a set of policies to achieve both the 50 percent reduction in CO_2 emissions by 2030 and the 90 percent reduction by 2050 relative to 2005 levels. The specific policy tools that we propose to advance clean energy investments in the state include a carbon tax; mandatory renewable energy and energy efficiency portfolio standards for the state's utilities and related efficiency incentives for operating buildings, transportation vehicles and industrial equipment; and various forms of financial incentives for private clean energy investors.

Working within this policy framework, we conclude that Colorado can reduce its emissions by 50 percent as of 2030 through maintaining clean energy investments in the state at about 3.5 percent of Colorado's GDP per year over 2021 – 2030. To reach the 2050 goal of a 90 percent emissions reduction will require another 1.2 percent of statewide GDP from 2031 – 2050.

We estimate that the combination of public and private investments at about 3.5 percent of state GDP will create about 100,000 jobs in Colorado per year through 2021 – 2030 and that investing about 1.2 percent of the state's GDP between 2031 – 2050 will produce between 40,000 – 50,000 jobs per year. One critical feature of the state's clean energy investment project should be to ensure that the jobs being created are good-quality jobs, in terms of wages, benefits, and working conditions, and that women and minorities are provided equal access to these jobs.

Raising unionization rates in these industries will provide an important foundation in support of these goals. As one feature of the overall clean energy transition project for Colorado, the state should therefore require neutrality with respect to union organizing campaigns in any clean energy investment projects that are either state-owned or partially financed by the state. It will also be important for the state to provide high-quality training programs for workers pursuing job opportunities in the expanding clean energy industries.

Of course, as Colorado's clean energy economy expands rapidly, the fossil fuel industry in the state will necessarily contract. The consumption of oil and gas in Colorado will need to decline by 40 percent as of 2030 while coal contracts by 70 percent in order to hit the 50 percent emissions reduction target. As of 2050, coal and natural gas should no longer be consumed in the state. Oil may still be needed to a modest extent as a liquid fuel.

How will this clean energy investment project impact the workers and communities in the state that are now dependent on the state's fossil fuel industry? At present, about 34,000 people in Colorado are employed in either the oil, natural gas, or coal industries, and in ancillary sectors such as oil and gas support activities or pipeline construction. However, only a small fraction of these 34,000 workers will face displacement in any given year. We estimate that, after accounting for attrition through voluntary retirements, about 700 workers per year will face displacement between 2021 – 2030 and about 300 per year from 2031 - 2050. We propose generous Just Transition programs to support all dislocated workers, including income, retraining, and relocation support, along with guaranteeing the full value of their pensions. We also propose transitional support programs for communities that will be hard hit by the downsizing of the state's fossil fuel industry, such as has already begun to take shape through the state's Rural Response, Recovery and Resilience program.

The study consists of 10 sections. These are:

1. Introduction
2. Sources of Energy and CO_2 Emissions for Colorado
3. Determinants of Colorado's Emissions Levels
4. Prospects for Energy Efficiency Gains
5. Prospects for Clean Renewables
6. Clean Energy Investment Levels and Emissions Reductions
7. Job Creation through Clean Energy Investments
8. Just Transition for Fossil Fuel Industry Dependent Workers
9. A Clean Energy Investment Policy Agenda
10. Achieving a 90 percent CO_2 Emissions Reduction by 2050

The main findings and conclusions of the study are as follows:

Current CO_2 Emissions Levels in Colorado

As of 2015[2], CO_2 emissions in Colorado were at 93.1 million tons, with 90.2 million tons generated by burning fossil fuels and the remaining 2.9 tons resulting from burning biomass. This emissions level is roughly 20 percent above the state's 1997 level of 75.4 million tons. Colorado's real GDP grew by about 65 percent between 1997 and 2015. Thus, Colorado has made some progress in terms of reducing CO_2 emissions increases relative to the state's GDP growth rate. But this must be understood as only a modest first step relative to the challenges of advancing an adequate climate stabilization project.

Energy Consumption and CO_2 Emissions Sources

As of 2015, the primary sources of Colorado's energy supply are natural gas (33.3 percent), petroleum (31.1 percent) and coal (23.0 percent). These three fossil fuel energy sources account for nearly 88 percent of all of Colorado's energy consumption, with total statewide energy consumption at 1.48 quadrillion British Thermal Units (Q-BTUs). They also account for 97 percent of the state's CO_2 emissions, with the relative contributions at 28 percent from burning natural gas and approximately 34 percent each from burning oil and coal respectively. The remaining CO_2 emissions come from burning biomass energy sources, which supplies about 3 percent of Colorado's total energy supply. Clean renewable sources in total, including wind, hydro, solar, and geothermal account for 6.2 percent of Colorado's total energy supply, with wind being by far the largest source here, at 4.7 percent of total supply. These figures make clear that transforming these clean renewable sources into a major provider of energy in Colorado as of 2030 and the predominant source as of 2050 will be a formidable challenge.

Prospects for Energy Efficiency

Colorado operates at an energy efficiency level that is about 13 percent better than the U.S. average. The state improved its overall efficiency level by about 20 percent between 1997 -2015. Those gains occurred through the combination of higher auto fuel efficiency standards, along with improvements in the operations of the state's commercial buildings and in industrial energy consumption. Additional efficiency gains will need to result through further improvements in buildings, automobiles and the equipment powering industrial activities as well as the expansion of public transportation systems. We conclude that major efficiency improvements—in the range of 30 – 40 percent—are possible at relatively low upfront capital expenditures. We assume, specifically, that the average costs throughout the full range of energy efficiency investments will be $35 billion per Q-BTU in efficiency gains.

Prospects for Clean Renewable Energy Sources

We focus on expanding Colorado's share of energy supply that will be provided through three clean renewable sources—wind, solar and geothermal energy. We distinguish between the costs *to consumers* of expanding the supply from these three sources, as opposed to the *upfront capital expenditures* of building more clean renewable energy productive capacity. In terms of costs to consumers, we review evidence from the U.S. Energy Information Agency (EIA) showing that, as of 2022, the average costs of delivering a given supply of electricity from clean renewable sources will be roughly equal to, if not cheaper than, virtually all fossil-fuel based technologies. Consumers should therefore experience *no price increases* when they purchase energy from clean renewable sources. We also review evidence from the EIA on the one-time costs of expanding productive capacity in clean renewable sources. We conclude, as a high-end figure, this average cost will be about $200 billion per Q-BTU of new capacity.

Clean Energy Investments to Achieve Emissions Reduction Goal

To explore the prospects of bringing Colorado's CO_2 emissions down by 50 percent, to 48 million tons by 2030, we work with a few basic assumptions as to the state's economic trajectory between now and 2030. In particular, we assume that the state's average rate of GDP growth through 2030 will be 2.4 percent, the same growth rate that prevailed between 1997 and 2017. Within this growth framework, we then consider two alternative scenarios with respect to the state's energy infrastructure. The first is that the energy infrastructure remains basically intact through 2030. The second is that Colorado undertakes a major expansion in clean energy investments between 2021 – 2030. Following from these investments, the Colorado economy both raises energy efficiency and expands its reliance on clean renewable energy sources to the extent necessary to bring statewide CO_2 emissions down to 48 million tons or below. We show that, over 2021 – 2030, if the combination of public and private investments throughout Colorado average about $2.7 billion per year in energy efficiency and $11.8 billion per year in clean renewable energy—for a total level of clean energy investments at about $14.5 billion per year—the state can bring CO_2 emissions down to about 47 million tons by 2030. Total investment spending at this level would average about 3.5 percent of the state's projected GDP between 2021 – 2030, assuming the state's GDP grows at 2.4 percent per year over this period.

Job Creation through Clean Energy Investments

We estimate the employment effects in Colorado of advancing clean energy investments at the level of about $14.5 billion per year over 2021 – 2030. After estimating the number of jobs that this overall investment level will generate, we then consider indicators of job quality, the profile of the workers engaged in these activities at present, and the prevalent types of specific jobs associated with the major areas of both energy efficiency and clean renewable energy investments. Overall, we find that, for 2021, the first year of the large-scale investment expansion, the extent of job creation will be about 110,000 jobs, equal to about 3.7 percent of the state's total workforce. Assuming that labor productivity in these activities improves at an average rate of 1 percent per year, total job creation through $14.5 billion in clean energy investments will be about 100,000 in 2030.

In terms of job quality, we find that average total compensation for the newly created areas of employment will range between about $61,000 and $100,000. We show the proportions of workers in these jobs who have private pensions, are covered by private health insurance and are union members. We also report on the educational credentials of workers currently employed in these areas, as well as the racial and gender composition of workers in these jobs.

Among other results, we find that these jobs are held disproportionately by white male workers and that unionization rates range mostly between 7 - 13 percent of the respective workforces. The growth in employment in these industries that will be generated by large-scale new investments should create increased opportunities both for women and minority workers to be employed in these industries as well as to raise unionization rates. The rise in unionization, in turn, should help improve compensation levels in these industries as well as the diversity of the workforce. Providing high-quality worker training programs will further expand employment opportunities in the growing clean energy sectors. This is especially important for creating equal clean energy job opportunities for women and minorities, who are presently underrepresented in the relevant sectors.

Just Transition for Fossil Fuel Industry Dependent Workers and Communities

In order for Colorado to bring total CO_2 emissions down to no more than 48 million tons by 2030, we estimate that consumption of oil and natural gas fossil fuels in the state will need to fall by approximately 40 percent relative to its 2015 level and coal consumption will need to fall by 70 percent. It follows that production activity and employment in fossil fuel-dependent industries throughout Colorado will also decline by approximately these same proportions—oil and gas employment declining by 40 percent and coal by 70 percent as of 2030. We also assume that employment declines will be proportional in the ancillary fossil fuel related industries, with the largest of these being support activities for oil and gas operations and oil and gas pipeline construction and transportation.

At present, about 34,000 people are employed in all fossil-fuel related activities. We propose a set of measures—a "Just Transition" program—to compensate both workers and communities that are, at present, dependent on the fossil fuel industry for their livelihood. We then discuss community transition measures in the next section.

The single most important finding of our work on this question is that, once we take account of attrition through workers in the industry retiring voluntarily at 65, there will be an average of only about 688 job losses per year throughout the state, 585 of which are non-managerial workers.

We develop a detailed Just Transition program for all non-managerial workers presently employed in fossil fuel related industries. The detailed policy package includes five components. These are:

1. Pension guarantees for retired workers who are covered by employer-financed pensions, starting at age 65;
2. Retraining to assist displaced workers to obtain the skills needed for a new job and 100 percent wage replacement while training;
3. Re-employment for displaced workers through an employment guarantee, with 100 percent wage insurance. With wage insurance, workers are guaranteed that their total compensation in their new job will be supplemented to reduce any losses relative to the compensation they received working in the fossil fuel based industry;
4. Relocation support for 50 percent of displaced workers, assuming only 50 percent will need to relocate; and
5. Full Just Transition support for workers 65 and over who choose to continue working rather than retire.

We approximate the overall costs of supporting 585 non-managerial displaced fossil fuel related workers per year as including the following components:

1. 100 percent compensation insurance for three years, totaling $100.3 million;
2. Retraining for 2 years, totaling $9.4 million;

3. 100 percent wage replacement for 293 workers who train full-time for one year, adding a net of $22.0 million; and
4. Relocation support, totaling $14.7 million per year.

The average costs of the program will amount to about $234,000 per displaced worker, once we also account for roughly $16,000 of unemployment insurance benefits that the State will not have to spend while these workers receive Just Transition benefits. This equals to $78,000 per worker per year over a three-year period of support. Total costs will average about $114 million per year over the duration of the Just Transition program.

A Clean Energy Investment Policy Agenda

We consider what would constitute an effective package of policies for reaching this combined public and private clean energy investment level averaging $14.5 billion per year between 2021 – 2030. Our proposed policy framework builds from the set of measures that are already in operation in Colorado through the *Colorado Climate Plan*. We consider the prospects for building on these already existing policies, as well as new proposals, within four broad categories:

Market-shaping taxes and regulations that take account of the social costs of burning fossil fuels as an energy source and help build demand for energy efficiency and clean renewable energy sources. These include a carbon tax, along with energy efficiency and renewable energy portfolio standards for the state's utilities, as well as upholding the existing auto efficiency standards under the state's Clean Car Law.

We estimate the revenue potential of a statewide carbon tax under four different scenarios. With a carbon tax set at a low-end figure of $15 per ton of carbon fixed through 2021 – 2030, the tax would generate an average of about $1.1 billion per year in revenue. A tax that begins at $25 per ton of carbon and rises to $75 per ton as of 2030 would generate an average of $3.3 billion per year over 2021 – 2030. This revenue will be available to provide rebates for lower-income households and to help pay for both public and private clean energy investments.

We recognize the difficulties that would be faced in implementing a carbon tax in Colorado due to the state's Taxpayer Bill of Rights (TABOR). It is therefore clear that other effective initiatives will be needed to either complement or fully substitute for a carbon tax.

Direct public spending that includes investments in infrastructure, procurement and research and development (R&D). This would include expanding the state's existing procurement program for purchasing electric vehicles.

Private investment incentives that lower the costs and risks for private investors for investments in energy efficiency and clean renewable energy sources. These would build off of the state's existing programs in the areas of Property Assessed Clean Energy (PACE) financing, along with loan guarantees, and tax incentives.

Transitional support for communities that will be disproportionately hurt through the contraction of the state's fossil fuel related industries.

The total amount of employment in the fossil fuel and ancillary industries in Colorado is relatively low, at about 34,300. This amounts to about 1.2 percent of total statewide employment. As such, only a relatively small number of communities in the state will experience job losses that will significantly affect the overall level of economic activity in that community. Nevertheless, some communities will experience the effects of the contraction of the fossil fuel industry to a disproportionate extent.

We calculate that there would be 7 counties in the state in which employment losses through a clean energy transition would amount to 2 percent or more of total employment, including Moffat, Weld, Cheyenne, Los Animas, Mesa, Gunnison, and Yuma. Implementing an effective transition program for the state overall should begin by focusing its efforts within these 7 counties. The most direct way to support these communities in transition will be to channel a relatively high proportion of new clean energy investments into these communities.

The first stages have already been made in Colorado toward developing a transitional support policy framework. This is the state's "Rural Response, Recovery and Resilience program (4R)." However, to date, there are few specifics or funding initiatives in place to support this program. It will therefore be especially useful to consider some prior experiences with transitional support programs, in the U.S. and elsewhere.

As one important example, Pueblo Colorado, both the city and county, are themselves already actively engaged in a green community transition. In 2008, the county successfully recruited Vestas, a Denmark-based firm that is one of the world's largest wind turbine manufacturers, to locate a production facility in Pueblo. The plant has been operating since 2010. Pueblo is also the home to Comanche Solar, the largest solar farm east of the Rockies, at 156 megawatts. These renewable energy projects for Pueblo are part of its overall green transition program. The program's overarching commitment is for the community to rely, by 2035, solely on renewable energy sources to supply its electricity. While Pueblo has made important commitments in advancing the community's green energy transformation, it is also encountering significant obstacles, which we review. Overall, Pueblo's varying experiences to date underscore both the opportunities and challenges that will be faced by communities in Colorado more generally in their efforts to transition away from relying on their existing fossil fuel infrastructure in favor of a clean energy infrastructure. These experiences also make clear the importance of policymakers operating with a range of tools that they can deploy flexibly, depending on the specific circumstances faced by any given community.

Achieving a 90 percent Emissions Reduction by 2050

If Colorado is able to bring overall CO_2 emissions in the state down to no more than 48 million tons by 2030—an approximately 50 percent decline relative to the 2005 emissions level of 95.2 million tons—the state will also be able to reduce emissions by 90 percent relative to 2005 by 2050. Emissions in Colorado in 2050 would then be at 9 million tons. Colorado should be able to achieve this 90 percent emissions reduction through continuing the clean energy investment project that would have proceeded from 2021 – 2030. On an annual basis, the scale of the investments in energy efficiency and clean renewable energy between 2031 – 2050 that will be needed to achieve the 90 percent emissions reduction goal by 2050 will be significantly more modest than what we describe for the project through 2030. Over 2031 – 2050, we estimate that the average annual clean energy investments necessary to reach the

90 percent emissions reduction goal by 2050 will amount to about 1.2 percent of Colorado's average GDP, as opposed to the average investment level of 3.5 percent of GDP for the project over 2021 – 2030. In addition, addressing one of the climate stabilization goals emphasized by Governor Polis, we demonstrate that Colorado will be able to supply 100 percent of its electricity needs from clean renewable sources by 2040 as one feature of the broader project of reducing CO_2 emissions by 90 percent as of 2050.

The impact of Colorado's 2031 – 2050 clean energy investment project on job opportunities throughout the state will be more modest than the 2021 – 2030 phase of the project, since investment spending will be much lower, at 1.2 percent of GDP on average, as opposed to 3.5 percent of GDP. Nevertheless, job creation through the combination of public and private investments will still be strongly in the positive direction. We estimate average job creation through the 2031 – 2050 clean energy investment project as ranging between about 40,000 – 50,000 jobs per year. We also estimate that Just Transition policies for displaced workers over this period in both the fossil fuel and ancillary industries—including income, retraining, and relocation support for all affected workers—would amount to about $54 million per year.

A GREEN GROWTH PROGRAM FOR COLORADO

Climate Stabilization, Good Jobs, and Just Transition

1. INTRODUCTION

This study examines the prospects for a transformative clean energy investment project for Colorado. Taken as a whole, this investment project should be understood as a major initiative within the state to advance the fundamental goal of global climate stabilization. These investments should be undertaken by both the public and private sectors in Colorado, supported by a combination of public investments and incentives for private investors.

The first specific aim of this project is for Colorado to achieve, by 2030, a 50 percent reduction in carbon dioxide (CO_2) emissions below the level the state reached in 2005. The second, equally important, goal is to achieve this 2030 emissions reduction while also expanding job opportunities and raising average living standards throughout Colorado.

The expansion of both public and private clean energy investments will need to focus on 1) dramatically improving energy efficiency standards in Colorado's stock of buildings, automobiles and public transportation systems, and industrial production processes; and 2) equally dramatically expanding the supply of clean renewable energy sources—primarily wind, solar, and geothermal power—available at competitive prices to all sectors of Colorado's economy.

In addition to these goals for 2030, this study also explores the prospects for achieving the longer-term aim of bringing down CO_2 emissions in Colorado by 90 percent as of 2050 relative to the state's 2005 level, while concurrently expanding job opportunities and raising average living standards throughout the state. We also integrate, as a component of this 2050 emissions reduction trajectory, the proposal of Colorado Governor Jared Polis for the state to obtain 100 percent of its electricity supply from clean renewable sources as of 2040. This overall framework is also well aligned with the commitment announced last December by Xcel Energy, the state's largest power utility, to operate with 80 percent carbon-free energy as of 2030 and carbon-free electricity as of 2050.

Over the course of this study, we show that all these goals are achievable. We also document how clean energy investments will provide the state with a major new engine of job creation. Critically, we also show how Colorado's clean energy transition will deliver *lower energy costs for all state consumers.* This would result because raising energy efficiency standards means that, by definition, consumers will spend less for a given amount of energy services, such as being able to travel 50 miles on a gallon of gasoline with a high-efficiency automobile as opposed to 30 miles with a less efficient vehicle. For an average Colorado household, we roughly estimate cost savings by 2030 would be about 36 percent of their total energy bill, or roughly $1,700 per year. This would be after the household would have spent up to 5 years paying off their investments in more efficient equipment through their lowered energy bills. Moreover, the costs of supplying energy through wind, solar, geothermal and hydro power are now, on average, roughly equal to or lower than those for fossil fuels and nuclear energy.

The project to rapidly and dramatically drive down greenhouse gas emissions in Colorado is representative of the type of climate stabilization initiative that needs to be advanced throughout the world without further delay. The December 2015 UN-sponsored Paris Climate Agreement was a major milestone on behalf of the global project of climate stabilization. Coming out of the conference, all 196 countries formally recognized the grave dangers posed by climate change and committed to take action to substantially cut emissions generated by their respective economies.

In June 2017, U.S. President Donald Trump announced that the United States would pull out of the Paris agreement. This decision dealt a severe blow to the prospects for putting the global economy onto a sustainable path toward climate stabilization. But Trump's decision also elicited strong opposition throughout the U.S. Initiatives in Colorado itself provide important examples of this opposition. As one critical case in point, the state has maintained its commitment to achieving high fuel efficiency standards for automobiles and to promote zero-emissions vehicles, despite objections from the Trump administration. More generally, the state government has continued to advance its *Colorado Climate Plan*, which includes a broad range of emissions reduction measures.

But these initiatives to date, in Colorado and elsewhere throughout the world, also need to be evaluated relative to the current trajectory for global warming. In fact, the pledges made by all countries combined at the Paris conference are not close to being adequate to stabilize the climate at a global mean temperature at between 1.5 – 2.0 degrees (Celsius) above pre-industrial levels no later than 2100—the goal that the Paris Agreement itself had recognized as necessary to achieve climate stabilization. Rather, according to the credible estimate by the environmental research NGO Climate Action Tracker, if all countries were to keep to the pledges they made at Paris, the global mean temperature would rise by between 3.0 – 3.2 degrees by 2100.[3] In addition, even these inadequate pledges were not made legally binding in Paris.

Further, the most recent October 2018 report by the Intergovernmental Panel on Climate Change (IPCC), the most authoritative global organization advancing climate change research, emphasized the importance of limiting the increase in global mean temperatures to 1.5 degrees above pre-industrial levels as opposed to 2.0 degrees. This IPCC report concludes by limiting the global mean temperature increase to 1.5 rather than 2.0 degrees by 2100 will have major impacts in terms of limiting the negative impacts of climate change. These include the risks of heat extremes, heavy precipitation, droughts, sea level rise, biodiversity losses, and corresponding impacts on health, livelihoods, food security, water supply, and human security.

The IPCC concludes that to achieve the 1.5 degrees maximum global mean temperature increase target as of 2100, global net CO_2 emissions will have to fall by about 45 percent as of 2030 and reach net zero emissions by 2050.[4] Therefore, the goal for Colorado to achieve a 50 percent emissions reduction by 2030 and a 90 percent reduction by 2050 is in basic alignment with the most recent IPCC targets.

The Colorado target is also in line with the November 2018 report of the European Commission, *A Clean Planet for All: A European Strategic Long-term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy."* The EU report recognizes that "in order to limit temperature increase to 1.5^0C, net-zero CO_2 emissions at a global level needs to be achieved around 2050 and for all other greenhouse gases somewhat later in the century." The report concludes that the EU will need to "achieve greenhouse gas emissions neutrality by 2050," (p. 5).

It is also the case that the November 2018 *Fourth Climate Assessment Report* of the U.S. federal government is unequivocal in recognizing the severe risks that are resulting through climate change. This report begins with the following overview:

> The impacts of climate change are already being felt in communities across the country. More frequent and intense extreme weather and climate-related events, as well as changes in average climate conditions, are expected to continue to damage infrastructure, ecosystems, and social systems that provide essential benefits to communities. Future climate change is expected to further disrupt many areas of life, exacerbating existing challenges to prosperity posed by aging and deteriorating infrastructure, stressed ecosystems, and economic inequality (2018, p. 25).

However, unlike both the IPCC and EU reports, this U.S. government study offers little by way of specifics with respect to both the extent of emissions reductions needed to reach a viable climate stabilization path as well as actions necessary to achieve major emissions reductions.[5] At the same time, the U.S. government study does review evidence on the social and economic costs of failing to take action to mitigate climate change. The report draws on a 2017 study by Hsiang et al., "Estimating Economic Damage from Climate Change in the United States." Hsiang et al. summarize their main findings as follows:

> The combined value of market and nonmarket damage across analyzed sectors—agriculture, crime, coastal storms, energy, human mortality and labor—increases quadratically in global mean temperature, costing roughly 1.2 percent of gross domestic product per $+1^0$C on average. Importantly, risk is distributed unequally across locations….By the late 21st century, the poorest third of counties are projected to experience damages between 2 and 20 percent of county income under business-as-usual emissions (2017, p. 1362).

As both the U.S. government report and Hsiang et al. emphasize, a great deal of uncertainty is unavoidable in making any such estimates. Nevertheless, the need for action remains overwhelming, not on the basis of certainty with respect to consequences, but rather on the basis of reasonable probabilities. Indeed, we need to think of a Colorado clean energy project—as well as similar projects throughout the U.S. and global economies—as the equivalent of an insurance policy to protect ourselves and the planet against the serious prospect, though not the certainty, of severe negative impacts from climate change. The only serious matter in dispute should therefore be how much should we be willing to pay to purchase an adequate amount of climate change insurance.[6] This study can therefore be seen as a means of assessing the costs of such an insurance policy relative to the benefits that the state will accrue through the investments that will build a state-wide clean energy economy.

This study focuses on measures to reduce that portion of total greenhouse gas emissions produced by burning fossil fuels—oil, coal and natural gas—to generate energy.[7] Climate change cannot be entirely blamed on we humans consuming oil, coal, and natural gas to generate energy. But people consuming fossil fuels for energy can be blamed for about 74 percent of the problem. CO_2 emissions from burning coal, oil and natural gas alone produce about 63 percent of all greenhouse gas emissions, while another 11 percent is caused mainly by methane leakages during extraction. Agricultural production is the other major source of greenhouse gas emissions, accounting for about 13 percent in total, in about equal shares of methane and nitrous oxide. Controlling methane and nitrous oxide emissions from agricultural as well as other, smaller sources of emissions will of course be necessary to advance a successful global climate stabilization project. But this study will focus on the roughly 75 percent of the problem that we can solve by burning less oil, coal and natural gas.[8]

Colorado's current climate initiatives, as summarized in the *2018 Climate Plan*, are certainly worthy and have produced significant positive results. For example, wind and solar power generated 20 percent of the state's electricity supply as of 2017. As of 2018, Colorado ranked 7th of all 50 states in the number of renewable energy jobs, at 17,254. Moreover, all 65 counties in the state have workers employed in some clean energy activities. The total number of clean energy jobs were at 57,591, 1.8 percent of Colorado's workforce.[9]

But as we discuss below, they are not adequate to enable Colorado to advance a sufficiently robust program in support of global climate stabilization. Further, as with the Paris agreements, most features of the Colorado climate program amount to various types of incentive programs but do not include legally binding regulations.

Still, the *Colorado Climate Plan* is a valuable starting point from which the state can advance a climate stabilization program that is adequate to the challenges we face. That is why this study builds from the *Climate Plan* in proposing a set of policies to achieve both the 50 percent reduction in CO_2 emissions by 2030 and the 90 percent reduction by 2050 relative to 2005 emissions levels. The specific policy tools that we propose advance clean energy investments in the state include a carbon tax; mandatory renewable energy and energy efficiency portfolio standards for the state's utilities and related efficiency incentives for operating buildings, transportation vehicles and industrial equipment; and various forms of financial incentives for private clean energy investors.

Operating within this policy framework, we conclude that Colorado can reduce its emissions by 50 percent as of 2030 through maintaining clean energy investments in the state at about 3.5 percent of Colorado's GDP per year over 2021 – 2030. To reach the 2050 goal of a 90 percent emissions reduction will require another 1.2 percent of statewide GDP from 2031 – 2050.

We estimate that the combination of public and private investments at about 3.5 percent of state GDP will create about 100,000 jobs in Colorado per year through 2021 – 2030 and that investing about 1.2 percent of the state's GDP between 2031 – 2050 will produce between 40,000 – 50,000 jobs per year. One critical feature of the state's clean energy investment project should be to ensure that the jobs being created are good-quality jobs, in terms of wages, benefits, and working conditions, and that women and minorities are provided equal access to these jobs.

Raising unionization rates in these industries will provide an important foundation in support of these goals. As one feature of the overall clean energy transition project for Colorado, the state should therefore require neutrality with respect to union organizing campaigns in any clean energy investment projects that are either state-owned or partially financed by the state. It will also be important for the state to provide high-quality training programs for workers pursuing job opportunities in the expanding clean energy industries.

Of course, as Colorado's clean energy economy expands rapidly, the fossil fuel industry in the state will necessarily contract. The consumption of oil and gas in Colorado will need to decline by 40 percent as of 2030 while coal contracts by 70 percent in order to hit the 50 percent emissions reduction target. As of 2050, coal and natural gas should no longer be consumed in the state. Oil may still be needed to a modest extent as a liquid fuel.

How will this clean energy investment project impact the workers and communities in the state that are now dependent on the state's fossil fuel industry? At present, about 34,000 people in Colorado are employed in either the oil, natural gas, or coal industries, and in ancillary sectors such as oil and gas support activities or pipeline construction. However, only a small fraction of these 34,000 workers will face displacement in any given year. We estimate that, after accounting for attrition through voluntary retirements, about 700 workers per year will face displacement between 2021 – 2030 and about 300 per year from 2031 - 2050. We propose generous Just Transition programs to support all dislocated workers, including income, retraining, and relocation support, along with guaranteeing the full value of their pensions. We also propose transitional support programs for communities that will be hard hit by the downsizing of the state's fossil fuel industry, such as has already begun to take shape through the state's Rural Response, Recovery and Resilience program.

As of 2005, CO_2 emissions in Colorado totaled to 95.2 million metric tons (as noted in the Highlights section, for simplicity we hereafter refer to this metric tons measure of CO_2 emissions as simply "tons.") From this 2005 benchmark figure, we can specify the state's emission reduction targets as follows:

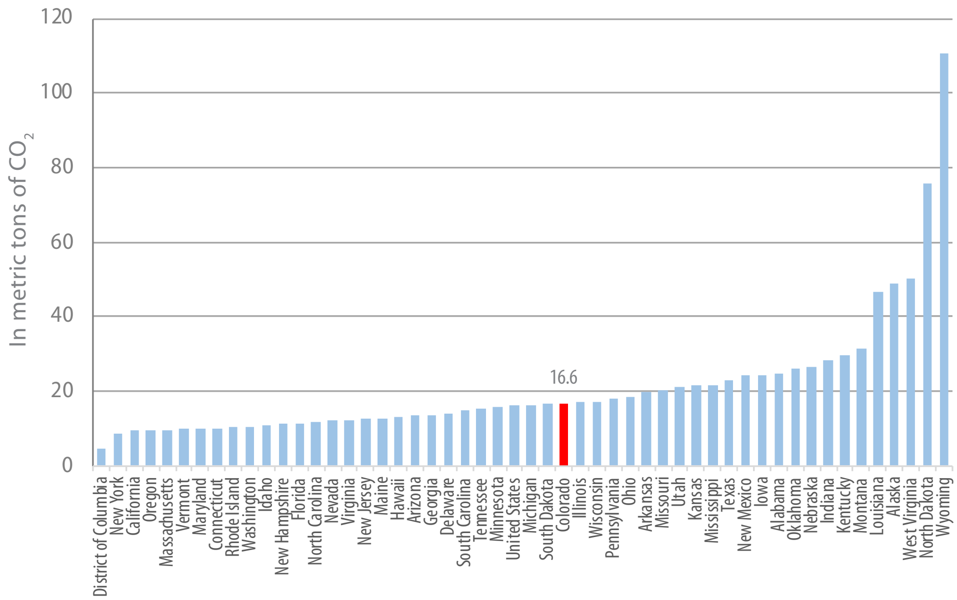
- 50 percent reduction as of 2030 = emissions decline to 47.6 million tons. We round this figure up to 48 million tons.
- 90 percent reduction as of 2050 = emissions decline to 9.5 million tons. We round this figure down to 9 million tons.

As of the more recent 2015 data, Colorado is contributing about 1.8 percent of the 5.2 billion tons in total emissions generated in the United States.[10] Scaled to Colorado's population size, emissions in Colorado are at 16.6 tons per capita. This figure places Colorado at almost exactly the average figure for the U.S. as a whole, which is 16.4 tons per capita. Comparing Colorado with other U.S. states, emissions are much lower, for example, in New York and California, at 8.5 and 9.3 tons per capita respectively. However, per capita emissions are much higher in some other states, including Texas at 22.8 tons per capita, West Virginia at 50.0 tons per capita, and Wyoming at 110.5 tons per capita. Figure 1 shows the distribution of per capita emissions levels for all 50 U.S. states. It is clear from the figure that Colorado is right in the middle of the state-by-state distribution.

In comparison with other countries, emissions generated in Colorado are roughly 23 percent above those for Canada, at 13.2 tons, and 80 percent above the 9.2 per capita emissions figure in Germany. Emissions are much lower in a country like India, where the figure is 1.6 tons of CO_2 per capita, only 10 percent as high as the Colorado figure. But this is only because India's average per capita income is approximately $1/30^{th}$ the figure for Colorado. We return to this issue below.

Overall, as we will review, Colorado is currently well positioned to make a significant contribution in driving down global CO_2 emissions, while also maintaining healthy state-level economic growth and expanding job opportunities throughout the state.

FIGURE 1: Carbon Dioxide Emissions Per Capita, All States, 2015



Source: U.S. Energy Information Administration, U.S. Census.

2. SOURCES OF ENERGY AND CO_2 EMISSIONS FOR COLORADO

In this section, we review the sources of energy supply and demand in Colorado, as well as the factors generating CO_2 emissions in the state. This discussion will provide necessary background for advancing a viable framework to lower emissions much further, to about 48 million tons by 2030 and to 9 million tons by 2050.

Table 1 shows Colorado's energy consumption profile both in terms of sources and uses of energy. In this table and throughout the study, we measure all energy sources uniformly in terms of British Thermal Units (BTUs). A BTU represents the amount of thermal energy necessary to raise the temperature of one pound of pure liquid water by one degree Fahrenheit at the temperature at which water has its greatest density (39 degrees Fahrenheit). Burning a wood match to its end generates about 1 BTU of energy. We will present figures on energy production and consumption, as appropriate, in terms of both trillions and quadrillion BTUs, referring to the acronyms T-BTUs and Q-BTUs respectively.

TABLE 1
Colorado Energy Consumption by Sector and Energy Source, 2015
Figures are T-BTUs and percentages

	Buildings						
	Residential	Commercial	All Buildings	Industrial	Transportation	TOTAL	% of TOTAL
1. Total	**343.2**	**290.2**	**633.4**	**439.3**	**407.6**	**1,480.3**	**100.0**
2. % of Total	**23.2**	**19.6**	**42.8**	**29.7**	**27.5**	**100.0**	
3. Natural gas[1]	158.8	94.5	253.3	229.4	9.9	492.6	33.3
4. Petroleum	10.4	14.4	24.9	62.2	378.6	465.7	31.5
5. Coal	113.1	125.6	238.7	101.7	0.4	340.8	23.0
6. Wind	23.6	26.2	49.9	19.6	0.1	69.6	4.7
7. Biomass	8.5	1.8	10.3	7.2	18.5	36.0	2.4
8. Hydro	5.1	5.8	10.9	4.2	0.0	15.1	1.0
9. Solar	3.0	2.6	5.6	0.6	0.0	6.2	0.4
10. Geothermal	0.3	0.2	0.5	0.3	0.0	0.8	0.1
11. Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12. Net interstate flow of electricity[2]	--	--	--	--	--	54.0	3.6
13. Net electricity imports	--	--	--	--	--	0.0	0.0

Notes: 1. Natural gas excludes supplemental gaseous fuels to the amount of 4.2 T-BTUs in the individual components. 2. Electricity use is distributed within each energy source and sector. Electricity figures include losses distributed by source and sector.
Source: https://www.eia.gov/state/data.php?sid=CO; US Energy Information Agency (EIA)

As one measure of how much energy is provided by 1 Q-BTU of energy, as we see in Table 1, total energy consumption in Colorado in 2015 was 1,480.3 trillion BTUs, or approximately 1.5 Q-BTUs. This means that, roughly, 1 Q-BTU provided all the energy consumed for all purposes in Colorado over an 8-month period in 2015.

Moving into the specifics of Table 1, we see in rows 1 and 2 how total energy consumption is divided between the sectors of Colorado's economy. As we see, about 43 percent of all consumption is used to operate buildings, both residential and commercial structures. The remaining 57 percent is mainly distributed in roughly equal shares between transportation and industrial uses. About 4 percent of all energy generated in Colorado is exported to other states as electricity.

In rows 3 – 12 of Table 1, we see how the state's energy supply is broken down by energy sources. As we see in row 3, natural gas is the most heavily utilized energy source in Colorado, providing about 33 percent of all the state's energy supply. Natural gas is used mostly in buildings and in industrial activities. Petroleum consumption is nearly equal to that for natural gas, providing 31.5 percent of the state's energy supply. Most of the state's petroleum consumption, not surprisingly, is used for transportation—i.e. 81 percent of total petroleum consumption goes to power cars, buses, trucks, and airplanes in Colorado. Meeting the state's transportation needs in turn accounts for nearly 28 percent of the state's total energy consumption. The next largest source of energy supply in Colorado is coal, which provides nearly 23 percent of the state's total energy supply.

After coal, wind power is the next largest source of energy, but at a much lower 4.7 percent share of total supply. At the same time, wind power has expanded rapidly in Colorado over the past 15 years. As recently as 2003, wind supplied only 0.1 percent of Colorado's total energy supply. We will consider further below this rapid expansion in Colorado's supply in wind power.

Biomass energy, at 36 T-BTUs, was Colorado's next largest energy source, at 2.4 percent of total supply in 2015. As described by the U.S. Environmental Protection Agency, the term "biomass" describes:

> …many different fuel types from such sources as trees, construction, wood and agricultural wastes; food crops; sewer sludge; and manure. Agricultural wastes include materials such as corn husks, rice hulls, peanut shells, grass clippings, and leaves.[11]

Biomass is a renewable energy source. But it produces CO_2 emissions when it is burned. We therefore treat biomass as a "high-emissions" renewable source, as opposed to the "clean renewable" sources, which generate zero emissions in supplying energy. The clean renewables include solar, hydro, and geothermal in addition to wind.[12]

The additional clean renewable sources, hydro, solar and geothermal, account for only 1.5 percent of all of Colorado's energy supply. Nuclear energy does not supply any energy in Colorado.

In combination, natural gas, petroleum and coal provide nearly 88 percent of all energy in Colorado, while wind, hydro, solar and geothermal—the clean renewables—combine to provide 6.2 percent in total. It is clear that expanding overall energy supply in the state from clean renewable sources will be a formidable challenge. Significant initial progress has already been achieved with respect to wind energy, as we have seen. This progress with expanding wind energy supply should therefore serve as a framework for also dramatically advancing clean renewable sources across-the-board in Colorado.

Electricity Supply and Demand

To further clarify the profile of energy consumption in Colorado, we show data in Tables 2 and 3 on the uses and sources of electricity in the state.

Electricity, of course, is unique in that it is an intermediate energy source, relying on several primary sources—primarily coal, natural gas, and wind in Colorado, but also hydro, solar, and biomass—for its generation. It is also unique in that, as Table 2 shows, approximately two-thirds of all energy consumed is lost in the conversion process from the primary energy sources to electricity supply, while only one-third is channeled into energy that is consumed. That is why, as we see in Table 2, electricity production requires 572 T-BTUs of Colorado's total energy consumption, amounting to 39 percent of all energy consumed in the state, while, as an energy source to final consumers in the state's building, transportation and industrial sectors, electricity provides only about 13 percent of the total energy supplied. One evident way to raise energy efficiency, in Colorado and elsewhere, would therefore entail reducing the percentage of energy losses through electricity use.[13]

In terms of electricity demand, we see in Table 3 that the most prevalent use is for the operation of buildings, accounting for about 72 percent of all electricity demand. Industrial processes utilize the remaining 28 percent of all electricity. At present, electricity is not used to a measurable extent in transportation. But the share of electricity demand for transportation would rise sharply if the use of electricity-powered cars were to grow significantly.

Table 3 also shows the primary energy sources used in Colorado to generate electricity. As we see, coal is presently the dominant source of electricity generation in the state, providing, as noted in Table 3, 64 percent of total supply. Natural gas is the next largest source of electricity supply, providing 19 percent of the total. As noted above, the supply of wind power in Colorado has grown rapidly since 2004. As of 2015, it provides the raw material for 13.4 percent of all electricity consumed in Colorado. Among other clean renewable sources, hydro is generating 2.9 percent of Colorado's electricity and solar is providing 0.4 percent. Overall then, clean renewable sources—wind, hydro, and solar—are generating 16.7 percent of the state's electricity as of 2015. Following from these figures, it again becomes clear that transitioning Colorado into providing 100 percent of its electricity supply through clean renewable sources will be a major challenge.

TABLE 2
Colorado Total Electricity Consumption and Energy Losses in Electricity Generation, 2015

Total energy consumed in generating electricity	572.3 T-BTUs (38.7% of state energy consumption)
Electricity consumption as share of overall energy consumption	184.6 T-BTUs (12.5% of state energy consumption)
Energy losses as share of energy consumed in generating electricity	67.7%

Source: US EIA State Energy Data System.

TABLE 3
Colorado Electricity Consumption, 2015
Figures are T-BTUs

	Buildings					
	Residential	Commercial	All Buildings	Industrial	Transportation	TOTAL
Coal	40.1	44.6	84.7	33.4	0.1	118.2 *64.0% of total*
Natural gas	12.0	13.3	25.3	10.0	0.0	35.3 *19.1% of total*
Wind	8.4	9.3	17.7	7.0	0.0	24.7 *13.4% of total*
Hydro	1.8	2.0	3.8	1.5	0.0	5.3 *2.9% of total*
Solar	0.3	0.3	0.6	0.2	0.0	0.8 *0.4% of total*
Bioenergy	0.1	0.1	0.3	0.1	0.0	0.3 *0.2% of total*
Petroleum	0.0	0.0	0.0	0.0	0.0	0.0
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0
Geothermal	0.0	0.0	0.0	0.0	0.0	0.0
Total	62.7	69.6	132.3	52.2	0.1	184.6
Share of total (in %)	34.0%	37.7%	71.7%	28.3%	0.0%	100.0%

Source:https://www.eia.gov/state/data.php?sid=CO; US Energy Information Agency (EIA).

CO_2 Emissions Sources for 2015 and 2030

Table 4 shows how Colorado generated 93.1 million tons of CO_2 as of 2015 (with energy consumption figures now expressed in this table in terms of Q-BTUs). In column 1, we see again that natural gas is the largest source of fossil fuel energy supply in the state, at 0.49 Q-BTUs. Column 2 shows that burning natural gas in Colorado generated 26.1 million tons of CO_2 emissions, which amounts to a rate of 53.3 million tons of CO_2 per Q-BTU of energy, as shown in column 3. Petroleum use in Colorado is modestly lower than natural gas, at 0.47 Q-BTUs. Petroleum is also a somewhat dirtier energy source than natural gas, generating 68.1 tons of CO_2 per Q-BTU of energy. Thus, overall emissions from petroleum in Colorado in 2015 was 32 million tons. Coal is the dirtiest fossil fuel energy source, generating in Colorado 94.4 million tons of CO_2 per Q-BTU of energy. Coal consumption in Colorado, at 0.34 Q-BTUs is about 30 percent lower than the amounts for natural gas and petroleum. But because coal is significantly dirtier than either natural gas or petroleum, it is still the largest source of emissions in the state, generating 32.1 million tons of CO_2, slightly higher than the figure for petroleum. Biomass consumption is much smaller than that from the

TABLE 4
Sources of CO_2 Emissions for Colorado: *2015 Actuals and 2030 Projections*

	2015 Actuals			**2030 Projections**	
	1) 2015 Energy Consumption *(in Q-BTUs)*	**2) 2015 CO_2 Emissions** *(in million metric tons)*	**3) CO_2 Emissions per Q-BTU** *(= column 2/ column 1)*	**2030 Energy Consumption** *(in Q-BTUs)*	**2030 CO_2 Emissions** *(in millions of tons; = column 3 x column 4)*
Natural Gas	0.49	26.1	53.3	0.29	15.5
Petroleum	0.47	32.0	68.1	0.28	19.1
Coal	0.34	32.1	94.4	0.10	9.4
Biomass	0.04	2.9	71.7	0.04	2.9
Totals	**1.3**	**93.1**	--	**0.71**	**46.9**

Notes: Assumption made for the 2030 projected scenario is that oil and natural gas are reduced by 40 percent and coal is reduced by 70 percent.
Source: US EIA, https://www.eia.gov/environment/emissions/state/analysis/.

fossil fuel sources, at 0.04 Q-BTUs as of 2015. But emissions from biomass are nevertheless significant at 2.9 million tons. This is because, as we see in column 3 of Table 4, emissions per Q-BTU of energy are higher than petroleum at 71.7 tons per Q-BTU of energy.

It is clear from these figures that driving down overall emissions in Colorado from 93 to 48 million tons by 2030 will require substantial cuts in the burning of all fossil fuel sources. One illustrative scenario that could achieve the necessary emissions reductions would be for both natural gas and petroleum consumption to decline by about 40 percent as of 2030, while coal consumption declines by 70 percent. Working within this framework, let us assume that natural gas and petroleum will continue to be consumed in Colorado at roughly their current proportions as of 2030. Natural gas will also continue to be consumed primarily to generate electricity while petroleum will continue to be used primarily as a liquid fuel for transportation. Under this assumption, total natural gas consumption will need to fall from 0.49 to 0.29 Q-BTUs by 2030, and petroleum will need to decline from 0.47 to 0.28 Q-BTUs. A 70 percent cut in coal consumption will bring coal consumption down to 0.10 Q-BTUs as of 2030. As we see in Table 4, at these levels of natural gas, petroleum and coal consumption, total CO_2 emissions in Colorado as of 2030 would amount to slightly less than 47 million tons, after assuming that biomass consumptions and emissions would remain constant through 2030. Columns 4 and 5 of Table 4 present the calculations through which we derive this result.

3. DETERMINANTS OF COLORADO'S EMISSIONS LEVELS

In order to develop an effective strategy for achieving Colorado's emissions reduction goals, it will be useful to present a more detailed breakdown of the factors generating the state's current levels of emissions. More specifically, it will be valuable to decompose the emissions per capita ratio for Colorado, as well as other states and the U.S. overall, into three component parts. This yields three ratios, each of which provides a simple measure of one major aspect of the climate change challenge, for Colorado, the rest of the U.S. states and elsewhere. That is, CO_2 emissions per capita can be expressed as follows:

Emissions/population = (GDP/population) x (Q-BTUs/GDP) x (emissions/Q-BTU).

These three ratios provide measures of the following in each state, regional, or country setting:

1. *Level of development*: Measured by GDP per capita (i.e. GDP/population);
2. *Energy intensity*: Measured by Q-BTUs/GDP;
3. *Emissions intensity*: Measured by emissions/Q-BTU.

In Table 5, we show these ratios for Colorado, as well as, for comparison purposes, some other U.S. states. Some significant observations emerge through considering these ratios. The first, most generally, is that there are three distinct ways in which any country,

TABLE 5
Determinants of Per Capita CO_2 Emissions Levels in Various States, 2015
Level of development, energy intensity and emissions intensity
Figures are exclusive of biomass emissions

CO_2 Emissions/population = (GDP/population) x (Q-BTUs/GDP trillion dollars) x (Emissions/Q-BTU)

	Per Capita CO_2 Emissions *(in metric tons)*	Per Capita GDP *(in current US$)*	Energy Intensity Ratio: *Q-BTUs/trillion dollars GDP*	Emissions Intensity Ratio: *CO_2 emissions/Q-BTU*
Colorado	16.6	$58,014	4.7	61.0
United States	16.4	$56,090	5.4	54.0
New York	8.5	$73,577	2.6	45.1
California	9.3	$64,310	3.1	47.3
Texas	22.8	$58,713	8.0	48.5
West Virginia	50.0	$39,453	10.7	118.0
Wyoming	110.5	67,350	13.2	124.6

Source: EIA for emissions figures, U.S. Census for population figures, and Bureau of Economic Analysis for state-level GDP figures. Because of data limitations, the emission figures reported in this table are exclusive of biomass emissions.

state or region can achieve a low figure for per capita emissions. The first is for the relevant economic area—the state, country or region—to operate at a low level of economic activity—i.e. at a low GDP level. Thus, as mentioned above, the Indian economy operates with a very low figure for emissions per capita of 1.6. This is entirely due to the fact that per capita income in India is also still extremely low, at about $1,600.

By contrast, per capita income in Colorado as of 2015 was about $58,000. This is close to the figure for the U.S. overall, at $56,000. Colorado is ranked 12th in per capita income relative to the other U.S. states.

With respect to this average income level, Colorado could, hypothetically, reduce its per capita emissions figure by half as of 2030 by also cutting per capita GDP in half, to around $29,000, while maintaining its existing energy infrastructure fully intact. But this is obviously not a program for expanding well-being while also reducing emissions. To the contrary, the aim of a statewide clean energy project, again, is to achieve the 2030 emissions reduction level to no more than 48 million tons of CO_2 while the state's economy grows at a healthy rate and job opportunities expand.

We therefore need to focus on the two other factors that, as a matter of straightforward accounting, are responsible for Colorado's current level of per capita emissions at present. These are:

1. *Energy efficiency:* The state operates at an energy efficiency level that is about 13 percent below the national average, with an energy intensity ratio of 4.7 Q-BTUs per $1 trillion in GDP versus the U.S. national average of 5.4. But Colorado also utilizes energy far less efficiently than either New York, whose energy intensity ratio is 2.6, or California, with a 3.1 energy intensity ratio. New York's high efficiency level is due primarily to the intensive use in the state of both rail transit and apartment-based residential dwellings. This would be difficult for Colorado to replicate. But California has achieved its high efficiency level largely through high automobile efficiency standards. One of the main policy initiatives in Colorado should therefore be to replicate the California high auto efficiency standard.
2. *Clean-burning energy:* The state's emissions intensity ratio of 61.0 million tons per Q-BTU of energy is 13 percent above the U.S. average of 54.0. The main factor driving up this ratio is Colorado's continued heavy reliance on coal, especially to generate electricity. As such, the program to substitute clean renewable energy for coal for generating electricity is capable of delivering major CO_2 emissions reductions in the state.

In addition to these factors explaining Colorado's level of per capita emissions at present, it is also important to recognize that the state has achieved gains over time in what is termed "absolute decoupling"—i.e. achieving absolute reductions in emissions per capita levels over the recent past even while both average incomes and population in the state have grown. We can see the factors driving the absolute decoupling trend in Table 6. As the table shows, per capita emissions fell between 1997 and 2015 from 19.4 to 16.6 tons, while per capita GDP rose from $49,149 to $58,014. This amounts to an average reduction in emissions per capita of about 0.9 percent per year while average per capita incomes rose by 0.9 percent per year. This absolute decoupling resulted through gains in both energy efficiency and in the share of renewable energy supplied within the state.

TABLE 6
Determinants of Colorado Per Capita CO_2 Emissions, 1997 and 2015
Level of growth, energy intensity and energy mix
Figures are exclusive of biomass emissions

Colorado	Total CO_2 Emissions from Fossil Fuel Consumption *(in million metric tons)*	Population	Per Capita Emissions *(in metric tons)*	GDP *(in 2015 dollars)*	Per Capita GDP *(in 2015 dollars)*	Energy Consump-tion *(in Q-BTUs)*	Energy Intensity Ratio *(Q-BTUs per trillion of 2015 dollars GDP)*	Emissions Intensity Ratio *(CO_2 emissions/ Q-BTU)*
1997	75.4	3.89 million	19.4 tons/capita	$191.7 billion	$49,149	1.13	5.9	66.7
2015	90.3	5.44 million	16.6 tons/capita	$315.6 billion	$58,014	1.48	4.7	61.0

Source: See Table 5.

Thus, in terms of energy efficiency, we see in Table 6 that the state's energy intensity ratio fell from 5.9 to 4.7, a 20.0 percent decline. This is equal to a 1.3 percent average improvement in the state's overall efficiency every year from 1997 – 2015. Similarly, Colorado's emissions intensity ratio fell from 66.7 to 61.0 in CO_2 emissions per Q-BTU of energy consumed in the state. This reduction in the state's emissions intensity ratio was driven mainly by the strong expansion in the supply of wind energy as a source of electricity.

Colorado's absolute decoupling trajectory is certainly a favorable development. At the same time, for the state to reduce emissions by 50 percent by 2030 will require a much more aggressive, absolute, decoupling trend. Specifically, emissions will need to fall by an average of 3.8 percent per year. We assume that this nearly 4 percent per year decline in emissions will occur while average incomes in the state will be rising, at a rate at least equal to the 0.9 percent rate that prevailed from 1997 – 2015.

To accomplish these two ends will therefore require an intensive project to both raise energy efficiency standards and to expand the state's clean renewable energy generating capacity. These are the issues to which we now turn.

4. PROSPECTS FOR ENERGY EFFICIENCY GAINS

As we saw in Table 1, buildings account for about 43 percent of all energy consumption in Colorado, while industry and transportation, respectively, account for a bit less than 30 percent each. Achieving large-scale gains in efficiency will therefore need to address all three areas of statewide energy consumption. The most in-depth recent study of the potential gains available in the U.S. economy through energy efficiency investments is the 2010 report by the National Academy of Sciences (NAS), called *Real Prospects for Energy Efficiency in the United States*. This study provides detailed descriptions of the main research findings in all major areas of energy consumption in the U.S. economy. For our purposes here, we will want to draw on the main conclusions of the study as well as more recent relevant work regarding the gains that can be achieved with buildings and automobiles.[14]

But before considering these details, it is important to emphasize at the outset of this section that, by definition, *energy efficiency investments save money for energy consumers*. This is because energy efficiency investments entail using less energy to achieve the same, or higher, levels of energy service through the adoption of improved technologies and practices. We consider this point further at the end of this section.

Buildings

The NAS study provides extensive evidence showing that energy consumption in both commercial and residential buildings could fall by approximately 30 percent or more below a reference case for 2030 set by the U.S. Department of Energy. These gains in the range of 30 percent are available through a wide range of "low cost" investments in energy efficiency. By "low cost" investments, we refer to the NAS measure of the "cost of conserved energy." Low-cost investments are those in which the costs of conservation are below the market price of energy from the relevant energy source. For buildings, the relevant energy threshold is the price of delivered electricity or natural gas. Thus, in considering the use of electricity in commercial buildings, the NAS finds that in all the main areas of consumption—including lighting, space cooling, office equipment, ventilation, refrigeration, space heating and other uses of the buildings' thermal shells—savings are available relative to the reference case in the range of 35 percent.

The NAS estimated the costs of these savings as being 2.8 cents per kilowatt hour as of the study's 2010 publication date. More recent estimates of the cost of conserved energy are within the same range as the NAS figure. For example, Molina (2014) also estimated the average cost for savings in the electricity sector in all U.S. states as being 2.8 cents per kilowatt hour. Ackerman et al. (2016) estimated the figure to be between 2.4 and 2.6 cents per kilowatt hour. Rosenow and Bayer (2016) estimated weighted average costs of conserved energy as being 2.1 cents in California and 3.2 cents in Vermont.

As of 2016, the average cost of purchasing electricity throughout the U.S. was 10.4 cents per kilowatt hour, while the figure for Colorado specifically was 9.8 cents.[15] But these average electricity prices are nearly four times higher than the costs of achieving energy savings through energy efficiency investments in buildings. The NAS estimates the gross upfront costs of achieving these energy savings at about $28 billion per Q-BTU of savings. These are the costs of the initial investments in energy efficiency measures—i.e. the investment costs that will be necessary in order to generate the average cost savings of 2.8 cents per kilowatt hour over time. These upfront investment costs are important for our estimates of the costs of advancing the clean energy investment program in Colorado, since these will be the costs that must be borne initially in order to achieve energy savings over time. The more recent studies do not provide a separate figure for these upfront investment costs.

The NAS does also analyze the additional potential savings through the use of newer technologies. The study notes that:

> The conservation supply curves…do not take into account a number of newer technologies and whole-building design approaches. These technologies and approaches add to the energy-savings potential identified in the conservation supply curves. Thus, the panel judges that these supply curves represent the lower estimate of energy-saving potential (2010, p. 80).

The NAS study highlights seven areas in which advanced technologies are "the most promising for further improving the energy efficiency of buildings." These include solid state lighting, advanced cooling systems, lower energy consumption in home electronics, reduced consumption in servers and data centers, advanced window technology, and better construction methods for both home and commercial-buildings.

In advancing beyond the lowest cost opportunities for efficiency gains, we therefore have to ask whether we can achieve these further gains at the same average up-front investment cost of $28 billion per Q-BTU level. In fact, there are valid reasons to assume that the up-front costs could actually come down as energy efficiency investments are advanced at a large scale in Colorado. These include the following considerations:

- **The average cost of gaining a given amount of efficiency in Colorado buildings remains well within the market price of electricit**y. Even if we allow that the average up-front costs of achieving efficiency gains in Colorado buildings are, at present, significantly higher than the 2010 average figure cited by the NAS study of $28 billion per Q-BTU, it remains the case that the lifetime cost savings at around 2.8 cents per kilowatt hour remain at nearly one-fourth the current average price of electricity in the state of 9.8 cents.
- **The returns on investment in building efficiency are high, but the market has been thwarted because of underdeveloped market and financing infrastructures.** The systems of financing and risk-sharing that enable businesses and homeowners to capture the benefits of high returns without having to carry the full burden of initial financial risk remains immature. Developments in these areas should come rapidly once the initial set of business models, market structures, and financial innovations take hold.
- **The absolute level of efficiency gains attainable in buildings is very high, as evidenced by the growing number of recently constructed carbon neutral buildings.** Of course, the costs of getting buildings to the point of carbon neutrality are also high at this point, meaning that before reaching carbon neutrality, we begin to approach a point of diminishing returns on investments—i.e. rising costs needed to achieve a given gain in efficiency. At the same time, as the market for efficiency investments expands, the costs of the best upcoming technologies begin to fall. As the NAS study notes, this

has certainly been true with LED lighting. Similar opportunities are emerging in the other six areas mentioned above—cooling, home electronics, servers and data centers, windows, and construction of both homes and commercial buildings.

Despite all of these factors suggesting falling costs as the level of investment expands, there have also been many instances of over-optimism in assessing the prospects for raising efficiency standards in buildings. Thus, while the engineering evidence consistently finds, for example, that investments in building efficiencies will have rapid payoffs, it is still necessary to obtain financing for projects to proceed. Another issue is the hassle factor involved in undertaking such projects. Considering home-weatherization efficiency programs specifically, Allcott and Greenstone write that "Weatherization takes time, and for most people it is not highly enjoyable: the process requires one or sometimes two home energy audits, a contractor appointment to carry out the work and sometimes additional follow-up visits and paperwork," (2012, p. 16). Such matters can create serious difficulties for individual homeowners in particular.

The implication that follows is not that the engineering level of analysis is wrong, but rather that both public policy and private initiatives are needed to tackle the financial issues and the hassle factors that are involved in building efficiency projects. Given these considerations, and the fact that we are assuming that the gains in efficiency will need to occur rapidly between 2021 – 2030, it will be prudent to assume that costs will be within the range, or even somewhat higher than the average estimated by the NAS.

For our purposes, we therefore assume the costs of achieving gains in building efficiency to be in the range of $35 billion per Q-BTU, i.e. 25 percent higher than the NAS estimate. Throughout the study, we will deliberately choose to overstate rather than understate the costs of reducing emissions through investments in energy efficiency and clean renewable energy sources.

Transportation

For the purposes of our discussion, we focus here on the case for achieving gains in automobile efficiency as of 2030, since it is the state's dominant transportation mode. For example, about 84 percent of all workers in the state commute to their jobs with cars, trucks, or vans.[16]

The starting point for considering efficiency gains in auto transit is the agreement reached in 2011 between the Obama Administration and 13 major auto manufacturers to raise the miles per gallon (mpg) standard for new U.S. cars to 54.5 mpg as of 2025. Pollin et al. analyzed the impact of this measure in detail in the 2014 study *Green Growth*. The analysis in *Green Growth* also drew largely on the 2010 NAS study on efficiency prospects for the overall U.S. economy. The main finding on this issue in *Green Growth* was that achieving a 30 percent reduction in emissions from the U.S. auto fleet by 2030 is attainable and at a cost that will be comparable to the costs for achieving efficiency gains in buildings.

More specifically, Pollin et al. found that raising the 2025 mandated efficiency level of new cars from its previous level of 35.9 mpg to 54.5 mpg will mean that the average car on the road as of 2030 will operate at an efficiency level of 42.4 mpg. This efficiency level is roughly 15 percent lower than the average gasoline-powered Toyota Prius sold in U.S. markets in 2016, which are at approximately a 50 mpg level of efficiency.[17]

This average figure for 2030 will, of course, include not only cars produced in 2025 and thereafter—all of which will be at least at the 54.5 mpg level by mandate—but earlier model cars as well that were not subject to this mandate and thereby operate much less efficiently. We also estimated that, had the U.S. continued to maintain the earlier mandate for 2025 of 35.9 mpg, the overall fleet as of 2030 would be at an average efficiency level of 28.7 mpg. The average efficiency gain from 28.7 to 42.4 mpg is an improvement of roughly 48 percent. The NAS estimated the average cost increase for achieving this higher level of efficiency at about 25 percent above the retail price of standard gasoline engine cars. The average car owner will then also save about $1,000 per year in gasoline purchases.

In August 2018, the Trump Administration announced that it was "freezing" the Obama fuel efficiency standards. Administration officials have said that "freezing" these standards does not necessarily mean that they are revoking them, but rather that they are, at this point, putting the standards up for review.[18] In any case, some states are already operating with high fuel efficiency standards. This includes Colorado. Indeed, following soon after the Trump Administration's August 2018 announcement, Colorado's state air-quality control commissioners voted unanimously in favor of developing a rule proposed by health department staffers to require new cars and light trucks to meet California's miles-per-gallon standards for tailpipe pollution.[19] The California standard, in turn, is consistent with those set by the Obama administration. In addition, in January 2019, Governor Polis announced as one of his first actions in office an executive order to promote electric vehicles in Colorado. More specifically, his order directs the state to create a team across state agencies to develop the infrastructure needed to support more electric vehicles and invest money it won in a settlement with Volkswagen into electrifying the state's vehicle fleet. It also asks the state's transportation department to create an electric vehicle policy. This zero-emissions vehicle program would be in addition to the low-emissions standards adopted in 2018.[20] It is possible that the Trump Administration will attempt to challenge the authority of states to maintain standards above those set by the federal government. But any such efforts are likely to entail a protracted legal process. Colorado can therefore proceed, along with California and other states, in maintaining and defending its efficiency standard against any forthcoming Trump Administration efforts to weaken them.

Colorado should also commit to expanding the availability of public transportation throughout the state. This will also help support transportation efficiency standards and to make low-cost transportation options widely accessible. As we discuss further below, we assume that state-level investments to expand public transportation will be comparable to the financial incentives provided to raise the state's auto efficiency standards. We also conclude that the costs of achieving efficiency gains throughout the state's various transportation sectors are likely to be in the same range as those for building efficiency investments, i.e. at about $35 billion per Q-BTU of energy savings as a high-end approximation.

Industry

Achieving efficiency gains in Colorado's industrial sector will primarily entail changes in production methods. The other way that Colorado could achieve significant gains in industrial efficiency would be through shifting the composition of Colorado's industrial structure in favor of low energy intensity industries, such as information technology and services, and away from high energy intensity industries such as manufacturing. But we are assuming that, at least through 2030, Colorado's existing industrial composition will remain roughly intact. The major additional energy-efficiency gains in industrial production should therefore result from two types of changes in production methods:

1. **Crosscutting investments.** These are investments that are applicable in a wide range of industrial settings. The most important example is combined heat and power, or CHP, systems. CHP systems in industry are capable of dramatically improving energy efficiency through using waste process heat to generate a productive low-cost energy source.
2. **Industry-specific investments.** This includes a wide range of specific energy-saving measures and process improvements, especially in the high-energy intensity activities. In Colorado, these would include the cement manufacturing industry, iron and steel mills, and glass container manufacturing. For both cement manufacturing and iron and steel production, the National Academy of Sciences study describes a range of areas in which major efficiency gains are available utilizing only proven technologies and processes. Overall, the NAS study found that, utilizing only existing technologies, efficiency gains in industry in the range of 25 percent are attainable at relatively low costs.[21]

Overall, the NAS study finds that the upfront costs for achieving efficiency gains in industry should be comparable to those in buildings and transportation, i.e. within the range of $30 billion per Q-BTU of energy savings. For the purposes of our discussion, we will assume here as well a higher average cost figure of $35 billion per Q-BTU of energy savings.

Cost Savings and Rebound Effects

We began this section of the study by noting that, by definition, energy efficiency investments will save money for consumers. The basics are straightforward. As of 2016, average household energy consumption in Colorado was about $4,600, equal to 5 percent of average household income of about $88,000. We estimate that energy efficiency investments in Colorado between 2021 – 2030 can generate efficiency gains of 36 percent. This would mean that, by 2030, average household energy costs could decline to $2,900, a $1,700 savings. It is true that, to realize these savings, households would need to invest in purchasing a more fuel efficient vehicle, such as a hybrid car as opposed to a gasoline car, and to raise the efficiency standards in their residences. We can assume roughly that to pay off those investments with interest would absorb the $1,700 annual energy savings for an initial 5-year period. Afterwards, the household would be spending $1,700 less to purchase a given level of energy services—e.g. driving a given number of miles per year in one's car; or heating, cooling and lighting one's house by a given amount.

In recognizing this, it is also important to consider that raising energy-efficiency levels in Colorado will generate "rebound effects." Rebound effects refer to the increases in energy consumption that will result from the lower energy costs achieved by the efficiency gains. However, such rebound effects are likely to be modest within the context of a broader project in Colorado focused on reducing CO_2 emissions and stabilizing the climate. Among other factors, energy-consumption levels in the U.S. are close to saturation point in the use of home appliances and lighting—e.g., Colorado residents are not likely to clean dishes more frequently because they have a more efficient dishwasher. The evidence shows that consumers in the U.S. and other advanced economies are more likely to heat and cool their homes and drive their cars when they have access to more efficient equipment. But the evidence shows that these increased energy consumption levels are usually modest. This is why, for example, at present, Germany operates at an average efficiency level that is roughly 50 percent higher than that of the U.S. while maintaining a roughly comparable average living standard. There is no evidence that large rebound effects have emerged as a result of these higher efficiency standards in Germany.

In addition, the impact of even any modest rebound effects that might occur in Colorado will be mitigated to the extent that energy efficiency investments are accompanied by an expansion in the supply of clean renewable energy. That is, energy consumption can rise through rebound effects without causing an increase in emissions as long as the increased consumption levels are provided by clean renewable energy sources. We therefore turn now to considering the prospects for expanding the supply of clean renewable energy in Colorado.

5. PROSPECTS FOR CLEAN RENEWABLES

What Is Clean Energy?

Assuming that, through aggressive energy efficiency investments, Colorado succeeds in bringing down overall statewide energy consumption dramatically, it will still be necessary to greatly expand the state's reliance on clean energy sources in order for total CO_2 emissions to fall by 50 percent, to no more than 48 million tons, by 2030. We saw in Table 4 that one path for bringing down CO_2 emissions to no more than 48 million tons would be to cut consumption of natural gas and petroleum by 40 percent each by 2030, while coal consumption falls by 70 percent. The remaining demand for energy will then need to be filled by clean energy sources—i.e. energy sources for which CO_2 emissions are zero or near-zero. What are these clean energy sources?

Solar, wind and geothermal power will all need to be major energy sources moving forward. They all supply energy with zero emissions. There are, of course, issues that will need to be addressed in dramatically expanding the use of these energy sources. Especially with respect to wind and solar—which have much greater potential for expansion than geothermal—these include intermittency, transmission, and storage capacity, as well as the environmental impacts of building out and siting the wind turbines and solar panels. None of these obstacles are insurmountable.[22]

The problems are more significant with respect to the other renewable sources, i.e. bioenergy and hydro. Corn ethanol, for example, is currently the most heavily consumed biofuel in the United States. Depending on the refining methods used, the emissions produced by corn ethanol can be comparable to burning petroleum. This is also true for biomass energy when—as is mostly the case—the energy sources and production practices are not carefully managed to minimize carbon emissions. Biomass and biofuels can also be a carbon-neutral source of energy if the raw materials are wastes and nonfood crops and if these raw materials are refined through the use of renewable sources of process energy. But these techniques for producing bioenergy are utilized only minimally at present in the United States.

As we reported in Table 1, hydro power is a modest source of energy supply at present in Colorado. But it is also neither likely nor desirable that large-scale hydro projects will expand significantly beyond their current capacity in Colorado or the U.S. more generally. One factor here is that the most favorable sites for constructing large-scale dams are already built out and operating at capacity. Beyond this existing capacity, there are likely to be serious environmental issues connected with additional large-scale dam construction in terms of disrupting existing communities and ecosystems. Prospects are more favorable for expanding electricity-generating capacity from small-scale hydro sites. The Colorado Energy Office reports that the state has substantial untapped capacity for hydro development within the state's existing agricultural-related infrastructure. They also report that the state has more than 30 potential small-scale hydro power sites at reclamation facilities with the potential to produce more than 105,000 MWh per year (equal to 0.3 T-BTUs).[23] These hydro sources could therefore be significant supplements to expanding the capacity from solar, wind and geothermal energy.

What are the possibilities for dramatically lowering emissions in Colorado through continuing to rely on non-renewable energy sources? As we have seen, there are large differences in the emissions levels resulting through burning oil, coal, and natural gas respectively, with natural gas generating about 40 percent fewer emissions for a given amount of energy produced than coal and 15 percent less than oil. It is therefore widely argued that natural gas can be a "bridge fuel" to a clean energy future, through switching from coal to natural gas to produce electricity. But this approach is not likely to be viable. Even within the context of the Obama-era clean energy regulatory framework, an implausibly large 100 percent fuel switch to natural gas would result, by itself, in lowering overall emissions by only about 4 percent.[24] This scenario, moreover, does not take account of the leakage of methane gas into the atmosphere that results through extracting natural gas through fracking. Recent research finds that when more than about 5 percent of the gas extracted leaks into the atmosphere through fracking, the impact eliminates any environmental benefit from burning natural gas relative to coal. Various studies have reported a wide range of estimates as to what leakage rates have actually been in the United States, as fracking operations have grown rapidly. A recent survey paper puts that range as between 0.18 and 11.7 percent for different specific sites in North Dakota, Utah, Colorado, Louisiana, Texas, Arkansas, and Pennsylvania. It would be reasonable to assume that if fracking expands on a large scale, in Colorado or elsewhere, it is likely that leakage rates will fall closer to the higher-end figures of 12 percent, at least until serious controls could be established. This then would diminish, if not eliminate altogether, any emission-reduction benefits from a coal-to-natural gas fuel switch.[25]

Some analysts consider "clean energy" to include nuclear power and carbon capture and sequestration (CCS) technologies. Nuclear power does generate electricity without producing CO_2 emissions. But it also creates major environmental and public safety concerns, which have only intensified since the March 2011 meltdown at the Fukushima Daiichi power plant in Japan. At present, Colorado does not rely on nuclear energy at all. There does not appear to be support for introducing nuclear into Colorado's energy mix as a means of achieving the state's emission reduction targets.

Under the most widely understood carbon capture technology, the emitted carbon is captured, then transported usually through pipelines, to subsurface geological formations, where it would be stored permanently. Such technologies have yet not been proven at a commercial scale, despite decades of research and development initiatives. Moreover, the dangers of carbon leakages from flawed transportation and storage systems will only increase to the extent that the technologies are commercialized and operating under an incentive structure in which maintaining safety standards will reduce profits.

Significant, if still preliminary, advances have been achieved recently in terms of lowering costs and perhaps also addressing the problem of long-term carbon storage. Thus, a recent study reported that a new technique has lowered the price of carbon removal from $600 to $100 per ton of carbon. Moreover, this technology is capable of converting the gaseous carbon into a liquid, with the liquid carbon then becoming available as a synthetic liquid fuel source for aviation and other transportation purposes. However, to date, even one of the main developers of the technology, David Keith, acknowledges that their work is still in its early phases and that there are "a hundred ways in which we can fail."[26]

In terms of developments in Colorado specifically, Xcel has said that it does plan to rely, at least in part, on carbon capture technology in achieving its emission reduction goals for 2030 and 2050. At the same time, Xcel's President and CEO Ben Fowke has acknowledged that carbon capture technology "has a long way to go." As such, for Xcel to move forward in meeting its emission reduction targets, clean renewables—primarily wind and solar power—will clearly have to be at the center of the project. These are technologies that are well understood, already operating at a large-scale, and, without question, safe. Moreover, as we will examine further below, costs have come down dramatically in recent years. As Fowke recognizes, "wind and solar are now 70 to 80 percent less expensive than they were just a decade ago. Do you think the technology will be there by 2050? I think so."[27] We therefore focus our analysis on the prospects of dramatically expanding Colorado's energy supply from clean renewable sources, primarily wind and solar power.

At present, as shown in Table 1, wind power is providing 4.7 percent of the total energy supply in Colorado. Hydro is providing another 1.0 percent. Solar is at 0.4 percent and geothermal at 0.1 percent. What would be the costs associated with this expansion of clean renewable energy supply? We need to consider any such costs from two distinct perspectives. The first is what the cost increases would likely be for energy consumers, as they substitute wind, solar, or geothermal energy for the existing fossil fuel energy sources. The second is the costs of building the new generating capacity for wind, solar, and geothermal power.

Costs to Consumers

To consider costs to consumers, we refer to the U.S. Energy Department's calculations as the "levelized costs" of supplying electricity through alternative energy sources. The Energy Information Agency (EIA), an office within the Energy Department, describes levelized costs as representing:

> The per-kilowatt hour cost (in real dollars) of building and operating a generating plant over the assumed financial life and duty cycle. Key inputs to calculating levelized costs include overnight capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs and an assumed utilization rate for each plant type.[28]

In short, levelized costs takes account of *all costs* of producing and delivering a kilowatt of electricity to a final consumer. The cost calculations begin with the upfront capital expenditures needed to build the generating capacity, continue through to the transmission and delivery of electricity, and include the costs of energy that is lost during the electricity-generation process.

In Table 7, we present details on average levelized cost figures for four major clean renewable energy sources—hydro, onshore wind, geothermal and photovoltaic solar energy. The figures come directly from the EIA. In panel 7A, we present these average cost figures in the United States, measured in dollars per megawatt hours of electricity. In panel 7B, we present the same data, but expressed now in terms of billions of dollars per Q-BTU of electricity supplied. We show figures on total average levelized costs for these four clean renewable energy sources, as well as the six components comprising these overall average costs—i.e. capital costs, fixed operations and maintenance, variable operations and maintenance, transmission, capacity utilization rates, and tax credits, as they apply. Focusing now on overall costs in dollars per megawatt hour, we see that, for operations entering service in 2022, the average costs per megawatt hour are $41.60 for geothermal, $48.00 for onshore wind, $49.90 for solar, and $61.70 for hydro.

TABLE 7A

Estimated Average Levelized Costs of Electricity from Clean Renewable Energy Sources

Plants entering service in 2022, simple averages for regional values

In dollars per megawatt hour

	Hydro	Onshore Wind	Geothermal	Solar PV
Levelized capital costs	$48.2	$43.1	$30.1	$51.2
Levelized fixed operations and maintenance	$9.8	$13.4	$13.2	$8.7
Levelized variable operations and maintenance	$1.8	$0.0	$0.0	$0.0
Levelized transmission investment	$1.9	$2.5	$1.3	$3.3
Capacity factor	64.0%	41.0%	90.0%	29.0%
Total system LCOE	$61.7	$59.1	$44.6	$63.2
Levelized tax credit	--	-$11.1	-$3.0	-$13.3
Total LCOE, including tax credit	$61.7	$48.0	$41.6	$49.9

Source: US EIA, "Levelized Costs and Levelized Avoided Cost of New Generation Resources," in the Annual Energy Outlook 2018.

TABLE 7B

Estimated Average Levelized Costs of Electricity from Clean Renewable Energy Sources

Plants entering service in 2022, simple averages for regional values

In billions of dollars per Q-BTU

	Hydro	Onshore Wind	Geothermal	Solar PV
Levelized capital costs	$14.1 billion	$12.6 billion	$8.8 billion	$15.0 billion
Levelized fixed operations and maintenance	$2.9 billion	$3.9 billion	$3.9 billion	$2.5 billion
Levelized variable operations and maintenance	$0.5 billion	0.0	0.0	0.0
Levelized transmission investment	$0.6 billion	$0.7 billion	$0.4 billion	$1.0 billion
Capacity factor	64.0 %	41.0%	90.0%	29.0%
Total system LCOE	$18.1 billion	$17.3 billion	$13.1 billion	$18.5 billion
Levelized tax credit	--	-$3.3 billion	-$0.9 billion	-$3.9 billion
Total LCOE, including tax credit	$18.1 billion	$14.0 billion	$12.2 billion	$14.6 billion

Notes: Cost conversion factor: for converting $1 per MwH to $1 billion per Q-BTU, we divide by 3.412

Source: US EIA: "Levelized Costs and Levelized Avoided Cost of New Generation Resources," in the Annual Energy Outlook 2018.

In Table 8, we now show, for comparison purposes, total levelized cost figures for nonrenewable sources of electricity, including: 1) coal, with existing carbon capture and sequestration (CCS) technology; 2) natural gas utilizing conventional technology; 3) natural gas with CCS; and 4) nuclear energy. CCS encompasses a number of specific technologies that capture CO_2 from point sources, such as power plants and other industrial facilities.

Column 1 of Table 8 reports the overall average levelized cost figures for these non-renewable sources. These figures range between $49.00 using conventional natural gas, $74.90

TABLE 8
Average Levelized Costs of Electricity Generated with Clean Renewables versus Fossil Fuels and Nuclear Energy

	Average Total System Levelized Costs		Average Costs Relative to Onshore Wind (in percentage)	Average Costs Relative to Solar PV (in percentage)	Average Costs Relative to Geothermal (in percentage)
	(In USD per megawatt hours)	(In billions of USD per Q-BTUs)			
Coal: *Advanced with carbon capture and sequestration*	$130.10	$38.1 billion	+171.0%	+160.7%	+212.7%
Natural Gas:					
Conventional	$49.00	$14.4 billion	+2.1%	-1.8%	+17.8%
With carbon capture and sequestration	$74.90	$22.0 billion	+56.0%	+50.1%	+80.0%
Nuclear	$92.60	$27.1 billion	+92.9%	+85.6%	+122.6%

Notes: (a) Cost conversion factor: for converting $1 per MwH to $1 billion per Q-BTU, we divide by 3.412. (b) Average costs relative to renewable sources reflect the percentage change in the conventional source of energy relative to the source of renewable energy.

Source: United States Energy Information Agency, "Levelized Costs and Levelized Avoided Cost of New Generation Resources," Annual Energy Outlook, 2018.

with natural gas and CCS technology, $92.60 with nuclear energy, and $130.10 with coal produced with CCS technology.

In columns 3 – 5 of Table 8, we then show the cost figures for these four non-renewable energy sources relative to onshore wind, solar PV and geothermal energy. As we see, advanced coal with CCS technology ranges between roughly 161 – 223 percent more than the three clean renewable sources. Natural gas produced conventionally is about 1.8 percent less than solar PV, but 2 percent more than onshore wind and 18 percent more than geothermal. When natural gas is produced using CCS technology, it becomes 50 percent more expensive than solar PV, 56 percent more than wind, and 80 percent more than geothermal. Finally, nuclear energy ranges between 86 percent more than solar PV, 93 percent more than onshore wind, and 123 percent more than geothermal energy.

We emphasize that these cost figures from the EIA are simple averages. They do not show differences in costs due to regional or seasonally-specific factors In particular, solar energy costs will vary significantly by region and season. Moreover, both wind and solar energy are intermittent sources—i.e. they only generate energy, respectively, when the sun is shining or the wind is blowing. Of course, these factors will need to be fully accounted for when clean renewable energy systems are designed to provide a major share of an economy's overall energy load.

Keeping all such considerations in mind, we can still roughly conclude from these figures that, for the most part, clean renewable energy sources are rapidly emerging into a position at which they can produce electricity at comparable or lower costs than non-renewable sources. As such, assuming that wind, solar and geothermal energy production can be scaled up to meet demand in Colorado by 2030, then the costs to the state's consumers of purchasing this energy should not be significantly different from what these consumers would have paid for non-renewable energy. Indeed, overall, the costs to consumers of purchasing electricity from clean renewable sources, including hydro as well as wind, solar, and geothermal power, are likely to be *lower* than what they would be from either coal or natural gas with CCS technology or nuclear power.[29]

Costs of Expanding Renewable Capacity

As we can see in Table 7, by far the largest share of overall costs in generating electricity from renewable sources are capital costs—i.e. the costs of producing new productive equipment, as opposed to the costs of operating that productive equipment once it has been built and is generating energy. The figures in Table 7 show that, once we account for the federal tax credit for renewable energy investments, the levelized capital costs amount to 90 percent of overall costs for onshore wind, 75 percent for geothermal, and 103 percent for solar PV.

Still, these figures are average levelized costs of producing a megawatt or Q-BTU of electricity once the necessary capital equipment is installed and operating. But it is also important to estimate these capital costs as a lump sum—i.e. how much investors need to spend *upfront* to put this capital equipment into place and in running order.

We produce estimates of these lump sum capital costs in Table 9. Specifically, these figures represent the present values of total lump-sum capital expenditures needed to produce one Q-BTU of electricity from onshore wind, solar PV, and geothermal energy.[30] As we see, the average lump-sum costs range from $112 billion per Q-BTU for geothermal, $160 billion for onshore wind, and $190 billion for solar.

If we assume that, roughly speaking, new clean renewable productive capacity will consist of 45 percent respectively from wind and solar PV technologies, and 10 percent from geothermal energy, this would place the average costs of producing one Q-BTU of overall renewable energy equipment at about $169 billion, which we can round up to $170 billion per Q-BTU of clean renewable capacity. This $170 billion figure can therefore serve as a benchmark for estimating the average costs of expanding the supply of clean renewable energy in Colorado. At the same time, as with our cost estimate for raising the state's energy efficiency standards, we will want to err, if anything, on the side of overestimating, rather than underestimating, the costs of expanding clean renewable energy in Colorado. Moreover, with the expansion of the state's clean energy supply proceeding rapidly over 2021 – 2030, the average costs are likely to rise as production bottlenecks emerge. We therefore will assume that the average costs of expanding the clean energy supply in Colorado will be $200 billion per Q-BTU, i.e. about 18 percent higher than the $170 billion average figure we have derived from the U.S. Energy Department's levelized costs data.[31]

TABLE 9
Capital Expenditure Costs for Building Renewable Electricity Productive Equipment
Present values of total lump-sum capital costs per Q-BTU of electricity

Wind	$160 billion
Solar PV	$190 billion
Geothermal	$112 billion
Average costs *assuming investments are 45% wind, 45% solar, and 10% geothermal*	**$169 billion**

Sources: Table 7 for levelized capital costs per Q-BTU for alternative energy sources. See Pollin et al. (2014) pp. 136 – 37 for methodology in converting levelized costs per Q-BTU into lump-sum capital costs.

6. CLEAN ENERGY INVESTMENT LEVELS AND EMISSIONS REDUCTIONS

The 10-year clean energy investment initiative being proposed in this study is designed to achieve, again, two interrelated fundamental goals. The first is to bring total CO_2 emissions in Colorado down by 50 percent, to under 48 million tons by 2030, from its 2005 level of 95.2 million tons. The second is to advance this climate stabilization program while the Colorado state economy grows at an adequate rate between now and 2030, so that existing jobs are protected, job opportunities expand, and average well-being rises throughout the state. In this section of the study, we describe the clean energy investment levels that will be needed to bring together these two goals.

To explore the prospects for achieving the 2030 emissions reduction goal within the context of a growing Colorado economy, we must, unavoidably, work with some assumptions as to the state's real economic growth trajectory between 2021 - 2030. Thus, we assume that the Colorado economy will grow in real (i.e. inflation-adjusted) terms between now and 2030 at an average rate of 2.4 percent per year. This is the average annual growth rate that Colorado experienced over the most recent 20-year period, i.e. 1998 - 2017. We do not have any basis for assuming that this growth trajectory should change significantly through 2030. If anything, we might assume that the growth trajectory would be higher between 2021 – 2030. The 20-year period 1998 – 2017 includes the 2007 – 2009 Great Recession, the most severe U.S. economic downturn since the 1930s Great Depression. It is not likely that the U.S. economy, or the Colorado economy more specifically, is likely to experience another downturn of that severity over 2021-2030.

In Table 10, we first report on Colorado's real GDP as of 2015 and the projected level in 2030, assuming the economy's average real growth rate is maintained at 2.4 percent through 2030. We see that, under this growth assumption, Colorado's real GDP will be approximately $454 billion in 2030, growing from the 2015 figure of $318 billion. Within this full time period, we are most interested in the years 2021 – 2030, over which Colorado will be achieving its 50 percent emissions reduction relative to the 2005 level. Assuming again a 2.4 percent average annual growth rate, then 2021 GDP will be $367 billion and 2030 GDP will be $454 billion. The midpoint figure over the 2021 – 2030 decade will be effectively January 1, 2026. Colorado's real GDP will be at $411 billion at that midpoint figure.

TABLE 10
Colorado GDP Levels, 2015 Actual and Projections for 2021, 2026, and 2030

2015 GDP	$318 billion
Projected average growth rate through 2030	2.4%
Projected 2021 GDP	$367 billion
Projected 2030 GDP	$454 billion
Projected midpoint GDP between 2021 - 2030 (2026)	$411 billion

Source: BEA and authors' calculations.

Within this framework, we can then project an energy and CO_2 emissions profile for Colorado for 2030. We consider two distinct scenarios. For the first 2030 scenario, we assume that the state's energy infrastructure as of 2015 remains basically intact through 2030. We see the results of this scenario in Table 11. Specifically, in column 1 of Table 11, we show the actual breakdown of energy consumption and emissions as of 2015. In column 2, we then present projected figures, assuming Colorado's economy grows at an average annual rate of 2.4 percent through 2030 and the state's energy infrastructure remains basically intact. We term this the "steady state" energy infrastructure trajectory for Colorado. In this scenario, all energy sources with the exception of hydro grow at exactly the state's overall 2.4 percent annual GDP growth rate. We are assuming hydro remains at a fixed level of production, and that the increase in overall energy supply commensurate with a 2.4 percent average annual growth rate is provided through wind power.

TABLE 11
Colorado Energy Consumption and Emissions: 2015 Actuals and Alternative 2030 Projections

	1) 2015 Actuals	2) 2030 with approximate Steady State Energy Infrastructure *(= categories grow at 2.4% average annual rate)*	3) 2030 through Clean Energy Investment Program
1) Real GDP	\$318	\$454	\$454
2) Energy intensity ratio *(Q-BTUs / \$1 trillion of GDP)*	4.7	4.7	3.0 *(through energy efficiency investments)*
3) Total energy consumption (Q-BTUs)	1.48	2.11	1.35
Energy mix			
Non-renewables and bioenergy *(Q-BTUs)*	1.34	1.91	0.71
4) Natural gas	0.493	0.703	0.29
5) Petroleum	0.466	0.664	0.28
6) Coal	0.341	0.487	0.10
7) Bioenergy	0.036	0.051	0.036
8) Nuclear	0.000	0	0
Clean renewables *(Q-BTUs)*	0.092	0.185	0.68
9) Wind	0.07	0.16	0.31
10) Hydro	0.015	0.015	0.015
11) Solar and geothermal	0.007	0.01	0.37
Emissions *(inclusive of bioenergy emissions)*			
12) Total CO2 emissions *(million metric tons)*	93.1	132.7	46.9
13) Emissions Intensity Ratio *(CO2 emissions per Q-BTUs)*	62.9	62.9	34.7
14) CO2 emissions per capita *(with 2015 actual population = 5.4 million and projected 2030 population = 6.7 million)*	17.1	19.8	7.0

Sources: Tables 1, 4 and 5; authors' calculations.

Thus, we see in row 2, columns 1 and 2, that Colorado's energy intensity ratio remains constant between 2015 and 2030, at 4.7 Q-BTUs per $1 trillion in GDP. The state's emissions intensity ratio also remains constant, as shown in row 13, columns 1 and 2, at 62.9 million tons in CO_2 emissions per Q-BTU of energy. We see the impact of this 2.4 percent average economic growth pattern on statewide CO_2 emissions in row 12 of Table 11. That is, total CO_2 emissions increases from 93.1 to 132.7 million tons, an increase of 43 percent. This overall increase in emissions is also equal to an average annual 2.4 percent rate of increase over 2015 – 2030.

In column 3 of Table 11, we then show the impact on the energy mix and emissions levels of a clean energy program focused on bringing down CO_2 emissions to 48 million tons by 2030. The first component of this program is energy efficiency investments. As noted in section 4, we assume energy efficiency investments will span across the building, transportation and industrial sectors of the Colorado economy. Following from that prior discussion, we assume that, by 2030, Colorado is capable of reducing the economy's energy intensity ratio from the 2015 level of 4.7 to 3.0 Q-BTUs per $1 trillion of GDP. This would be a 36 percent gain in overall energy efficiency in the state. It would bring Colorado to an efficiency level approximately equal to the level at which California operated in 2015. Correspondingly, total energy consumption at the 2030 GDP level, would fall from 2.11 to 1.35 Q-BTUs, or a change of 0.75 Q-BTUs.

Following our discussion in section 4, we assume, as a high-end figure, that the average costs of achieving 1 Q-BTU of efficiency gains will be $35 billion. As such, the level of investment needed to reduce consumption by 0.75 Q-BTUs will be $26.2 billion (=$35 billion x 0.75). Spread out over 10 years, this level of efficiency investments will average $2.6 billion per year.

We then need to consider the energy mix that will be necessary to allow for 1.35 Q-BTUs of consumption while still maintaining emissions at no more than 48 million tons. As we have seen in Table 4, in order to bring overall CO_2 emissions in Colorado down to 48 million tons by 2030, one viable path would be for the consumption of natural gas and petroleum to fall by 40 percent respectively relative to 2015 levels, while coal consumption declines by 70 percent. As we see in column 3 of Table 11, this implies that natural gas consumption is at 0.29 Q-BTUs as of 2030, petroleum is at 0.28 Q-BTUs and coal is at 0.10. We also assume that high-emissions bioenergy will not increase above its 2015 level, given that it generates emissions at roughly the level of coal.[32] Colorado also continues to operate without any reliance on nuclear energy in this scenario. In combination then, the non-renewable energy sources along with high-emissions bioenergy would provide Colorado with a total of 0.71 Q-BTUs of energy in 2030.

This then entails that 0.68 Q-BTUs of energy will need to be provided by clean renewable sources in order for Colorado's overall energy consumption to reach 1.35 Q-BTUs in 2030. As noted above, we assume that the supply of hydro power remains constant through 2030, at 0.015 Q-BTUs.

As of 2015, wind, solar, hydro and geothermal energy combined to supply 0.092 Q-BTUs to Colorado. Effectively then, roughly 0.59 Q-BTUs of *new supply* needs to be provided by wind, solar, and geothermal in order to bring Colorado's total energy supply to 1.35 Q-BTUs in 2030, with emissions falling to under 48 million tons as of 2030.

As discussed in section 5, we assume, as a high-end estimate, that the average lump-sum capital expenditures needed to expand clean renewable energy supply by 1 Q-BTU will be $200 billion. This then means that, to expand clean renewable energy supply in Colorado by

0.59 Q-BTUs, will require about $118 billion in new capital expenditures. Working, again, with the assumption that this is a 10-year investment program, this implies that the average level of expenditures per year to increase the supply of clean renewable energy by 0.59 Q-BTUs in 2030 will be $11.8 billion per year.

In Table 12, panels A-C, we summarize the main features of the 2030 clean energy investment program. These include the following:

TABLE 12A – 12C
Colorado Clean Energy Investment Program for 2021– 2030

12A) Energy Efficiency Investments

1. 2030 Energy Intensity Ratio	3.0 Q-BTUs per $1 trillion GDP *(36% improvement over 4.7 Q-BTU per $1 trillion GDP steady state figure)*
2. Total energy consumption	1.35 Q-BTUs *(= 36% reduction relative to 2.11 Q-BTU steady state figure)*
3. Energy saving relative to steady state	0.76 Q-BTUs *(= 2.11 – 1.35 Q-BTUs)*
4. Average investment costs per Q-BTU in efficiency gains	$35 billion per Q-BTU
5. Costs of energy savings	$26.6 billion *(= $35 billion x 0.76 Q-BTUs in savings)*
6. Average annual costs over 2021–2030	$2.7 billion *(= $26.6 billion/10)*
7. Average annual costs of efficiency gains as % of midpoint GDP	0.7% *(= $2.7 billion/$411 billion)*

12B) Clean Renewable Energy Investments

1. Total renewable supply necessary	0.68 Q-BTUs *(= 1.35 Q-BTUs – 0.67 supplied by non-renewables)*
2. Expansion of renewable supply relative to 2015 level	0.59 Q-BTUs *(= 0.68 – 0.09 Q-BTUs)*
3. Average investment costs per Q-BTU for expanding renewable supply	$200 billion per Q-BTU
4. Costs of expanding renewable supply	$118 billion *(= 0.59 Q-BTUs x $200 billion)*
5. Average annual costs over 2021–2030	$11.8 billion *(= $118 billion/10)*
6. Average annual costs of renewable supply expansion as % of midpoint GDP	2.9% *(= $11.8 billion/$411 billion)*

12C) Overall Clean Energy Investments: Efficiency + Clean Renewables

1. Total clean energy investments	$145 billion *(= $26.6 billion for energy efficiency + $118 billion for renewables)*
2. Average annual investments	$14.5 billion *(= $145 billion/10)*
3. Average annual investments as share of midpoint GDP	3.5% *(= $14.7 billion/$411 billion)*
4. Total energy savings or clean renewable capacity expansion	1.35 Q-BTUs *(= 0.76 Q-BTUs in energy saving + 0.59 in clean renewable supply expansion)*

Note: The figures in this table for both non-renewables and renewables supply are exclusive of high-emissions bioenergy.
Source: See Tables 9 – 11.

- **Efficiency.** \$2.7 billion per year in energy efficiency investments between 2021 – 2030, amounting to about 0.7 percent of Colorado's projected midpoint GDP between 2021 – 2030. These efficiency investments will generate 0.76 Q-BTUs of energy savings relative to the state economy's steady state growth path through 2030.
- **Clean renewables.** \$11.8 billion per year for investments in wind, solar, and geothermal energy production. This will amount to about 2.9 percent of Colorado's projected midpoint GDP between 2021 – 2030. It will generate an increase of 0.59 Q-BTUs of clean renewable supply by 2030.
- **Overall program and emissions reduction.** Combining the efficiency and clean renewable investments, the program will therefore cost about \$14.5 billion per year, or 3.5 percent of Colorado's projected midpoint GDP between 2021 – 2030. Overall, this program will generate 1.35 Q-BTUs in either energy savings relative to the steady state scenario or expanding the clean renewable energy supply. The end result of this program will be that overall CO_2 emissions in Colorado in 2030 will be 48 million tons, 50 percent less than its level for 2005. Colorado will have achieved this 50 percent emissions reduction while the state's economy also will have grown at an average rate of 2.4 percent per year through 2030.

Is \$14.5 Billion per Year in Clean Energy Investments Realistic?

The short answer is "yes." To understand why, it is important to consider our estimate of Colorado's annual clean energy investment needs within the broader context of the state's overall economic trajectory. As we have already noted above, this \$14.5 billion annual investment figure represents about 3.5 percent of Colorado's average GDP over 2021 – 2030, assuming that the state continues to grow at about 2.4 percent per year over that 10-year period. In other words, our estimate of Colorado's annual clean energy investment needs for bringing CO_2 emissions down in the state by 50 percent as of 2030 implies that roughly 96 percent of all economic activity in Colorado can continue to be directly engaged in activities *other than* clean energy investments.

As an additional valuable metric, we roughly estimate that, for 2017, the level of annual clean energy investments in Colorado was already in the range of \$2 billion or higher.[33] From this figure, we conclude that clean energy investments in the state between 2021 – 2030 will need to increase about six-fold relative to current investment levels. This will certainly be a substantial challenge. But, as we discuss in Section 9 below, Colorado does already have a policy infrastructure in place to support clean energy investments, mainly through incentivizing private investors. Increasing the level of clean energy investments will therefore primarily entail strengthening this policy framework on the basis of its existing foundation.

7. JOB CREATION THROUGH CLEAN ENERGY INVESTMENTS

In this section, we estimate the employment effects of advancing a clean energy investment program in the state at the level we developed in the previous section—i.e. at about $2.7 billion per year in energy efficiency investments over the 10-year investment cycle between 2021 – 2030 and $11.8 billion per year in clean renewable investments over this same 10-year cycle. Total annual clean energy investments will therefore amount to $14.5 billion per year, about 3.5 percent of Colorado's midpoint GDP over 2021 – 2030, assuming the state's economy grows at an average annual rate of 2.4 percent in this period.

After estimating the number of jobs that this investment project will generate, we then consider indicators of the quality of these jobs. These quality indicators include average compensation levels, health care coverage, retirement plans, and union membership. We also provide data profiling the types of workers who are employed at present in the job areas that will be created by clean energy investments, including evidence on both educational credentials of these workers as well as their racial and gender composition. We then report on the prevalent types of jobs that will be generated by the energy efficiency and clean renewable energy investments.

Before proceeding with describing our estimates, we will first provide a brief overview of the methodology we used to generate our results. We provide a fuller discussion of our methodology in Appendix 2.

Methodological Issues in Estimating Employment Creation

Our employment estimates are figures generated directly with data from national surveys of public and private economic enterprises within Colorado and organized systematically within the official state-level input-output (I-O) model. The "inputs" within this model are all the employees, materials, land, energy and other products that are utilized in public and private enterprises within Colorado to create goods and services. The "outputs" are the goods and services themselves that result from these activities that are then made available to households, private businesses and governments as consumers within both domestic and global markets. Within the given structure of the Colorado economy, these figures from the input-output model provide the most accurate evidence available as to what happens within private and public enterprises when they produce the economy's goods and services. In particular, these data enable researchers to observe how many workers were hired to produce a given set of products or services, and what kinds of materials were purchased in the process.

Here is one specific example of how our methodology works. If we invest an additional $1 million on energy efficiency retrofits of an existing building, how will the business undertaking this retrofit project utilize that million dollars to actually complete the project? How much of the $1 million will they spend on hiring workers, how much will they spend on non-labor inputs, including materials, energy costs, and renting office space, and how much will be left over for business profits? Moreover, when businesses spend on non-labor inputs, what are the employment effects through giving orders to suppliers, such as lumber and glass producers or trucking companies?

We also ask this same set of questions for investment projects in renewable energy as well as spending on operations within the non-renewable energy sectors. For example, to produce $1 million worth of wind energy productive capacity, how many workers will need to be employed, and how much money will need to be spent on non-labor inputs? Through this approach, we are able to make observations as to the potential job effects of alternative energy investment and spending strategies at a level of detail that is not available through any alternative approach.

Direct, Indirect and Induced Job Creation

Spending money in any area of any economy, including Colorado, will create jobs, since people are needed to produce any good or service that the economy supplies. This is true regardless of whether the spending is done by private businesses, households, or government entities. At the same time, for a given amount of spending within the economy, for example, $1 million, there are differences in the relative levels of job creation through spending that $1 million in different ways. Again, this is true regardless of whether the spending is done by households, private businesses or public sector enterprises.

There are three sources of job creation associated with any expansion of spending—direct, indirect, and induced effects. For purposes of illustration, consider these categories in terms of investments in home retrofitting or building wind turbines:

1. *Direct effects*—the jobs created, for example, by retrofitting buildings to make them more energy efficient or building wind turbines;
2. *Indirect effects*—the jobs associated with industries that supply intermediate goods for the building retrofits or wind turbines, such as lumber, steel, and transportation;
3. *Induced effects*—the expansion of employment that results when people who are paid in the construction or steel industries spend the money they have earned on other products in the economy. These are the multiplier effects within a standard macroeconomic model.

In this study, we focus on direct and indirect effects. We do also consider induced effects, if more briefly. Estimating induced effects—i.e. multiplier effects—within I-O models is much less reliable than the direct and indirect effects. In addition, induced effects derived from alternative areas of spending within a national economy are likely to be comparable to one another. Nevertheless, we will report the induced effect figures that are generated through the Colorado I-O model, even while we give them less emphasis in our analysis.

Within the categories of direct plus indirect job creation, how is it that spending a given amount of money in one set of activities in the economy could generate more employment than other activities? As a matter of simple arithmetic, there are only three possibilities. These are:

1. *Labor Intensity.* When proportionally more money of a given overall amount of funds is spent on hiring people, as opposed to spending on machinery, buildings, energy, land,

and other inputs, then spending this given amount of overall funds will create relatively more jobs.

2. *State-level content*. When a given amount of money is spent on Colorado's clean energy investment program, some of the spending will occur outside of the Colorado economy. The I-O model enables us to estimate Colorado-specific spending proportions as opposed to outside-the-state spending. In fact, as we describe below, we will make low-end assumptions in our estimates as to the share of spending that will be internal to Colorado.

3. *Compensation per worker*. If $1 million in total is spent on employing workers in a given year on a project, and one employee earns $1 million per year working on that project, then only one job is created through spending this $1 million. However, if, at another enterprise, the average pay is $50,000 per year, then the same $1 million devoted to employing workers will generate 20 jobs.

Time Dimension in Measuring Job Creation

Jobs-per-year vs. job years. Any type of spending activity creates employment over a given amount of time. To understand the impact on jobs of a given spending activity, one must therefore incorporate a time dimension into the measurement of employment creation. For example, a program that creates 100 jobs that last for only one year needs to be distinguished from another program that creates 100 jobs that continue for 10 years each. It is important to keep this time dimension in mind in any assessment of the impact on job creation of any clean energy investment activity.

There are two straightforward ways in which one can express such distinctions. One is through measuring *job years*. This measures cumulative job creation over the total number of years that jobs have been created. Thus, an activity that generates 100 jobs for 1 year would create 100 job years. By contrast, the activity that produces 100 jobs for 10 years would generate 1,000 job years.

The other way to report the same figures would be in terms of *jobs-per-year*. Through this measure, we are able to provide detail on the year-to-year breakdown of the overall level of job creation. Thus, with the 10-year program we are using in our example, we could express its effects as creating 100 jobs per year for 10 years.

This jobs-per-year measure is most appropriate for the purposes of this study, in which our focus is on measuring the impact on employment opportunities of clean energy investments. The reason that jobs-per-year is a better metric than job years is because the impact of any new investment, whether on clean energy or anything else, will be felt within a given set of labor market conditions at a point in time. Reporting cumulative job creation figures over multiple years prevents us from scaling the impact of investments on job markets at a given point in time. For example, if clean energy investments create 100,000 jobs in a given year, we are able to scale that to the size of the Colorado labor market in that year. At present, 2.7 million people are employed in Colorado. Adding 50,000 jobs would therefore amount to an increase in employment of about 1.9 percentage points.

If we then assume that the clean energy investments continue for 10 years at the same scale, that would mean 50,000 jobs per year would be created through these investments. That would continue to expand employment opportunities in Colorado by around 1.5 percent per year (allowing also for the natural growth of the state's labor market). However, if we measure this employment impact in terms of cumulative job creation, the 10 years worth of investment would, by this measure, amount to 500,000 jobs. It is misleading to compare that cumulative job creation figure to the total of 2.8 million jobs in Colorado at a specific point in time (e.g. 2021). If we did want to scale the cumulative job creation figure of 500,000, the appropriate comparison would be with the cumulative job figures for the whole state over 10 years, i.e. a cumulative level of employment over 10 years of 28 million jobs (i.e. 2.8 million jobs x 10 years). But this 28 million cumulative jobs figure is not a particularly clear or useful way to understand labor market conditions at any given point in time.

The case of construction jobs. One specific area where it is important to proceed clearly on this issue is in consideration of construction industry job creation. Construction industry jobs created by clean energy investments are frequently regarded as being short-term, while manufacturing jobs are seen as inherently longer term. However, especially in evaluating the impact of alternative areas of spending within a broad clean energy investment agenda, the distinctions are not so straightforward. Of course, any single construction project is limited by the amount of time required to complete that project, while manufacturing activity in a single plant can continue indefinitely, as long as the manufacturer is able to sell the goods being produced at a profit. But if we consider any large-scale clean energy construction project, total job creation over time can vary widely, depending precisely on the annual level of expenditure that is laid out to complete the project.

Consider, for example, a project to retrofit the entire publicly-owned building stock in Colorado, in which we assume the entire budget devoted to labor in the project is $5 billion, and each worker on the project receives $50,000 per year in total compensation. This means that, in total, the project will generate 100,000 job years, no matter how these job years are divided up over time. If the annual labor-cost budget for the project is $500 million over 10 years, that means the project will generate 10,000 jobs per year over 10 years, making it a long-term source of job creation. However, if the annual budget rose to $5 billion, that means the project would generate 100,000 jobs, but over just one year.

Incorporating Labor Productivity Growth over the 10-Year Investment Cycle

The figures we use for the input-output tables are based on the technologies that are prevalent at present for undertaking these clean energy investments. Yet we are estimating job creation through clean energy investments that will occur over a 10-year cycle between 2021 - 2030. The relevant production technologies are likely to change over this 10-year period, so that a different mixture of inputs may be used to produce a given output.

For example, new technologies are likely to emerge, making other technologies obsolete. Certain inputs could also become more scarce, and, as result, firms may substitute other less expensive goods and services to save on costs. The production process overall could also become more efficient, so that fewer inputs are needed to produce a given amount of output. Energy efficiency investments do themselves produce a change in production processes—i.e. a reduction in the use of energy inputs to generate a given level of output. In short, the input-output relationships in any given economy—including its employment effects of clean energy investments—are likely to look different in 2030 relative to the present.

We have addressed this issue in depth in previous research (e.g. Pollin et al. 2015, pp. 133 - 44). For the purposes of this study, we will work with two simple assumptions: 1) current input-output relationships will prevail as of 2021, the year in which the clean energy investment program commences in full; and 2) between 2021- 2030, average labor productivity in clean energy investments rises by 1 percent per year.

Job Creation Estimates

In Tables 13 and 14, we present our estimates as to the job creation effects of investing in energy efficiency in Colorado. Tables 15 and 16 then present comparable estimates for investments in clean renewable energy in the state. In both cases, we report two sets of figures—first, job creation per $1 million in expenditure, then, job creation given the annual level of investment spending we have proposed, i.e. $2.7 billion per year in energy efficiency and $11.8 billion per year in renewable energy. We first report figures for direct and indirect jobs, along with the totals for these main job categories. We then include the figures on induced jobs, and show total job creation when induced jobs are added to that total.

Beginning with the energy efficiency investment figures in Table 13, we show the job creation figures per $1 million in spending for our five categories of efficiency investments: building retrofits; industrial efficiency; electrical grid upgrades; public transportation expansion and upgrades; and high-efficiency private auto purchases. As Table 13 shows, direct plus indirect job creation per $1 million in spending ranges between 5.3 jobs for electrical grid upgrades to 12.7 jobs for public transportation expansion and upgrades.

Spending to bring high efficiency automobiles into operation rapidly will be an important component of the overall efficiency investment initiative. However, our assumption, as shown in Table 13, is that this will not be a source of new job creation. This is because producing high efficiency automobiles will basically substitute for producing lower-efficiency models. Roughly the same level of employment will be needed either way.[34]

In Table 14, we show the level of job creation through spending $2.7 billion per year on these efficiency projects in Colorado. We have assumed that 60 percent of the $2.7 billion total is channeled into building retrofits, and the remaining 40 percent supports the other

TABLE 13
Job Creation in Colorado through Energy Efficiency Investments
Job creation per $1 million in efficiency investments

	Direct Jobs	Indirect Jobs	Direct + Indirect Jobs total	Induced Jobs	Direct, Indirect + Induced Jobs Total
Building retrofits	6.2	2.7	8.9	3.3	12.2
Industrial efficiency	6.2	2.4	8.6	3.7	12.3
Electrical grid upgrades	3.9	1.4	5.3	2.1	7.4
Public transport expansion/upgrades	10.1	2.6	12.7	3.2	16.0
Expanding high efficiency automobile fleet	0.0	0.0	0.0	0.0	0.0

Sources: See Appendix 2.

TABLE 14
Job Creation in Colorado through Energy Efficiency Investments
Job creation through spending $2.7 billion per year in efficiency investments

ASSUMPTIONS FOR ENERGY EFFICIENCY INVESTMENTS

- 60% on building retrofits
- 10% on industrial efficiency measures
- 10% on electrical grid upgrades
- 10% on public transportation expansion/upgrades
- 10% on expanding high-efficiency auto fleet
  - No job creation through auto purchase subsidies

	Spending Amounts	Direct Jobs	Indirect Jobs	Direct + Indirect Jobs Total	Induced Jobs	Direct, Indirect + Induced Jobs Total
Building retrofits	$1.62 billion	10,044	4,374	14,418	5,346	19,764
Industrial efficiency	$270 million	1,674	648	2,322	999	3,321
Electrical grid upgrades	$270 million	1,053	378	1,431	567	1,998
Public transportation expansion/upgrades	$270 million	2,727	702	3,429	864	4,320
Expanding high efficiency automobile fleet	$270 million	0	0	0	0	0
TOTALS	**$2.7 billion**	**15,498**	**6,102**	**21,600**	**7,776**	**29,403**

Source: See Table 13.

efficiency investment areas equally, at 10 percent of the total each. The result of efficiency investment spending at this level, as we see, will be the creation of 15,498 direct jobs and 6,102 indirect jobs, for a total of 21,600 direct plus indirect jobs through this energy efficiency investment program. Including induced jobs adds another 7,776 jobs to the total figure. This brings the total job creation figure for efficiency investments, including induced jobs to 29,403 jobs.

In Table 15, we show the job creation figures for our three clean renewable energy categories—wind, solar, and geothermal power. As we see, the extent of direct plus indirect jobs ranges from 3.8 – 7.2 per $1 million in spending. Adding induced jobs brings the range to between 5.2 – 10.6 jobs per $1 million in spending.

TABLE 15
Job Creation in Colorado through Clean Renewable Energy Investments
Job creation per $1 million in clean renewable investments

ASSUMPTIONS:

- 10 percent of new manufacturing activity retained in Colorado State

	Direct Jobs	Indirect Jobs	Direct + Indirect Jobs Total	Induced Jobs	Direct, Indirect + Induced Jobs
Wind	3.1	0.7	3.8	1.4	5.2
Solar	4.8	1.0	5.8	2.0	7.8
Geothermal	4.8	2.4	7.2	3.4	10.6

Source: See Appendix 2.

Based on these proportions, we see in Table 16 the levels of job creation in Colorado associated with $11.8 billion in annual spending on clean renewable energy. We divide the overall level of annual spending to include $5.31 billion per year respectively for wind and solar power and $1.18 billion for geothermal. We also assume, as a low-end estimate, that of this total level of new investments in clean renewables needed to deliver an additional 0.59 Q-BTUs of energy in Colorado by 2030, only 10 percent of the total *manufacturing activity* will take place within Colorado. In other words, we assume that 90 percent of the manufacturing goods needed to produce 0.59 Q-BTUs of clean renewable energy in Colorado as of 2030 will be imported from outside the state.

Following from these assumptions, we see in Table 16 that total direct plus indirect job creation generated in Colorado by this large-scale expansion in the state's clean renewable energy supply will be 59,472 jobs. If we include induced jobs, then the total rises to 81,538 jobs.

Table 17 brings together our job estimates for both energy efficiency and clean renewable energy through spending about $14.5 billion per year on this project in Colorado from 2021 - 2030. We show total figures for direct plus indirect jobs only, then we also show the total when induced jobs are included. We also provide estimates for 2021, the first year of the full-scale investment program, and for 2030, the last year of the investment cycle. The employment levels fall in 2030 relative to 2021 because of our assumption that average labor productivity rises at an average rate of one percent per year in the relevant sectors of Colorado's economy.

We see in row 10 of Table 17 that total direct and indirect job creation as of 2021 is 81,072 jobs and 110,941 jobs when we add induced jobs to the total. As we see in row 11, this level of job creation amounts to about 3 to 4 percent of total employment in Colorado as of 2018, the range depending on whether we include induced jobs in the total. In row 12, we show our job estimates for 2030, assuming productivity gains at an average annual rate of 1 percent. These job figures are 74,800 for direct plus indirect employment and 101,000 when we include induced job creation.

TABLE 16
Annual Job Creation in Colorado through Clean Renewable Energy Investments
Job creation through spending $11.8 billion per year in clean renewable investments

ASSUMPTIONS FOR CLEAN RENEWABLE INVESTMENTS

- 45% on wind energy
- 45% on solar PV energy
- 10% on geothermal energy
- 10% of new manufacturing activity in Colorado

	Spending Amounts	Direct Jobs	Indirect Jobs	Direct + Indirect Jobs Total	Induced Jobs	Direct, Indirect + Induced Jobs Total
Wind	$5.31 billion	16,461	3,717	20,178	7,434	27,612
Solar	$5.31 billion	25,488	5,310	30,798	10,620	41,418
Geothermal	$1.18 billion	5,664	2,832	8,496	4,012	12,508
TOTALS	**$11.8 billion**	**47,613**	**11,859**	**59,472**	**22,066**	**81,538**

Source: See Table 15.

TABLE 17
Annual Job Creation in Colorado through Combined Clean Energy Investment Program

Initial Year of Job Estimate Is 2021

Industry	Number of Direct and Indirect Jobs Created	Number of Direct, Indirect and Induced Jobs Created
$2.7 billion in Energy Efficiency		
1) Building retrofits	14,418	19,764
2) Industrial efficiency	2,322	3,321
3) Electrical grid upgrades	1,431	1,980
4) Public transportation expansion/upgrades	3,429	4,320
5) Total energy efficiency job creation	21,600	29,403
$11.8 billion in Clean Renewables		
6) Wind	20,178	27,612
7) Solar	30,798	41,418
8) Geothermal	8,496	12,508
9) Total clean renewable job creation	59,472	81,538
10) TOTAL *(= rows 5+9)*	**81,072**	**110,941**
11) TOTAL AS SHARE OF 2018 COLORADO STATE EMPLOYMENT	**2.7%**	**3.7%**
12) 2030 JOB ESTIMATE, with 1 percent annual productivity growth	**74,800**	**101,000**

Sources: See Tables 13 – 16. Colorado's 2018 employment=3.0 million.

Indicators of Job Quality

In Table 18, we provide some basic measures of job quality for the jobs that will be generated through clean energy investments in Colorado. These basic indicators include: 1) average total compensation (including wages plus benefits); 2) entry-level compensation; 3) the percentage of workers receiving health insurance coverage; 4) the percentage having retirement plans through their employers; and 5) the percentage that are union members.

Starting with compensation figures, we see that the averages range between about $61,400 for workers in the mass transit sector to between nearly $95,000 for workers employed in the industrial efficiency sector and nearly $100,000 in the geothermal energy sector. The range for entry-level compensation is much lower. The lower entry-level compensation is still in mass transit, at around $28,000. The higher entry-level compensation figures are with industrial efficiency, at around $38,000, wind energy, at nearly $40,000, and geothermal, at $43,000.

TABLE 18
Indicators of Job Quality in Colorado Clean Energy Industries: Direct and Indirect Jobs Only

	Energy Efficiency Investments				Clean Renewable Energy Investments		
	1. Building Retrofits *(14,418 workers)*	**2. Industrial Efficiency** *(2,322 workers)*	**3. Grid Upgrades** *(1,431 workers)*	**4. Mass Transit** *(3,429 workers)*	**5. Wind** *(20,178 workers)*	**6. Solar** *(30,798 workers)*	**7. Geothermal** *(8,496 workers)*
Average total compensation	$74,600	$94,600	$83,800	$61,400	$84,800	$78,800	$99,700
Entry level* total compensation	$34,400	$38,200	$33,100	$28,100	$39,700	$34,800	$43,200
Health Insurance coverage, percentage	48.3%	64.6%	65.4%	37.9%	56.8%	53.6%	58.2%
Retirement plans, percentage	30.9%	42.3%	51.8%	32.6%	50.0%	47.2%	43.7%
Union membership, percentage	8.6%	7.4%	5.2%	13.9%	9.1%	12.7%	7.1%

Note: *We approximate each entry-level total compensation figure by assuming that the ratio between entry-level compensation and average compensation is equal to that of the 10th wage percentile relative to the average wage within the same sector. We use the CPS to estimate the 10th wage percentile and average wage within each sector.

Source: See Appendix 3.

There is also significant range among workers in terms of their health insurance coverage. At the low end, about 38 percent of workers in the mass transit sectors have private health insurance, while roughly 65 percent of workers in industrial efficiency and grid upgrades are covered. The figures in all the clean renewable areas—wind, solar, and geothermal—are between 54 - 58 percent.

The range of coverage with respect to private retirement plans is similar to health insurance. The low-end figures are with building retrofits and mass transit, in which between 31 – 33 percent have private pension coverage, while 52 percent of workers in grid upgrades have such pensions. The figures on union coverage are generally low. Coverage ranges between 5.2 percent for grid upgrades and 13.9 percent for mass transit.

These indicators of job quality will be valuable for purposes of comparison when we consider the jobs that will be lost in Colorado as a result of the contraction of fossil fuel production and consumption in the state through 2030. What is especially important to highlight now—in anticipating our discussion in section 8 on workers in Colorado's fossil fuel related industries—is that, for the most part, the compensation figures in clean energy industries are lower than those for fossil fuel industry-based workers. As such, one of the aims of a clean energy investment agenda for Colorado should be to raise wages, benefits and working conditions in the newly-created clean energy investment industries.

Raising unionization rates in these industries will provide an important foundation in support of these goals. As one feature of the overall clean energy transition project for Colorado, the state should therefore require neutrality with respect to union organizing campaigns in any clean energy investment projects that are either state-owned or partially financed by the state. We return to this issue below when we discuss policy proposals.

Educational Credentials and Race/Gender Composition for Clean Energy Jobs

In Table 19, we present data on both the educational credentials for workers in jobs tied to clean energy investment activities in Colorado and the race and gender composition of these workers.

Educational Credentials

With respect to educational credentials, we categorize all workers who would be employed directly or indirectly by clean energy investments in Colorado according to three educational credential groupings: 1) shares with high school degrees or less; 2) shares with some college or Associate degrees; and 3) shares with Bachelor's degree or higher.

As Table 19 shows, the distribution of educational credentials varies widely depending on the specific clean energy industry. In the area of building retrofits, about half of the workers have high school degrees or less. With grid upgrades, mass transit, wind and geothermal energy, roughly one-third have high school degrees or less. In the industrial efficiency and solar energy sectors, only about 27- 28 percent of workers are at this lower educational credential level.

At the other end of the credential range, over half of all workers in industrial efficiency have Bachelor's degrees or higher and nearly 50 percent are at this educational level in the solar industry. This is roughly twice the proportion prevailing with building retrofit workers. With grid upgrades, wind and geothermal energy areas, between 34 – 39 percent hold Bachelor's degrees or more.

If we consider this range of clean energy investment areas as a whole, it is clear that there will be new jobs generated at roughly comparable proportions for workers at all educational credential levels. Here again, it will be useful to be able to compare these patterns

TABLE 19
Educational Credentials and Race/Gender Composition of Workers in Colorado Clean Energy Industries: Direct and Indirect Jobs Only

	Energy Efficiency Investments				Clean Renewable Energy Investments		
	1. Building Retrofits *(14,418 workers)*	**2. Industrial Efficiency** *(2,322 workers)*	**3. Grid Upgrades** *(1,431 workers)*	**4. Mass Transit** *(3,429 workers)*	**5. Wind** *(20,178 workers)*	**6. Solar** *(30,798 workers)*	**7. Geothermal** *(8,496 workers)*
Share with high school degree or less	48.7%	27.1%	37.8%	35.6%	36.8%	27.9%	36.6%
Share with some college or Associate degree	27.0%	19.7%	28.4%	31.1%	26.1%	25.4%	24.3%
Share with Bachelor's degree or higher	24.3%	53.2%	33.8%	33.3%	37.1%	46.7%	39.1%
Racial and gender composition of workforce							
Pct. non-white	35.6%	23.8%	27.6%	30.0%	29.1%	23.7%	29.7%
Pct. female	17.9%	32.9%	29.6%	23.8%	28.4%	36.6%	24.7%

Source: See Appendix 3.

in educational levels for jobs in clean energy with those that will be displaced through the contraction in Colorado's fossil fuel industries. We consider this in section 8.

Race and Gender Composition

It is clear from the figures in Table 19 that, at present, the jobs created by clean energy investments are held predominantly by white male workers. At the same time, with two exceptions, the share of jobs held by non-white workers are roughly in line with their representation in the Colorado workforce (about 28 percent).[35] Non-white workers are under-represented in the clean energy sectors of industrial efficiency and solar. With respect to gender composition, women are under-represented across all sectors. The share of female employment is between 18 – 37 percent, even while women make up 46 percent of Colorado's workforce.

Despite these large disparities in the current composition of the workforce associated with clean energy investments in Colorado, the large-scale expansion of these investments will provide a major opportunity to increase opportunities for non-white and female workers. An initiative focused on equal opportunity in the growing clean energy investment areas could be readily integrated into the broader investment project.

Prevalent Job Types with Clean Energy Investments

To provide a more concrete picture of the jobs that will be created in Colorado through investments in energy efficiency and clean renewable energy, in Tables 20 - 22 we report on the prevalent job types associated with the various efficiency and renewable energy activities. Table 20 provides data for investments in building retrofits, our largest category of energy efficiency investments. Table 21 combines data for the other efficiency investment areas, i.e. industrial efficiency, electric grid upgrades, and public transportation expansion and upgrades. Table 22 then reports these same figures combined for our three areas of clean renewable energy investments, i.e. wind, solar, and geothermal power. In all cases, we report on the job categories in which we estimate that 5 percent or more of the new jobs will be created through clean energy investments.

TABLE 20
Building Retrofits: Prevalent Job Types in Colorado Industry
(Job categories with 5 percent or more employment)

Job Category	Percentage of Total Industry Employment	Representative Occupations
Construction	48.3%	Construction laborers, carpenters, plumbers
Management	15.1%	Construction managers, chief executives, marketing managers
Sales	9.2%	First-line sales supervisors/managers, sales representatives, real estate brokers
Office and administrative support	6.1%	Secretaries, accounting clerks, customer service representatives
Installation and maintenance	5.1%	Heating, air conditioning, refrigeration mechanics and installers; heavy vehicle service technicians; electrical power-line repairers

Sources: See Appendix 3.

TABLE 21
Industrial Efficiency, Electric Grid Upgrades, Public Transportation Expansion/Upgrades: Prevalent Job Types in Colorado Industry
(Job categories with 5 percent or more employment)

Job Category	Percentage of Total Industry Employment	Representative Occupations
Transportation and material moving	26.1%	Bus drivers, truck drivers, freight and stock laborers
Management	15.4%	Financial managers, construction managers, sales managers
Construction	14.1%	Construction laborers, pipefitters, electricians
Business and financial operations	9.7%	Management analysts, wholesale buyers, cost estimators
Production	7.3%	Welding workers, machinists, first-line supervisors/managers
Office and administrative support	5.6%	Secretaries, auditing clerks, expediting clerks

Sources: See Appendix 3.

TABLE 22
Wind/Solar/Geothermal: Prevalent Job Types in Colorado Industry
(Job categories with 5 percent or more employment)

Job Category	Percentage of Total Industry Employment	Representative Occupations
Construction	24.5%	First-line construction supervisors, painters, electricians
Management	15.7%	Construction managers, marketing managers, chief executives
Office and administrative support	9.2%	First-line supervisors/managers, customer service representatives, secretaries
Arts, design, entertainment, sports, and media	8.1%	Photographers, designers, communications workers
Production	8.0%	Machinists; crushing, grinding, polishing, mixing, and blending workers; electrical technicians
Sales	6.5%	Sales representatives, real estate brokers, product promoters
Life, physical, and social science	5.6%	Environmental scientists, geoscientists, physicists
Business and financial operations	5.3%	Wholesale buyers, market research analysts, human resources workers

Sources: See Appendix 3.

It is difficult to summarize the detailed data on job categories presented in these tables. But it will be useful to underscore a few key patterns. First, a high proportion of jobs will be created in the construction industry through all of the clean energy investment activities. Of course, this is true with the 48 percent of jobs created through building retrofit investments. But we also find that 14 percent of investments in the other areas of energy efficiency investments and 25 percent in the clean renewable sectors will be in construction. The specific types of construction industry jobs will vary widely, given the different types of construction projects that will be pursued. Thus, investments in building retrofits as well as the other areas of efficiency investments will create large numbers of jobs for laborers, carpenters, and electricians. This pattern of job creation holds as well with renewable-energy based construction work.

Management as well as office and administrative support also constitute a large share of overall job creation across all categories. Management ranges between 15 - 16 percent in all the tables, while office and administrative support accounts for about 5 – 9 percent of all jobs.

What emerges generally from these tables is that clean energy investments will generate a wide range of new employment opportunities. This broad range of new opportunities will be available for workers in Colorado that will have been displaced by the contraction of the state's fossil fuel industry activities, as well as more broadly throughout the state's labor force.

Requirements for Generating Good-Quality Jobs

What is clear from the evidence we have reviewed is that: 1) large-scale job creation will certainly result in Colorado through clean energy investments in the range of $14.5 billion per year, or 3.5 percent of state GDP over 2021 – 2030; but that 2) these jobs will not necessarily be good jobs. As we have seen, average compensation varies widely in the various clean energy sectors, from roughly $61,000 to $100,000, depending on the sector. Entry-level compensation levels also range widely, from $28,000 in mass transit to $43,000 in geothermal energy. Meanwhile, union membership is low across-the-board, at between 5 – 14 percent of workers. These low unionization rates mean that there is not an entity in place that will advocate strongly for high job-quality standards as clean energy employment levels in the state expand.

This is an important consideration, since an effective union presence and strong labor standards will be critical in determining whether the jobs created through clean energy investments in Colorado will be good jobs. This becomes clear in comparing the respective experiences in the solar installation sectors in California and Arizona. The California sector operates within a framework of relatively strong unions and labor laws while these are both relatively weak in Arizona. A 2014 study by University of Utah economist Peter Phillips describes how these distinct institutional settings play out within the respective state-level solar installation labor markets. Phillips writes:

> Jobs building utility-scale solar electricity generating facilities are not inevitably good jobs paying decent wages and benefits and providing career training within construction. Under some labor market conditions, many solar farm jobs can be bad jobs paying low wages, with limited benefits or none at all, working for temporary labor agencies with no prospect for training, job rotation, or career development.

> In California, this low-road approach to utility-scale solar construction is uncommon for several reasons. First, when any federal funds are involved, the project is governed by federal prevailing wage regulations mandating that, for each occupation on the project, the wage in the local area that prevails for that occupation, based on Davis-Bacon surveys, must be paid.
>
> All states are covered by the federal Davis-Bacon Act, but in some states, such as Arizona, for some construction crafts, nonunion rates prevail in many counties, meaning that prevailing wage jobs can be paid low wages with limited benefits. In California, union strength has meant that in most cases on prevailing wage solar projects, workers will get paid good wages with good benefits. State right-to-work laws play a role in determining union strength. By undercutting union strength, Arizona's right-to-work law plays a role in determining the low-road practices found on some solar farm construction in that state. In contrast, California's resistance to right-to-work regulations reinforces federal Davis-Bacon wage mandates, thereby helping lead California's solar farm work along a high-road approach to construction.

In addition to the support for good clean energy industry jobs provided by unions and labor standards, it will also be critical that workers have access to high-quality training programs that will enable them to enter their new jobs with the skills they need to succeed. Without high-quality and accessible training opportunities, the likelihood increases that labor force quality standards will become compromised. Sam Appel of the Blue/Green Alliance of California has documented this problem in California's energy efficiency sector, writing as follows:

> Poor installation of energy efficiency (EE) measures is a pervasive problem in California, and nationally. Industry, government, and academic studies show that poor installation of EE measures often results in energy savings losses of up to 50 percent compared to projected savings goals. The California Energy Commission, for instance, reports that up to 85 percent of replacement HVAC systems are installed or designed incorrectly, resulting in substantial unrealized energy savings. Ratepayer-funded studies also find that lighting control systems installed by workers without lighting-control specific certification result in high rates of installations errors leading to lost savings.
>
> Poor workforce standards and insufficient training pipelines are the root cause of pervasive installation errors. California's Investor Owned Utilities (IOUs) confirm that workers installing ratepayer-subsidized HVAC systems rarely have the technical knowledge, skills, or abilities necessary to implement industry standards for HVAC quality installation and, as a result, there are "high failure rates for job performance on routine tasks." To paint a picture, less than half of HVAC technicians in California are even aware of basic national standards for work quality, according to studies conducted by California agencies.
>
> Without explicit workforce standard policies on the books … California EE program administrators have relied on code compliance, contractor licensing requirements, and safety and building permit requirements to ensure proper installation. These minimal, insufficient requirements lead to the proliferation of a low skill, low pay workforce.

The problems described by Appel with poor workforce standards and insufficient training pipelines in the California energy efficiency sector are also being reported by employers in the sector from their distinct perspectives. In Tables 23 and 24 below, we report on the results of a 2018 survey conducted by the U.S. Labor Department, in which, among other questions, employers in clean energy sectors were asked whether they faced difficulties in

TABLE 23

Firms that Reported Hiring Difficulties in Solar, Wind, and Energy Efficiency Sectors

A) Energy Efficiency; 2018 Employment = 2.3 million

	2018 Employment Level	Firms Reporting Hiring Difficulties		
		Somewhat Difficult	Very Difficult	All Firms Reporting Difficulties
Construction	1.30 million	32%	52%	84%
Professional/business services	484,481	21%	61%	82%
Manufacturing	321,581	14%	58%	72%
Wholesale trade, distribution, transport	180,339	24%	48%	72%
Other Services	42,881	40%	36%	76%

B) Solar Electric Power; 2018 Employment = 242,343

	2018 Employment Level	Firms Reporting Hiring Difficulties		
		Somewhat Difficult	Very Difficult	All Firms Reporting Difficulties
Construction	177,320	54%	31%	85%
Professional/business Services	48,142	57%	16%	73%
Manufacturing	46,539	60%	18%	78%
Other services	32,937	54%	23%	77%
Wholesale trade, distribution, transport	26,759	73%	6%	79%
Utilities	3,295	31%	31%	62%

C) Wind Electric Power; 2018 Employment = 111,166

	2018 Employment Level	Firms Reporting Hiring Difficulties		
		Somewhat Difficult	Very Difficult	All Firms Reporting Difficulties
Construction	36,706	58%	28%	86%
Professional/business Services	27,058	66%	15%	81%
Manufacturing	26,490	53%	26%	79%
Wholesale trade, distribution, transport	11,783	77%	8%	85%
Utilities	6,231	50%	33%	83%
Other services	2,898	40%	33%	73%

Sources: *The 2019 U.S. Energy & Employment Report*, https://www.usenergyjobs.org/.

hiring new workers. We show the survey results in the three largest areas of clean energy employment to date in the U.S.—i.e. energy efficiency, in which 2018 employment was at 2.3 million; solar electricity, with 242,343 people employed; and wind electricity, with 111,166 people employed. We show the results for each clean energy sector broken out according to sub-sectors, including construction; professional/business services; manufacturing; wholesale trade, distribution and transport; utilities; and other services.

In the energy efficiency sector, the largest source of employment by far is in construction, with 1.3 million out of the total employment of 2.3 million—i.e. 56 percent of total energy efficiency investment. We see in Table 23 that fully 84 percent of employers reported difficulties in hiring workers, with 52 percent finding it "very difficult" to hire qualified workers.

The results are only moderately lower in the other sub-sectors within energy efficiency. Thus, manufacturing firms reported the lowest level of hiring difficulties, at 72 percent. As we see in Tables 23 B and C, as well as in the summary Table 24, these patterns are similar in the solar and wind electricity sectors and sub-sectors as well.

The survey further found that "lack of experience, training or technical skills" was the most important reason that employers were facing difficulties in hiring workers. The other, less significant factors were location and a relatively small applicant pool.

The study's conclusion from these survey results is that "The need for technical training and certifications was also frequently cited, implying the need for expanded investments in workforce training and closer coordination between employers and the workforce training system," (2019, p. 6).

It is clear therefore that high-quality and accessible workforce training programs need to be included as an important component of Colorado's overall clean energy transition project. In Section 9, the policy section of the study, we discuss both the existing relevant training programs in Colorado as well as initiatives elsewhere in the U.S. These discussions will provide a basis for considering approaches to expanding high-quality programs throughout the state as its clean energy investment projects grow.

TABLE 24
Summary Figures: All Firms Reporting Hiring Difficulties in Energy Efficiency, Solar Electricity and Wind Electricity Sectors

	Energy Efficiency	Solar Electricity	Wind Electricity
Construction	84%	85%	86%
Professional/business Services	82%	73%	81%
Manufacturing	72%	78%	79%
Wholesale trade, distribution, transport	72%	77%	85%
Utilities	---	79%	83%
Other services	76%	62%	73%

Source: *The 2019 U.S. Energy & Employment Report*, https://www.usenergyjobs.org/

Relative Job Creation through Alternative Spending Targets

What would be the impact on job creation of channeling a given amount of funds into other areas of Colorado's economy, as opposed to pursuing the investments on which we have focused in energy efficiency and clean renewable energy? To consider this question, in Table 25, we report figures as to the job creation impacts of spending in three alternative areas: the fossil fuel industry itself, traditional infrastructure—i.e. roads, bridges, tunnels, airports and related areas—and tax cuts. The impact of any tax cuts on jobs results through Colorado State's residents having more money to spend on their standard baskets of goods and services. As with our previous discussions in this section, we are focusing on the direct and indirect categories of job creation.

As we see in Table 25, the largest impact on job creation among the alternative spending areas is energy efficiency, which generates 8.0 direct and indirect jobs per $1 million in spending in Colorado. This is a combined figure for energy efficiency investments, based on the relative weights we have assigned earlier (i.e. from Table 14—60 percent on building retrofits, and 10 percent respectively on industrial efficiency, electrical grid upgrades, public transportation, and high-efficiency autos). The figure for renewable energy is lower, at 5.0 direct plus indirect jobs per $1 million. In this case, we are generating this overall renewable energy figure through following the proportional spending levels we report in Table 16, i.e. solar PV and wind both receiving 45 percent of total spending and geothermal energy obtaining the remaining 10 percent.

Considering now the three alternative spending areas, we see that traditional infrastructure investments in Colorado will generate 8.3 direct plus indirect jobs per $1 million in spending. This is followed by tax cuts, at 7.5 jobs per $1 million, and then oil and gas, at 3.0 jobs.

Overall then, we see that, comparatively speaking, clean energy investments are an effective source of job creation, even after we assume that the state generates only 10 percent of the manufacturing activity in the clean energy sector. We make this assumption because the expansion of the state's clean energy sector will be very rapid over 2021 – 2030. This will entail importing most of the manufactured products from other states and countries, at least over this initial decade of intense investment activity.

Nevertheless, combining energy efficiency and clean renewable investments will generate more jobs per dollar of expenditure than any combination that would include the fossil fuel industry. It is especially notable that the job creating opportunities for energy efficiency investments, in particular, are nearly three times greater than what would result through a project focusing only on expanding Colorado's fossil fuel infrastructure.

TABLE 25

Job Creation in Colorado Generated through Alternative Spending Targets

Direct plus indirect job creation per $1 million in spending

ASSUMPTIONS

1. For energy efficiency, spending proportions are: 60% on building retrofits, and 10% each on industrial efficiency, electrical grid upgrades, public transportation, and high-efficiency autos.
2. For clean renewables, solar PV and wind both receiving 45% of total spending and geothermal energy obtaining the remaining 10%.
3. Colorado retains only 10% of manufacturing activity in the clean energy sector.

	Direct Jobs	Indirect Jobs	Direct + Indirect Jobs
Clean energy investments			
-- Energy efficiency	5.7	2.3	8.0
-- Clean renewables	4.0	1.0	5.0
Alternative Colorado spending			
-- Infrastructure	5.9	2.4	8.3
-- Household tax cuts	5.4	2.1	7.5
-- Oil and gas	1.5	1.5	3.0

Source: See Appendix 2.

8. JUST TRANSITION FOR FOSSIL FUEL INDUSTRY DEPENDENT WORKERS

As we have shown above, in order for Colorado to bring total CO_2 emissions down from its 2015 level of 93.1 million tons to no more than 48 million tons by 2030, consumption of fossil fuels in the state will need to fall by 50 percent relative to its 2015 level of 1.34 Q-BTUs to about 0.67 Q-BTUs. As we have seen, natural gas consumption in Colorado in 2015 was 0.49 Q-BTUs, or 33 percent of total statewide energy consumption, petroleum consumption was nearly equal at 0.47 Q-BTUs, at 32 percent of total consumption, and coal was at 0.34 Q-BTUs, equal to 23 percent of the state's total energy consumption.

The issue on which we focus in this section is what the impact will be on workers in industries in Colorado that are dependent on statewide consumers continuing to purchase fossil fuel energy. We assume that production activity and employment in these industries will also decline by approximately 50 percent as of 2030.[36] In particular, we develop here a Just Transition program for the workers in these fossil fuel dependent sectors who will face displacement as a result of the statewide contraction in fossil fuel consumption.

In principle, there are 10 industries that would likely be heavily affected by a significant cut in fossil fuel consumption and production. Of course, the first two would be oil and gas extraction and coal mining. There are also 8 ancillary industries that would be impacted. The first two would be support activities for both oil/gas extraction and coal mining. Six additional industries that would be impacted are: oil and gas pipeline construction and transportation; natural gas distribution; fossil fuel electric power generation; petroleum bulk stations and terminals; petroleum refining; and mining, oil, and gas field machinery and equipment manufacturing.

Treatment of Indirect and Induced Employment Effects

We should note that these ancillary industries approximately match up with the industries in which *indirect employment* occurs resulting through fossil fuel sector production, as defined in the input-output tables, and as we have described above. In estimating the number of workers who would require some form of support through a Just Transition program, it is more accurate to focus on the direct employment figures for these eight ancillary fossil fuel industries as opposed to utilizing the indirect employment data from the input-output tables. For our purposes of developing a Just Transition program, we are able to incorporate important details on employment conditions in these eight ancillary industries by working with the available employment data on the specific eight industries as opposed to relying on a single generic category of indirect employment for the oil/gas and coal industries. At the same time, for the purposes of drawing comparisons with the figures we have presented above on employment creation through clean energy investments, it is useful to keep in mind that the figures we are reporting here on ancillary employment relative to the oil/gas and coal industries are the equivalent of the indirect employment figures we report in the clean energy industries.

In drawing out the comparison between employment impacts of clean energy investments versus employment losses through the fossil fuel industry contraction, we should also consider the relative size of the *induced employment effects* of the fossil fuel industry contraction, as we have also described that employment effect above. As we noted above, induced employment effects refers to the expansion of employment that results when people in any given industry—such as clean energy or fossil fuels—spend money and buy products. This increases overall demand in the economy, which means more people are hired into jobs to meet this increased demand. It follows that the loss of incomes through a contraction of employment will create a reverse induced employment effect. People will have less money to spend, overall demand for goods and services will contract, and therefore the demand for employees will decline correspondingly. However, because of the way we have proposed to implement a Just Transition program for fossil fuel related industry workers in Colorado, there will be no loss of income for fossil fuel dependent workers in the state, even as the industry itself contracts. It follows that implementing the Just Transition program will mean that there will also be no reverse induced employment effects in Colorado even as the fossil fuel industry itself contracts in the state. This will become clear after we describe the features of the proposed Just Transition program. We therefore return to this issue briefly at the end of this Just Transition section.

Measuring Fossil Fuel Employment Levels

In Table 26, we show employment levels for the 10 fossil fuel and ancillary industries in Colorado as of 2017. The first thing that stands out in Table 26 is there are only three large areas of employment. These include support activities for oil and gas, which is nearly 40 percent of the total in all sectors; oil and gas extraction, which is 32 percent of the total, and oil and gas pipeline construction and transportation, which is 15.4 percent of the total. In combination, these three industries employ 29,900 workers in Colorado, equal to 87 percent of all the state's employment in the fossil fuel and ancillary industries.

Of the remaining 13 percent of fossil fuel dependent jobs in Colorado, as Table 26 shows, 3.6 percent are in coal mining, and 0.6 percent are in coal-support activities. The remaining percentages are 2.8 percent for natural gas distribution; 1.9 percent for fossil fuel electric power generation; 1.7 percent are with petroleum bulk stations and terminals; 1.3 percent are in petroleum refining, and 1.0 percent are in mining, oil, and gas field machinery and equipment manufacturing.

Characteristics of Fossil Fuel and Ancillary Industry Jobs[37]

Table 27 provides basic figures on the characteristics of the jobs in Colorado for workers in fossil fuel dependent sectors. We focus first on the roughly 87 percent of the jobs that are in either support activities for oil and gas, oil and gas extraction, and pipeline construction and transportation (shown in columns 1 - 3 of Table 27). As the table shows, on average, these are relatively high-quality jobs. The average overall compensation is very high in oil and gas extraction, at $224,000. It is also high, if not at the level of extraction, with both support activities for oil and gas and pipeline construction and transportation, with compensation averaging $106,000 and $105,000 respectively. Overall, most of the existing pool of jobs

TABLE 26
Number of Workers in Colorado Employed in Fossil Fuel Production Activities and Ancillary Industries, 2017

Industry	Number of Employed Workers
Oil and gas extraction	10,982 *(32.0% of total)*
Coal mining	1,237 (3.6% of total)
Ancillary industries	
Support activities for oil/gas	13,633 *(39.7% of total)*
Support activities for coal	189 (0.6% of total)
Natural gas distribution	971 *(2.8% of total)*
Fossil fuel electric power generation	657 (1.9% of total)
Petroleum refining	460 *(1.3% of total)*
Petroleum bulk stations and terminals	574 *(1.7% of total)*
Oil and gas pipeline construction and transportation	5,286 *(15.4% of total)*
Mining, oil, and gas field machinery and equipment manufacturing	340 *(1.0% of total)*
TOTAL	**34,329**
TOTAL AS SHARE OF COLORADO STATE EMPLOYMENT	**1.2%**

Source: See Appendix 3. Support Activities for Oil/Gas includes "Drilling of oil and gas wells." Employed workers include self-employed workers. BLS estimate of Colorado's 2017 employment level=2.9 million..

in the fossil fuel related industries in Colorado offer better compensation levels than in the industries that would be growing through large-scale investments in energy efficiency and clean renewable energy.

In terms of private health insurance coverage, virtually all the industries are providing coverage for at least 80 percent of their workers, with the majority at over 90 percent. The one exception is pipeline construction and transportation, where only about 61 percent of employees receive health coverage. Overall here as well, health insurance coverage is higher than is generally true with the industries that would expand as a result of clean energy investments.

Union membership is generally low, including at between 5.1 and 7.7 percent for the three big employers—i.e. support activities for oil and gas, extraction, and pipeline construction and transportation. The industries that have significantly higher unionization rates are coal mining, at 29 percent, natural gas distribution, at 25 percent, and electric power generation, at 17 percent. Table 27 also reports figures on educational credential levels for workers in each of the 10 industries, as well the percentages of non-white and female workers. With

TABLE 27
Characteristics of Workers in Colorado Fossil Fuel and Ancillary Industries

	1. Support Activities for Oil and Gas* (13,633 workers)	2. Oil and Gas Extraction (10,982 workers)	3. Oil and Gas Pipeline Construction and Transportation (5,286 workers)	4. Coal Mining (1,237 workers)	5. Natural Gas Distribution (971 workers)
Average total compensation	$106,000	$224,000	$105,000	$119,000	$178,000
Health Insurance coverage percentage	78.1%	93.7%	60.5%	96.3%	85.8%
Union membership percentage	5.1%	5.7%	7.7%	29.3%	24.8%
Educational credentials					
Share with high school degree or less	38.4%	17.2%	47.9%	66.0%	21.3%
Share with some college or Associate degree	27.4%	22.5%	30.3%	24.5%	34.2%
Share with Bachelor's degree or higher	34.2%	60.3%	21.9%	9.5%	44.5%
Racial and gender composition of workforce					
Pct. non-white workers	24.5%	14.3%	36.3%	12.5%	11.3%
Pct. female workers	18.1%	31.6%	15.2%	4.6%	22.6%

TABLE 27 (*cont.*)
Characteristics of Workers in Colorado Fossil Fuel and Ancillary Industries

	6. Fossil Fuel Electric Power Generation (657 workers)	7. Petroleum Bulk Stations and Terminals (574 workers)	8. Petroleum Refining (460 workers)	9. Mining, Oil, and Gas Field Machinery and Equip. Manuf. (340 workers)	10. Support Activities for Coal* (189 workers)
Average total compensation	$146,000	$84,000	$181,000	$79,000	$69,000
Health Insurance coverage percentage	91.4%	84.9%	92.1%	91.8%	78.1%
Union membership percentage	16.7%	0.0%	9.1%	9.1%	5.1%
Educational credentials					
Share with high school degree or less	24.4%	27.2%	21.6%	38.7%	38.4%
Share with some college or Associate degree	38.0%	28.2%	33.4%	37.8%	27.4%
Share with Bachelor's degree or higher	37.6%	44.6%	45.0%	23.5%	34.2%
Racial and gender composition of workforce					
Pct. non-white workers	19.7%	13.6%	18.1%	22.2%	24.5%
Pct. female workers	23.5%	37.4%	19.8%	10.2%	18.1%

* For these sectors, the job quality measures (aside from compensation), and the demographic measures are based on a more aggregated sector that includes support activities for oil and gas and coal. Data on unionization among Colorado coal miners is taken from the Annual Coal Report for 2017 instead of the CPS. See: https://www.eia.gov/coal/annual/pdf/table20.pdf.

Source: See Appendix 3.

respect to educational credentials, the range is fairly wide. Thus, in oil and gas extraction, 60 percent have Bachelor's degrees and only 17 percent have high school degrees or less. At the other end, in support activities for oil and gas, 34 percent have Bachelor's degrees and 38 percent have high school degrees or less.

The share of female workers is quite low in each of the three large employers. Thus, in support activities for oil and gas, 18 percent is female; in oil and gas extraction, 32 percent is female, and in pipeline construction and transportation, 15 percent is female. As noted above, 46 percent of Colorado's labor force is female. Non-white workers, on the other hand, are over-represented in pipeline construction and transportation (36 percent), somewhat under-represented in support activities for oil and gas (24 percent), and significantly under-represented in oil and gas extraction (14 percent), compared to their proportion of Colorado's labor force (28 percent).

We can gain further detailed information on workforce and employment conditions for workers in these fossil fuel dependent industries in Colorado through the data in Tables 28 - 31. In these four tables, we report on the various job categories associated with each of the employers in the three large fossil fuel related employers in the state—oil and gas extraction, support activities for oil and gas, and pipeline construction and transportation—along with coal mining. For each of these four industries, we show the most prevalent job categories and the representative occupations in each job category.

The key finding that emerges from these tables is that the fossil fuel related industries in Colorado provide a wide range of employment opportunities for the roughly 34,000 workers

TABLE 28
OIL AND GAS EXTRACTION: Prevalent Job Types in Colorado Industry, 10,982 Workers
(Job categories with 5 percent or more employment)

Job Category	Percentage of Total Industry Employment	Representative Occupations
Management	21.4%	General managers; chief executives; property managers
Architecture and engineering	19.4%	Petroleum engineers; engineering technicians; environmental engineers
Office and administrative support	9.0%	Secretaries; administrative assistants; bookkeeping clerks
Extraction	8.6%	Mining machine operators; derrick operators, rotary drill operators
Financial specialists	6.9%	Accountants, auditors; financial analysts
Life, physical, and social science	6.6%	Environmental scientists; geoscientists; chemists
Construction	6.3%	First-line construction supervisors; construction equipment operators; structural iron and steel workers
Transportation and material moving	5.7%	Truck drivers; pumping station operators; crane operators
Business operation specialists	5.4%	Human resources workers; compliance officers, management analysts

Source: See Appendix 3.

TABLE 29

COAL MINING: Prevalent Job Types in Colorado Industry, 1,237 Workers

(Job categories with 5 percent or more employment)

Job Category	Percentage of Total Industry Employment	Representative Occupations
Extraction	46.2%	Mining machine operators; explosive workers, earth drillers
Construction	14.8%	First-line construction supervisors; construction equipment operators; electricians
Installation, maintenance, and repair	12.2%	Truck mechanics, heavy vehicle service technicians, machine maintenance workers,
Management	8.8%	Human resource managers, chief executives, operations managers

Source: See Appendix 3.

TABLE 30

OIL AND GAS EXTRACTION SUPPORT ACTIVITIES: Prevalent Job Types in Colorado Industry, 13,633 Workers

(Job categories with 5 percent or more employment)

Job Category	Percentage of Total Industry Employment	Representative Occupations
Extraction	24.2%	Derrick operators, rotary drill operators, extraction worker helpers
Management	13.8%	Operations managers, property managers, marketing managers
Construction	9.9%	First-line construction supervisors, construction equipment operators, pipelayers
Transportation and material moving	9.8%	Pumping station operators, truck drivers, laborers
Office and administrative support	9.0%	Secretaries, accounting clerks, general office clerks
Architecture and engineering	7.6%	Petroleum engineers, engineering technicians, surveyors
Production	5.6%	Inspectors, welding workers, stationary engineers
Installation, maintenance, and repair	5.3%	Heavy vehicle service technicians, industrial machinery mechanics, riggers

Source: See Appendix 3.

currently employed in these industries. Thus, with the two largest statewide employers in the fossil fuel industries—oil and gas extraction and support activities for oil and gas—there are large numbers of jobs in extraction, of course, but also management, office and administrative support, architecture and engineering, transportation and construction, among other occupations.

Overall, from the data presented in Tables 28 – 31, we see that there are a large number of jobs that match up well with new types of employment that will be generated through clean energy investments in Colorado. But that obviously will not be the case with *all occupa-*

TABLE 31
OIL AND GAS PIPELINE CONSTRUCTION AND TRANSPORTATION: Prevalent Job Types in Colorado Industry, 5,286 Workers
(Job categories with 5 percent or more employment)

Job Category	Percentage of Total Industry Employment	Representative Occupations
Construction	50.3%	Pipefitters, pipelayers, construction laborers
Management	15.6%	Construction managers, financial managers, operations managers
Office and administrative support	5.7%	Administrative assistants, bookkeeping clerks, information clerks
Transportation and material moving	5.0%	Pumping station operators, industrial truck operators, excavator operators

Source: See Appendix 3.

tions in which workers are now employed in Colorado's fossil fuel related industries. As such, any Just Transition program to support displaced workers in Colorado's fossil fuel related industries will need to be focused on the specific background and skills of each of the impacted workers. We now turn to considering the specific dimensions and features of such a Just Transition program.

Features of a Just Transition Program

We present here a Just Transition program for workers in Colorado that has three major elements. These are:

1. Guaranteeing the pensions for the workers in affected industries who will retire up until the year 2030;
2. Guaranteeing re-employment for workers facing displacement;
3. Providing income, retraining, and relocation support for workers facing displacement.

We describe each feature of this program in what follows, as well as provide estimates of the costs of effectively operating each measure within the overall program. In Section 9 below, we consider the distinct issues with respect to providing support for heavily impacted communities.

To translate these general principles of a Just Transition for fossil fuel industry related workers into specific policies, and to estimate the costs of providing these policies, we now examine a basic policy package. We present the provisions of this policy package in Table 32.

As we see in Table 32, the detailed policy package includes five components. These are:

1. Pension guarantees for retired workers who are covered by employer-financed pensions, starting at age 65;
2. Retraining to assist displaced workers to obtain the skills needed for a new job and 100 percent wage replacement while training;

TABLE 32
Policy Package for Laid Off Workers

Pension guarantees for workers (65+) voluntarily retiring	*- Legal pension guarantees*
Immediate re-employment through employment guarantee plus wage insurance and retraining support	*- Year 1: Re-employment with training and full wage insurance* *- Year 2: Additional year of training and full wage insurance* *- Year 3: Full wage insurance*
Retraining followed by re-employment through employment guarantee plus wage insurance	*- Year 1: Full-time training and full wage replacement* *- Year 2: Re-employment with additional year of training and full wage insurance* *- Year 3: Full wage insurance*
Relocation support	*- $50,000 for ½ of workers*

3. Re-employment for displaced workers through an employment guarantee, with 100 percent wage insurance. With wage insurance, workers are guaranteed that their total compensation in their new job will be supplemented to reduce any losses relative to the compensation they received working in the fossil fuel based industry;[38]
4. Relocation support for 50 percent of displaced workers, assuming only 50 percent will need to relocate; and
5. Full Just Transition support for workers 65 and over who choose not to retire.

Steady versus Episodic Industry Contraction

We will provide further details and cost estimates for each of these measures within the overall policy package. But before moving into the discussion of these cost estimates, it is first necessary to understand how any such policy measures will be affected by the conditions under which the fossil fuel industry contraction occurs in Colorado. Specifically, the scope and cost of any set of Just Transition policies will depend heavily on whether the contraction is steady or episodic.

Under a pattern of steady contraction, there will be uniform annual employment losses between 2021 – 2030 in the affected industries. But it is not realistic to assume that the pattern of industry contraction will necessarily proceed at a steady rate. An alternative pattern would entail relatively large episodes of employment contraction, followed by periods in which no further employment losses are experienced. This type of pattern would occur if, for example, one or more relatively large firms were to undergo large-scale cutbacks at one point in time as the industry overall contracts, or even for such firms to shut down altogether.

The costs of a 10-year Just Transition will be much lower if the transition is able to proceed smoothly rather than through a series of episodes. One reason is that, under a smooth transition, the proportion of workers who will retire voluntarily in any given year will be substantially greater than if several large businesses were to shut down abruptly and lay off their full work force at a given point in time. Another factor is that it will be easier to find new jobs for displaced workers if the pool of displaced workers at any given time is smaller.

We proceed here by assuming that Colorado will successfully implement a relatively smooth contraction of its fossil fuel industry. In his inaugural State of the State address in January 2019, Governor Polis emphasized that his administration is committed to providing the state's fossil fuel workers with a fair level of support during the industry's phase-out.[39] We interpret the governor's comments to indicate that his administration will be prioritizing, among other goals, a smooth transition process. A smooth transition should be workable as long as the state's policymakers remain focused on that goal.

Estimating Attrition by Retirement and Job Displacement Rates

In Table 33, we show figures on annual employment reductions in Colorado's coal and coal-related industries over 2021 – 30 that would result from a smooth 70 percent contraction in production. These coal-related industries include coal mining itself, coal-based electric power generation, support activities for coal mining and mining machinery and equipment manufacturing for coal.

In Table 34, we conduct the same exercise for workers in the oil and gas related industries, given that contraction in oil and gas over 2021 – 2030, at 40 percent, will be less sharp than that for coal. In this table, we therefore report results for: support activities for oil and

TABLE 33
Attrition by Retirement and Job Displacement for Workers in Colorado: Coal Industries

ASSUMPTION: 70 PERCENT CONTRACTION OF COAL INDUSTRIES

	1. Coal Mining	2. Coal-Based Electric Power Generation	3. Support Activities for Mining	4. Mining Machinery and Equipment Manufacturing	TOTALS
1) Current employment, total	1,237	507	189	92	2,025
2) Job Losses over 10-year transition, 2021-2030 *(= row 1 x .7)*	866	355	132	65	1,418
3) Average annual job losses over 10-year production decline *(= row 2/10)*	87	35	13	6	142
4) Number of workers reaching 65 over 2021–2030 *(= row 1 x % of workers 53 and over in 2018)*	383 *(31% of all workers)*	172 *(34% of all workers)*	36 *(19% of all workers)*	28 *(30% of all workers)*	619 *(31% of all workers)*
5) Number of workers per year reaching 65 during 10-year transition period *(= row 4/10)*	38	17	4	3	62
6) Number of workers per year retiring voluntarily *(= row 5 x 0.85)*	32	14	3	3	52
7) Number of workers requiring re-employment *(= row 3 – row 6)*	55	21	10	3	89

Source: See Appendix 3.

TABLE 34
Attrition by Retirement and Job Displacement for Workers in Colorado: Oil and Gas Industries

ASSUMPTION: 40 PERCENT CONTRACTION OF OIL AND GAS INDUSTRIES

	1. Support activities for oil and gas operations	2. Oil and gas extraction	3. Oil and gas pipeline construction and trans-portation	4. Natural Gas Distri-bution	5. Petroleum Bulk Stations and Terminals	6. Petroleum refining	7. Mining machinery and equip-ment manu-facturing	8. Natural gas-based electric power generation	TOTALS
1) Current employment, total	13,633	10,982	5,286	971	574	460	248	150	32,304
2) Job Losses over 10-year transition, 2021–2030 *(= row 1 x .4)*	5,453	4,393	2,114	388	230	184	99	60	12,922
3) Average annual job losses over 10-year production decline *(= row 2/10)*	545	439	211	39	23	18	10	6	1,292
4) Number of workers reaching 65 over 2021–2030	2,590	3,624	1,269	223	166	156	69	51	8,148
(= row 1 x % of workers 53 and over in 2018)	*(19% of all workers)*	*(33% of all workers)*	*(24% of all workers)*	*(23% of all workers)*	*(29% of all workers)*	*(34% of all workers)*	*(28% of all workers)*	*(34% of all workers)*	*(25% of all workers)*
5) Number of workers per year reaching 65 during 10-year transi-tion period *(= row 4/10)*	259	362	127	22	17	16	7	5	815
6) Number of workers per year retiring voluntarily *(= row 5 x 0.85)*	220	308	108	19	14	14	6	4	693
7) Number of workers requiring re-employ-ment *(= row 3 – 6)*	325	131	103	20	9	4	4	2	598

Source: See Appendix 3.

gas operations; oil and gas extraction; oil and gas pipeline construction and transportation; natural gas distribution; petroleum bulk stations and terminals; petroleum refining; mining machinery and equipment manufacturing; and natural gas-based electric power generation.

In Table 35, we then combine the results for the coal and oil and gas industries into one set of figures. We focus on these combined figures in Table 35 for estimating the effects of industry contraction on overall employment in all of Colorado's fossil fuel-related industries. In the rows of Table 35, we show the calculations through which we estimate employment losses in both the coal- and oil/gas related industries, assuming the 70 percent contraction in the coal sectors and 40 percent contraction in oil and gas.

We also then show the proportion of workers who will move into voluntary retirement at age 65 by 2030. Once we know the share of workers who will move into voluntary retirement at age 65, we can then estimate the number of workers who will be displaced through

TABLE 35
Summary Table: Attrition by Retirement and Job Displacement for Workers in Colorado: Coal, Oil and Gas Industries, Combined

	1. Coal Industries	2. Oil and Gas Industries	TOTALS
1) Current employment, total	2,025	32,304	34,329
2) Job Losses over 10-year transition, 2021-2030 *(= row 1 x .7)*	1,418	12,922	14,339
3) Average annual job losses over 10-year production decline *(= row 2/10)*	142	1,292	1,434
4) Number of workers reaching 65 over 2021–2030 *(= row 1 x % of workers 53 and over in 2018)*	619 *(31% of all workers)*	8,148 *(25% of all workers)*	8,797 *(26% of all workers)*
5) Number of workers per year reaching 65 during 10-year transition period *(= row 4/10)*	62	815	877
6) Number of workers per year retiring voluntarily *(= row 5 x 0.85)*	53	693	746
7) Number of workers requiring re-employment *(= row 3 – row 6)*	89	599	688

Sources: See Appendix 3.

the industry-wide contraction. As described above, the Just Transition program will provide support for all displaced workers through a re-employment guarantee along with wage replacement, retraining, and relocation support.[40]

All forms of Just Transition support will be fully available to those workers 65 and over who choose to continue working. We therefore need to estimate how many workers 65 and older are likely to choose to remain employed. For the fossil fuel sector taken as a whole, we approximate that about 15 percent of workers who are 65 and over choose to continue on their jobs.[41] We therefore assume that this same 15 percent of older workers will choose to continue working while the fossil fuel industry undergoes its contraction between 2021 – 2030. Specifically, we incorporate into our calculations in Tables 33 – 35 an estimate that, of the total number of workers reaching age 65 in any given year, 85 percent will retire voluntarily while 15 percent will choose to continue working.

We can see, step-by-step, how these various considerations come into play through the figures we show in in Table 35 on the coal industries in column 1. These are the total figures for the coal industries derived in Table 33. As we see in column 1 of Table 35, there are at present 2,025 workers in Colorado employed in all coal-related industries. We assume that these industries will face a 70 percent contraction as of 2030 relative to its 2015 production level. As we see in row 2 of the table, this means that total employment in the industry will fall by 70 percent, i.e. that 1,418 jobs will be lost by 2030. That means that 607 jobs will be retained in the state's coal-related industries as of 2030. If we then assume that the contraction in the industry proceeds at a steady rate between 2021 – 2030, this means that 142 jobs in the industry will be lost each year, as we see in row 3 (i.e. 1,418 job losses in total/10 years of industry contraction = 142 job losses per year).

We see in row 4 that, of the workers presently employed in the coal-related industries in Colorado, 619, or 31 percent, will be between 56 – 65 over 2021 – 2030. If all these workers were to voluntarily retire at a steady rate over 2021 – 2030, this would mean that 62 workers will move into retirement every year over the 10-year period. However, we are assuming that only 85 percent of these workers will retire once they reach 65. That is, as we see in row 6, we estimate that 53 workers in the coal-related industries will retire voluntarily every year between 2021 – 2030.

Given that total job losses each year will average 142 over the 2021 – 2030 period, that in turn means that the total number of workers in the coal-related industries requiring re-employment will be 89 per year. We show this figure in row 7 of Table 35.

This is a critical result. The point it conveys is that, under a steady pattern of job contraction in Colorado's coal-related industries to reach a 70 percent job cut as of 2030, the Just Transition program will need to focus in two areas: 1) Guaranteeing the pensions for the 53 workers per year moving into voluntary retirement; and 2) Providing all the forms of re-employment support, including the re-employment guarantee, for the 89 workers facing displacement.

We show the equivalent calculations for the oil and gas industries in column 2 of Table 35. As we see in rows 6 and 7 of column 2, for the oil and gas industries, which now employs 32,304 workers in Colorado, we estimate that there will be 693 workers each year moving into voluntary retirement, and 599 who will require retraining, re-employment with wage insurance, and relocation support.

Combining the results for both the coal- and oil/gas-related industries in column 3 of Table 35, we estimate that under a steady contraction of the fossil fuel industries in Colorado between 2021 – 2030, 746 workers per year will move into voluntary retirement and 688 will become displaced.

Why Job Displacements Equals Only 688 Workers per Year

This result represents a major conclusion within our overall framework for advancing a viable Just Transition program for Colorado. It will therefore be useful to examine it in more detail before moving on.

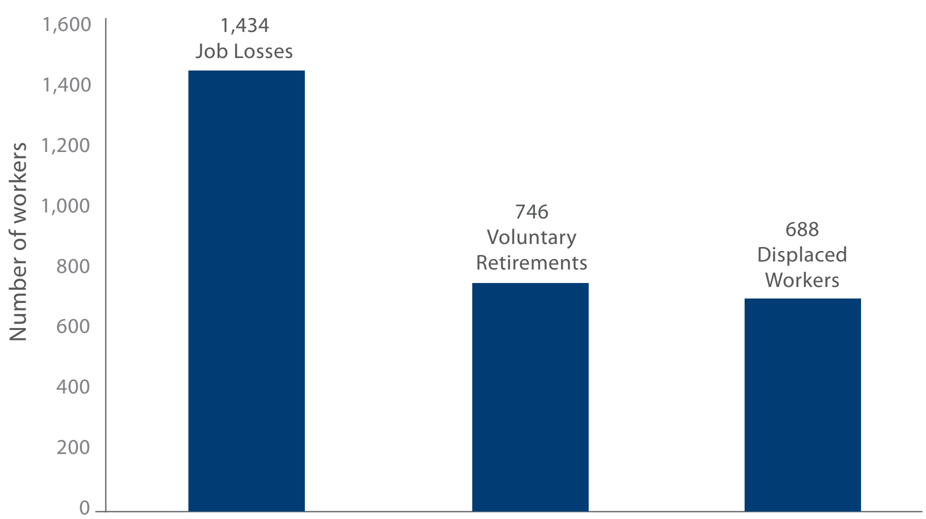
Given that there are approximately 34,000 people employed in the 10 fossil fuel related industries in Colorado as of 2015, it may appear implausible that there should be only 688 workers per year who would be displaced through a 70 percent contraction in coal and a 40 percent contraction in oil and gas production as of 2030. But this finding is not due to any kind of unreasonable assumptions or incomprehensible mathematical manipulations. In fact, it is a quite straightforward and intuitive result, following from the main findings that we present in Table 35. Consider the following simple, logical steps:

1. **Total number of workers and job losses.** While there are, again, approximately 34,000 people employed in total in Colorado's fossil fuel related industries, as we have discussed above, we estimate that, as a first approximation, employment contraction in the industry will be 40 percent as of 2030. This implies that about 60 percent of the 34,000 jobs—i.e. about 20,000 jobs—will remain intact as of 2030. The total job losses as of 2030 will therefore be about 14,000, i.e. 40 percent of the current industry employment level of about 34,000.

2. **Job losses per year.** The total of 14,000 jobs will not all be lost at once. Rather, the 40 percent job losses in these industries will occur over the full period 2021 – 2030. As an average figure, that translates to 1,400 jobs lost per year between 2021 – 2030.
3. **Voluntary retirements.** We show in Table 35 that about 26 percent of all workers currently employed in Colorado's fossil fuel related industries will turn 65 between 2021 and 2030. We assume that 85 percent of these workers will move into voluntary retirement between 2021 and 2030, while 15 percent will choose to continue working. As we show in Table 35, this amounts to 746 workers moving into voluntary retirement per year.
4. **Combining job losses and voluntary retirements.** Working now with our exact estimates, we find that 14,339 jobs in the state's fossil fuel related industries will be lost per year between 2021 – 2030 and that 746 workers will move into voluntary retirement. It follows then that an average of 688 workers (= 14,339 - 746) will require re-employment.

In Figure 2, we illustrate these main features of our calculations as applied to the combined figures for both the coal, as well as oil and gas industries shown in Table 35.

FIGURE 2: Estimated Annual Job Losses, Voluntary Retirements and Workers Displaced in Colorado's Fossil Fuel Related Industries, 2021–2030



Source: See Table 35.

Pension Guarantees for Retiring Workers

What becomes clear from the evidence on the steady rate of contraction for Colorado's fossil fuel related industries is that guaranteeing workers' pension funds must be a centerpiece of the state's overall Just Transition program. This is especially important, given that the fossil fuel dependent industries will be contracting over 2021 – 2030. They will likely face financial challenges as a result.

In Table 36, we provide evidence on the status of the pension funds for the firms currently operating in Colorado in all of the major relevant industries. The table shows the names of the 25 firms operating in Colorado as well as, in parentheses, these firms' parent companies, where applicable.

We have divided the 25 firms into three main groups:

- 7 publicly-traded firms that provide pensions to their employees;
- 10 publicly-traded firms that do not provide pension plans; and
- 7 private firms for which there is no publicly-available information on pensions or other financial data.

We also list separately one private non-profit cooperative firm, Elk Ridge Mining and Reclamation. Elk Ridge is a non-profit wholesale electric power supplier. We do not have financial data on Elk Ridge other than their income level for 2015-17, which we report in Table 36.

Given the differences between these 25 firms, one cannot generalize about the specific issues around protecting the pensions of their employees. Focusing first on the 7 publicly-traded firms in panel A which do provide pensions for their workers, we see that 5 of the firms are carrying unfunded liabilities, while 2 have overfunded pension funds. Of the five with unfunded liabilities, none of the unfunded liabilities are large relative to the firms' other financial indicators. Thus, Chevron has the largest unfunded liability, at $1.51 billion. However, its net income for 2015-17 was $13.5 billion and its dividend payments amounted to $24.2 billion. Kinder Morgan is carrying the next largest unfunded liability, at $274 million. But it also received $1.2 billion in income and paid out $6.8 billion in dividends over 2015-17. With these 7 firms, it is reasonable to conclude that all of their pension funds are financially sound at present. This status needs to be guaranteed through financial regulations as Colorado's fossil fuel industry contracts.

Considering now the 10 publicly-traded firms shown in panel B which do not provide pensions for their employees, we see from the available data that 8 of the firms experienced net income losses over 2015 – 17. In addition, most of these firms neither paid out dividends to shareholders nor engaged in stock buybacks over 2015 – 17. The two firms that were profitable over 2015 – 17 were Pioneer Natural Resources and GCC Energy, though the profits of Pioneer were a modest $4 million. The workers employed by these firms will not face any threat of losing their pensions, since they have not been provided with pension plans to begin with. But given their lack of pension fund support, it will be critical that the workers at these firms be provided with the full range of additional Just Transition support as they face displacement. This is especially the case since the financial data that we have on these 10 firms suggests that most of them are already financially vulnerable.

TABLE 36

Status of Pension Funds and Overall Financial Conditions for Fossil Fuel Related Firms Operating in Colorado, 2015–2017

All the data are for parent companies (Parent companies in parentheses)

A) Firms with Publicly Reported Pension Fund Data

	Unfunded Pension Liabilities, 2017	Net Income, 2015–2017	Dividends, 2015–2017	Share Buybacks, 2015-2017
1. BP America Production Company (BP PLC)	$0 *(overfunded by $360 million)*	-$2.8 billion	$17.4 billion	$343 million
2. Burlington Resources Oil & Gas, LP (ConocoPhillips)	$180 million	-$8.7 billion	$6.2 billion	$3.1 billion
3. Chevron USA, Inc (Chevron Corp.)	$1.51 billion	$13.5 billion	$24.2 billion	$0
4. Kerr-McGee Oil & Gas Onshore, LP (Anadarko Petroleum Corp.)	$44 million	-$9.8 billion	$769 million	$1.2 billion
5. Kinder Morgan CO2 Company, LP (Kinder Morgan, Inc.)	$274 million	$1.2 billion	$6.8 billion	$262 million
6. Twentymile Coal, LLC (Peabody Energy Corp.)	$59 million	-$2.4 billion	$1 million	$176 million
7. Mountain Coal Company, LLC (Arch Coal, Inc.)	$0 *(overfunded by $16 million)*	-$1.4 billion	$24 million	$302 million

B) Publicly Traded Firms without Pension Plans

	Net Income, 2015–2017	Dividends, 2015–2017	Share Buybacks, 2015–2017
1. Bill Barrett Corporation (HighPoint Resources)	-$643 million	$0	$0
2. Bonanza Creek Energy Operating Company, LLC (Bonanza Creek Energy, Inc.)	-$924 million	$0	$0
3. Extraction Oil & Gas, LLC	-$548 million	-$11 million	$5 million
4. Noble Energy, Inc.	-$4.5 billion	$653 million	$0
5. PDC Energy, Inc.	-$442 million	$0	$0
6. Piceance Energy, LLC (Par Pacific Holdings, Inc.)*	-$97 million	$0	$1 million**
7. Pioneer Natural Resources USA, Inc. (Pioneer Natural Resources Co.)	$4 million	$39 million	$0**
8. SRC Energy, Inc.	-$59 million	$0	$4 million**
9. Whiting Oil and Gas Corporation (Whiting Petroleum Corp.)	-$4.8 billion	$0	$0
10. GCC Energy, LLC (Grupo Cementos De Chihuahua)	$190 million	$26 million	$0

*The actual parent company of Piceance Energy, LLC is Laramie Energy II, LLC. There is very little public data about either company. However, Par Pacific Holdings, Inc. has a 42.3% ownership interest.

**Only reported Oct. through Nov. in form 10-K.Source: See Appendix 4.

TABLE 36 ***(cont.)***

Status of Pension Funds and Overall Financial Conditions for Fossil Fuel Related Firms Operating in Colorado, 2015–2017

All the data are for parent companies (Parent companies in parentheses)

C) Private Firms with No Publicly Reported Financial Data
1. Caerus Picance, LLC
2. Great Western Operating Company, LLC
3. Hilcorp Energy Company
4. Ursa Operating Company, LLC (Ursa Resources Group II, LLC)
5. WPX Energy Rocky Mountain, LLC (Terra Energy Partners, LLC)
6. Blue Mountain energy (Deseret Generation and Transmission Co-Operative)
7. Trapper Mining, Inc.

D) Private Cooperative Firm with No Pension Fund Data
1. Elk Ridge Mining and Reclamation, LLC (Tri-State Generation and Transmission Association, Inc.). No pension fund data. Reported Income, 2015–17: $147 million.

Source: See Appendix 4.

We cannot generalize about the 7 private firms listed in panel C, since we have no financial data on their operations. But it is likely that, like the 10 firms listed in panel B, they are not providing pensions for their workers.

Because of the large differences in the situations facing these 25 firms according to the three main categories in which they fall, it would be most useful to focus on some general points on the issue of pension fund protection as a feature of a Just Transition program. The first point is that, given that the coal-related firms will need to contract by 70 percent by 2030 and the oil/gas firms by 40 percent, we cannot expect those that are carrying pension funds to replenish them over this period as a matter of course. It should therefore be a priority of Colorado state policy to mandate full funding, to the extent that this is possible within existing state law or through establishing new regulations. This could also be achieved in coordination with federal government regulators, at the Pension Benefit Guarantee Corporation (PBGC). One way to enforce this would be to prohibit the relevant companies from paying dividends or financing share buybacks until their pension funds have been brought to full funding and then maintained at that level. As needed, the state government, again in coordination with the PBGC, could consider placing liens on company assets when pension funds are underfunded. Through such measures, the pension funds for most of the affected workers can be protected through a regulatory intervention alone, without the government having to provide financial infusions to sustain the funds.

At the same time, it will be likely that one or more of the firms will experience serious financial crises in the future, especially given the fact that the market for their products will be contracting substantially through 2030 and beyond. As a roughly comparable case in point, some coal companies operating throughout the U.S. do now already face critical conditions with their pension funds, due to cutbacks in U.S. coal demand. Under such conditions, the pension commitments to the affected workers, in coal nationally as well as all fossil fuel and ancillary industries in Colorado, will still need to be fully honored.

In addressing the ongoing crisis with coal industry pensions, the Obama administration had proposed in 2015 a measure to support the pensions, under its "Power Plus" program that aimed broadly to support coal communities and workers.[42] This proposal was blocked in the U.S. Congress by the Republican majority. But the broader point is that the equivalent of such a measure must be understood as a centerpiece for any Just Transition program for Colorado. Without having further detailed information on the current status of the pension plans for all 25 firms, we cannot estimate what the funding would need to be for a Colorado-level equivalent of the Obama administration's Power Plus program. But, in general, a pension insurance-type policy is a measure that deserves careful attention in ongoing work to develop specifics of a Colorado Just Transition program.

Support for Displaced Workers under Steady Employment Contraction

As we saw in Table 35, an average of 688 workers per year in Colorado's fossil fuel and ancillary industries will face displacement through a 70 percent contraction in production in the state's coal industry and a 40 percent contraction in oil and gas. This will be after 746 workers per year voluntarily retire at age 65 through 2021 – 2030, with their positions not being replaced when they move into retirement. The state's Just Transition program should, again, provide four types of support for displaced workers: 1) guaranteed re-employment; 2) income support through wage insurance; 3) retraining; and 4) relocation support.

We assume in our calculations that workers in managerial positions in the fossil fuel industry will be able to move more readily into comparable positions in other sectors, including the expanding clean energy industry in Colorado and elsewhere. This is because the general skill set to perform managerial skills will be similar across sectors of the economy. This is far less likely to be the case for workers engaged in mining or energy extraction activities. Because managers constitute about 15 percent of all employees in the fossil fuel industries, our focus in estimating the costs of a Just Transition program will be on covering the roughly 585 workers displaced who do not hold managerial positions.[43]

It is certainly possible that workers in other occupations within Colorado's existing fossil fuel-related sectors will also be able to move into their new guaranteed jobs without either: 1) facing a pay cut for which they would be compensated through wage insurance; 2) having to retrain, whose costs would be covered by the Just Transition program; or 3) relocate, whose costs the Just Transition program would also cover. Among the occupations listed in Tables 28 – 31 as being prevalent in the various fossil fuel-related sectors, the ones, in addition to managers, in which displaced workers might move more readily into new jobs could include: Business Operation Specialists, Financial Specialists, Physical and Social Scientists, Architecture and Engineering, Office and Administrative Support, and truck drivers as one occupation within the job category of Transportation and Material Moving. To the extent that these workers are able to move into guaranteed new jobs without having to take a pay cut, retrain or relocate, the total funding requirements for the state's Just Transition program would fall correspondingly. Nevertheless, for the purposes of our analysis, it is preferable that, if anything, we err through overstating rather than understating the costs of the Just Transition program. As such, we proceed by assuming that Colorado's Just Transition program will need to provide full benefits to support 585 workers per year between 2021 – 2030.

Guaranteed Re-employment

These new employment opportunities could perhaps be in the expanding clean energy sectors, with approximately 80,000 new direct plus indirect jobs created per year in Colorado through clean energy investments at the level of $14.5 billion per year (see Table 12). The new clean energy projects are likely to be financed at least partially through public-sector funding. Given such public sector funding, the state could require job preference provisions for the displaced workers.

As a broader back-up provision, the job guarantees could be provided within Colorado's state and municipal job markets. At present, total employment in either state or municipal employment in Colorado is about 360,000 (with state employment at roughly 100,000 and municipal at 260,000). Between this pool of 360,000 jobs and the additional roughly 80,000 jobs generated by clean energy investments, it should not be difficult to find good, new job opportunities for the roughly 585 fossil fuel industry dependent workers per year who will face displacement (excluding top managers). These 585 workers constitute 0.14 percent of the 440,000 jobs that are either in Colorado's state or municipal government sectors or will be created by the clean energy investments in the state needed to drive down CO_2 emissions to 48 million tons by 2030.

Income Support

Though it should not be difficult to find new employment opportunities for the 585 non-managerial fossil fuel and ancillary industry workers that will be displaced annually on average, there is a high likelihood that the new jobs will be at lower pay levels than the previous jobs. It will therefore be necessary for these workers to be provided with wage insurance so that they experience no income losses in their transition from fossil fuel industry jobs into new positions.

To provide some initial specifics on the costs of such a measure, we propose that all displaced workers receive 100 percent compensation insurance for three years. That is, they will be paid the full difference between any disparities in the compensation they receive in their new jobs relative to what they received in their previous jobs in the fossil fuel or ancillary industries.

The data in Table 37 presents a framework for calculating a rough estimate as to what the costs would be for such a compensation insurance program. In column 1, the table shows the figures we have seen in Tables 33 – 35 on the number of displaced workers that require re-employment annually through the project of cutting coal production by 70 percent and oil and gas by 40 percent as of 2030, now adjusted to only include non-managerial workers. Column 2 then shows the average compensation in each of the affected industries at present.

In column 3, we show the difference between these average industry-specific compensation figures relative to the average compensation level for Colorado state and local gov-

TABLE 37

Estimating Annual Costs of 100 Percent Compensation Insurance for Displaced Fossil Fuel Industry Dependent Workers, Excluding Top Managers

Average 2017 compensation for Colorado state and local government employees = $75,000

	1) Number of workers per year requiring re-employment	2) Average compensation in industry, 2017	3) Difference between fossil fuel and public sector jobs (= column 2 - $75,000)	4) Annual costs for compensation insurance (= columns 1 x 3)
Coal Industries				
1. Coal mining	47	$119,000	$44,000	$2,068,000
2. Coal-based electric power generation	18	$146,000	$71,000	$1,278,000
3. Support activities for coal	9	$69,000	$0	$0
4. Mining machinery and equip. manuf.	3	$79,000	$4,000	$12,000
Oil and Gas Industries				
5. Support activities for oil and gas	276	$106,000	$31,000	$8,556,000
6. Oil and gas extraction	111	$224,000	$149,000	$16,539,000
7. Oil and gas pipeline construction and trans-portation	88	$105,000	$30,000	$2,640,000
8. Natural gas distribution	17	$178,000	$103,000	$1,751,000
9. Petroleum bulk stations and terminals	8	$84,000	$9,000	$72,000
10. Petroleum Refining	3	$181,000	$106,000	$360,400
11. Oil, and gas field machinery and equip. manuf.	3	$79,000	$4,000	$12,000
12. Oil and gas based electric power generation	2	$146,000	$71,000	$142,000
TOTALS	**585**	---	---	**$33.4 million**
AVERAGE WAGE INSURANCE COST PER WORKER				**$57,000** (=$33.4 million/585 workers)
TOTAL INSURANCE COSTS FOR 3 YEARS OF COVERAGE				**$100.3 million** (=$33.4 million x 3 years)

Sources: Estimates based on data in Tables 27, 33-35. Note that with the exclusion on top managers, the number of displaced workers requiring re-employment support equals 85 percent of the number of displaced workers in Tables 33-35, i.e., 85 percent of 688, or 585.

ernment employees, which, as we see, was $75,000 in 2017. Of course, we cannot assume that all displaced workers will be moved into Colorado public sector jobs once they are laid off from their fossil fuel or ancillary industry job. Some will certainly move into the rapidly expanding clean energy industries. But because the public sector employment market can serve as the underlying basis for the displaced workers' re-employment guarantees, it is reasonable to work with the Colorado public sector compensation figure as a benchmark for our wage/compensation insurance exercise.

Thus, for example, with workers in the coal mining industry, we see in column 3 of Table 37 that the difference in average compensation between these workers in their present jobs and an average Colorado public sector job is $44,000. We therefore calculate that average compensation insurance per year for these workers will be $2.1 million (i.e. $44,000 x 47 workers). We then perform the same calculation for the displaced workers in other industries that require re-employment as well. From this we estimate that one year's worth of total compensation insurance for all 585 displaced workers per year will be $33.4 million, about $57,000 per worker.[44] Three years' worth of total compensation insurance for all displaced workers will therefore be $100.3 million.

Retraining Support

As we have seen above (Tables 20-22), the range of new jobs that are being generated through clean energy investments is wide. These jobs vary widely in terms of their formal educational credentials as well as special skill requirements. Some of the jobs will require skills closely aligned with those that the displaced workers used in their former fossil fuel industry jobs. These include a high percentage of construction-related jobs for efficiency investments as well as most management, administrative and transportation-related positions throughout the clean energy industries. In other cases, new skills will have to be acquired to be effective at the clean energy industry jobs. For example, installing solar panels is quite distinct from laying oil and gas pipelines. This is why a Just Transition program must include a provision for retraining for the displaced fossil fuel industry workers. The Just Transition program will also need to serve as a job placement clearinghouse for all displaced workers.

There will be two components of this job retraining program for displaced workers. The first will be to finance the actual training programs themselves. We can estimate this with reference to the overall costs of providing community college education. An upper-end figure for annual non-housing costs for community college in Colorado is around $6,000.[45] We then also allow an additional $2,000 per year per worker to cover other expenses during their training program, such as purchases of textbooks and equipment. We assume that workers would require the equivalent of two full years of training, which they would most likely spread out on a part-time basis, as they move into their guaranteed jobs. By this measure, the full costs of the training program for 585 workers would be about $9.4 million (= 585 x $16,000). We therefore assume this $9.4 million figure for retraining costs under a smooth transition scenario.

In addition, it will be likely that some displaced workers will need to receive their retraining before they move into their new jobs. These workers will need to continue to receive wage replacement support while they pursue full-time retraining. As a rough approximation as to these additional costs for full-time retraining for some workers, let us assume that one-half of all displaced workers each year will require as much as one year of full-time retraining. That would amount to about 293 workers per year requiring full compensation during their 1-year retraining period. From the figures in Table 37, we estimate that full compensation for the average fossil fuel worker is $132,000.[46] The gross costs of this wage replacement program for workers in full-time retraining would therefore be $38.7 million per year.

At the same time, the net costs of this wage replacement program would be significantly lower. This is because the state will not need to pay for one year of wage insurance for these 293 workers while they undergo retraining with full wage replacement benefits. As we saw in Table 37, the average annual wage insurance costs will be $57,000 per worker. Thus, the savings for not paying wage insurance to these workers would be $16.7 million (= $57,000 x 293). The net cost of the wage replacement portion of the retraining program would therefore be about $22.0 million per year (i.e. = $38.7 million - $16.7 million).

Relocation Support

Some of the displaced workers will need to be relocated to begin their new jobs. For the purposes of our discussion, we assume that one-half of the 585 displaced workers per year will need relocation allowances, at an average of $50,000 per displaced worker.[47] That would bring the annual relocation budget to about $14.7 million.

Overall Costs for Supporting Displaced Workers

An approximation of the overall costs of supporting 585 non-managerial displaced workers will include the following:

1. 100 percent compensation insurance for three years, totaling $100.3 million;
2. Retraining for 2 years, totaling $9.4 million
3. 100 percent wage replacement for 293 workers who train full-time for one year, adding a net of $22.0 million; and
4. Relocation support, totaling $14.7 million.

This would bring the overall costs of supporting these 585 displaced workers to about $146 million. However, we need to make one additional adjustment to these spending figures. These spending figures do not take into account that displaced workers receiving Just Transition wage insurance will not be drawing benefits from Colorado's unemployment insurance program. The fact that these displaced workers will receive wage insurance through the Just Transition program instead of unemployment insurance effectively represents a cost savings for the State. We estimate that, in the absence of the Just Transition program, the State's total expenditures on unemployment insurance benefits for the 585 displaced workers would be about $9.1 million annually, or $91 million over the entire period.[48]

Taking this cost savings into account, this brings the overall costs of supporting these 585 displaced workers to about $137 million ($146 million - $9 million). This amounts to an average of about $234,000 per worker. This amounts to $78,000 per worker per year over 3 years of support.

We also reiterate that, if anything, this is a high-end estimate of what the overall Just Transition costs are likely to be. This is because, as noted above, workers in other occupations within Colorado's existing fossil fuel-related sectors will also be able to move into their new guaranteed jobs without either: 1) facing a pay cut for which they would be compensated through wage insurance; 2) having to retrain, whose costs would be covered by the Just Transition program; or 3) relocate, whose costs the Just Transition program would also cover. To the extent that these workers are able to move into guaranteed new jobs without having to take a pay cut, retrain or relocate, the total funding requirements for the state's Just Transition program would fall correspondingly.

In Table 38, we show estimates of the full costs of providing this set of Just Transition benefits, this time accounting for how the costs change from year to year as well as accounting for all of the cohorts of displaced workers—585 workers displaced each year over the entire 10-year transition between 2021 and 2030. As Table 38 shows, the total level of annual spending will vary, depending largely on the number of cohorts of displaced workers that are receiving Just Transition benefits.

For example, in 2021, the first cohort of 585 displaced workers will receive support through the Just Transition program. These workers will receive retraining support, alongside full wage replacement if they need to train full-time before re-employment, or wage insurance if they are immediately re-employed. Additionally, the program will cover the moving expenses of those workers in this cohort who need to relocate. Columns 1 – 3 of the first row of Table 38 show the annual cost of these benefits totals to $74.7 million. In column 4, we net

TABLE 38

Annual Costs of Just Transition Support for Colorado's Displaced Fossil Fuel-Related Industry Workers, Excluding Top Managers

Support for 585 Displaced Workers Per Year During 2021-2030 Transition, Costs in millions

Year	Income Support	Retraining Support	Relocation Support (1 cohort every year)	Unemployment Insurance Savings (1 cohort every year)	Total (Cols. 1+2+3-4)
2021	$55.4 million (1 cohort)	$4.7 million (1 cohort)	$14.7 million	$9.1 million	$65.6 million
2022	$88.8 million (2 cohorts)	$9.4 million (2 cohorts)	$14.7 million	$9.1 million	$103.7 million
2023	$122.2 million (3 cohorts)	$9.4 million (2 cohorts)	$14.7 million	$9.1 million	$137.1 million
2024	$122.2 million (3 cohorts)	$9.4 million (2 cohorts)	$14.7 million	$9.1 million	$137.1 million
2025	$122.2 million (3 cohorts)	$9.4 million (2 cohorts)	$14.7 million	$9.1 million	$137.1 million
2026	$122.2 million (3 cohorts)	$9.4 million (2 cohorts)	$14.7 million	$9.1 million	$137.1 million
2027	$122.2 million (3 cohorts)	$9.4 million (2 cohorts)	$14.7 million	$9.1 million	$137.1 million
2028	$122.2 million (3 cohorts)	$9.4 million (2 cohorts)	$14.7 million	$9.1 million	$137.1 million
2029	$122.2 million (3 cohorts)	$9.4 million (2 cohorts)	$14.7 million	$9.1 million	$137.1 million
2030	$122.2 million (3 cohorts)	$9.4 million (2 cohorts)	$14.7 million	$9.1 million	$137.1 million
2031	$66.8 million (2 cohorts)	$4.7 million (1 cohort)	$0.0 million	$0.0 million	$71.5 million
2032	$33.4 million (1 cohort)	$0.0 million	$0.0 million	$0.0 million	$33.4 million
Total	**$1,221.8 million**	**$93.8 million**	**$146.5 million**	**$91.0 million**	**$1,371.1 million**
				Annual Average	**$114.3 million**

Note: Income support includes both wage insurance for workers when re-employed as well as wage replacement for workers training full-time. Retraining support includes training costs only
Sources: See Tables 32, 37 and accompanying text.

out the cost of the unemployment insurance benefits ($9.1) that the State would not have to spend since these workers are receiving benefits through the Just Transition program. Column 5 shows that the total net cost of Just Transition benefits in this first year would therefore be $65.6 million.

In the following year, 2022, the first cohort will continue to receive Just Transition benefits in the form of wage insurance, as well as another year of training support, a total net cost of $38.1 million. A second cohort of 585 of displaced workers will join the first, for a total of 1,170 workers in the Just Transition program in 2022. This net cost of Just Transition benefits for this second cohort of displaced workers will be the same amount of $65.6 million as for the first cohort in their first year. Therefore, for 2022, the cost of the total benefits for these 1,170 displaced workers is $103.7 million ($38.1 million + $65.6 million). For each year thereafter through 2030, a new cohort of displaced workers will enter the Just Transition program. As Table 38 shows, the highest annual cost of the Just Transition program is $137.1 million.

By 2024, the first cohort of displaced workers will have received 3 years of support and will leave the program. For each year thereafter, another cohort of workers will have completed their three years of program participation. By 2030, when the last cohort of displaced workers enters the Just Transition program, the annual program costs will decrease through 2032, the last year of the program.

In total, Just Transition benefits provided to 5,850 workers between 2021 and 2032 is $1.4 billion, averaging at $114 million per year.

Just Transition Program Prevents Induced Employment Losses

As described above, because of the way we have proposed to implement a Just Transition program for fossil fuel related industry workers in Colorado, there will be no loss of income for fossil fuel dependent workers in the state, even as the fossil fuel industry itself contracts. It follows that implementing the Just Transition program will mean that there will also be no reverse induced employment effects in Colorado resulting from the contraction of the fossil fuel industry in the state. This should now be clear within the context of the Just Transition program that we have outlined above. Specifically, as we have seen, the state's fossil fuel industry workers will either move into voluntary retirement with no loss of pension income or they will transition into the new jobs that will be guaranteed to them. Further, workers will experience no loss of income in transitioning to their new jobs because of the wage insurance component of our Just Transition program. Given these features of the Just Transition program, there will be no reduction in the induced employment levels generated by spending from the workers formerly employed in the fossil fuel industries, since none of these workers will experience income losses resulting from Colorado's transition into a clean energy economy.

9. A CLEAN ENERGY INVESTMENT POLICY AGENDA

We have seen in Section 6 that, for Colorado to achieve a 50 percent reduction in CO_2 emissions by 2030 relative to 2005—i.e. from an overall level of emissions of 95.2 to 48 million tons—the state's economy will need to invest an average of $14.5 billion per year to both dramatically raise the state's energy efficiency standards and to equally dramatically expand the available supply of clean renewable energy. This figure amounts to about 3.5 percent of Colorado's average GDP between 2021 – 2030, assuming that the state's GDP grows by an average of 2.4 percent per year over that 10 year period.

In this section, we consider what would constitute an effective package of policies for reaching this overall investment level averaging $14.5 billion per year. As we have discussed above, we estimate that, for 2017, private investment in clean energy in Colorado amounted to roughly $2.4 billion. We are therefore proposing that overall clean energy investments will need to increase, on average, by 6-fold to achieve a 50 percent emissions reduction as of 2030.

We can divide the policy agenda according to four broad categories. These are:

Market-shaping taxes and regulations that take account of the social costs of burning fossil fuels as an energy source and help build demand for energy efficiency and clean renewable energy sources.

Direct public spending that includes investments in infrastructure, procurement and research and development (R&D).

Private investment incentives that lower the costs and risks for private investors for investments in energy efficiency and clean renewable energy sources.

Transitional support for regions, communities and workers facing cutbacks and job losses through the contraction of the fossil fuel industry.

In Section 8, we have already examined at length the issue of a Just Transition for workers facing displacement through the contraction of Colorado's fossil fuel industries. In this section, we therefore focus on the areas of regulation, public spending, private investment incentives, and transitional support for communities.

We emphasize at the outset that the majority of new investment spending will need to come from private investors. Carefully targeted public investments can serve both to complement and incentivize private investments. We also emphasize at the outset that Colorado already operates with a range of measures in most of the policy areas listed. These policies are described in the *Colorado Climate Plan*, the most recent edition of which was published in 2018. We draw on the 2018 *Climate Plan* as well as related materials in what follows.

Carbon Pricing

One widely-recognized regulatory approach for reducing CO_2 and other greenhouse gas emissions is to establish a price on carbon that reflects the environmental costs of emissions. This can be done in two distinct ways—either through setting a firm limit on emissions—a carbon cap—or through establishing a carbon tax.

Depending on the specific design features of the policy, the cap or tax can be an effective tool supporting a large-scale transition out of fossil fuels and into energy efficiency and clean renewable energy investments. This policy can also generate large amounts of tax revenue. The revenue, in turn, can be used to support three equally critical but distinct purposes:

- Financing a share of the overall clean energy investment levels;
- Supporting Just Transition policies;
- Returning a share of the revenues back to taxpayers so that their living standards are not reduced through having to pay higher fossil fuel prices.

To date, Colorado does not have a carbon pricing policy in place. The recently-elected Governor Jared Polis expressed ambivalent views on a carbon tax during the 2018 gubernatorial campaign. Yet he has also consistently supported carbon taxes as a federal government policy. A *Denver Post* story in October 2018 described the Governor's position as follows:

> He's long supported a federal carbon tax, which targets fossil fuels to reduce greenhouse gas emissions. At a debate last week, Polis said he would consider a state-level carbon tax if elected governor, as long as the new revenue were used to reduce state income taxes. He later clarified that while he's open to the idea, a carbon tax is "not part of my agenda."[49]

As with most policy interventions, both carbon taxes and carbon caps have strengths and weaknesses. There is a longstanding debate as to their relative merits. The 2017 study *Colorado's Climate Blueprint: Actions for Addressing Climate Change and Safeguarding Our Future* highlights the strength of both approaches, referring to them as "market-based carbon policies."[50] The study argues as follows:

> A market-based carbon policy puts a price on carbon, so businesses and consumers realize the cost of emitting carbon pollution and can make rational choices whether—and how—to reduce their pollution. Market-based policies provide flexibility for businesses to calculate whether to reduce their emissions or pay to continue emitting, and they incentivize businesses to make the cheapest reductions first, lowering prices for consumers. A broad, market-based carbon policy provides the overarching framework that links the sector-specific policies … so that if one sector is able to achieve more substantial emission reductions than another sector, it is rewarded (2017, p. 27).

We do not delve into the debate as to the relative merits of a carbon tax versus a cap. Rather, we focus first on the revenue prospects with a carbon tax, as opposed to a cap.[51] Below, we then consider one version of a cap—i.e. renewable and energy efficiency portfolio standards.[52]

With the carbon tax, our specific aim is to provide estimates of the revenue that would be generated by a carbon tax, allowing for the tax rate to vary. Our estimates incorporate the key assumption of this study, which is that the level of CO_2 emissions in Colorado will decline by 50 percent, from its 2005 level of 95.2 million tons to under 48 million tons as of 2030. Moreover, we assume that the clean energy program for the state is implemented in full only over the 10-year period, 2021 – 2030. We therefore assume that the carbon tax is implemented in 2021 and continues through 2030.

Before presenting details as to the revenue potential of a carbon tax for Colorado, we recognize the difficulties that would be faced in implementing this measure due to the state's Taxpayer's Bill or Rights or TABOR. TABOR is a constitutional measure that was enacted in Colorado in 1992 that limits the annual growth in state revenues to the sum of the annual inflation rate and the annual percentage change in the state's population. Overriding TABOR requires direct voter approval. TABOR was suspended in 2005 but reinstated in 2010. TABOR would therefore have to be suspended again or overridden by voters for Colorado to enact a carbon tax. Note that a TABOR suspension or override would also be needed not just to enact a carbon tax, but for any measure that would generate funds to support a clean energy program for the state.[53]

We provide revenue estimates for the carbon tax under four separate scenarios. In all cases, we are estimating the tax revenues over a 10-year cycle between 2021 - 2030. We also assume under all scenarios that statewide CO_2 emissions fall 46 million tons, relative to their 2015 level of 93.1 million tons. This reduction would achieve the 2030 emissions goal of under 48 million tons.

1. In 2021, the tax rate begins at $15 per ton and remains at $15 per ton over the full 10-year period.
2. In 2021, the tax rate begins at $15 per ton and rises steadily over the 10-year period to $75 per ton.
3. In 2021, the tax rate begins at $25 per ton and remains at $25 per ton over the full 10-year period.
4. In 2021, the tax rate begins at $25 per ton and rises to $75 per ton over the full 10-year period.

We see the full results of the calculations through these four scenarios in Tables 39A – 39D. Table 40 provides a summary of the most pertinent information.

As Table 39A shows, if we begin with the lowest tax rate of a flat $15 per ton, the revenue generated by the tax will be approximately $1.4 billion in 2021. By 2030, with emissions having fallen by 46 million tons, the flat $15 per ton tax will generate approximately $700 million. Average revenue over the full 10-year cycle under this scenario will be about $1.1 billion.

As we see in the summary Table 40, revenues from the tax will of course rise when we assume higher tax rates. Thus, when we assume that the tax escalates from $15 to $75 per ton over the 10-year cycle, the average annual tax revenue is $2.9 billion. With a flat $25 per ton tax rate for the 10-year cycle, the average annual revenue is $1.8 billion. Finally, when the tax begins at $25 per ton and rises to $75 per ton by the end of the 10-year cycle, the average annual tax revenue is $3.3 billion.[54]

If Colorado is going to mount an initiative that has a serious chance of accomplishing its stated goal—of driving down CO_2 emissions in the state by 50 percent as of 2030—it is

TABLES 39A – 39D: Revenue Generation through a Carbon Tax for Colorado

A) Tax Rate Flat at $15 per Ton over 10-Year Cycle

Year	Annual Emissions (millions of tons— emissions fall to 50% of 2005 level)	Carbon Tax Rate: dollar per ton of CO_2 emissions	Annual Tax Revenue (in billions $$)
2021	93.1	$15	$1.4 billion
2022	88.0	$15	$1.3 billion
2023	82.8	$15	$1.2 billion
2024	77.7	$15	$1.2 billion
2025	72.6	$15	$1.1 billion
2026	67.5	$15	$1.0 billion
2027	62.3	$15	$0.9 billion
2028	57.2	$15	$0.9 billion
2029	52.1	$15	$0.8 billion
2030	46.9	$15	$0.7 billion
Annual Averages	**70.0**	**$15**	**$1.1 billion**

Source: Figures are based on the table's assumptions. See the text for details.

B) Tax Rate Rises from $15 – $75 per Ton over 10-Year Cycle

Year	Annual Emissions (millions of tons— emissions fall to 50% of 2005 level)	Carbon Tax Rate: dollar per ton of CO_2 emissions	Annual Tax Revenue (in billions $$)
2021	93.1	$15.0	$1.4 billion
2022	88.0	$21.7	$1.9 billion
2023	82.8	$28.3	$2.3 billion
2024	77.7	$35.0	$2.7 billion
2025	72.6	$41.7	$3.0 billion
2026	67.5	$48.3	$3.3 billion
2027	62.3	$55.0	$3.4 billion
2028	57.2	$61.7	$3.5 billion
2029	52.1	$68.3	$3.6 billion
2030	46.9	$75.0	$3.5 billion
Annual Averages	**70.0**	**$45.0**	**$2.9 billion**

Source: Figures are based on the table's assumptions. See the text for details.

TABLES 39A – 39D *(cont.)*: Revenue Generation through a Carbon Tax for Colorado

C) Tax Rate Flat at $25 per Ton over 10-Year Cycle

Year	Annual Emissions (millions of tons— emissions fall to 50% of 2005 level)	Carbon Tax Rate: dollar per ton of CO_2 emissions	Annual Tax Revenue (in billions $$)
2021	93.1	$25	$2.3 billion
2022	88.0	$25	$2.2 billion
2023	82.8	$25	$2.1 billion
2024	77.7	$25	$1.9 billion
2025	72.6	$25	$1.8 billion
2026	67.5	$25	$1.7 billion
2027	62.3	$25	$1.6 billion
2028	57.2	$25	$1.4 billion
2029	52.1	$25	$1.3 billion
2030	46.9	$25	$1.2 billion
Annual Averages	**70.0**	**$25**	**$1.8 billion**

Source: Figures are based on the table's assumptions. See the text for details.

D) Tax Rate Rises from $25 – $75 per Ton over 10-Year Cycle

Year	Annual Emissions (millions of tons— emissions fall to 50% of 2005 level)	Carbon Tax Rate: dollar per ton of CO_2 emissions	Annual Tax Revenue (in billions $$)
2021	93.1	$25.0	$2.3 billion
2022	88.0	$30.6	$2.7 billion
2023	82.8	$36.1	$3.0 billion
2024	77.7	$41.7	$3.2 billion
2025	72.6	$47.2	$3.4 billion
2026	67.5	$52.8	$3.6 billion
2027	62.3	$58.3	$3.6 billion
2028	57.2	$63.9	$3.7 billion
2029	52.1	$69.4	$3.6 billion
2030	46.9	$75.0	$3.5 billion
Annual Averages	**70.0**	**$50.0**	**$3.3 billion**

Source: Figures are based on the table's assumptions. See the text for details.

TABLE 40
Summary Results on Revenues for Alternative Colorado Carbon Tax Scenarios

	2021 Revenue	Total Revenue over 2021–2030	Average Annual Revenue between 2021–2030
Flat $15 per ton tax	$1.4 billion	$10.5 billion	$1.1 billion
Tax escalates from $15 to $75 per ton between 2021–2030	$1.4 billion	$28.7 billion	$2.9 billion
Flat $25 per ton tax	$2.3 billion	$17.5 billion	$1.8 billion
Tax escalates from $25 to $75 between 2021–2030	$2.3 billion	$32.7 billion	$3.3 billion

Source: Estimates from Tables 39A – D.

likely that a carbon tax revenue figure at the higher end of the range that we have estimated will be necessary—or to be more precise, either a carbon tax or an alternative source of new state revenues will be needed to help finance Colorado's clean energy transition. That is, the necessary revenue would likely need to be around $3 billion per year. This is especially the case since, again, the revenues generated will need to be channeled into supporting three distinct purposes: financing the clean energy investment project; financing the Just Transition for fossil fuel workers and communities; and returning a share of the revenues back to taxpayers to ensure that their overall costs of living are not reduced as a result of the increased fossil fuel prices.

Renewable Energy and Energy Efficiency Portfolio Standards

Colorado currently operates with renewable energy and energy efficiency standards. As noted above, these policies represent one variant on a carbon cap policy.

The first voter-led Renewable Energy Standard passed in 2004. It has since been updated 3 times.[55] The current requirements are as follows:[56]

- Investor-owned utilities (IOUs): 30% of electricity must come from renewable sources by 2020
- Electric cooperatives serving 100,000 or more meters: 20% by 2020
- Electric cooperatives serving fewer than 100,000 meters: 10% by 2020
- Municipal utilities serving more than 40,000 customers: 10% by 2020

As we saw in Table 3, as of 2015, wind, hydro, and solar energy account for 19 percent of all electricity consumed in Colorado. Especially given the rapid expansion of wind energy, the 20 percent overall renewable goal by 2020 is clearly achievable.

With respect to energy efficiency standards, the 2018 *Climate Plan* states as follows:

> In 2007, the Colorado Legislature passed House Bill 07-1037, requiring investor-owned gas and electric utilities to develop demand-side management ("DSM") programs to encourage energy efficiency. House Bill 07-1037 set goals for the reduction of electricity sales and electric-peak

> demand by 5 percent of the 2006 level by 2018; in 2017 this was extended through House Bill 17-122Z requiring the Public Utilities Commission to set goals of at least 5 percent peak demand reduction and 5 percent energy savings by 2028 as compared to 2018 levels. To meet these goals, utilities offer DSM programs that provide rebates to customers for the installation of energy efficiency measures in their homes or businesses. Since the programs began in 2009, Colorado's investor-owned gas and electric utilities have reduced electricity sales by 2,481,298 megawatt-hours and electricity demand by 564 MW (p. 39).

Colorado's other major initiative in the area of energy efficiency standards has been the enactment of automobile fuel efficiency standards in 2018 and Governor Polis's early efforts to also promote zero-emissions vehicles in the state. We discussed these initiatives in Section 4, along with the Trump Administration's efforts to block these measures. To the extent that these measures can be enacted and enforced, they will certainly play a major role in Colorado being able to achieve its emissions reduction targets.

The Climate Plan describes progress in raising efficiency standards. But, as we reviewed with respect to the trend in energy-intensity, there has been no significant improvement in energy efficiency between 1997 and 2015. At 4.7 Q-BTUs per $1 trillion dollars of GDP as of 2015, Colorado's energy intensity ratio is 13 percent lower than the 5.4 ratio for the U.S. overall, but is roughly 50 percent higher than those for either New York or California.

Strengthening the state's portfolio standards, both for renewables and efficiency levels, needs to be a priority within the overall clean energy policy package. This will be especially important in the event that Colorado does not enact a carbon tax policy.

Net Metering

Net metering is the compensation arrangement between a utility and a customer with an on-site generation system, typically a solar photovoltaic system. Net metering gives the customer credit for power generation at the utility's retail rate and allows a customer to bank generation during hours or months when it exceeds the customer's consumption. Net metering is an important policy tool for encouraging private building owners, including private homeowners, to invest in solar photovoltaic systems on their property.

Colorado does currently have net metering policies in place. Utilities are required to provide net metering for customer generators at non-discriminatory rates, under these specific conditions: For all investor-owned utilities, customers producing up to 120 percent of their annual average consumption are eligible for net metering. Electric cooperatives and municipal utilities with 5,000 or more customers must offer net metering for residential systems up to 10kW and commercial/industrial systems up to 25kW. [57]

By overall U.S. standards, these are fairly generous terms for a state net metering program. But this program will need to become significantly more generous to provide a sufficiently strong incentive for homeowners to purchase solar equipment for their residences. More specifically, the requirements should move toward utilities being required to purchase 100 percent of on-site power at either the rate at which the utility is selling electricity or better terms still.

Financing

Colorado supports clean energy investments through a large number of financing programs. We highlight below some of the more significant programs.

PACE Financing

One important example is Property Assessed Clean Energy (PACE) financing. During his 2018 gubernatorial campaign, Governor Polis expressed strong support for PACE financing as an effective clean energy investment financing tool.

PACE financing applies a long-established principle in infrastructure finance—the special assessment district—which uses local taxing authorities to collect payments on debt that finances publicly beneficial infrastructure investments. PACE financing harnesses public tax collection authorities to establish a strong form of repayment security and offers long-term fixed-rate loans to finance clean energy projects and building retrofits. PACE does not need to rely on general obligation funds from local governments nor any form of public subsidy, and can be financed purely through the private sector. The security created by placing repayment on the tax bill makes clean energy projects more affordable for borrowers, and more attractive for participating financial institutions.

Under typical PACE financing arrangements, property owners borrow from a local government or bank to finance clean energy investments. The amount borrowed is then repaid via a special assessment on property taxes, or another locally-collected tax or bill. The security of the tax collection mechanism reduces the risk to the private lender or bond investor, and the note on the property offers collateral to secure the loan.

Under PACE financing, when a property owner participating in the program sells the property, then the repayment obligation legally transfers with the property. This feature creates an important incentive for building owners who might otherwise be disinclined to tie up their personal credit. Also, because, formally speaking, PACE financing is a tax bill, it can be accounted for as an operating expense and not a form of traditional debt. Because tax bills can generally be passed through in commercial lease arrangements, PACE financing also offers an important tool for overcoming the so-called "split incentive" with energy efficiency investments. This occurs when building owners are reluctant to take on capital expenses that reduce utility bills for their tenants, but that provide them with no direct financial benefit. By allowing the pass-through of costs of raising the efficiency standards of buildings, PACE financing closely aligns the interests of the owner and tenant in lowering energy costs in the building. These features of PACE financing mean that the risks of lending for energy efficiency projects are reduced and the costs of borrowing can correspondingly decline. Further, PACE potentially offers a deduction of the repayment obligation from federal taxable income, as part of the local property tax deduction.[58]

A variation on PACE is "on-bill financing." With on-bill financing, a loan that pays for an energy efficiency or renewable energy investment is repaid through a utility bill and secured by a strong contract with the utility.

As noted above, Colorado does already operate a PACE financing program called C-PACE. Under this program, commercial and multifamily property owners are able to finance qualifying energy efficiency, water conservation, and other clean energy improvements on existing and newly constructed properties, with repayment of the financing through a voluntary assessment on their property tax bill.[59] Businesses and property owners can receive up to 100 percent of their costs financed over a 20-year period, through PACE financing. At present, there is only one C-PACE lender in the state, Lever Energy Capital. Lever Energy is allowed to originate up to $500 million in C-PACE financing.[60] It will be a critical feature of the overall Green Growth program for Colorado to expand the PACE financing program significantly, as Governor Polis has suggested.

Loan Guarantees

Loan guarantees help support the financing of clean energy projects by reducing the risks borne by early investors. Emerging companies frequently struggle to raise the necessary capital to bring new clean energy technologies to commercial scale due to the large amount of financing required. Through loan guarantees, the government backs loans issued by private lenders, promising to repay the outstanding balance in the event of default or bankruptcy.

Colorado does have a loan guarantee program in place to support clean energy investments. That is the Green Colorado Credit Reserve. The Green Colorado Credit Reserve is a loan loss reserve created by the Colorado Energy Office to incentivize lenders to make commercial loans of up to $250,000 for energy efficiency and renewable energy projects. The Green Colorado Credit Reserve guarantees 15 percent of the amount of the loan in the case of loan default.[61]

This, or an equivalent, state-level loan guarantee program could be significantly expanded without the state having to incur large costs. The experience with the federal-government-level clean energy loan guarantee program that was included in the 2009 Obama stimulus program—the American Recovery and Reinvestment Act (ARRA)—strongly supports this conclusion.

This federal Department of Energy Loan Guarantee Program helped underwrite about $14 billion in new clean energy investments as part of the ARRA. Even after taking full account of the large-scale and widely-publicized failure of the Northern California solar company Solyndra under this loan guarantee program, the default rate and corresponding government financial obligations stemming from this program were modest. As discussed in Pollin et al. (2014), the federal government's obligations resulting from defaults on guaranteed loans amounted to $596 million, or 4.3 percent of the $14 billion in outstanding guarantees. Some significant share of this $596 million—perhaps as much as 50 percent of the total obligation—was then also recovered by the federal government when it sold the assets of the firms that defaulted. This included Solyndra and one other firm, Abound Solar. This means that the program experienced losses in the range of $300 million, or about 2.1 percent of the $14 billion in new loans that the government guaranteed. This experience shows that clean energy loan guarantee programs can be a cost-effective policy for leveraging relatively small amounts of taxpayer funds.

Tax Incentives

Colorado operates with a large number of clean energy tax incentive programs. A partial list of the most significant of these programs include the following:

- Residential renewable energy systems that produce energy for use on that property are exempt from Colorado property taxation.[62]
- Electricity from renewable energy systems exempt from sales and use tax.[63]
- Local property and sales tax exemptions for renewable investment projects.

For example, a state law, passed in 2007 (SB 07-145), that authorizes counties and municipalities to offer property and/or sales tax rebates or credits to residential and commercial renewable energy systems.[64] The City of Boulder, for example, has a Solar Sales and Use Tax Rebate program in place.

Overall Perspective on Financing Tools

Given this large number of clean energy investment financing tools already operating in Colorado—C-PACE, on-bill financing, loan guarantees, and tax incentives, as well as other smaller-scale policy tools—one can easily become enmeshed in the details of the specific measures and perhaps lose focus on the overall issues at hand. Clearly, the first aim of all these measures, working in combination, is to deliver an abundance of low-cost financing for the state's transformational clean energy investment project. Toward that end, the state should utilize the combination of specific financing tools that can most effectively support this overarching aim. It is beyond the scope of this study to determine what this most effective combination of policies should be. But it is clear that the extent of financing subsidies being provided by Colorado at present are not nearly adequate for successfully mounting the clean energy transition that is being envisioned.

We also emphasize here a second purpose of Colorado's clean energy transition. This is to expand employment opportunities in the state. But the goal here should not be to simply generate more jobs through clean energy investments, but rather an abundance of *good-quality jobs* for state residents. In behalf of this second aim, we reiterate the importance of encouraging an increase in unionization rates in the state's growing clean energy sectors. Thus, the state needs to require neutrality with respect to union organizing campaigns when it provides financial support for clean energy investment projects that are either state owned or subsidized by public funds.

Auto Fuel Efficiency Standards and Electric Vehicle Deployment

As discussed in Section 4, Colorado is maintaining its commitment to uphold the California fuel efficiency standards as one component of its Clean Car Law, first enacted in 2009.[65] The California standard requires that, as of 2025, new cars operate at a 54.5 miles per gallon standard, a roughly 50 percent increase over the currently prevailing California standard of 36 miles per gallon.

In June 2018, in response to the Trump administration's rollback of national vehicle emission standards, then Colorado Governor Hickenlooper signed an executive order entitled, "Maintaining Progress on Clean Vehicles."[66] In August, the state's air quality control commissioners followed up on the governor's initiative by unanimously upholding the California standard for Colorado.

In addition to this regulatory standard, Colorado also offers a range of financial incentives to support this transition to the 54.5 per gallon fuel efficiency level as of 2025. These include tax credits to support purchases of alternative fueled vehicles, including electric, plug-in hybrid, compressed natural gas, liquefied natural gas, liquefied petroleum gas, or hydrogen.[67] It also includes grants to support the financing of both electric vehicles and charging stations for these vehicles.[68] Under this program, consumers can receive rebates to cover 80 percent of the difference between the cost of an electric car and similar gasoline car, up to about $8,300.

In addition, as noted in Section 4, in January 2019, Governor Polis announced as one of his first actions in office an executive order to promote electric vehicles in Colorado. More specifically, his order directs the state to create a team across state agencies to develop the infrastructure needed to support more electric vehicles and invest money it won in a settlement with Volkswagen into electrifying the state's vehicle fleet. It also asks the state's transportation department to create an electric vehicle policy. This zero-emissions vehicle program would be in addition to the low-emissions standards adopted in 2018.

It will be critical to achieving Colorado's emissions reduction targets that the state succeed against the Trump Administration in upholding these efficiency standards. Emissions from transportation sources account for nearly 30 percent of total statewide emissions, with the largest share of transportation consumption coming from automobiles.

Energy Efficiency and Renewable Energy Worker Training Programs

As we have discussed in Section 7, there is clearly a need for expanding training programs to provide workers with adequate opportunities to acquire new skills to perform effectively in the range of clean energy investment activities. This is especially important for generating new opportunities for women and minorities—i.e. groups of people who have long been badly underrepresented in the areas of manufacturing and construction that will grow substantially through clean energy investments. At the same time, as we have documented in Section 7, clean energy investments do also mainly generate direct jobs in the same areas of employment in which people already work. This then raises the question: how much needs to be spent by government to ensure sufficient opportunities for workers to perform well in these clean energy areas?

It will be useful to review some recent history with worker training programs associated with expanding clean energy investments. The largest single federal government initiative, which was initially included as part of the 2007 Energy Independence and Security Act (signed into law by then President George W. Bush) established a federal "Energy Efficiency and Renewable Energy Training Program." This program was then initially funded as part of the 2009 American Recovery and Reinvestment Act, with a $500 million budget provided over a four-year period. Funding for the program ended in 2013, and no further support has been provided.

While in operation, this supported the following: national training grants that were geographically distributed; state training grants; demonstration grants that were prioritized for low-income populations, termed the "pathways out of poverty" demonstration program; and research on training needs and labor markets. The specific types of training programs included in this measure were: occupational skills training; safety and health training; basic skills and job readiness training; college training programs; internship programs; apprenticeship programs and skill upgrading and retraining. Of the total annual allocation of $125 million per year, about 60 percent went for the various training programs themselves, 20 percent for the "pathways out of poverty" measures, and the remaining 20 percent for labor market research.

Assessments of this program have been mixed. A 2012 report from the U.S. Department of Labor found that the program had been only partially successful in placing workers into jobs in clean energy sectors.[69] A 2013 study by an outside consulting group, IMPAQ International, reported that, according to the majority of program administrators, funding to support the programs was not available for a sufficiently long time.[70]

In Colorado, several worker training programs have been in operation since the federal funding support was first provided in 2009. These include the following:

- **Energy Providers Coalition for Education (EPCE) Workforce Preparedness for Smart Grid Deployment Project**[71]

This project was funded at $5.4 million, and lasted from June 2010 to June 2013. It trained more than 1,800 electric power industry workers across a wide range of job categories on alternative energy sources and the Smart Grid.

- **Sustaining a Green Collar Workforce: An Interdisciplinary Approac**h[72]

This project was funded at $850,000, and lasted from July 2009 to June 2013. The project advanced environmental sustainability and energy technology education through curriculum development, materials preparation, professional development, and hands-on energy science experiences in the Red Rocks Community College Energy Laboratory.

- **Solar Instructor Training Network**[73]

This program began in 2009 and continues to the present, at four locations in Colorado: Front Range Community College (Fort Collins and Lakewood); Lamar Community College; and Pueblo Community College. The program increased the number of qualified solar instructors at the community college level from just over 50 in 2006 to more than 1,000 today.

These programs have made valuable contributions. But, following from the mixed assessments noted above of the federal training programs from 2009 – 2013, any Colorado-based initiative will need to be expanded significantly and sustained over time in order to improve employment opportunities and raise productivity in the state's clean energy investment projects. We can draw from the experience of Colorado's EPCE program to provide a rough measure of the scale of support needed for an effective statewide program. Thus, as reported in Section 7, we estimated that clean energy investments in Colorado at $14.5 billion per year would generate about 64,000 direct jobs in energy efficiency and renewable energy. If we assume that roughly 75 percent of the people filling these jobs will require training, that will bring the total number of workers requiring training to be 50,000. As we saw above, the EPCE program trained 1,800 workers with a $5.4 million budget, which amounts to $3,000 per student. That implies that $150 million will be needed to train 50,000 workers. The $3,000 per worker figure for training is, of course, less than the $8,000 per worker figure we assumed would be appropriate for displaced fossil fuel workers. It is also one-half the $6,000 amount, on average, for a year's tuition in one of Colorado's community colleges. It would require more research than we can provide in this study to determine what the appropriate level of funding should be, and also how many workers would be needing this funding.

Transition Programs for Fossil Fuel Industry Dependent Communities

As we have seen, the total amount of employment in the fossil fuel and ancillary industries in Colorado is relatively low, at about 34,300. This amounts to about 1.2 percent of total statewide employment. As such, only a relatively small number of communities in the state will experience job losses that will significantly affect the overall level of economic activity in that community. The losses experienced in these communities will also be somewhat offset by the job guarantee and wage insurance features of our proposed Just Transition program. Nevertheless, some communities will experience the effects of the contraction of the fossil fuel industry to a disproportionate extent.

The largest relative impacts are likely to be in the communities tied to the oil and gas extraction industries. This is because the combination of the oil and gas extraction industries and the support activities for oil and gas employ nearly 25,000 people. This amounts to about 72 percent of all fossil fuel-based employment in the state.

In Table 41, we present data on employment in Colorado's fossil fuel related industries, distributed by county. These figures provide a useful reference for assessing which areas in the state will be most negatively impacted by the contraction of the state's fossil fuel sector. Correspondingly, from these figures, we can also identify which areas in the state will be most in need of community transition support. As Table 44 shows, these employment by county figures total to 27,364 jobs, which represents 80 percent of the 34,329 jobs in total in the state's fossil fuel industries. We have not been able to identify by location of employment the other roughly 7,000 fossil-fuel related jobs in the state.

The impacted counties in Table 41 are listed according to their level of fossil-fuel related employment. As we see, the two largest concentrations of fossil fuel related jobs are in Weld County, with 8,324 jobs and Denver County, with 8,321 jobs. Thus, nearly 50 percent of Colorado's total of 34,329 fossil fuel related jobs are located in these two counties. Still, there is a major difference in how the contraction in Colorado's fossil fuel related industries will impact the two counties, despite the fact that their overall fossil-fuel related employment levels are nearly identical. This is because, in Weld County, overall private sector employment is 89,974. Fossil fuel employment therefore represents 9.3 percent of the county's overall employment level. Four of Weld County's largest private employers are in the oil and gas industry—Haliburton, Noble Energy, Anadarko Petroleum, and Select Energy Services. A 50 percent contraction in the state's fossil fuel industry as of 2030 would then mean a nearly 5 percent decline in the county's overall employment level. With Denver County, overall employment is 436,205. The county's level of fossil fuel employment, at 8,321, therefore represents a much lower 1.9 percent of the county's total employment. No fossil fuel-based companies are among the largest 10 employers in the City of Denver.[74] A 50 percent cut in fossil fuel related activity will have a modest impact, with less than 1 percent of all employment in the county dependent on the fossil fuel industry.

We can generalize from these comparative figures for Weld and Denver Counties in developing an approach for identifying the areas of Colorado that are likely to be most in need of transitional assistance. As a starting benchmark, we calculate that, based on the data that is available to us at present, there would be 7 counties in the state in which employment losses through a clean energy transition would amount to 2 percent or more of total employment. As we list in Table 42, these counties are Moffat, Weld, Cheyenne, Los Animas, Mesa, Gunnison, and Yuma. Implementing an effective transition program for the state overall

TABLE 41
Employment in Colorado's Fossil Fuel Related Industries, by County, 2017

County	(1) Employment in Fossil Fuel Related Industries	(2) Private Sector Employment	(3) % of County Employment in Fossil Fuel Related Industries
Weld County	8324	89,974	9.3%
Denver County	8321	436,205	1.9%
Mesa County	2624	51,715	5.1%
Adams County	2054	167,612	1.2%
Arapahoe County	1334	291,585	0.5%
La Plata County	630	21,036	3.0%
Garfield County	580	20,596	2.8%
Larimer County	467	125,148	0.4%
Jefferson County	436	197,457	0.2%
Routt County	403	13,057	3.1%
Moffat County	395	3,684	10.7%
Douglas County	379	107,696	0.4%
Boulder County	322	150,730	0.2%
Gunnison County	298	6,562	4.5%
Las Animas County	238	3,452	6.9%
Logan County	147	5,757	2.6%
Montezuma County	121	6,478	1.9%
Yuma County	115	2,900	4.0%
El Paso County	106	221,747	0.0%
Cheyenne County	35	397	8.8%
Rio Blanco County	22	1,611	1.4%
Eagle County	13	29,132	0.0%
TOTALS	**27,364**	**1,954,531**	**1.4%**

Note: Our estimate of total fossil-fuel based employment in Colorado is 34,329 (see Table 26). These county-level figures therefore account for 79.7 percent of total statewide fossil fuel employment.

Sources: U.S. Department of Labor, Quarterly Census of Employment and Wages, 2017 Annual Averages.

should begin by focusing its efforts within these 7 counties. The most direct way to support these communities in transition will be to channel a relatively high proportion of new clean energy investments into these communities.

In total, employment losses in these seven counties would amount to about 6,000 jobs. That is about 35 percent of the total level of employment losses that should result through a 50 percent reduction in fossil fuel related activities statewide. As a first approximation, it might therefore be appropriate that these counties should, in combination, receive about $5.1 billion per year in clean energy investments, which is equal to 35 percent of $14.5 bil-

TABLE 42
Colorado Counties with over 2 Percent Employment Loss through 50 Percent Contraction in Statewide Fossil Fuel Economic Activity

County	% Employment Loss through 50% Fossil Fuel Contraction	Total Employment Loss through 50% Fossil Fuel Contraction
Moffat County	5.4%	198
Weld County	4.7%	4,162
Cheyenne County	4.4%	17
Los Animas County	3.5%	119
Mesa County	2.6%	1,312
Gunnison County	2.3%	149
Yuma County	2.0%	58
TOTAL EMPLOYMENT LOSSES IN THESE COUNTIES	---	**6,015**

Source: See Table 41.

lion. This will provide these counties with substantial compensation for the contraction of their fossil fuel industry related jobs and tax revenues.

The first stages have already been made in Colorado toward developing a transitional support policy framework. This is the state's "Rural Response, Recovery and Resilience program (4R)."[75] This is a pilot program of the Colorado Department of Local Affairs (DOLA) to help mineral extraction-dependent economies. The program provides "strategic technical and financial assistance" to eight counties for a five-year period, helping economies diversify away from fossil fuels. Current eligible counties include: Delta, Montrose, Gunnison, Moffat, Rio Blanco, Grand, Clear Creek, and Routt. However, to date, there are few specifics or funding initiatives in place to support this program. It will therefore be especially useful to consider some prior experiences with transitional support programs, in the U.S. and elsewhere.

To begin with, Pueblo, both the city and county, are themselves already actively engaged in a green community transition.[76] In 2008, the county successfully recruited Vestas, a Denmark-based firm that is one of the world's largest wind turbine manufacturers, to locate a production facility in Pueblo. The plant has been operating since 2010. Pueblo is also the home to Comanche Solar, the largest solar farm east of the Rockies, at 156 megawatts. The solar energy produced at the Comanche farm is purchased by Xcel Energy, as a major source for Xcel's Colorado renewable energy portfolio.[77]

These renewable energy projects for Pueblo are part of its overall green transition program. The program's overarching commitment is for the community to rely, by 2035, solely on renewable energy sources to supply its electricity. According to Clark Markuson, director of Pueblo county Department of Economic Development, the intent is for Pueblo to "become the renewable energy hub for Colorado and likely the region."

While Pueblo has made important commitments in advancing the community's green energy transformation, it is also encountering significant obstacles. Most important is that Pueblo is under contract through 2030 with Black Hills Energy to supply the county with its electricity. Black Hills generates electricity through the coal-fired Pueblo Airport Generating Station on the outskirts of the town. Pueblo has the option to exit the contract with Black Hills. But the costs of doing so will be very high. This is because Black Hills is protected contractually to be reimbursed by Pueblo for the costs the firm invested in building its coal plant.

Pueblo experienced another setback in December 2018 when its County Commissioners rejected a proposal by the firm Invenergy to build a 700-acre solar farm on the southern portion of the county. While the County Commissioners affirmed their commitment to expanding renewable energy in the community, they were unwilling to support this particular project, because its location was adjacent to a residential housing neighborhood. As one of the residents of the areas explained in opposing the project, "If you invest in a property, you don't want some industrial solar plant to come in and ruin the value."[78]

Overall, Pueblo's varying experiences to date underscore both the opportunities and challenges that will be faced by communities in Colorado more generally in their efforts to transition away from relying on their existing fossil fuel infrastructure in favor of a clean energy infrastructure. These experiences also make clear the importance of policymakers operating with a range of tools that they can deploy flexibly, depending on the specific circumstances faced by any given community.

One model for developing such investment and financial support programs is the Worker and Community Transition program that operated through the U.S. Department of Energy from 1994 – 2004. This initiative was targeted at 13 communities which had been heavily dependent on federal government operated nuclear power and weapons facilities but subsequently faced retrenchment due to nuclear decommissioning. One study of the program, by Lynch and Kirshenberg (2000), published in the *Bulletin of the Energy Communities Alliance*, concluded as follows:

> Surprisingly, the 13 communities, as a general rule have performed a remarkable role in attracting new replacement jobs and in cushioning the impact of the cutbacks at the Energy-weapons complex across the country…The community and worker adjustments to the 1992 – 2000 DOE site cutbacks have been strong and responsive, especially when compared with any other industrial adjustment programs during the same decade.

The experience in Piketon, Ohio provides a good case study of how this program has operated in one community. Piketon had been the home of a plant producing weapons-grade uranium that closed in 2001. The workers in the plant were represented by the Oil Chemical and Atomic Workers union (OCAW—which merged in 1999 with the Paper, Allied-Industrial, Chemical, and Energy Workers International Union (PACE), which in turn merged with the United Steel Workers in 2005). The union leadership was active in planning the plant's repurposing project. The closure could have been economically devastating for the region, but the federal government provided funding to clean up the 3,000 acre complex. The clean-up operation began in 2002, and is scheduled to take 40 years to complete.[79] Currently 1,900 workers are employed decontaminating the site at a cost of $300-$400 million a year. The contractor hired to clean up the site employs union workers and the president of the USW local union is enthusiastic about the long-term prospects for the project and the site (Hendren 2015).

Another large-scale restoration project was at the former plutonium production plant in Hanford, Washington. The plutonium plant began operating in 1943. The Worker and Community Transition program began in 1993, continuing at full scale through 2000. According to the U.S. government's own assessment in 2000, the program was largely successful both in preventing involuntary job losses for workers at the former plant and in supporting new community investments.[80]

Despite the positive achievements with projects such as Piketon and Hanford, Lynch and Kirshenberg also note more generally that "The most serious problem facing the energy-impacted communities…was the lack of a basic regional economic development and industrial diversification capacity for most of the regions affected by the cutbacks…" A separate study by Lowrie et al. (1999) reaches the same conclusion. They write:

> The community transition efforts thus far are inadequate, and the cleanup funds being distributed to the sites have become a substitute for adjustment to a post-Department of Energy world. Continued dependence on cleanup jobs at the sites rather than transitioning to a non-DOE economy will exact a toll on long-term economic sustainability (1999, p. 121).

To address this problem directly, community assistance initiatives could encourage the formation of new clean energy businesses in the affected areas. One example of a successful diversification program was the repurposing of a nuclear test site in Nevada to what is now a solar proving ground. More than 25 square miles of the former nuclear site are now used to demonstrate concentrated solar power technologies and help bring them to commercialization.[81]

An example of the type of community transition projects that could be viable in Colorado has been outlined for Colstrip, Montana in a 2018 study *Doing It Right: Colstrip's Bright Future with Cleanup*.[82] This study is authored jointly by the Northern Plains Resource Council and the International Brotherhood of Electrical Workers (Local 1638). As the study documents, the Colstrip Steam Electricity Station, owned by Talen Energy, contains 4 electricity generating units that supply the region with electricity. The plant employs 388 workers. Moreover, coal for the plant is supplied by the nearby Rosebud mine, which employs another 373 workers. However, two of the four units are scheduled to close by July 2022.

The coal ash generated by these 2 plants are disposed of in ash ponds spread over 278 acres in the area. The ash ponds have produced serious contamination of the local groundwater. As a result of a series of lawsuits, Talen Energy has been required to remediate the groundwater contamination, with the completion of the project to occur no later than 2049.

Doing it Right documents the types of jobs that would be created by this remediation project. They include: heavy equipment operator, electrician, environmental engineer, groundwater sampling technician, septic system operator, as well as more generic occupations such as mechanic, fence erector, truck driver, security guard, and construction crews.

The authors of the study acknowledge that their estimate as to the number of jobs that will be generated by the remediation project is still preliminary. But the evidence they provide suggests that the number of jobs created is likely to be in the range of 200, i.e. about half of the nearly 400 jobs that currently exist at the two power plants. The remediation project would therefore not provide a full one-for-one replacement in terms of total employment in the area relative to the job losses resulting from the closing of the two power plants. But the remediation project will provide an alternative foundation on which to maintain a healthy local economy. Jobs created through building a new clean energy infrastructure in the area will expand opportunities further off of this new foundation. The study does also point out that, in general, remediation of brownfield sites throughout the U.S has lead to increases in property values while, not surprisingly, allowing sites to remain contaminated greatly detracts from their commercial value.

There are also important cases of successful repurposing projects in other countries. Most prominent has been the experience in Germany's Ruhr Valley, which has been the traditional home for its coal, steel and chemical industries. Since the 1990s, the region has advanced industrial policies to develop new clean energy industries.[83] For example, RAG AG, a German coal mining firm, has been developing plans to convert coal mines that are scheduled to close in 2018 into hydroelectric power storage facilities to stabilize energy production when solar or wind power fluctuates. In periods of slack solar and wind energy production, water that was earlier pumped into a surface pool during excess supply periods is dropped through 1,000 meters of pipes to drive the underground turbines. In addition to hydroelectric power storage, the company is also erecting wind turbines on the top of tall waste heaps and installing solar panels on the slopes. Other firms in the region have branched into producing wind and water turbines. This regional transition project has succeeded through mobilizing the support of the large coal, steel and chemical companies and their suppliers, along with universities, trade unions and government support at all levels.

Colorado's Energy Intensive and Trade Exposed Facilities

Several industries in the U.S., including glass, steel, pulp and paper, aluminum, chemicals, and cement manufacturing employ energy-intensive production processes and are highly exposed to global competition. Energy Intensive and Trade Exposed (EITE) is a formal term used to describe such industries. A major concern with climate change legislation is that such measures will create disproportionate costs on the EITE industries, which in turn will weaken the manufacturing competitiveness of the U.S., or as the case may be, a particular state such as Colorado. It is also possible that putting disproportionately high regulatory compliance costs on EITE firms within one geographic area, such as Colorado, could cause these firms to relocate operations to places with less stringent standards.

In Table 43, we list the largest EITE firms in Colorado. The list includes all firms in the state that emitted at least 25,000 tons of greenhouse gases in 2017.[84] There were 10 such firms in total. The total emissions of these 10 firms amounted to 2.6 million tons of CO_2, equal to 2.8 percent of the state's 2015 total emissions of 93.1 million tons. Of these 10 firms, the three largest emitters are all cement manufacturers: Holcim Inc., GCC Rio Grande, and Cemex Construction Materials South. The next largest emitter is CF&L Steel, an iron and steel mill. The three cement manufacturers by themselves account for 1.9 million tons of CO_2 emissions as of 2017, equal to 75 percent of all emissions from the EITE firms and 2.0 percent of total emissions in Colorado. Including the emissions from the one steel mill among the EITE firms brings the total for the largest emitters to 2.2 million tons, equal to 85 percent of all emissions from the EITE firms in Colorado and 2.4 percent of all statewide emissions.

Overall then, these EITE firms are not a major source of overall emissions generated in Colorado. At the same time, they do provide a large number of people in the state with good jobs. As of 2017, there were about 4,700 people employed in cement manufacturing and 2,100 people employed in primary metal manufacturing, including copper and aluminum

TABLE 43
CO_2 Emissions from Energy Intensive and Trade Exposed Facilities in Colorado, 2017

Firm	City	Industry	CO_2 Emissions (millions of tons)
Holcim (US), Inc. - Portland Plant	Florence	Cement manufacturing	0.88 (34.3% of total)
GCC Rio Grande, Inc.	Pueblo	Cement manufacturing	0.73 (28.5% of total)
Cemex Construction Materials South, LLC	Lyons	Cement manufacturing	0.34 (13.3% of total)
CF & I Steel L.P. d.b.a. Rocky Mountain Steel Mills	Pueblo	Iron and steel mills	0.24 (9.2% of total)
Owens-Brockway Glass Container, Inc. Plant 28	Windsor	Glass container manufacturing	0.11 (4.1% of total)
Rocky Mountain Bottle Company	Wheat Ridge	Glass container manufacturing	0.09 (3.3% of total)
Sterling Ethanol, LLC	Sterling	Ethyl alcohol manufacturing	0.05 (2.1% of total)
Natural Soda	Rifle	Other basic inorganic chemical manufacturing	0.05 (1.8% of total)
Yuma Ethanol, LLC	Yuma	Ethyl alcohol manufacturing	0.05 (1.8% of total)
Front Range Energy	Windsor	Ethyl alcohol manufacturing	0.04 (1.4% of total)
Total			**2.57 million tons**

Sources: USEPA (2018); USEPA (2009); Metcalf (2013).

as well as iron and steel. These jobs also pay better than what the average employed person in Colorado receives. In 2017, average total compensation was $77,000 in cement manufacturing and $79,000 in primary metals manufacturing. These figures are about 10 percent higher than the average total compensation for all Colorado employees, which was $72,000.[85]

In recognizing these employment and compensation figures, the state's clean energy transition project should be designed to achieve the state's overall emissions targets without creating an excessive burden on the state's three cement manufacturers, and, to a lesser extent, the other EITE firms operating in Colorado. Toward that end, the following simple exercise is illustrative. Let us assume that emissions from all 10 EITE firms in Colorado remain flat through 2030 at 2.6 million tons per year. For the state to still achieve the 2030 emissions reduction target of 48 million tons overall—falling by 50 percent from 95.2 million tons as of 2005—would then entail that emissions from all other sectors would need to fall by 51 percent, as opposed to 50 percent. This additional percentage point decline in emissions for the state's economy outside these EITE firms is certainly achievable within the context of the overall clean energy investment program that we have described above.

This is not to suggest that the state's EITE facilities should be fully exempt from having to reduce their emissions, but to illustrate a point. That is, it is not difficult to develop an overall plan for achieving dramatic emissions reductions in Colorado without having to place a disproportionate burden on the state's EITE facilities, the cement manufacturers in particular.

10. ACHIEVING A 90 PERCENT CO_2 EMISSIONS REDUCTION BY 2050

If Colorado is able to bring overall CO_2 emissions in the state down to no more than 48 million tons by 2030—a 50 percent decline relative to the 2005 level of 95.2 million tons—it should also be able to achieve a 90 percent emissions reduction by 2050. CO_2 emissions in Colorado would then be 9 million tons as of 2050. Indeed, Colorado should be able to achieve this 2050 emissions reduction goal basically through continuing the clean energy investment project that would have proceeded from 2021 – 2030. Moreover, on an annual basis, the scale of the investments in energy efficiency and clean renewable energy between 2031 – 2050 that will be needed to reach a 90 percent emissions reduction by 2050 should be significantly more modest than what we have described above for the project through 2030.

As we saw in Table 12, our estimate of the clean energy investment costs for bringing emissions down to no more than 48 million tons by 2030 was about 3.5 percent of Colorado's GDP per year between 2021 – 2030. Over 2031 – 50, as we will see, we estimate that the average annual clean energy investments costs necessary to bring emissions down to 9 million tons to be about 1.2 percent of Colorado's average GDP. The impact of the investment project on job opportunities throughout the state are therefore likely to also be more modest than during 2021 – 2030, though still strongly in the positive direction.

This study certainly does not attempt to develop a full assessment as to the technical feasibility of achieving a 90 percent emissions reduction in Colorado by 2050. A related analysis was developed for New York State, in a 2013 study by Jacobson et al. The purpose of this study was to examine the technical feasibility of converting the state's energy infrastructure to operate through 100 percent renewable sources as of 2030. As Jacobson et al. state, their study "analyzes a plan to convert New York State's all-purpose (for electricity, transportation, heating/cooling and industry) infrastructure to one derived entirely from wind, water and sunlight…generating electricity and electrolytic hydrogen," (p. 585). Under their plan, overall energy consumption would fall by 37 percent in 2030 relative to the 2012 level through energy efficiency measures. The energy mix that they propose would be feasible for 2030 would include 50 percent wind, from both offshore and onshore sites; 38 percent solar, with photovoltaic systems in power plants and on rooftops as well as from concentrated solar technology; 5.5 percent hydro, relying mainly on existing productive capacity; 5 percent geothermal, and 1.5 percent wave and tidal power.

Other researchers, focused on regions and countries, have also concluded that conversion to an economy relying on clean renewable sources to meet 100 percent of energy demand is technically feasible within a few decades or less. One important study reaching this conclusion is by the Harvard University physicist Mara Prentiss. Prentiss concludes in her 2015 book, *Energy Revolution: The Physics and the Promise of Efficient Technology,* that "Electricity generated by renewable energy can easily provide 100 percent of the average energy consumption of the United States during those next 50 years, virtually eliminating the negative environmental consequences associated with fossil fuel consumption," (2015, p. 304).[86]

Within a framework that recognizes the technical feasibility of bringing CO_2 emissions down by 90 percent in Colorado by 2050, our focus here is to assess the economic trajectory of how this goal can be accomplished while the state's economy and job opportunities continue to grow. Of course, considering how such a trajectory is likely to proceed entails making a series of assumptions about the economy's long-term growth path. This exercise necessarily becomes increasingly speculative the further out one moves in time. To keep our discussion as realistic as possible, we rely on a small number of assumptions that are credible within the body of knowledge that is available to us at present.

The assumptions on which we will rely are as follows:

1. *Economic growth.* We assume that economic growth in Colorado proceeds at basically the same rate as we have assumed for 2021 – 2030, i.e. at 2.4 percent per year.
2. *Energy efficiency.* We have already assumed that Colorado will have achieved major gains in energy efficiency between 2021 – 2030, specifically that the state's energy intensity ratio will have fallen from 4.7 to 3.0 Q-BTUs per $1 trillion of GDP—a 36 percent improvement. We assume that further efficiency gains are possible through continued investments, and that the costs of achieving these efficiency gains will remain at $35 billion per Q-BTU, the same cost figure for our 2021 – 2030 scenario. We make this assumption of stable overall costs, based on two ideas: 1) technological improvements will occur in raising efficiency standards; but 2) the 'low-hanging fruit' possibilities for efficiency gains will have dissipated. We assume that these two factors will roughly counteract each other.
3. *Clean renewable energy.* Technological advances in generating, storing and transmitting renewable energy will certainly occur between 2031 – 2050, especially given that these industries will have scaled up dramatically over 2021 – 2030. But to proceed cautiously, we assume only a modest rate of average technological improvement for renewables overall—that the average costs of creating 1 Q-BTU of renewable capacity falls at an average rate of 1 percent per year between 2031 – 2050.
4. *Job creation.* We assume that labor productivity in all clean energy investment activity improves at an average annual rate of 1 percent per year. This is the same rate that we have assumed for 2021 – 2030.

Working from these assumptions on 1) economic growth; 2) the costs of achieving energy efficiency gains and an expanded clean renewable energy supply; and 3) labor productivity, we then develop projections as to how Colorado's economy would advance toward bringing CO_2 emissions down to 9 million tons by 2050. We present these results in Tables 44 - 49.

In Table 44, we show Colorado's GDP projection for 2050 based on a 2.4 percent average annual growth rate for 2031 – 2050. This growth path begins at the 2030 GDP baseline of $454 billion. This figure is itself a projection, of course, which we derived through assuming that Colorado's GDP would grow at an average annual rate of 2.4 percent between 2015 – 2030, starting from the 2015 actual GDP level of $318 billion. Based on these assumptions, as we see in Table 44, Colorado's GDP will be $730 billion. We then calculate the midpoint GDP level between 2031 – 2050 under this scenario. As we see, this midpoint figure is $592 billion.

In Table 45, we then estimate the investment costs necessary to bring Colorado's energy intensity ratio down from the 2030 figure of 3.0 to 2.0 Q-BTUs of energy/$1 trillion in GDP. We had projected in Table 11 that Colorado would be at the 3.0 intensity ratio by

TABLE 44
Colorado Average Economic Growth Projection for 2031–2050

ASSUMPTION IS 2.4% AVERAGE GDP GROWTH

Projected 2030 GDP level *From Table 10*	$454 billion
Projected 2050 GDP level	$730 billion
Midpoint GDP level for investment spending estimates *(= (2030 GDP + 2050 GDP)/2)*	$592 billion

Source: See Table 10; authors' calculations

TABLE 45
Energy Efficiency Investments Needed to Bring Colorado Energy Intensity Ratio to 2.0 by 2050

Energy Intensity Ratio = Q-BTUs of energy/GDP in trillions of dollars
2.4% average GDP growth

1) 2050 GDP assumption *from Table 44*	$730 billion
2) Total 2050 energy consumption at 3.0 energy intensity ratio *(=3.0 x $0.73 trillion)*	2.19 Q-BTUs
3) Total energy consumption at 2.0 energy intensity ratio *(=2.0 x $0.73 trillion)*	1.46 Q-BTUs
4) Gains in energy efficiency through 2031–2050 efficiency investments *(= rows 2 – 3)*	0.73 Q-BTUs
5) Costs of achieving energy efficiency gains *(= row 4 x $35 billion)*	$25.6 billion
6) Costs per year over 20-year investment cycle *(row 5/20)*	$1.3 billion/year

Sources: Table 44 and authors' projections.

2030 under the clean energy investment program we outlined for 2021 – 2030. Table 45 shows that to arrive at a 2.0 energy intensity ratio by 2050 will require $25.6 billion in new energy efficiency investments between 2031 – 2050 under the 2.4 percent growth scenario. Considered on an annual basis, these total costs amount to an average of $1.3 billion per year under the 2.4 percent growth scenario.

In Table 46, we perform a comparable set of calculations for clean renewable energy investments between 2031 – 2050. We begin these calculations with the assumption of a 2.0 energy intensity ratio for 2050. This then entails that, in 2050, overall energy consumption in Colorado will be at 1.46 Q-BTUs. We then see in row 2 of Table 46 that petroleum consumption in 2050 will be at 0.13 Q-BTUs, the maximum amount that can be consumed while maintaining overall statewide CO_2 emissions at 9 million tons. Petroleum will continue

TABLE 46
Clean Renewable Energy Investments Needed to Reach 90 Percent Emissions Reduction by 2050
(= CO_2 emissions at 9 million tons)

1) 2050 energy consumption level with 2.0 energy intensity ratio *From Table 45*	1.46 Q-BTUs
2) Petroleum consumption	0.13 Q-BTUs
3) CO_2 emissions generated by petroleum consumption *From Table 4*	9 million tons *(0.13 Q-BTUs x 0.68 tons/Q-BTUs of emissions)*
4) Total clean renewable energy supply required *(= row 1 – 2)*	1.33 Q-BTUs
5) Clean renewable energy supply as of 2030 *From Table 12*	0.68 Q-BTUs
6) Renewable energy expansion needed by 2050 *(= rows 4-5)*	0.65 Q-BTUs
7) Midpoint cost per Q-BTU of expanding clean renewable supply *Assumes average costs decline at 1% per year relative to 2030*	$180 billion per Q-BTU
8) Total costs of reaching 1.33 Q-BTUs in renewable supply *(= row 6 x 7)*	$117 billion
9) Average annual costs over 20-year investment cycle *(= row 8/20)*	$5.9 billion

Sources: Tables 4, 12 and 45 and authors' projections.

to be used modestly in 2050 to provide liquid fuel. Both coal and natural gas will have been supplanted entirely by clean renewable sources for generating electricity. High-emissions biomass will also be eliminated as an energy source in Colorado. Burning 0.13 Q-BTUs of petroleum will then produce 9 million tons of CO_2—this then being the sole source of CO_2 emissions in Colorado as of 2050.

In Table 12, we derived that, as of 2030, total energy supplied by clean renewable sources would be at 0.68 Q-BTUs through the clean energy investment project from 2021 – 2030. From this baseline figure, we can derive that the expansion of clean renewable capacity will need to be at 0.65 Q-BTUs. As we see in rows 6 – 9 of Table 46, achieving this higher level of productive capacity in clean renewables will require a level of investment averaging $5.9 billion per year.

In Table 47, we then summarize these results for bringing Colorado's total CO_2 emissions to 9 million tons as of 2050. As we see, we estimate these overall costs to be $143 billion, which averages to $7.2 billion per year over 2031 – 2050. As a share of Colorado's projected midpoint GDP over 2031 - 2050, these annual cost figures would amount to 1.2

TABLE 47
Overall Estimated Costs of Achieving 90 Percent Emissions Reduction in Colorado by 2050

1) Total energy efficiency investment costs *From Table 45*	$26 billion
2) Total renewable energy investment costs *From Table 46*	$117 billion
3) Total clean energy investment costs *(= rows 1 + 2)*	$143 billion
4) Average annual costs per year for 20-year investment cycle *(= row 3/20)*	$7.2 billion
5) Average annual costs per year as percentage of midpoint GDP *(= row 4/Table 44 figure)*	1.2 percent

Sources: See Tables 45 and 46.

percent of GDP. As mentioned above, these figures are significantly below the cost level we have estimated for the initial 2021 – 2030 investment period that would be necessary to bring Colorado's CO_2 emissions down to 48 million tons by 2030. We estimate these costs to amount to about 3.5 percent of the state's average GDP.

Achieving a 100 Percent Renewable Electricity Standard by 2040

One of the climate stabilization goals emphasized by Governor Polis is for Colorado to supply 100 percent of the state's electricity needs from clean renewable energy sources by 2040. In fact, this goal is realistically attainable within the framework of the state's broader project of reducing CO_2 emissions by 90 percent as of 2050. In order to demonstrate this, it is only necessary to incorporate a few additional modest assumptions and details into our 90 percent emissions reduction framework for 2050. We work through this detailed analysis in Appendix 6.

Employment Creation through 2031 – 2050 Investment Project

In Table 48, we provide rough estimates as to the level of employment creation that would be generated by the clean energy investment levels necessary to bring Colorado's CO_2 emissions down to 9 million tons by 2050. We have estimated these employment figures based on two assumptions: 1) the overall clean energy investment spending levels for 2031 – 50 as a proportion of the 2021 – 2030 spending level; and 2) our assumption of a 1 percent average annual increase in labor productivity in these clean energy investment projects.

We saw in Table 17 that, for 2030, our estimate of total employment—direct, indirect and induced employment—through clean energy investments at $14.5 billion would be 101,000 jobs. This figure is repeated in row 1 of Table 48. In row 2, we then calculate average annual clean energy investment spending for 2031 – 2050 as a share of 2030 spending—

TABLE 48
Average Annual Colorado Employment Creation through Clean Energy Investments, 2031 – 2050

1) Estimated job creation through 2030 clean energy investments *From Table 17*	101,000
2) Approximate average annual investment spending as pct. of 2030 spending *From Tables 12 and 47*	50% *(= $7.2 billion/14.5 billion)*
3) 2031 Employment creation	51,000 *(= 101,000 x .50)*
4) 2050 Employment creation, with 1% average annual labor productivity growth	42,000

Sources: Tables 12, 17 and 47.

that is $7.2 billion/$14.5 billion, or roughly 50 percent. From this figure, as we see in row 3, we estimate total employment through clean energy investments in 2031 as being 51,000. With a 1 percent average rate of labor productivity growth through 2050, we then estimate that job creation will be at 42,000 as of 2050.

Just Transition Program

In Table 49, we provide estimates for the Just Transition program for 2031 – 2050. The figures we present in Table 49 are derived from the material we have developed for the 2021 –2030 period in section 8 of this paper, including in Tables 26 and 35.

With the 2021 – 2030 analysis, we reported in Table 26 that a total of 34,329 workers were employed in Colorado as of 2017 at jobs in either fossil fuel production or ancillary industries. Again, fully 87 percent of these jobs are in oil and gas extraction, support activities for oil and gas extraction, and pipeline construction and transportation. In Table 35, we provide the estimate that by 2030, a total of 14,339 of these jobs, equal to 42 percent of the jobs, will be lost. This results from our assumption that oil and gas consumption in Colorado will decline by 40 percent as of 2030 and coal will decline by 70 percent. These cuts in consumption will then correspond to equivalent cuts in production activity and employment levels. This result also implies that, as of 2030, 19,990 jobs will remain in these industries across Colorado (=34,329 – 14,339). We round this figure up to 20,000 jobs, as we see in row 1 of Table 49.

Starting from the goal that, as of 2050, Colorado will have reduced its emissions level by 90 percent relative to its 2005 level of 95.2 million tons--i.e. to about 9 million tons in total as of 2050—this also implies that emissions will need to fall by 80 percent between 2030 and 2050. This follows from our result that emissions will be at no more than 48 million tons as of 2030. The emissions decline from 48 million tons in 2030 to 9 million tons in 2050 is an 80 percent decline (i.e. (48 – 9)/48 = 0.8).

That in turns means that employment in Colorado's fossil fuel industries will also fall by 80 percent between 2030 and 2050—from 20,000 to 4,000 jobs. Job losses in the fossil fuel

TABLE 49
Costs of Just Transition Program for Displaced Workers in Fossil Fuel and Ancillary Sectors: 2031–2050 Scenario

1) Projected number of workers employed in fossil fuel and ancillary industries in 2030 *From Table 35*	20,000
2) Employment contraction, 2031 – 2050 *(80% contraction)*	16,000
3) Average employment contraction per year	800 *(= row 2/20)*
4) Projected number of workers reaching retirement between 2031–2050 *(assumes 50% of workers are 45 years and over in 2031)*	10,000 *(= row 1/2)*
5) Average annual attrition through retirement	500 *(= row 4/20)*
6) Average number of workers displaced annually, 2031–2050 *(= row 3 – row 5)*	300
7) Annual costs of 100% compensation insurance, retraining and relocation support *(at $234,000 per non-managerial worker)*	$54 million for smooth transition *[=(row 6 x 0.85 x $234,000 x 20 cohorts)/ 22 years JT program duration]*

Source: Projections based on figures from Tables 35 and 38.

industries will therefore amount to 16,000 jobs, equal to an average rate of job loss of 800 jobs per year under a smooth contraction scenario. We show these figures in rows 2 and 3 of Table 49.

Of the 20,000 workers employed in these jobs as of 2030, we assume that half of them will retire voluntarily between 2031 – 2050. This retirement rate is proportionally higher than the 22 percent voluntary retirement rate that we estimated for 2021 – 2030 based on demographic data, and as reported in Table 35. This is because the 22 percent figure was for 10 years only, as opposed to the 20-year stretch between 2031 – 2050. It is also reasonable to assume that, over Colorado's 30-year transition out of fossil fuels, the average age of the industry's workforce will tend to skew older over time. Younger workers will increasingly recognize that there will not be a secure future for them in the fossil fuel industry. Thus, on an average annual basis, we approximate that 500 workers per year will reach retirement age between 2031 – 2050.

With the average annual rate of job contraction being 800 jobs while the average rate of attrition though retirements at 500 jobs per year, this means that the average number of workers who will face displacement over 2031 – 2050 will be 300. We show this in row 6 of Table 49. Of these 300 workers, 255 non-managerial workers (85 percent of 300) will need to receive the full package of Just Transition support that we described in Section 8 for the period 2021 – 2030. This includes 100 percent compensation insurance when these displaced workers move into their guaranteed new jobs; as well as both retraining and relocation support. We estimated in Section 8 that the average total cost for providing such Just Transition support for displaced workers would be about $234,000 per worker. This level of support would then imply an overall cost for Just Transition support for displaced workers at $54 million per year, as we show in row 7 of Table 49.

Beyond such support for displaced individual workers, our Just Transition program for 2021 – 2030 does also include transitional support for fossil fuel dependent communities. Such support should also be continued over 2031 – 2050, as the fossil fuel industry contraction in Colorado proceeds. At this point, we can only vaguely speculate as to which communities throughout the state would be most in need of such support throughout 2031 – 2050. But the need to continue providing such support will remain strong.

Appendix 1
Deriving an Estimate of Current Clean Energy Investment Level in Colorado

A) Estimating Colorado's Clean Energy Investment Level as Proportional to Overall U.S. Clean Energy Investments.

- Clean energy investments in U.S. in 2017: $56.9 billion[87]
- Colorado GDP in 2017: $345.2 billion[88]
- U.S. GDP in 2017: $19.5 trillion[89]
- Colorado share of GDP: $345.2 billion/$19.5 trillion = 1.8 percent

Colorado clean energy investment as proportional share of U.S. figure: 1.8 percent x $56.9 billion = $1.0 billion

B) Information indicating clean energy investments in Colorado are likely more than proportional relative to U.S. average:

- Over $5.4 billion of renewable energy projects have been built in eastern Colorado from 2000-2016.[90]
- Solar investments in 2016 totaled more than $510 million.[91]
- Xcel energy was approved by the Public Utilities Commission for a $2.5 billion investment to bring 1,100 megawatts of wind and 700 MW of solar to its grid by 2026.[92]
- Electricity from renewable sources has more than doubled since 2010 to around 20% of Colorado's net electricity generation in 2016, led by increased wind power from the state's roughly 1,900 turbines.[93]
- Between 2005 and 2016, wind energy increased from 1.5% to 17.3% of electricity generated in the state.[94]
- As of December 2017, Colorado ranks 10th in installed solar power capacity, and 11th in solar electricity generation in the U.S.[95]
- As of July 2017, Colorado ranks 10th in wind power capacity.[96]
- As of October, 2018, Colorado ranks 14th in energy efficiency policy and programs, according to the ACEEE (American Council for an Energy-Efficient Economy).[97]
- Clean energy jobs in Colorado represent 0.8 percent of total employment in the state, ranking it fourth in the U.S. For the U.S. as a whole, clean energy jobs represent 0.5 percent of overall employment.[98]

Given this range of evidence, we conclude that current levels of clean energy investments in Colorado are likely in the range of $2 billion as a lower-end figure.

Appendix 2
Estimating Employment Creation through Clean Energy Investments In Colorado

Employment Estimating Methodology

The employment estimates for Colorado State were developed using an input-output model. Here we used IMPLAN v3, an input-output model which uses data from the U.S. Department of Commerce as well as other public sources. The data set used for the estimates in this report is the 2016 Colorado State data supplied by IMPLAN. An input-output model traces linkages between all industries in the economy as well as institutional sources of final demand (such as households and government). A full discussion of the strengths and weaknesses of input-output (I-O) models and their application to estimating employment in the energy sector can be found in Appendix 4 of Pollin et al. (2014).

One important point to note here is that I-O models to date do not identify renewable energy industries such as wind, solar, or geothermal, or energy efficiency industries such as building retrofits, industrial efficiency, or grid upgrades. However, all of the components that make up each of these industries are contained in existing industries within the models. For example, the hardware, glass production, and installation industries that are all activities within "solar" are each an existing industry in the I-O model. By identifying the relevant industries and assigning weights to each, we can create "synthetic" industries that represent each of the renewable energy and energy efficiency industries within the model. Below we show the industries and weights used in this study. A full discussion of the methodology for creating synthetic industries can be found in Garrett-Peltier (2017).

The energy industries and weight of each component industry are shown in Table A2.1, on the next page.

Scaling Manufacturing Activity

The employment estimates produced in the IMPLAN model are disaggregated into over 400 sectors. The expansion of clean energy that we propose in this report is significant, and occurs rather rapidly, over a 10-year period. While it may be possible for construction and service activities to keep pace with the rapid scaling up of clean energy consumption in Colorado State, we assume that manufacturing facilities will take longer to develop, and that while manufacturing activity will indeed expand within the state, in the first 10 years of clean energy expansion some of the clean energy manufacturing will develop out of state. Here we make the conservative assumption that manufacturing will only increase 10% relative to the overall increase in clean energy activity. Thus, the employment multipliers will be lower in this constrained case than if we were to assume that all sectors, including manufacturing, scaled up at the same pace. In the IMPLAN model, to incorporate this change, we reduce manufacturing activities by 90 percent to generate conservative estimates of jobs (see Table A2.2).

For the purposes of this study, and to err on the side of underestimating rather than overestimating employment, we use the constrained multipliers in the right-most column in our estimates in Table A2.2.

TABLE A2.1
Composition and Weights for Modelling Energy Industries within the I-O Model

Energy Industries	Composition and Weights of Industries
Building retrofits	50% maintenance and repair construction of residential structures, 50% maintenance and repair construction of non-residential structures.
Industrial efficiency	30% environmental and technical consulting services, 20% repair construction of non-residential structures, 10% air purification and ventilation equipment manufacturing, 10% heating equipment manufacturing, 10% A/C, refrigeration, and warm air heating equipment manufacturing, 10% all other industrial machinery manufacturing, 10% turbine and turbine generator set units manufacturing.
Grid upgrades	25% construction of new power and communication structures, 25% mechanical power transmission equip¬ment manufacturing, 25% miscellaneous electrical equipment and component manufacturing, 25% other electronic component manufacturing.
Public transport/rail	30% construction of other new non-residential structures, 21% motor vehicle body and parts manufacturing, 6% railroad rolling stock manufacturing, 43% transit and ground passenger transportation.
Wind	26% construction of new power and communication structures, 12% plastic and resin manufacturing, 12% fabricated structural metal manufacturing, 37% other industrial machinery manufacturing, 3% mechanical power transmis¬sion equipment manufacturing, 3% electronic connector manufacturing, 7% miscellaneous professional, scientific, and engineering services.
Solar PV	30% construction of new power and communication structures, 17.5% hardware manufacturing, 17.5% mechanical power transmission equipment manufacturing, 17.5% capacitor, resistor, coil, transformer, and other inductor manufacturing, 17.5% miscellaneous professional, scientific, and engineering services.
Geothermal	15% drilling wells, 45% construction of new non-residential structures, 10% pump and pumping equipment manufacturing, 30% scientific research and development services.
Nuclear	100% nuclear electric power generation.
Oil and gas	3% extraction of natural gas and crude petroleum, 5% drilling oil and gas wells, 4% support activities for oil and gas, 9% natural gas distribution, 55% petroleum refineries, 1.5% industrial gas manufacturing, 2.5% pipeline transportation.
Coal	21% coal mining, 4% support activities for mining, 40% electric power gen¬eration, 35% rail transportation.

TABLE A2.2
Employment Multipliers per $1 million in Unconstrained and Constrained Cases

	Direct, Indirect, and Induced Jobs per $1 Million	
	If All Sectors Expanded 100 Percent	Constrained: Manufacturing Expands 10% Only
Wind	9.7	5.2
Solar PV	10.5	7.8
Geothermal	11.3	10.7

Appendix 3
Estimating Job Characteristics for Clean Energy and Fossil Fuel Industry Jobs

Characteristics of Jobs Created by Clean Energy Investments

Our strategy for identifying the types of jobs that would be added to the economy due to an investment in one of the energy efficiency and clean energy sectors involves two steps.

The first step is to calculate, for each specific investment program, the level of employment generated in each of 526 industries through our input-output model (IMPLAN) as explained in Appendix 2.

Next, we apply this information on the industry composition of the new employment created by an investment with data on workers currently employed in the same industrial mix of jobs. We use the characteristics of these workers to create a profile of the types of jobs and the types of workers that will likely hold the jobs created with each investment. These characteristics include types of occupations, gender, race/ethnicity, union status, credential requirements, earnings and job-related benefits.

Our information about the workers currently employed in the industrial mix of jobs created by an investment comes from the Current Population Survey (CPS). The CPS is a household survey administered by the U.S. Census Bureau, on behalf of the Bureau of Labor Statistics of the U.S. Labor Department. The basic monthly survey of the CPS collects information from about 60,000 households every month on a wide range of topics including basic demographic characteristics, educational attainment, and employment status. Among a subset of its monthly sample—referred to as the outgoing rotation group (ORG)—respondents are asked more detailed employment-related questions, including about their wages and union status. The CPS' survey in March includes a supplement, referred to as the Annual Social and Economic survey (ASEC) that asks additional questions, particularly about income, poverty status, and job-related benefits. We pool up to four years of the most current CPS data available as of the writing of this report for our analyses.[99]

To create a profile of the types of jobs and the types of workers that will likely hold the jobs created with each investment, we weight the CPS worker data with the industry shares generated by IMPLAN. This creates a sample of workers with an industry composition that matches that of the jobs that we estimate will be added by investing in a clean energy/energy efficiency sector.

Specifically, we use the IMPLAN industry shares to adjust the sampling weights provided by the CPS. The CPS-provided sampling weights weight the survey sample so that it is representative at various geographic levels, including national and state. We adjust the CPS-provided sampling weights by multiplying each individual worker's sampling weight with the following:

$$S \times \frac{\text{IMPLAN's estimate of the share of new jobs in worker i's industry j}}{\sum \text{CPS sampling weights of all workers in industry j}}$$

where S is a scalar equal to the number of direct and indirect jobs produced overall by the level of investment being considered. For example, say Colorado's investment in mass transit of $1 billion would generate 10,000 direct and indirect jobs, then S is equal to 10,000.

Some of the 526 IMPLAN industries had to be aggregated to match the industry variable in the CPS, which has 242 categories, and vice versa. For example, among IMPLAN's 526 sectors, there are 13 construction sectors while the CPS has only one construction industry. In the end, 194 industry sectors are common to both IMPLAN and the CPS.

We use these adjusted sampling weights to estimate the job-related health insurance and retirement benefits, and union membership among workers in the specific industrial mix of jobs associated with each type of investment. We also estimate demographic characteristics, such as percent female and percent non-white, as well as, workers' educational attainment. Finally, we determine what are the most prevalent occupations held by workers in the industrial mix of jobs associated with each type of investment.

The total compensation estimates for jobs in clean energy sectors are based on the 2017 Quarterly Census of Employment and Wages (QCEW). The QCEW tabulates employment levels monthly and wages quarterly through a joint effort by the Bureau of Labor Statistics of the U.S. Labor Department and the State Employment Security Agencies (SESAs). The QCEW provides a near-census of U.S. jobs (98 percent), and includes all unemployment insurance (UI) covered workers. A small group of workers are not covered by the QCEW. These workers include: members of the armed forces, the self-employed, proprietors, domestic workers, unpaid family workers, and railroad workers covered by the railroad unemployment insurance system.

As with estimating worker characteristics, we use the industry shares of employment generated by IMPLAN to estimate total compensation for jobs in clean energy sectors. Specifically, we used the IMPLAN industry shares, for the direct and indirect jobs, to estimate weighted average annual wages for each clean energy sector.

We then inflate this figure to add the value of the average level of benefits typically received by workers in the industrial mix of jobs associated with each type of investment. To determine how much we should inflate the average pay rate by, we calculate a ratio of total compensation to wages/salaries using 2017 data from the Bureau of Economic Analysis (BEA, Tables 6.2D and 6.3D). Specifically, for each clean energy or energy efficiency investment, we create a weighted average of the total compensation data using the IMPLAN industry shares aggregated up to the 2-digit level, and then again for the wage/salary data. We then apply the ratio of: (the weighted average of total compensation)/(weighted average of wages/salary) to our estimates of average pay.

All dollar figures are inflated to 2018 dollars using the CPI-U.

Characteristics of Jobs in Fossil Fuel Related Industries

The primary data sources that we use to estimate characteristics of jobs in the fossil fuels industries is the American Community Survey (ACS) and the Quarterly Census of Employment and Wages (QCEW) described above.

The ACS is an annual household survey administered by the U.S. Census Bureau and serves as the Census' primary method for collecting detailed information about the U.S. workforce and overall population in between decennial censuses. The ACS is specifically designed to provide estimates at the state and local levels, surveying roughly 3 million households. In order to get sufficient sample sizes to generate reasonable estimates on workers in each of Colorado's fossil fuel sectors, we pool the most recent five years of ACS data available, 2013-2017.[100]

We use the ACS to estimate the characteristics of workers and their jobs in the fossil fuel industries, including workers' health insurance coverage, educational attainment, age, race and gender. We also use the ACS to identify the most prevalent occupations among the jobs in fossil fuel industries. The ACS, however, does not collect data on union status of workers. For unionization rates, we use the 2013-2017 CPS-ORG data files (described above) for all the fossil fuel related industries, except for coal mining. The unionization rate among Colorado coal miners is taken from the, "Annual Coal Report for 2017" published by the EIA (see: https://www.eia.gov/coal/annual/pdf/table20.pdf). We do not use the CPS for coal miners because of the CPS-ORG's small sample.

The ACS industry categories do not match up exactly with the fossil fuel sectors that we analyze in this report. As a result, in some cases, our ACS estimates are based on industry categories at a higher level of aggregation than the 6-digit NAICS code level that we are able to get employment and compensation figures for from the QCEW.

As noted above, the annual average 2017 employment and wage levels we report in the main text are estimates published directly by the QCEW. There are two exceptions. In both cases, we combine similar individual sectors into larger aggregated sectors. For the annual wage, we use an employment-weighted average. Specifically, we combine the figures for "Drilling oil/gas wells" and "Support activities for oil and gas." This is because all of our other job characteristics, based on the ACS data (discussed above) are only available for these sectors combined. We also combine the sectors "Pipeline transportation of natural gas," "Pipeline transportation of refined petroleum," and "Oil and gas pipeline and related structures construction" for a similar reason and for ease of exposition.

To estimate total compensation figures, we use, as in the case of the clean energy compensation estimates, BEA figures to inflate the QCEW annual wage figures. More specifically, for each fossil fuels sector, we use the BEA figures for relevant 2-digit NAICS sector.

All dollar figures are inflated to 2018 dollars using the CPI-U.

Including Self-Employed Workers to Fossil Fuel Employment Estimates

We added an estimate of the number of self-employed workers to our fossil fuel sectors due to the findings of past research that indicates a high level of self-employment in oil and gas related industries (See: "A profile of mining, including oil and gas," by Headwaters Economics, Economic Profile Systems, available at: www.headwaterseconomics.org). We used the Nonemployer Statistics data (NES) from the U.S. Census Bureau to estimate the number of self-employed workers in each of the fossil fuel sectors. The NES Statistics cover businesses with no paid workers and that are subject to federal income taxes, with a minimum of $1,000 ore more in receipts ($1 or more in the construction sector). Estimates are available for 450 NAICS categories. This data set is the primary data source available to study the self-employed at detailed geographic levels. (See: https://www.census.gov/programs-surveys/nonemployer-statistics/about.html).

For some sectors, we had to use more aggregated data in the NES data (e.g., NAICS 333 for mining machinery manufacturing and NAICS 221 for fossil fuel power generation). To approximate the employment numbers of the specific industries we want to include in our fossil fuels sectors, we estimated the ratio of the employment level in the disaggregated sectors as a share of the aggregated sectors, and applied these ratios to the aggregated figures available in the NES.

Disaggregating Employment in the Fossil-fuel Based Electricity Generation Sector

In the above discussion of the Just Transition program, cuts to coal and oil/gas production will occur at different rates. As a result, we need to estimate job losses separately for coal-related activities versus oil- and gas- based activities. At the same time, the QCEW employment figures do not disaggregate between coal-based fossil fuel electric generation and oil/gas based fossil fuel electric generation. In order to approximate how employment would be distributed between these more detailed sectors, we use the proportion of electricity consumption based in each type of fossil fuel. Specifically, we assume that 23 percent of employment in fossil fuel based electricity generation is gas-based and 77 percent is coal-based (see Table 3: 35.3 T-BTU of electricity consumption is coal-based and 118.2 T-BTU is natural gas-based).

Comparing Fossil Fuel Employment Estimates: PERI's vs. Metro Denver's

The Metro Denver Economic Development Corporation's 2017 report, "ENERGY: Colorado Industry Cluster Profile," estimates significantly higher employment figures for fossil fuel and ancillary industries in Colorado, about 44,400 compared to PERI's 34,300. The main drivers for this large difference between employment figures are:

1. Metro Denver includes sectors that are dominated by non-fossil fuel related businesses.
2. Metro Denver includes sectors that we do not consider fossil-fuel related at all.
3. The Metro Denver report includes industries that we do not consider to be part of the fossil fuel sector because they do not depend on fossil fuels per se, but rather exist as part of Colorado's energy sector as a whole.
4. Any remaining differences are likely due to the fact that Metro Denver uses a different source of data than this report.

We discuss each of these issues in turn below.

1. Metro Denver includes sectors that are dominated by non-fossil-fuel-related businesses. Similar to PERI's approach, the Metro Denver report includes sectors that currently interact with—i.e., are ancillary to—businesses directly engaged in producing fossil fuels (e.g., oil and gas extraction). These industries include natural gas distribution and fossil fuel electric power generation.

Metro Denver, however, also includes sectors with businesses that are only partly engaged in activities that use fossil fuels. For example, Metro Denver includes the sector, "Power and Communication Line and Related Structures Construction" (NAICS 2017: 237130) as part of the fossil fuels "subcluster." According to U.S. Census documentation[101], this sector, "Power and Communication Line and Related Structures Construction," includes the following types of businesses:

- Alternative energy (e.g., geothermal, ocean wave, solar, wind) structure construction
- Power line stringing
- Cellular phone tower construction

- Radio transmitting tower construction
- Co-generation plant construction
- Satellite receiving station construction
- Communication tower construction
- Nuclear power plant construction
- Telephone line stringing
- Electric light and power plant (except hydroelectric) construction
- Transformer station and substation, electric power, construction
- Electric power transmission line and tower construction
- Underground cable (e.g., cable television, electricity, telephone) laying

This "Power and Communication Line and Related Structures Construction," sector is not exclusively, or it seems, even predominantly, related to fossil fuels (in contrast to, for example, NAICS 237120, "Oil refinery construction"). As a result, we exclude this sector. For similar reasons, we also exclude the sector, "Coal and other mineral and ore merchant wholesalers," which the Metro Denver report includes. We do include some sectors that the Metro Denver report does not. For example, we include jobs in the NAICS sector: 424710, "Petroleum bulk stations."

2. Metro Denver includes sectors that we do not consider fossil-fuel related at all. These include hydroelectric power generation and nuclear electric power generation.

3. The Metro Denver report includes industries that we do not consider to be part of the fossil fuel sector because they do not depend on fossil fuels per se, but rather exist as part of Colorado's energy sector as a whole. These sectors we expect will remain, regardless of the energy source(s) that dominate in Colorado's economy. The sectors that Metro Denver includes, and that we exclude, are:

- Electric bulk power transmission;
- Electric power distribution;
- Financial sector businesses engaged in investment and trading activities;
- Engineering services, surveying and mapping.

The jobs in these industries make up just over 40 percent of the total number of Metro Denver's fossil fuel sector jobs, or about 18,000. The remaining jobs included in Metro Denver's fossil fuel sector jobs, about 27,000 jobs is below, but more in line with, the 34,000 fossil fuel sector jobs that we report.

4. Any remaining differences are likely due to the fact that Metro Denver uses a different source of data than this report. As they note, they use data from: Dun & Bradstreet, Inc. Marketplace database, July-Sept 2010; Market Analysis profiles 2011-2016; Development Research Partners (see p. 9). Our employment figures come from the U.S. Labor Department.

Appendix 4
Detailed Sources for Pension Fund and Income Data

Methodology

Colorado is one of the largest fossil fuel producing states in the country, ranking fifth in oil production, sixth in natural gas production, and tenth in coal production.[102] It was impossible to identify and analyze pension and income data for every single firm within the fossil fuel and ancillary industries in Colorado due to data limitations and the large number of fossil fuel firms (there are over 300 in oil and gas production alone[103]). For Tables 36 and A4.1 – A4.4, we narrowed our analysis to include the top twenty oil and gas producing companies and all six coal mining companies.

We included the oil and gas production companies for the following reasons. First, over 70% of fossil fuel industry jobs fall under NAICS code categories 21112 ("Crude petroleum extraction"), 21113 ("Natural gas extraction"), and 212112 ("support activities for oil and gas operations"). While ranked lists of companies specific to each NAICS code are unavailable, ShaleXP provides a list of the top twenty oil and gas producing companies in Colorado, which together account for 87% of oil production and 90% of gas production in the state.[104] Thus, we can assume that these companies make up a significant percentage of workers that will be affected by a clean energy transition. To our knowledge, a similar list for companies providing support for oil and gas operations (NAICS code 212112)—a much broader category—does not exist.

While the percent of fossil fuel jobs in "coal mining" (NAICS code 21211) was much smaller (less than 5%), it still constituted a significant number of jobs (1,230). Moreover, as documented by Pollin and Callaci (2018), among the fossil fuel and ancillary industries only pension funds within the coal industry are truly distressed. Thus, it was important to include the six coal mining companies in the pension fund analysis.

Of the twenty-six companies, seventeen are publicly traded companies, one is a not-for-profit cooperative corporation, and eight are privately held. Pension and income data are unavailable for the eight privately held companies.

Sources for Pension Data

The pension plan data came from ERISA Form 5500s[105]:

- Form 5500, the main form filed by employee benefit plans with at least 100 participants;
- Form 5500 SF, filed by plans with fewer than 100 participants;
- Schedule SB, which contains information on assets and liabilities for single-employer pension plans;
- Schedule MB, which contains similar information for multiemployer plans.

Sources for Income Data by Company (parent companies in parentheses)

Bill Barrett Corporation (HighPoint Resources): SEC filings (10-Ks) https://www.sec.gov/Archives/edgar/data/1725526/000172552619000062/hpr-12312018x10xk.htm

Bonanza Creek Energy Operating Company, LLC (Bonanza Creek Energy, Inc.): SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0001509589&type=10-k&dateb=&owner=exclude&count=40

BP America Production Company (BP PLC): 2017 Annual Report https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/investors/bp-annual-report-and-form-20f-2017.pdf

Burlington Resources Oil & Gas, LP (ConocoPhillips): SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0001163165&type=10-k&dateb=&owner=exclude&count=40

Chevron USA, Inc (Chevron Corp.): SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0000093410&type=10-k&dateb=&owner=exclude&count=40

Elk Ridge Mining Reclamation, LLC (Tri-State Generation & Transmission Association, Inc.): SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0001637880&type=10-k&dateb=&owner=exclude&count=40

Extraction Oil & Gas, LLC (Extraction Oil & Gas, Inc.): SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0001655020&type=10-k&dateb=&owner=exclude&count=40

GCC Energy, LLC (Grupo Cementos De Chihuahua): 2017 Annual Report http://www.gcc.com/wp-content/uploads/2018/09/GCC-Reporte-anual-2017-vf-Ingl%C3%A9s.pdf

Kerr-McGee Oil & Gas Onshore, LP (Anadarko Petroleum Corp.): SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0000773910&type=10-k&dateb=&owner=exclude&count=40

Kinder Morgan CO2 Company, LP (Kinder Morgan, Inc.): SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0001506307&type=10-k&dateb=&owner=exclude&count=40

Mountain Coal Company, LLC (Arch Coal, Inc.): SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0001037676&type=10-k&dateb=&owner=exclude&count=40

Noble Energy, Inc.: SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0000072207&type=10-k&dateb=&owner=exclude&count=40

PDC Energy, Inc.: SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0000077877&type=10-k&dateb=&owner=exclude&count=40

Piceance Energy, LLC (Par Pacific Holdings, Inc.): SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0000821483&type=10-k&dateb=&owner=exclude&count=40

Pioneer Natural Resources USA, Inc. (Pioneer Natural Resources Co.): SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0001038357&type=10-k&dateb=&owner=exclude&count=40

SRC Energy, Inc.: SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0001413507&type=10-k&dateb=&owner=exclude&count=40

Twentymile Coal, LLC (Peabody Energy Corp.): SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0001064728&type=10-k&dateb=&owner=exclude&count=40

Whiting Oil and Gas Corporation (Whiting Petroleum Corp.): SEC filings (10-Ks) https://www.sec.gov/cgi-bin/browse-edgar?action=getcompany&CIK=0001255474&type=10-k&dateb=&owner=exclude&count=40

Other Sources:

For general information about the twenty-six companies, we used subsidiary and parent company websites, www.shalexp.com, and www.drillingedge.com.

Appendix 5
Identifying Colorado's Energy Intensive and Trade Exposed (EITE) Facilities

To our knowledge, there is no official listing of EITE facilities located in Colorado. We generating the list of firms in Table 43, and the information reported on each of them, as follows:

Definitions of EITC facilities

We utilized definitions from two sources:

- USEPA (2009):[106] lists 44 NAICS 6-digit industries considered EITE.
- Metcalf (2013):[107] updated the list of industries based on EPA's criteria.

Data on Greenhouse Gas Emissions from Individual Facilities

The Environmental Protection Agency's Greenhouse Gas Reporting Program (GHGRP) provides data on facility name, location, NAICS code, CO_2 emissions, and CO2e emissions.[108, 109] GHGRP reporting is required for 41 categories of facilities if they meet any of the following conditions:[110]

- GHG emissions from covered sources exceed 25,000 metric tons CO2e per year.
- Supply of certain products would result in over 25,000 metric tons CO2e of GHG emissions if those products were released, combusted, or oxidized.
- The facility receives 25,000 metric tons or more of CO_2 for underground injection.

We then compared the NAICS codes of the facilities from the GHGRP data to the NAICS codes from the two sources we used for the definition of EITE facilities—i.e. USEPA 2009 and Metcalf 2013. Using Metcalf (2013) resulted in one additional industry (ethanol) being included, and thus slightly higher emissions figures. These higher figures are the ones we reported in Table 43.

For the "Industry" column in Table 43, we used 2017 NAICS 6-digit industry names. The NAICS codes from the GHGRP were from 2007, so we updated these to reflect 2017 NAICS.

Appendix 6
Achieving a 100 Percent Renewable Electricity Standard by 2040

We demonstrate in this appendix how Colorado can achieve a 100 percent renewable electricity standard as a component of its broader aim of reducing CO_2 emissions in the state by 90 percent relative to its 2005 level.

Overall Energy Consumption in 2040

In Table A6.1, we show figures on energy consumption, electricity consumption and related data, starting with the 2015 actual data and moving forward with our projections through 2050. As throughout the study, we begin with the assumption that Colorado's economic growth will proceed at a steady rate of 2.4 percent per year from 2015 to 2050. Within that framework, we have already shown how, through investments in energy efficiency, Colorado's energy intensity ratio will fall from 4.7 Q-BTUs per $1 trillion in GDP to 2.0 as of 2050, a 58 percent improvement in efficiency over a 30-year period. Within that trajectory for energy efficiency gains, we have also already shown how Colorado's energy intensity ratio will fall to 3.0 by 2030 before reaching the 2.0 figure as of 2050. Assuming these gains in the energy intensity ratio proceed at a steady rate between 2031 – 2050, this implies that in 2040, the state's energy intensity ratio will be approximately 2.5. Working from our estimates for GDP and energy intensity as of 2040, we can then estimate total energy consumption in 2040, which will be 1.42 Q-BTUs.

TABLE A6.1
Framework for Colorado Achieving 100 Percent Electricity Supply from Renewables as of 2040

REAL GDP GROWTH ASSUMPTION: 2.4 PERCENT AVERAGE ANNUAL GROWTH, 2015– 2050

	2015/2020 *(actual figures for 2015)*	2030 Projected	2040 Projected	2050 Projected
Real GDP *(in 2015 dollars)*	$316 billion	$454 billion	$570 billion	$730 billion
Energy intensity ratio *(Q-BTUs per $1 trillion in GDP)*	4.7 *(assume this ratio for 2020)*	3.0	2.5	2.0
Total energy consumption	1.48 Q-BTUs *(assume this level for 2020)*	1.36	1.43	1.46
Energy consumed for electricity consumption	0.57 Q-BTUs *(assume this level for 2020)*	0.73 Q-BTUs	0.94 Q-BTUs	1.20 Q-BTUs
Electricity generation from renewable sources	16.9% *(assume this level for 2020)*	84%	100%	100%

Sources: See Tables 3 and 46.

Electricity Consumption in 2040

What share of the 1.42 Q-BTUs in total energy consumed in 2040 will be needed to generate electricity? We can estimate this through the following steps.

Electricity consumption in 2050. We have already derived that, as of 2050, total energy consumption in Colorado will be 1.46 Q-BTUs, and of this total, 1.33 Q-BTUs will come from clean renewable sources. The remaining 0.13 Q-BTUs will be supplied by petroleum, to be used as a liquid fuel in transportation. Of the 1.33 Q-BTUs of clean renewable energy supplied as of 2050, we assume that 90 percent will be used to generate electricity. The other 10 percent will be used for non-electricity generating uses with both concentrated solar power and geothermal power technologies. As such, we estimate that total energy consumption used for generating electricity as of 2050 will be about 1.2 Q-BTUs (i.e. 1.20 Q-BTUs = 1.33 x 0.9).

As we first reported in Table 2 and repeat in Table A6.1, total energy consumption in Colorado to generate electricity was 0.57 Q-BTUs, 39 percent of all energy consumption in Colorado for 2015. We assume that these actual electricity consumption figures for 2015 will be maintained as of 2020. Given this assumption, energy used for electricity will increase at an average rate of 2.5 percent per year between 2021 - 2050. This is while average overall energy consumption remains essentially flat between 2020 – 2050. This is due to the increase in energy efficiency, as Colorado's energy intensity ratio falls from 4.7 to 2.0 through investments in energy efficiency.

With energy demand for electricity rising at an average annual rate of 2.5 percent between 2020 – 2050, this means that overall demand for energy to generate electricity will be 0.94 Q-BTUs in 2040. In short, for Colorado to achieve 100 percent renewable energy by 2040 will require that total clean renewable energy be at 0.94 Q-BTUs.

Renewable Electricity Supply Needs for 2040. As we have discussed, as of 2030, total clean renewable supply will be at 0.68 Q-BTUs (see Table 12). This means that the increase in renewable supply as of 2040 will need to be 0.26 Q-BTUs relative to the 2030 starting point to reach a supply level of 0.94 Q-BTUs (i.e. 0.94 Q-BTUs – 0.68 Q-BTUs = 0.26 Q-BTUs).

The Costs to Expand Renewable Electricity Supply. We have estimated that, between 2031 – 2050, the average cost of expanding clean renewable capacity by 1 Q-BTU will be $180 billion. This means that to expand clean renewable supply in Colorado by 0.26 Q-BTUs between 2031 – 2040 the cost will be $47 billion (i.e. $180 billion x 0.26 = $47 billion). As an average over the 10-year period 2031 – 2040, this amounts to $4.7 billion per year.

As we have seen in Table 46, we have already projected average spending on renewables between 2031 – 2050 to be $5.9 billion per year. The $4.7 billion per year for 2031 – 2040 needed to reach the 2040 goal of 100 percent renewable electricity is therefore less than the average annual clean renewable spending figure needed over 2031 – 2050.

It is true that the average clean renewable spending level of $5.9 billion represents a figure that rises over the 20-year period 2031 – 2050 as GDP grows in absolute dollars under the 2.4 percent average GDP growth trajectory. For our present concerns, we need to focus just on the 10-year period 2031 – 2040. The midpoint GDP figure over this period will be $515 billion, assuming a 2.4 percent average annual GDP growth rate starting in 2015.

Therefore, the $4.7 billion annual investments in clean renewable energy over the decade to achieve the 100 percent renewable electricity goal will be 0.9 percent of Colorado's average annual GDP over the 2031 – 2040 decade. This is a readily attainable goal within our overall growth framework for Colorado.

Overall then, it is through the foregoing series of calculations that we are able to reach the conclusion that the goal of providing 100 percent of Colorado's electricity supply through renewable sources as of 2040 is clearly achievable within the state's broader project of reducing emissions to 9 million tons as of 2050—a 90 percent emissions reduction level as of 2050 relative to 2005.

Endnotes

1 Our basic measures of CO_2 emissions throughout this study are units of metric tons. However, to simplify, for the most part we refer hereafter to this unit as "tons" of CO_2 emissions.

2 We discuss below the issues involved in including the emissions figures for biomass. Emissions figures for 2016 became available as we were completing this study. But it was not possible to integrate this additional year of data into our analysis. In any case, as noted below, the difference between the 2015 and 2016 emissions levels are very small.

3 http://climateactiontracker.org/global.html.

4 The precise wording of the IPCC's assessment is as follows: "In model pathways with no or limited overshoot of 1.5 degrees, global net anthropogenic CO_2 emissions decline by about 45 percent from 2010 levels by 2030 (40 -60 percent interquartile range), reaching net zero around 2050 (2045 – 2055 interquartile range)," IPCC, 2018, p. 14.

5 Despite this absence of details, President Trump dismissed the study outright by his own government experts. Trump's response was, "I don't believe it," https://www.cnn.com/2018/11/26/politics/donald-trump-climate-change/index.html.

6 See Pollin (2015, Chapter 8) for a more extended discussion of clean energy investments as a climate change insurance policy.

7 We also consider in this study CO_2 emissions from burning biomass energy sources in Colorado. The emissions from biomass are a much smaller but still significant source of Colorado's overall CO_2 emissions, at 3.1 percent of total emissions as of 2015.

8 We rely on three main sources for data on global CO_2 and overall greenhouse gas emissions: the U.S. Energy Information Agency's (EIA) *International Energy Statistics*, the International Energy Agency's (IEA) *World Energy Outlook*, and the World Bank's World Development Indicators. There are small differences in details among these three sources. To reconcile these differences, we try to use the source that provides the most recent set of figures for the global economy. We use less recent data, as needed, when they provide an improved level of detail.

9 Figures cited here come from: https://www.eia.gov/todayinenergy/detail.php?id=37233; and https://www.e2.org/releases/report-57500-coloradans-now-work-in-clean-energy/.

10 We focus on the 2015 data as the most recent benchmark in this study. However, as of February 2019, the U.S. Energy Information Agency (EIA) has published CO_2 emissions figures by states as of 2016. Yet, we have been unable to incorporate these most recent 2016 figures into the study, since our study had been fully drafted prior to these 2016 data having been released in February 2019. As reported by the EIA, emissions in Colorado did fall between 2015 and 2016, from 90.4 to 89.0 million tons, a 1.5 percent decline. This is a meaningful reduction in Colorado's emissions over that one-year period. But working with the 2015 data, as we have throughout this study, rather than the most recent 2016 figures, does not change any of our substantive results or policy recommendations.

11 U.S. Environmental Protection Agency, "Non-Hydroelectric Renewable Energy Sources" (2013), available at http://www.epa.gov/cleanenergy/energy-and-you/ affect/non-hydro.html. Biomass can be converted into energy in solid, liquid, or gas form. A biomass energy source converted into liquid form is a biofuel.

12 The net emissions generated by biomass sources vary over time. This is because the plant sources of biomass energy absorb CO_2 in their growing process. However, the amount of time required for the CO_2 absorption process to offset the CO_2 emissions from burning biomass ranges between about 20 – 30 years, depending on the specific energy-generating process. As such, within the 10 – 30 frame on which this study focuses, we treat biomass energy emissions in Colorado as a contributor to the state's overall level of emissions. See Walker et al. (2010) for a detailed analysis on this issue and Pollin et al. (2014, pp. 113-116) for a summary discussion.

13 Various approaches to reduce energy losses in electricity generation are described in Prentiss (2015).

14 Pollin et al. (2014) provides an extensive review of the NAS study.

15 It is also important to recognize that this average cost figure of 10.4 cents per kilowatt hour includes a wide range of prices according to region and the sectors consuming electricity. For details, see https://www.eia.gov/electricity/state/ and https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a.

16 https://www.bts.gov/print/node/205071.

17 The estimates in *Green Growth* for average fuel efficiency levels for automobiles as of 2030 are lower than those derived by both the Energy Information Agency, whose estimate was at 44.0 mpg and the Environmental Protection Agency, whose estimate was 49.3 mpg. We are working with the lower estimate, so that we remain conservative in assessing the prospects for achieving efficiency gains within the auto transport sector. The references for the EIA figure are: Vehicle age from BLS CEX survey http://www.bls.gov/cex/pumd_data.htm#csv, file ovb15.csv, variable VEHICYR. Projected CAFÉ standards from EIA, http://www.eia.gov/outlooks/aeo/data/browser/#/?id=7-AEO2016&cases=ref2016~ref_no_cpp&sourcekey=0, Light Duty Vehicles. The reference for the EPA figures is: Vehicle age from BLS CEX survey http://www.bls.gov/cex/pumd_data.htm#csv, file ovb15.csv, variable VEHICYR.

18 Thus, the White House spokeswoman Sarah Sanders was reported on 8/2/18 to have said "The reporting that we're reversing Obama-era fuel-efficiency standards and preempting the tougher California standards is simply false. We're simply opening it up for a comment period, and we'll make a final decision at the end of that." https://www.washingtonpost.com/national/health-science/2018/08/01/90c818ac-9125-11e8-8322-b5482bf5e0f5_story.html?utm_term=.e206b8d06315.

19 The August 2018 Colorado initiative is described here: https://www.denverpost.com/2018/08/16/colorado-push-for-less-pollution-from-gas-powered-vehicles/.

20 https://www.denverpost.com/2019/01/17/colorado-jared-polis-zero-emmission-standards/.

21 Pollin et al. (2014) pp. 62 -70 discusses in detail the prospects for industrial efficiency gains, based on the NAS study.

22 Prentiss (2015) examines these issues in depth, and concludes that a U.S. energy infrastructure relying primarily on solar and wind is achievable, certainly within 50 years and probably well before then (see also personal correspondence with Robert Pollin, 2/14/19).

23 https://www.colorado.gov/pacific/energyoffice/hydropower.

24 See Pollin et al. (2014), Chapter 5.

25 Ramon Alvarez et al. "Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure," *Proceedings of the National Academies of Sciences (PNAS)*, 2012, www.pnas.org/cgi/doi/10.1073/pnas.1202407109; Joe Romm, "Methane Leaks Wipe Out any Climate Benefit of Fracking, Satellite Observations Confirm," *Think Progress*, 2014, https://thinkprogress.org/methane-leaks-wipe-out-any-climate-benefit-of-fracking-satellite-observations-confirm-2ac26dd30381/; Robert W. Howarth, "Methane Emissions and Climactic Warming Risk from Hydraulic Fracturing and Shale Gas Development: Implications for Policy, Energy and Emission Control Technologies," 2015:3, pp. 45 – 54; and J. Peischl et al. "Quantifying atmospheric methane emissions from oil and natural gas production in the Bakken shale region of North Dakota," *Journal of Geophysical Research,* 2016, pp. 6101 – 6111.

26 https://www.bbc.com/news/science-environment-44396781.

27 https://www.apnews.com/8e5e0db68a324683aecf5d99f0563700.

28 http://www.eia.gov/outlooks/aeo/electricity_generation.cfm.

29 This conclusion is broadly consistent with the findings of the 2018 study by Christopher Clark of Vibrant Clean Energy, "Retirement of Colorado Coal-fired Power Plants Using the WIS:dom Optimization Model." Clark examined the effects of retiring all coal-fired power plants in Colorado by 2025 as opposed to keeping them active until 2040. He found that retiring all coal-fired plants would generate about $2.6 billion in savings for Colorado's electricity consumers relative to allowing the coal-fired plants to continue operating through 2040. The loss of the coal-fired electricity would be replaced by a combination of natural gas, wind, solar and renewable energy storage capacity with the relative mix of these sources depending on the trajectory of relative capital costs between wind and solar. Clark's model also found that cumulative CO_2 emissions in Colorado are reduced by half when the coal plants are retired in 2025 compared with continuing to 2040.

30 The full methodology for generating these costs is presented in Pollin et al. (2014) pp. 136-37.

31 This average cost figure will also be sensitive to the actual proportions in which, respectively, wind, solar and geothermal energy sources expand. It is also possible that small-scale hydro and low-emissions bioenergy sources could also contribute to the overall mix of clean renewable energy supply in Colorado, even while, to keep our formal estimating model relatively simple, we focus on the prospects for wind, solar and geothermal only. Further, within this model, we clearly are assuming that most of the renewable energy capacity

expansion will come from wind and solar. But Colorado does have significant resources to expand its geothermal supply (https://www.colorado.gov/pacific/energyoffice/geothermal-0). At present, the state's geothermal resources are used for heat pumps and directly for pools, spas, greenhouse agriculture, aquaculture, space heating and district-wide heating, but not for generating electricity. This is why we assume that the expansion of geothermal into electricity generation will be relatively modest. This is the case even though, as Table 9 shows, as a U.S. average, the capital costs for creating geothermal electricity generating capacity, at $112 billion per Q-BTU, are lower than those for both wind (at $160 billion per Q-BTU) and solar (at $190 billion per Q-BTU.)

32 See Pollin et al. (2014), pp. 113 – 115 on emissions generated by conventional bioenergy sources, including biomass and corn ethanol.

33 In Appendix 1, we explain how we derive this rough estimate of $2 billion or higher in clean energy investments in Colorado for 2017.

34 Nevertheless, it is still critical to support the purchase of high-efficiency autos by consumers, through, for example, subsidizing credit for such purchases. We return to this point later.

35 According to the U.S. Census, 28 percent of Colorado's labor force was non-White and/or Hispanic/Latino in 2017. The Colorado Department of Local Affairs estimates that 46 percent of Colorado's labor force is female.

36 We emphasize that this assumption of a 50 percent decline in production and employment in Colorado's fossil fuel related industries by 2030, tied to a 50 percent decline in statewide consumption, also as of 2030, is only a *rough approximation*—though we believe it is the most reasonable such approximation. There are reasons to assume that production and employment in the affected industries will decline by less than the full fall in consumption. One factor could be that fossil fuel related business firms located in Colorado could still maintain higher levels of demand for their products with out-of-state customers, even while in-state demand declines by 50 percent. It is also possible that Colorado's fossil fuel related businesses will find it profitable to maintain a disproportionately large workforce even while overall demand declines because doing so maintains their operations at the most effective level. By contrast, it could also follow with some firms that the decline in demand for their products will encourage them to lay off workers by a more than proportional extent—i.e. to reorganize production with a higher level of capital intensity. (This pattern would be consistent with the increasing capital intensity of oil production work itself, as reported in the *New York Times*, 2/20/17, https://www.nytimes.com/2017/02/19/business/energy-environment/oil-jobs-technology.html). Some firms could also shut down altogether due to the steady decline in demand (Pollin and Callaci (2016) discuss this latter prospect more fully). Given this range of possibilities—some of which are counteracting—on balance, we conclude, again, that the most reasonable working assumption for our purposes is that the decline in production and employment in Colorado's fossil fuel related industries will be commensurate with the decline in statewide consumption. However, this assumption does not mean that the decline in production through 2030 will proceed smoothly. In what follows, we consider two sets of possibilities: that the rate of decline is smooth; and, alternatively, that the rate of decline is episodic.

37 As we describe in Appendix 3, the sources for these figures on fossil fuel industry workers are publicly available data provided by the U.S. Bureau of Labor Statistics. In addition to these government sources, we have also examined firm-specific data on three fossil fuel firms with operations in Colorado. These are Tristate, which provides electricity generated by both fossil fuel and renewable sources; the Public Service Company of Colorado (PSCO), which also provides electricity from both fossil fuel and renewable sources; and the coal mining firm Trapper. The data that are available from these firms that parallel the data we are reporting based on the publicly available sources include: 1) number of workers; 2) the percentage of non-white workers; 3) the percent of female workers; and 4) the percentage of workers who will reach age 65 between 2021 and 2030. We have found that the firm-specific data on these firms are broadly consistent with the figures we report based on the publicly available data. The sources for these firm-specific data are as follows. *Tristate*: https://www.tristategt.org/content/generation; https://www.tristategt.org/content/transmission; https://www.tristategt.org/renewables; *PSCO*: https://www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=298400; *Trapper*: http://business.craig-chamber.com/list/member/trapper-mine-10.

38 For convenience, we use the terms "wage insurance" and "wage replacement" for the policy tools described in this section. But as the passage in the main text notes, we are in fact referring to both insurance and replacement policies for the full level of compensation that the displaced fossil fuel related industry workers will have been receiving at the time of their displacement.

39 https://www.coloradochannel.net/sessions/?id=96657.

40 We recognize that some workers in Colorado, including some members of the International Brotherhood of Electrical Workers (IBEW) Local 111, have the option to retire with pensions as early as age 55. For the purposes of our cost estimates of the Just Transition program, having workers retire before age 65 and move onto their pensions will lower the overall costs of the Just Transition program. This is because, under the Just Transition program, all workers who choose to retire will be guaranteed their pensions, but they will not need to receive income, retraining, or relocation support. As such, the estimates that we report for overall Just Transition costs are overstated to the extent that we are not incorporating into our budget calculations the reduced costs resulting from IBEW workers voluntarily retiring between the ages of 55 and 64.

41 We generate this 15 percent estimate as follows: The retention rate of retirement-age workers (65+ years old) is lower among fossil fuel sectors than the total U.S. economy more broadly. For example, in the workforce overall, 65+ year old workers comprise 6 percent. Among the fossil fuel sectors that we focus on in this study, the share is only 3 percent. Similarly, evidence from a survey of human resource professionals in the oil, gas, and mining sectors indicates that it is harder to retain older workers in these fossil fuel sectors as compared to other industries: about 36 percent of human resource professionals report that it is easy to retain older workers in fossil fuel sectors as compared to 44 percent in other industries (see: https://www.shrm.org/hr-today/trends-and-forecasting/research-and-surveys/Documents/Preparing_for_an_Aging_Workforce-Oil_Gas_and_Mining_Industry_Report.pdf). To approximate the retention rate of retirement-age workers in fossil fuels, we start with the BLS' estimate of the share of the non-institutionalized civilian population that is 65+ years old and still in the labor force, or 19 percent. We then apply the relative difference in the ease of retaining such workers specifically in the fossil fuel sectors compared to other industries to approximate the retention rate of retirement-age workers in fossil fuels, i.e., (36 percent/44 percent) x 19 percent = 15 percent.

42 https://obamawhitehouse.archives.gov/the-press-office/2015/03/27/fact-sheet-partnerships-opportunity-and-workforce-and-economic-revitaliz.

43 We estimate that 15 percent of these displaced workers hold top managerial positions. We base this 15 percent figure on the data presented in Tables 28-31 that show the share of fossil fuel sector jobs that are currently held by top managers. These figures range between 9 percent in coal mining and 21 percent in oil and gas extraction. The midpoint figure, 15 percent, is approximately equal to the share of top managers in the other major fossil fuel sectors of oil and gas extraction support activities, and oil and gas pipeline transportation and construction.

44 Our $57,000 estimate overstates the costs of wage insurance. This is because we estimate the wage insurance benefit on the basis of average compensation across all workers within each fossil fuel sector, including the compensation of top managers whose average pay exceeds that of non-managerial fossil fuel sector workers. As a result, the average wage insurance benefit excluding managerial fossil fuel sector workers will typically be lower than $57,000 average that we use as our estimate.

45 The student share of resident tuition and fees for some representative community colleges in Colorado include Community College of Denver, at $5,757 and Colorado Northwest Community College, at $5,604. See: https://secure.collegeincolorado.org/College_Planning/Explore_Schools/Compare_Schools/Compare_Schools.aspx.

46 This $132,000 figure is the average of the compensation figures for the fossil fuel sectors presented in column 3 of Table 37, weighted by the number of displaced workers requiring re-employment (column 1 of Table 37).

47 According to the 2015 article in Moneyzine "Relocation Expenses," these expenses for an average family range between $25,000 and $50,000 (https://www.money-zine.com/career-development/finding-a-job/job-relocation-expenses/). The costs include: selling and buying a home, including closing costs; moving furniture and other personal belongings; and renting a temporary home or apartment while house-hunting for a more permanent residence. For our calculations, we assume the upper-end figure of $50,000.

48 We base this figure on the following calculations. First, we assume that all displaced workers would be eligible for unemployment insurance benefits (UI). To be eligible, workers must have earned at least $2,500 over roughly the past year, and must be unemployed through no fault of their own, such as being laid off. As we noted above, the average displaced worker's annual earnings exceed, by far, the minimum earnings requirement for eligibility: the average displaced worker earns about $132,000 annually, with about 25 percent of this compensation received in the form of benefits, i.e., $106,000 in wages and $26,000 in benefits. Second, at an average level of $106,000 annual earnings, these workers would receive the maximum benefit level of $597 per week. Finally, the maximum duration of UI benefits is 26 weeks. Therefore, the maximum benefit

that the average displaced worker in the fossil fuels sector would amount to about $15,600 (26 x $597 = $15,552). UI benefits for 585 displaced workers would total $9.1 million annually (585 displaced workers annually x $15,600 = $9.1 million), or $91 million over the entire 10-year transition period.

49 https://www.denverpost.com/2018/10/25/colorado-governor-election-energy-environment/.

50 https://westernresourceadvocates.org/publications/colorados-climate-blueprint/.

51 See Pollin et al. (2014) for a brief discussion of the relative merits of the two approaches, along with further, more extensive, references to the relevant literature. One especially relevant recent study is Petersen and Elgie (2015), which describes the successful implementation of the carbon tax in neighboring British Columbia. The British Columbia carbon tax has been in operation since 2008, and is generating about $1.1 billion per year in revenues, while supporting the province's environmental goals.

52 We recognize that there are other ways to design a carbon cap policy. See Boyce (2018) for an excellent discussion on various approaches to designing carbon pricing, either through a cap or a tax.

53 See Center on Budget and Policy Priorities (2017) for an analysis of the impact of TABOR on Colorado's economy.

54 We do not examine here the impact of the tax on retail prices for energy or energy-intensive products purchased in Colorado. A basic reference on this issue is Metcalf (2009). He finds, for example, that a $15 per ton carbon tax for the U.S. economy would raise prices as follows: 14.1 percent for electricity and natural gas; 10.9 percent for home heating; 8.8 for gasoline; 2.2 percent for air travel; and between 0.3 and 1 percent for other commodities.

55 Colorado Energy Office: Renewable Energy Standard. Available online at https://www.colorado.gov/pacific/energyoffice/renewable-energy-standard, checked on 11/23/2018.

56 DSIRE (2018): Renewable Energy Standard. NC Clean Energy Technology Center. Available online at http://programs.dsireusa.org/system/program/detail/133, updated on 6/14/2018.

57 Energy.gov: Net Metering. Available online at https://www.energy.gov/savings/net-metering-10, checked on 11/23/2018.

58 This and other features of PACE financing are summarized at the DSIRE website here: http://www.dsireusa.org/solar/solarpolicyguide/?id=26.

59 Colorado Energy Office: Colorado C-PACE. Available online at https://www.colorado.gov/pacific/energyoffice/colorado-c-pace, checked on 11/23/2018.

60 Kohler, Judith (2018): Program boosting commercial buildings' energy efficiency making impact in Denver. In *The Denver Post*, 9/12/2018. Available online at https://www.denverpost.com/2018/09/12/commercial-building-energy-efficiency-in-denver/.

61 DSIRE (2016): Green Colorado Credit Reserve. NC Clean Energy Technology Center. Available online at http://programs.dsireusa.org/system/program/detail/5583, updated on 5/19/2016.

62 Colorado Department of Revenue (2018): Sales 83: Components Used to Produce Energy from Renewable Sources or in Biogas Production Systems. Available online at https://www.colorado.gov/pacific/sites/default/files/Sales83.pdf.

63 DSIRE (2015): Property Tax Exemption for Residential Renewable Energy Equipment. NC Clean Energy Technology Center. Available online at http://programs.dsireusa.org/system/program/detail/4210, updated on 7/23/2015.

64 DSIRE (2015): Local Option - Property Tax Exemption for Renewable Energy Systems. NC Clean Energy Technology Center. Available online at http://programs.dsireusa.org/system/program/detail/2501, updated on 10/8/2015.

65 http://www.ecy.wa.gov/programs/air/cleancars.htm.

66 State of Colorado Office of the Governor (2018): B 2018 006 EXECUTIVE ORDER. Available online at https://www.colorado.gov/governor/sites/default/files/b_2018-006_maintaining_progress_on_clean_vehicles.pdf.

67 Colorado Energy Office: Alt Fuel Vehicle Tax Credits. Available online at https://www.colorado.gov/pacific/energyoffice/alt-fuel-vehicle-tax-credits, checked on 11/23/2018. Value of credits for 2018-2022 can be found here: https://leg.colorado.gov/content/alternative-fuel-vehicle-tax-credits.

68 Clean Air Fleets: Charge Ahead Colorado. Available online at http://cleanairfleets.org/programs/charge-ahead-%20colorado, checked on 11/23/18.

69 The DOL study found, in particular, that "the impact of the Recovery Act Green Jobs training program has been limited in terms of reported employment outcomes…entered employment and retention results are far lower than planned" (2012, p. 29).

70 See also the reports by the Congressional Research Service (Bradley 2013) and the U.S. Government Accountability Office (2013), which were also mixed in their assessments.

71 https://www.smartgrid.gov/project/council_adult_and_experiential_learning.html and https://www.smartgrid.gov/files/cael-oe0000450.pdf.

72 https://www.nsf.gov/awardsearch/showAward?AWD_ID=0903055.

73 https://www.energy.gov/eere/education/federal-energy-and-manufacturing-workforce-training-programs and https://www.energy.gov/eere/solar/solar-training-network ; https://www.americansolarworkforce.org/.

74 Xcel Energy is closest, as the 11th largest employer in the City of Denver.

75 https://www.colorado.gov/pacific/dola/rural-response-recovery-and-resilience-4r-program.

76 http://www.cpr.org/news/story/coal-fired-past-or-green-powered-future-pueblo-looks-for-a-new-economic-leg-up.

77 https://communityenergysolar.com/project/comanche-solar/.

78 https://www.kktv.com/content/news/Residents-concerned-about-proposed-solar-farm-in-Pueblo-County-502039472.html.

79 In May 2016 Congress legislated to maintain funding for the site: http://www.portman.senate.gov/public/index.cfm/press-releases?ID=84DB38D2-5B4C-434F-BC68-B14E60DFA440.

80 The 2000 annual report of the U.S. Office of Worker and Community Transition describes in detail the program as it was implemented in Hanford, (http://www.lm.doe.gov/Office_of_the_Director/Work_Force_Restructuring/Work_Force_Annual_Reports/fy2000part2.aspx).

81 U.S. Department of Energy, "U.S. Departments of Energy and Interior Announce Site for Solar Energy Demonstration Projects in the Nevada Desert," Press release, 7/8/10, http://energy.gov/ articles/us-departments-energy-and-interior-announce-site-solar-energy-demonstration-projects-nevada.

82 https://bloximages.chicago2.vip.townnews.com/mtstandard.com/content/tncms/assets/v3/editorial/3/78/378a5b32-d4e0-504c-982d-bd230ab7ea5a/5b6107590de60.pdf.pdf.

83 The description in this paragraph is based on Galgoczi (2015) and Dohmen and Schmid (2011).

84 In Appendix 5, we describe our methodology for identifying this group of firms.

85 These figures come from the QCEW employment survey database.

86 Prentiss does, however, recognize that, beyond providing the average level of energy demanded at any given time is the challenge of meeting the specific energy demand needs, given that wind and solar power both are intermittent energy sources. Thus, she explains that technological advances will also be necessary to achieve an energy infrastructure that relies on renewable energy for 100 percent of supply. She writes that "The question of whether renewable energy could provide all of the actual instantaneous energy needs of the United States is an open question that depends on how fluctuating renewable energy sources can be harnessed to provide power on demand. A revolutionary advance in large-scale energy storage would greatly ease the transition to a 100 percent renewable- energy economy; however, a combination of increases in energy efficiency due to widespread adoption of existing technologies and "smart grid" that pool energy supply and demand over large geographical areas may allow a renewable energy economy to flourish even without large-scale energy storage," (2015, p. 2). A broadly similar assessment as to the potential for renewable energy to supply 100 percent of energy needs for India was developed by Prof. S.P. Sukhatme in his 2013 paper, "Can India's Future Needs of Electricity be Met by Renewable Energy Sources?"

87 https://about.bnef.com/clean-energy-investment/ .

88 https://fred.stlouisfed.org/series/CONGSP .

89 https://fred.stlouisfed.org/series/GDPA .

90 http://www.metrodenver.org/d/m/3T6 (page 5 of "Energy: Colorado Industry Cluster" report, prepared by Development Research Partners).

91 https://www.colorado.gov/pacific/energyoffice/solar.

92 http://www.kunc.org/post/state-regulators-give-ok-xcel-energy-s-25-billion-clean-power-plan#stream/0 ; https://www.xcelenergy.com/staticfiles/xe-responsive/Company/Rates%20&%20Regulations/Resource%20Plans/CO-Energy-Plan-Fact-Sheet.pdf.

93 https://www.eia.gov/state/?sid=CO .

94 https://www.colorado.gov/pacific/energyoffice/wind .

95 https://www.eia.gov/state/?sid=CO .

96 https://www.denverpost.com/2017/07/27/colorado-wind-power/ .

97 https://aceee.org/sites/default/files/pdf/state-sheet/2018/colorado.pdf .

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