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# Arizona's Energy Future

99th Arizona Town Hall
November 6 - 9, 2011

Background Report Prepared by Arizona State University

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*September 2011*

*We thank you for making the commitment to participate in the 99th Arizona Town Hall to be held at the Grand Canyon on November 6-9, 2011. You will be discussing and developing consensus with fellow Arizonans on the future of energy in Arizona.*

*An essential element to the success of these consensus-driven discussions is this background report that is provided to all participants before the Town Hall convenes. As they have so often done for past Arizona Town Halls, Arizona State University has prepared a detailed and informative report that will provide a unique and unparalleled resource for your Town Hall panel sessions.*

*Special thanks go to editors Clark Miller and Sharlissa Moore of the Consortium for Science, Policy, and Outcomes at ASU for spearheading this effort and marshaling many talented professionals to write individual chapters.*

*For sharing their wealth of knowledge and professional talents, our thanks go to the many authors who contributed to the report. Our deepest gratitude also goes to University Vice President and Dean of the College of Public Programs for ASU, Debra Friedman, and Director of the School of Public Affairs for ASU, Jonathan Koppell, who made great efforts to ensure that ASU could provide this type of resource to Arizona.*

*The 99th Town Hall could not occur without the financial assistance of our generous sponsors, which (at the time of this printing) include Premier Partner APS; Contributing Partner SRP; Collaborating Partners Bank of America; Freeport, McMoRan Copper & Gold Foundation; Southwest Gas and Blue Cross Blue Shield of Arizona; Supporting Partners NRG Energy, Inc. and Carondelet Health Network; and Civic Partners CORE Construction, Kennedy Partners, Ryley, Carlock & Applewhite, and Sundt Construction.*

*When the 99th Town Hall ends, ASU's background report will be combined with the recommendations from the Town Hall into a final report. This final report will be available to the public on the Town Hall's website and will be widely distributed and promoted throughout Arizona. The Town Hall's report of recommendations and background report will be used as a resource, a discussion guide and an action plan for Arizona's energy future.*

*Sincerely,*

Ron Walker

*Ron Walker*
*Board Chair, Arizona Town Hall*

# Ninety-ninth Arizona Town Hall

November 6-9, 2011

## Arizona's Energy Future

Background Report Prepared by Arizona State University

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Christopher Baker is currently a resident of Chandler, Arizona and is a graduate of Chandler High School. Mr. Baker has a Bachelor's Degree in Business Management from the W.P Carey School of Business at Arizona State University and is currently a third year law student at the University's Sandra Day O'Connor College of Law, where he is focusing on environmental and energy law. He plans to practice law in the areas of business development, natural resources, water, and land use. Mr. Baker has a diverse professional background, including an accomplished sales career in the fields of logistics, hospitality, and construction.

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Dr. George Basile is professor in the School of Sustainability and a Senior Sustainability Scientist at the Global Institute of Sustainability at Arizona State University. He is an internationally recognized creative thinker in the field of sustainability. He has served as the executive director of the Decision Theater at ASU, exploring decision making, resource intelligence, and sustainability; as Chief Scientist and EVP of the Natural Step, an award-winning international nongovernmental organization (NGO) focused on strategic planning for sustainability; and led his own consultancy. He has worked extensively in the area of "resource intelligence" (such as energy, water and product development), led strategic planning and sustainability efforts with numerous Fortune 500 companies and served on the boards of commercial start-ups and NGOs. He has published and presented widely in the field of sustainability, including more than 30 articles and reports, and he is coauthor of the textbook Strategic Leadership toward Sustainability (Blekinge Institute of Technology: Psilanders Grafiska, 2005 and forthcoming new addition, Studentlitteratur Press, 2011). His latest work includes the forthcoming three-volume set "the Business of Sustainability" (Praeger Press, Fall, 2011).

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Bill Brandt is the Director of Strategic Integration at Light Works at Arizona State University. He is a senior executive leading complex business development and M&A transactions in Asia and Europe with 20 years of experience. He has directed, executed and delivered private market refining, chemical and oil and gas transactions typically ranging from $50m to $1bn and public market transactions ranging from $500m to $30bn. He was recognized within BP as a Distinguished Advisor for expertise in business development, M&A, joint ventures and financial valuations. He has deep experience in China including transactions with CNOOC, Sinopec and PetroChina. He is an outstanding team developer and creator of the learning and development program for the next generation of BP M&A executives. He is also an internal consultant and university lecturer on negotiation in different cultures.

**Harvey Bryan**

Dr. Harvey Bryan is a specialist in building technology who has written over one hundred papers and articles, many of which focus on the interface between technology and the design of ecologically responsible environments. He has previously taught at MIT and Harvard and is currently a full professor at Arizona State University, where his research received support from numerous public and private sponsors. Professor Bryan is active in several professional and technical societies; he has served on the ASHRAE committee responsible for developing the 90.1 Energy Standard, is presently serving on the ASHRAE TC 2.8 and SPC 189 committees which are concerned with Buildings Impact on the Environment, as well as the AIA's Committee on the Environment. He was on the Board of Directors of the Arizona Chapter of the U.S. Green Building Council and is certified in both BREEAM (a rating system widely used in Europe and Canada) as well as LEED. He is currently serving on the Board of Directors on the Green Building Initiative which developed the Green Globes' rating system. Professor Bryan has a B.Arch. from Arizona State University, an M.Arch., M.S. and a Ph.D., all from the University of California at Berkeley, he is a Fulbright Fellow, a Fellow of the American Institute of Architects as well as a Fellow of the American Solar Energy Society.

**Teresita Clashin**

Teresita Clashin (Navajo) is completing her Masters of Environmental and Urban Planning in the ASU School of Geographical Sciences and Urban Planning. She worked as an intern for four years and is now the full-time Management Research Analyst for American Indian Policy Institute. As an intern, she was the key staff support for a project that conducted two tribal planning symposia at ASU in 2007 and 2008. The symposia brought together over 50 tribal planners from Arizona and New Mexico to discuss tribal planning needs and how the university could better meet those needs. Prior to entering ASU for her undergraduate degree in planning, Ms. Clashin worked for three years in the Solid Waste program of the Tohono O'odham Nation.

**Matthew Croucher**

Dr. Matthew Croucher is an Assistant Research Professor in the Department of Economics in the W. P. Carey School of Business, and an Economist for the L. William Seidman Research Institute. A key member of the Az SMART team, Dr. Croucher's research and consulting interests include the economics of conventional and renewable energy, climate change policy, and infrastructure development. His clients include Arizona Public Service (APS) and Salt River Project, the two primary utility companies serving the Phoenix metro area, as well as the Arizona Investment Council. Dr. Croucher was primarily responsible for the economic and cost components of Az SMART. At ASU, he has been involved in numerous projects including Infrastructure Needs and Funding Alternatives for Arizona: 2008-2032 for the Arizona Investment Council, an optimal inventory model for Sky Mall Inc, Arizona 2030, and work on P3s for the Pew Center.

### Gary Dirks

Dr. Gary Dirks is director of LightWorks, an Arizona State University initiative that capitalizes on ASU's strengths in solar energy and other light-inspired research. He also is the Julie Wrigley Chair of Sustainable Practices, a professor of practice in the School of Sustainability, Distinguished Sustainable Scientist, and a member of the Global Institute of Sustainability board of trustees. Before joining ASU, Dirks was president of BP Asia-Pacific and BP China, where he brought an innovative approach to business, particularly through projects that supported sustainable development and energy security. Dirks currently is Chairman of the China/U.S. Center for Sustainable Development, was Chairman of the British Chamber of Commerce in China, and has served on the boards of the India Council for Sustainable Development and the China Business Council for Sustainable Development.

### Anthony Evans

Dr. Anthony Evans is a Senior Research Fellow for the L. William Seidman Research Institute at ASU. A member of the Az SMART team, Dr. Evans has completed a study of taxes and incentives for the solar industry and is currently investigating energy security issues. He is also currently contributing to two solar projects commissioned by the Arizona Department of Commerce. One of these projects explores the state's potential for exporting solar power; the other, the mapping and auditing of an Arizona solar logistics chain to evaluate the industry's employment potential. Prior to joining the Institute, Dr. Evans held a number of senior UK and European marketing roles in the private sector, including two years at The Stagecoach Group PLC, one of the UK's leading transport providers. Dr Evans can also draw upon significant management experience from the entertainment world, leading and implementing European marketing strategies for such well-known brands as Thomas the Tank Engine, Bob the Builder and Guinness World Records.

### Stephen Goodnick

Dr. Stephen Goodnick received his B.S. degree in engineering science from Trinity University, San Antonio, TX, in 1977, and the M.S. and Ph.D. degrees in Electrical Engineering from Colorado State University, Fort Collins, in 1979 and 1983, respectively. He was an Alexander von Humboldt Fellow with the Technical University of Munich, Munich, Germany, and the University of Modena, Modena, Italy, in 1985 and 1986, respectively. He was a faculty member of Electrical and Computer Engineering at Oregon State University from 1986-1996. He served as Chair and Professor of Electrical Engineering with Arizona State University, Tempe, from 1996 to 2005. He served as Deputy Dean for the Ira A. Fulton School of Engineering during 2005-2006, served as Associate Vice President for Research for Arizona State University from 2006-2008, and currently is Deputy Director for ASU LightWorks. He is currently President Elect of the IEEE Nanotechnology Council, and President of the IEEE- Eta Kappa Nu Electrical and Computer Engineering honor society. His areas of expertise are in modeling and simulation of electronic materials and devices across multiple length and time scales, including Ensemble Monte Carlo simulation of ultrafast carrier relaxation in quantum confined systems, coupled electromagnetic/transport modeling of high frequency devices and photonic structures, full-band Monte Carlo simulation of high speed semiconductor devices, electro-thermal modeling of electronic devices, and quantum transport in nanostructure materials and devices.  He has published over 200 refereed journal articles, books and book chapters, including Transport in Nanostructures (with D. K. Ferry and J. Bird, Cambridge 1997, 2010), and Computational Electronics: Semiclassical and Quantum Device Modeling and Simulation (with D. Vasileska and G. Klimeck, CRC Press, 2010). He is a Fellow of IEEE (2004), as well as a member of APS, SPIE, and AAAS.

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Dr. Joseph R. Herkert, PE is Lincoln Associate Professor of Ethics and Technology in the School of Letters and Sciences and the Consortium for Science, Policy & Outcomes at Arizona State University. He has taught engineering ethics and science, technology and society courses for more than twenty-four years. His work on engineering ethics has appeared in engineering, law, social science, and applied ethics journals. He is co-editor of The Growing Gap Between Emerging Technologies and Legal-Ethical Oversight (Springer 2011), past Editor of IEEE Technology & Society, and a founding Associate Editor of Engineering Studies. He is PI or Co-PI on three National Science Foundation grants on graduate ethics education in science and engineering, including one on energy ethics. Herkert serves as Chair of the Liberal Education/Engineering and Society (LEES) Division of the American Society for Engineering Education and is a Distinguished Life Member of the Executive Board of the National Institute for Engineering Ethics. He is a registered Professional Engineer (Indiana) with five years experience as a consultant in the electric power industry. Herkert received his BSEE from Southern Methodist University and his DSc in Engineering and Policy from Washington University in St. Louis. He has been honored for his contributions by LEES and by the IEEE Society on Social Implications of Technology.

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Dr. Tim James is Director of Research and Consulting at the L. William Seidman Research Institute, an Economics Research Professor at the W. P. Carey School of Business, and Senior Sustainability Scientist at ASU's Global Institute of Sustainability. Dr. James leads the multi-disciplinary Az SMART team at ASU —a multi-million dollar, three year research project examining the complex interaction of policy, economics, security, environmental and technical issues impacting upon Arizona's ability to become a world leader in solar power innovation and development. He also has extensive experience in consulting and research for both the public and private sectors globally. A small selection of organizations Dr. James has advised include the U.K. Prime Minister, the European Commission, the UK Rail Passenger Council, the state of New Jersey, the Arizona Commerce Authority, Boeing, Intel, the Texas Department of Transport, Goldman Sachs, Morgan Stanley, UBS, the Pew Center on the States, and the Arizona Investment Council. Dr. James has widespread radio, TV and written media experience including advising and making programs for the BBC.

### Patricia Mariella

Dr. Pat Mariella is the Director of the Arizona State University American Indian Policy Institute. She oversees the research projects and professional certification programs developed by the Policy Institute. She came to ASU after eleven years as Executive Director of the Department of Environmental Quality (DEQ) of the Gila River Indian Community. Prior to joining Gila River in 1995, Dr. Mariella worked for four years at the Arizona Department of Environmental Quality as the director of the Arizona Comparative Environmental Risk

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Kristin Mayes is Professor of Practice and Director of the Program on Law and Sustainability at the Sandra Day O'Connor College of Law at Arizona State University. From 2003-2010, she served on the Arizona Corporation Commission, including, from 2006-2010, as the Commission's Chair. She holds a JD from ASU and a Master of Public Administration from Columbia University. As Director of the Program on Law and Sustainability, she is developing a core curriculum for students in law and sustainability, and will seek projects in which students and faculty will work with utilities, corporations and governments on energy and conservation related projects.

### Clark Miller

Dr. Clark Miller is associate director of the Consortium for Science, Policy & Outcomes. His research focuses on science and technology policy, including particular emphases on the governance of new and emerging technologies and the global politics of expertise. Before joining ASU, he taught at Wisconsin and Iowa State and held a Postdoctoral Fellowship in Science, Technology and Public Policy at the Kennedy School of Government at Harvard University. He also is a recipient of a prestigious National Science Foundation CAREER Award and over a dozen other major grants. He serves on the advisory board of the Nanotechnology Informal Science Education Network and the Center for Engineering, Ethics, and Society at the National Academy of Engineering. He is a founding co-organizer and member of the governing council of the Science and Democracy Network, a global professional community for research on the politics of science and technology.

### Sharlissa Moore

Sharlissa Moore is a fourth-year student in ASU's Human and Social Dimensions of Science and Technology Ph.D. program. Her research explores the human and social aspects of energy innovation and renewable energy development. She is also a Research Associate for ASU's Consortium for Science, Policy, and Outcomes. Previously, she worked for ASU's Senior Vice President for Knowledge Enterprise Development, where she studied energy policy and management of large-scale research projects. Sharlissa is engaged in the professional science and technology policy domain, having worked for the White House Office of Science and Technology Policy and the Science and Technology Policy Institute. She is also the President of Student Pugwash USA, a non-profit organization that engages students and young professionals in exploring the social and policy aspects of science and technology.

## Robert Pahle

Dr. Robert Pahle works with a variety of 3D modeling technologies and databases to support researchers and activities at the Decision Theater. He holds an engineering diploma (master's degree) in architecture from the University of Siegen, Germany, and has taught classes in building structure and design at ASU. He has a Ph.D. in environmental design and planning, focusing on dynamic, real-time informative warning systems and intelligent buildings. Robert is fluent in German and English.

## Martin Pasqualetti

Dr. Martin Pasqualetti's service, teaching, and research reflect his interest in energy and sustainability. He was twice appointed by the Arizona Governor as Chair of the Arizona Solar Energy Advisory Council. He is on the Board of Directors of the Arizona Solar Center, and is an Associate Member of the National Wind Coordinating Collaborative in Washington, D.C. He is Associate Editor of Environmental Sciences, and is on the Editorial Boards of the International Journal of Sustainable Energy Technologies, Land Use Policy, and The Open Environmental Journal. Pasqualetti founded and was twice President of the Energy and Environment Specialty Group of the Association of American Geographers, and has advised several government agencies, including the U.S. Department of Energy, as well as organizations such as the Southwest Center for Environmental Research and Policy (SCERP), Natural Resources Defense Council, and Resources for the Future. Pasqualetti has published books on wind power, nuclear power plant decommissioning, landscape evolution, public perception of risk, as well as articles and book chapters on solar power, geothermal power, wind power, oil sand development, the social costs of nuclear power, and renewable energy at the U.S./Mexico Border. At ASU, he teaches undergraduate courses on Energy and Environment, Energy in the Global Arena, the Geography of Natural Resources, and the Geography of the United States and Canada.

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Dr. Benjamin Ruddell holds a Ph.D. in Civil Engineering from the University of Illinois at Urbana-Champaign, and is currently on the faculty in the Department of Engineering at Arizona State University's College of Technology and Innovation. He also holds the title of Senior Sustainability Scientist through the Global Institute of Sustainability at ASU. His expertise and research is focused on water resources, water footprinting, the integration of water and energy solutions, ecohydrology and climate, and engineering urban sustainability.

## Shawn Williams

Shawn Williams (Tohono O'odham) is an undergraduate at ASU in the Biology and Society program. Mr. Williams is a student worker in the American Indian Policy Institute and provides research support.

# Acronyms

| | |
|---|---|
| Acre feet | AF |
| Arizona Center for Algae Technology and Innovation | AzCATI |
| Arizona Corporation Commission | ACC or 'the Commission' |
| Arizona Public Service | APS |
| Arizona State University | ASU |
| Balance of Systems and Installation costs | BOS |
| British Thermal Unit | BTU |
| Bureau of Labor Statistics | BLS |
| Corporate Average Fuel Economy | CAFE |
| Carbon dioxide | $CO_2$ |
| Central Arizona Project | CAP |
| Compressed natural gas | CNG |
| Concentrating solar power (solar thermal) | CSP |
| Department of Energy | DOE |
| Distributed generation | DG |
| Electric Energy Efficiency Standards | EEES |
| Energy Efficiency Resource Standards | EERS |
| Energy Information Administration | EIA |
| El Paso Electric | EPE |
| European Union | EU |
| Federal Highway Administration | FHWA |
| Gross Domestic Product | GDP |
| Gross vehicle weight rating | GVWR |
| Greenhouse gases | GHG |
| Gigawatt | GW |
| Heating, ventilation, and air conditioning | HVAC |
| Kilowatt | kW |
| Kilowatt-hour | kWh |
| Kilovolt | kV |
| Kinder Morgan | KM |
| Leadership in Energy and Environmental Design | LEED |
| Levelized cost of energy | LCOE |
| Low Income Home Energy Assistance Program | LIHEAP |
| Mobile Army Surgical Hospital | MASH |
| Megawatt | MW |
| National Renewable Energy Laboratory | NREL |
| Natural gas vehicles | NGVs |
| Natural gas to liquid fuel | GTL |
| Navajo Generating Station | NGS |
| North American Electric Reliability Corporation | NERC |
| Org. for Economic Cooperation and Development | OECD |
| Organization of the Petroleum Exporting Countries | OPEC |
| Renewable Energy Standard | RES |
| Renewable Portfolio Standard | RPS |
| Salt River Project | SRP |
| San Carlos Irrigation Project | SCIP |
| Solar Photovolatic panels | PV |
| Southwest Gas | SWG |
| Terawatt | TW |
| Texas Transportation Institute | TTI |
| Tucson Electric Power | TEP |
| Uniscourse Energy Services | UNS |
| Vehicle to Grid | V2G |
| Watt | W |
| Watt-hour | Wh |
| Western Electricity Coordinating Council | WECC |

# Chapter 1: **Introduction**

*Clark A. Miller and Sharlissa Moore*

## Energy's Long-Term Importance

As Arizona's citizens, businesses, and policy leaders look to the future, energy must be an important focus of the state's long-term planning. In Arizona, and around the world, energy has enormous economic significance:

- The energy industry in Arizona represents about 4% of the state's GDP, or $10 billion of economic activity annually, including close to 20,000 jobs.[1]
- Arizonans and Arizona businesses also spent $17.6 billion on energy in 2006, including $9.3 billion for gasoline and jet fuel and $5 billion for electricity. Of these expenditures, an estimated 68%, or $12 billion, left the state largely to pay for imports of fuels. [2]
- This amounts to approximately $3,000 per person, per year.
- According to *The Arizona Republic*, two of Arizona's top 30 employers are energy companies: Pinnacle West (#20) and SRP (#30). Pinnacle West (which owns APS) and the Salt River Project (SRP) together employed over 11,000 people in 2010.
- Globally, nine of the 12 largest companies in the world are energy companies, as measured by revenues on the *Global Fortune 500*. Eight of these are oil companies. Also, energy companies hold six of the top 10 spots on the *Financial Times Global 500*, as measured by market capitalization.[3]

Even these impressive figures understate the importance of energy to Arizona today. Energy powers the economy and day-to-day life in Arizona and around the world. Factories and businesses run on electricity. Quality of life depends to a great extent on relatively uninterrupted flows of low cost electricity and fuels. For example, Arizona's cities and highway infrastructures depend on the uninterrupted flows of fuels, as do many aspects of people's lives. Most Arizonans drive every day, whether to work, school, church, or play. Every day, people use refrigerators and air conditioners, iPads and iPhones, barbeques and high definition TVs, all of which consume energy. As a result, major disruptions to energy flows—e.g., $4/gallon gasoline, blackouts, oil embargos—have rapid and enduring consequences. The economy slows. Workers could have difficulty commuting long distances to their jobs. At worst, energy disruptions can lead to the loss of life, for example through exposure to temperature extremes or accidents.

Globally and at home, energy technologies also carry risks for those who operate or live near them (see Chapter 8). Rare accidents at power plants, such as this spring's meltdown at the Fukushima Daichi nuclear power plant in Japan or the 1984 accident at the Chernobyl nuclear power plant, can put both workers and nearby residents at serious risk of radiation exposure. Major oil spills, while also infrequent, cause environmental and economic impacts to vast areas of ocean and coastlines and the populations that live and work along them. More commonly, people acquire health complications as a result of pollutants generated by the burning of fossil fuels, such as coal. Pollution from power plants is linked to an estimated 13,000 deaths in the United States annually.[4]

Because energy is the lifeblood of the economy and society, energy companies have built extensive infrastructures to provide energy to consumers reliably and at low cost. Because these infrastructures—e.g., power plants, transmission lines, mines, wells, pipelines, etc.—are large and extensive, they require significant upfront investment of money and time, often taking years or even decades to plan and build. Since most power plants have 30-50 year planned lifetimes—and many reliably produce power for even longer than that—energy choices can have significant implications for long periods of time. Similarly, for consumers, personal energy investments are often expensive and have long-term consequences. For example, a new, more energy efficient system for heating and air conditioning can cost thousands of dollars and have an expected lifetime of 15-20 years: so, too, can buying a car that gets better gas mileage or installing solar panels on a house's roof. Making such changes can significantly reduce energy costs over time but only with large, up-front investments. Energy is thus a long-term issue, both for individuals and for the state of Arizona.

Arizona's energy future will be shaped by the choices made by everyone: consumers and citizens, business and policy leaders, researchers and entrepreneurs. For example, utility companies make choices about what types of new power plants to build. Companies and entrepreneurs decide what kinds of products to invent, design, and sell. Within limits, consumers make choices about how much energy they consume and what kinds energy technologies to purchase, such as appliances, automobiles, or solar panels. Citizens decide whom to elect to legislatures, public utility commissions, water commissions, county boards, and other offices. In turn, these leaders decide how to govern our energy systems.

## An Introduction to Energy and to the Report

At its most basic, energy is a form of work. To move a box of oranges from a farm to a market, you could either pick it up and carry it on foot or use a machine (e.g., a pickup truck) to do the work for you. In either case, energy is expended to carry out this task. Similarly, energy does different forms of work for people. For example, it can be used to produce heat (e.g., for cooking) or light (e.g., allowing people to stay up and work past sunset or helping to keep streets safe at night.)

Primary energy is in the form of fuels, such as coal, oil, natural gas, and biomass, as well as geothermal, solar and wind. Some of these fuels can be converted into electricity, which is a secondary form of energy. For example, natural gas can be used directly to operate some household appliances, like an air conditioner or a clothes dryer, or as a fuel for power plants that generate electricity, and these appliances could run on electricity. Power plants are often described using the fuel that powers them (such as "natural gas-fueled," "coal-fired," or "hydroelectric"). The verb "generate" is commonly used to describe the production of electricity. "To generate" and "to produce" are used interchangeably throughout the report.

Most people view energy from a consumer perspective, as something that they buy, either at a gas station or from a utility company. This consumer perspective poses important questions. How much does it cost to buy a gallon of gasoline? How high is my electricity bill this month? Why did my power go out, and when will it come back on? In most parts of the state, consumers assume that energy will be available to them when it is needed, that it will cost more next year than it did this year but hopefully not by too much, and that if the power goes out it will come back on reasonably quickly. Arizona's energy future, however, also relates to broader questions about how energy is produced and transported and how energy relates to other pressing social issues.

The energy system is made up of an array of complex technological systems that are connected to social, economic, and political patterns. The United States uses significantly more electricity during the daytime than at night. Arizona also uses significantly greater amounts of electricity in the summer than in the winter due to intense summer temperatures. In contrast, Arizona uses greater amounts of natural gas in the winter to heat houses. Because the energy system is complex and dynamic, change will take a long time. New energy facilities can take a decade or more to approve and build and tend to be very expensive, but once built they can be in operation for 40-60 years. Energy planning is thus a long-term challenge that requires long lead times and consistent effort.

This report provides readers with a background overview of Arizona's energy systems, as well as the challenges and opportunities confronting the state of Arizona in the field of energy in coming years. The rest of this Chapter provides an overview of how energy works, followed by a discussion of six major factors that are likely to impact discussions of the future of energy in the state.

Chapters 2 and 3 focus on energy production and consumption. Energy production or generation is the process by which power is produced in power plants. To use or consume energy means purchasing energy and converting it into work done on our behalf. We consume electricity when we buy it from our utility and use it to run our microwave, for example, or when we buy gasoline and burn it to drive our car. Chapter 2 describes how much coal, oil, natural gas, uranium, wind, and sunlight are available in Arizona. It also describes the number of power plants in the state that use each type of fuel and how much electricity they are capable of producing. Chapter 3 subsequently describes energy consumption in the state, detailing how much fuel and electricity the state uses. Chapter 4 focuses on the relationship between energy and the state's economy and Chapter 5 focuses on energy efficiency and conservation.

The next section of the report includes four chapters describing important aspects of Arizona energy policy, including connections between energy and other important issues facing Arizona. Chapter 6 foucses on the relationship between energy and water, Chapter 7 on energy and the state's Native American communities and lands, Chapter 8 on the benefits and risks associated with energy production, and Chapter 9 on energy security.

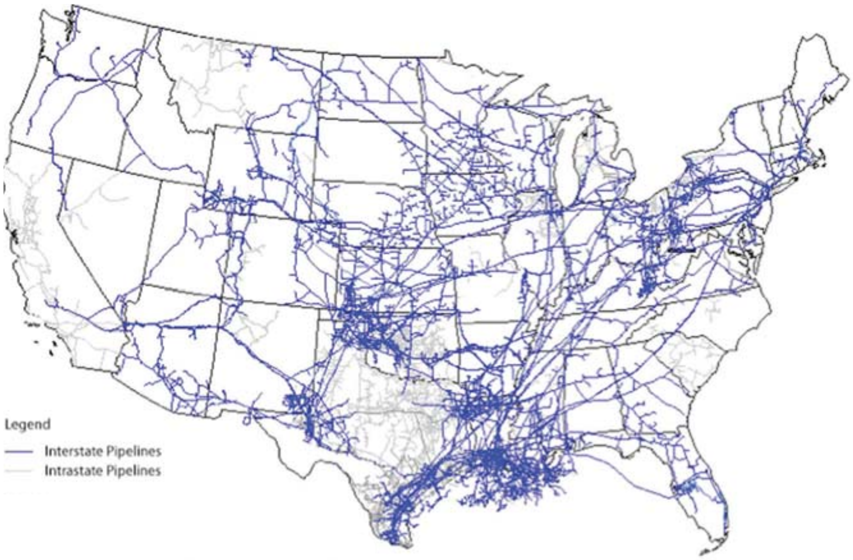
The report concludes with three chapters that look toward the future of energy in Arizona. Chapter 10 details the future implications of Arizona's recently established standards for renewable electricity production and energy efficiency. It then describes possible scenarios for future electricity production and consumption in the state. Chapter 11 addresses the future of energy fuels and the possibility that Arizona might be able to convert its abundant sunlight into liquid fuels to power vehicles. Finally, Chapter 12 explores the potential role of the energy sector as a source of innovation and jobs for Arizonans.

The back of the report contains a glossary of energy terms used throughout the report, as well as a guide to understanding the units of measurement used to describe energy quantities (e.g. megawatt, British Thermal Unit, ton).

## How the Energy System Works: Views from Arizona, the Region, and the Globe

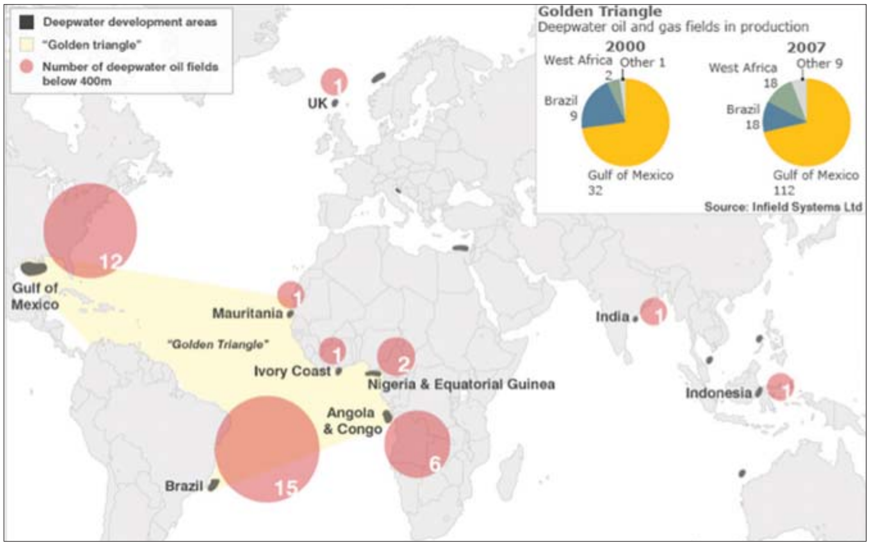
The rest of this chapter will provide an overview of energy in Arizona, the larger regional and global dynamics of the energy industry, and the major factors that will impact the state's energy choices. The word energy refers both to electricity and to transportation and other fuels. To begin, it is useful to understand how energy is produced, transported, and consumed. This process is quite different for fuels than for electricity.

**FIGURE 1** | U.S. Natural Gas Pipelines



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

**FIGURE 2** | Offshore Oil Drilling



Source: Petroleum Economist

## Fuels

While Arizona has some coal (see Chapter 2), it imports almost all of the fuels used for transportation and electricity. Coal is shipped into the state by train. Gasoline, jet fuel, and natural gas are imported via pipelines (see Chapters 2 and 9). These fuels are initially derived through mining or drilling deep below the earth's surface. In the United States, the majority of coal is mined in West Virginia and Wyoming. Companies also drill for natural gas in many parts of the United States. This fuel is then transported around the country through an extensive network of pipelines (see Figure 1).

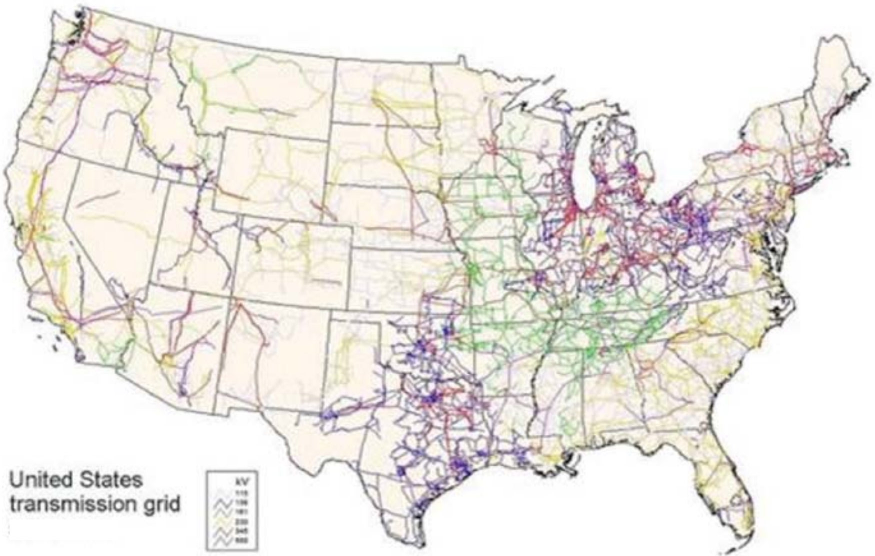
Energy companies drill for oil worldwide. Areas of the world with large amounts of oil reserves include the Middle East and Persian Gulf, the North Sea off of Scotland, and Norway, Nigeria, Venezuela, Russia, and Indonesia. In the United States, oil is drilled primarily in Texas, Alaska, and, using enormous offshore oil rigs, in the Gulf of Mexico.

In recent years, both in the United States and around the world, offshore oil production has become increasingly important as a source of oil (see Figure 2). Once pumped out of the ground, crude oil is transported around the globe via ships to refineries, where it is converted into a wide variety of products, including gasoline and jet fuel. These fuels are then transported via pipeline and truck to gas stations and airports and other fuel retailers.

## Electricity

While fuels travel the globe to get to Arizona, electricity is a very different story. Unlike fuels, electricity is primarily a regional industry. The U.S. electricity industry operates three electricity grids: one in the East, ranging from Maine to Florida to Minnesota; a second centered in Texas; and a third in the West, which includes Arizona (see Figure 3). Arizona exports 28% of its electricity, though it imports some of the fuels used to generate this electricity.[5]

**FIGURE 3** | U.S. Electricity Grids



Source: FEMA

Electricity is typically produced in medium- to large-scale power plants of a variety of types. Hydropower facilities (usually associated with dams on rivers) use falling water as their source of energy to create electricity. Nuclear power plants use nuclear reactions in uranium fuel to produce heat and then convert that heat into steam as their source of electricity. Coal-fired and natural gas-fired power plants burn coal or natural gas to accomplish the same thing. Wind turbines are driven by the wind. Solar power plants either capture the sun's energy and convert it directly into electricity (via photovoltaic panels) or use the sun's energy to create heat and steam (via solar thermal plants).

Once the electricity has been produced it must be transported from power plants to consumers, which is accomplished via a web of transmission lines, otherwise known as the electricity grid. The western U.S. grid, which runs from Arizona to Washington, is operated by the Western Electricity Coordinating Council. Theoretically, power produced in Arizona could be consumed anywhere along the West Coast, but much of the electricity Arizona exports goes to California. Arizona's electricity exports have historically come from large coal-fired power plants in the northern part of the state, as well as the Palo Verde nuclear plant in Phoenix. In the 1990s, several natural gas-fired power plants were built in the state with the intention of exporting power to California, but they have been used relatively infrequently due to high costs of natural gas and limited capacity on transmission lines. Recently, utility companies in California announced plans to stop importing power from large coal-fired power plants in Arizona, following to a 2007 California state law that requires utilities to transition away from electricity production that releases large amounts of greenhouse gases. This decision illustrates how energy choices made by other states in the region influence the state of Arizona. In another example, California developed targets for renewable energy production that are creating a demand for new renewable energy power plants to be built in Arizona. Exporting electricity entails tradeoffs. On the one hand, it brings in revenue and creates jobs in Arizona. On the other hand, like any other kind of export, whether agricultural crops or computer chips, electricity generated for export consumes water, results in pollution, and produces risks in Arizona to generate power for customers in a different state.

### Energy Policy and Regulation

Energy policy and regulation are important features of the state, regional, and global context of energy production and consumption. In Arizona, the state constitution tasks the Arizona Corporation Commission (ACC) with electricity regulation. State law also regulates some aspects of the fuels industry, such as pollution controls, vehicle emissions controls, fuel taxes, standard weights and measures, and so forth. For both electricity and fuels, some aspects of energy markets are regional and global, making those facets of Arizona's energy future subject not only to choices within the state but also to decisions made by citizens, consumers, companies, and governments elsewhere.

The electricity industry is regulated because, in most locations, electric utilities are monopolies. Very few U.S. consumers can choose which utility provides their electricity. Arizonans are either a customer of Arizona Public Service (APS), the Salt River Project (SRP), Tucson Electric Power (TEP), or one of several other smaller electric utilities or cooperatives. To ensure consumer protection, state regulators control the prices utilities may charge customers. The ACC, for example, not only sets prices but also has an important role in deciding where new power plants or new transmission lines may be built. The ACC also set mandatory targets that utilities must meet for renewable energy generation and energy efficiency standards (see Chapter 10).

The ACC regulates most of the major utilities, including APS, TEP, and electric cooperatives (see the glossary for the definition of an electric cooperative). The ACC also regulates most natural gas, water, and telephone utilities. There are three broad exceptions to the ACC's jurisdiction. The first is the SRP, which is separately regulated under the state constitution. The second is municipal electric, natural gas, water, and sewer utilities, which are run by cities. The third exception is the Native American reservations in the state, which are sovereign entities, which make their own energy choices.

The state legislature and governor also affect the energy industry through energy policies and legislation, as do the U.S. Congress and Executive Branch. The state legislature and governor also impact energy companies through tax policies on both business income and utility sales of electricity to consumers. In recent years, an important aspect of state energy policy has been the provision of incentives to lure energy business, and especially solar energy businesses, to the state (see Chapter 12). In addition to approval from the ACC, energy companies must receive approval from county boards of supervisors in order to build and operate new power plants and transmission lines. They must also receive a certificate of environmental compatibility from the Arizona Department of Environmental Quality. If the project involves tribal lands, it must also be approved by the tribal government. If the project involves federal lands, it must also receive approval from certain federal agencies.

## Major Dimensions of Arizona's Energy Choices

Finally, we offer an overview of six major factors that impact energy choices. The first three are *emerging factors* that have become particularly important in recent years (energy security, climate change, and green jobs), while three others reflect more *enduring factors* that will likely always be important in energy decisions (cost and affordability, reliability, and sustainability). These categories are neither exhaustive nor exclusive.

## Emerging Factors in Arizona's Energy Choices

### Energy Security and Availability

One of the most important factors impacting energy today is new threats to energy security. Energy security is energy industry's ability to maintain a stable and secure energy infrastructure that provides reliable and affordable supplies of energy. Threats to energy security come from a wide range of sources. Some examples include:

- Conflict and violence that may threaten energy supply infrastructure, e.g., civil uprisings in the Middle East or terrorist attacks on energy facilities;
- Energy technologies may be subject to risks of catastrophic failure that seriously impinge on the ability to deliver energy, e.g., the 2011 nuclear disaster in Fukushima or the 2005 explosion and fire at a BP refinery in Texas that closed the plant for two years;
- Individuals may lose access to secure sources of energy due to insufficient funds, e.g., if they become unemployed;
- Demand for energy may significantly outstrip the ability of energy companies to provide supply, leading to unsustainable increases in energy prices.

Today, Arizona's energy supplies are reasonably secure (see Chapter 9), thanks to extensive, complex technological systems that extract energy resources like coal, oil, natural gas, and uranium; convert them to electricity or refine them into gasoline and jet fuel; and transport them around the globe in enormous quantities. The effectiveness of those systems has made possible not only relatively inexpensive energy but also for that energy to be reliably delivered to our houses and businesses. But there are growing concerns about our ability to maintain cheap, reliable energy flows. These threats are especially visible with regard to oil, but some security experts are also concerned about terrorist threats to power plants. Also of concern is nuclear proliferation from the diversion of uranium and plutonium from nuclear energy reactors to nuclear weapons programs.

Risks to the world's oil supply come in several major forms. The past two years have brought turmoil in Middle East oil-producing countries, including in Iran, Egypt, Libya, Bahrain, Syria, and Iraq. Saudi Arabia—which holds both the world's largest oil reserves and the bulk of its spare production capacity—has not yet experienced significant political unrest but neighbors many of the countries that have. Threats to Saudi oil supply (or worse, actual disruptions) would raise oil prices rapidly, to well above current levels. Political conflict in oil-rich areas is not limited to the Middle East. Oil-rich countries like Nigeria and Venezuela have also experienced unrest.

As these factors contribute to rising oil prices, global demand is also growing. In the summer of 2008, gasoline prices rose to $4 per gallon due to a growing global economy, particularly rapid growth in emerging economies in China, India, and Brazil. As a result, the costs of many commodities, including oil, increased. Global demand weakened with the global economic crisis from 2008-10, but it appears to be picking up pace. Together with Middle East unrest, these pressures again increased gasoline prices to $4 per gallon in late spring 2011.

The world is producing record volumes of oil, but its ability to continue to produce even more oil in question. For the most part, the world's easy-to-reach oil has already been produced (meaning, it has been pumped from wells and refined into fuel). And since existing oil fields decline each year, oil companies must continually search for and produce new oil fields. To do so, they push the envelope of technology and operate in more extreme environments. Some oil companies are drilling in ultra-deep water—i.e., in ocean depths over 5,000 feet, or about 1 mile, to 9,600 feet—at intense temperature and pressure. In 2008, the 20 most prolific oil-producing rigs in the Gulf of Mexico were located in deepwater and six in ultra-deep water.[6] When these fields are depleted, oil companies will likely move into greater water and drilling depths. As a consequence of the drive to develop oil fields in more extreme locations, outside observers have begun to question whether companies can supply enough oil to meet the demands of a growing global economy. By 2035, for example, the International Energy Agency projects that global production will need to increase by 20% to meet demand, which will result in a doubling of the price of oil in inflation-adjusted dollars.[7]

## Climate Change

The second major emerging factor impacting energy choices is changes in the earth's climate system due to rising concentrations of greenhouse gases. Energy production is the primary cause of climate change, and the United States is responsible for 20% of the world's emissions (for only 5% of the world's people). Currently 85% of U.S. emissions of greenhouse gases come from the energy sector. Seventy-eight percent of U.S. greenhouse gas emissions come from the burning of fossil fuels.[8, 9] U.S. emissions of carbon dioxide from burning fossil fuels stem primarily from electricity production (41%), transportation (33%), industrial and commercial uses (18%), and residential heating (6.5%). Worldwide, 57% of greenhouse gas emissions come from the burning of fossil fuels for energy.[10]

On a per person basis, Arizona's greenhouse gas emissions were lower than the national average by about one-third in 2006 (14 tons of $CO_2$ equivalent per person vs. 22 tons nationally). In Arizona, the transportation sector is responsible for 39% of total emissions and 38% come from the electricity sector.[11] While this is largely a consequence of Western geography, very low-density patterns of urban development—especially at the furthest edges of metropolitan areas—can increase long-term commitments to high fuel consumption and increase high carbon emissions from transportation. Generally, Arizona's electricity sector produces slightly lower emissions than the national average, in part because of the large contribution of low-emissions nuclear and hydropower plants to the state's electricity generation. However, the significant reliance on large-scale coal-fired power plants somewhat balances this advantage out. Despite this relatively good position, Arizona also had one of the fastest growth rates of greenhouse gas emissions in the country in 2006. (See Chapter 3.)

Evidence continues to grow that emissions of carbon dioxide and other greenhouse gases are fundamentally altering the earth's climate system, leading to significant changes in weather patterns around the globe, including rapidly melting ice sheets and more extreme weather events.[12] Specific regional impacts of climate change are very difficult to model. However, most climate models agree that the U.S. Southwest will become warmer. Most global models suggest that the world's arid regions, including the U.S. Southwest, may experience even less average annual rainfall in the future. The Western United States is also projected to experience significant additional average temperature rises. According to the Arizona government's Climate Change Advisory Group, "Arizona is already experiencing the effects of a hotter, drier climate."[13] Changes in wildfire patterns, forest ecology, and snowmelt runoff have already been observed that are consistent with models' predictions.[14]

Climate change and energy security are closely linked. According to the International Energy Agency's 2010 World Energy Outlook, "[I]f governments do nothing or little more than at present [to reduce greenhouse gas emissions], then demand [for oil] will continue to increase, supply costs will rise, the economic burden of oil use will grow, vulnerability to supply disruptions will increase and the global environment will suffer serious damage."[15] Efforts to reduce greenhouse gas emissions from the energy sector focus on three major strategies: improving energy efficiency, reducing energy consumption, and shifting toward energy technologies that emit less or no carbon dioxide. Such technologies include nuclear, solar, wind, and geothermal approaches.

## Green Jobs

The third emerging factor for Arizona's energy choices is the potential for innovation and growth in the renewable energy sector. As competition continues to heat up in the global economy, new opportunities for high technology innovation will be an important tool for regions looking to create new, high-wage jobs. In particular, many observers note that consumer preferences for improving sustainability are driving a rapidly growing economy in the field of "green innovation," with many countries around the world investing heavily in new industries to meet this demand. Already, alongside the United States, Germany and China have taken the lead in promoting jobs and innovation related to sustainability.

As Bill Brandt describes in Chapter 12, Arizona is potentially well positioned to compete in several areas of the green economy, especially in the field of solar energy. This potential advantage derives from several important factors. One is the state's general business climate. A second is the omnipresence of the sun. The amount of sunlight that is available in Arizona is arguably higher than in any other state. A third advantage stems from the historical strengths of the Arizona economy in high technology sectors, including aerospace and defense and information technology, each of which provide relatively strong foundations for solar energy manufacturing in terms of their existing technological capacities and workforce training. Arizona also has strong research universities with considerable strengths in the field of solar energy research. For example, the newly funded Quantum Energy and Sustainable Solar Technology Engineering Research Center at Arizona State University will help promote the development of high efficiency, low-cost solar panels. Roger Angel, the director of University of Arizona's Steward Observatory Mirror Laboratory—one of the world's leading telescope mirror research centers—is also the CEO of a spin-off company from the laboratory's research. The company, REhnu, produces mirrors for concentrating solar power plants. Finally, Arizona has already begun to successfully recruit a number of the world's largest solar companies to build solar panel manufacturing facilities in Arizona, including SunTech and First Solar. Already, these businesses are adding substantially to the Arizona economy. Tempe-based First Solar, for example, expects net sales in 2011 of $3.8 billion.

The growth of the solar energy industry in the state is being driven partly through policy decisions. One such policy is the renewable energy standard, established by the Arizona Corporation Commission (ACC), which requires ACC-regulated utilities to meet 15% of their energy needs from renewable energy sources by 2025. The Renewable Energy Standard also requires that 30% of this renewable energy must be generated through distributed generation, for example, by rooftop photovoltaic systems. The Arizona Commerce Authority and cities also develop policies that promote economic growth. These policies have helped to provide incentives to solar panel manufacturers to set up their facilities in Arizona, which brings additional jobs and economic growth to the state.

## Enduring Elements in Arizona's Energy Choices

The rise of energy security, climate change, and green jobs as significant, relatively new factors in energy discussions adds to a set of more enduring factors have long been significant and will continue to be significant in planning for Arizona's energy future.

### Price & Affordability

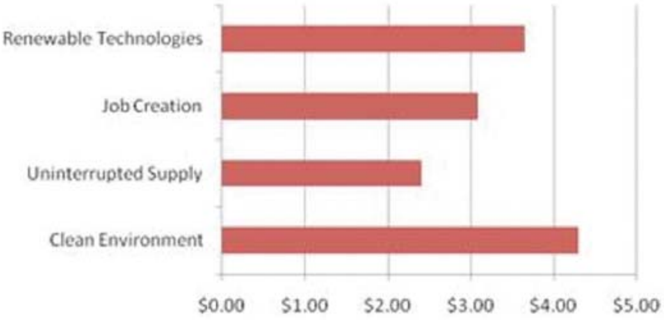
Price and affordability have arguably been the single most important aspects of planning for Arizona's energy historically, and rising energy costs, coupled with rising poverty and financial stress due to the economic crisis, have only further highlighted their significance. Specifically, energy prices have increased. For example, Arizona's average retail electricity price went from 24.73 $/million BTU in 2000 to 31.44 $/million BTU in 2009, an increase of 27% (see the glossary for the definition of a BTU, or British Thermal Unit).[16] Gasoline prices have been volatile, with average prices swinging dramatically from $1.54 to $4.05 over the past 72 months, but with an upward overall trend.[17] General expectations are for this upward trend in energy prices to continue in the future for both electricity and fuels. The underlying reasons for these trends are different, however. While gasoline prices are largely tied to global supply and demand, electricity prices are mostly regulated at the state level and are mostly tied to domestic resources. Proposed changes to utility rate structures or other initiatives like promoting new investments in renewable energy that may affect consumer prices are contentious and play out at the local level. At the same time, a diverse energy mix can help to stabilize energy prices by providing a buffer against commodity price increases.

While the cost of energy affects everyone in Arizona, it has disparate impacts on different populations. For example, low-income households struggle with high energy costs or a lack of access to energy, an issue known as energy poverty. Arizona's poverty rate has risen from 13.9% in 2000 to 21.2% in 2010,[18] making it harder for people to make ends meet. A 2006 report commissioned by the nonprofit National Low Income Energy Consortium (NLIEC) found that Arizona households that are eligible for the Low Income Home Energy Assistance Program (households at or below 150% of the federal poverty level) spend an average of 10% of their income on energy, while the average U.S. household spends only 3% of its income on energy.[19] Further, 73% of these households have a vulnerable member (i.e., an elderly, young, or disabled family member).[20] Additionally, several low-income populations lack sufficient access to energy; for example, according to a Navajo Nation report in 2004, 18,000 of the 48,000 homes on the Navajo reservation are not connected to the grid,[21] and Arizona's homeless population lacks access to sufficient cooling, leaving them vulnerable to heat-related death.[22] The DOE and Arizona utility companies have programs to help low-income and medically disadvantaged consumers afford their bills. However, the NLIEC report found there was insufficient financial assistance to even out the low-income energy burden. (See Chapter 8.)

Senior citizens, who live on a fixed income, are another vulnerable population to energy consumer price increases. In Arizona, AARP, a senior citizen advocacy group, is paying close attention to the impact of rising utility prices and new initiatives, like "decoupling," on Arizona's population over 65. Decoupling would change the way utility companies are compensated for technology investments. Currently, utilities can only incorporate technology investments (such as new power plants) into their electricity rates if they are necessary to meet growing electricity demand. Utilities thus have no financial incentive to invest in technologies that would reduce energy demand, for example, by improving energy efficiency. Decoupling would allow utilities to incorporate energy efficiency technologies into their rate calculations, resulting in some circumstances where consumers would have to pay more even though their energy consumption did not go up. AARP recently launched an advocacy campaign opposing decoupling precisely for this reason, as seniors on fixed incomes might receive higher electricity bills to help finance new energy efficiency technologies but might not be able to afford to take advantage of those technologies themselves[23] (see Chapter 5). Utility company Arizona Public Service (APS) argues that the new rate plan is necessary in order for it to fund energy efficiency measures.

As the example above illustrates, the issue of citizens' willingness to pay in order to change particular dimensions of our energy system will be an important factor in shaping Arizona's energy future. A recent public deliberative polling exercise conducted by APS found that the public strongly approved of increasing the usage of solar power plants and wind turbines. Further, the majority of citizens were willing pay more on their monthly utility bill for new initiatives like renewable technologies, job creation, uninterrupted supply, and a clean environment. The amounts identified by the survey were modest: $3 or $4 dollars per month for these programs (see Figure 2). It is significant that people are willing to pay something; that said, how much they are willing to pay probably depends on circumstances and survey methods. These questions were asked independently, not cumulatively, for example. It is also unclear whether survey respondents realized that they are already paying several dollars per month for these programs on their monthly bill. Absent real-world contexts, it is difficult to determine how much extra consumers would be willing to pay. If confronted in reality with a $48/year addition to their utility bill, customers might produce a significant policy backlash. If such price increases are added on gradually over a period of several years, customers might willingly accept twice that amount without giving it a second thought.

**FIGURE 4** | Amount Consumers Are Willing to Pay for Clean Energy Innovation



Source: APS report 2011[24]

## Reliability

Maintaining reliability at an affordable cost even with increasing energy demand is a key issue for Arizona's energy future. Despite their vast complexity, electrical power systems operate remarkably well most of the time (see Chapter 9). Commercial and residential consumers both expect and rely heavily upon the reliable functioning of the electrical grid. In fact, it is useful to view the grid, as many utility companies do, as providing the service of reliability rather than electricity. Electricity end-use services are not limited to lighting, but they also provide us with water, internet, and the usage of a variety of electrical appliances from refrigerators to hair dryers. For residential consumers, reliable electricity is essential for cooling during the long, intense summers in southern Arizona and heating in the northern Arizona winter. The consequences of losing electricity during the summer months can be fatal, especially for vulnerable populations, such as the elderly.[25] Further, the ability to respond swiftly to damage caused by storms/monsoons is an important aspect of reliability. For example, the July 2011 massive dust storm in Phoenix left thousands of people without power.

Energy availability and use are also closely correlated with a healthy economy. Arizona does not have a particularly energy-intensive economy, but its businesses cannot function without reliable electricity. A major commercial use of electricity is for cooling office buildings;[26] a power outage during the middle of a hot Phoenix day could send thousands of workers home due to lost internet and climate control, impacting both company profits and consumer services. Manufacturing sites, like the Intel Corporations' wafer fabrication plants in Chandler for example, would come to standstill. Such manufacturing sites also depend on reliability in power quality. (See Chapter 5 for more on energy and the economy.)

Arizona's electricity grid is highly reliable at present; yet changes may be coming. On the one hand, extreme weather events, possibly linked to climate change, are increasingly posing new risks to the electricity grid. According to the U.S. Energy Information Administration, grid outages due to extreme weather events have risen over the past two decades.[27] In 2011, a spectacularly strong series of tornadoes hit northern Alabama, one of them cutting the power lines providing electricity to the cooling systems at the nuclear reactor at Brown's Ferry, forcing it to shut down and halt its production of electricity. At the same time, changes in grid technology affect reliability. These changes are being driven by several factors, including growth in intermittent sources of energy, such as solar and wind energy production; growth in distributed generation of solar energy from rooftop and small-scale solar energy facilities; and growth in smart meter usage, which will allow more dynamic control of end-user energy consumption.

Nor is electricity the only form of energy that residents and businesses depend upon to be reliable. Transportation consumes the largest overall proportion of energy in the state. Major Arizona cities like Phoenix and Tucson are heavily car dependent, with much of the population commuting to work by car. Reliable and affordable delivery of fuel affects workers ability to commute—particularly from exurbs—as well as affecting the prices of all consumer goods. Because it imports almost all of its transportation fuel, Arizona is vulnerable to global supply fluctuations and also accidents. For example, a 2003 pipeline rupture in Texas left Tucson and Phoenix short of gasoline. More recently, a February 2011, disruption in natural gas pipelines shut down several Arizona power plants (and left parts of New Mexico without natural gas for home heating during one of the coldest parts of last winter). In summary, as we consider transitioning our energy system in Arizona, the reliability of energy supply will be an important factor.

### Sustainability

The final enduring factor shaping planning for energy futures is sustainability. In its simplest terms, sustainability means the ability to continue to grow the economy without undermining the ability of future generations to enjoy social, economic, and environmental wellbeing. Three factors—social, economic, and environmental sustainability—are often described as the triple bottom line, in an effort to expand corporate decision-making processes beyond the financial bottom line. Advocates of the triple bottom line argue it should be applied to evaluate strategies for moving forward sustainably.

Sustainability intersects energy in numerous ways. Energy is the largest and most complex industrial sector on the planet. Not surprisingly, therefore, how we produce and consume energy has significant implications for economic, social, and environmental sustainability. While much of the current emphasis on sustainability focuses on greenhouse gas emissions, other sustainability issues are arguably just as important. Energy production is a major source of human health impacts, for example. In India and China, rapid growth in automobiles and coal-fired power plants has increased urban air pollution and led to significant growth in asthma rates among urban children. While pollution levels are lower in Arizona than in most cities in Asia, they remain significant, especially when compounded by the problem of dust. Specifically, asthma affects 1 in 5 of Arizona's youth and 1 in 7 adults.[28] Coal and uranium mining continues to put workers at risk of serious health effects. In Arizona, the U.S. Environmental Protection Agency is currently reevaluating the adequacy of pollution control technologies at the Navajo Generating Station to determine whether it meets federal air quality standards (see Chapter 7). Catastrophic risks also remain a danger in the energy industry, as illustrated by the 2005 Texas oil refinery fire, the 2010 Deepwater Horizon oil spill in the Gulf of Mexico, and the 2011 Fukushima nuclear accident in Japan.

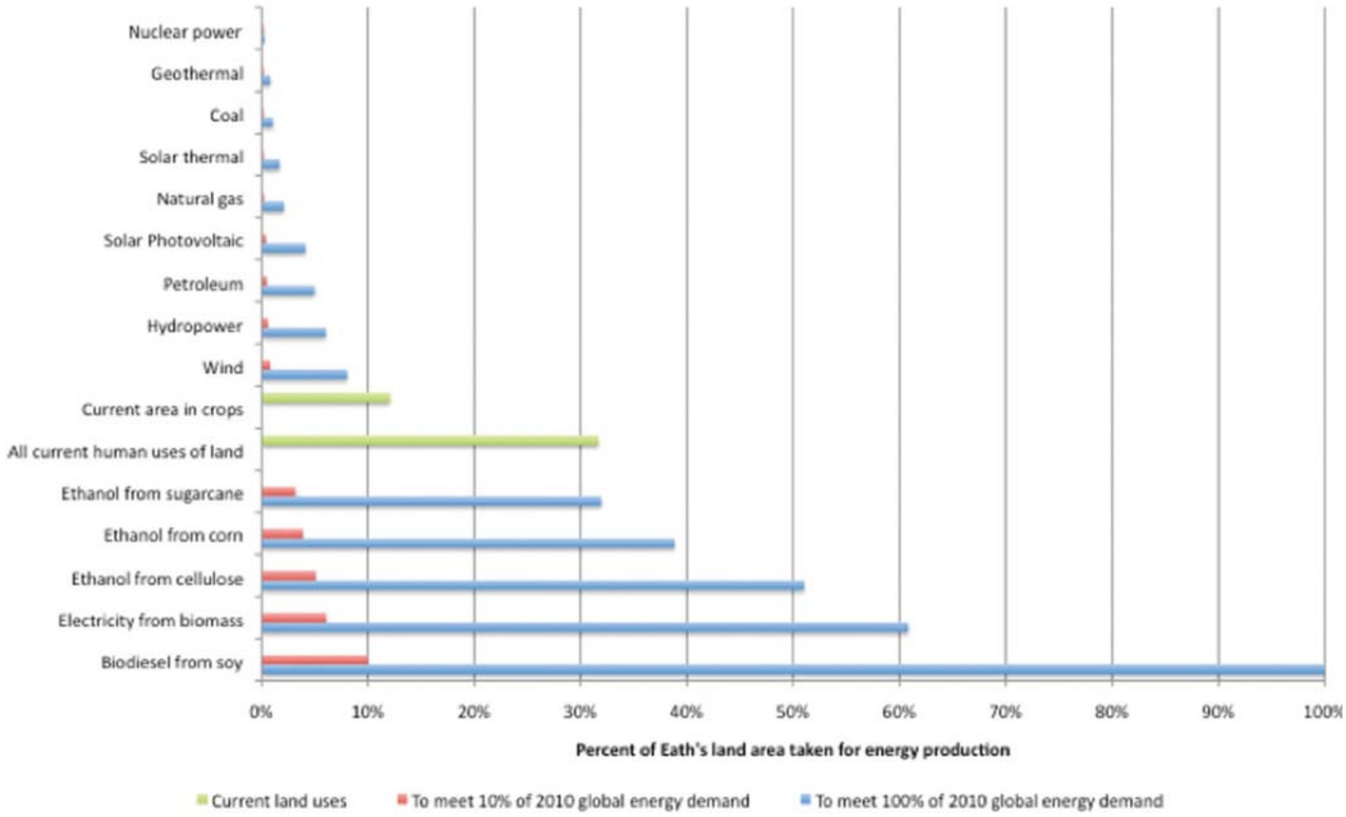
Energy generation is also closely tied to the use of land, water, and other resources. All energy generation technologies require land or space. Understanding just how much land is needed is a surprisingly complicated task (see Figure 3 for an estimation). For instance, while coal-fired plants, natural gas plants, and nuclear plants themselves have relatively small land footprints, coal mining, uranium mining, and storage for nuclear waste also factor into the land footprint. Alternative energy sources like solar panels, solar power plants, hydropower, and wind consume even more land (although with wind power, the land under the turbines can still largely be used for other purposes; and some of the 'land' used for solar panels is actually on rooftops). Additionally, solar and wind land use is contiguous, meaning that wind turbines and solar power plants themselves cover thousands of acres in one area, while the area used for mining coal and the area used for a coal-fired power plant could be thousands of miles apart. Agricultural sources of energy, such as ethanol and biofuels, appear to be the most land-use intensive energy resources, as growing these crops takes large swaths of land. In Figure 3, oil appears to use less land; however, this does not take into account massive oil spills, such as last summer's Deepwater Horizon spill in the Gulf of Mexico.

To further complicate this issue, power plants must be hooked up to transmission lines, which also require land, to deliver the power where it is needed. Due to transmission lines' visual and environmental impacts, siting them is a contentious and lengthy process. Therefore, regulators often attempt to site these lines along a highway or other previously disturbed area. Ultimately, where power plants get sited is strongly linked to available transmission lines and new transmission line siting processes.

Also challenging is that these numerical estimates of the acreage needed tell us little about how humans and wildlife value and use particular places. Geographically suitable sites for particular energy uses (e.g., sunny areas or areas near coal mines) can negatively impact wildlife habitat, rural communities, or vulnerable human populations. Power plants sometimes require places that people previously valued for other uses. The federal Bureau of Land Management is currently conducting substantial reviews of the suitability of various sites for wind and solar generation and their environmental impacts in Arizona and the rest of the Desert Southwest.

The energy-water nexus represents another important connection between energy and other resource uses. This issue is particularly salient in Arizona's arid desert climate. All energy technologies use water in some phase of their lifecycle—steam turbine plants use water for cooling, producing biofuels requires watering crops, hydropower uses and reroutes river resources, and solar panels and mirrors need to be cleaned every once in a while. Not all water uses are the same, however. Some energy technologies consume water, meaning they withdraw it permanently from the water source. If water is converted to steam, for example, and released into the air, it is lost from the local water system. Other energy technologies only withdraw the water (called a "water withdrawal") and then return it to the original water source. Another aspect of

**FIGURE 5** | Alternative Energy and Land Use, Clinton Andrews et al. (2010)[29]



the water-energy nexus is that electricity is essential for water pumping and distribution. The coal-fired Navajo Generation Station plays an important role in providing water through the Central Arizona Project to Arizona's metropolitan areas. Planning for Arizona's energy future requires evaluating the water footprint of various technologies and planning accordingly. Land and water use are connected since energy generation technologies that require water must be sited in places where sufficient groundwater resources exist. Energy efficiency and water conservation methods can help reduce these footprints. (See Chapter 6 for a discussion on the energy-water nexus.)

Finally, understanding energy's connection to other resource uses pushes us to think about the life-cycle of the energy technology—from cradle-to-grave—and its implications for energy/resource security. Energy fuels, power plants, and other energy technologies require other resources like steel, rare earth metals, concrete, etc. Of particular concern are rare-earth metals, like lithium, that are used in the batteries of hybrid cars and solar panels. The United States must import these finite resources from abroad.

Overall, energy production requires a range of land, water, and other resources and may impact other aspects of the environment, such as air and water quality, or the risks to which people are exposed. Sustainability considerations suggest taking these factors seriously in evaluating both existing and future energy developments. Doing so in a comprehensive fashion, that assesses not only proposed new energy facilities but also alternatives that might be developed instead, can provide valuable insights to citizens and policy officials in making choices about Arizona's energy future.

## Notes

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# Section I:
# Energy in Arizona Today

# Section I: **Energy in Arizona Today**

This report is divided into two major sections. Section I, Energy in Arizona Today, explores the basic facts of energy in Arizona and puts those facts into broader contexts, including Arizona's economy and water; Native American tribes and lands; the costs, risks, and benefits of energy production; and energy security. Section II, Energy in Arizona's Future, subsequently offers a window into some possible futures of energy in the state.

## A. Basic Energy Facts

The first four chapters of Section I (Chapter 2-5) provide an overview of the basic facts of energy in Arizona. These chapters describe how much energy Arizona produces and consumes, its energy resources, and its energy efficiency. Together, the chapters offer a valuable perspective on the major energy fuels and technologies and their connection to the larger energy system, including the electricity grid, transportation infrastructures, and devices in the home and business that consume energy. The chapters describe both major components of the energy sector: electricity and fuels.

## B. Energy in Context

The second set of four chapters in Section I provide an integrated set of contexts that both impact and are impacted by energy production and consumption in Arizona.

Chapter 6 examines the relationship between energy production and water in Arizona, observing that while the production of energy uses water, the production of water also uses energy. Thus, moving water from place-to-place, pumping water out of aquifers, water treatment and purification, and heating water, all require substantial amounts of energy.

Chapter 7 puts energy in the context of Arizona's tribes, highlighting the importance of Arizona's Native American communities and lands in shaping energy production and policy. A significant fraction of Arizona's energy is generated on tribal lands, for example, using coal that is also mined on tribal lands. Energy also raises important questions of social, environmental, and economic justice for Arizona's tribes.

Chapter 8 examines the costs, benefits, and risks of energy production and consumption in Arizona, as well as their distribution across different populations in the state.

Finally, Chapter 9 analyzes the security of Arizona's energy supplies, highlighting the very high level of reliability of Arizona's current energy systems but also noting potential risks to that reliability.

# Chapter 2: **Energy Sources in Arizona**

*Robert Pahle*

## Overview

- Arizona's chief energy resources include coal, hydropower, solar, wind, and uranium. It has significant coal deposits but very few other fossil fuel resources. It also has among the highest solar power potential in the United States.
- Arizona uses energy from coal, hydropower, oil, sunlight (distributed and utility-scale), wind, and nuclear. It currently has no known geothermal production.
- There are rich uranium deposits near the Grand Canyon, but the area is currently under a mining moratorium due to potential environmental impacts.

Arizona has a variety of energy resources—fossil and renewable—that are available for use in energy production. Arizona's coal deposits are substantial, but it has few other fossil fuel resources. The coal deposits are concentrated in the Black Mesa Basin in the northeastern part of the state, along with two major coal-fired power plants. Arizona imports most of the rest of its fuels, including oil, gasoline, and natural gas. Arizona has the largest nuclear power plant in the country. It also has some deposits of uranium, the primary fuel for nuclear power plants. Its large desert areas offer some of the highest solar power potential in the country, though Arizona has harnessed relatively little of it. Additionally, the Colorado River is a tremendous source of hydropower. This chapter reviews these different energy sources, their current use, and their potential for the future.

### Coal

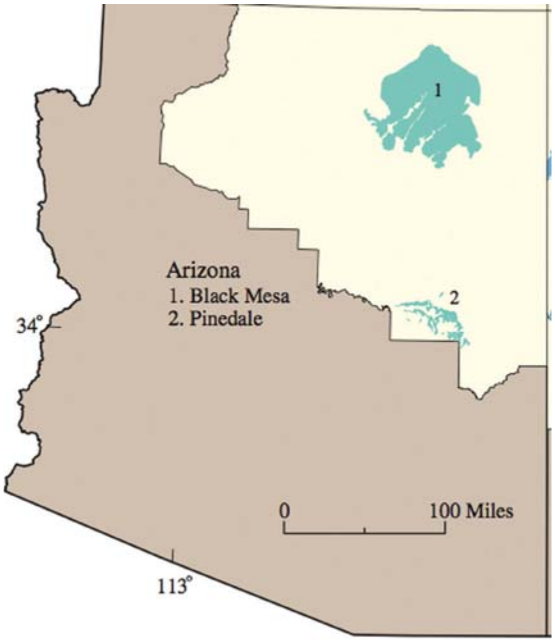
Of all of Arizona's energy resources, coal has the largest current impact on Arizona's energy production. Arizona currently produces about 7.5 million tons of coal each year, while it consumes 20.9 million tons of coal for electricity production.[1] Arizona's imports of coal come from New Mexico and Wyoming. The installed capacity of coal-fired power plants is about 6.2 GW (summer capacity).[2] This accounts for 35% of Arizona's electricity production. Coal mining and coal-fired electricity production are responsible, directly and indirectly, for about 4,500 jobs and $170 million in payroll in the state.[3]

Arizona has two major coalfields - the Black Mesa Coal Field and the Pinedale Coal Field (see Figure 1 for locations). (See also Chapter 7 for a discussion of coal on Native American lands.) The Black Mesa field consists of three main coal formations (Dakota, Torvea and Wepo). The Pinedale Coal Field consists of two main coal formations with no active production.[4] In 2009, Arizona produced 7.5 million tons of coal and imported 13.4 million tons for power production. Estimates of the size of Arizona's coal reserves vary widely. According to the U.S. Geological Survey, studies from the 1950s of the Arizona Black Mesa coalfield estimated that Arizona had approximately 21 billion tons of coal reserves.[5] The Energy Information Administration (EIA) estimated that in 1992 Arizona had 102 million tons of demonstrated underground coal reserves and 135 million tons of demonstrated surface coal reserves, for a total of 237 million tons of demonstrated coal reserves. Further, in 1992, there were estimated to be 51 million tons of total recoverable underground coal reserves and 106 million tons of surface coal reserves, for a total of 157 million tons of recoverable coal reserves. There is currently no underground coal mining in the state, only surface mining.[6] Current estimates of the quantity of coal reserves in Arizona are withheld to avoid disclosure of individual company data, which means that it is unclear just how much coal is currently available for mining.

## Hydropower

Arizona also derives significant current energy production from hydropower. There are several large-scale hydropower plants in Arizona that produce, together, a net summer capacity of about 2.7 GW of electricity. The biggest dams are the Glen Canyon Dam (1.3 GW) and the Hoover Dam (2.0 GW to 1 GW on the Arizona side); other dams are Davis Dam (251 MW), New Waddell Dam (45 MW), and Parker Dam (120 MW). (See the glossary for an explanation of MW and GW.)

**FIGURE 1** | Arizona's Coalfields



Source: U.S. Geological Survey, 2009[7]

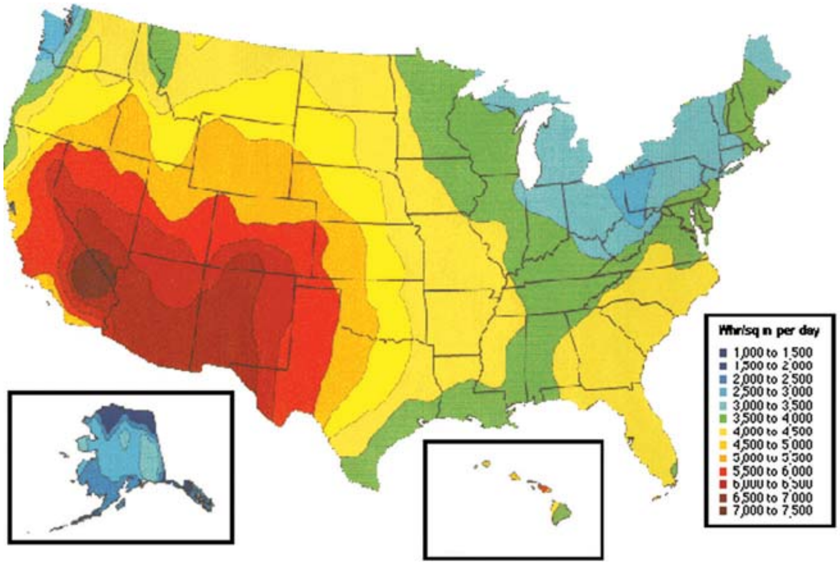
In 1997, the Idaho National Engineering and Environmental Laboratory published a hydropower resource assessment for Arizona.[8] This study looked at potential sites for developing future hydropower in the state. The authors estimate that, theoretically, the state has an additional 1.8 GW of hydropower available for development. However, the study's model estimates that much of this potential would face either practical or environmental challenges to its development. The study estimates, therefore, that a more realistic estimate for actual electricity production would be about 330 MW (or about a 12% increase from current levels). This potential production is roughly balanced between the Colorado and Gila rivers. The study did not consider the potential for small-scale hydropower development on the state's canals.

## Solar

The solar energy potential in Arizona is excellent. The state's average direct solar resource is 7,100 Watt-hours of energy each day, per square meter (or 7.1 $kWh/m^2/day$).[9] (For comparison, a single-story, 2,150 square-foot home occupies about 200 square meters in area). This is among the highest levels in the United States. One thousand Watt-hours is equivalent to the energy consumed by ten 100 Watt light bulbs running for one hour. Thus, on average, each day, the solar energy arriving in Arizona could power about three 100-Watt light bulbs for 24 hours, for each square meter of sunny land (or rooftop space). Put another way, the average U.S. household uses 1,076,000 Watt-hours of electricity each month.[10] This much solar energy arrives, over a month, for every five square meters of area. Of course, current solar panel technology cannot convert anywhere close to all of the sun's energy to electricity, so it would actually require considerably more area of solar panels to produce 1,076 kWh of electricity (probably closer to 40 square meters, or 20% of the area of a typical 2,150 square foot home). (See the glossary for more information on energy units of measurement, such as the kWh.)

In contrast to Arizona's total potential solar resource, the currently installed capacity of solar energy generation is comparably low, at 101 MW, with another 1 GW under construction as of 2011. There are two major avenues for the development of solar energy in Arizona: utility-scale solar power, which focuses on facilities producing hundreds of MW or even GW-scale energy production and distributed solar power, which includes both mid-scale solar production, focused on commercial building rooftops or neighborhood-scale facilities in the range of a few hundred kilowatts to a few megawatts, and household-scale distributed generation focused on individual home rooftops. (See the glossary for the definition of "distributed generation".)

**FIGURE 2** | Solar Radiation Map for the U.S.



Source: http://www.azsolarcenter.org/images/articles/az/solmap.gif

## Utility-Scale Solar Power

The development of utility-scale, or large-scale, solar power plants requires large amounts of relatively flat space. Developments in these areas may intensely impact local flora and fauna. Arizona's diverse and sensitive natural resources represent a significant potential limit on Arizona's solar development potential. Depending on the importance given to environmental impacts, much of Arizona's lands are difficult to develop. Even giving heavy weight to natural resources and topography, however, Arizona's overall solar generation potential is still in excess of 60 GW. In comparison, Arizona's peak demand is about 20 GW, though this number does not take into account the possibility of exporting Arizona's renewable electricity to other states. (See "peak load" in the glossary.)

As with other large-scale power plants, solar power plants require an excellent connection into the power grid. The best locations in this regard are close to the transmission lines to California. The federal Bureau of Land Management has identified sites in this area to "fast track," meaning to speed up the permitting process of, 2.7 GW of solar power plant applications. However, existing transmission lines are already transporting significant amounts of energy, and so the current power grid may not be able to handle more than about 1.5 GW of new energy from these locations. In the southeastern part of Arizona there are large areas with less sensitive flora and fauna that could produce about 58 GW of solar energy. The limitations on development in this area imposed by the capacity of the existing power grid are even more severe, however. Here only about 500 MW could be transmitted to the demand centers (i.e., cities)—far less than the 58 GW potential for solar energy development. Hence, any large-scale new development of utility-scale solar energy will require the addition of significant new transmission lines.

Utility-scale solar power plants face other challenges. For example, these facilities would have a significant visual impact on the landscape and, as discussed in Chapter 6, may use significant water resources if they are "wet-cooled" concentrated solar power plants (see glossary for explanation of these terms). Both issues may give rise to public concerns among nearby residents. Some reports that discuss the deployment of solar power also suggest that manufacturing limits will prevent significant short- and medium-term development of solar facilities.[11]

### Distributed Solar Power

The second major potential avenue for solar energy development is the use of PV or photovoltaic panels on rooftops (commercial or residential) or in smaller, neighborhood-scale installations. The idea of producing energy where it is used is appealing for many people, because it generates a sense of energy independence, it may lower electricity costs, and it significantly reduces the loss of energy during transmission. Thus, it is not surprising that, despite moderately high up-front costs, the number of distributed solar installations in Arizona has grown rapidly in recent years as federal, state, and utility incentives have grown. According to 2010 data reported by APS and SRP, for example, most zip codes within the greater Phoenix area now have between 100-500 kW of installed solar PV systems on rooftops, while a few zip codes have over 1 MW of installed PV. Across Phoenix, the average kilowatts per solar installation is in the range of 2-7 kW, or 45-150% of the average household energy consumption for Arizona households.[12]

In addition to individual household-level solar installations, the potential also exists to build larger-scale installations on public or commercial buildings, parking garages, or open but unused space in neighborhoods. Arizona State University, for example, has built and is building a number of mid-scale solar generation facilities ranging from a few hundred kW to 5 MW in capacity. Overall, the current phase of solar development on the university's four campuses is planned for a total of 10 MW of capacity. A recent study of buildings owned by the city of Phoenix indicates the city has 15-27 MW of solar rooftop capacity.[13]

Household and mid-scale rooftop PV opportunities are shaped by three variables. First, rooftop installations are more expensive per unit of energy created than other kinds of energy and so are dependent on incentive programs to make them economically viable. Even so, they are primarily an option for wealthier individuals and communities or for businesses and institutions. Second, large-scale adoption of distributed generation would require that the electricity grid be modernized to handle significant amounts of distributed generation. Some of this work is already under way with the installation in many parts of Arizona of new electricity meters (often called smart meters) that can measure both the amount of electricity a building takes off the grid and how much its solar panels put back on the grid (see glossary for the definition of smart meters). Other requirements for upgrading the electricity grid to handle extensive amounts of rooftop solar energy generation are not yet fully understood, but current installed amounts of solar remain far below levels that might cause problems for the grid. Finally, rooftop systems are limited, ultimately, to the total amount of rooftops or other appropriate space. Again, current installed amounts fall far short of what is available, so this is only a long-term worry and only if solar is hugely successful.

Estimates vary considerably from location-to-location, but a recent survey of current research suggests that many locations are likely to see on the order of 20-50% of total roof area available for PV installation.[14] A study of a 16.7 square kilometer area around downtown Phoenix found that buildings occupied between 18% and 32% of this area, depending on the type of land use (residential, commercial, industrial, etc.)[15] Combining lower-end estimates would suggest that roughly 4% of the total land area covered by a typical community might be available for rooftop PV, not including non-rooftop alternatives, such as parking lots. Based on the total area of the city of Phoenix, this would work out to be 580 million square feet. A recent study of New York City found 615 million square feet of rooftop space appropriate for solar energy, with a total potential of 5.8 GW of solar production.[16]

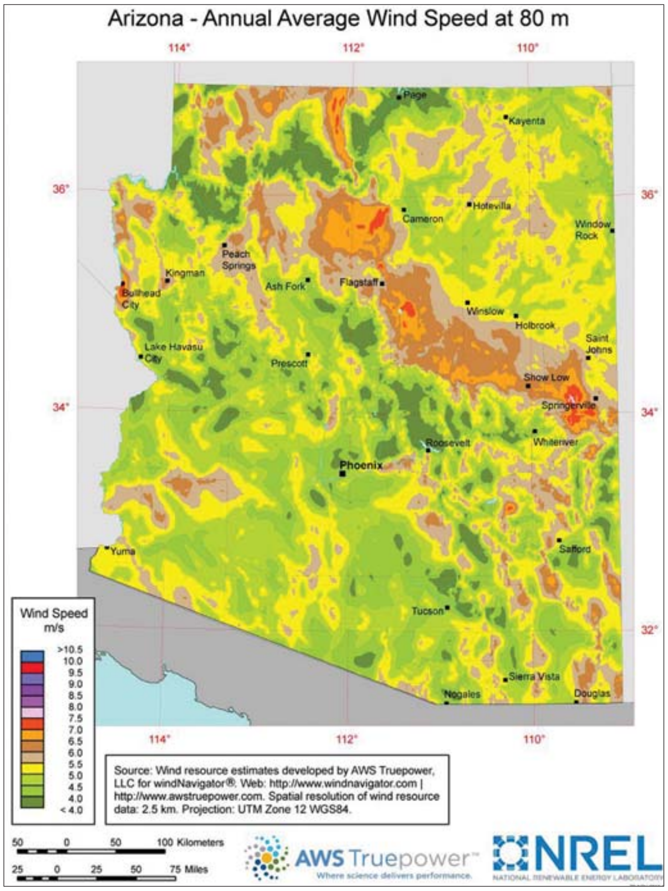
## Wind

There are several small wind power generators in Arizona with the capacity to produce 63 MW (summer capacity).[17] In 2006, NREL conducted an in-depth study of the wind zones and their potential.[18] Most of the potential sites are located on the Mogollon Rim in northeast Arizona. Other wind sources are also available on the higher rims and ridge crests throughout the state. The total theoretical potential for Arizona is around 23 GW. However, military training zones may impact wind power development potential.

## Geothermal

In Arizona there is no recorded geothermal production. There are several hot springs locations throughout the state. The best known locations are at Childs on the Verde River, Apache Junction, and in the Bradshaw Mountains. The two hottest springs in the state (Clifton and Gillard) are in the Clifton-Morenici area. Even though the water temperatures at these springs may exceed 284 degrees Fahrenheit at depth, they could only be used for low-grade steam. A Black and Veatch report suggests a possible capacity at Clifton and Gillard of about 35 MW.[19] However, there are no planned projects at the moment.

**FIGURE 3** | Wind Energy Resources in Arizona



Source: National Renewable Energy Laboratory

**FIGURE 4** | Wind Power Potential in Arizona

| Region | Capacity by Wind Power Class | | | | | Total Capacity |
|---|---|---|---|---|---|---|
| | 3 | 4 | 5 | 6 | 7 | |
| **53** | 2,042 | 255 | 47 | 9 | 1 | **2,355** |
| **54** | 12,764 | 586 | 240 | 104 | 12 | **13,706** |
| **55** | 3,376 | 407 | 62 | 18 | 1 | **3,864** |
| **56** | 129 | 22 | 2 | 0 | 0 | **152** |
| **57** | 713 | 115 | 33 | 16 | 2 | **879** |
| **58** | 194 | 60 | 12 | 2 | 0 | **267** |
| **59** | 1,321 | 370 | 123 | 53 | 4 | **1,870** |
| Total | **20,538** | **1,814** | **519** | **202** | **20** | **23,093** |

Source: Donna Heimiller, NREL, 2006
Note: Total technical potential, assuming 5 MW of capacity per square km

## Natural Gas

Most of Arizona's natural gas is imported from out of state. The electric power sector dominates natural gas consumption in Arizona, consuming roughly three-fourths of natural gas used in the state. Arizona has extensive natural gas-fired power plants, totaling 13 GW of capacity in the summer.[21] TransCanada recently finished construction of a new 575 MW natural gas-fired power plant in Coolidge, southeast of Phoenix. It supplies power to SRP.

Most of the rest of Arizona's natural gas is consumed by heating, cooking, and other household uses. Arizona winters are generally mild, so winter energy consumption is low. To satisfy heating needs, 40% of Arizona households rely on natural gas and the remainder on electrical heating.

Arizona chiefly relies on interstate deliveries to meet most of its natural gas demand. It is part of the transportation corridor for shipping gas from production areas in Texas and the Rocky Mountains to the southern California region via several major natural gas pipelines.[22]

## Oil

Arizona's crude oil production is minimal. There are 19 wells, and the production of 40,000 barrels per day is insignificant in relation to the overall U.S. production. The installed capacity for oil-fired power plants is relatively small at 93 MW (summer capacity).[23]

Arizona currently has no refineries and receives its petroleum product supply via two pipelines, one from southern California and the other from El Paso, Texas (See Chapter 9). A new refinery in Yuma County, Arizona, about 100 miles southwest of Phoenix, was initially approved in 2006. It was delayed, however, because the Quechan tribe expressed concerns about disturbing cultural artifacts, and the Mexican government refused to supply the refinery with crude oil. The refinery was reapproved in 2008 for a new location in Mohawk Valley, four miles east of the Yuma location. The status of the refinery is currently unknown and construction has not begun. The facility would have a capacity to refine 163,000 barrels per day of crude oil and produce 6.3 million gallons per day of petroleum fuels, including several blends that conform to standards in Arizona and California to reduce the chemicals in the fuel that cause air pollution.

Currently, an oxygenated motor gasoline blend is used in the Tucson area during the winter and in Maricopa County year-round to reduce smog. The area just south of Phoenix, Arizona requires the use of a motor gasoline blend. This is due to the high average temperatures, which can cause vehicles to stall when gasoline transitions from liquid to gas inside the engine.

## Nuclear and Uranium

Arizona has one nuclear power plant (the Palo Verde Nuclear Generating Station, see Chapter 3) with an installed summer capacity of about 3.9 GW. Uranium is the primary fuel for nuclear power plants. The average grade of uranium oxide in Arizona is .64%, which is among the highest grade and the most profitable source available. The total amount of minable uranium in Arizona is estimated to be in the range of 35 million pounds.

About one-third of the minable pipes, or underground breccia rock masses that contain uranium, in Arizona are near the Grand Canyon National Park. Based on environmental concerns about the degradation of the Grand Canyon, the U.S. Department of the Interior declared in 2009 a two-year moratorium (i.e., ban) on new mining claims in the area around the Grand Canyon. In June 2011, the moratorium was extended by an additional six months in order for additional environmental review to be conducted. A potential 20-year moratorium on new mining claims near the Grand Canyon is currently under consideration.[24] The only active uranium mine in Arizona is the Denison Mine. It is an underground operation that mines 335 tons per day, four days a week. Construction on a new mine is underway at the nearby Pinenut deposit, which is expected to deliver first ore in 2012.

## Notes

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# Chapter 3: **Energy Consumption and Production in Arizona: Status and Trends**

*Stephen Goodnick*

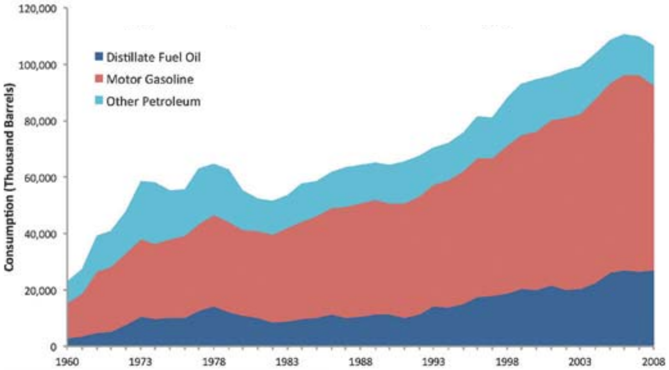
## Overview

- Arizona ranks 20th in the nation for electricity consumption. Arizona exports approximately 28% of the electricity it generates.
- Of the electricity consumed in Arizona, 40.9% comes from coal, 26.1% from natural gas, 27.4% from nuclear, 6.4% from hydroelectric, and 0.045% from petroleum.
- Arizona has seen the fastest growth in greenhouse gas (GHG) emissions in the United States between 1990-2005, but its per capita emissions grew at about the same rate as U.S. averages. Growth in GHG emissions in Arizona was likely due to population growth.
- The Palo Verde Nuclear Generating Station is the largest nuclear plant and the second largest power plant in the United States.
- Arizona has the greatest solar power potential in the country and has a large wind corridor in the northern part of the state.
- Arizona currently generates about 11 MW of solar electricity, and there are approximately 3 GW of planned projects in development stages.

## The Major Types of Energy Consumption in Arizona

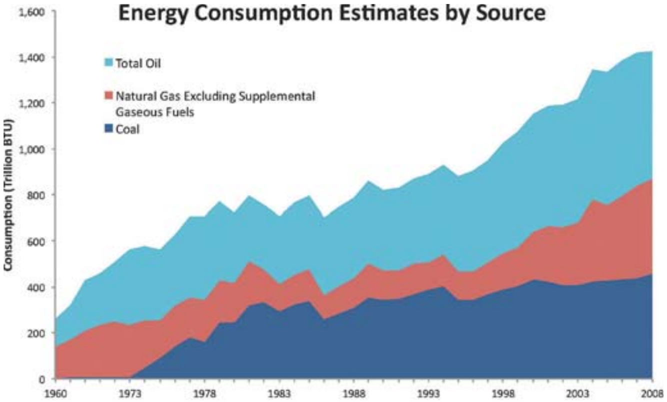
The main forms of energy consumption in Arizona are liquid fuels and electricity. Liquid fuels include motor gasoline, distillate fuel oil (primarily diesel and jet fuel), and other fuel forms, such as liquefied petroleum gas and residual oil. Figure 1 plots the growth over time of the consumption of various liquid fuel forms in Arizona, measured in thousands of barrels. This figure shows that the major consumption of liquid fuel energy is associated with transportation, mostly motor gasoline. The overall upward trend is commensurate with the overall increase in Arizona's population over the same period. Fluctuations in consumption tend to be in response to price and supply, e.g., the downward trend in consumption in response to the 1979 oil crisis.

**FIGURE 1** | Arizona Energy Consumption Estimates for Primary Sources of Liquid Fuels



Source: U.S. Energy Information Administration (EIA)[1]

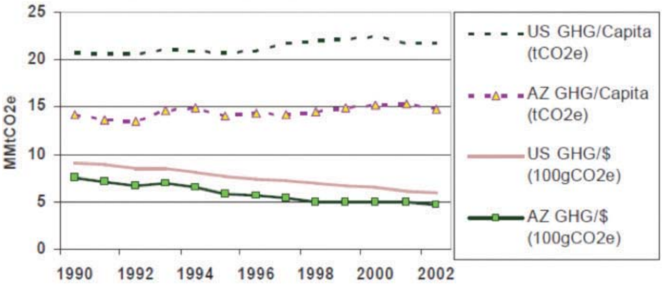
**FIGURE 2** | Arizona Energy Consumption from Conventional Sources



Source: Adapted from data from EIA[2]

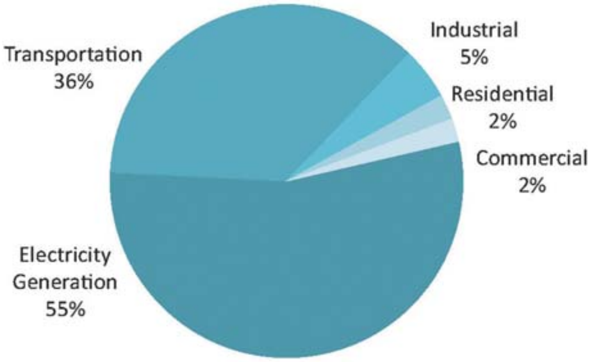
Figure 2 plots the growth in consumption of coal, natural gas, and all oil products, from 1960 to 2008. The “total oil” trend, shown in green, includes primarily transportation-related fuels, whereas coal (shown in blue) and a major fraction of natural gas (shown in red) are consumed in electrical energy generation. Over 70% of natural gas usage in 2008 was for electricity (e.g. water heating, cooking, and other household uses); the rest was primarily for heating. The main trend illustrated in Figure 2 is that the growth in energy consumption over the past decade has been met by increased use of natural gas, whereas reliance on coal has remained relatively flat.

**FIGURE 3a** | Arizona and U.S. GHG Emissions, per Capita and Per Unit Gross Product (2000$)



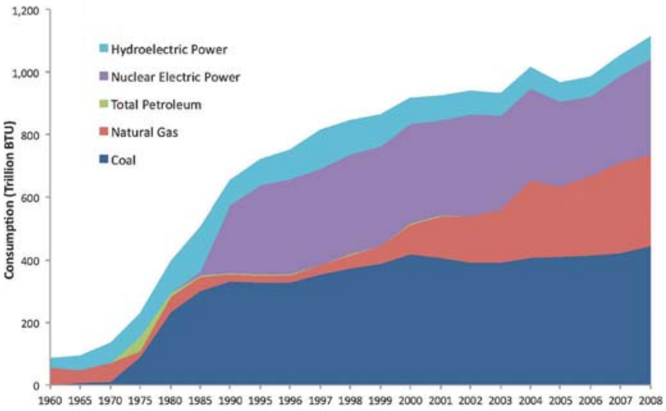
Source: U.S. Energy Information Administration (EIA)

**FIGURE 3b** | Arizona's Breakdown of GHG Emissions by Sector, with Emissions from Exported Power Included



Source: U.S. Energy Information Administration (EIA)

**FIGURE 4** | Estimated Electrical Power Consumption in Arizona by Generation Type[4]



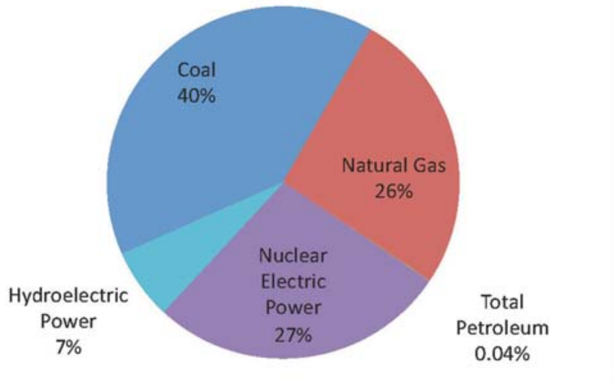
Source: Adapted from data from EIA[5]

One impact of Arizona's growth in fossil fuel-based energy consumption has been GHG emissions. In 2005, Arizona completed a GHG emissions inventory and forecast.[3] Among the findings was that Arizona had the fastest growth in GHG emissions in the United States, increasing nearly 56% from 1990 to 2005. Per capita emissions, however, were lower than the U.S. averages due to the relatively small per capita energy usage previously noted. Nearly 80% of the total GHG emissions were attributable to transportation (on-road vehicles) and energy supply (power plants). Figure 3 shows a plot, excerpted from the GHG emissions inventory, of the per capita and per unit gross product generation of GHG emissions. The Arizona per capita emissions, seen in Figure 3a, rose at roughly the same rate as the national average. Therefore, Arizona's large overall change in GHG emissions is likely due to the large growth in population over the same period. Note, however, that emissions from electricity exported out of Arizona were not included in these calculations (see Figure 3b.)

## Electric Power Consumption in Arizona

Figure 4 provides a breakdown of the total estimated consumption of electric power within Arizona by generation type since 1960. Hydroelectric power was an early source of a large fraction of Arizona's power generation. It has its historic roots in the Salt River Project's (SRP) Theodore Roosevelt Dam project and later development on the Colorado River through the Hoover, Parker, and Glen Canyon dams. As Arizona's population grew rapidly starting in the 1970s, the increasing demand for power consumption was first met by coal, through mining at Black Mesa, and later by nuclear power, with the completion of the first two units of the Palo Verde nuclear plant in 1986. Since the late 1990s, natural gas provided most of the increased electrical generation in the state, as shown in Figure 2.

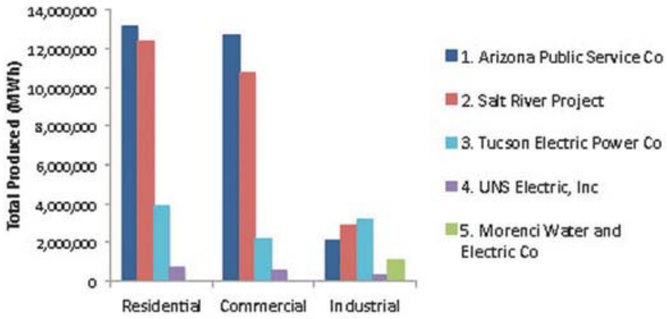
**FIGURE 5** | Estimated Electrical Power Consumption in 2008 by Generation Type[6]



A breakdown of the relative contributions of each sector as of 2008 is shown in more detail in Figure 5. As of 2008, the contribution of renewable energy sources, such as wind and solar, are not significant enough to be visible on this pie chart, as is the case with other petroleum sources of electrical power (i.e., residual fuel oil and petroleum coke). Coal power is the largest component of the energy portfolio followed by nuclear, natural gas, and finally, hydroelectric.

There are five main retailers of electricity in Arizona, the largest two being Arizona Public Service (APS) and the Salt River Project (SRP), followed by Tucson Electric Power Co. (TEP), UNS Electric, and Morenci Water and Electric Co. Figure 6 shows each company's relative market share for residential, commercial, and industrial energy generation.

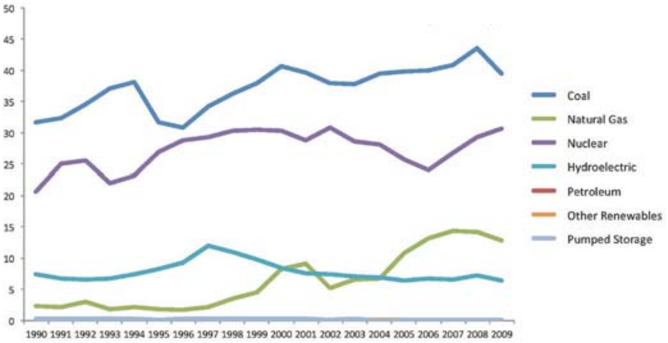
**FIGURE 6** | Top Five Retailers by Commercial Sector in Arizona[7]



Source: Annual Electric Power Industry Report. U.S. Energy Information Administration, Form EIA-861

Figure 7 shows the combined proportion of different fuel sources, illustrating that coal makes the largest contribution to utilities' electric generation, followed by nuclear, gas, and hydroelectric.

**FIGURE 7** | Primary Utility Generation by Energy Source (MWh) (petroleum, pumped storage, and renewables are all essentially close to zero on this graph)[8]



Most of Arizona's electric power generation comes from large-scale production. Table 1 provides a rank-ordered list of the largest power plants in the state by net summer capacity (in MW). The Palo Verde nuclear facility is the largest single generation site (and the largest nuclear facility in the United States), with close to 4 GW of generation capacity. The second largest plant is the 2 GW Navajo generating station, a coal-fired plant near Page, Arizona. The 2 GW Gila River power station is

**TABLE 1** | Largest 10 Electric Generation Facilities in Arizona[9]

| Arizona Plant | Primary Energy Source or Technology | Operating Company | Net Summer Capacity (MW) |
|---|---|---|---|
| **Palo Verde** | Nuclear | Arizona Public Service Co | 3,942 |
| **Navajo** | Coal | Salt River Project | 2,250 |
| **Gila River Power Station** | Gas | Gila River Power Station LP | 2,060 |
| **Springerville** | Coal | Tucson Electric Power Co | 1,614 |
| **Glen Canyon Dam** | Hydroelectric | US Bureau of Reclamation | 1,312 |
| **Santan** | Gas | Salt River Project | 1,227 |
| **Mesquite Generating Station** | Gas | Mesquite Power LLC | 1,073 |
| **Harquahala Generating Project** | Gas | New Harquahala Generating Co, LLC | 1,054 |
| **Hoover Dam** | Hydroelectric | US Bureau of Reclamation | 1,040 |
| **Cholla** | Coal | Arizona Public Service Co | 1,021 |

**TABLE 2** | Arizona Electricity Sources in MWh (2002-2006 Annual Average)

| Arizona Plant | In-State Generation | Imported Generation | Exported Generation | Net In-State Use |
|---|---|---|---|---|
| **Coal** | 38,526,671 | 13,706,962 | 9,308,761 | 42,924,872 |
| **Natural Gas** | 30,135,321 | 636,079 | 468,670 | 30,302,730 |
| **Nuclear** | 27,492,437 | | 14,680,961 | 12,811,476 |
| **Biomass** | 12,058 | | 12,058 | 0 |
| **Geothermal** | 65,323 | | 65,323 | |
| **Hydro** | 8,760,777 | 133,529 | 6,280,250 | 2,614,056 |
| **Solar** | 16,892 | | | 16,892 |
| **Total** | 104,944,156 | 14,541,893 | 30,750,700 | 88,735,349 |

Source: The Water Costs of Electricity in Arizona by M. J. Pasqualetti and S. Kelly[10]
Note: Net in-state use is calculated as the sum of in-state generation and imported generation minus exported generation. The use of 'import' and 'export' is intended to connote to or from the state, recognizing that local dams were built to serve several states, even when they are located in Arizona.

the largest gas powered facility, and the Glen Canyon and Hoover dam plants are the largest hydroelectric facilities in the state.

A 2008 report by M. J. Pasqualetti and S. Kelly at Arizona State University[11] calculated the exported generation for various fuel types as summarized in Table 2. The exported power represents approximately 28% of the net in-state use. Figure 8 illustrates Arizona's net export of electricity to surrounding states, where California is by far the largest consumer.

Additionally, in a report on the economic impact of APS on Arizona's economy, it was noted that 46% of the net generation from the Palo Verde Nuclear Plant and the Four Corners coal-fired plant is exported to California and Texas.

## Arizona's Nuclear Energy Profile

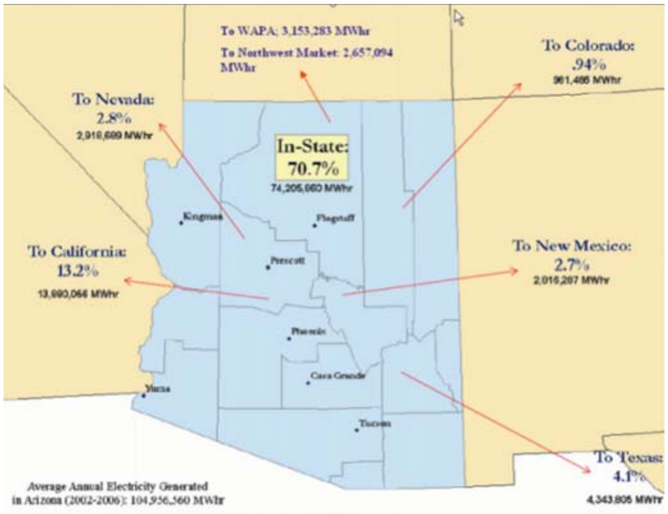
The following facts about Arizona's sole nuclear power plant, Palo Verde, are excerpted from the EIA's State Energy Profile.[13]

- The Palo Verde plant is the largest nuclear plant in the nation and the second largest power plant of any type after the Grand Coulee dam in Washington.
- Palo Verde is one of the few power plants in the nation that contain three reactors (no U.S. power plants have more than three, although some foreign plants have more than four).
- Unit 2 was reengineered to produce a greater capacity and is now the nation's largest electric power unit in terms of capacity.
- On November 18, 2005, the U.S. Nuclear Regulatory Commission approved an increase in power production at two of Palo Verde's reactors.

### Contribution of Nuclear Power

- Although it has only one nuclear power plant, Arizona is among the 15 states with the largest nuclear capacity.
- Nuclear power accounts for only about 15% of Arizona's total electric capacity, but nearly 25% of its electricity generation, third after coal and natural gas. (See the glossary for an explanation of 'capacity.')
- Over 50% of Palo Verde's total electrical generation is exported.

**FIGURE 8** | Net Export of Electric Energy Generation to Neighboring States



Source: M. J. Pasqualetti and S. Kelley[12] See Figure 1 in Chapter 9 (page 108) for a similar map with the average annual electricity consumed in Arizona from other states

> **"One of the reasons for the large impacts [of APS on Arizona's economy] is that energy exports make up a significant share of APS's net generation. For example, exports to California and Texas make up 46% of the Palo Verde and Four Corners plants' combined net generation."**
>
> Source: http://www.aps.com/files/_files/pdf/rateinfo/APSEconImpactStudy.pdf

### License Renewals and New Applications

On December 15, 2008, a license renewal application was submitted and later approved for all three of Palo Verde's reactors. Reactor one has the soonest license expiration date—in June 2025.[14]

### Arizona Renewable Energy Capacity

At present, renewable sources of electricity are a relatively small fraction of the total energy consumed in Arizona. Figure 9 shows the relative consumption of biomass and solar photovoltaics (PV) compared to hydroelectric power generation as of 2008. The decline in hydroelectric power consumption from 1997 to 2007 is most likely a result of prolonged drought in the Southwest, coupled with management of water-flows in environmentally sensitive areas such as the Grand Canyon.

## Arizona Renewable Energy Capacity

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In 2006, the Arizona Corporation Commission (ACC) implemented a renewable portfolio standard (RPS), requiring utilities to generate 15% of their energy from renewable resources by 2025. Thirty percent of the target must be from distributed generation (i.e., small decentralized power generation in the range of 3 kW to 10 MW, e.g., rooftop solar PV), with multiple credits awarded for solar generation and systems manufactured in Arizona. Table 3 provides a list of current and planned large-scale solar energy development projects in Arizona. This table illustrates that while the current installed capacity as of 2010 is small (about 11 MW, which does not include distributed generation), the planned projects represent close to 3 GW of capacity, which is comparable to Arizona's total hydroelectric capacity. This growth would be more than a 300-fold increase in the current solar power production of the state, which would represent a dramatic transition. Note that there is substantial uncertainty that all of the projects listed as 'in development' will be completed. The distributed generation of electricity through rooftop solar panels is also growing rapidly. Based on utility filings from the ACC, in 2010, there was 90 MW of distributed solar generation in Arizona. In 2010, for example, APS reported 59 MW of distributed solar generation, nearly ten times as much as the 6 MW of large-scale solar facilities it operated. Based on planned large-scale projects (still subject to financing, environmental review, etc.) and growth in the installation of rooftop solar panels, Arizona's utilities are on track for meeting Arizona's RPS by the target date of 2025.

In terms of wind energy, the northern portion of Arizona has a high potential for wind development. Based on utility filings with the ACC, in 2010, there

**FIGURE 9** | Relative Contributions of Different Forms of Renewable Energy to the Total Energy Consumption in Arizona[15]

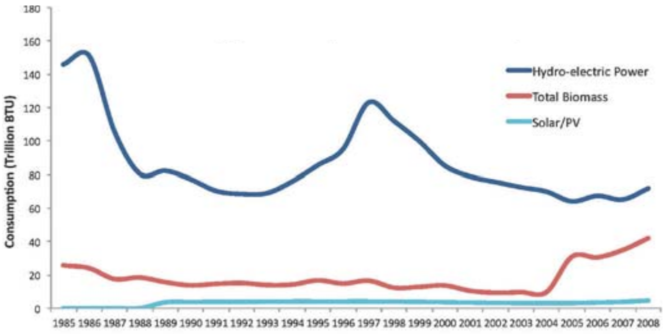


**TABLE 3** | Current and Planned Solar Electric Energy Generation Projects in Arizona, and Their Peak Capacity (MW)

| Project Name | Capacity (MW) | Status | Technology | Location | Electricity Purchaser | Developer |
|---|---|---|---|---|---|---|
| **Saguaro Solar** | 1 | Operating | Trough CSP | Red Rock | APS | Solargenix |
| **Maricopa Solar** | 2 | Operating | Dish-engine CSP | Phoenix | SRP | Tessera Solar |
| **Prescott Solar** | 3 | Operating | Solar PV | Prescott | APS | APS |
| **Springerville Generating Station** | 5 | Operating | Solar PV | Springer-ville | TEP | Global Solar Energy |
| **Solana** | 280 | Under Construction | Trough CSP | Gila Bend | APS | Abengoa Solar |
| **Paloma Solar** | 17 | Under Construction | Solar PV | Gila Bend | APS | First Solar |
| **Ajo** | 5 | Under Construction | Solar PV | Ajo | APS | Recurrent Energy |
| **Cotton Center** | 17 | Under Construction | Solar PV | Gila Bend | APS | Solon |
| **Prescott** | 10 | Under Construction | Solar PV | Prescott | APS | SunEdison |
| **Cooper Crossing** | 20 | Under Construction | Solar PV | Pinal County | SRP | SunPower |
| **Kingman** | 200 | Under Construction | Trough CSP | Kingman | | Albiasa |
| **UA Tech Park Thermal Storage** | 5 | Under Construction | Trough CSP | Tucson | TEP | Bell Independent |
| **Sonoran Solar** | 375 | Under Construction | Trough CSP | Maricopa County | - | Blvd. Association |
| **Quartsite Solar** | 100 | In Development | Tower CSP | La Paz County | - | SolarReserve |
| **Crossroads Solar** | 150 | In Development | Tower CSP | Gila Bend | - | SolarReserve |
| **Solar CAT** | 10 | In Development | Dish-engine CSP | - | - | SouthwestSolar |
| **Agua Caliente** | 290 | In Development | Solar PV | Yuma County | PG&E (California) | First Solar |
| **-** | 25 | In Development | Solar PV | Tucson | TEP | Fotowatio Renewable. |
| **Florence Solar** | 6 | In Development | Solar PV | Florence | | GWS Technologies |
| **-** | 25 | In Development | Solar PV | Cochise | | Matinee Energy |
| **-** | 150 | In Development | Solar PV | Dragoon | | Matinee Energy |
| **-** | 20 | In Development | Solar PV | Coconino County | Sunshine Solar | Pacific Blue Energy Corp. |
| **-** | 150 | In Development | Solar PV | Gila Bend | | Pacific Blue Energy Corp. |
| **Mesquite Solar** | 700 | In Development | Solar PV | Arlington | PG&E (California) | Sempra Generation |
| **-** | 5 | In Development | Solar PV | Tucson | TEP | Solon |
| **Hyder** | 26 | In development | Solar PV | Hyder | APS | SunEdison |
| **Chino Valley** | 29 | In development | Solar PV | Chino Valley | APS | SunEdison |

Note: CSP stands for concentrating solar power and PV for photovoltaics[16] Adapted from the Solar Energy Industries Association, Feb 2011[17] was 240 MW of wind energy in Arizona. There is currently one utility-scale wind farm in Arizona, the Dry Lake Wind Power Project in Navajo County. The Dry Lake Wind Power Project is situated on a combination of private, state, and Bureau of Land Management public lands. The site currently has 61 wind turbines, providing a total capacity of 127 MW. The project, which went online in 2009, was built by Oregon-based Iberdrola Renewables Inc., which also operates the project. It was financed through a power purchase agreement with SRP.

In terms of planned wind power development, there are a number of projects in progress, recently summarized in a report for the National Renewable Energy Laboratory by the Arizona Wind Working Group.[18] Currently, there are approximately 1.7 GW of wind power in either project development, permitting, or financing stages by companies, such as BP Wind Energy, Foresight Wind Energy, Iderdrola Renewables, Renergy/NZ Legacy, Sempra Energy, and Verde Resources. All of these projects are located in northern Arizona.

## Arizona Energy Prices

### Electricity

The average retail price of electricity in Arizona is relatively low compared to the rest of the United States. Figure 10 shows the average retail price for residential, commercial, and industrial electricity over time, expressed in 2009 dollars and adjusted for inflation. As can be seen, the inflation-adjusted price of energy has decreased over the past two decades until an upturn in recent years, with current average prices (all sectors) less than 10 cents/kWh. The reason for the decrease is not well understood, but it coincides with the ramp-up of energy generation from Palo Verde. This made Arizona an exporter of electricity, which may have helped to subsidize prices.

Figure 11 shows the unadjusted for inflation average price of retail electricity in Arizona compared to other states over two decades. As shown, electricity prices in Arizona were similar or greater than the national average until the last five years when the price did not trend upwards as fast as it did in California and the rest of the United States. Note that neighboring states, such as New Mexico and Nevada, as well as Texas, have substantially lower rates than Arizona, but Arizona's energy prices are lower than the national average and California.

**FIGURE 10** | Average Retail Price of Electricity in Arizona by Sector Based on 2009 Dollars (2009 cents/kWh)[19]

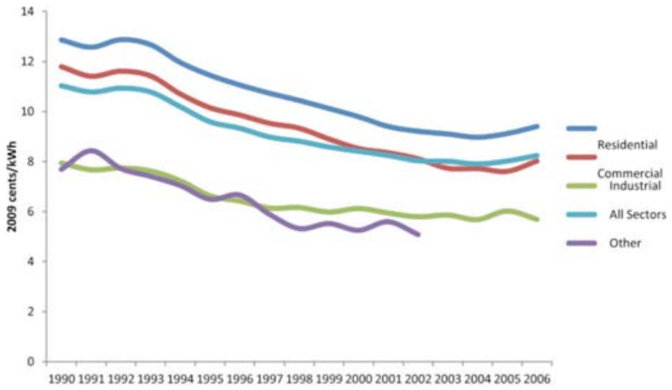
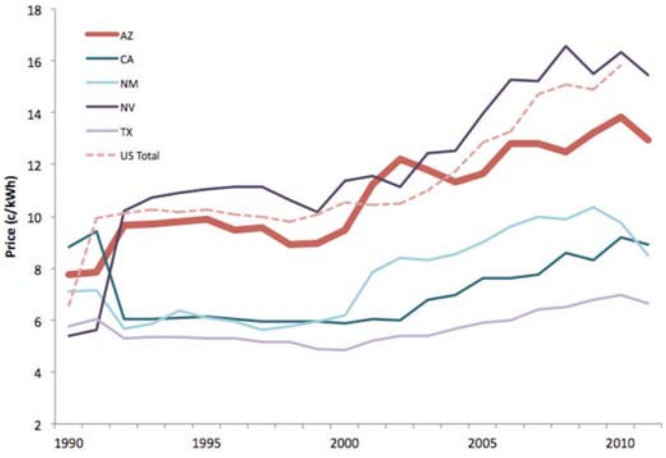


**FIGURE 11** | Comparison of Average Retail Price of Electricity for Several States[20]



Source: Adapted from "EIA Current and Historical Monthly Retail Sales, Revenues and Average Revenue per kWh by State and by Sector (From EIA-826)."

## Fuel Prices

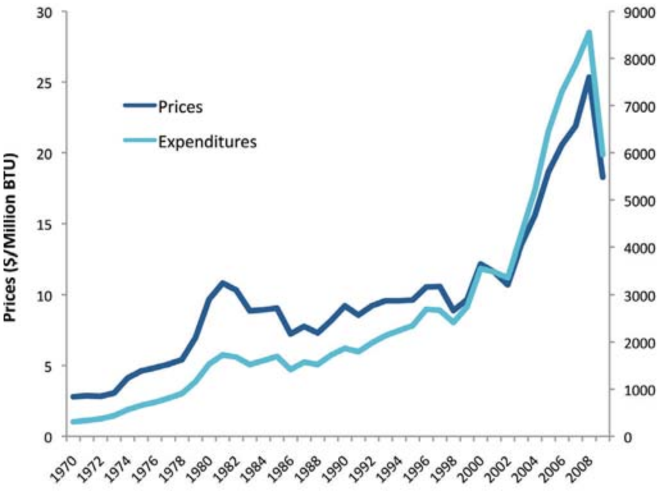
Figure 12 shows the average price and average expenditures in terms of dollars per British Thermal Unit (BTU) of motor gasoline. (See the glossary for a definition of BTUs.) There is, again, an overall upward trend in cost, with regions of slow or flat growth in the 1990s. The trend, similar to that of electricity, is that in the future the price of transportation fuels will rise.

## Renewable Energy Price

The cost of renewable energy has been steadily decreasing over the past three decades, as shown in Figure 13. The cost may be considered in terms of what experts call the levelized cost of energy (LCOE), which takes into account the cost of construction, fuel, and operating expenses over the lifetime of the facility. The LCOE for renewables is estimated based on a number of factors, such as the capacity factor (what fraction of the time the system is producing its maximum amount of electricity), the estimated lifetime of the system, and the construction cost.

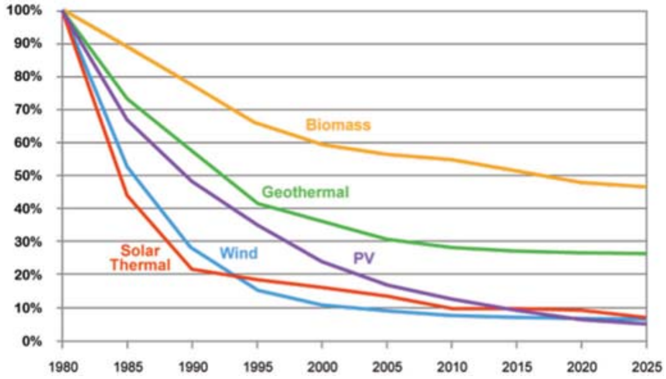
Wind energy is currently the cheapest form of renewable energy and its LCOE is almost as cheap as power produced by the current electrical grid.[21] Northern Arizona has been identified as a wind generation corridor, with a potential capacity for several GW of generation.

**FIGURE 12** | Average Motor Gasoline Price Estimates for Arizona from 1970 until the Present



Source: Based on EIA Table ET6. Transportation Sector Energy Price and Expenditure Estimates, 1970-2009, Arizona

**FIGURE 13** | Relative Decrease in Energy Prices as Percentage of 1980 Levels for Biomass, Geothermal, Solar Thermal, Wind, and PV



Source: NREL Energy Analysis Office (www.nrel.gov/analysis/docs/cost_curves_2005.ppt)

The LCOE of large-scale concentrating solar power (CSP) (or solar thermal) plants is the lowest among different forms of solar generation, and currently most of the large-scale solar projects under construction in Arizona are CSP plants. (See the glossary for the definitions of CSP and PV.) However, the cost of PV panels is currently dropping faster than any technology. If this trend is sustained, and system prices are brought below $1/W, PV will achieve grid parity, i.e., the point at which the effective consumer price of solar is the same as the consumer price of electricity from traditional sources.[22]

Figure 14 shows the main driver for this decrease in PV price, which is a reduction in manufacturing costs as manufacturers produce more panels.[23] Already, the cost of solar panels manufactured by First Solar Inc. (headquartered in Arizona) is below $1/Watt, and other PV technologies are rapidly reaching this cost. The remaining system costs include the balance of systems (BOS) costs—or all costs of the PV systems other than the panel e.g., wiring, switches, inverters, support racks—and the cost of transportation and installation of modules. As seen in Figure 14, the BOS and transportation costs are not decreasing as rapidly as the price of the solar panels themselves and would have to be reduced for PV to reach grid parity.

Due to the relatively low price of electricity in Arizona, new sources of energy have a competitive difficulty. The major utilities have introduced Green Pricing Programs in order to levelize the cost of alternative energy through price premiums for generation of wind, solar, geothermal, hydro, and biomass sources of energy.

Table 4 provides a summary of the different programs offered by different utilities within the state. The impact of such incentives on the installed cost of photovoltaic systems over the past three years is shown by data from the three major Arizona utilities (APS, SRP, and TEP) in Figure 15. As can be seen, the installed current system price is presently close to $5/W without incentives, and with incentives, it is closer to $1/W. A $1/W installed price is essentially equivalent to the cost of conventional electricity in Arizona, when averaged over the lifetime of the PV system, hence reaching grid parity in terms of bare cost of electricity. The various incentives for solar installations are provided in Tables 4 and 5.

**FIGURE 14** | Cost of PV Modules, the Balance of Systems (BOS) and Installation Costs and the System Price of PV as a Function of the Cumulative Installed Capacity

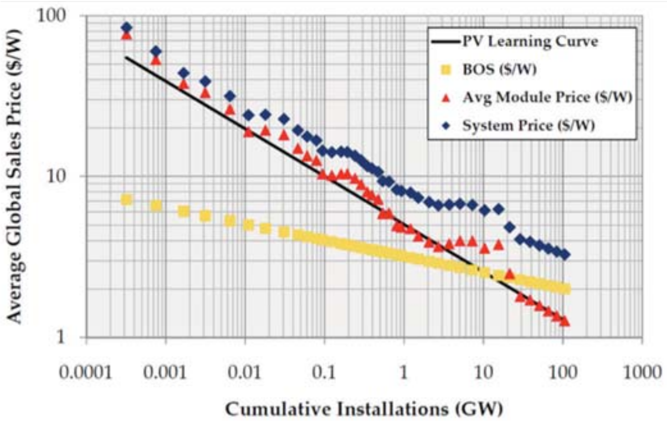


**FIGURE 15** | Initial Cost of PV Systems in Arizona Based on Utility Data for Different Size Systems Over the Past Two Years, with and Without Incentives

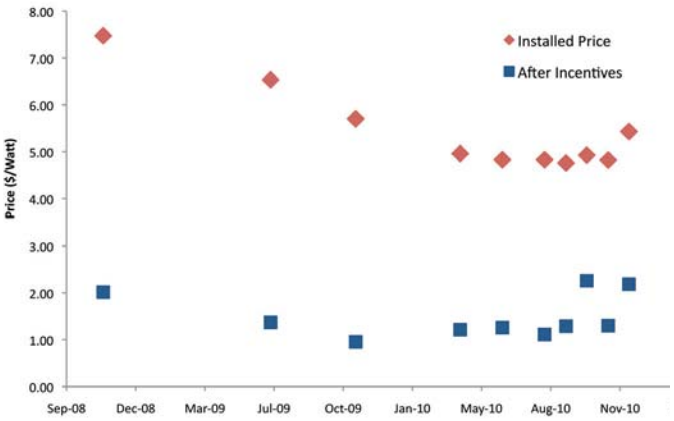


**TABLE 4** | Arizona Utility Green Pricing Programs (2010)

| State-Specific Utility Green Pricing Programs (last updated August 2010) | | | | | |
|---|---|---|---|---|---|
| **State** | **Utility Name** | **Program Name** | **Type** | **Start Date** | **Premium** |
| **AZ** | Arizona Public Service | Green Choice | Wind and Geothermal | 2007 | 0.4¢/kWh |
| **AZ** | Salt River Project | EarthWise Energy | Central PV, Wind, Landfill Gas, Small Hydro, Geothermal | 1998/2001 | 3.0¢/kWh |
| **AZ** | Tri-State Generation & Transmission: Columbus Electric Cooperative, Inc. | Renewable Resource Power Service | Wind, Hydro | 2001 | 0.8¢/kWh |
| **AZ** | Tucson Electric | GreenWatts | Landfill Gas, PV | 2000 | 10¢/kWh |
| **AZ** | UniSource Energy Services | GreenWatts | PV | 2004 | 10¢/kWh |

Source: National Renewable Energy Laboratory, Golden, Colorado
Notes: Utility green pricing programs may only be available to customers located in the utility's service territory. For additional details, please see the full green pricing products table[24]

**TABLE 5** | Summary Information on Arizona's Top Three Electric Utilities (2009)

| Arizona Solar Incentives | |
|---|---|
| **Non-Residential Solar & Wind Tax Credit (Corporate)** | |
| **Incentive Type** | Corporate Tax Credit |
| **Eligible Renewable/ Other Technologies** | Passive Solar Space Heat, Solar Water Heat, Solar Space Heat, Solar Thermal Electric, Solar Thermal Process Heat, Photovoltaics, Wind, Solar Cooling, Solar Pool Heating, Daylighting |
| **Applicable Sectors** | Commercial, Industrial, Nonprofit, Schools, Local Government, State Government, Tribal Government, Fed. Government, Agricultural, Institutional |
| **Amount** | 10% of installed cost |
| **Maximum Incentive** | $25,000 for any one building in the same year and $50,000 per business in total credits in any year |
| **Renewable Energy Production Tax Credit (Corporate)** | |
| **Incentive Type** | Corporate Tax Credit |
| **Eligible Renewable/ Other Technologies** | Solar Thermal Electric, Photovoltaics, Landfill Gas, Wind, Biomass |
| **Applicable Sectors** | Commercial<br>Wind and Biomass: $0.01/kWh, paid for 10 years |
| **Amount** | Solar: Varies by year (see below), paid for 10 years |
| **Maximum Incentive** | $2 million per year |
| **Eligible System Size** | 5 MW minimum |
| **Carryover Provisions** | Unused credit may be carried forward for 5 years |

| City of Maricopa - Solar Rebate Program | |
|---|---|
| **Incentive Type** | Local Rebate Program |
| **Eligible Renewable/ Other Technologies** | Photovoltaics |
| **Applicable Sectors** | Commercial, Residential |
| **Amount** | $0.60 per watt DC |
| **Maximum Incentive** | $3,000 |
| **Eligible System Size** | Residential: 1 kW up to 10 kW<br>Commercial: 1 kW up to 20 kW |

| Non-Residential Solar & Wind Tax Credit (Personal) | |
|---|---|
| **Incentive Type** | Personal Tax Credit |
| **Eligible Renewable/ Other Technologies** | Passive Solar Space Heat, Solar Water Heat, Solar Space Heat, Solar Thermal Electric, Solar Thermal Process Heat, Photovoltaics, Wind, Solar Cooling, Solar Pool Heating, Daylighting |
| **Applicable Sectors** | Commercial, Industrial, Nonprofit, Schools, Local Government, State Government, Tribal Government, Fed. Government, Agricultural, Institutional |
| **Amount** | 10% of installed cost |
| **Maximum Incentive** | $25,000 for any one building in the same year and $50,000 per business in total credits in any year |
| **Eligible System Size** | No size restrictions specified |
| **Carryover Provisions** | Unused credits may be carried forward for up to 5 consecutive taxable years |

| Renewable Energy Production Tax Credit (Personal) | |
|---|---|
| **Incentive Type** | Personal Tax Credit |
| **Eligible Renewable/ Other Technologies** | Solar Thermal Electric, Photovoltaics, Landfill Gas, Wind, Biomass |
| **Applicable Sectors** | Commercial |
| **Amount** | Wind and Biomass: $0.01/kWh, paid for 10 years<br>Solar: Varies by year (see below), paid for 10 years |
| **Maximum Incentive** | $2 million per year |
| **Eligible System Size** | 5 MW minimum |
| **Carryover Provisions** | Unused credit may be carried forward for 5 years |

| Residential Solar and Wind Energy Systems Tax Credit | |
|---|---|
| **Incentive Type** | Personal Tax Credit |
| **Eligible Renewable/ Other Technologies** | Passive Solar Space Heat, Solar Water Heat, Solar Space Heat, Photovoltaics, Wind, Solar Ovens, Solar Cooling, Solar Pool Heating, Daylighting |
| **Applicable Sectors** | Residential |
| **Amount** | 25% |
| **Maximum Incentive** | $1,000 maximum credit per residence, regardless of number of energy devices installed |
| **Eligible System Size** | Not specified |
| **Equipment Requirements** | System must be new and in compliance with all applicable performance and safety standards; must carry a minimum 2-yr warranty on collectors, heat exchangers, and storage units; other equipment and installation must carry a minimum 1-yr warranty. |
| **Carryover Provisions** | Excess credit may be carried forward for up to five years |

| **Solar and Wind Equipment Sales Tax Exemption** | |
|---|---|
| **Incentive Type** | Sales Tax Incentive |
| **Eligible Renewable/ Other Technologies** | Passive Solar Space Heat, Solar Water Heat, Solar Space Heat, Solar Thermal Electric, Photovoltaics, Wind, Solar Pool Heating, Daylighting |
| **Applicable Sectors** | Commercial, Residential, General Public/Consumer |
| **Amount** | 100% of sales tax on eligible equipment |
| **Maximum Incentive** | No maximum |

## Utility Rebate Program

- APS - Energy Efficiency Solutions for Business
- APS - Multifamily Energy Efficiency Program
- APS - Renewable Energy Incentive Program
- APS - Residential Energy Efficient Rebate Program
- Electric District No. 3 - Solar Rebate Program
- Mohave Electric Cooperative - Heat Pump Rebate Program
- Mohave Electric Cooperative - Renewable Energy Incentive Program
- Southwest Gas Corporation - Combined Heat and Power Program
- Southwest Gas Corporation - Commercial High-Efficiency Equipment Rebate Program
- Southwest Gas Corporation - Large Commercial Energy-Efficiency Boiler Program
- Southwest Gas Corporation - Residential High-Efficiency Equipment Rebate Program
- SRP - EarthWise Solar Energy Incentive Program
- SRP - PowerWise Business Solutions Energy Efficiency Rebate Program
- SRP - Residential Energy Efficiency Rebate Program
- Sulphur Springs Valley EC - Residential Energy Efficiency Rebate
- Sulphur Springs Valley EC - SunWatts Rebate Program
- TEP - Commercial Energy Efficiency Rebate Program
- TEP - Renewable Energy Credit Purchase Program
- TEP - Residential Energy Efficiency Rebate Program
- TEP - Small Business Energy Efficiency Rebate Program
- Trico Electric Cooperative - SunWatts Incentive Program
- UES - Commercial Energy Efficiency Rebate Program
- UES - Commercial Energy Efficiency Rebate Program (Gas Customers)
- UES - Renewable Energy Credit Purchase Program
- UES - Residential Efficiency Program

## Notes

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# Chapter 4: **Energy and the Economy**

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## Overview

- Economic growth and energy use in Arizona are closely related to population growth. Population growth in the state has been driven by migration, which is expected to continue (but at a slower rate) over the coming two decades.
- Industrial users are not significant consumers of energy or electricity in Arizona. More than 85% of all energy consumption in Arizona is by non-industrial sectors. The transportation sector accounts for about one-third, and residential and commercial sectors account for about one-half, of total primary energy use.
- In Arizona, the transportation sector's share in total energy consumption is higher than the national average. Almost all demand for petroleum products comes from the state's transportation sector. The increasing price levels and volatility of crude oil will continue to affect transportation patterns and demand for petroleum products across the United States. The resulting impact on Arizona's economy may be more pronounced given the transportation industry's above average share of the state's total energy consumption.
- Arizona's main domestic fossil fuel resource is coal, which is abundant and cheaper than oil and natural gas. Nearly all coal consumed in the state is used as fuel for Arizona's coal-fired power plants. Due to Arizona's domestic supply advantage, its coal prices are lower than the national average.
- Natural gas consumption in the state has grown significantly over the years due to an increase in natural gas-fueled power generation. Natural gas prices for electric power producers are very competitive in Arizona. However, average natural gas prices paid by the commercial, industrial, and residential users are above national averages. This has been attributed to a decline in average consumption levels while fixed costs (see glossary) have stayed the same.
- Commercial and residential sectors account for 85% of all electricity consumption in Arizona, with the rest used in the industrial sector. The relative share of residential sector electricity consumption in the state is higher than the national average.
- Electricity prices to all end-use sectors are lower in Arizona than the U.S. average and than neighboring states.
- A large portion of commercial and residential sector electricity use is by buildings. Energy-efficient practices and technologies to moderate energy use in buildings should be encouraged. Arizona is also one the few states without a uniform statewide energy building code, though many cities have adopted their own codes.

# Part I

## Arizona's Energy Industry, Energy Consumption and Prices

In 2009, the energy industry's contribution to the Arizona economy was estimated at $10 billion, representing about 4% of the state's gross domestic product (GDP) of nearly $250 billion.[1] According to the Bureau of Labor Statistics and industry sources, Arizona's energy industry created employment for 18,000 to 20,000 people (2008-2009).[2] For the same year, the state's total energy expenditures (dollars spent on energy by end-users) were estimated at $17.6 billion. The majority of energy dollars spent by Arizonans went towards petroleum products ($9.3 billion), followed by electricity ($5 billion), natural gas ($2.3 billion), and coal ($754 million), with the rest on fuel for nuclear energy (uranium) and other energy resources (like biomass).[3]

In Arizona, the transportation sector is the largest consumer of energy. It is followed by the residential, commercial, and finally, the industrial sector. In the United States overall, the industrial sector's use of energy is the highest. Arizona's energy consumption profile is similar to its neighbors. For instance, California and Utah also expend the majority of their energy use on transportation. However, these states spend more energy in the non-residential (commercial and industrial) sectors of the economy than Arizona. In fact, among its neighbors (and regional competitors), Arizona is the only state where residential sector consumption trumps commercial and industrial uses. Throughout this chapter, tables are provided comparing Arizona and neighboring states to help the reader evaluate Arizona's energy consumption patterns in a regional context.

**FIGURE 1** | Total Energy Consumption (all sources) in Arizona by End-Use Sector, Compared to the United States and Neighboring States, 2009 (billion Btu)

| 2009 | Total Energy Consumption (Billion Btu) | | | | | Total Energy Consumption—Sector Shares (%) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Transport | Commercial | Industrial | Residential | Total | Transport | Commercial | Industrial | Residential |
| **Arizona** | 493,623 | 352,104 | 207,760 | 400,827 | **1,454,314** | 34% | 24% | 14% | 28% |
| **California** | 3,129,539 | 1,578,660 | 1,769,997 | 1,527,311 | **8,005,508** | 39% | 20% | 22% | 19% |
| **Colorado** | 417,897 | 291,763 | 409,873 | 332,692 | **1,452,225** | 29% | 20% | 28% | 23% |
| **Nevada** | 215,111 | 128,634 | 191,129 | 172,704 | **707,579** | 30% | 18% | 27% | 24% |
| **New Mexico** | 202,385 | 122,395 | 227,361 | 117,954 | **670,095** | 30% | 18% | 34% | 18% |
| **Utah** | 235,585 | 152,255 | 201,518 | 165,122 | **754,479** | 31% | 20% | 27% | 22% |
| **United States** | 26,965,634 | 17,895,632 | 28,559,038 | 21,026,602 | **94,446,906** | 29% | 19% | 30% | 22% |

Source: The Department of Energy's Energy Information Administration (EIA), State Energy Data System (SEDS), http://www.eia.gov/emeu/states/_seds_updates.html, link active as of July 18, 2011

## Primary Energy

Arizona's main domestic fossil fuel resource is coal. It is mostly used as fuel for power plants in the region and remains the dominant fuel for Arizona's electric power generation, as well as a reliable and cheap source of energy. There is an abundant supply of coal in Arizona, in nearby states like New Mexico, and in the United States overall.[4] This supply advantage means that coal prices in Arizona have generally remained lower than the national average and competitive over the years with the prices in surrounding states. The state's 2009 annual expenditures on coal were reported as $754 million. In 2008, the National Mining Association reported that direct and indirect employment by coal mining in Arizona accounted for 4,490 jobs and a combined payroll of $170 million.[5] (See Chapters for more information on coal mining in Arizona.)

**FIGURE 2** | Average Annual Prices for Coal to the Electric Power Sector in Arizona, Compared to the United States and Neighboring States, 2000-2009 ($ per million Btu)

| | Average Price to the Electric Power Sector | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **State** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
| **Arizona** | **$1.2** | **$1.2** | **$1.2** | **$1.3** | **$1.3** | **$1.4** | **$1.4** | **$1.6** | **$1.7** | **$1.8** |
| **California** | $1.4 | $1.1 | $1.9 | $1.8 | $1.9 | $1.4 | $1.7 | $1.9 | $2.2 | $2.2 |
| **Colorado** | $0.9 | $0.9 | $1.0 | $1.0 | $1.0 | $1.1 | $1.3 | $1.3 | $1.4 | $1.6 |
| **Nevada** | $1.4 | $1.5 | $1.5 | $1.4 | $1.5 | $1.5 | $1.6 | $1.8 | $2.0 | $1.9 |
| **New Mexico** | $1.3 | $1.3 | $1.3 | $1.4 | $1.4 | $1.5 | $1.7 | $1.9 | $2.2 | $2.2 |
| **Utah** | $1.0 | $1.1 | $1.0 | $1.0 | $1.1 | $1.1 | $1.2 | $1.4 | $1.4 | $1.6 |
| **U.S. Average** | **$1.2** | **$1.2** | **$1.3** | **$1.3** | **$1.4** | **$1.5** | **$1.7** | **$1.8** | **$2.1** | **$2.2** |

Note: Industrial end-use sector prices have been omitted from this figure, since they represent only 2% of total coal consumption in Arizona. There is no commercial, residential or transportation consumption of coal in the state
Source: EIA, State Energy Data System (SEDS), http://www.eia.gov/emeu/states/_seds_updates.html, as of July 18, 2011

One primary concern with coal as an energy source is its associated greenhouse gas emissions. Several technologies (like carbon capture and storage, see the glossary) are in development to mitigate this adverse environmental impact, as well as plans for more stringent pollution controls on Arizona's largest coal-fired plant, the Navajo Generating Station. (See Chapter 7.) However, these technologies will also make coal more expensive from an economic standpoint than it is today.

In contrast to Arizona's abundant coal, Arizona has to import almost all of its petroleum products via pipelines. Petroleum products are of vital importance to the state's transportation sector. According to 2009 data, transportation demand accounts for 88% of total petroleum products consumption in Arizona (73% of which is motor gasoline). Past experience[6] has shown that the state's transportation sector, which is the largest energy-consuming sector in Arizona, is vulnerable to supply disruptions (see Chapter 9).

Prior to the 2008 recession, Arizona's total expenditures for petroleum products had exceeded $10 billion per year, peaking at $14 billion in 2008 (consistent with the peaking global crude oil prices at the time). Since then, both consumption and prices, and therefore total expenditures, have somewhat moderated. According to the U.S. Department of Energy's Energy Information System (EIA), the state's 2009 expenditures for petroleum products amounted to $9.3 billion, of which, $6 billion were direct expenditures on motor gasoline.[7]

Average prices paid by Arizonans for petroleum products used in transportation (such as gasoline and jet fuel) have closely tracked the U.S. average for the past decade. Industrial end-users, which constitute most of the remaining non-transportation demand in Arizona (10% of total), pay prices that are lower than national averages and are generally competitive with Arizona's neighbors' prices.

**FIGURE 3** | Average Annual Prices for Petroleum Products in Arizona for Select End-Use Sectors and Motor Gasoline Prices, Compared to the United States and Neighboring States, 2000-2009 ($ per million Btu)

| Average Price to the Transportation Sector | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **State** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
| **Arizona** | **$11.4** | **$10.7** | **$10.0** | **$12.3** | **$14.8** | **$18.2** | **$20.0** | **$21.2** | **$25.3** | **$17.6** |
| **California** | $10.8 | $10.5 | $9.6 | $11.7 | $14.2 | $16.9 | $19.1 | $20.4 | $25.0 | $17.9 |
| **Colorado** | $11.5 | $11.4 | $10.5 | $11.8 | $13.6 | $17.3 | $19.6 | $21.4 | $25.5 | $17.3 |
| **New Mexico** | $11.2 | $10.6 | $10.2 | $11.7 | $13.9 | $18.0 | $20.3 | $22.1 | $26.5 | $18.5 |
| **Nevada** | $11.7 | $10.9 | $10.1 | $12.0 | $14.9 | $17.8 | $19.9 | $21.2 | $25.7 | $18.2 |
| **Utah** | $11.1 | $10.5 | $9.9 | $11.5 | $13.6 | $17.1 | $19.4 | $21.0 | $26.1 | $18.0 |
| **U.S. Average** | **$10.7** | **$10.2** | **$9.6** | **$11.2** | **$13.4** | **$16.9** | **$19.1** | **$20.6** | **$25.2** | **$17.5** |

| Motor Gasoline Average Price | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **State** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
| **Arizona** | **$12.2** | **$11.6** | **$10.7** | **$13.5** | **$15.6** | **$18.6** | **$20.6** | **$21.9** | **$25.3** | **$18.3** |
| **California** | $12.5 | $12.2 | $11.2 | $13.8 | $16.2 | $18.9 | $21.3 | $23.0 | $26.4 | $20.1 |
| **Colorado** | $12.4 | $12.4 | $11.4 | $12.7 | $14.9 | $18.2 | $20.6 | $22.6 | $25.5 | $18.2 |
| **New Mexico** | $12.0 | $11.5 | $10.9 | $12.4 | $14.7 | $18.3 | $20.8 | $22.8 | $25.7 | $18.7 |
| **Nevada** | $13.5 | $12.8 | $11.7 | $13.9 | $16.6 | $19.1 | $21.4 | $22.9 | $26.2 | $19.6 |
| **Utah** | $12.3 | $11.7 | $11.0 | $12.9 | $15.0 | $18.0 | $20.3 | $22.2 | $25.8 | $18.8 |
| **U.S. Average** | **$11.9** | **$11.3** | **$10.7** | **$12.3** | **$14.7** | **$17.9** | **$20.3** | **$22.0** | **$25.5** | **$18.5** |

| Average Price to Industrial End-Users | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **State** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
| **Arizona** | **$6.5** | **$6.7** | **$6.2** | **$7.5** | **$8.7** | **$11.3** | **$13.1** | **$13.8** | **$18.7** | **$12.7** |
| **California** | $6.9 | $7.0 | $7.0 | $8.7 | $10.3 | $12.6 | $14.8 | $15.2 | $19.6 | $15.2 |
| **Colorado** | $6.9 | $8.0 | $7.8 | $7.4 | $9.5 | $12.8 | $15.7 | $15.7 | $20.9 | $14.6 |
| **New Mexico** | $6.5 | $6.8 | $5.7 | $6.7 | $8.6 | $11.2 | $12.5 | $13.8 | $18.0 | $11.9 |
| **Nevada** | $7.4 | $7.3 | $6.7 | $7.0 | $9.2 | $11.6 | $13.2 | $15.1 | $19.2 | $13.1 |
| **Utah** | $6.2 | $7.1 | $7.3 | $6.7 | $8.6 | $12.5 | $15.4 | $17.1 | $19.9 | $13.3 |
| **U.S. Average** | **$7.3** | **$6.8** | **$6.5** | **$7.8** | **$9.4** | **$11.9** | **$14.3** | **$15.8** | **$20.3** | **$13.7** |

Note: Commercial and residential end-use sector prices have been omitted from this figure, since they represent less than 2% of total petroleum products consumption in Arizona.
Source: EIA, State Energy Data System (SEDS), http://www.eia.gov/emeu/states/_seds_updates.html, as of July 18, 2011

Much like the situation with crude oil, Arizona's domestic production of natural gas is only a tiny fraction of its demand (less than 0.5% of total consumption in 2008,)[8] and nearly all of the state's natural gas supply is brought in via pipelines. The electric power generation sector is the largest consumer of natural gas in Arizona by a wide margin, representing more than 70% of total consumption (in 2009). Commercial and residential users account for another 18% of total (about 9% each), followed by industrial and transportation sectors. According to the EIA, about four out of 10 Arizona households use natural gas for space heating purposes.[9] Arizona's total end-use sector expenditures for natural gas were about $2.3 billion in 2009, down from the 2005-2008 average of over $3.1 billion.

Average natural gas prices in Arizona have been very favorable for the electric power sector. They have remained below the national average for the past decade and more competitive than most of Arizona's neighboring states. In contrast, the average natural gas prices paid by residential, commercial, and industrial end-users have exceeded U.S. averages and Arizona's neighbors. For instance, in 2009, the average Arizona residential customer paid nearly twice as much as the average customer in California, New Mexico, Colorado, or Utah, and residential sector prices were almost 50% higher than the national average. Industrial and commercial sector end-users in neighboring states paid, on average, 20% to 30% less for natural gas than Arizona's commercial end users (with the exception of Nevada). Further, the U.S. average price for natural gas for commercial and industrial end-users was also about 23% cheaper than those in Arizona (see Figure 4). Industry representatives have suggested that one of the main reasons for higher than average natural gas prices in Arizona is the decline in average consumption by end-users, which resulted in higher rates to cover the fixed costs of existing natural gas distribution infrastructure.[10]

Two other important primary energy sources for Arizona are hydro (as running water or stored energy in dams) and solar energy. These energy sources are mainly converted into electricity and are therefore discussed in the following section on electricity.

**FIGURE 4** | Average Annual Natural Gas End-Use Prices in Arizona, Compared to the United States and Neighboring States, 2000-2009 ($ per million Btu)

| | All Sectors Average Price | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **State** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
| **Arizona** | **$6.0** | **$6.2** | **$5.5** | **$6.4** | **$6.8** | **$8.8** | **$8.1** | **$8.4** | **$9.7** | **$6.4** |
| **California** | $6.5 | $8.8 | $5.1 | $7.0 | $7.6 | $9.6 | $8.8 | $8.7 | $10.1 | $6.4 |
| **Colorado** | $5.2 | $6.7 | $4.6 | $5.3 | $7.0 | $8.7 | $9.2 | $6.9 | $8.5 | $6.6 |
| **New Mexico** | $4.9 | $5.6 | $4.6 | $6.5 | $7.6 | $9.1 | $8.9 | $8.4 | $9.6 | $6.0 |
| **Nevada** | $5.1 | $8.1 | $5.9 | $6.2 | $6.8 | $8.4 | $8.6 | $8.1 | $9.1 | $7.2 |
| **Utah** | $4.9 | $6.4 | $5.1 | $5.9 | $6.8 | $8.2 | $8.8 | $7.2 | $7.7 | $6.7 |
| **U.S. Average** | **$5.6** | **$6.9** | **$5.3** | **$7.1** | **$7.9** | **$9.9** | **$9.6** | **$9.3** | **$10.8** | **$7.7** |

**Average Price to the Electric Power Sector**

| State | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Arizona** | **$4.8** | **$4.6** | **$3.2** | **$5.1** | **$5.7** | **$8.0** | **$6.3** | **$6.7** | **$8.4** | **$4.1** |
| **California** | $5.8 | $9.3 | $3.7 | $5.4 | $5.9 | $7.9 | $6.5 | $6.5 | $8.0 | $4.3 |
| **Colorado** | $4.0 | $3.8 | $2.5 | $4.3 | $5.4 | $7.2 | $6.0 | $4.2 | $6.8 | $4.1 |
| **New Mexico** | $3.9 | $4.2 | $3.0 | $5.2 | $5.8 | $8.0 | $6.4 | $6.1 | $8.0 | $4.0 |
| **Nevada** | $4.7 | $8.0 | $4.4 | $5.2 | $5.6 | $7.2 | $6.6 | $6.1 | $7.9 | $5.3 |
| **Utah** | $3.8 | $4.6 | $4.4 | $4.6 | $5.2 | $6.9 | $6.2 | $5.6 | $7.6 | $4.5 |
| **U.S. Average** | **$4.5** | **$5.2** | **$3.6** | **$5.4** | **$6.0** | **$8.3** | **$6.9** | **$7.1** | **$9.0** | **$4.8** |

**Average Price to Residential End-Users**

| State | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Arizona** | **$9.3** | **$10.4** | **$11.9** | **$11.2** | **$12.0** | **$13.2** | **$16.0** | **$16.8** | **$17.2** | **$17.3** |
| **California** | $8.6 | $10.3 | $7.0 | $9.0 | $9.7 | $11.6 | $11.5 | $11.4 | $12.4 | $9.2 |
| **Colorado** | $6.2 | $8.3 | $5.6 | $6.5 | $8.4 | $10.0 | $10.1 | $8.7 | $9.6 | $8.7 |
| **New Mexico** | $6.3 | $7.9 | $6.3 | $8.2 | $9.3 | $10.9 | $12.4 | $11.6 | $12.0 | $9.3 |
| **Nevada** | $6.4 | $8.8 | $9.4 | $8.7 | $9.7 | $11.9 | $13.8 | $13.5 | $12.9 | $12.8 |
| **Utah** | $5.9 | $7.7 | $6.0 | $6.9 | $7.7 | $9.2 | $10.4 | $8.9 | $8.5 | $8.6 |
| **U.S. Average** | **$7.6** | **$9.4** | **$7.7** | **$9.2** | **$10.5** | **$12.3** | **$13.3** | **$12.7** | **$13.5** | **$11.8** |

**Average Price to Commercial End-Users**

| State | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Arizona** | **$6.6** | **$7.8** | **$8.3** | **$7.7** | **$8.5** | **$9.6** | **$11.9** | **$12.5** | **$12.7** | **$11.9** |
| **California** | $7.9 | $9.2 | $6.0 | $8.0 | $8.5 | $10.4 | $10.2 | $10.1 | $11.4 | $7.5 |
| **Colorado** | $5.4 | $7.7 | $4.8 | $5.9 | $7.4 | $9.1 | $9.3 | $8.0 | $8.9 | $7.5 |
| **New Mexico** | $5.1 | $6.2 | $4.9 | $6.7 | $7.8 | $9.1 | $10.4 | $9.7 | $10.2 | $7.3 |
| **Nevada** | $5.4 | $7.8 | $7.5 | $7.0 | $8.1 | $10.0 | $11.7 | $11.5 | $10.8 | $10.6 |
| **Utah** | $4.7 | $6.4 | $4.9 | $5.6 | $6.4 | $7.8 | $9.1 | $7.6 | $7.3 | $7.2 |
| **U.S. Average** | **$6.6** | **$8.3** | **$6.5** | **$8.1** | **$9.2** | **$11.0** | **$11.6** | **$11.0** | **$11.9** | **$9.7** |

**Average Price to Industrial End-Users**

| State | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Arizona** | **$4.7** | **$6.2** | **$6.4** | **$6.5** | **$6.8** | **$8.3** | **$9.7** | **$10.2** | **$10.2** | **$8.0** |
| **California** | $5.5 | $6.5 | $4.8 | $7.0 | $7.7 | $9.6 | $9.1 | $9.0 | $10.5 | $6.4 |
| **Colorado** | $4.7 | $6.6 | $4.8 | $4.4 | $6.5 | $8.4 | $11.2 | $7.1 | $8.6 | $6.5 |
| **New Mexico** | $4.5 | $4.2 | $4.0 | $5.4 | $6.5 | $8.4 | $8.7 | $8.3 | $10.1 | $5.3 |
| **Nevada** | $5.0 | $6.8 | $7.4 | $8.4 | $8.3 | $9.4 | $11.6 | $11.2 | $10.7 | $10.9 |
| **Utah** | $3.7 | $5.0 | $3.7 | $4.7 | $5.6 | $7.0 | $7.6 | $6.0 | $6.8 | $5.4 |
| **U.S. Average** | **$4.6** | **$5.7** | **$4.5** | **$6.2** | **$7.0** | **$9.1** | **$8.8** | **$8.3** | **$10.1** | **$6.5** |

Source: EIA, State Energy Data System (SEDS), http://www.eia.gov/emeu/states/_seds_updates.html, as of July 18, 2011

Prior to the 1970s, the majority of Arizona's electricity needs were met through a mix of hydroelectric and natural gas resources. The legacy of this period bears two of the nation's largest hydroelectric development projects: the 2,080 MW Hoover Dam (completed in 1937) and the 1,312 MW Glen Canyon Dam (completed in 1964). The Hoover and Glen Canyon dams are the two largest man-made reservoirs in the United States.[11] Today, the hydroelectric potential in and around Arizona has largely been developed, and while these plants still provide a large amount of electricity to consumers, their relative share in the state's electric power supply mix has declined, accounting for 6% of total in 2009.

The 1970s saw a surge in construction of coal-fired power generation capacity in Arizona. Today, coal-fired plants supply 36% of Arizona's electricity. Construction of the nation's largest nuclear power plant, Palo Verde, started in 1976, and the last of Palo Verde's three reactors was completed in 1988. In 2009, Palo Verde's output accounted for over a quarter of total electricity produced in Arizona.[12] Recently, the federal Nuclear Regulatory Commission extended the operating license for the plant through 2047 (see Chapter 3).[13] This extension, coupled with Arizona's abundant coal resources, implies that nuclear energy and coal-fired facilities will continue to play a large role in meeting Arizona's electricity supply for the foreseeable future.

In addition to the important role played by coal and nuclear resources, natural gas became a third source of electricity generation in the state. Over the past 20 years, natural gas became the fuel of choice for new power plants not only in Arizona but across the United States. The relatively lower cost of natural gas (compared to oil), its high energy content, and its lower greenhouse gas emissions (compared to coal) has made it a favorable fossil fuel. Moreover, the scalability of natural gas-fueled turbine technology, relatively low capital costs, and short construction lead times have also spurred investment. Between 1990 and 2009, the natural gas-fueled power generating capacity in Arizona nearly quadrupled. In 2009, natural gas-fueled power plants supplied about 31% of the electricity consumed in Arizona.[14]

This trend toward using natural gas for electrical power generation is expected to continue: SRP commissioned the construction of Arizona's latest natural gas-fired power plant in 2008, which was recently completed.[15] Since Arizona relies on pipelines for the supply of natural gas into the state, the development of new natural gas-fueled plants is dependent on spare pipeline capacity. According to the Federal Energy Regulatory Commission (see glossary), Arizona will not face a shortage of such pipeline capacity in the near future. On the other hand, the state does not have any natural gas storage, which is a limitation during high demand ("peak") periods.[16, 17]

In November 2006, the Arizona Corporation Commission (see glossary) adopted a revised renewable energy standard that requires investor-owned electric utilities to source at least 15% of their energy supplies from renewable resources by 2025, with the added requirement that 30% of that amount be from distributed generation[18] facilities, starting in 2012. (See Chapter 10.)[19] While Arizona has yet to exploit its solar potential on a large scale (and make it a sizeable contributor to the energy supply), it still ranks fourth in the United States in terms of installed solar power capacity (behind California, New Jersey, and Colorado).[20] The state added a record amount of solar power in 2010, and dozens of projects are proposed and under development by the state's largest utilities and independent power producers (see Chapter 3).[21, 22]

In Arizona, the two largest end-user sectors of electricity are the residential and commercial sectors. In 2009, the residential sector consumption represented 45% of total electricity used in the state, and the commercial sector consumption another 40%. Industrial sector consumption makes up the remaining 15%.

The distribution of electricity consumption between residential and consumer sectors is more balanced across the United States and among Arizona's neighboring states. For instance, the residential and commercial sectors, on average, consume 38% and 36% of total electricity in the United States, respectively and the industrial sector consumes 26% of the total. Among Arizona's neighbors, the commercial and residential sector consumption shares are generally lower, while the share of industrial sector consumption of electricity is generally higher. California somewhat resembles Arizona with its low industrial sector electricity consumption (18% of total), though, in California, the commercial sector is the largest end-user of electricity (47% of total). (See Figure 5.)

**FIGURE 5** | Electricity Consumption Arizona by End-Use Sector, Compared to the United States and Neighboring States, 2009 (Billion Btu)

| 2009 | Total Electricity Consumption by End-Use Sectors (Billion Btu) | | | | | Total Energy Consumption—Sector Shares (%) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Transport | Commercial | Industrial | Residential | Total | Transport | Commercial | Industrial | Residential |
| **Arizona** | - | 100,264 | 38,216 | 112,073 | **250,553** | 0.0% | 40% | 15% | 45% |
| **California** | 2,881 | 413,212 | 163,214 | 306,393 | **885,699** | 0.3% | 47% | 18% | 35% |
| **Colorado** | 149 | 68,269 | 46,305 | 59,412 | **174,135** | - | 39% | 27% | 34% |
| **Nevada** | 28 | 30,538 | 45,874 | 40,535 | **116,976** | 0.0% | 26% | 39% | 35% |
| **New Mexico** | - | 29,801 | 21,868 | 22,191 | **73,860** | 0.0% | 40% | 30% | 30% |
| **Utah** | 110 | 34,923 | 29,322 | 29,771 | **94,126** | - | 37% | 31% | 32% |
| **United States** | 26,547 | 4,460,057 | 3,130,312 | 4,655,587 | **12,272,503** | 0.2% | 36% | 26% | 38% |

Source: EIA, State Energy Data System (SEDS), http://www.eia.gov/emeu/states/_seds_updates.html, as of July 18, 2011

Electricity prices for end-users have been rising in Arizona but at a slower rate than the rest of the United States. Electricity prices in Arizona are also lower than the U.S. average, and they are generally competitive with prices in the neighboring states. Recent prices indicate that, in particular, Colorado, New Mexico, and Utah have lower electricity prices (across all sectors) than Arizona, whereas California, Nevada, and the rest of the United States tend to have higher prices. This price difference is due to the underlying (primary) energy resource mix used for electric power generation, where a larger share of coal used for power generation tends to reduce end-use electricity prices because coal is much cheaper than natural gas, while a growing reliance on natural gas for power generation increases prices (a trend more prominent in Arizona and California than the other states in the region).

More than three-quarters of Arizona's total power generation capacity (i.e., the total capacity of all power plants put together) is controlled by utilities. Independent power producers own the remainder. According to the EIA, in 2009, several dozen utilities operated in Arizona, some of which served solely industrial or irrigation customers. The top three utilities—the Arizona Public Service Company (APS), the Salt River Project (SRP),[23] and Tucson Electric Power (TEP)—controlled half of the power generating capacity in the state. These utilities further accounted for 70% of all power generated and 87% of all retail electricity sales to Arizona's end-use sectors in 2009. Residential users represent nearly 90% of all utility customers and roughly half of utility revenues. Figure 7 provides summary indicators for these three utilities for 2009. (See Chapter 3 for more on Arizona's electric utilities.)

**FIGURE 6** | Average Annual End-Use Electricity Prices in Arizona, Compared to the United States and Neighboring States, 2000-2009 ($ per million Btu)

**All Sectors Average Price**

| State | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Arizona** | **$21.2** | **$21.3** | **$21.1** | **$21.5** | **$21.8** | **$22.8** | **$24.1** | **$25.0** | **$26.7** | **$28.0** |
| California | $27.8 | $32.9 | $35.8 | $34.6 | $33.3 | $34.2 | $37.7 | $37.6 | $36.7 | $38.9 |
| Colorado | $17.3 | $17.7 | $17.6 | $19.9 | $20.4 | $22.5 | $22.4 | $22.8 | $25.3 | $24.4 |
| New Mexico | $19.4 | $21.1 | $19.9 | $20.7 | $21.0 | $22.1 | $21.7 | $22.0 | $24.7 | $24.0 |
| Nevada | $18.1 | $23.1 | $24.8 | $24.4 | $25.2 | $26.5 | $28.3 | $29.4 | $29.1 | $30.5 |
| Utah | $14.3 | $15.4 | $15.9 | $15.9 | $16.8 | $17.4 | $17.6 | $18.9 | $19.1 | $19.9 |
| **U.S. Average** | **$20.0** | **$21.4** | **$21.2** | **$21.9** | **$22.4** | **$23.9** | **$26.2** | **$26.8** | **$28.6** | **$28.9** |

**Average Price to Residential End-Users**

| State | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Arizona** | **$24.7** | **$24.3** | **$24.2** | **$24.5** | **$24.8** | **$26.0** | **$27.5** | **$28.3** | **$30.1** | **$31.4** |
| California | $31.9 | $35.4 | $37.0 | $35.8 | $35.8 | $36.7 | $42.0 | $42.3 | $40.5 | $43.2 |
| Colorado | $21.4 | $21.9 | $21.6 | $23.9 | $24.7 | $26.6 | $26.4 | $27.1 | $29.7 | $29.3 |
| New Mexico | $24.5 | $25.6 | $24.9 | $25.5 | $25.4 | $26.8 | $26.5 | $26.7 | $29.3 | $29.4 |
| Nevada | $21.3 | $26.6 | $27.6 | $26.4 | $28.4 | $29.9 | $32.5 | $34.6 | $35.0 | $37.7 |
| Utah | $18.4 | $19.7 | $19.9 | $20.2 | $21.1 | $22.0 | $22.3 | $23.9 | $24.2 | $24.9 |
| **U.S. Average** | **$24.1** | **$25.2** | **$24.7** | **$25.6** | **$26.2** | **$27.7** | **$30.5** | **$31.2** | **$33.0** | **$33.7** |

**Average Price to Commercial End-Users**

| State | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Arizona** | **$20.5** | **$20.8** | **$20.5** | **$20.8** | **$21.3** | **$21.7** | **$23.5** | **$24.2** | **$26.2** | **$27.4** |
| California | $28.9 | $34.5 | $38.0 | $36.6 | $34.1 | $34.9 | $37.8 | $37.6 | $36.8 | $39.3 |
| Colorado | $16.6 | $17.0 | $16.8 | $19.4 | $20.2 | $22.3 | $22.0 | $22.3 | $25.1 | $23.9 |
| New Mexico | $19.8 | $21.3 | $20.6 | $21.6 | $21.7 | $22.9 | $22.3 | $22.5 | $25.4 | $24.6 |
| Nevada | $19.3 | $24.2 | $26.0 | $25.7 | $26.6 | $27.8 | $29.7 | $29.6 | $29.5 | $31.2 |
| Utah | $15.0 | $16.1 | $16.2 | $16.4 | $17.3 | $17.8 | $18.0 | $19.2 | $19.5 | $20.4 |
| **U.S. Average** | **$21.5** | **$23.0** | **$22.8** | **$23.5** | **$23.9** | **$25.4** | **$27.7** | **$28.3** | **$30.4** | **$29.8** |

**Average Price to Industrial End-Users**

| State | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Arizona** | **$15.5** | **$15.4** | **$15.2** | **$15.8** | **$15.7** | **$17.1** | **$16.7** | **$17.7** | **$19.3** | **$19.5** |
| California | $20.9 | $27.1 | $28.7 | $28.1 | $27.2 | $28.0 | $29.6 | $29.3 | $29.4 | $29.5 |
| Colorado | $12.5 | $13.1 | $13.3 | $15.0 | $15.0 | $16.8 | $17.2 | $17.5 | $19.5 | $18.7 |
| New Mexico | $13.7 | $16.0 | $13.1 | $14.5 | $15.3 | $16.4 | $16.3 | $16.4 | $18.7 | $16.8 |
| Nevada | $14.6 | $19.2 | $21.2 | $21.4 | $21.2 | $22.6 | $23.5 | $24.3 | $23.4 | $23.4 |
| Utah | $9.8 | $10.3 | $11.2 | $11.1 | $11.8 | $12.4 | $12.3 | $13.3 | $13.5 | $14.1 |
| **U.S. Average** | **$13.6** | **$14.8** | **$14.3** | **$15.0** | **$15.4** | **$16.8** | **$18.0** | **$18.7** | **$20.0** | **$20.0** |

Source: EIA, State Energy Data System (SEDS), http://www.eia.gov/emeu/states/_seds_updates.html, as of July 18, 2011

**FIGURE 7** | Summary Information on Arizona's Top Three Electric Utilities, 2009

| 2009 Data | Arizona Public Service Corporation (APS) | | Salt River Project (SRP) | | Tucson Electric Power (TEP) | |
|---|---|---|---|---|---|---|
| **Generating capacity owned in Arizona (MW)[1]** | | **6,293** | | **5,428** | | **2,229** |
| % Coal | | 27.9% | | 26.2% | | 62.6% |
| % Gas / Oil | | 53.9% | | 54.2% | | 37.2% |
| % Nuclear | | 18.2% | | 12.5% | | - |
| % Hydroelectric | | - | | 7.1% | | - |
| % Other (incl. solar and wind) | | 0.1% | | 0.1% | | 0.2% |
| **System peak demand (summer, MW)** | | **7,218** | | **6,560** | | **2,725** |
| **Total electricity sources (MWh)** | **34,298,810** | **100%** | **34,893,001** | **100%** | **14,966,254** | **100%** |
| Net Generation | 27,374,371 | 79.8% | 25,097,338 | 71.9% | 10,407,832 | 69.5% |
| Wholesale purchases | 6,849,772 | 20.0% | 9,812,107 | 28.1% | 4,572,425 | 30.6% |
| Net exchange (negative for net exports) | (88,629) | -0.3% | (16,444) | 0.0% | 52,960 | 0.4% |
| Wholesale transfers ("net wheeled")[2] | 163,296 | 0.5% | - | 0.0% | (66,963) | -0.4% |
| **Total Electricity uses / disposition (MWh)** | **34,298,810** | **100%** | **34,893,001** | **100%** | **14,966,254** | **100%** |
| Retail electricity sales | 28,173,296 | 82.1% | 26,181,333 | 75.0% | 9,370,743 | 62.6% |
| Sales for resale[3] | 4,106,209 | 12.0% | 7,254,326 | 20.8% | 4,653,090 | 31.1% |
| Self consumption | 63,256 | 0.2% | - | 0.0% | 9,374 | 0.1% |
| Total transmission and distribution losses | 1,956,049 | 5.7% | 1,457,342 | 4.2% | 933,047 | 6.2% |
| **Total retail electricity sales (MWh)** | **28,173,296** | **100%** | **26,181,333** | **100%** | **9,370,743** | **100%** |
| Residential | 13,214,097 | 46.9% | 12,505,098 | 47.8% | 3,905,696 | 41.7% |
| Commercial | 12,745,766 | 45.2% | 10,821,974 | 41.3% | 2,239,271 | 23.9% |
| Industrial | 2,213,433 | 7.9% | 2,854,261 | 10.9% | 3,225,776 | 34.4% |
| **Total retail revenues ($ thousands)** | **2,961,907** | **100%** | **2,362,082** | **100%** | **842,093** | **100%** |
| Residential | 1,495,277 | 50.5% | 1,275,748 | 54.0% | 377,783 | 44.9% |
| Commercial | 1,286,772 | 43.4% | 917,498 | 38.8% | 239,559 | 28.4% |
| Industrial | 179,858 | 6.1% | 168,836 | 7.1% | 224,752 | 26.7% |
| **Number of customers** | **1,117,199** | **100%** | **945,898** | **100%** | **401,101** | **100%** |
| Residential | 992,077 | 88.8% | 851,755 | 90.0% | 364,755 | 90.9% |
| Commercial | 121,316 | 10.9% | 94,095 | 9.9% | 35,714 | 8.9% |
| Industrial | 3,806 | 0.3% | 48 | 0.0% | 632 | 0.2% |
| **Average sales (MWh/customer), for all customers** | | **25** | | **28** | | **23** |
| Residential | | 13 | | 15 | | 11 |
| Commercial | | 105 | | 115 | | 63 |
| Industrial | | 582 | | 59,464 | | 5,104 |
| **Average revenues ($/customer), for all customers** | | **$2,651** | | **$2,497** | | **$2,099** |
| Residential | | $1,507 | | $1,498 | | $1,036 |
| Commercial | | $10,607 | | $9,751 | | $6,708 |
| Industrial | | $47,256 | | $3,517,417 | | $355,621 |
| **Average revenues (cents/kWh), for all customers** | | **10.5** | | **9.0** | | **9.0** |
| Residential | | 11.3 | | 10.2 | | 9.7 |
| Commercial | | 10.1 | | 8.5 | | 10.7 |
| Industrial | | 8.1 | | 5.9 | | 7.0 |
| **No. of Employees[4]** | | 6,700 | | 1,358 | | 4,461 |
| **Retail revenues as % of Arizona GDP[5]** | | 1.19% | | 0.95% | | 0.34% |

Figure 7 Notes: (1) All capacity owned by these utilities (not the capacity they operate, or run) that is located in Arizona, plus the Four Corners coal-fired generating facility near the Arizona- New Mexico border. Excludes commitments to purchase power from assets owned by other entities (independent power producers). Utilities may operate power plants that they do not have 100% ownership interest. These utilities also have power plants in states other than Arizona. Capacity (MW) figures from respective company website and/or annual reports.

(2) Including transmission losses due to wheeling.

(3) Sales not directly to end-use customers. For instance, this line item would include sales to power marketers.

(4) Obtained from each company's public filings. For APS, this figure includes APS, Parent Company and marketing and trading employees who support the regulated electricity retail business.

(5) GDP = Gross Domestic Product. Calculation based on GDP in current dollars from the Bureau of Economic Analysis, GDP by State, http://www.bea.gov/regional/gsp/.

Source: EIA Form 861 (2009) unless otherwise noted, and excluding percent share and ratio calculations.

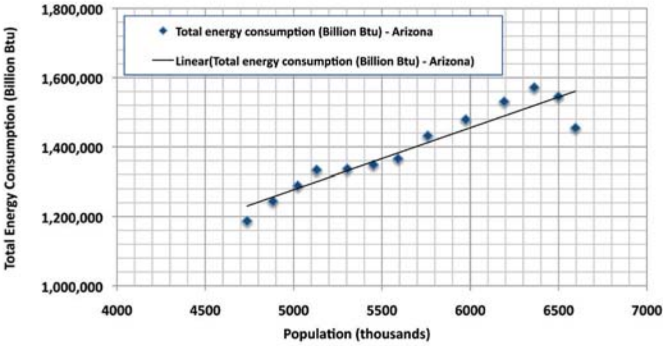
## Part II

## Energy and the Economy

Arizona's economy is dominated by activity in the services sector. Figures for 2009 indicate that services account for almost 70% of the state's economy. The combined share of the primary and secondary sectors such as agriculture, manufacturing, mining, utilities, and construction, make up about 18% of the state's 2009 gross domestic product (down from 23% in 2000). In particular, the more energy intensive sectors, such as manufacturing and mining, constitute only 7.5% and 2% of Arizona's GDP, respectively.[24] This distribution of Arizona's economic sectors is not substantially different from the U.S. economy, which is also dominated by the services sector (at 67%), although Arizona's percentage of manufacturing is lower than the national average. The composition of Arizona's economy is also quite similar to its neighbors, including California, Nevada, and Colorado. The Utah and New Mexico's economies are slightly different, to the extent that their  primary and secondary sectors contribute a larger share of GDP. Based on sub-sectoral data provided by the federal Bureau of Economic Analysis, the energy sector (including mining and exploration of fossil fuels, pipeline transport, and the electric power sector) is about $10 billion, or roughly 4%, of Arizona's total GDP.

The energy needs of Arizona and the United States have been, and continue to be, closely related to population growth (see Figure 9). Since the 1960s, Arizona's population growth has outstripped the nation's population growth. From 1960 to 2009, the number of people who call Arizona home has grown from 1.3 million to 6.6 million. Put differently, the population in the state has nearly doubled every 20 years. Arizona has always been a more urban state than the U.S. average; in 2009, nine out of ten Arizonans lived in metropolitan areas.

**FIGURE 9** | Scatter Plot of Total U.S. Energy Consumption Against Population, Using 1997–2009 Data



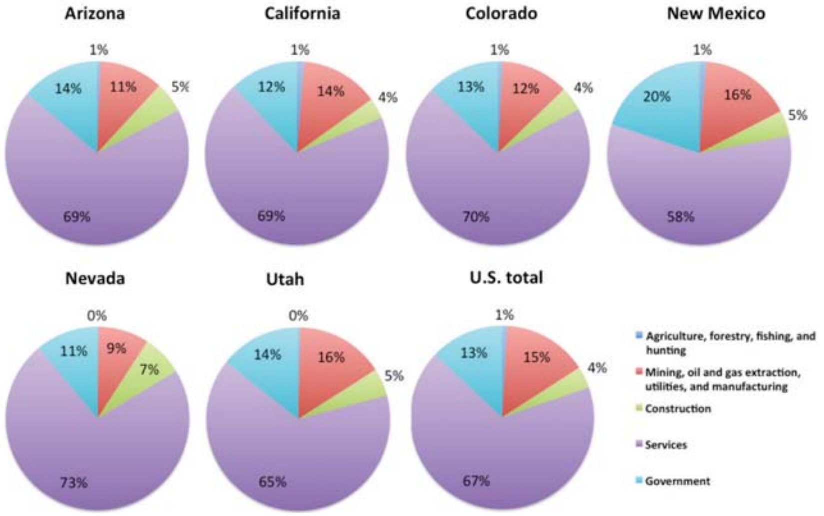
Sources: Population figures from the U.S. Census (http://www.census.gov/compendia/statab/cats/population.html) and total energy consumption figures from the EIA (see http://www.eia.gov/emeu/states /_seds_updates.html).

Although Arizona ranks in the middle of U.S. states for total energy consumption, per capita energy consumption in the state is relatively low and has been relatively constant over the past decade, except for a post-2008 decline due to the global recession. Compared to its neighboring states (and regional competitors), Arizona's energy consumption per dollar of GDP, which is also called the energy intensity of the economy, suggests that the state's economy

**FIGURE 8** | GDP for Arizona, Neighboring States, and the United States, 2009 (millions of current dollars)

| Category/Sector | Arizona | California | Colorado | New Mexico | Nevada | Utah | U.S. Total |
|---|---|---|---|---|---|---|---|
| **All Industry Total** | **$249,711** | **$1,847,048** | **$250,664** | **$76,871** | **$125,037** | **$111,301** | **$14,014,849** |
| **Private Industries** | **$215,335** | **$1,623,602** | **$218,481** | **$61,562** | **$111,244** | **$95,406** | **$12,196,534** |
| Agriculture, forestry, fishing, and hunting | $1,469 | $24,753 | $2,095 | $968 | $261 | $400 | $133,137 |
| Mining, oil and gas extraction | $3,816 | $16,723 | $9,428 | $5,839 | $3,743 | $2,581 | $240,843 |
| Utilities | $5,800 | $30,652 | $3,360 | $1,460 | $2,402 | $1,565 | $268,107 |
| Construction | $13,545 | $67,236 | $10,735 | $3,479 | $9,047 | $5,429 | $537,460 |
| Manufacturing | $18,545 | $206,152 | $17,112 | $5,145 | $5,044 | $13,224 | $1,584,834 |
| Wholesale Trade | $13,762 | $97,730 | $12,508 | $2,664 | $4,692 | $5,305 | $780,784 |
| Retail trade | $18,971 | $107,063 | $13,488 | $5,106 | $7,734 | $7,531 | $819,648 |
| Transportation and Warehousing* | $6,849 | $42,918 | $6,380 | $1,905 | $4,438 | $3,911 | $389,498 |
| Information | $6,931 | $122,695 | $22,625 | $2,354 | $2,427 | $3,875 | $639,350 |
| Finance and insurance | $19,454 | $104,761 | $17,152 | $2,932 | $13,964 | $10,731 | $1,171,612 |
| Real estate and rental and leasing | $39,431 | $309,359 | $33,404 | $9,357 | $17,152 | $14,293 | $1,868,673 |
| Professional and technical services | $15,248 | $166,840 | $24,007 | $6,629 | $6,138 | $7,118 | $1,068,506 |
| Management of companies and enterprises | $3,162 | $24,987 | $4,693 | $408 | $2,872 | $1,662 | $246,472 |
| Administrative and waste services | $9,956 | $50,690 | $7,531 | $2,114 | $3,163 | $2,892 | $386,292 |
| Educational services | $2,497 | $17,953 | $1,814 | $445 | $451 | $1,359 | $154,913 |
| Health care and social assistance | $20,088 | $118,058 | $15,490 | $5,766 | $6,604 | $6,627 | $1,057,948 |
| Arts, entertainment, and recreation | $2,157 | $22,010 | $2,921 | $438 | $2,679 | $779 | $127,297 |
| Accommodation and food services | $8,272 | $49,166 | $7,596 | $2,455 | $16,203 | $2,787 | $385,760 |
| Other services, except government | $5,382 | $43,855 | $6,140 | $2,100 | $2,231 | $3,335 | $335,401 |
| **Government** | **$34,376** | **$223,446** | **$32,183** | **$15,309** | **$13,794** | **$15,895** | **$1,818,315** |

* Excluding the Postal Service



Source: GDP figures from the U.S. Bureau of Economic Analysis (http://www.bea.gov/regional/gsp/). Construction was reported separately in the pie charts, since some economists categorize the sector as secondary (and thus bundling it with manufacturing), yet others do not

**FIGURE 10** | Electricity Consumption Arizona by End-Use Sector, Compared to the United States and Neighboring States, 2009 (Billion Btu)

| 2009 | GDP (Millions of Current Dollars) | Population (Thousands) | GDP Per Capita | Energy Consumption<br>Total (Billion BTU) | Per Capita (Million Btu Per Capita) | Per Dollar of GDP (BTU Per $) |
|---|---|---|---|---|---|---|
| **Arizona** | **249,711** | **6,596** | **37,859** | **1,454,314** | **$220** | **5,824** |
| California | 1,847,048 | 36,962 | 49,972 | 8,005,508 | $217 | 4,334 |
| Colorado | 250,664 | 5,025 | 49,886 | 1,452,225 | $289 | 5,794 |
| Nevada | 125,037 | 2,643 | 47,307 | 707,579 | $268 | 5,659 |
| New Mexico | 76,871 | 2,010 | 38,251 | 670,095 | $333 | 8,717 |
| Utah | 111,301 | 2,785 | 39,971 | 754,479 | $271 | 6,779 |
| **United States** | **14,014,849** | **307,007** | **45,650** | **94,446,906** | **$308** | **6,739** |

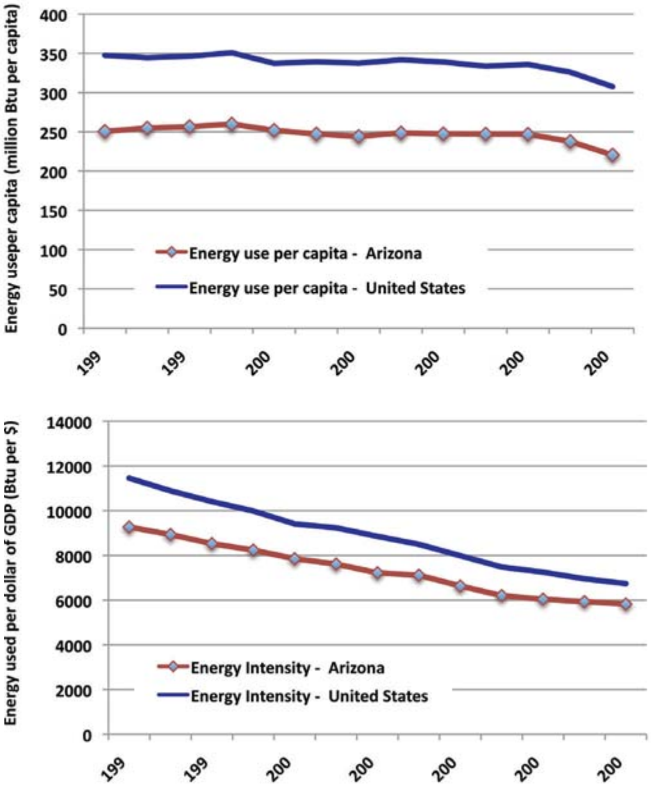
Sources: GDP figures from the U.S. Bureau of Economic Analysis (http://www.bea.gov/regional/gsp/); population figures from the U.S. Census (http://www.census.gov/compendia/statab/cats/population.html); total energy consumption figures and average retail electricity prices from the EIA (see http://www.eia.gov/emeu/states /_seds_updates.html and http://www.eia.gov/cneaf/electricity/esr/table4.html)

is one of the least energy intensive in the United States, after California (see Figure 10). The relatively low share of manufacturing in Arizona and California compared to rest of the United States explains much of this difference in energy intensity.

Generally speaking, declining energy intensity is a feature of developed economies, in which energy-intensive sectors, such as manufacturing, are replaced by service sector industries (such as tourism, media, finance, and insurance). Typically, a declining energy intensity would indicate that less energy is used to generate the same level of GDP. Figure 11 demonstrates the declining trend in energy intensity both in Arizona and the United States.

Arizona also differs from U.S. averages for consumption of energy; the state's share of residential, transportation, and commercial usage lies above the national average and industrial sector consumption lies below the national average. Electricity consumption in the state accounts for more than 25% of total energy used for non-transportation purposes. In addition to being the primary source for space cooling, the EIA has estimated that more than one-half of Arizona households also rely on electricity as their main energy source for space heating. Retail power prices in the state for the residential and commercial sectors are lower than the national average and California, but above those in Colorado, New Mexico, and Utah.

**FIGURE 11** | Recent Trends in Per Capita Energy Use and Energy Intensity, Arizona and the United States, 1997-2009



Sources: GDP figures from the U.S. Bureau of Economic Analysis (http://www.bea.gov/regional/gsp/); population figures from the U.S. Census (http://www.census.gov/compendia/statab/cats/population.html); total energy consumption figures and average retail electricity prices from the EIA (see http://www.eia.gov/emeu/states /_seds_updates.html and http://www.eia.gov/cneaf/electricity/esr/table4.html)

**FIGURE 12** | Transportation Characteristics of the 20 Largest Urbanized Areas in the United States, 2008

| Urbanized Area,[1] Ranked By Population | State(s) | Estimated Population (Thousands) | Net Land Area (Square Miles) | Persons Per Square Mile | Total Roadway Miles | Miles of Roadway Per Thousand Persons | Total DVMT (Thousands) | Total DVMT Per Capita | Total Estimated Freeway Lane Miles[2] | Average Daily Traffic Per Freeway Lane Mile |
|---|---|---|---|---|---|---|---|---|---|---|
| New York-Newark | NY, NJ, CT | 18,704 | 4,485 | 4,170 | 43,697 | 2.3 | 299,125 | 16.0 | 7,225 | 16,151 |
| LA-Long Beach-Santa Ana | CA | 12,448 | 1,971 | 6,316 | 24,897 | 2.0 | 275,665 | 22.0 | 5,607 | 23,572 |
| Chicago | IL, IN | 9,035 | 3,624 | 2,638 | 25,951 | 2.9 | 172,793 | 19.1 | 3,021 | 18,379 |
| Miami | FL | 5,431 | 1,499 | 3,623 | 15,761 | 2.9 | 129,658 | 23.9 | 2,189 | 18,017 |
| Philadelphia | PA, NJ, DE, MD | 5,297 | 2,257 | 2,347 | 19,459 | 3.7 | 105,820 | 20.0 | 2,413 | 14,850 |
| Dallas-Fort Worth-Arlington | TX | 4,936 | 2,371 | 2,082 | 19,939 | 4.0 | 123,087 | 25.0 | 3,649 | 17,118 |
| Atlanta | GA | 4,548 | 3,027 | 1,503 | 19,879 | 4.4 | 127,008 | 27.9 | 2,515 | 18,200 |
| Washington | VA, MD, DC | 4,368 | 1,305 | 3,347 | 11,987 | 2.7 | 98,702 | 22.6 | 2,078 | 18,372 |
| Boston | MA, NH, RI | 4,131 | 2,241 | 1,843 | 16,969 | 4.0 | 92,756 | 23.0 | 2,550 | 15,657 |
| Detroit | MI | 3,898 | 1,439 | 2,709 | 14,822 | 4.0 | 99,634 | 26.0 | 1,916 | 15,822 |
| **Phoenix** | **AZ** | **3,481** | **1,115** | **3,122** | **12,553** | **4.0** | **78,147** | **22.0** | **1,593** | **18,286** |
| San Francisco-Oakland | CA | 3,239 | 1,054 | 3,073 | 7,156 | 2.0 | 69,147 | 21.0 | 1,931 | 19,266 |
| Houston | TX | 3,205 | 1,821 | 1,760 | 17,537 | 6.0 | 106,872 | 33.0 | 3,264 | 16,550 |
| Seattle | WA | 3,152 | 1,185 | 2,660 | 12,019 | 4.0 | 69,800 | 22.0 | 1,856 | 16,019 |
| San Diego | CA | 3,017 | 984 | 3,066 | 5,260 | 2.0 | 68,086 | 23.0 | 1,957 | 19,217 |
| Minneapolis-St. Paul | MN | 2,673 | 1,192 | 2,242 | 12,362 | 5.0 | 65,529 | 25.0 | 1,723 | 16,737 |
| Tampa-St. Petersburg | FL | 2,326 | 1,072 | 2,170 | 9,629 | 4.0 | 62,866 | 27.0 | 884 | 15,420 |
| San Juan | PR | 2,319 | 1,075 | 2,157 | 7,634 | 3.0 | 32,334 | 14.0 | 793 | 15,379 |
| St. Louis | MO, IL | 2,227 | 1,359 | 1,639 | 11,214 | 5.0 | 66,114 | 30.0 | 2,344 | 12,566 |
| Denver-Aurora | CO | 2,221 | 814 | 2,729 | 8,345 | 4.0 | 50,784 | 23.0 | 1,255 | 16,032 |

Source: Adapted from U.S. Department of Transportation, Federal Highway Administration, Highway Statistics 2008, available at http://www.bts.gov/publications/state_transportation_statistics/state_transportation_statistics_2009/index.html, as of June 14, 2011[27]

As discussed previously, the transportation sector consumes almost all petroleum products in Arizona (98% of gasoline and 87% of all petroleum products, such as diesel and ethanol). Arizonans rely heavily on their vehicles for transportation, and motor vehicle registrations in the state increased by 55% between 1990 and 2008, reaching 4.4 million vehicles.[25] Despite this growth, among the states, Arizona ranks 46th in vehicles per licensed driver and 37th in terms of per capita vehicle miles traveled. According to data from the Federal Highway Administration on the transportation characteristics of the largest U.S. urban areas, the Phoenix metro area is centrally ranked in terms of the daily per vehicle miles traveled per capita (at 22 miles). However, in terms of roadway miles per capita and average daily traffic per freeway lane mile, it is within the top 10.[26]

Roadway congestion is another important indicator of energy consumption in the transportation sector. Congestion results in wasted driver's time and fuel. According to research conducted by the Texas Transportation Institute (TTI),[28] among the nation's top 29 metro areas with populations over one million, Phoenix ranked in the middle based on 2005 data (i.e., 15th in annual delay per traveler and 13th in wasted fuel due to congestion). TTI's most recent update indicates that in 2009, Phoenix's ranking has improved for both metrics (down to 20th in annual delay per traveler and 18th in wasted fuel due to congestion). Possibly, the city's relative abundance of roadways per capita (as noted in the previous paragraph) has played a role in this reduction, as well as the light rail service that opened in late 2008. However, the TTI studies also show that congestion has been reduced for many of the 15 largest metro areas from 2005 to 2009, which suggests that part of metro Phoenix's gains can also be attributed to the U.S.-wide decline in economic activity as a result of the 2008 recession.[29]

In the United States, about 40% of all primary energy consumption can be attributed to commercial and residential buildings. Buildings also represent nearly three quarters of all electricity and one-third of total natural gas consumption (on-site) in the country.[30] Although there is no state-specific information on energy consumption by buildings, one can conservatively assume that these national energy consumption indicators are broadly applicable to Arizona. It is, therefore, important to understand the energy use characteristics of residential and commercial buildings. Two of the most important characteristics are size (square footage) and age. Size important because space heating and cooling needs constitute a large portion of energy used by

**FIGURE 13** | Characteristics of U.S. Housing by Census Division and Region, 2005

| | Size and Share in Total U.S. | | | Vintage (Construction Year) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Census Division | | Average Home Size (SF) | | | | | | | | |
| | Share of U.S. Stock | Total SF (1) | Heated SF | Prior to 1950 | 1950 to 1969 | 1970 to 1979 | 1980 to 1989 | 1990 to 1999 | 2000 to 2009 | All Vintages |
| **Northeast** | **19%** | **2,423** | **1,664** | **6.7%** | **5.2%** | **2.4%** | **2.1%** | **1.3%** | **0.8%** | **18.5%** |
| New England | 5% | 2,552 | 1,680 | 2.1% | 1.2% | 0.5% | 0.5% | 0.3% | 0.3% | 4.9% |
| Middle Atlantic | 14% | 2,376 | 1,658 | 4.6% | 4.0% | 1.9% | 1.6% | 1.0% | 0.5% | 13.6% |
| **Midwest** | **23%** | **2,566** | **1,927** | **5.7%** | **5.8%** | **3.6%** | **2.5%** | **3.7%** | **1.7%** | **23.0%** |
| East North Central | 16% | 2,628 | 1,926 | 4.3% | 3.9% | 2.7% | 1.8% | 2.1% | 1.1% | 16.0% |
| West North Central | 7% | 2,424 | 1,930 | 1.4% | 1.9% | 0.9% | 0.7% | 1.6% | 0.6% | 7.1% |
| **South** | **37%** | **2,295** | **1,551** | **4.0%** | **6.9%** | **6.4%** | **7.5%** | **7.5%** | **4.3%** | **36.6%** |
| South Atlantic | 20% | 2,370 | 1,607 | 2.0% | 3.4% | 3.5% | 4.2% | 4.3% | 2.2% | 17.4% |
| East South Central | 6% | 2,254 | 1,544 | 0.9% | 1.3% | 0.9% | 1.0% | 1.3% | 0.7% | 6.2% |
| West South Central | 11% | 2,184 | 1,455 | 1.2% | 2.3% | 4.7% | 2.2% | 1.8% | 1.4% | 13.6% |
| **West** | **22%** | **1,963** | **1,366** | **3.4%** | **4.6%** | **4.5%** | **4.6%** | **3.1%** | **1.5%** | **21.8%** |
| Mountain | 7% | 2,149 | 1,649 | 0.7% | 1.2% | 1.3% | 1.5% | 1.3% | 0.9% | 6.8% |
| Pacific | 15% | 1,878 | 1,238 | 2.8% | 3.4% | 3.3% | 3.1% | 1.8% | 0.6% | 15.0% |
| **United States** | **100%** | **2,309** | **1,618** | **19.9%** | **22.5%** | **17.0%** | **16.7%** | **15.6%** | **8.3%** | **100%** |

Source: Figure adapted from Tables 2.2.3 and 2.2.4 in Section 2.2: Residential Sector Characteristics of the Buildings Energy Data Book (2010), March 2011, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, available at http://buildingsdatabook.eren.doe.gov/, as of June 15, 2011 buildings. Age is important because older buildings tend to be less energy efficient, despite being smaller. According to regional data compiled by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, more than half of all homes in the United States are thirty years or older. In the Mountain census division, which includes Arizona,[31] residential structures are slightly newer. Nevertheless, the majority of homes in the Mountain states were constructed between 1950 and 1980, and the Mountain states' share of homes built since 2000 is below the national average.

As one of the important drivers of the high residential sector energy (and electricity) consumption, the average home size in Phoenix is still 30% to 40% larger than the national average (and also larger than the average reported for the Mountain census region).

Commercial buildings account for one-third of all electricity consumption in the country, nearly 60% of which is used for lighting, space heating, and cooling.[32] According to the DOE, some of the most energy-intensive commercial spaces include healthcare facilities and establishments that serve or sell food (part of the retail sector). These are two of Arizona's largest economic sectors, with retail and healthcare accounting for 16% of Arizona's GDP in 2009.[33] A large number of states have mandated, or are in the process of developing, dedicated Building Energy Codes[34] to manage and improve energy used in commercial and residential structures. Arizona is one of nine states with no current plans to implement statewide energy building codes. This is because Arizona is a home rule state, meaning that codes are adopted and enforced at the local level.[35]

Arizona is an arid state with limited water resources, and this constraint affects all economic sectors. Ultimately, the availability of water could limit all growth and development in the state. Therefore, water conservation in all sectors would contribute to the long-term viability of Arizona's water resources.[36] Within the energy production sector, water use is a essential but not substantial compared to the other sectors of the economy. (See Chapter 6.)

## Part III

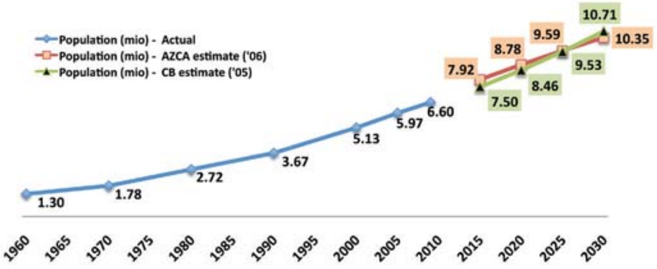
## Outlook for the Economy and Energy Use in Arizona

### Population Growth

As explained earlier, population growth is the primary driver of economic growth and energy consumption in Arizona. Since the 1960s, the population growth in the state has significantly outpaced the rest of the United States. Whereas in 1960 Arizona was the 35th most populated state in the nation, in 2009, it ranked 14th. This growth is fueled to a large extent by migration, both domestic and international, (which outpaced natural population growth by a 2-to-1 margin between 2000 and 2009). This migration trend is expected to continue over the next two decades, though at a slightly declining rate, according to 2006 estimates by the Arizona Commerce Authority. Projections by both the U.S. Census Bureau (2005)[37] and the Arizona Commerce Authority (2006) indicate Arizona's population is likely to surpass the ten million mark by 2030, suggesting an annual average growth rate of over 2%. These two projections are plotted in Figure 14.

These projections, however, predate the 2008 recession. Given the evidence, the authors do not believe that the recession has altered the underlying fundamentals of population growth in Arizona (e.g., favorable climate, low cost of living, access to affordable housing) or people's perception of these factors. However, it may be some time before Arizona's population growth reaches the pre-recession projected levels and once again becomes the engine of economic growth in the state. As of June 2011, recovery of the U.S. housing market is still lagging behind the economy. Combined with the persistent high unemployment rate in Arizona (on average, 0.4% higher than the national unemployment rate between August 2008 and June 2011),[39] the mobility of prospective migrants into the state remains thwarted.

**FIGURE 14** | Arizona Population, Historical and Projected, 1960–2030 (millions)



Note: The AZCA estimate ('06) label represents the Arizona Commerce Authority's 2006 population projections, and the CB estimate ('05) represents the interim population projections of the U.S. Census Bureau, published in 2005[38]

As mentioned earlier, Arizona is a largely urban state, with nearly 95% of residents living in urban areas. It is unlikely that the urban nature of the state will change over the foreseeable future. It is reasonable to assume that Phoenix and Tucson (and the surrounding cities) will absorb most of the population growth. A 2008 study by Arizona State University's Morrison Institute of Public Policy speculated that the growing interlinkages between Phoenix and Tucson suggest the two cities could merge, creating the "megapolitan" of the Southwest, or the "Sun Corridor," by 2040.[40, 41]

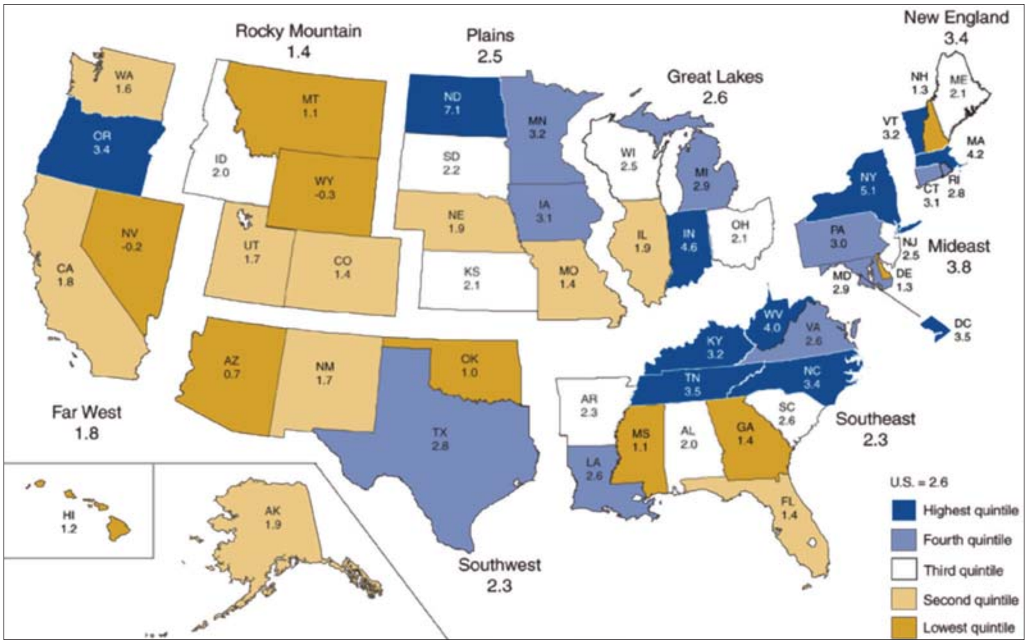
Whether this urban convergence translates into higher or lower population density for Phoenix, Tucson, and the cities in between is difficult to pinpoint. Increasing volatility in oil prices, the relative affordability of housing in centralized neighborhoods versus in exurban developments, the appetite of cities to extend public services over ever-larger areas, shifting public opinion towards "smart and sustainable" growth with an emphasis on quality of life, and existing water and land use constraints (such as tribal and park) will all play a role in how Arizona's cities evolve. Conditions today favor denser growth and a reversal of the past exurban development patterns. It would take several years for such a trend reversal, if realized, to have a measurable impact on energy use.

## The Economy

Economic growth in Arizona has stalled significantly due to the 2008 recession. Recovery is taking longer than in the rest of the nation, due to the disproportionate role the housing market, which triggered the crisis, played in the state's economy. The most recent estimates from the U.S. Bureau of Economic Analysis indicate Arizona was in the lowest quintile of states in terms of GDP growth during 2010 (see Figure 15). Growth in durable goods manufacturing—not prominent in Arizona—has been key in those states with the highest GDP growth in 2010. This lag in Arizona's economic recovery is expected to persist until the housing market improves.

As mentioned earlier, the more energy-intensive industries, such as manufacturing, do not play a large role in Arizona's economy. Of the existing industrial consumers of energy in the state, mining and utilities do not always have a choice in location, as siting decisions are impacted by proximity to supply (i.e., coal and mineral deposits) or, in the case of power plants, proximity to urban centers or transmission lines. It is not clear that energy costs today are the biggest impediment to the expansion of existing industrial sectors in Arizona or to attracting new industrial sectors to the state. Depending on the manufacturing industry, several different factors may determine manufacturing investment decisions. Labor market and availability of skilled workers, taxes, availability of business parks, transportation convenience, and proximity to markets, are important, and

**FIGURE 15** | Percent Change in Real GDP by State, 2009-2010



Source: Map adapted from the U.S. Bureau of Economic Analysis, news release dated June 7, 2011, "Economic Recovery Wide-spread Across States in 2010," available at http://www.bea.gov/newsreleases/regional/gdp_state/gsp_newsrelease.htm (link active as of June 30, 2011)

the existence of industrial clusters (such as Silicon Valley) tend to attract industries and related commercial activity to an area. Climate might be another factor at the margin for industries in which processes might be sensitive to ambient temperature. While a nationwide push towards revitalizing the U.S. manufacturing sector is underway, it is prudent to assume that the share of manufacturing and the overall sectoral composition of Arizona's economy will remain heavily biased towards the services sector for the foreseeable future.

## Impact on Energy Use

Energy consumption in all end-use sectors—residential, commercial, industrial, and transportation sectors—was reduced by the lingering economic recession. Total energy demand in Arizona declined by about 2% in 2008 and 6% in 2009. The state's industrial sector demand for energy shrank by more than 15% during 2009. Statistics for 2010 are expected to show continuing economic contraction, though less severe than in 2009. As population growth (migration) gradually picks up, growth in energy demand will also likley recover to near pre-recession levels.

On the other hand, the services-oriented nature of Arizona's economy and the growing national emphasis on energy efficiency for heating, ventilation, and air conditioning equipment,[42] lighting and home appliances,[43] as well as the tightening of fuel efficiency standards for vehicles,[44] will also reduce total energy demand growth. As the economy recovers, the declining energy intensity trend is expected to continue. Additionally, the Arizona Corporation Commission recently introduced an energy efficiency standard for all regulated electricity providers, requiring a cumulative annual electricity savings of at least 22% by 2020 (see Chapter 10). This may assist with reducing the energy intensity level in Arizona.

The EIA projects total energy demand by all end-use sectors to grow from 0.5% to 1.5% per year in the Mountain census region[45] (which includes Arizona) over the forecast period, 2011-2035. Residential demand in the region for energy is expected to grow slowest, followed by industrial and transportation sectors, while the commercial sector demand is projected to grow fastest.[46] The EIA further expects the transportation demand for ethanol fuels and electricity to grow significantly faster (by 5% and 11% per year, respectively) than gasoline. Even so, actual levels of electricity used for transportation will likely remain too low to significantly impact total growth in electricity demand. These projected trends may reasonably be expected to be overall reflected in the Arizona economy. One exception may be Arizona's relative share of and rate of growth in residential energy use. Due to the characteristics of the existing housing[47] in the Desert Southwest, residential electricity consumption is projected to grow faster than the national average, at about 2% annually over the next decade.[48] These growth estimates broadly correspond to the population growth estimates discussed earlier.

Moreover, Arizona's Renewable Portfolio Standard may foster the large-scale development of the state's solar resources, even though it is designed primarily to alter the resource mix of the domestic energy supply (rather than the amount of supply) (see Chapter 10). Ultimately, this may result in solar power export opportunities, especially to California. As a result, Arizona's electric power supply industry, which is already a net exporter, may grow at a pace beyond internal demand projections.

## Notes

1 Gross domestic product (GDP) figures from the U.S. Bureau of Economic Analysis, http://www.bea.gov/regional/gsp/, as of June 15, 2011.

2 The data reported in the text refers to the employment figures for mining and logging and utilities (2009), from the State and Area Employment, Hours, and Earnings (Specifically, database series ID SMU04000001000000001 and SMU04000004322000001) by the U.S. Bureau of Labor Statistics. (See http://www.bls.gov/data/#employment, active as of July 18, 2011.) Figures narrowed using utility reports on employment and National Mining Association estimates of coal mining employment for 2008.

3 The Department of Energy's Energy Information Administration (EIA), State Energy Data System, Table ET1. Primary Energy, Electricity, and Total Energy Price and Expenditure Estimates, 1970-2009, Arizona. Available at http://www.eia.gov/state/seds/hf.jsp?incfile=sep_prices/total/pr_tot_AZ.html&mstate=Arizona, as of July 18, 2011.

4 Information on Arizona coal reserves is withheld by the EIA, but the reserves are described as large. Neighboring New Mexico has a demonstrated reserve base of over 11 million short tons of coal. At Arizona's average rate of annual consumption of about 20,000 short tons (since the year 2000), solely New Mexico's demonstrated reserves represent more than 500 years of available coal resources. (Source: EIA, "Recoverable Coal Reserves at Producing Mines, Estimated Recoverable Reserves, and Demonstrated Reserve Base by Mining Method," http://www.eia.gov/cneaf/coal/page/acr/table15.html, link active as of July 15, 2011.)

5 National Mining Association, "Coal in Arizona," based on 2008 Mine Safety and Health Administration employment data. Available at http://www.nma.org/pdf/americas_power_states/az.pdf, link active as of July 18, 2011.

6 A rupture in the pipeline from El Paso in the summer of 2003 not only caused a spill, but also resulted in the shutdown of the pipeline section between Tucson and Phoenix. Even though the supply interruption involved only one of the pipelines serving the state and lasted about a month, it was sufficient to cause shortages at Phoenix gas stations. Kinder Morgan, the operator of the pipeline, had to pay $6 million in damages to Arizona. (Phoenix Business Journal, "Kinder Morgan to pay $6M for 2003 gas pipeline break," January 19, 2005, at http://www.bizjournals.com/phoenix/stories/2005/01/17/daily33.html, and Bruno, T.V., "Examination of Kinder Morgan's Tucson to Phoenix 8-Inch Pipeline," March 16, 2004. Report to the Office of Pipeline Safety, at http://www.azgovernor.gov/estf/opskm.pdf).

7 EIA, State Energy Data System, Table ET1. Primary Energy, Electricity, and Total Energy Price and Expenditure Estimates, 1970-2009, Arizona. Available at http://www.eia.gov/state/seds/hf.jsp?incfile=sep_prices/total/pr_tot_AZ.html&mstate=Arizona, as of July 18, 2011.

8 EIA, Table P6. Energy Production in Physical Units by Source, Arizona, 1960-2008. Available http://www.eia.gov/emeu/states/state.html?q_state_a=AZ&q_state=Arizona, as of June 15, 2011.

9 EIA, State Energy Profiles: Arizona - Analysis. Available at http://www.eia.gov/state/state-energy-profiles-analysis.cfm?sid=AZ, and State Energy Data System (SEDS): Updates by Energy Source, Natural Gas, http://www.eia.gov/emeu/states/ _seds_updates.html, both as of June 15, 2011.

10 Based on conversations with the Arizona Town Hall Report Review Committee members.

11 United States Society on Dams. Dam, Hydropower and Reservoir Statistics, available at http://www.ussdams.org/uscold_s.html, and Largest Hydropower Projects (World and U.S.), available at http://npdp.stanford.edu/dampower.html, both as of June 14, 2011.

12 EIA, Table 5. Electric Power Industry Generation by Primary Energy Source, 1990 through 2009 (MWh), available at http://www.eia.gov/cneaf/electricity/st_profiles/arizona.html, as of June 14, 2011.

13 APS Press Release, "NRC Grants 20-Year License Extension for Palo Verde," April 22, 2011, available at http://www.aps.com/main/news/releases/release_655.html, as of June 16, 2011.

14 EIA, Table 5. Electric Power Industry Generation by Primary Energy Source, 1990 through 2009 (MWh), available at http://www.eia.gov/cneaf/electricity/st_profiles/arizona.html, as of June 14, 2011.

15 As of June 2011, the 575 MW plant in Coolidge, southeast of Phoenix, is nearly operational. TransCanada, the builder, operator, and fuel supplier to the plant, and SRP signed a 20-year power purchase agreement for 100% of the output from the merchant facility. (Source: TransCanada Corporation, Coolidge Generating Station, see http://www.transcanada.com/coolidge.html, as of June 16, 2011.)

16 FERC says "[t]he Western market experienced a dramatic increase in gas production over the past five years and now constitutes 36% of total U.S. Dry Gas production compared to 29% in January 2005. … This region has added new pipeline capacity to export the growing supply. … Another important infrastructure addition is the new Transwestern Pipeline Phoenix Lateral, which is able to move 0.5 Bcf/d of San Juan gas from Transwestern's mainline in north-central Arizona into Phoenix. This affords customers a competitive choice between Transwestern and El Paso gas supplies to meet the increase in gas demand in the Phoenix region's largely gas-fired generation. The new lateral can help mitigate storage capacity limitations in the Southwest especially during peak periods." (Source: Federal Energy Regulatory Commission, "Market Oversight – Natural Gas Markets: Western," http://www.ferc.gov/market-oversight/mkt-gas/western.asp, as of July 15, 2011). Also, the EIA, "The Basics of Underground Natural Gas Storage," available at http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications /storagebasics/storagebasics.html, as of July 15, 2011.

17 Meanwhile, Multifuels LP of Texas has proposed to build a natural gas storage facility that would utilize underground salt caverns in Eloy, Arizona. The proposed Picacho Peak Gas Storage facility would have up to 8 billion cubic feet of total storage capacity and be connected to nearby interstate pipelines. The company plans to start construction during 2011. Should the construction go ahead as planned, the facility could be operational sometime between 2013 and 2015. (Source: Picacho Peak Gas Storage, LLC, 2011, http://www.picachopeakgs.com /default.htm, link active as of August 12, 2011).

18 See the glossary for the definition of distributed generation.

19 Database for State Incentives for Renewable Energy and Efficiency (DSIRE), Arizona: Incentives/Policies for Renewables & Efficiency – Renewable Energy Standard, available at http://www.dsireusa.org/incentives/incentive.cfm?Incentive _Code=AZ03R&re=1&ee=0, as of June 20, 2011.

20 Arizona's installed solar electric capacity was reported to be 101 megawatts (MW). Source: Navarro, Mireya, "The Top 10 Solar States," post-dated April 29, 2011, at the New York Times Green Blog http://green.blogs.nytimes.com/2011/04/29/the-top-10-solar-states/, as of June 12, 2011.

21 Fifty-five megawatts were added in 2010. Source: Eric Wesoff, "U.S. Solar Market Insight: 2010 Year in Review," Greentech Media, March 10, 2011, available at http://www.greentechmedia.com/articles/read/seia-report/, as of June 12, 2011.

22 For instance, Solana, a 280 megawatt solar concentrator project, is currently under development jointly by Abengoa Solar of Spain and APS. It will be one of largest solar power generating facilities worldwide when completed. The site is about 70 miles southwest of Phoenix. Source: National Renewable Energy Laboratory (NREL), Concentrating Solar Power Projects: Solana Generating Station, see http://www.nrel.gov/csp/solarpaces/project _detail.cfm/projectID=23 for more details, link as of June 12, 2011.

23 Specifically, Salt River Project Agricultural Improvement and Power District because SRP also encompasses the Salt River Valley Water Users' Association, a private corporation that delivers water to Phoenix area consumers. See http://www.srpnet.com/ about/Facts.aspx, as of June 15, 2011.

24 U.S. Bureau of Economic Analysis, Gross Domestic Product by State (millions of current dollars), available at http://www.bea.gov/regional/gsp/, link active as of June 29, 2011.

25 Population growth over the same period was 76%, which indicates a ratio of approximately one vehicle per licensed driver, or one vehicle per 1.5 residents in the state.

26 As mentioned earlier, Arizona is a highly urbanized state, and many transport statistics focus on the metro areas. However, the transportation needs of the state's rural residents are also important. Many Arizonans who live in rural areas do not have the same public transport options as residents of the metropolitan areas, and depend even more heavily on their vehicles and the state's roadways.

27 Notes: (1) Based on "federal-aid urbanized areas" that have 50,000 or more persons that, at a minimum, encompass the land area delineated as the urbanized area by the U.S. Census Bureau. In other words, the FHWA's (Federal Highway Administration) definition of the "federal-aid urbanized areas" used in the table above are based directly on the definition of urban areas by the U.S. Census Bureau. In order to better capture urban roadways, the FHWA, most often, adds to, and does not subtract from the Census Bureau's definition of an urban area. The FHWA uses "Phoenix" as a broad label to refer to the same urban area as categorized by the U.S. Census Bureau (#69184 for Phoenix-Mesa, see http://www.census.gov/geo/www/ua/st2kua.txt, as of July 18, 2011) . (FHWA, Highway Performance Monitoring System, "Office of Highway Policy Information Field Manual: Appendix I. Urbanized Area Codes" (September 2010), at http://www.fhwa.dot.gov/ policy/ohpi/hpms/fieldmanual/appendixi.htm, as of July 18, 2011.) (2) Lane miles estimated by the Federal Highway Administration (FHWA).

28 Lomax, Schrank, et al., "Urban Mobility Report," Texas Transportation Institute at Texas A&M University, 2007 and 2010 editions, available at http://mobility.tamu.edu, as of June 28, 2011.

29 Ibid. The TTI study (2007), reported that for the 14 largest (population over three million) urban areas, the average annual time delay per traveler was 54 hours and 38 gallons of fuel wasted per traveler, based on 2005 data. For the 25 urban areas with population between 1 to 3 million, 2005 data showed that the average annual time delay per traveler was 25 hours, and amount of fuel wasted was 25 gallons per traveler. Estimates for Phoenix were 48 hours of annual average time delay per traveler and 34 gallons of wasted fuel per traveler. In the 2010 update to the study, which used 2009 data, there were 46 urbanized areas with population of 1 million or higher. For the 15 metro areas with population over 3 million, the average annual delay per traveler due to congestion declined to 50 hours. The amount of fuel wasted per traveler remained relatively unchanged, at 39 gallons. For the 31 metro areas with population between 1 to 3million, average annual delay per traveler increased to 31 hours. For this group, too, the amount of fuel wasted per traveler remained relatively unchanged, at 26 gallons.

30 U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Buildings Energy Data Book (2010), Chapter 1: Buildings Sector, available at http://buildingsdatabook.eren.doe.gov/, as of June 15, 2011.

31 In addition to Arizona, the Mountain census region includes Idaho, Montana, Nevada, Wyoming, Colorado, Utah, and New Mexico.

32 The remaining 40% of use is fragmented in smaller percentages across refrigeration, water heating, electronics (including computers), cooking, some manufacturing done by commercial enterprises, and

other. (Source: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Buildings Energy Data Book (2010), Table 3.1.4 http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/3.1.4.pdf, as of July 18, 2011).

33 U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Buildings Energy Data Book (2010), Chapter 2: Commercial Sector, available at http://buildingsdatabook.eren.doe.gov/, as of June 15, 2011.

34 According to the EERE, "building energy codes and standards set minimum requirements for energy-efficient design and construction for new and renovated buildings that impact energy use and emissions for the life of the building." (Source: EERE Building Energy Codes Program, available at http://www.energycodes.gov/why_codes/, as of June 16, 2011.)

35 From the EERE's Building Energy Codes Program, Status of Code Adoption: Residential (see http://www.energycodes.gov/ states/maps/residentialStatus.stm) and Status of Code Adoption: Commercial (see http://www.energycodes.gov/states/ maps/commercialStatus.stm), links as of June 16, 2011.

36 According to APS and ADWR, the Palo Verde nuclear power plant is the only nuclear energy facility in the world that uses treated sewage effluent for cooling water. The plant uses 20 billion gallons of wastewater from area municipalities annually.

37 Updated state population projections based on the 2010 Census were pending at the time this document was prepared (June 30, 2011).

38 Sources: Historical population figures and the CB estimate ('05) series from the U.S. Census Bureau: Table 12. Resident Population—States: 1960 to 2009, available at http://www.census.gov/compendia/statab/cats/population.html, and Interim State Population Projections (2005), available at http://www.census.gov/population/www/projections/ projectionsagesex.html (links active as of June 28, 2011). The AZCA estimate ('06) series from the Arizona Commerce Authority, Arizona Population Projections 2006-2055, available at http://www.azcommerce.com/econinfo/ demographics/Population%20Projections.html (link active as of June 30, 2011).

39 The 0.4% number is the average of the monthly differences between seasonally-adjusted monthly estimates of unemployment rate in the United States and in Arizona, from the U.S. Bureau of Labor Statistics (BLS) from August 2008 through June 2011. (The original data series for Arizona can be found at http://data.bls.gov/timeseries/LASST04000003 and the comparable series for the United States can be found at http://data.bls.gov/timeseries/LNS14000000, links active as of August 12, 2011). In the recent months, this gap between Arizona and the United States has been narrowing, which is encouraging. It is also worth noting that two of Arizona's neighbors, California and Nevada, have higher unemployment rates (preliminary estimates for June 2011 are 11.8% and 12.4% respectively, compared to Arizona's 9.3%). For the same period (June 2011) the national unemployment rate was reported as 9.1% by the BLS.

40 Grady Gammage, Jr., et al., "Megapolitan: Arizona's Sun Corridor," May 2008, Morrison Institute of Public Policy.

41 The report compared this to the emergence of similar new urban corridors around the United States, such as those between Austin-San Antonio in Texas, and Orlando-Tampa in Florida, in addition to existing ones such as the Washington, D.C.-Baltimore area.

42 For instance, the latest revision to the Department of Energy's air conditioning and furnace efficiency standards will adjust for regional differences in climate and energy use. Specifically, gas furnaces installed in colder states will need to be more efficient than the national average. Similarly, cooling systems installed in the warmer states will be required to have an efficiency rating above the national standard. These new standards will become effective in between 2013-2015. (Source: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "Residential Furnaces and Central Air Conditioners and Heat Pumps Direct Final Rule." The DOE is accepting public comments on the revised standards until October 17, 2011.)

43 Such as the voluntary Energy STAR labeling program.

44 The CAFE –Corporate Average Fuel Economy– standards are described by the National Highway Traffic Safety Administration as "the sales weighted average fuel economy, expressed in miles per gallon (mpg), of a manufacturer's fleet of passenger cars or light trucks with a gross vehicle weight rating (GVWR) of 8,500 lbs. or less, manufactured for sale in the United States, for any given model year. Fuel economy is defined as the average mileage traveled by an automobile per gallon of gasoline (or equivalent amount of other fuel) consumed as measured in accordance with the testing and evaluation protocol set forth by the Environmental Protection Agency (EPA)." (See http://www.nhtsa.gov/cars/rules/cafe/ overview.htm, as of June 30, 2011). Manufacturers who do not comply with the CAFE standards are subject to monetary penalties, making the production of less efficient cars more expensive. Thus, CAFE standards do not directly incentivize end-users to select fuel-efficient vehicles. They also have no direct effect on fuel prices. While advocates argue that most of the gains in fuel economy since 1978 (the first year a CAFE standard was established) can be attributed to the CAFE standards, critics counter that rising fuel prices resulted in customers demanding more fuel efficient vehicles.

45 In addition to Arizona, the Mountain census region includes Idaho, Montana, Nevada, Wyoming, Colorado, Utah and New Mexico.

46 EIA, Annual Energy Outlook 2011, published April 26, 2011. Report Number: DOE/EIA-0383 (2011). Online data tables available at http://www.eia.gov/forecasts/aeo/data.cfm, as of June 29, 2011. Estimates cited in text are based on the EIA's reference case projections.

47 North American Electric Reliability Corporation. 2010 Long Term Reliability Assessment of North America, October 2010, pp. 304-309, available at http://www.nerc.com/files/2010%20LTRA.pdf, as of June 14, 2011.

48 For NERC's electric power system reliability assessment purposes, North America is divided into regions and sub-regions based on transmission control areas. The Desert Southwest (DSW) sub-region consists of Arizona, most of New Mexico, southern Nevada, and the westernmost part of Texas and is a subset of the WECC –Western Electric Coordinating Council– region.

# Chapter 5: **Energy Efficiency—The Arizona Challenge**

*Harvey Bryan*

## Overview

- Energy efficiency measures have the potential to significantly reduce energy consumption. Energy efficiency is different from energy conservation, which means changing behavior to reduce energy use, like adjusting the thermostat or riding a bike.
- There is much Arizona can learn from the initiatives that California has already taken on energy efficiency—for example decoupling and demand side management.
- The EPA's Energy Star program is one example of an energy efficiency program. This program labels electronics and other devices that use 20-30% less energy than required by federal standards. The Energy Star program has been adopted in over a dozen countries.
- McKinsey and Co. found that energy efficiency is currently the lowest cost energy resource in our economy.

Energy efficiency is the goal of reducing the amount of energy required to provide products and services. Improvements in energy efficiency involve maintaining or increasing levels of service while decreasing energy use through the adoption of more efficient technologies or production processes. A parallel strategy to energy efficiency is energy conservation, which means changing behavior or lifestyle to reduce energy use, such as using public transit or a bicycle instead of a car. While both strategies are important and should be coupled as often as possible, energy efficiency, is different than energy conservation. This is because the mechanisms for achieving positive outcomes for each of these strategies are very different. The focus of this chapter will be primarily on energy efficiency while energy conservation will be briefly discussed.

There are numerous rationales for improving energy efficiency: it reduces costs to the consumer; it reduces the need for costly and new energy infrastructure; it improves the reliability of energy supply; it reduces energy imports and improves national security; and it reduces GHG emissions. Today, energy efficiency is increasingly being viewed as a key strategy for addressing the problem of reducing the emission of GHGs. For example, the European Commission recently adopted a roadmap to achieve an 80% reduction in European Union emissions of GHGs by 2050. This roadmap found that the most cost-effective pathway to achieve this goal is through aggressively pursuing energy efficiency strategies.[1]

Finally, energy efficiency and renewable energy may be viewed as twin pillars of a sustainable energy policy.[2] Currently, national and most state energy policies pursue these two tracks separately. Energy efficiency offers the greatest potential of slowing energy demand in the short and near-term while renewable energy develops the installed capacity to make significant long-term reductions in fossil fuel use. There are important synergies between Renewable Portfolio Standards (RPS) and Energy Efficiency Resource Standards (EERS). The Arizona Corporation Commission (ACC) has already taken major steps in this direction by adding the EERS to the state's existing RPS (See Chapter 10). Our EERS require Arizona's investor-owned utilities to achieve a 22% savings in energy by 2020.[3] (Refer to Chapter 1 or the glossary for an explanation of investor-owned utilities and how they are regulated.) While some adjustments to Arizona's RPS are now needed to put it in line with several neighboring states as well as with Arizona's new EERS, this accomplishment makes Arizona one of the few states in the country to have integrated its energy efficiency and renewable policies.

It has been known since the mid-1970s that energy conservation, along with the behavior of building occupants, has significant impact on building energy use. This was confirmed in the mid-1990s in a study of 10 identical all-electric homes where energy use in the most energy efficient homes was two-and-a-half (2.6) times higher than in the most energy efficient homes.[4] While energy researchers knew conservation and occupant behavior were significant, most conservation programs provided insufficient feedback on overall energy use to occupants regarding their behavior to provide them with the knowledge and incentive necessary to maintain low energy use behaviors. Traditional utility-funded Public Service Announcements have not proved to have lasting impact. Cost-driven energy conservation also often failed as energy costs returned to normal. However, the biggest problem engaging building occupants has been that utility meters are difficult to read and interpret, and monthly utility bills do not show customers how behavioral changes might impact energy consumption. This problem has been recently addressed by advances made in microprocessor and wireless technology resulting in the development of a host of low-cost, commercially available, real-time energy feedback devices. These devices use an LCD display and can be mounted on a wall or desktop to provide an array of energy usage information to the building occupant. Some sell for as little as a $150 and can be easily programmed as well as downloaded to a PC for storage and further data analysis.

With the advent of these devices, several studies have been completed to determine their effectiveness at reducing energy consumption. The results from most of these studies have been impressive. An Oxford University meta-investigation of over 20 of these studies found that real-time electricity feedback devices lower energy usage by 5% to 15%.[5] If these devices could be deployed on a large scale, combined with educational programs and use of social media, significant energy conservation savings on a national scale would likley result.

## Arizona's Current Rankings

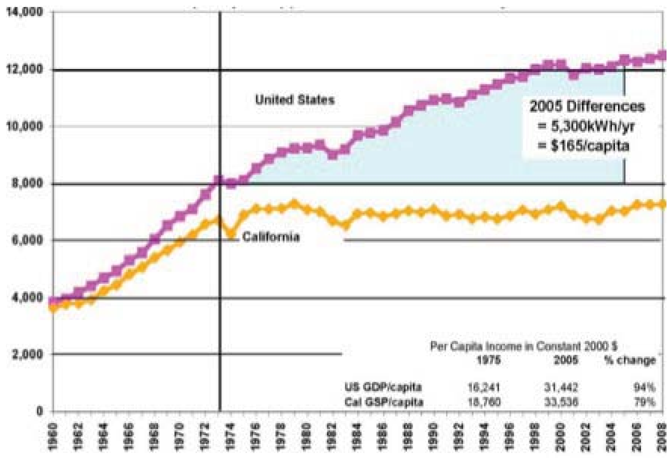
The most widely agreed-upon metric used for ranking energy efficiency on either a national or state level is the energy consumed per person (usually measured in BTUs or KWh per capita; see the glossary for a definition of BTUs and KWh). DOE's Energy Information Administration (EIA) publishes national and state comparisons.[6] While it might seem that Arizona, with its suburban- and automobile-oriented lifestyle, would use a lot of energy in comparison to other parts of the country, the reality is the opposite. Arizona ranks 46th out of 51 of the states and District of Columbia in per capita energy consumption, and Arizona's per person energy use is 28% below the U.S. average. In 2009, the latest year that the EIA published state-by-state comparisons, Arizona's energy consumption per person was 220.8 million BTUs while the U.S. average was 308.0 million BTUs.[7] As far as energy costs are concerned, Arizonans often complain about high summer air conditioning bills; the reality is Arizona has the second lowest energy expenditures in the country on a per person basis. Arizona ranks 50th out of 51 of the states and District of Columbia in per capita energy expenditure. For 2009, total Arizona energy expenditures per person were $2,662, or 23% below the U.S. average of $3,461.[8] This is the result of warmer temperatures, a lack of heavy industry in the state, newer and more efficient energy infrastructure, newer and more efficient buildings, and a generally newer and more efficient automotive fleet. While predicting the future of energy is always a challenge, these figures suggest that there is still room for further improvement on energy efficiency. For example, smarter land-use and transportation policy are also important factors to be explored. One of the primary "lessons learned" from research done on the Superstition Vistas is that a land-use pattern with mixed uses and centers that facilitates the use of public transit would have a significant impact in reducing energy use and GHG emissions.[9] These factors could be part of the policy discussion on energy efficiency.

Even though Arizona has relatively low overall energy use, by another measure, we still fall short. The U.S. Energy Policy Act of 2005 set an energy efficiency goal for all states to meet by 2012. For Arizona, this goal was 194.7 million BTUs per capita.[10] We are, unfortunately, not on track to meet this goal, even with the recession. Nor are any other states. Today, many corporations, states, and local jurisdictions are setting energy consumption reduction goals for 2020 to be in the range of 20-30% of current energy use. If, for example, the ACC's 22% EERS was applied across all of Arizona's energy uses (it is not, currently, as it only applies to electricity, not gasoline, and even in the electricity sector it only applies to investor-owned utilities), the 2020 goal would be to reduce Arizona's consumption to a total annual energy use of 172 million BTUs per person. A reduction to this level would reduce energy use and energy expenditures by about 20% per person from current levels. Mechanisms should be put in place for other state organizations beyond the ACC and investor-owned utilities to embrace this target.

## The California Experience

There are lessons to be learned on energy efficiency from California. California homes and businesses are full of personal electronics, appliances, and an array of other electricity-consuming devices. Yet, today, Californians use about the same amount of electricity per capita that they did about 35 years ago, while the rest of the country increased per capita electricity usage by over 50% during the same period (see Figure 1). Early on, California policymakers understood that significant energy efficiency could not be achieved until utility profits were decoupled from actual electricity sales. Decoupling breaks this link between profits and sales and removes the incentives to profit from growth in energy sales and the disincentives of investing in energy efficiency programs. With decoupling in place, California was able to develop an array of demand-side management programs (see glossary) as well as strict building and appliance standards. In place now for 35 years, these standards and programs are paying huge dividends. It has been estimated that from 2000-2009, energy efficiency programs in California provided nearly

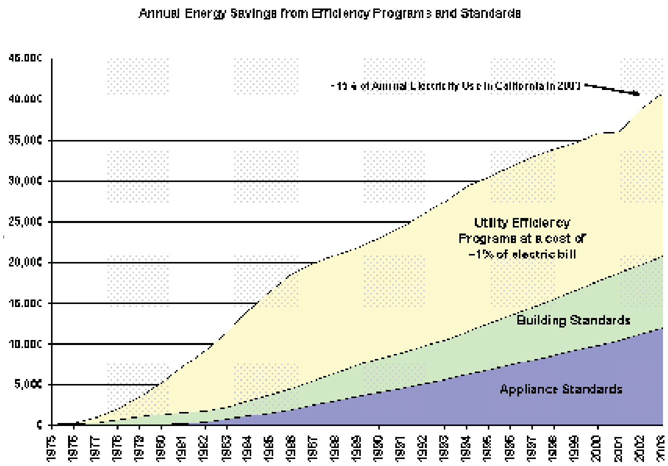
**FIGURE 1** | U.S. vs. California Per Capita Electricity Consumption from 1960-2006



Source: A. Rosenfeld, California Energy Commission (2006)

$5 billion in savings to ratepayers.[11] These programs have a track record of providing the lowest cost energy resource, less than three cents per kWh, or half of the California Public Utilities Commission's benchmarks for base load power.[12] Energy efficiency has been so successful that California policymakers have introduced a prioritization policy called "loading order," which requires that all new generation proposals be first met with energy efficiency, then with demand response (i.e., managing customer usage when energy use is high), then with renewables, then with distributed generation, and only lastly with a new fossil-fired power plant.[13]

**FIGURE 2** | California's Cumulative Energy Savings from 1975-2003



Source: California Energy Commission (2005)

Tracing energy savings directly to energy efficiency activities is not an easy task. The California Energy Commission estimated that the cumulative energy savings from 1975 through 2003 amounted to 40,000 GWh of electricity and 12,000 MW (12 GW) of reduced demand (see Figure 2).[13] Today, those numbers might be closer to 50,000 GWh in cumulative electricity savings and 15,000 MW (15 GW) of reduced demand. These are significant numbers, especially the 12,000 MW of reduced demand, which would be equivalent to 24 new 500-MW power plants. Assuming a conservative average-installed-cost of $1,500/kW for new generating capacity over that 28-year period would result in $18 billion of avoided costs of power plant construction. On top of that amount, the annual energy savings is approximately 16% of the electricity used in California in 2003. One half of these savings was the result of utility's demand side management programs, while the balance estimated Building and Appliance Standards programs.

Arizona's situation today is similar to California's when it began its energy efficiency programs. Arizona's new Energy Efficiency Resource Standards (EERS) will require the state's investor-owned utilities to significantly accelerate their existing demand side management programs. To meet these standards, utilities will need to move away from component-based incentives (such as fixed rebates for components like lamps, motors, etc.) to more performance-based incentives (such as ones that improve the operations of a whole building over time). A whole new class of low-cost distributed meters and sensors are now available to provide building managers and occupants with real-time performance data. Demand side management programs that take advantage of this information to optimize building operations could significantly improve both energy and demand savings. A significant effort would need to be made on Building Energy Standards. Arizona is a "Home Rule" state, allowing local jurisdictions to govern themselves as they see fit, so, unlike California, Arizona cannot mandate a statewide building energy standard. Presently only about one-third of Arizona jurisdictions have any building energy standards (usually some version of the International Energy Conservation Code) and many of these jurisdictions are not enforcing them rigorously. This is more problematic with residential buildings than with commercial buildings. Arizona could institute educational programs that will help local jurisdictions understand the need for establishing such standards. As far as Appliance Standards are concerned, unlike California, Arizona is too small of a state and does not have enough resources to have much impact here. In addition, the federal government is embarking on new appliance rulemaking that Arizona would mostly likely be required to follow. There are two specialty appliances, pool pumps and pool/spa heating systems, that do have a considerable energy impact in Arizona and most likely will not be included in the federal rulemaking effort and for which Arizona might want establish standards.

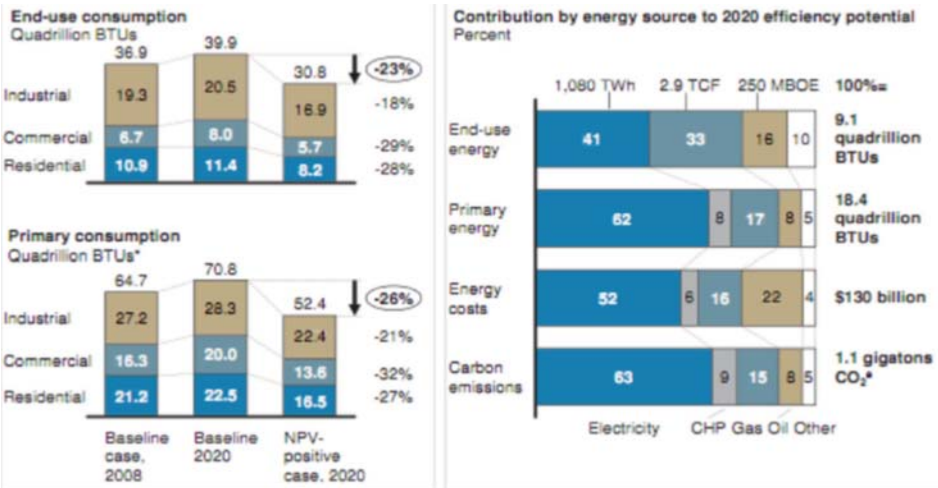
## The Energy Star Experience

The Energy Star program was created in the early 1990s by the U.S. Environmental Protection Agency (EPA) as an attempt to reduce energy consumption and GHG emissions. Today, it is an international program that has been adopted by more than a dozen countries. Devices that use 20-30% less energy than required by federal standards are allowed to carry the Energy Star logo. As of 2006, over 40,000 products have been labeled, ranging from most major appliances, office equipment, lighting, home electronics, and home heating and cooling systems.[14] In 1995, Energy Star introduced labels for new homes and, in 2006, it was estimated that 12% of new homes in the United States had been labeled. In 2006, EPA estimated the Energy Star program saved U.S. consumers about $14 billion.[15] The Energy Star program has not been without controversy. In 2008, an EPA Office of the Inspector General audit discovered that there had been some inaccurate product claims reported.[16] To keep cost manageable, the EPA allowed manufacturers to test and report on their own products, and the EPA only selectively spot-checked the results. The EPA responded by requiring more third-party verification of product performance.

On the whole, the Energy Star program has been extremely successful and an excellent example of a public-private partnership to improve energy efficiency. Today, the Energy Star logo is ubiquitous in industries like information technology and household appliances and is rapidly gaining traction in many other industries. It has demonstrated that, with modest investment, significant energy and economic savings can result. The question now is how much energy and economic savings could result if the United States had a focused national policy in energy efficiency.

## The McKinsey Report

**FIGURE 3** | Forecasted Reductions in Energy Use from Energy Efficiency



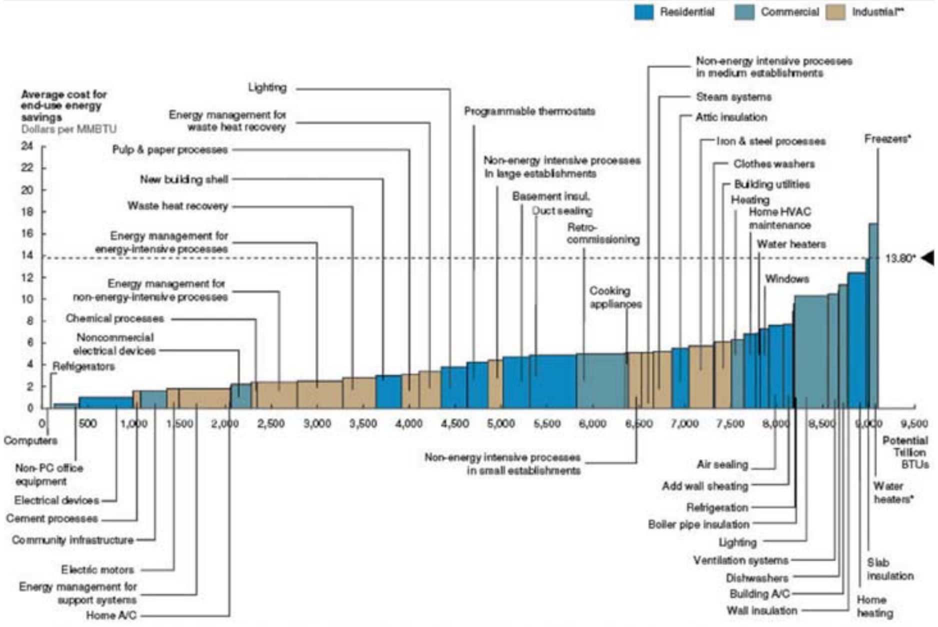
BTU =British Thermal Unit, TWh =Terawatt hour, TCF = Trillion Cubic Feet of Gas, CHP =Combined Heat & Power,
MBOE = Million Barrels of Oil Equivalent, NPV = net present value

Source: EIA Annual Energy Outlook 2008, McKinsey analysis

In 2009, McKinsey & Company, a global management consulting firm, performed an exhaustive review of the potential of energy efficiency in the U.S. economy. In "Unlocking Energy Efficiency in the U.S. Economy," they concluded that energy efficiency is currently the lowest cost energy resource in our economy.[17] By energy resource they mean that energy efficiency programs could help significantly to avoid the need for building more energy production. McKinsey estimated that energy efficiency could reduce end-use energy consumption in 2020 by 23% or 9.1

quadrillion BTUs (based on the EIA's projections, excluding transportation energy) (see Figure 3).

**FIGURE 4** | U.S. Energy Efficiency Supply Curve (2020)

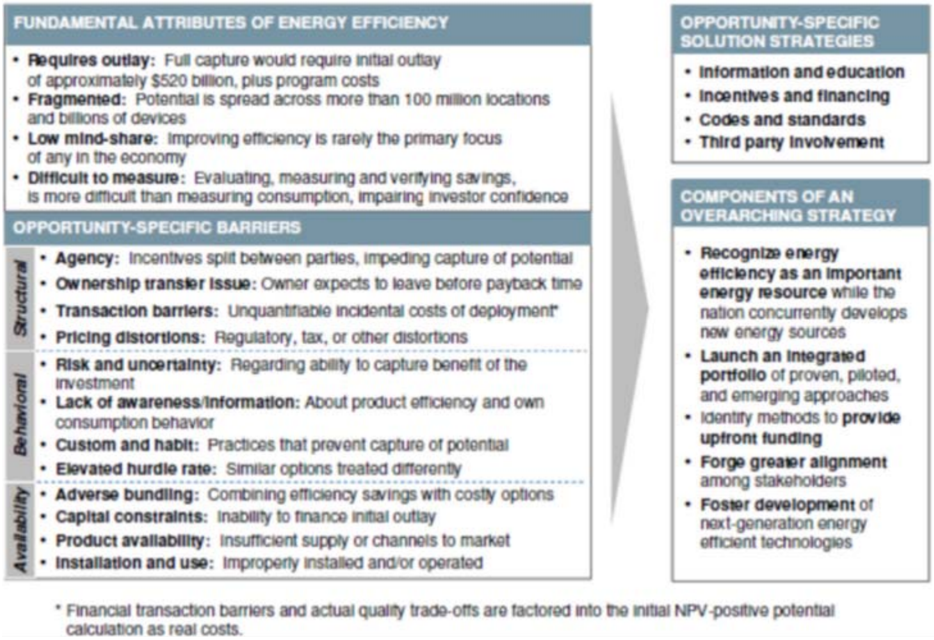


* Average price of avoided energy consumption at the industrial price; $35.60/MMBTU represents the highest regional electricity price used; new build cost based on AEO 2008 future construction costs

** Our 49th source of savings, refining processes, offers no NPV-positive savings

Source: EIA Annual Energy Outlook 2008, McKinsey analysis

**FIGURE 5** | Opportunities and Attributes of Energy Efficiency



FUNDAMENTAL ATTRIBUTES OF ENERGY EFFICIENCY

- **Requires outlay:** Full capture would require initial outlay of approximately $520 billion, plus program costs
- **Fragmented:** Potential is spread across more than 100 million locations and billions of devices
- **Low mind-share:** Improving efficiency is rarely the primary focus of any in the economy
- **Difficult to measure:** Evaluating, measuring and verifying savings, is more difficult than measuring consumption, impairing investor confidence

OPPORTUNITY-SPECIFIC BARRIERS

Structural
- **Agency:** Incentives split between parties, impeding capture of potential
- **Ownership transfer issue:** Owner expects to leave before payback time
- **Transaction barriers:** Unquantifiable incidental costs of deployment*
- **Pricing distortions:** Regulatory, tax, or other distortions

Behavioral
- **Risk and uncertainty:** Regarding ability to capture benefit of the investment
- **Lack of awareness/information:** About product efficiency and own consumption behavior
- **Custom and habit:** Practices that prevent capture of potential
- **Elevated hurdle rate:** Similar options treated differently

Availability
- **Adverse bundling:** Combining efficiency savings with costly options
- **Capital constraints:** Inability to finance initial outlay
- **Product availability:** Insufficient supply or channels to market
- **Installation and use:** Improperly installed and/or operated

OPPORTUNITY-SPECIFIC SOLUTION STRATEGIES

- **Information and education**
- **Incentives and financing**
- **Codes and standards**
- **Third party involvement**

COMPONENTS OF AN OVERARCHING STRATEGY

- **Recognize energy efficiency as an important energy resource** while the nation concurrently develops new energy sources
- **Launch an integrated portfolio** of proven, piloted, and emerging approaches
- Identify methods to **provide upfront funding**
- **Forge greater alignment** among stakeholders
- **Foster development** of next-generation energy efficient technologies

* Financial transaction barriers and actual quality trade-offs are factored into the initial NPV-positive potential calculation as real costs.

Source: McKinsey analysis

The McKinsey report estimates that to achieve these savings would require investment of $520 billion through 2020 (or about $1,700 per person), resulting in $1.2 trillion gross energy savings to the U.S. economy (or $3,900 per person). In other words, these investments would pay for themselves twice over. Such impressive energy savings will not be achievable if demand for energy efficiency cannot be stimulated and delivered to 300 million people, 100 million buildings, and hundreds of thousands of industrial enterprises that make literally billions of products. To make this case, the McKinsey report performed net present value (NPV) calculations out to 2020 for an array of energy efficiency actions. Net present value is a way of calculating how much an investment is worth to an investor. The McKinsey report assumes $13.80 per million BTUs for 2020 energy cost, which is a very conservative assumption—68% below the EIA's 2008 Annual Energy Outlook business-as-usual forecasted energy price for 2020.[18] Any action that costs less than $13.80 per million BTUs dash line would thus represent a good investment (see Figure 4; those investments falling below the dashed line would be NPV positive). In other words, any item that falls below the dashed line in the figure above would ultimately save consumers money by 2020. Also, the width of each action item represents the potential energy savings (in trillion BTUs) and the height of each action item represents the average annualized cost (in dollars per million BTUs) of that item.

The McKinsey Chapter clearly articulates the benefits of energy efficiency and its potential to impact the nation's energy use. It also addresses the complex and persistent set of barriers that has impeded the deployment of energy efficiency initiatives to date. They report authors ask: if all these actions would save people significant money, why is our economy not deploying them more rapidly? They then identify an array of barriers and generate a strategic "map" (see Figure 5) to aid in holistically addressing the energy efficiency challenge. On the left of Figure 5 are lists of the challenges and barriers grouped into three categories: structural, behavioral, and availability. On the right, are specific solutions, as well as an overarching strategy for engaging the full potential of energy efficiency.

## Final Observations

The McKinsey report made five important concluding observations about how to rapidly deploy energy efficiency opportunities at a scale and within a timeframe that can impact the global and regional challenges confronting Arizona and the United States today. They are equally relevant to this Chapter:

1. Recognize energy efficiency as an important energy resource that can help meet future energy needs while the nation concurrently develops new no-and low-carbon energy resources.
2. Formulate and launch at both national and regional levels an integrated portfolio of proven, piloted, and emerging approaches to unlock the full potential of energy efficiency.
3. Identify methods to provide the significant upfront funding required by any plan to capture energy efficiency.
4. Forge greater alignment between utilities, regulators, government agencies, manufacturers, and energy consumers.
5. Foster innovation in the development and deployment of next-generation energy efficiency technologies to ensure ongoing productivity gains.[17]

### Notes

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8 Energy Information Administration. (2009). Energy Prices and Expenditures, Ranked by State, 2009. Retrieved from. http://www.eia.gov/state/seds/hf.jsp?incfile=sep_sum/plain_html/rank_pr.html

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# Chapter 6: **Arizona's Energy/Water Nexus**

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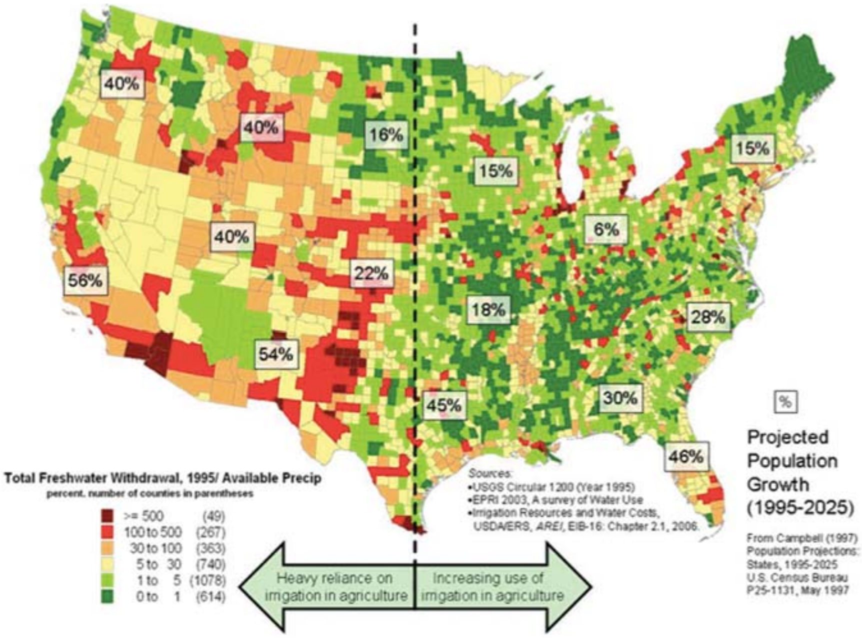
## Overview

- Many traditional sources of energy use considerable water, as do some forms of renewable energy. This makes water an important factor in decisions about energy options.
- The generation of electricity from photovoltaics and wind power require virtually no water.
- When Arizona exports power, it, in a sense, also exports the water used to generate that power. This is also true of other state exports, such as agricultural crops.
- When water use is reduced or water is re-used, this saves electrical power. When electrical power use is reduced, this saves water.
- A significant percentage of Arizona's energy is used to supply water, and vice versa.

The intersection between water and energy has received a great deal of attention in Arizona and around the United States in recent years, and for good reason. Energy and water are two of the cornerstone resources of our civilization, their use is significantly intertwined, and demand for both is rising rapidly. For this reason water and energy sustainability were the topic of a 2010 Blue Ribbon Panel on Water Sustainability[1] created by the Arizona Governor's Office and of a National Energy-Water Technology Roadmap process conducted under the leadership of Sandia National Laboratory.[2, 3]

Of particular concern in Arizona and the Southwest is the growing scarcity of water in the desert. Since the 1990s, people in the Colorado River Basin, which includes primarily Colorado, Arizona, Nevada, and California, have used more water than was recharged by rainfall and snowmelt, drawing down water in reservoirs.[4] This drawdown in water has resulted from considerable growth in population, industry, and agriculture; Arizona's population has grown rapidly and is projected to continue to grow 34% between 1995 and

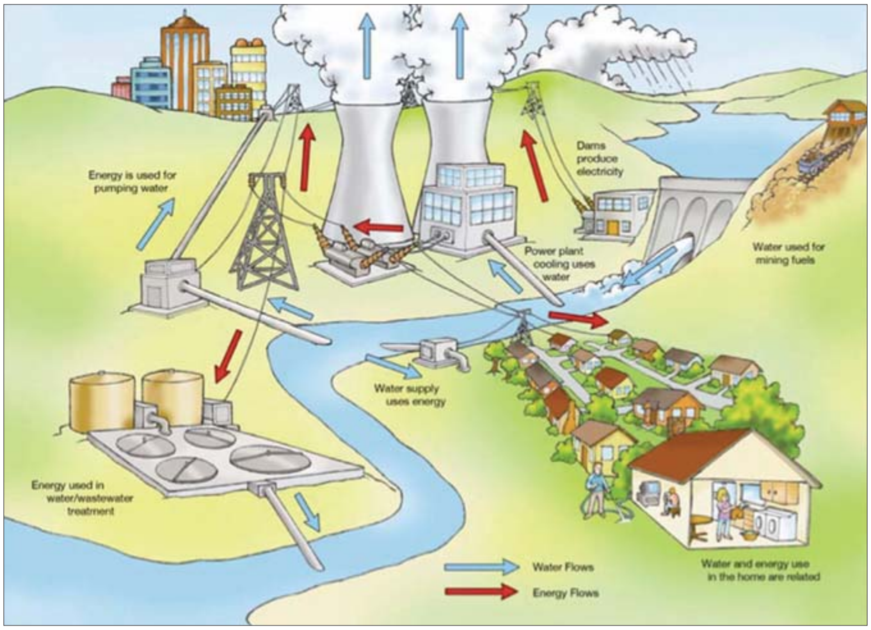
**FIGURE 1** | Emerging Water Stress and Projected Population Growth



Source: Pate et al. 2007[6]

2025.[5] At the same time, the region has suffered a very long drought. Nationwide, and in Arizona, areas of greatest population growth are unfortunately correlated with areas of water scarcity (Figure 1). When supplies are tight, this increases the value of the water resources. Ensuring that water is valued accurately, in turn, helps ensure that Arizonans get the greatest benefit from scarce water resources. In the past, large-scale water infrastructure projects, such as the Central Arizona Project (CAP) (see glossary) and the Salt River Project, helped Arizona escape local water constraints. Such projects are unlikely to find sequels in the 21st century, however. In part, environmental, political, and economic constraints limit these kind of large infrastructure projects. At the same time, water scarcity has grown across the nation, reducing opportunities for moving water to the Southwest. Consequently, Arizona must increasingly live within the constraints of its existing water resources.

**FIGURE 2** | The Inter-Relationship Between Water and Energy



Source: Pate et al. 2007

Water and energy have a unique symbiotic relationship in the human economy (see Figure 2). Water is necessary in the process of making electricity for most types of energy resources, and especially for cooling power plants that use thermoelectric processes (e.g., coal, nuclear, natural gas, solar thermal) and hydroelectric power. At the same time, electrical power is needed to make water available, mostly to pump it from where it is to where it is needed, but also for purification. Thus, the more energy Arizona uses, the more water Arizona uses, and vice versa. Electricity has a "water footprint,"[7] meaning that there is a measurable quantity of water consumed for each unit of electricity produced. Likewise, water has an energy footprint, meaning that there is a measurable quantity of electricity consumed for each unit of water produced. This mutual relationship between water and energy makes both domains more expensive, but it also offers opportunities. Savings in one domain will also create savings in the other domain. The "water intensity" of electrical power production is the amount of water required to produce a given amount of electrical power and is a measure of the water cost of power. According to SRP,[8] a reduction of 10% in water use in the 410,000 households in Phoenix would save enough electricity to power 7,000 homes.[9] Energy planning and water planning are thus closely coupled. As demand for both water and electricity expands, Arizona will need to make difficult decisions about whether electrical power generation is worth the water cost.

## Water Supply for Electrical Power

It is widely known that the kinetic energy of falling water can produce electricity by turning generators. This is a low-pollution and highly efficient process, and Arizona derives significant electrical power from this source, primarily from the large dams on the Colorado and Salt Rivers.

Less well known is that the process of making electricity in thermoelectric power plants, such as nuclear, coal, and gas-fired plants, requires water for cooling. Water is even needed for some modern renewable-energy sources, such as concentrating solar power or biofuels, because these power sources are still thermoelectric. The most common thermoelectric process involves boiling water into pressurized steam (for example, by burning coal or biofuels), which then drives a steam turbine connected to a generator that produces electricity. After passing through the turbine, the steam is either cooled and then recycled as condensed water or vented directly to the atmosphere. The efficiency of the process is proportionate to the temperature difference across the steam turbine, so it is crucial that the "downstream" end of the process (where the water is condensed or released) is cooled to the lowest possible temperature. Water has a very large heat capacity and is available in large quantities, so it is an excellent resource for cooling in the thermoelectric process.

### Units of Measure for Water and Electrical Power

**1 Acre-Foot (AF) of Water** = 325,851 Gallons of water, or roughly the amount used by an affluent single family residence in the Phoenix area

**1 Kilowatt-Hour (kWh) =** ten 100-Watt lightbulbs running for one hour

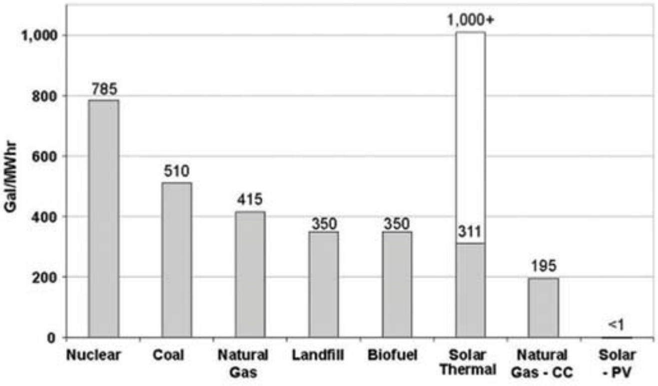
**1 Megawatt-Hour (MWh) =** one thousand kWh

**1 Gigawatt-Hour (GWh) =** one million kWh

Energy use intensity is measured in KiloWatt-Hours per Acre-Foot (kWh/AF)

When both hydroelectric and thermoelectric power plants are factored in, the evaporation of water to produce electricity has become large enough to attract national attention. As a country, the amount of water used for thermoelectric power plant cooling now exceeds the amount of water used for agriculture.[10] This does not mean that cooling and irrigation evaporate a comparable amount of water, but it does mean that comparable volumes of water have to be available for both enterprises, at least nationally. In Arizona, the amount of water used for agriculture still far exceeds the amount of water used for power production. But the latter is nevertheless a significant amount, and it is attracting the attention of many policymakers to the energy/water nexus.

**FIGURE 3** | Average Water Consumption[11] per MWh[12] for Existing Electrical Power Generating Facilities Supplying Arizona (2002-2006), From Scott and Pasqualetti (2011)[13, 14]



Note: The actual value for the single, 1 MW, experimental, concentrating solar power facility in Arizona is 311 gal/MWh,but this under-represents the true water obligations of solar-trough technology. More realistic values, based on experience in California and discussion with industry representatives, is at least 1,000 gal/MWh, unless dry-cooling is employed.)

Water use at Arizona's electrical power plants can be calculated using data from the U.S. Department of Energy and Arizona utilities. Of the conventional sources of electricity currently produced in Arizona, nuclear power uses the most (Figure 3), followed by coal, and conventional natural gas plants. What is perhaps somewhat surprising is that concentrating solar power (CSP) (see glossary) may also require a lot of cooling water. There is a difference in water consumption between "wet-cooled" systems that require constant intake of large amounts of water and "dry-cooled" systems that recycle water in a closed loop very much like is common in automobile radiators and thereby reduce water consumption to a minimum (see glossary). Photovoltaic power plants, wind power plants, and some CSP systems require little water.

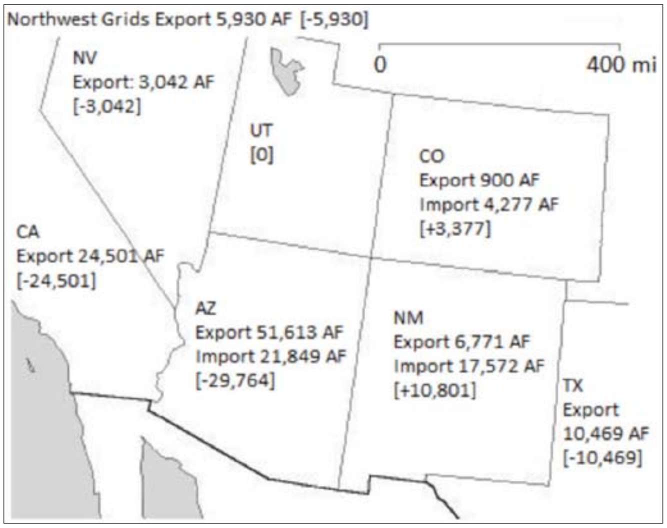
The water cost of power has many consequences for power policy and business. One of the most important is power plant siting, which is subject to two major constraints: transmission and water. All power plants must be located close to power transmission lines that can deliver their electricity to urban power users. However, thermoelectric power plants must also be located where a large source of water is available. For this reason most of the world's large electrical power plants are sited on bodies of water, usually on major rivers, lakes, or the ocean. Because Arizona has few large surface water sources near its urban areas, the primary source of water for power plant cooling in Arizona is groundwater. The major exceptions are the Navajo Generating Station, which is on the Colorado River, and the Palo Verde nuclear power plant, which uses recycled wastewater. Palo Verde is the world's only nuclear facility cooled by recycled water; without this water resource the power plant could not be located where it is, at substantial distance from a major source of surface or groundwater.

Water for cooling has become a major factor in winning approval from regulatory agencies. The Toltec Power Plant, an 1,800 MW gas-fired facility proposed for a site near Eloy, Arizona was denied a Certificate of Environmental Compatibility in January 2002, in part because the Arizona Corporation Commission determined that the 10,000 acre feet (AF) per year the plant would pump from groundwater would cause environmental damage.[15] More recently, the 340 MW Hualapai Valley solar proposal was derailed because its water demand was deemed too high for local water availability.[16]

All future plans for electrical power plants in Arizona will face such siting and economic challenges. One solution to the problem of insufficient cooling water supplies is to use "dry cooling" technologies that require less water. This alternative typically saves 90% of the water requirements of traditional "wet cooling" designs. However, dry-cooled thermoelectric plants are more expensive to build and operate than wet-cooled plants, because of expensive heat exchangers, and they run at a lower efficiency than wet-cooled plants, because the downstream temperature from the steam turbine is not as low when dry-cooling is used. This means that using dry-cooling will be more expensive, and these higher costs will inevitably be passed on to the consumers of electricity. Alternative energy solutions—such as solar photovoltaic and wind turbine power technologies—do not require any cooling water in the generation phase, but these renewable energy plants remain relatively expensive compared with many thermoelectric and hydroelectric power plants. Another alternative is to site new power plants wherever there might be adequate water supplies, even if this is far from Arizona's cities and transmission lines, or even outside the state's borders. This option would sidestep the water-supply issues, but it might require development of costly transmission lines, and it could cost Arizona business opportunities associated with electricity generation.

Energy security is also relevant to discussions of the energy/water nexus. Security of energy supply can be an important factor in decisions about power plant siting and generation technology. If maintaining secure power plants within Arizona's borders is important, then security considerations may dictate that Arizona adopt a policy favoring more expensive, local, low-water electrical generation over less expensive, out-of-state energy sources. Or, Arizona could choose to reallocate existing water supplies from agricultural or industrial purposes to electrical generation. This has already been done; for example, the 280 MW Solana solar concentrating power project under construction near Gila Bend was sited on agricultural land that typically used up to 10 times more water for farming but with a lower economic value than electricity.

**FIGURE 4** | Arizona is a Net Exporter of 29,764 AF of Water Embedded in Electrical Power[17] (AF = Acre-Feet)



The energy/water nexus will also influence the degree to which Arizona expands its current role as an exporter of electrical power or whether Arizona chooses to become a net importer of electrical power. Currently, Arizona exports considerable energy to neighboring states. In the process, it also effectively 'exports' around 30,000 acre-feet of water per year to produce power that is transmitted to other states; this water is, in a sense, 'embedded' in the electricity (Figure 4). As neighboring states in the United States and Mexico continue to grow and face their own problems with water shortages and air pollution, their demand for energy from Arizona will grow, especially from Southern California. Ironically, this pattern will be reinforced by alternative water supply systems, such as the saltwater desalination process being implemented in San Diego and proposed for several sites along the California coast. Exporting electricity provides economic benefits for Arizona, but it costs water, whereas importing electricity costs economic opportunities but saves water. This is, of course, true for other products as well, especially agricultural products such as cotton.

In summary, Arizona's policy choices regarding the energy/water nexus can have impacts on technology choices, siting of power plants, energy security, land use, and international and inter-state relations.

## Electrical Power for Water Supply

Every use of water in Arizona involves electricity and other forms of energy. The ancient civilizations in the Valley of the Sun relied on gravity-fed, canal-conveyed water supplies from the rivers. Arizona still uses gravity, but Arizona also must use electricity-intensive pumps. This is just one example of the energy costs of water. Electricity costs are incurred in many parts of the water supply process, for example:

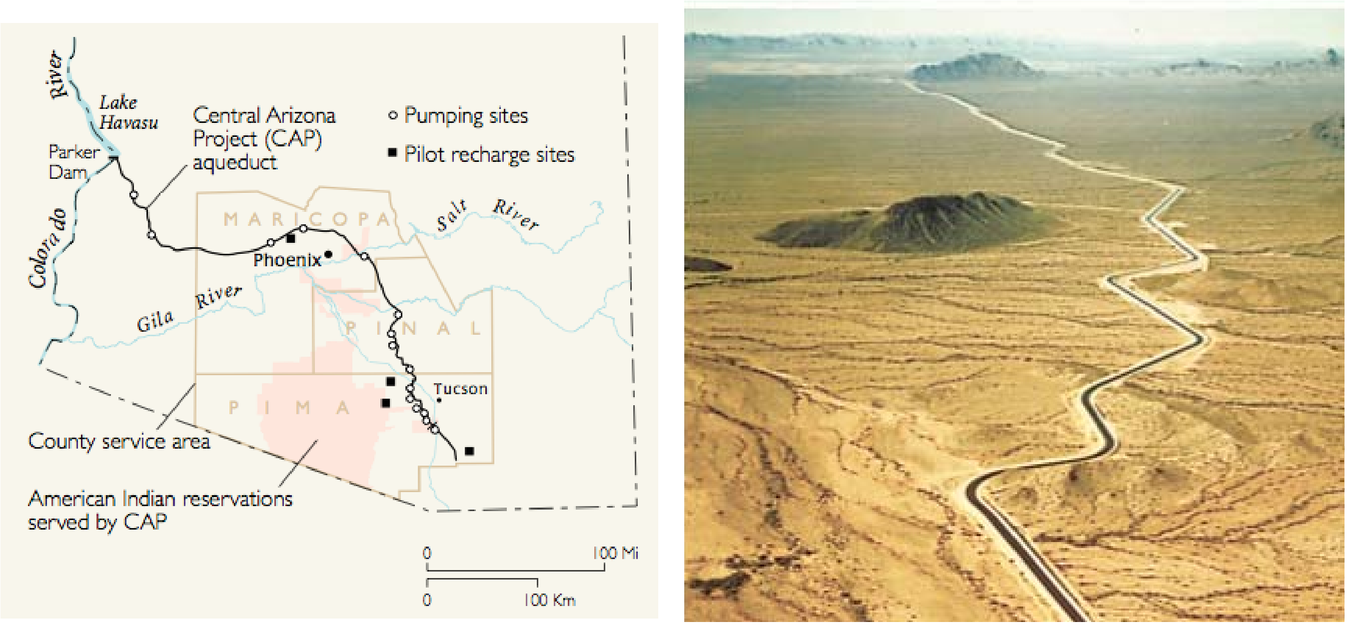
- An artificial river of water is lifted hundreds or thousands of feet in elevation from the Colorado River, and from groundwater aquifers, for delivery to the major cities and agricultural irrigation districts of Central and Southern Arizona.
- Potable water delivered by municipalities to residential, commercial, and industrial customers is subjected to energy-intensive treatment processes and is then sent via electrically powered pumps to customers' homes and places of business.
- Treatment and reuse of sewage water on golf courses, landscaping, and the Palo Verde nuclear power plants requires pumping from sewers to the wastewater treatment plant, followed by the use of energy in the treatment process itself, and then more pumping to get the water to the golf course.

- When Colorado River water is used to replenish the groundwater in Phoenix,[18] this results in more pumping costs when the groundwater is later used by cities and farms. Indirect electrical costs can also accrue; for example, during a severe drought, water deliveries from the hydro-electric reservoirs for dry-season agriculture and water supply could potentially prevent the use of that water for power generation.
- Because electric pumps for water supply and wastewater services are so crucial for public safety in Arizona's cities, electrical utilities maintain expensive backup equipment and levels of redundancy that would not otherwise be required; this adds to the overall cost of electricity.

A comprehensive accounting of the electrical power costs of water services in Arizona is more cumbersome than calculating the water costs of power service for many reasons, including that there are far more water providers (and self-supplied water users) than energy producers, so the available data is more complicated and less complete. Nevertheless, several approximations may be made. The section below reviews the categories of water uses in Arizona, describes the typical profile of energy use for each category, presents some results from recent research on the topic, and discusses possible options for how Arizona might best conserve its electrical power resources through wise water resources decision-making.

According to the Arizona Department of Water Resources Water Atlas, 6.86 million acre-feet of water (i.e., 2.24 trillion gallons of water)[iii] was used to meet human water demands in Arizona. Forty-one percent of this water came from the Colorado River (24% via the canals of the CAP), 39% from the groundwater aquifers, 16% from the Salt and Verde Rivers as stored and delivered by the SRP, and 3% from recycled sewage in urban areas. Water banking projects are also being conducted by recharging Phoenix-area aquifers using extra surface water, to sustain the viability of the aquifer. Of this total water, self-supplied industries used 6%, municipal water providers and their customers used 25%, and irrigated agriculture used 69%.[19] Overall water demand is slowly shifting from agricultural to municipal water uses as urban sprawl and population growth displace agricultural areas in Central and Southern Arizona.

**Figure 5** | Schematic and Aerial View of the Central Arizona Project[21]

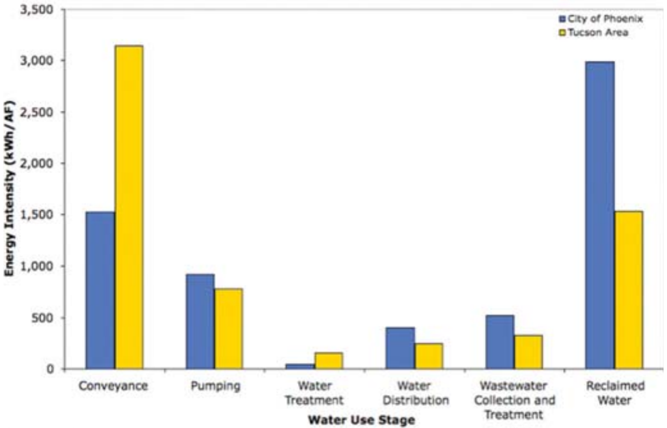


Source: USGS Circular 1182

A segment of the CAP aqueduct snakes through the desert west of Phoenix

The Central Arizona Project (CAP) pumping of water uses relatively high amounts of energy per gallon of water delivered, as a result of the 336 miles of total length and thousands of vertical feet of lift required to deliver water to Tucson (see Figure 5). Pumping CAP water from the Colorado River to Phoenix requires over 1,500 kWh per Acre-foot of water, and pumping the same water to Tucson requires 3,200 kWh per acre-foot of water due to the increased distance[20] (see Figure 6). By contrast, the amount of electricity used to supply water from the Salt and Verde Rivers and from groundwater aquifers is significantly lower, since this water only needs to be pumped for shorter distances.

**Figure 6** | Electrical Energy Intensity of Water and Wastewater Services for the City of Phoenix and Tucson Metropolitan Area[32]



Source: Scott et al. 2009

Arizona's largest water use is for irrigation. The energy consumption for this water use ends with its pumping and delivery to the fields. For drinking water, however, energy is also required to treat the water to potable standards, and wastewater treatment (especially to achieve potable reuse quality standards) consumes even more power. Nationwide, roughly 4% of total electricity generated is used by water utilities for water treatment and distribution.[22]

Total energy use for water is higher in dry western states that pump and convey large amounts of water for cities and for irrigated agriculture. Recent estimates by the state of California have placed its fraction of total electrical power consumed for all water-related purposes at 19%,[23] including water-related power costs such as water heating in industry and in the home. The comparable number in Arizona is 9.5% of total electricity for all water-related uses (see Table 1 notes).[24] Neglecting end uses such as water heating, which comprise more than half of the total,[25] 3.5% of Arizona's total electricity is consumed by water supply and treatment, a number similar to the national average (see Table 1 notes). If Arizona is spending an estimated $628 million per year on electricity for water-related uses (see Table 1), this means that 3.3% of Arizona's total $18.9 billion annual expenditure on energy[26] is for water-related electrical uses. Table 1 presents rough estimates for the average water use, electrical consumption, energy use intensity, and electricity costs for Arizona's major water use categories, based on a synthesis of several water and energy studies.

Relatively precise numbers are now becoming available for power use for water delivery in specific Arizona municipalities, thanks to recent work funded in part by the Department of Energy's Sandia National Laboratory, the Arizona Water Institute, and ASU's Decision Center for a Desert City. In the typical municipal water system, at least 80%, and up to 98%, of power consumption is associated with pumping to distribute pressurized potable treated water to houses and businesses, with the remainder of power consumption associated with water treatment processes.[27] In Phoenix and Tucson, average energy intensity for potable water treatment and delivery is approximately 500 kWh per acre-foot.[28, 29] By comparison, for recycled sewage to be treated and used to water golf courses, landscaping, and to cool power plants, the energy intensity in Phoenix is close to 3,500 kWh per acre-foot and in Tucson is close to 2,000 kWh per acre-foot[30, 31] (See Figure 6). However, because using this recycled water avoids pumping and treating additional raw surface water from the CAP system, recycled water is a relative bargain, saving both energy and water compared with raw water supplies in Arizona.

**TABLE 1** | A Summary of Water Use, Electricity Use, and the Associated Costs in Arizona

| | Water[a] (MAF) | Electricity[b] (GWh) | Intensity[i] (GWh/MAF) | Electricity Cost[d] (USD) |
|---|---|---|---|---|
| **Water Supply and Treatment[a]** | 6.86 | | | |
| Urban and Industrial | 2.13 | 1898 | 893 | $162,089,200[g] |
| Agricultural | 4.73 | 492 | 104 | $42,061,800 |
| **Wastewater Treatment[c]** | 0.71 | 77 | 109 | $65,575,800[g] |
| **End Uses of Water[e]** | 2.13 | 4888 | 2295 | $417,435,200 |
| **Total** | **6.86** | **7355** | | **$628,117,000**[f] |

MAF= Millions of Acre Feet
GWh= gigawatt hours
kWh/AF= kilowatt hours per acre foot

a ADWR Water Atlas (2010), using 2006 numbers: 69% of Arizona water is consumed by agriculture, 25% by urban/municipal, and 6% by self-supplied industrial users.

b Electrical numbers are from Hoover (2009, 2010) and personal conversations with Joe Hoover, computed using various years and sources. Owing to incomplete data availability, these electrical consumption numbers are relatively uncertain and may be significantly underestimated. These numbers have not been peer reviewed, and should be understood as rough estimates.

c Assuming that an average of one third of municipal and industrial water use is collected and treated as wastewater after the primary use, and given that 31% of Arizona's 6.86 MAF of water is used by urban municipalities and self-supplied industries (ADWR Water Atlas 2010), an estimated 0.31 / 3 = 10.4% of Arizona's 2.13 MAF urban and industrial water use is treated as wastewater. This yields an electrical energy intensity of 142 kWh/AF, which is significantly below the national average of 517 kWh/AF for urban wastewater treatment (EPRI 2002). This estimate could be low due to overestimated wastewater volumes, underestimated wastewater treatment electricity consumption, or because some large self-supplied industrial uses of water require very little or no electricity to treat their wastewater.

d Assuming electricity cost of 8.54 cents per kWh, or $85,400 per GWh (SWEEP 2009).

e End uses typically include water heating and specialized industrial processes; this number includes Residential and Industrial end uses but omits other end uses. The energy intensity of heated water in residences can be extremely high (measured in tens of thousands of kWh/AF). This number is highly uncertain because much water heating is done using natural gas and because calculating industrial, commercial, and agricultural energy intensities depend on missing electrical usage data. Residential electrical end use intenstities have been estimated by APS and the Salt River Project (Collins 2010, etc.).

f Compare this $628 Million number with the $18.9 Billion (SWEEP 2009) that Arizona spent on all energy in 2007. $628M / $18.9B = 3.3% of total Arizona expenditures on all energy sources are expended for water related uses. 77,193 GWh (SWEEP 2009) of total electricity is generated in Arizona, so the 7355 GWh for water related uses represents 7355 / 77,193 = 9.53% of the total electricity use in Arizona (following Hoover 2010).

g Given that in total U.S. water utilities spend roughly $4 Billion per year on electricity for water supply and treatment (USEPA 2008), and given that Arizona has roughly 2% of the U.S. population, then Arizona's share of water and wastewater utility electricity spending is roughly $80 Million; compare this with the roughly $162M x 0.25 / 0.31 = $131M spent annually on electricity by Arizona's public water supply utilities, plus the roughly $6.6M spent on electricity by public wastewater utilities to treat Arizona's wastewater. Therefore, Arizona water and wastewater utilities spend, on average, roughly $137.6M / $80M = 1.7 times the national per-capita average on electricity for water supply and treatment. This is reasonable because of Arizona's relatively high electrical demands for water pumping to move water through the CAP project to its major urban centers.

i GWh/MAF converts directly to kWh/AF with a 1:1 ratio.

## Water Policy for Sustainable Electrical Power in Arizona

In 2010, Arizona Governor Jan Brewer convened a Blue Ribbon Panel on Water Sustainability,[33] with the goal of providing recommendations for water and water-related energy policy in Arizona. Because many of the leading experts on the topic contributed to this panel, the following discussion of policy will begin with a summary of the panel's recommendations for water sustainability related to energy use in Arizona:

- Increase the volume of reclaimed water (meaning treated wastewater) reused for beneficial purposes in place of raw or potable water,
- Advance water conservation, increase the efficiency of water use by existing users, and increase the use of recycled water for beneficial purposes in place of raw or potable water,
- Reduce the amount of energy needed to produce, deliver, treat, reclaim and recycle water by the municipal, industrial, and agricultural sectors,
- Reduce the amount of water required to produce and provide energy by Arizona power generators, and,
- Increase public awareness and acceptance of reclaimed and recycled water uses and the need to work toward water sustainability.

Because water savings produce power savings, water sustainability is also power sustainability. In many cases water conservation is the most cost-effective means of reducing power generation requirements and costs. The National Regulation Research Institute  recommends electricity-saving changes in how municipalities deliver their water:

- Using higher-efficiency pumps, variable-speed pumps and efficient computerized control systems,
- Consolidating water utilities to increase economies of scale and improve efficiency,
- Fixing water system leaks (leaks typically consume 10% to 20% of total water deliveries, due to aging pipes and infrastructure), and
- Adopting a formal quality management system for water leaks and energy consumption.

For residential water users, there exists a collection of energy uses that are not directly related to water supply, but which are related to water use in the home. Chief among these is energy use (electricity or natural gas) associated with heating water in home appliances, such as the water heater, stovetop/range, dishwasher, and clothes washing machines. These appliances use energy in kWh-per-gallon quantities that dwarf the electricity required to pump and treat the water used for cooking, showering, and washing. SRP claims that roughly 80% of water-related energy uses in Phoenix residences are due to water heating, not water pumping or treatment. When aggregated by the millions, these residential appliances (and their industrial and commercial equivalents) use large amounts of energy to make the delivered water useful for a specific purpose. Improving the efficiency of these devices' water use and power use can effectively reduce the energy associated with water use. Renewable energy technologies, especially solar water heating, can dramatically reduce the water-heating energy use in the home. Improvements in domestic and industrial indoor water use efficiency, and the use of water-saving xeriscaping techniques for outdoor water uses, have resulted in declining per-capita water consumption in Arizona.[36] This translates into electrical power savings.

In Arizona, outdoor water uses for landscaping are often largest sources of residential water use, so "smart controllers" and control systems to reduce over-application of water can result in dramatic overall water savings. Xeriscaping programs should be utilized with care, both because of evidence that homeowners tend to dramatically over-water xeriscaped landscaping (thus negating the desired water savings), and because of an emerging awareness of the role of vegetation in mitigating the urban heat island effect.[37]

Agricultural irrigation represents the single largest opportunity to save both water and power in Arizona. For agricultural water users, well-understood methods of irrigation efficiency can significantly reduce total water requirements. Drip irrigation and controlled flood irrigation methods are both more efficient than sprinkler systems for most crops. Finally, because farm irrigation equipment and pumps are often of a lower efficiency than equivalent municipal systems, these systems are a prime target for improvements in efficiency.

Looking into the future, a number of changes are on the horizon that threatens to increase the amount of power that is used for water supply in Arizona. The future challenges of a water and energy policy include:

- Increased groundwater recharge can increase power consumption due to the additional pumping cycle introduced each time a gallon is recharged and re-extracted.
- Depletion of groundwater aquifers due to over-pumping can result in damage to groundwater quality, requiring more treatment before groundwater is used (and therefore more energy), and in increased pumping costs due to lowered water tables.
- Utilization of increasingly distant water supplies in Utah, Nevada, Colorado, or the ocean to supplement Arizona's current renewable supply would require pumping energy even greater than that used by the CAP project.
- The threat of emerging micro- and nano-contaminants, along with growing *E. Coli* and bacterial contamination of many water sources, may motivate the U.S. Environmental Protection Agency to mandate more expensive and energy-intensive water and wastewater treatment protocols (such as ultraviolet disinfection or superfiltration).
- Climate change may reduce dry-season water levels in Arizona's reservoirs, creating an indirect power-generation cost by reducing the availability of hydroelectric facilities for power generation, and
- Growing cities may require added outdoor water use to provide the heat-island mitigation and other ecosystem services associated with vegetation use in major urban areas.

By understanding the fundamentals of power use for water services in Arizona, and the fundamentals of water use for electrical power generation, it is possible to appreciate that the path to greater energy sustainability includes the conservation of water. This knowledge can provide the foundation for a more sustainable and beneficial energy future for Arizona.

## Notes

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9 This represents a marginal savings of 2% of residential energy consumption due to a 10% reduction in water use. SRP uses a basis of 120,000 gallons per year of water use for an average Phoenix household. An additional 80 million gallons of water would also be saved at the Palo Verde power plant which powers most of Phoenix, due to the decreased electrical requirements for water supply to those households.

10 Electric Power Research Institute. (2002). *Water and Sustainability (Volume 4): U.S. Water Consumption for Water Supply & Treatment—The Next Half Century.* Topical Report.

11 The actual value for the single (1 MW), experimental, concentrating solar power facility is 311 gal/MWh, but this is seen as unrepresentative of the true water obligations of solar-trough technology. More realistic values, based on experience in California and discussions with industry representatives, is at least 900 gal/MWh (and perhaps more), unless dry-cooling is employed (Scott and Pasqualetti, 2011).

12 Unit Sense: 1 Acre-Foot (AF) of water is equal to 325,851 gallons of water. 1 KiloWatt-Hour (kWh) = ten 100-Watt lightbulbs running for one hour. 1 GigaWatt-Hour (GWh) is one million kWh, and 1 MegaWatt-Hour (MWh) is one thousand kWh. Water use intensity is measured in KiloWatt-Hours per Acre-Foot (kWh/AF).

13 Scott, C. & M.J. Pasqualetti. 2011. Energy and Water Resources Scarcity: Critical Infrastructure for Growth and Economic Development in Arizona and Sonora. *Natural Resources Journal,* 50(3): 645-682.

14 See footnote 11.

15 ACC (Arizona Corporation Commission). (2002). Toltec Power Project Denied. Retrieved from http://www.azcc.gov/divisions/utilities/news/pr01-31-02.htm.

16 Adams, S. (2010). Hualapai must be dry to fly. *Kingman Daily Miner.* http://kdminer.com/Main.asp?SectionID=1&SubSectionID=1&ArticleID=40780.

17 The amount of water "exported" via power exports is calculated by computing the net power export, and associating that export with the amount of water consumed for the production of the power. Sometimes called net 'virtual water' (Allan 1993), the more power that is produced in Arizona for export, the more of Arizona's water will leave the state.

18 Nationwide, groundwater supply consumes roughly 30% more electricity per unit volume of water supplied as compared with surface water supply (EPRI Volume 4, 2002). This does not consider the electricity costs of lifting and conveying surface water from distant sources, e.g. the Central Arizona Project canals.

19 Arizona Department of Water Resources. (2010). Water Atlas.

20 Scott, C., M. Pasqualetti., J. Hoover., G. Garfin., R. Varady., & S. Guhathakurta. (2009). Water and Energy Sustainability with Rapid Growth and Climate Change in the Arizona-Sonora Border Region. *Arizona Water Institute.*

21 USGS Circular 1182.

22 Electric Power Research Institute. (2002). *Water and Sustainability (Volume 4): U.S. Water Consumption for Water Supply & Treatment—The Next Half Century.* Topical Report.

23 California Energy Commission. (2005). California's Water-Energy Relationship. Final Staff Report. CEC-700-2005-011-SF.

24 Hoover, J.H., (2009). The Arizona Water–Energy Nexus: Electricity for Water and Wastewater Services. M.A. Thesis. Tucson, University of Arizona.

25 For example, roughly 80% of electrical usage associated with water in residences in the Salt River Project service area in and around Phoenix, Arizona is due to hot water heating; the balance is associated with water pumping and treatment (Collins 2010).

26 Southwest Energy Efficiency Project (SWEEP) (2009), Arizona Fact Sheet: Energy Efficiency and Energy Consumption.

27 Electric Power Research Institute. (2002). *Water and Sustainability (Volume 4): U.S. Water Consumption for Water Supply & Treatment—The Next Half Century.* Topical Report.

28 Scott, C., M. Pasqualetti., J. Hoover., G. Garfin., R. Varady., & S. Guhathakurta. (2009). Water and Energy Sustainability with Rapid Growth and Climate Change in the Arizona-Sonora Border Region. *Arizona Water Institute.*

29 This compares favorably with the national industry standards of roughly 500 to 800 kWh per Acre-foot for treatment of water to potable quality (EPRI, 2002), owing in part to the relatively new and energy-efficient technology used in Phoenix and Tucson water treatment plants compared with older plants throughout the U.S.

30 ibid.

31 These power costs are comparable with the roughly 2000 KWH per Acre-foot to treat brackish groundwater and the worst-case water treatment energy usage of 4000 KWH per Acre-foot to desalinate salt water using Reverse Osmosis or thermal distillation methods (EPRI, 2002). Of course, treated wastewater is a form of brackish or salt water, depending on who or what is discharging into the system.

32 The energy intensity of potable water supply in Phoenix and Tucson is significantly higher than the average for the State of Arizona as a whole, due to higher treatment standards, significant recycling of treated sewage, and especially the massive energy costs of the Central Arizona Project water that feeds these two cities. Treatment and reclamation numbers are based on a sample of treatment plants rather than on comprehensive accounting of energy use, so the real numbers may be somewhat different. In particular, it has since been argued that the energy intensity of reclaimed water in Phoenix is significantly lower than the roughly 3000 kWh/AF stated in this figure, and future publications may reflect a more accurate accounting.

33 Arizona Department of Water Resources Blue Ribbon Panel. (2010). Final Report of the Governor of Arizona's Blue Ribbon Panel on Water Sustainability. Retrieved from http://www.azwater.gov/AzDWR/waterManagement/BlueRibbonPanel.htm.

34 Chakroff, David D. (2008). Reducing Electricity Used for Water Production: Questions State Commissions Should Ask Regulated Utilities. National Regulatory Research Institute Water Research and Policy. Retrieved from http://nrri.org/pubs/water/reducing_electricity_used_for_water_08-06.pdf.

35 Collins, K. (2010). The Electricity Embedded in Water: Two Sides of the Same Coin. Presentation to the Governor's Blue Ribbon Panel. March 5, 2010.

36 Arizona Department of Water Resources. (2010). 2010 Water Atlas.

37 Gober, P., A. Brazel, R. Quay, S. Myint, S. Grossman-Clarke, A. Miller & S. Rossi. (2010). Using watered landscapes to manipulate urban heat island effects: how much water will it take to cool Phoenix?, *Journal of American Planning Assoc.* 76(2010), pp. 109–121.

# Chapter 7: **Tribes and Energy within Arizona**

*Pat Mariella, Teresita Clashin, and Shawn Williams*

## Overview

- Almost of all the mineral-based energy resources within Arizona, particularly coal, are on tribal lands.
- The 2,250 MW Navajo Generating Station, which is on the Navajo Nation, is the second largest power plant in Arizona. There are also numerous natural gas pipeline segments, transmissions lines for electricity and hydroelectric dams on tribal lands in the state.
- Tribal governments have jurisdiction over tribal lands and resources and are critical players in energy production and distribution within Arizona. Tribal governments are not political sub-divisions of the state, and there are federal and tribal laws and policies that specifically apply to energy development on tribal lands.
- There are significant solar, wind, and biomass resources on tribal lands in Arizona. Like other governments, tribal governments are developing partnerships to pursue larger-scale development of these resources. In addition, tribal governments are making significant use of on-site renewable energy (particularly solar panels) for homes as well as public buildings and facilities.
- Tribal governments are seeking greater ownership and control over mining, power plant, and transmission line projects on their lands.
- More than 14% of American Indian households on reservations lack electricity, compared to less than 1.5% of non-Indian households.

Tribes are critical to energy production in Arizona and are key players in the future of energy throughout much of the West. Collectively, Indian tribes occupy 28% of the total land area of Arizona, and almost all of the mineral-based energy sources within Arizona, particularly coal, are on tribal land. The Black Mesa region of Arizona, home of the Hopi and Diné (Navajo) peoples, is the location of large coal deposits. Yet, paradoxically, more than 14% of American Indian households on reservations lack electricity compared to less than 1.5% of non-Indian households.[1]

In 2009, Arizona produced 7.5 million tons of coal and imported 13.4 million tons for power production.[2] Estimates of the size of Arizona's coal reserves vary widely. According to the U.S. Geological Survey, studies in the 1950s of the Arizona Black Mesa coalfield estimated that Arizona had approximately 21 billion tons of coal reserves. The EIA estimated that in 1992 Arizona had 102 million tons of demonstrated underground coal reserves and 135 million tons of demonstrated surface coal reserves, for a total of 237 million tons of demonstrated coal reserves. Further, in 1992, there were 51 million tons of total recoverable underground coal reserves and 106 million tons of surface coal reserves, for a total of 157 million tons of recoverable coal reserves. There is currently no coal underground mining in the state, only surface mining.[3] Current estimates of the quantity of coal reserves in Arizona are withheld to avoid disclosure of individual company data, which means that it is unclear just how much coal is currently available for mining.

Tribal lands are located throughout the state in a wide variety of geological and meteorological settings, many that are well-suited to renewable energy development. There are 22 federally recognized tribal governments within the boundaries of the state of Arizona that vary in land base, population size, and cultural traditions, some near urban areas and others in remote locations. Arizona includes the tribe with the largest land base in the United States (the Navajo Nation, whose land extends into New Mexico and Utah), as well as a tribal government with no current land base (the San Juan Southern Paiute). Tribal governments are not political sub-divisions of the state, and they retain substantial sovereign powers, particularly within their own jurisdictions. However, tribal governments, including those within Arizona, are also affected by federal energy laws and policies that have evolved over the past century, a number of which were specifically enacted to control energy resources within Indian Country. Increasingly over the past 30 years, federal laws and policies have attempted to remove legal barriers and identify resources for tribal governments to manage and control the development of energy resources on their lands. In addition, tribal governments are working to control and manage the transmission and delivery of electricity through tribal utilities.[4]

The American Indian people who lived within what is today the state of Arizona developed ways of life that were energy-efficient and well adapted to the land and climate. Even today, households on tribal lands continue to use the least electricity of any population within the state. Yet while more than 18,000 households in the Navajo Nation do not have electricity,[5] two of the largest coal-fired electrical generating stations in the Southwest are located there (Four Corners Power Plant and Navajo Generating Station), and the coal that powers them comes from Navajo and Hopi lands.[6] As a result of historical rights-of-ways, many of the large natural gas pipelines and transmission lines that traverse Arizona run through tribal lands. The natural gas pipelines are a source of power generation at Fort Mojave and potentially in other tribal locations. Importantly, many tribes have substantial potential for wind, solar, and biomass power generation because of their locations, substantial land base, and generally rural land-use traditions that result in tracts of undeveloped land.

This chapter briefly attempts to summarize a significant and complex set of challenges and opportunities relating to energy production and energy use on tribal lands within Arizona. While continuing to make use of revenues from coal mining and coal-fired power generation, tribes are also establishing a range of renewable energy projects,

**FIGURE 1** | Tribes within Arizona

from utility-scale wind projects to off-grid solar panels on remote home sites. Similar to other governments, tribes are working though the challenges of accessing federal energy tax credits through financial partnerships. Tribes are also making major efforts to construct homes, governmental buildings, and facilities that are energy efficient, in some cases using traditional materials and design elements. Importantly, tribal governments are actively seeking to increase their ownership in power generation and transmission, now and into the future.

## Utility-Scale Power Generation on Tribal Lands in Arizona

### Navajo Generating Station

Over 40% of the electricity generated in Arizona comes from coal, and a significant portion of the coal-fired electricity generated in Arizona comes from power plants located on leased land within the Navajo Nation. The Navajo Generating Station, near Page, Arizona, is operated by the Salt River Project (SRP) and is owned by a partnership of five utility companies as well as the U.S. Bureau of Reclamation.[7] The Navajo Generating Station produces over 17 million megawatt hours (MWh) of energy on an annual basis delivered to Arizona, Nevada, and California. The coal that is burned at the Navajo Generating Station comes from the Kayenta Mine, also on the Navajo Nation land; the mine is owned and operated by Peabody Energy through lease agreements with the Navajo Nation and the Hopi Tribe.

### Four Corners Power Plant

While the Four Corners Power Plant is located in New Mexico, it lies near the Arizona border on the land of the Navajo Nation. Part of the electricity generated at Four Corners is provided to Arizona, as well as New Mexico, California, and Texas. The coal burned at Four Corners comes from the Navajo Mine in New Mexico located on land leased by the Navajo Nation to BHP Billiton.

### South Point Energy Center

The first merchant power plant to be built on tribal lands, South Point Energy Center, was completed in 2001 on leased land of the Fort Mojave Tribe in Arizona. Owned by Calpine, South Point uses natural gas and has the capacity to produce 540 MW aimed at meeting the peak summer power demand in Arizona, California and Nevada.

## Benefits, Costs, and Pressures on Coal-Fired Power Plants

The Navajo Generating Station provides over 500 jobs to the area around Page, Arizona, over 80% of which go to American Indians. The plant and the associated Kayenta coal mine provided $137 million in revenue to the Navajo Nation government, as well as wages to tribal members. According to testimony presented in Congressional hearings in May 2011, the revenue from the coal mines, the leases, and rights-of-way provide almost 30% of the Navajo Nation's tribal budget and close to 88% of the portion of the Hopi Tribe's operating budget that comes from non-governmental sources.

Power from the Navajo Generating Station provides 95% of the power needed to pump the Central Arizona Project's (CAP) water from the Colorado River to central Arizona (see the glossary for more on CAP). CAP provides almost 90% of Tucson's water and 40% of Phoenix's water. The federal Bureau of Reclamation is a major partner in CAP. Revenue from the sale of the power generated by the Navajo Generating Station is used to repay the federal government loans provided for the construction of CAP. In the future, revenue from the Navajo Generating Station is anticipated to cover the costs of tribal water system developments.

The type of coal extracted from mines on tribal lands in northeastern Arizona and northwestern New Mexico (i.e. sub-bituminous coal) produces less sulfur emissions when burned than other types of coal mined in the United States. Even so, burning coal in power plants is one of the largest smokestack-sources of air pollution in the country. The Navajo Generating Station is one of the oldest coal-fired plants in Arizona; therefore, its pollution control technology is also older. It is the 11th largest power-plant source of nitrogen oxide emissions in the United States. Nitrogen oxide emissions are a component of smog that increase the number and severity of asthma attacks and have a burning effect on human lungs. Coal-fired plants also emit microscopic particles, called particulate matter or soot, which can enter our blood streams through the lungs, potentially increasing the risk of death from heart attacks and strokes. In addition, coal-fired power plants are the most significant smokestack-source of mercury, which can cause neurological damage, particularly in children. Following the 1990 amendments to the Clean Air Act, the federal Environmental Projection Agency (EPA) required many coal-fired plants, including the Navajo Generating Station, to reduce emissions. New rules proposed by the EPA to protect human health under the Clean Air Act would require additional emission reductions by most coal-fired stations, particularly for older plants.

The pollutants emitted from Navajo Generating Station not only have an impact on surrounding locations, they also are transported through the air and contribute to reduced visibility at the Grand Canyon and other national parks and wilderness areas in the Four Corners region, which are significant tourist destinations. As required by the Federal Clean Air Act, the EPA is developing a permit for the Navajo Generating Station to reduce emissions to protect visibility. The additional emissions control technology would require substantial investment by the utilities that own the plant, and they have expressed concerns about the costs of the most stringent pollutant-reducing technologies the EPA has proposed. The utilities have suggested that they would consider shutting down the plant rather than paying the costs for the new equipment. Given the significant economic reliance on revenues associated with the plant by the both the Hopi Tribe and Navajo Nation, the possibility of plant closure is a very important issue to both tribal governments.

In addition, the Navajo Generating Station releases 19 million tons of carbon dioxide per year making it the 5th largest power plant emitter of this greenhouse gas in the United States (see “greenhouse gases” in the glossary). Although there are no federal emission limits on greenhouse gases, and the immediate prospect of limits seems unlikely, there is a future possibility that the coal-fired plants, including Navajo Generating Station and Four Corners, will need to reduce carbon dioxide emissions. Research on technologies like carbon capture and sequestration (see glossary) might provide future possibilities for reducing these emissions and their potential impact on climate change.

The costs and benefits of power generation within the United States generate significant, and often polarized, debates throughout the country. There are also conflicts in Indian Country over energy production on tribal lands. The issues surrounding the Mohave Generating Station near Laughlin, Nevada, in the 1990s and earlier this decade exemplify the potential conflicts surrounding energy development by non-tribal entities on tribal lands. The Mohave Generating Station burned coal from the Black Mesa Mine, the largest strip mining operation in North America, which was operated at the time by Peabody Western Coal. The coal was transported from Black Mesa, on traditional lands of the Hopi and Diné people, through a 270-mile long pipeline that used water pumped from under Black Mesa to form coal slurry. Both the Navajo and Hopi tribal governments stated concerns about the mine's impact on the land and the pipeline's effect on the aquifer as well as air quality pollution from the plant. The multiple utility owners chose to close the Mohave Generating Station, in part, because of the increasing difficulty in obtaining water to produce the slurry, as well as the costs of increased air quality pollution controls. Black Mesa Mine was closed after the Mohave Generating Station closed.[8]

In general, people are more willing to accept costs (environmental, economic, social and cultural) when there are also concomitant benefits. However, costs and benefits affect individuals differently depending on employment, experiences, and other variables. The significant level of lease income to the Navajo and Hopi tribal governments, as well as wage-labor employment of the Navajo and Hopi from the coal-fired plants and mining operations, have been major factors affecting tribal government decisions. There are also individuals and groups within Navajo and Hopi, as well as non-tribal organizations, which want to see the pace of transition to other sources of economic revenue and employment increased. As a result, tribal governments are attempting to manage the costs and benefits while moving toward a future in which tribes have increased ownership and control of energy production on their lands. Similar to the concerns some Arizonans have about exporting energy to other states while Arizona bears the environmental and other costs (i.e. externalities), tribes and their members want to ensure that the benefits they derive from energy development, at the minimum, are no less than the costs of energy generation on their lands.

## Renewable Energy and Tribes

Tribes in Arizona have substantial potential for developing cost-effective utility-scale renewable energy, including wind farms (particularly in northern Arizona)[9] and solar thermal and PV generating stations (see the glossary for a description of these technologies). Tribes also are actively implementing distributed renewable energy (see glossary), and almost every tribe within Arizona has a number of solar panel projects underway. Tribal use of solar panels and solar water heating for governmental buildings, public facilities, and enterprises, combined with innovative use of traditional energy efficient design elements, may provide a model for rural Arizona as well as rural communities throughout the world.

### Financing and Other Challenges of Large Renewable and Coal-Based Energy Projects

One of the biggest challenges facing tribal governments in developing utility-scale renewable energy projects is financing. Tribal governments, like other governments, do not pay the federal taxes required of private corporations. As a result, tribes, like other governments/ governmental entities and schools, need to work with corporate partners who are eligible for federal tax credits designed to promote larger energy projects, particularly renewables. Tribal governments seeking to control energy development on their lands and private companies seeking to fund projects are gaining experience in working together. The Navajo Nation is currently conducting a public comment process on a new energy policy that lays out goals and guidelines for energy development. The new energy policy provides a roadmap for new partnerships and has the potential to transform future relationships between tribes and outside partners.[10]

Tribal leaders and their constituents are generally cautious about entering into partnerships with non-tribal entities, in part because of experiences in the past in which tribes often felt that they did not participate meaningfully or felt pressured to develop leases and agreements. The Navajo Nation recently settled a pending 12-year lawsuit against Peabody Energy, which supplies coal to the Navajo Generating Station, SRP, and utility company Southern California Edison. The tribe alleged that Peabody had failed to pay $600 million in royalties.[11] Tribes take a long-term view of development on their lands; the American Indian people have lived on their homelands for centuries (and longer), and they will continue to be based in their reservation lands into the future. Ivan Makil, a former president of the Salt River Pima-Maricopa Indian community, stated in testimony to Congress in 2002, "We are very aware that future generations of our people will live with the results of the decisions we make today. It is critical, therefore, that we make the very best decisions that we can."[12] As a result, when land use is involved, tribal leadership tends toward more extensive, deliberative decision-making processes. Furthermore, many tribes lack land use plans that identify sites for energy projects, and tribes are in the process of developing greater internal capacity and expertise to develop and manage large-scale energy development. Serious challenges with energy development in the past and the significant economic opportunities for the future has led tribal governments to seek increased ownership in power generation on their lands. The Navajo Nation established the Diné Power Authority to specifically expand its capacity and expertise to develop and control large-scale energy projects. Many tribes are developing energy departments, cross-departmental teams, and encouraging their members to obtain academic degrees and energy-related technical and professional skills to achieve this goal.

The following are a sampling of a range of renewable energy projects on tribal lands in Arizona that have been completed or are in progress.

### Wind

Eighty miles west of Flagstaff, the Navajo Nation is developing the Big Boquillas Wind Project, which will consist of 48 turbines capable of generating a total of 85 MW. The project is projected to begin producing energy by 2012.

The Hopi tribe is looking at the feasibility of several wind projects and is collaborating with Northern Arizona University, Arizona State University, and the Arizona Wind Working Group in the planning stages. The Sunshine Wind Park, 35 miles east of Flagstaff, is currently being evaluated with a goal of generating 60 MW, which would supply 14,000 homes.[13]

The Hualapai Tribe has completed assessments and is developing a business plan for a community-based wind energy program that will include increased transmission line capacity (see the glossary for an explanation of transmission lines).[14]

### Solar

In 2010, the Fort McDowell Yavapai Nation completed installation of a 12 kW demonstration solar panel project. The system consists of 54 solar panels installed on the roof a tribal government building. Over its lifetime, the project is expected to provide 25 Mwh of energy annually.[15]

The Gila River Indian Community Renewable Energy Team have developed plans for solar panels on the Governance Center, the major administrative facility in the community. The team also developed a plan for 5 to 7 MW of solar power near the Lone Butte Industrial Park near the border with Phoenix.[16]

### Biomass

A number of other tribes have applied for and received funding from the Department of Energy to develop renewable energy plans using biomass fuel including the Ak-Chin Indian Community (a biopower facility using fuels from poultry manure from a large, commercial egg farm on tribal land), the White Mountain Apache Tribe (a co-generation project using fuels from logging waste and forest thinning operations) and the Yavapai-Apache Nation (a biopower facility using fuels from forest-thinning materials).[17]

### Traditional Lifestyles and Energy Efficiency

The traditional lifestyles of American Indian peoples developed over millennia within the local environmental setting are very energy efficient. For example, in the southernmost, hotter parts of the state, traditional living areas made effective use of 'ramadas' (shades) that provided protection from the sun and maximized air flow for cooling porous pottery water jugs. The contents of the jugs were cooled by evaporation, and local materials (adobe) offered excellent insulation properties. Similarly, throughout Arizona, traditional homes were constructed to face east, which makes the best use of the sun to light and heat homes in cold weather. While many of the elderly desire to continue their traditional lifestyle, which has provided a substantial level of self-sufficiency, most American Indians of all ages also want the benefits of electrification. Distributed energy sources, such as solar panels, solar water heaters, and small wind turbines, may become a significant source of electricity, particularly in remote areas where homes are spread apart and far from existing power lines. These approaches may be more cost-effective, which is important for American Indians living on reservations who have the lowest income of any population in the United States.[18]

Tribes have also conducted community-wide residential weatherization projects for decades, particularly critical because of the large number of inexpensive, poorly insulated homes on tribal lands. Many tribes, particularly those tribes with additional resources from gaming and other enterprises, are returning to designs and materials that are energy-efficient and a cultural match. One innovative effort initiated by the Navajo Nation, Navajo Flexcrete, uses fly ash waste from coal-fired generating stations to manufacture lightweight, energy-efficient building blocks.

Tribes in Arizona are also motivated to develop renewable energy sources and to seek energy efficiencies because of climate change. Tribes with significant farming operations are concerned about the potential impact of higher temperatures on crops and water use. Tribes toward the lower end of the Colorado River are highly concerned about continued drought and the practical effect on water supply to their communities.

## Hydroelectric Generation and Tribal Lands

Throughout the 20th century, the federal government and private entities constructed dams on or near reservations including in Arizona, in part for hydroelectric power as well as for agricultural irrigation. In many cases, dams directly flooded tribal lands or inundated tribal homelands, including sacred and culturally-significant areas as well as traditional residential, fishing, agricultural, and gathering sites. The most well-known of these is probably Glen Canyon Dam, but others include Coolidge, Roosevelt, and Parker dams. These and other dams upstream of reservations also impact the flow of water that is critical to the agricultural economies of the tribes, particularly along the Gila, Colorado, Salt, and Verde Rivers and their tributaries. The hydroelectric power facilities at Coolidge Dam were intended to generate electricity for irrigation, wells, local towns, rural users, and mining operations, serving the needs of the San Carlos Irrigation Project (SCIP). The dam's power plant was constructed and began generating electricity around 1935; however, this facility was damaged by severe flooding in 1983. SCIP has subsequently purchased electricity from the Western Area Power Administration and private utilities.

Coolidge Dam was funded in part by the Department of Interior to protect the water rights of the Gila River Indian Community (home to the Akimel O'odham (Pima) and Pee Posh (Maricopa) tribes). Prior to the dam, tribal water had been diverted upstream by non-Indian farmers for decades, devastating the agricultural economy of the Gila River Indian Community. Coolidge Dam was built on the San Carlos Apache Reservation and the dam and reservoir resulted in the relocation of families, homes, and agricultural fields at San Carlos. However, despite federal funding from the Bureau of Indian Affairs, the dam did little to meet the needs for irrigation water at Gila River because the water was often diverted elsewhere. Similarly, the tribes on the lower Colorado River, including the Mohave, Quechan, Chemehuevi and Cocopah, traditionally agricultural peoples, were substantially affected by upstream diversions and changes in the annual flows of the river caused by the sequence of dams upstream.

More recently, the federal government and several tribal governments in Arizona have explored smaller-scale, hydroelectric projects that do not require a dam. For example, the Colorado River Indian Tribes generate electricity from Headgate Rock Dam near Parker, Arizona.

## Nuclear Energy and Tribal Lands: the Legacy of Uranium Mining

As the United States and the world discuss the future of nuclear energy, tribes in Arizona are still dealing with the troubling past of uranium mining on tribal lands in northern Arizona carried out as part of federal government programs to make nuclear weapons after World War II. Any potential future uranium mining or nuclear power projects on tribal lands face a legacy of disease and premature deaths as well as the substantial environmental contamination from previous uranium mining activities on tribal lands in northern Arizona. Tragically, the uranium was mined and transported without substantial precautions to protect workers. As a result, more than 500 American Indian uranium miners died of lung cancer and the U.S. Public Health Service estimates that hundreds more will die in coming years.[19]

## Transmission Lines

There are numerous transmission lines across tribal lands in Arizona. This was in part due to historical rights-of-way from a time period when the federal Department of the Interior managed transmission line siting processes on tribal lands. In some cases, tribes expressed interest in taking over ownership of these lines, as in the case of the Gila River Indian Community and the San Carlos Irrigation Project.

The Navajo Nation is in the process of planning the Navajo Transmission Project, a proposed 500 kilovolt transmission line that would extend from the Four Corners area across northern Arizona and into southern Nevada.

## The Future of Energy on Tribal Lands in Arizona

Tribal governments are key players in Arizona's energy picture because of their coal and land resources and the large power plants on their lands that are likely to play an ongoing, significant role in power generation into the future. To make use of increasing opportunities, tribal governments are systematically working toward ownership in power generation on their lands and increasing their expertise and capacity in energy development, financing, and project management. In addition, tribes are making use of traditional materials and designs to improve energy efficiency in their homes, public buildings, and other infrastructure.

Combined with these efforts, tribes are developing innovative, on-site renewable energy projects as well as large-scale solar, wind, and biofuel projects that have the potential to provide leadership, both within Arizona and throughout the United States, for our energy future.

## Notes

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3 Energy Information Administration. (January 1994). State Coal Profiles. DOE/EIA-0576.

4 For a detailed discussion of the evolution of federal energy policy and laws affecting tribal governments, see: Voggesser, Garrit, "The Evolution of Federal Energy Policy for Tribal Lands and the Renewable Energy Future." In *Indians and Energy.* Sherry Smith and Brian Frehner (eds.) Santa Fe: School for Advanced Research Press.

5 U.S. 2000 Census.

6 Nationally, 14% of American Indian households on reservation lands lack electricity, compared to 1.5% of non-Indian households within the United States. Source: "Energy Consumption and Renewable Energy Development on Indian Lands." (2000). U.S. Department of Energy.

7 Ownership in the Navajo Generating Station: Bureau of Reclamation 24%; Salt River Project 22%; Los Angeles Department of Water and Power 21%; Arizona Public Service 14%; Nevada Energy 11%; Tucson Electric Power 8%.

8 For a contextual history of the Black Mesa issue, see: Needham, Andres (2010). "A Piece of the Action: Navajo Nationalism, Energy Development, and Metropolitan Inequality." In *Indians and Energy,* Sherry Smith and Brian Frehner (eds.), Santa Fe: School for Advanced Research Press.

9 Williams, S., T. Acker, & M. Greve. (2008.) Estimating the Economic Benefits of Wind Energy Projects. *Wind Energy.* 11(4).

10 The authors would like to thank Mr. Steve Gundersen, President of Tallsalt Management, for his insights on the policy and tribal energy issues.

11 Peabody will pay $50 million immediately and then will provide $15 million toward infrastructure over the next 10 years. They will also increase scholarship money to Navajo students by $1.55 million and make $3.5 million in annual bonus payments.

12 Honorable Ivan Makil, President, Salt River Pima-Maricopa Indian Community. Senate Committee on Indian Affairs Hearing on S.343, May 8, 2002.

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# Chapter 8: **Benefits, Risks, and Costs of Electricity Generation**

*Joseph Herkert*

## Overview

- Energy production and use is essential for our modern economy, but it also entails significant environmental and social costs. Growing concerns about the impacts of conventional fuels (oil, coal, natural gas, and nuclear) have caused many to advocate for the development of alternative energy sources (including solar, wind, and biomass).
- Electric power production and use has significant economic and social benefits; however, each technology for generating energy has a unique set of risks, which requires tradeoffs in making energy choices.
- The estimated economic costs of electricity generation from new power plants vary considerably from study-to-study due to differing assumptions and time frames. There is general agreement on the costs of conventional technologies (coal, natural gas, and nuclear) but less agreement on the costs of alternative energy sources (solar, wind, and biomass). In some cases, alternatives are becoming more competitive with conventional sources.
- All technologies for generating electricity have social and environmental costs that are often not reflected in the price of electricity, again requiring tradeoffs. Accounting for social and environmental costs (e.g., through charging for carbon emissions) can increase the competiveness of alternative energy.
- The benefits and costs of electric power generation are generally not evenly distributed, thus raising questions of energy equity. Inequities can exist with respect to the distribution of risks of energy production and the availability of energy services. In addition to posing questions of social justice, equity issues can also lead to conflicts over the siting of power plants and transmission lines.

Energy is both literally and figuratively the engine of technological and economic development. In addition, the production and use of energy results in significant environmental and social impacts. Sorting out the costs, benefits, and risks of energy production and use is thus a daunting task.

In the twentieth century, fossil fuels became the fuels of choice due to their availability and relatively low cost. Coal, oil, and natural gas provide a significant portion of Arizona's energy needs. The greatest concern today about the continued use of these fuels is their contribution to global climate change through the release of carbon dioxide into the atmosphere. (All fossil fuels release $CO_2$ when burned, but coal releases more per unit of heating value than oil, which in turn produces more $CO_2$ than natural gas). Potential impacts of climate change include rising sea levels, higher temperatures, and changing precipitation patterns, which in turn, pose threats in such areas as human health, agriculture, and wilderness areas.

Fossil fuels also have other significant environmental and human health impacts—including air, water, and soil pollution. Air pollution, for example, causes significant damage to human health, agriculture, forests, and even the built environment. U.S. reliance on imported oil (primarily for transportation) raises important national security concerns. Fossil fuels are also nonrenewable resources, and though shortages of these fuels are not imminent, oil, especially, is becoming more difficult to find and extract and will one day need to be replaced by other sources of energy; in the meantime, prices will likely continue to rise as demand grows and supplies diminish.

Beginning in the middle of the twentieth century, nuclear power was considered a potential successor to fossil fuels. However, following accidents at the Three Mile Island (1979) and Chernobyl (1986) nuclear plants, the United States stopped building new plants (and cancelled many on order or under construction). The Palo Verde nuclear plant in Arizona is the largest nuclear installation in the United States. There was renewed hope over the past decade of a nuclear revival in the United States, but the Fukushima nuclear accident in Japan, caused by the 2011 earthquake and tsunami, has impacted the calculations of both businesses and government regulators and may limit new growth in this industry. Because some of the damage at Fukushima was to the plant's spent fuel pools, the accident has raised anew concerns about the lack of a long-term solution to the nuclear waste problem in the United States and the increasing amount of spent fuel stored in temporary storage facilities, mostly on-site at nuclear power plants. Arizona's Palo Verde nuclear plant has the second largest spent fuel inventory in the United States.[1] Also weighing on decisions to build new nuclear energy capacity are continuing questions about financial risk and nuclear weapons proliferation, which could become an issue if the United States were to begin "reprocessing" (i.e., recycling) spent reactor fuel.

Hydroelectric power is the most prominent renewable energy resource in use today (including in Arizona), but most suitable sites for large-scale development have been used (see Chapter 2 for more details). Similar to conventional resources, large dams have significant environmental and social impacts, including impacts on fish populations and tribal agriculture (see Chapter 7).

The difficulties posed by continued reliance on fossil fuels, nuclear power, and large hydro have caused many to advocate for a turn to alternative forms of renewable energy, including solar, wind, biofuels, geothermal, and small-scale hydro. The theoretical renewable energy resource base is vast and could provide for current energy needs many times over. Harnessing renewable energy in a cost-effective manner, however, requires overcoming three inherent characteristics of renewable energy resources:

- low power density (i.e., the amount of power produced per unit of land area), which requires a large collection area;
- intermittence, which requires energy storage, back-up power supplies, or significant changes in demand profiles; and
- geographical variation, which requires transportation and transmission.

While technological solutions are or will soon be available for dealing with these characteristics, they have, heretofore, resulted in high costs for renewable energy resources as compared to conventional fuels (see Table 2). In addition, renewable energy also has environmental and social impacts. Production of biofuels, for

**TABLE 1** | Benefits of Electric Generation Technologies

| Generation Technology | Some Examples of Benefits |
|---|---|
| **Coal** | Relatively low construction costs, high availability to generate electricity when needed |
| **Natural Gas** | Low construction costs, low land use, few waste products, high availability, high flexibility to quickly respond to changes in demand |
| **Nuclear** | Low land use, no carbon emissions, low non-carbon emissions, high availability |
| **Hydroelectric** | No emissions (both carbon and non-carbon), few waste products, high flexibility |
| **Wind** | Relatively low construction costs, low water requirements, no emissions (both carbon and non-carbon), few waste products |
| **Biomass** | Relatively low carbon emissions, high availability |
| **Geothermal** | Relatively low land use, relatively low emissions (carbon and non-carbon), relatively few waste products, high availability, relatively high flexibility |
| **Solar Photovoltaic** | Low water requirements, no emissions (carbon and non-carbon), few waste products |

Source: Electric Power Research Institute, 2010[4]

example, may conflict with food production, and wind power has been embroiled in controversies over bird deaths and aesthetics.

This chapter focuses primarily on the benefits and costs of electric power generation. The electricity sector is not only an important segment of Arizona's energy mix, but will become even more important as electric and hybrid vehicles become increasingly prominent.

## Benefits of Electricity Generation

The energy sector is a significant component of Arizona's economy. In 2009, the combined impact of the utility and mining sectors (including non-energy activities) alone accounted for 4% of Arizona's GDP and 1% of employment in the state.[2] These numbers can be deceiving, however, as virtually every sector of the state's economy is dependent upon energy consumption.

Electricity consumed in Arizona serves the needs of commercial (40%), residential (44%), and industrial (16%) customers.[3] While the overall benefits of electricity generation are unmistakable, there are significant tradeoffs when considering the benefits of different electric power generation technologies. The benefits of electricity generation by various technologies are summarized in Table 1.

## Economic Costs of Electricity Generation

Projected costs of new facilities for electricity generation are usually compared for alternative technologies in terms of "levelized cost of energy" (LCOE). LCOE takes into account the construction, fuel, and operating expenses over the expected life of the facility. LCOE is based on numerous assumptions, including the cost factors mentioned but also the size and expected performance characteristics of the facility, in-service date, discount rate, investment costs, etc. Because these assumptions can vary, LCOE may differ from study-to-study, sometimes significantly. Results may be particularly sensitive to fuel cost assumptions and financing costs for technologies with long lead times such as nuclear power plants.

There is general agreement on the range of LCOE from conventional energy technologies. For example, Arizona's Solar Market Analysis and Research Tool (Az SMART), a joint project of Arizona State University and the University of Arizona with industry and government partners, projects that the LCOE for advanced conventional coal generation, including current federal and state financial incentives, would be $103/MWh (2009$).[5] This is comparable to LCOE projections for the California Energy Commission ($116/MWh in 2008$) and within the range projected by the investment bank, Lazard Ltd. ($78-$144/MWh in 2008$).

The projected LCOE in four studies for various conventional generating resources is shown in Table 2.

**TABLE 2** | Costs of New Conventional Power Generation (Levelized cost per MWh)

| | Az SMART (f) | CA PUC (g) | EIA (h) | Lazard (i) |
|---|---|---|---|---|
| **Gas Peaking (a)** | - | $479 | $103 - 124 | $225 - 342 |
| **IGCC (b)** | $112 | $127 | - | $110 - 141 |
| **Nuclear (c)** | $132 | $183 | 114 | $107 - 138 |
| **Coal (d)** | $103 | $116 | $95 - 109 | $78 - 144 |
| **Gas Combined Cycle (e)** | $76 - 77 | $92 | $63 - 66 | $74 - 102 |

a) Conventional or advanced natural gas fired combustion turbine used to supply power when demand is high (known as peak demand)
b) Integrated gasification combined cycle; an emerging technology in which coal is converted into synthetic gas and used to fuel a combined cycle unit (combustion turbine in tandem with steam turbine)
c) Advanced nuclear reactor
d) Conventional or advanced coal fired steam turbine
e) Conventional or advanced natural gas fired combined cycle (combustion turbine in tandem with steam turbine)
f) Croucher and James, 2010 (2009$, includes current federal and state financial incentives)[6]
g) Energy + Environmental Economics, 2010 (2008$)[7]
h) US Energy Information Administration, 2010 (2009$)[8]
i) Lazard, 2009 (2008$, includes current federal tax incentives)[9]

The projected LCOE for electricity generation from alternative generating resources from these and other studies are, in some cases, more divergent, as shown in Table 3.

**TABLE 3** | Costs of New Alternative Generation (Levelized cost per MWh)

| | Az SMART (h) | CA PUC (i) | EIA (j) | Arizona Renewable Energy Assessment (k) | Frisvold et al. (l) | Lazard (m) |
|---|---|---|---|---|---|---|
| **Solar-PV (utility) (a)** | $272 | - | $211 | $278 - 365 | $191 - 266 | $131 - 196 |
| **Solar Thermal (utility) (b)** | $217 | $184 | $312 | $132 - 281 | $126 - 283 | $129 - 206 |
| **Biomass (c)** | $120 | $165 | $112 | $66 - 118 | - | $65 - 113 |
| **Geothermal (d)** | $79 | $92 | $102 | $46 - 81 | - | $58 - 93 |
| **Wind (e)** | $98 | $91 | - | $51 - 93 | - | $57 - 113 |
| **Residential PV (f)** | - | - | - | $358 - 509 | $176 - 363 | - |
| **Commercial PV (g)** | - | - | - | $321 - 407 | $142 - 239 | - |

a) Utility-scale solar photovoltaic panels
b) Utility-scale solar thermal electric generators
c) Direct combustion of biomass
d) Geothermal power plant
e) Utility-scale wind farm (onshore)
f) Solar photovoltaic panels on residential buildings
g) Solar photovoltaic panels on commercial buildings
h) Croucher and James, 2010 (2009$, includes current federal and state financial incentives)[10]
i) Energy + Environmental Economics, 2010 (2008$)[11]
j) US Energy Information Administration, 2010 (2009$)[12]
k) Black and Veatch Corporation, 2007 (2007$, includes current tax credits)[13]
l) Frisvold et al., 2009 (2010$, lower limit includes federal and state government and local utility incentives)[14]
m) Lazard, 2009 (2008$, includes current federal tax incentives)[15]

Despite the discrepancies in some of the projections, it is apparent from Tables 2 and 3 that some of the alternatives (especially biomass, geothermal, and wind) are becoming competitive with conventional generation. In addition, solar PV is becoming competitive with natural gas-driven turbines used for peaking power. This is highly significant for Arizona, since peak output from solar PV plants during the day often corresponds roughly to periods of high energy use.

Some of the studies included in Table 3 also factor in long-term cost trends that may prove favorable to alternative technologies as fuel prices rise and the cost of alternatives continues to decrease. Lazard, for example, projects that capital costs for solar PV panels will decrease by nearly half by 2018, which explains in part why their study concludes that the costs for solar energy will be generally lower than those in other studies.[16] In 2009, Frisvold et al. projected the LCOE for PVs will decrease about 30% by 2025.[17] Az SMART projects the LCOE of utility-scale PVs and solar thermal will fall 14-15% by 2030. (See the glossary for the definitions of solar PV and solar thermal.)

## Environmental and Social Costs of Electricity Generation

All energy sources entail environmental and social costs (which economists call external costs or externalities). External costs are real costs that are not reflected in the economic costs (i.e., the LCOE of electricity production or the price of gasoline at the pump) and may include such factors as environmental pollution and threats to national security from over-reliance on oil imports from regions prone to conflict (see Table 4).

While some externalities may be included in the economic cost of energy as a result of regulations (e.g., certain air pollutants regulated under the Clean Air Act), the costs of externalities not included are substantial. Recent studies have indicated that environmental and health damages from U.S. energy use amount to $120 billion (with more than half caused by generating electricity with coal), plus another $120 billion in damages caused by climate changes due to U.S. carbon emissions.[18]

Accounting for externalities is a difficult and controversial task. Including them, however, can paint a more realistic picture of the true cost of energy alternatives. For example, a recent study by the Hamilton Project concluded that accounting for externalities (both carbon and non-carbon related) would nearly double the LCOE of new coal-fired generation.[19] The estimated effect on fossil fuel generation costs of accounting for carbon emission costs alone in three studies is shown in Table 5.

## Energy and Equity

The costs of energy production, as expressed for example in LCOE for electricity production (including environmental and social costs), are average costs over the entire population that do not take into account the *distribution* of such costs among individuals and specific groups. Similarly, the benefits and risks of energy production are often expressed in a manner that does not account for how these risks and benefits are distributed.

The study of the equitable distribution of costs, benefits, and risks of energy production and use is part of the general study of social justice. While there are several types of social justice, the one of concern here is *distributive justice*, which considers "normative principles designed to guide the allocation of the benefits and burdens of economic activity"[22] accross different individuals and groups.

**TABLE 4** | Potential Environmental and Social Costs of Energy

| Energy Source | Some Examples of Environmental and Social Costs |
|---|---|
| **Oil** | National security, oil price shocks, air pollution, oil spills, climate change,  water use |
| **Natural Gas** | Air pollution, climate change, water pollution, distribution leaks |
| **Coal** | Air pollution, acid rain, climate change, land use and run off, health effects of mining, water use |
| **Nuclear** | Potential for radiation exposure,  long term waste disposal, water use |
| **Hydroelectric** | Water use, impacts on fish, land use |
| **Solar** | Land use, toxic materials, , water use (solar thermal) |
| **Biomass** | Land use, water use, air pollution, competition with food production |
| **Geothermal** | Air pollution, water pollution, land use, water use |
| **Wind** | Land use, noise pollution, aesthetics, bird deaths |

**TABLE 5** | Estimated Carbon Emission Costs (Levelized Cost per MWh)

| | AzSmart (a) | Economic Consulting Strategies, Inc. (b) | Union of Concerned Scientists (c) |
|---|---|---|---|
| **IGCC** | $24 | - | $16 - 48 |
| **Coal** | $26 | $10 - 30 | $17 - 50 |
| **Gas Combined Cycle** | $10 - 12 | $4 - 12 | $7 - 20 |

a) Croucher and James, 2010 (2009$, carbon price of $30 per ton of carbon emitted; includes current federal and state financial incentives)
b) Kelton et al., 2009 (2008$, carbon prices of $10 and $30 per ton of carbon emitted)[20]
c) Freese et al., 2011 (2010$, includes current incentives) [21]

In terms of energy production and use, distributive justice issues arise in various contexts, from the siting of power production facilities to the establishment of rates for electric power service. Energy equity can be analyzed in a number of ways, including the distribution of risks of energy production and the degree of availability of energy services to specific groups.

An example of risk distribution can be found in the case of the Palo Verde nuclear plant. While catastrophic accidents at nuclear power plants are rare events, the recent crisis at the Fukushima nuclear plant in Japan is a reminder that such events do occasionally occur. All U.S. nuclear power plants are required to have in place an emergency response plan for a 10-mile evacuation zone. The 4,000 or so individuals who live within 10 miles of Palo Verde[23] are at greatest risk in the event of an accident. Experience has shown, however, that 10 miles may not be enough of a buffer zone. For example, the "exclusion zone" resulting from the 1986 accident at Chernobyl is 18.6 miles. The U.S. Nuclear Regulatory Commission has recommended a 50-mile evacuation zone around the Fukushima plant. The more than half a million people who live within 50 miles of Palo Verde[24] are thus arguably at greater risk than the general population of the state, although the actual pattern of radiation exposure in the case of an accident would depend heavily on prevailing winds and precipitation. Since all Arizona residents who plug into the electric grid share more or less equally in the benefits of Palo Verde, those living closest bear a disproportionate share of the risk.

Similarly, higher risk profiles exist near the state's coal-fired and gas-fired plants (due primarily to the impacts of air pollution on human health), though these sites are dispersed throughout the state.[25] Unlike Palo Verde, where the main concern is catastrophic risk, the health risks from fossil fuel plants are ongoing. Here again, those living closest are subject to a disproportionate share of the risks of electricity production that benefits the entire state.

Energy facilities (including mines, power plants, and electric transmission lines) are often sited in rural communities, and while there may be some local economic benefits, rural residents often bear a disproportionate share of the risks, as well as being subjected to conflicts over land and water use (see Chapter 6 on energy and water) regarding agriculture and natural ecosystems. Even alternative energy sources may distribute the benefits and impacts of energy production unevenly (see box).

Siting of power plants and electric transmission lines have been particularly contentious in Arizona as they have been in many sections of the country. Since large power plants are often sited in rural areas, hundreds of miles of high voltage power lines are used to transmit power from the plants to the major load centers in urban areas (sometimes in other states). Lines are also constructed in, around, and between load centers in order to provide for flexibility and reliability of service. Among the questions raised by rural residents are the need for the plants and lines, the disproportionate share of the benefits of the projects accruing to the rural residents, interference with agriculture (especially irrigation), and damage to wildlife and desert ecosystems. While mechanisms exist for public involvement in siting decisions (e.g., members of the public may attend and comment at the meetings of Arizona's Line Siting Committee and stakeholder briefings, and public open house meetings are held throughout siting studies), many rural residents believe their needs are not fully considered.

**Proposed and recently sited solar power plants in the Desert Southwest have generated discussion about the distribution of the benefits and impacts of energy generation. Rural populations that live near these sites have protested a variety of impacts to local desert communities from power that will largely benefit urban areas. Examples include: use of overdrafted groundwater resources, new transmission lines proposed to bisect communities, visual impacts to pristine desert landscapes, and lowered real-estate values. Native American tribes have protested damage done to sacred and historic sites, such as the giant Blythe Intaglios (ground carvings) in California. Further, local environmentalists, scientists, and government agencies have expressed concern about the impacts from disturbing or blading/grading desert habitat, particularly to rare plant and animal species like the desert tortoise, the fringe-toed lizard, and desert pincushion, and to Microphyll woodlands.**

*Sharlissa Moore*

The situation is less clear-cut in cases where substantial benefits seem to go hand-in-hand with increased risks. For example, the "brown cloud" of air pollution in Phoenix puts local residents at greater risk than others in the state, but this problem is at least partially due to the driving habits of Phoenix area residents. Similarly, energy production (including coal mining) on Native American lands exposes residents to greater risks while also providing significant economic benefits (see Chapter 7). Another example lies in the fact that Arizona is currently a net-exporter of electricity (about 28% of generation in 2009), mostly to California. Arizonans therefore bear the environmental and social costs of energy consumed by Californians. On the other hand, benefits of this exchange may accrue to Arizonans in the form of lower electricity rates and utility jobs.

Equity issues can also arise in terms of access to energy services, in particular when energy or energy technology is not available at an affordable cost to the poor and underprivileged in society. According to Department of Energy statistics, in 2005, U.S. households with income under the poverty line used about 21% less electricity per household than the average U.S. household and about 41% less than households with annual income of $50,000 or more. While many factors contribute to this discrepancy (including size of dwelling), a significant difference can be found in the percentage of households using electric air conditioning (78.3% for households below the poverty line, 84.0% for the average household, 85.5% for the wealthiest households).[26] Lack of air conditioning can be of life-threatening significance in Arizona where 173 residents died between 1992 and 2009 from exposure to excessive heat while indoors, two-thirds of whom were 65 or over.[27] In the Phoenix area in 2002, 12% of the more than 200,000 households eligible for the Low Income Home Energy Assistance Program (LIHEAP) had no air conditioning. Despite using less energy, low-income people spend a greater percentage of their incomes on energy services due to poor insulation, inefficient HVAC systems and appliances, low-incomes, and high energy prices.[28] For example, the more than 400,000 LIHEAP-eligible households in Arizona on average spend 10% of their household income on residential energy compared to the 3% median spending for all U.S. households.[29]

Low income households also have less access to distributed alternative energy production facilities. O'Leary[30] found that installed residential photovoltaic capacity in the Phoenix area per person for areas with lower housing values was one quarter that of areas with middle-level housing values and about one fifteenth that of households with upper-level housing values (See Table 6).

Special care may be required to recognize equity issues in the production and use of energy since these issues are easily overlooked when the focus is on least cost solutions. Siting decisions for energy facilities could incorporate meaningful roles for community stakeholders and energy assistance programs could be carefully planned and implemented so as to provide equitable distribution of the costs, benefits and risks of an energy transition.

**TABLE 6** | Solar Equity in Greater Phoenix (Residential Photovoltaic Panels) (a)

| | Lower | Middle | Upper |
|---|---|---|---|
| **Housing Values** | < $90,000 | $90,000 - 170,000 | > $170,000 |
| **Total Capacity, kW (b) (Mean Average)** | 4 - 158<br>(51) | 41 - 555<br>(195) | 70-1167<br>(412) |
| **Total # of Installations (Mean Average)** | 8-86<br>(36) | 18-271<br>(108) | 28-387<br>(128) |
| **kW Per Person (c) (Mean Average)** | .00013-.0033<br>(.0013) | .0011-.0155<br>(.0052) | .0028-.0973<br>(.0193) |

a) Source: O'Leary, 2011
b) Kilowatts
c) Kilowatts per person

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# Chapter 9: **Arizona's Energy Security**

*Martin Pasqualetti*

## Overview

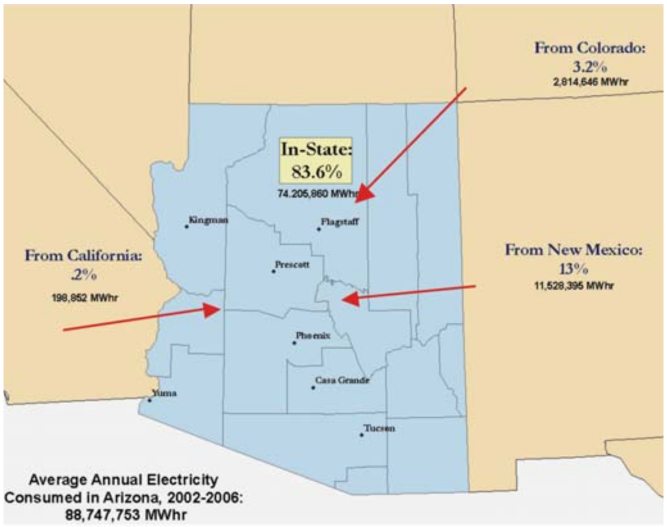
- Arizona is an 'energy desert;' it imports all but a few of its fossil fuel energy resources.
- Arizona's long and isolated energy supply network decreases energy security.
- Several notable, albeit brief, supply interruptions have occurred in the past several years.
- Greater development of renewable energy will increase energy security in Arizona.
- Greater storage capability of motor fuels and natural gas would increase energy security.
- Arizona's energy security will decline over time unless we take action to update and supplement the state's aging energy infrastructure.

What do we mean when we use the phrase 'energy security'? For most of us, it is the security of immediate personal energy supply. Does the corner service station have gasoline? Will my air conditioning work when I get home? Even the word 'security' has many connotations under many circumstances. It is something different for someone who commutes by bicycle than it is for someone who drives 50 miles each way to work. It does not have the same significance for a student in a classroom than it does for a soldier in combat or a patient undergoing heart surgery. Moreover, energy security varies according to many factors. For example, security of supply may be a matter of affordability or geopolitics; it can be influenced by climate change, competition, natural events, wars, piracy, terrorism, or accident. In Arizona, energy security has been reasonably good so far, but the question is whether it is a pattern that we can expect to continue into the future. This chapter explores what energy security means to Arizonans and what some of the concerns might be.

## An Energy Desert

Arizona is not only a climatological desert, but also an energy desert. That is, at least in terms of conventional energy reserves, almost all of the energy resources used to produce electricity in the state are imported, often over hundreds or even thousands of miles. Virtually all supplies of gasoline, jet fuel, diesel, natural gas, and uranium also come from outside state borders. Of the several coal-fired power plants that supply the state, only one receives its coal from Arizona reserves, the Navajo Generating Station, on the northern Arizona border, near Page. Even though 84% of the electricity Arizona uses is generated within the state (Figure 1), most of the fuel for these power plants comes from somewhere else. This is ironic, for we have abundant solar energy that is put to little commercial use, while it is the very abundance of sunshine that creates much of the demand for cooling during the scorching summers. Despite the heavy energy demands of summer air conditioning, however, Arizonans are collectively not especially profligate consumers of energy.

**FIGURE 1** | Average Arizona Electrical Sources, Including Imports, 2002-2006



Source: Pasqualetti and Kelley 2008[2]

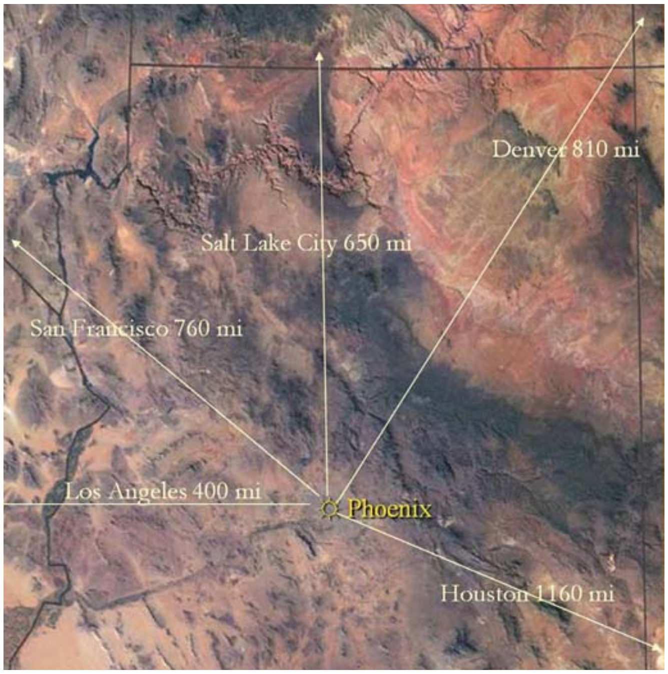
Actually, per capita energy consumption is low at 46th out of the 50 states,[1] and the state ranks near the middle of the states in total energy consumption. Of all sectors, transportation uses the most energy, amounting to about 20% more than residential.

U.S. citizens, including Arizonans, depend on highly reliable energy supplies. Yet, there are vulnerabilities in every system of supply, in part because of our relative isolation from energy resources, and also because much of our generating capacity requires that our supplies be carried by aging and complicated infrastructures (Figure 2). But supply by itself is not the whole story; in addition, we are also vulnerable to the extent that future increases in energy demand outstrip the capacity of existing infrastructures to deliver energy to us and to the extent that our infrastructure development does not keep pace with growing energy demands.

One level of vulnerability affects the other. For example, because demand is quickly increasing, we are in constant need of more infrastructure. Because of the isolation, the cost of adding infrastructure is expensive. Owing to the difficulties of gaining necessary permits, it is also time-consuming.

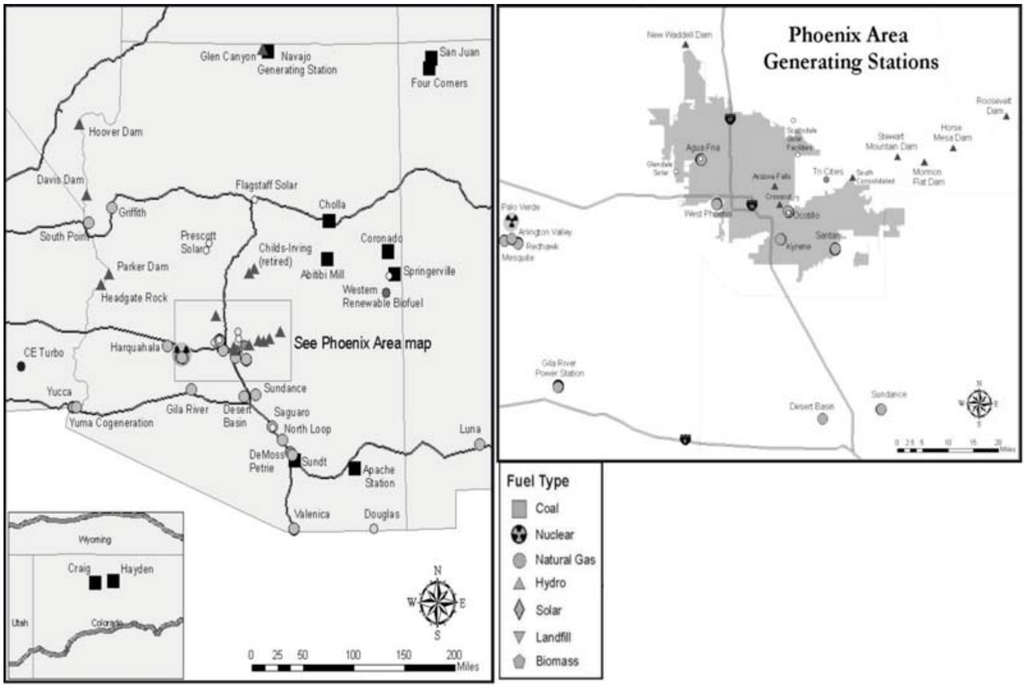
There has been increasing development in renewable energy, especially since the Arizona Corporation Commission approved the state's Renewable Energy Standard in 2006.[3] Currently, about 12% of the electricity used in the state comes from renewable energy resources. Almost all of this, however, is from hydropower facilities that are at least 40 years old. Except for the Dry Lake wind development near Snowflake, almost all the other renewable energy sources of electricity come from outside Arizona. The dependency on outside sources of energy—and the importance placed on coal-fired facilities that are almost all adjacent to distant state borders (or beyond)—requires lengthy distribution infrastructure, both for conventional energy resources as well as for electricity (Figures 3a and 3b).

**FIGURE 2** | The isolation of Arizona's centers of population results in a dispersed supply infrastructure. That is, electrical transmission lines, natural gas pipelines, and liquid fuel pipelines are all long and therefore more vulnerable to accidental and intentional interruptions.



What makes the situation different, however, are the factors not found in other states in the same combination, including a large and rapidly growing population, the almost total reliance on air conditioning for comfort during the torrid summers, the dominance of automobiles for transportation, and

**FIGURES 3a and 3b** | Arizona Power Plants Supplying Electricity to Arizona Users (2008)



Maps by Scott Kelley

the scarcity of water for power plant cooling. Taken together, these four factors present special challenges for those charged with meeting energy demands. That said, residents of the state are hardly ever without electricity, natural gas, or motor fuels. For the most part, especially considering the long distances that are common, the harsh natural conditions, and the complexities of the entire system of energy supply, the system providing all types of energy to Arizona consumers operates with remarkable reliability, at least in terms of actual provision of supplies. However, if we take price into account, the infrastructure is systematically falling short on its ability to deliver gasoline in the quantities necessary at historically reasonable prices.

## Liquid Fuels

Arizona has no significant oil production and no active oil refineries. Delivery of fuels relies on a network of "just-in-time" inventories and deliveries involving five oil industry sectors: 1) refineries, 2) pipelines, 3) terminals, 4) transport trucks, and 5) retail stations. The delivery of all liquid fuels is accomplished through the use of a single pipeline, operated by Kinder Morgan (KM) (see Figure 4). The eastern part of the KM pipeline connects Phoenix and Tucson to El Paso and gives Arizona access to petroleum products from Gulf Coast refineries (called the East Line). The western part of the KM line connects California refineries in Wilmington to Phoenix (West Line). The KM system transports gasoline, diesel, and jet fuel. A small percentage of the state's gasoline is trucked in from neighboring states.

Prior to 2003, KM's East Line System consisted of two pipelines: an 8-inch and a 12-inch, from El Paso to Tucson, and a single 8-12 inch multi-diameter pipeline from Tucson to Phoenix. Between 2003 and 2007, KM performed several expansion projects with the purpose of increasing the capacity of the East Line System.

Typically, 220,000 barrels per day are delivered, with aviation fuels coming predominantly from the west and motor fuels from the east. Typical transit

**FIGURE 4** | U.S. Gasoline Pipelines

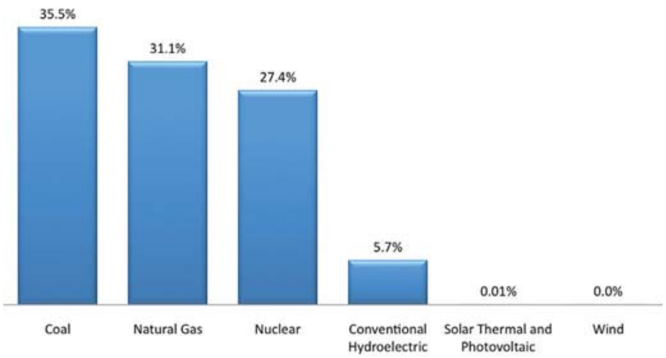
Source: Arizona Attorney General's Office times from the west are six days from California and four to five days from El Paso. KM does not own the fuels, only the pipelines, so there is no inventory ready to go.

The KM East Line is supplied by the Longhorn Pipeline that transports refined motor fuel products (gasoline and diesel) through a 700-mile, common carrier pipeline from Gulf Coast refineries to communities in West Texas and the El Paso gateway market. From there, shippers may use other pipelines, sending some of the fuel to New Mexico and Arizona.

Normally, product delivery through this system takes place without noticeable disruptions. However, this consistency was interrupted when the 48-year old East Line carrying gasoline from El Paso to Phoenix ruptured on the south side of Tucson on July 30th, 2003. On August 8, after test results indicated that a pipe defect caused the incident, KM shut down the line. As a result, Phoenix lost the source of up to 2.3 million gallons of gasoline a day. In addition to this inconvenience, the break in the high-pressure underground line spilled 10,000 gallons of gasoline, dousing five homes under construction on West Grant and North Silverbell roads, contaminating soil and groundwater in the area. Seven days after the rupture, on Aug. 6th, the Federal Office of Pipeline Safety, which regulates interstate hazardous liquid pipelines, issued a Corrective Action Order for the incident which, among other things, outlined procedures specific to pipeline seam failures for bringing the East Line back to normal operation.

The diminished supply of gas was hardly noticed by Phoenix motorists until the week after the shutdown. At first, the suppliers that obtain their inventory on the spot-market[4] ran out of gasoline and closed their pumps. On Tuesday August 12, 2003, ARCO, which operated 77 stations in the Phoenix area, reported supply problems. As station inventories were used up, other stations began closing. By the weekend of August 16, more stations were closed than open. Stations would open upon receiving a delivery and lines curling around the block would quickly form. When the station's tanks had been drained, the pumps would be flagged as empty as the station again closed.

**FIGURE 5** | Arizona Electricity Generation

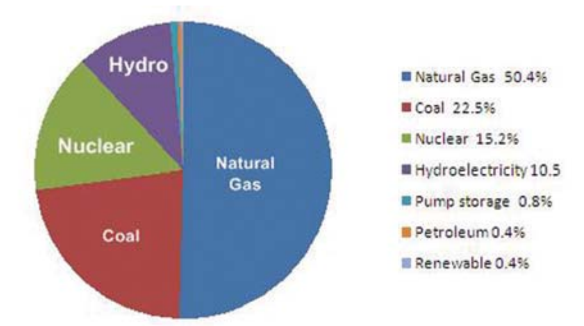


Source: Institute for Energy Research. Arizona Energy Facts, 2008. http://www.instituteforenergyresearch.org/states/arizona/

## Natural Gas

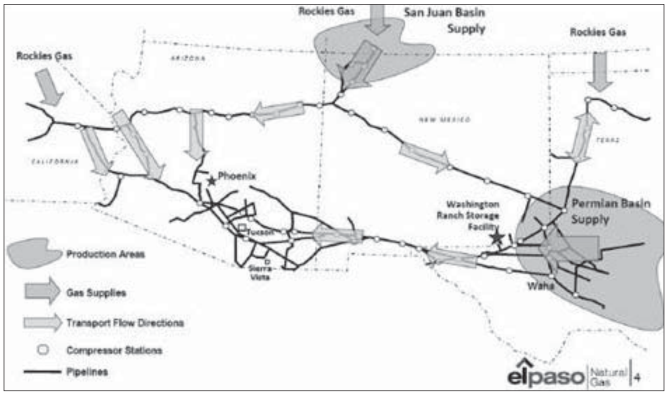
There are reportedly over 100 years of natural gas reserves in the United States, although little is in Arizona. Natural gas is used in Arizona for heating, cooking, and generating electricity. About 31% of the electricity demand in the state is satisfied from natural gas-fired power plants, and over 50% of generating capacity is gas-fired (see Figures 5 and 6). Three quarters of the natural gas consumption in Arizona is used to generate electricity. The reliance on natural gas has increased in the past 10 years

**FIGURE 6** | Generation Capacity in Arizona (2008)



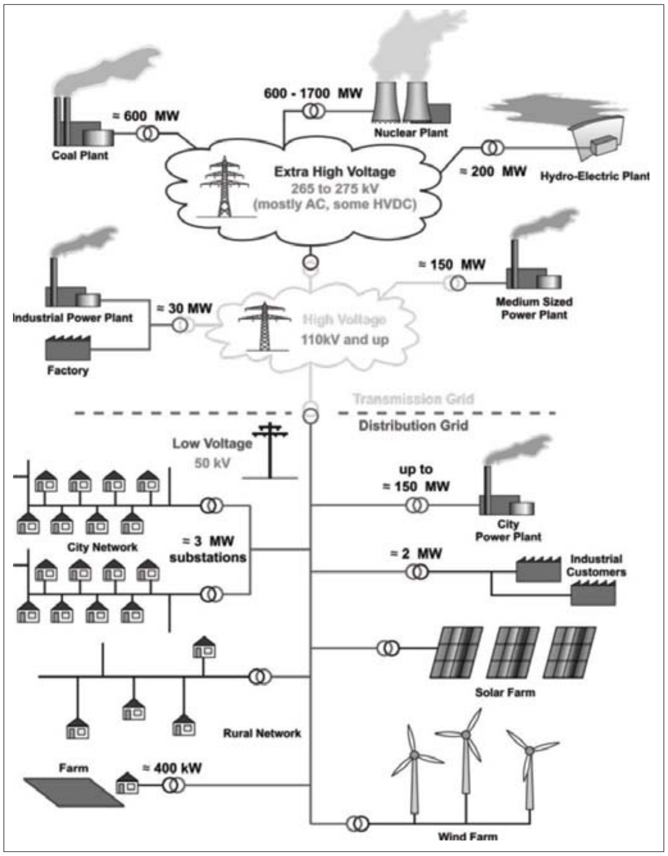
Source: U.S. Energy Information Administration, Form EIA-860, Annual Electric Generator Report, March 2010[5]

**FIGURE 7** | Two Major Basins Supply Natural Gas to Arizona



Source: El Paso Corporation

**FIGURE 8** | The Electrical Supply System is Complicated and Vulnerable to Interruptions



Source: Wikipedia. http://en.wikipedia.org/wiki/Grid_(electricity)

because combustion in power plants produces fewer worrisome pollutants, especially carbon dioxide. The other uses of natural gas are for home heating, water heating, cooking, and other residential uses. Almost two-fifths of Arizona households rely on natural gas as their primary energy source for home heating.

Ten interstate and nine intrastate natural gas pipeline companies provide transportation services to and within the Western Region (Arizona, California, Idaho, Nevada, Oregon, and Washington), the fewest number serving any U.S. region. Virtually all of the natural gas delivered to Arizona originates in Texas and New Mexico (see Figure 7).

Southwest Gas Corporation (SWG) and Unisource Energy Services (UNS) dominate the natural gas delivery market in Arizona. Together, these two firms serve 93% of all customers in Arizona. SWG is an investor-owned utility serving approximately 1.8 million customers; 986,000 of these customers are located in Arizona. Due largely to rapidly rising demand in its service territory, SWG is the fastest-growing natural gas distribution company in the United States. SWG serves 81% of Arizona's residential customers, 72% of the commercial customers and almost 93% of the industrial customers. The disproportionately large share of industrial customers reflects the fact that SWG serves the two major metropolitan areas of Arizona.

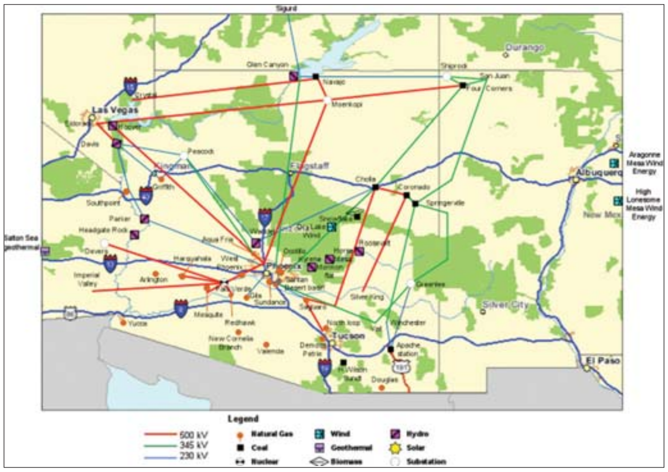
## Coal

Coal is the sole fossil fuel that Arizona has in abundance. The commercial reserves are beneath Black Mesa, land controlled by the Navajo nation and the Hopi tribe. There, Peabody Western extracts all of the commercial coal in the state at the Kayenta mine. About 8 million tons of coal per year is transported off Black Mesa using a 15-mile conveyor belt that runs from the mine to a storage silo immediately north of Black Mesa, adjacent to U.S. highway 160. A dedicated electric train moves two to three loads each day about 78 miles from the silo to the Navajo Generating Station near Page. There, it is piled in a large coal yard where it is blended for consistency. Coal for the other coal-fired power plants comes from the San Juan Basin of New Mexico. Interruptions have occurred along the various railroads serving these power plants, but none of these disruptions has lasted more than a few days.

## Electricity

The generation and distribution of electricity is a complex undertaking, involving ceaseless extraction of energy resources, generation of electricity, as well as distribution, which itself has several components (Figure 8). Just in Arizona, the high-voltage electrical transmission system is extensive, comprised of 500 kV, 345 kV, and 230 kV lines that connect load centers and power plants throughout the state and neighboring states (see Figure 9). They are the key elements in maintaining reliable electrical services. Power outages from downed or damaged transmission lines are not unexpected or even uncommon, especially during the stormy monsoon season. Usually these only produce pockets of disruption, and they are usually repaired within hours. However, some interruptions have been more serious. For example, on August 10, 1996, a large portion of Arizona went dark because a tree came into contact with a high voltage transmission line in southern Oregon, causing a cascading failure that rapidly spread throughout much of the West.[6] This incident, although rare, demonstrated how the electrical supply system in one location can create disruption in service hundreds or even thousands of miles away.

**FIGURE 9** | Generalized Map of Transmission and Electric Generating Stations Supplying Power to Arizona



Source: George Karady, ASU

**FIGURE 10** | Westwing Substation. Five Transformers Were Damaged in a July 4, 2006 Fire in Northwest Phoenix

Source: Arizona Public Service

Another incident, 10 years later—on July 4, 2006—involved a fire that destroyed a bank of transformers in northwest Phoenix, at the Westwing Substation, an important transmission portal into the Valley (Figure 10). A replacement unit was quickly located at the Bonneville Power Administration in Washington, but the 400,000-pound unit's journey back to Arizona took 21 days. Westwing was placed back in service on August 9, but APS had to ask Phoenix residents to curtail their electricity usage between 3 p.m. and 6 p.m. daily for more than a month.[7]

Arizona receives electricity generated at several hydroelectric dams on the Salt and Colorado Rivers. The amount that can be generated at these facilities is influenced, to some extent, by how much water is in storage. With the recent decade-long drought continuing, and with both Lake Powell and Lake Mead down to roughly 50% of capacity, somewhat less electricity is available from hydropower. However, less than 6% of the electricity used in Arizona comes from hydropower. This means that even large fluctuations from the dams are usually not as significant as the outage of one large fossil or nuclear plant.

As has been noted, maintaining energy security for Arizona naturally affects those who reside within its state borders, but it also affects those who are in other states as well. This relationship was illustrated when the massive Wallow Fire in eastern Arizona—the largest in state history—resulted in some tense moments for regional utility companies during June 2011.[8] For example, El Paso Electric (EPE) issued a statement that read: "In the event that the transmission lines are compromised or damaged as a result of fires or other threats, EPE's capability to import power from Palo Verde (50 miles west of Phoenix) may be reduced and as a result EPE may have to institute power curtailment/conservation measures. Some of these measures may include rolling blackouts."[9]

## Energy Storage

Energy storage is a tried and effective hedge against several types of supply interruptions. Coal storage is the most securely stored fuel. There are coal yards at almost all coal-fired power plants. In Arizona, these power plants typically hold 45-60 days of coal. All the coal-fired power plants that supply electricity to Arizona use similar on-site storage unless—as in the case of the Four Corners Power Plant in northwest New Mexico—the facility is a so-called 'mine-mouth' operation, which means the power plant is located next to the mine itself. In all cases, any supply interruptions of consequence would have to last more than 45-60 days to result in shortfalls of power generation, and then only if the plant was operating at full capacity.

Liquid fuels are also stored in Arizona. In addition to what is available within the pipelines themselves, liquid fuels are stored at terminals in Phoenix and Tucson; 'tank farms' serve as fuel storage and distribution centers in their respective areas. The Phoenix Terminal is located southwest of Van Buren Street and 51st Avenue. The Tucson terminal is near the intersection of I-10, E. Ajo Way, and S. Alvernon, and covers 160 total acres. Together they hold enough products to meet three to five days of average demand. As was demonstrated during the 2003 pipeline break, this is not very long.

Natural gas can be stored. Indeed, a substantial amount of natural gas is already stored. The Energy Information Administration reports a total of 8,655,740 cubic feet of natural gas storage in the United States at the end of 2009. There is no such storage in Arizona. However, there has been some consideration given to using existing salt deposits for this purpose. One such deposit lies beneath Luke Air Force Base (Copper Eagle Site), but the most appealing deposit is in Pinal County, where a private company (Arizona Natural Gas Storage, LLC) has proposed a facility northeast of Eloy.

Electricity storage is different from storage for the three fossil fuels, because it cannot be stored in large quantities. This means that secure supplies of electricity rely on the scheduled preventive maintenance of the entire supply system, as well as quick and practiced responses to any outages. As with the natural gas pipelines, several alternate routes are usually available in the case of interruptions. These alternatives increase security, although no system is entirely reliable, regardless of the form of the energy or power.

## A Case in Point

The public generally assumes the energy supply is secure. They fill up their gasoline tanks whenever they are low, flip on televisions, turn down air conditioners, all without much thought about security of supply. Most of the time, their faith is rewarded. But not always. A series of disruptions in early February 2011 provides a case in point. Seven power generators servicing Arizona 'tripped'; that is, none of these units were available to generate electricity.[10] The affected units were both coal and natural gas power plants, and the result was a sequence of rolling blackouts in the Phoenix Metropolitan Area. These outages, which typically lasted about 30 minutes, were necessary because demand for electricity could not be met by available supplies. The cause was reportedly the unusually cold weather that was gripping the Southwest at the time.

The impacts of the cold snap were not limited to disruptions at generation plants. For example, the disruption of natural gas delivery forced Southwest Gas to ask customers unaffected by the outage to keep gas usage as low as possible to help speed the restoration process. Receiving less publicity, and producing virtually no public notice, the same cold weather also temporarily interrupted gasoline delivery because there was insufficient power to operate pumps. In total, there was disruption to electricity supply, heating fuel, and gasoline, all attributed to the cold weather.

Nonetheless, the impacts were short-lived. Supplies were re-routed and the problem, at least from the standpoint of the customers, was resolved in relatively short order. Most people in Arizona suffered little more than a temporary interruption. It was, however, a major loss of supply that affected all sectors of the economy: industry (power plants), residential and commercial (heating), and transportation (gasoline). It illustrated a level of vulnerability not previously experienced—or anticipated—in the state. Had such a cascading event occurred in the summer, the impacts would have been much greater. It is also worth noting that the impact of these events on our neighboring state of New Mexico was much greater. Much of New Mexico went without natural gas supplies for close to a week, severely impacting the ability of families and businesses to heat their homes and workplaces during a very cold period.

## Vulnerabilities and Remedies

Transmission lines and pipelines, as we have noted, fail from time-to-time, sometimes producing substantial impacts and—although not in Arizona—even loss of life. So far, disruptions in energy supplies experienced in Arizona have not been long enough in duration or serious enough to cause more than inconvenience to consumers.

Whether Arizona has a high or low level of energy security is a topic worthy of substantive discussion among all the principal parties, including utility companies, regulatory agencies, emergency response teams, and the general public. While many groups, including utility companies, plan and train for emergency response, discussions that include all affected parties at once are rare. The most significant effort of a comprehensive type is the periodic appraisal of energy security that Arizona oversees as part of energy assurance planning mandated by the federal government. The next such assessment is due for completion in the first quarter of 2012.

Setting aside the impacts of higher energy prices on consumption, we can say that there have been no serious threats to the energy security of Arizona. Indeed, reliability for the delivery of natural gas, electricity, and gasoline is in the high 90% range. The question is: has this record been a matter of luck or a result of design, planning, and training? Whether we will be able to continue to maintain this record is the question. While we have had a reasonably strong record to date, there are indications that risks may be greater in the future. For example, across the United States, grid outages due to extreme weather events, similar to what occurred in the Southwest in February 2011, have risen rapidly over the past 30 years, perhaps as a result of changing climatic conditions. That raises, then, the question of whether we want to accept those risks or address them in some fashion to try to minimize them.

Setting aside for the moment matters of cost effectiveness, several actions could increase energy security in Arizona. These include the following:[11]

- establish natural gas storage;
- increase gasoline storage or lay additional delivery pipelines;
- install more transmission lines;
- transition to 'smart grid' technology (which would allow closer monitoring of usage and increase response options);
- accelerate the development of in-state renewable resources, such as wind and solar (which would reduce transmission distances and reliance on fuel delivery to power plants);
- increase the use of distributed solar generation (see glossary) (which would largely eliminate transmission requirements in those instances);
- increase surveillance of critical energy infrastructure; 'harden' security against unauthorized access to equipment, especially at remote sub-stations, storage facilities and surface pipelines;
- increase the use of energy efficiency as an alternative to expanding the energy supply network.

Without some combination of these adjustments to improve and make the energy infrastructure more robust and secure, Arizona's energy reliability is likely to decrease over time.

## Notes

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3 A spot market is a market in which a commodity is traded for immediate delivery.

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# Section II:
# Energy in Arizona's Future

# Section II: **Energy in Arizona's Future**

Arizona's energy system has been relatively stable over long periods of time. Neither the electricity sector nor the transportation sector have seen major changes in basic technologies, underlying infrastructure, or overall trends in recent decades. Yet, as highlighted in Chapter 1, several major considerations are increasingly driving discussions of the possibility of a significant energy transition, including climate change, insecurity in the oil industry, economic competitiveness, and green innovation. So far, the discussions are only that, discussions.

Section II offers a window into these discussions, with three chapters that look, respectively, at the future of the electricity sector, transportation fuels, and green innovation in Arizona. These chapters are not meant to be predictions of what will happen; they only present possibilities that are actively under discussion in the state. In laying out these possible futures, it is also important to know that we do not advocate specifically for any of them; they are merely scenarios to consider. We hope that they will provide useful fodder for Town Hall deliberations. We know that thinking ahead about the future of energy is critical to the state's long-term success.

Chapter 10 provides a glimpse into the future of electricity in Arizona. The baseline for this effort is provided by the state's current renewable energy and energy efficiency portfolio standards, and the chapter starts by describing what these standards will mean for future electricity development. The chapter then explores two technological and economic developments that might significantly impact this trajectory: faster than expected price declines for solar energy and an increase in the use of electrical vehicles by Arizona residents. The chapter ends with a brief discussion of what might happen after 2030, after the renewable energy and energy efficiency standards are complete, including the possibility of future nuclear development in the state.

Chapter 11 explores the future production of transportation fuels in Arizona. While Arizona has no oil, it does have a lot of sun, and sunlight can be converted into liquid fuels. Whether this could be done economically or not remains an open question, but both the U.S. military and Department of Energy have invested significantly into research to find out. The chapter explores what this option might mean for Arizona as a future producer of major transportation fuels.

Chapter 12 examines the possibility that new clusters of innovation, jobs, and economic growth may develop around novel energy technologies in Arizona. The chapter discusses several possibilities, including solar manufacturing, microbial biofuels, energy efficiency, military energy technologies, and others.

# Chapter 10:
# Electricity in Arizona: Current Status and Future Trends

*Kris Mayes, George Basile, and Christopher Baker*

## Overview

- Renewable generation currently contributes a small percentage to the state's electricity production; however, renewable production is on the rise under Arizona's Renewable Energy Standard (RES).
- The RES requires that electric utilities regulated by the Arizona Corporation Commission (ACC) produce or buy 15% of their total retail sales from renewable energy sources by the year 2025. The RES further requires that 30% of renewable energy be generated from distributed sources (e.g., rooftop solar).
- Arizona also has an aggressive net-metering program that enables customers who install solar panels and other at-home energy generation technologies to receive credit for excess energy that is contributed to the electricity grid. This program has been instrumental in the development of Arizona's solar industry.
- In 2010, the ACC adopted Electric Energy Efficiency Standards (EEES), which require large investor-owned utilities regulated by the ACC to implement programs to lower retail electric sales through energy efficiency.
- By meeting the RES and EEES standards, Arizona will significantly delay the need to build new power plants.

## Current State of Electricity in Arizona

Arizona is the 18th largest generator of electricity in the United States.[1] Electricity generated in Arizona is both consumed within the state and exported to neighboring states, most notably California. Additionally, Arizona imports out-of-state electricity in order to help meet consumptive demand within the state and also to aid in meeting renewable energy targets under the Arizona Renewable Energy Standard (RES). Imported electricity primarily comes from the Four Corners coal-fired power plant in northwestern New Mexico and a wind power facility in the same region. Although the majority of electricity generated in Arizona is produced by fossil fuel-fired and nuclear generation facilities, Arizona has a relatively diverse generation portfolio that includes significant hydroelectric resources and an emerging solar and wind sector.

Resources that are considered eligible for meeting the RES are biomass, biogas, geothermal, landfill gas, solar (i.e., photovoltaics, thermal, and day lighting), and wind.[2] The standard also allows for new renewable energy technologies to be included as eligible resources, subject to review and approval by the Arizona Corporation Commission (ACC or 'The Commission').[3] Each year, ACC-regulated utilities (see Chapter 1) must submit RES Implementation Plans outlining how they intend to meet the RES requirements for the following year. The Commission then reviews those plans for approval and or modification prior to approval.[4] Utilities may seek waivers of the requirements of the RES, but only for "good cause" and only with the approval of the ACC.[5]

Coal-fired generation currently accounts for the largest share of the Arizona's electricity portfolio and accounts for 41% of all electricity generated within the state.[6] Coal used in power generation in Arizona comes from a mine located in the Black Mesa Basin in northeastern Arizona and is also imported from coal mines in New Mexico and Wyoming.[7] Arizona is currently home to six coal-fired power plants of varying size and age. Navajo Generating Station is the largest coal-fired plant in Arizona and has a capacity of 2,250 megawatts (MW). This facility is located in Northern Arizona on the Navajo Indian Reservation near Page, Arizona, and is co-owned by multiple entities including Salt River Project (SRP). In response to federal regulatory guidelines and increased awareness of potential environmental and health impacts, Navajo Generating Station is currently undergoing a $45 million retrofit to install pollution-reducing technology.[8] However, these efforts may not be sufficient to bring the facility into compliance with emissions regulations promulgated by the Environmental Protection Agency in accordance with the Clean Air Act, which are designed to protect air quality and limit the amount of greenhouse gases and other pollutants. Ongoing regulatory scrutiny may determine that Navajo Generating Station will need further and substantially more expensive retrofits.[9]

Other notable coal-fired power plants in Arizona include the 995 MW Cholla Plant operated by Arizona Public Service (APS) near Holbrook; the 773 MW Coronado Plant operated by SRP near St. Johns; and the 1560 MW Springerville Generating Station operated jointly by Tucson Electric Power, Tri-State Generation, and Salt River Project. An additional 1,274 MW of coal-generated electricity is imported into Arizona from the Four Corners and San Juan facilities in New Mexico and 131 MW from facilities in Colorado.[10] Springerville Generating Station is home to the most recent and possibly the last coal burner to be constructed in Arizona, Unit 4, which was completed in 2009.[11]

At 41%, Arizona's dependence on coal is quite substantial. However, coal-fired electricity generation in Arizona only accounts for 2.3% of the nation's total use and is also significantly lower than many western states. Colorado and New Mexico generate approximately 70% of electricity from coal-fired plants, and Utah and Wyoming use coal for over 80% of electrical generation.[12] It is also probable that Arizona will begin to reduce its dependence on coal-fired plants as older plants are retired, pollution reduction efforts make coal plants less profitable, and as the deployment of renewable resources increases under the Arizona Renewable Energy Standard.

Palo Verde Nuclear Generating Station is the only nuclear power plant in Arizona and accounts for approximately 35% of the electricity generated within the state (see Chapter 3). This facility has the capacity to produce a total of 3,739 MW of electricity from three nuclear reactors.[13] Palo Verde is the largest nuclear power plant in the United States and provides electricity to over four million people in the Southwest. Construction of the nuclear facility began in 1976 and was completed in 1988 at a cost of $5.9 billion. The plant is operated by APS but is also co-owned by SRP, El Paso Electric, Southern California Edison, the Southern California Public Power Authority, and the Los Angeles Department of Water and Power.

Arizona is also home to 18 natural gas power plants, which have a combined production capacity in excess of 12,500 MW.[14] Because most of these plants only operate during times of peak electricity demand (see glossary), natural gas power plants only contribute 15.5% of Arizona's electricity generation, despite having the potential to produce more power than Arizona's coal and nuclear plants combined.[15] Natural gas generation facilities are used as "peaking plants" (see glossary) because of the higher cost of natural gas as a fuel source and because many of Arizona's natural gas plants are outdated and utilize inefficient technology, further increasing costs. New natural gas plants in Arizona are now often constructed using high efficiency combined-cycle generation technology. Most natural gas facilities in Arizona are owned by one of the three major utilities, APS, SRP, or TEP; however, independent power producers also own several natural gas facilities. Arizona does not have any producing natural gas wells. Natural gas is imported to the state via pipelines from Texas and New Mexico (See Chapter 9).[16]

Construction of the extensive dam and reservoir systems required to supply water to Arizona communities has provided multiple opportunities for hydroelectric generation. Approximately 8% of Arizona's electricity generation comes from hydroelectric power plants located on Arizona's river systems. The largest hydroelectric plants in Arizona are located on the Colorado River; these include the 1,296 MW Glen Canyon Dam facility, the 2080 MW Hoover Dam, and the 251 MW Davis Dam.[17] The U.S. Bureau of Reclamation operates all of the Colorado River hydroelectric facilities; SRP also operates multiple small hydroelectric generation facilities on dams in central Arizona.[18]

Renewable electricity generation in Arizona is on the rise. However, renewable energy resources, other than hydroelectricity, currently account for less than 1% of the electricity generated within the state.[19] Distributed solar generation resources, medium-scale commercial solar facilities, and several small landfill gas and woody biomass facilities currently generate renewable electricity in Arizona. Additionally, the 127 MW Dry Lake Wind Power Project, located near Heber, Arizona, is near completion and will sell 100% of power generated to SRP for use in the metropolitan Phoenix area.[20] Several large-scale photovoltaic solar and concentrated solar projects are also planned in Arizona; however, only the 250 MW Solana Solar Generating Station near Gila Bend is currently under construction, and the 280 MW Agua Caliente Solar Project in Yuma County appears ready to begin construction in the near future.[21]

## Arizona's Renewable Energy Standard and Energy Efficiency Resource Standards

Arizona has a long history of promoting renewable energy. The ACC[22] first required its utilities to produce and use solar energy in 1996, with the passage of the Solar Portfolio Standard. The Solar Portfolio Standard evolved into the Environmental Portfolio Standard in 2001, which required the state's investor-owned utilities (see glossary) and electric cooperatives to produce 1% of retail sales from renewable resources.[23]

In 2006, after four years of deliberation, public workshops, written comments, and a rulemaking process described by several Commissioners as the most exhaustive in the Commission's history, the ACC passed the Renewable Energy Standard.[24] Under the RES, electric utilities regulated by the ACC must produce or procure 15% of their total retail sales from renewable energy sources by the year 2025. The Commission created the RES with a view toward balancing utilities' energy portfolios and preventing any particular fuel source from dominating supplies. Natural gas prices, which can be volatile, were of particular concern for Commissioners when the RES was being developed.[25] The RES increases over time so that utilities must meet an increasing percentage of the RES until 2025, when it peaks at a15% requirement for regulated electric utility sales from renewable energy.[26] The RES requirements in each year are detailed in Table 1.

The RES also contains a carve-out for distributed energy resources that is considered one of the most ambitious in the nation. Of the 15% RES, 30% must come from distributed generation (see glossary), such as solar rooftop systems or backyard wind projects. This distributed generation requirement also includes a "ramp-up" feature, though it maxes out, or reaches its 30% peak, much more quickly than the overall standard does.[27] The distributed generation requirement also contains a provision that requires that half of the distributed resources obtained by the utilities must come from commercial projects, and half from residential projects.[28] The distributed generation carve-out is pictured in Table 2. The percentage of Arizona's RES that must come from distributed sources, such as solar rooftops and backyard wind systems, is also known as the "DG carve-out."

In addition to passing the RES, the ACC approved a significant net metering rule (see glossary). Under the net metering standard in Arizona, customers who put solar panels on their homes are entitled to receive credit from their utility company for excess generation from those solar systems (i.e., solar energy generated that is greater than the customer's actual use).[29] Regulated utilities provide rolling credit on a month-to-month basis to customers for the energy they produce but do not use. Customers are paid annually for any excess credit remaining.[30] Two features of Arizona's net metering standard stand out from other states' policies. The first feature is that, unlike in many states—where the total amount of electricity that can be net metered is limited on a utility-by-utility or statewide basis—there is no cap on the aggregate amount of energy that can be

**TABLE 1** | Percentage of Energy Generation That Utilities Must Source From Renewable Energy Generation by Target Date

| Year | Requirement |
|---|---|
| 2008 | 1.75% |
| 2009 | 2.00% |
| 2010 | 2.50% |
| 2011 | 3.00% |
| 2012 | 3.50% |
| 2013 | 4.00% |
| 2014 | 4.50% |
| 2015 | 5.00% |
| 2016 | 6.00% |
| 2017 | 7.00% |
| 2018 | 8.00% |
| 2019 | 9.00% |
| 2020 | 10.00% |
| 2021 | 11.00% |
| 2022 | 12.00% |
| 2023 | 13.00% |
| 2024 | 14.00% |
| After 2024 | 15.00% |

**TABLE 2** | The Amount of The Renewable Energy Standard that Must be Met with Distributed Renewable Generation Sources by Target Date

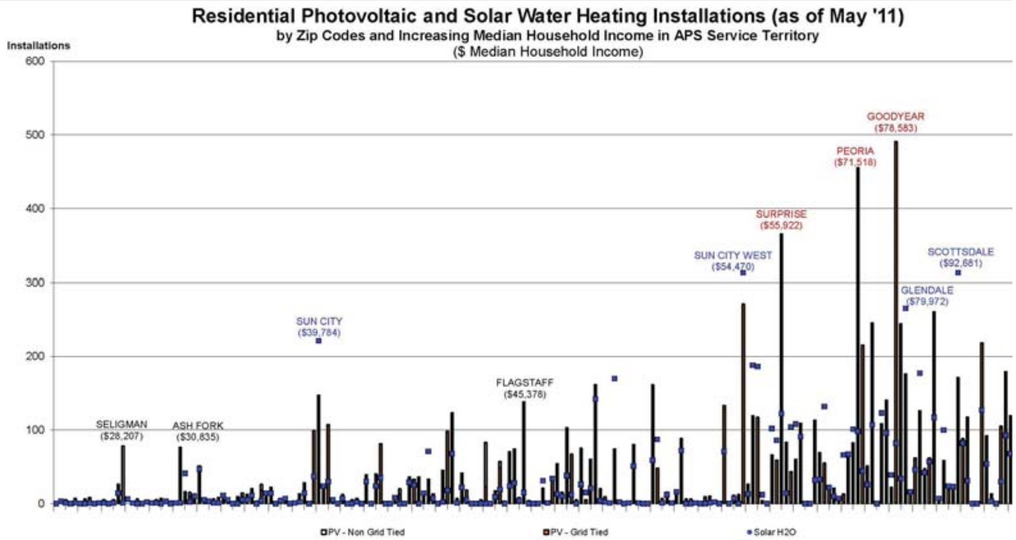
| Distributed Renewable Energy Requirement | |
|---|---|
| 2007 | 5% |
| 2008 | 10% |
| 2009 | 15% |
| 2010 | 20% |
| 2011 | 25% |
| After 2011 | 30% |

net metered in Arizona.[31] Therefore, every resident and business that chooses to “go solar” can receive net metering treatment for all of the excess energy they produce. This net metering provision is considered crucial by most solar experts, as it contributes to shortening the payback period for solar systems and makes them more economical for homeowners. The excess potential is somewhat constrained at each site.

The second distinguishing feature of Arizona’s net metering standard is that users may build solar systems up to 125% of their typical energy use.[32, 33] This provision allows customers to receive credit for producing more electricity than they would normally use. This provision is larger than in other states’ policies and is designed to help utilities effectively handle an increase in the amount of energy added to the utility grid by both homeowner- and business-owned solar systems. It also helps homeowners to be able to afford their solar systems through a more aggressive net metering policy (see also the glossary on net metering).

The distributed generation carve-out and supporting policies, such as Arizona’s net-metering rules and utility interconnection standards, have been widely cited by solar installers and solar manufacturers as reasons for their decision to locate their businesses in Arizona, as these pro-distributed generation policies create a predictable pipeline of projects for their products and services. Arizonans are also reacting positively to the availability of incentives to add solar to their homes and businesses. In 2010, demand for distributed solar systems (and the enabling utility rebates for solar) ran so high in APS service territory that APS sought additional funding from the Commission to keep the program operational throughout the year and to prevent long waiting lists. Demand for solar in SRP’s service territory was similarly robust. SRP ran out of the rebates it had set aside and, as a result, suspended the program for half a year. Data shows that the enthusiasm among Arizonans for solar crosses all geographical boundaries. The following graphic displays the wide distribution of solar systems across APS service territory by zip code.

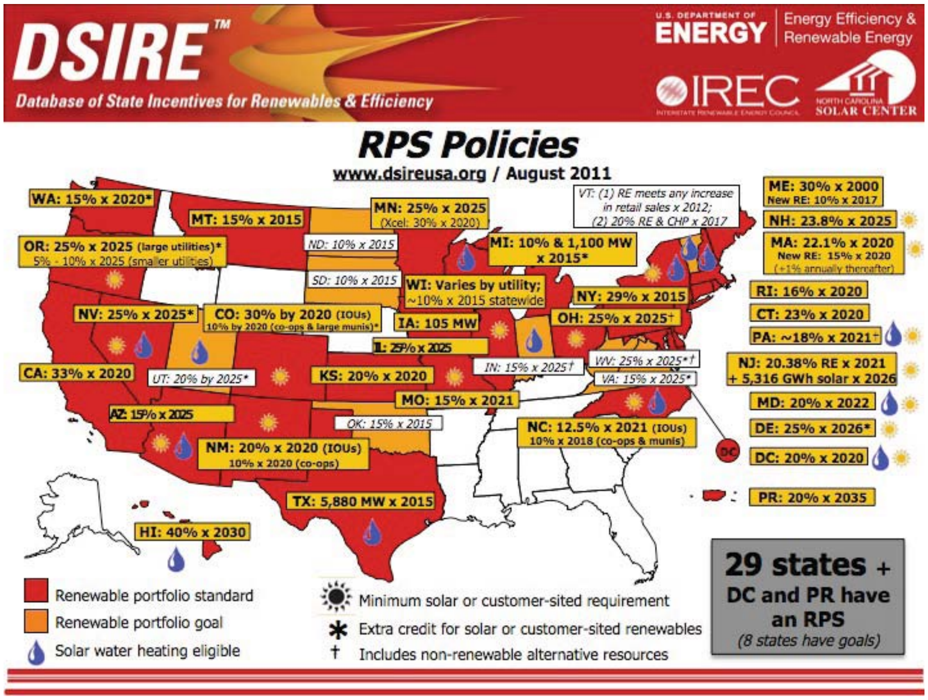
**FIGURE 1** | Graph Showing Where Residential Solar Systems Have Been Adopted in APS Service Territory Under the Res, by Zip Code



Source: APS

Funding for the renewable energy projects that allow the utilities to meet the RES comes from an adjustor mechanism that appears on customers’ utility bills. Each customer class (residential, commercial, and industrial) pays a different amount under the adjustor mechanism, calculated based on the amount of energy the customer uses.[34] For example, the average residential APS customer pays $4.05 per month to fund the RES.[35] Each affected utility must file tariffs yearly with the Commission, which are designed to collect sufficient revenue to fund the utility’s RES compliance efforts. All dollars are thereby reinvested back into utility plans for renewable energy projects in Arizona.

**FIGURE 2** | Current Distribution of Electricity Sources (left) and Projected Distribution 2025 (right) As a Result of the Renewable Energy Standard and the Electric Energy Efficiency Standards



Source: www.desireusa.org

SRP is not regulated by the ACC and, therefore, is not legally subject to the RES. (See Chapter 1 and the glossary under "SRP" for an explanation.) However, SRP has established a customer-financed renewable energy program, called the Sustainable Portfolio Principle, which establishes a goal that 15% of the utilities retail electricity sales to come from "sustainable resources" by 2025. This goal incorporates energy efficiency, renewable energy, and current hydroelectric resources, not just new renewable resources. SRP's program, therefore, is different from those of utilities subject to the Arizona RES.[36]

To date, most of the state's electric utilities are in compliance with the RES. In 2010, for instance, APS reported 703,770 MWh of renewable generation from utility-scale and customer-owned distributed systems in 2010, which exceeds the 2.5% RES requirement for the year.[37] Arizona utilities are announcing each year that they are signing a diversity of renewable energy contracts, including the 250 MW Solana solar CSO project being constructed by the Spanish company, Abengoa.

While it would appear that Arizona's RES is spurring renewable energy systems in a way not seen prior to 2000, and that the RES contains a stronger than normal focus on distributed systems, it is also true that the RES is no longer among the most aggressive in the West. During the mid-to-late 2000s, some states significantly enhanced their Renewable Portfolio Standards, well surpassing Arizona's 15% by 2025, including Colorado (30% by 2020), Nevada (25% by 2025) and California (33% by 2020). Figure 2 shows each state's current RPS.

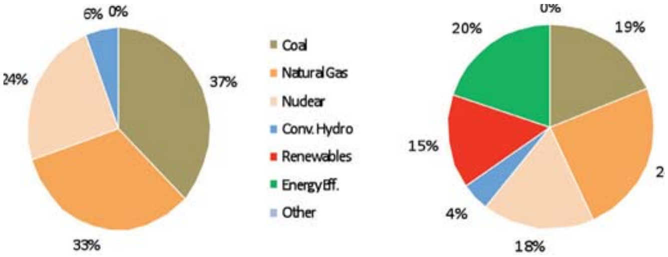
In August 2010 the ACC adopted a second standard, the Electric Energy Efficiency Standards (EEES), which require large investor-owned utilities regulated by the ACC (see glossary) to implement programs to lower retail electric sales through energy efficiency.[38] The goal of the EEES is for each utility to achieve a cumulative savings equal to 22% of the utility's retail electrical sales through improvements in energy efficiency by 2022. Energy-efficiency savings can be met through a combination of several means: (1) demand-side management (see glossary), which allows utilities to give incentives to customers to replace inefficient equipment or to alter energy-intensive processes; (2) peak demand (see glossary) reductions, which result from demand response and load management programs; (3) promulgation of energy-efficient building codes that result in quantifiable energy savings; (4) installation of combined heat and power generating facilities (see glossary); and (5) self-directed energy savings achieved by customers through their own initiative. Compliance requirements under the EEES began in 2011 and increase over time according to the schedule in Table 3.

**TABLE 3** | The Arizona Electric Energy Efficiency Standards Required Percentages by Target Date

| Calendar Year | Energy Efficiency Standard |
|---|---|
| 2011 | 1.25% |
| 2012 | 3.00% |
| 2013 | 5.00% |
| 2014 | 7.25% |
| 2015 | 9.50% |
| 2016 | 12.00% |
| 2017 | 14.50% |
| 2018 | 17.00% |
| 2019 | 19.50% |
| 2020 | 22.00% |

The adoption of the RES in Arizona, if fully implemented over the next 15 years, along with the implementation of the state's ambitious EEES, will reshape the state's overall energy landscape. Nuclear generation and existing hydroelectric facilities are not eligible for RES consideration; however, if nuclear and hydroelectric power were to be concurrently considered "clean energy"[39] along with renewable energy growth and energy-efficiency savings, clean energy will make up 57% of the state's electricity supplies in 2025, assuming all goals are met. Figure 3 demonstrates this transformation.

**FIGURE 3** | The Projected Effects of the Renewable Energy Standard and the Electric Energy Efficiency Standards



Courtesy of Southwest Energy Efficiency Project (SWEEP)

Environmental protection was not a primary driver behind the creation of the RES; however, the RES is likely to have significant environmental benefits. By supplanting the need for future fossil fuel resource, the RES will prevent billions of pounds of harmful emissions from entering Arizona's atmosphere. One study has found that by the year 2025 the RES could prevent the emission of 93 billion pounds of carbon dioxide, 186 million pounds of nitrogen oxide, 129 million pounds of sulfur dioxide, and 1,277 pounds of mercury.[40] Perhaps most significantly for an arid state like Arizona, the RES will save 23 billion gallons of water, since many forms of renewable energy use little to no water at all, in contrast to many forms of fossil fuel-driven electricity.[41] Overall, the RES will contribute significantly to Arizona's total electrical power supply, powering 500,000 homes in Arizona by 2025, and leading to the production of between 1,800 and 2,500 MW of renewable energy.[42]

The state's RES is also helping to drive decisions by cities and counties across Arizona regarding renewable energy. A number of municipalities have made decisions since the passage of the RES to solarize municipal buildings, adopt city-wide renewable energy goals, and deploy solar arrays to offset power needs at water and wastewater treatment facilities. For instance, the city of Tucson has become a leader in small-scale solar power development, having installed over 15 solar power systems on public facilities.[43] In 2008, Pima County, Tucson, and the U.S. Department of Energy came together as Tucson was named a "Solar City" in the Department of Energy's Solar Cities America Program.[44] The city of Flagstaff is currently exploring the development of new renewable energy resources in order to meet 33% of the city's total power needs. Initial installations of local solar, wind, and cogeneration systems are already in place across the Flagstaff region.[45] An example of regional businesses working with utilities on new resource-efficient and renewable energy technologies is apparent in the city of Peoria, which has supported the installation of 1.5 MW of concentrated solar power production using new "sunflower dish collectors" and "Stirling engine" solar energy converter systems that consume less water than other forms of concentrated solar power (see glossary).[46] The energy from these is sold to SRP. The city of Phoenix has adopted a 15% renewable energy goal by 2025 for its own power requirements,[47] and Phoenix City Councilman Bill Gates has spearheaded an effort in the Sunnyslope neighborhood, called the Sunnyslope Solar Challenge, to get hundreds of households and businesses to install solar on their rooftops. Another aggressive move by a local government came from Gila Bend, which adopted a "solar overlay" last year that allows for expediting zoning and permitting for utility scale solar projects. Since Gila Bend announced its expedited permitting process, three solar projects totaling over 300 MW have been approved and funded to be built within the solar overlay. The three projects, all with the support of APS, include three different core solar technologies: concentrated solar, photovoltaic panels, and thin-film solar—each bringing with it a mix of new businesses (e.g., Abengoa Solar and Solon SE) and existing businesses (e.g., First Solar) into the Gila Bend area.[48] Others are expected.

In addition to individual city actions, the state's universities have used the RES and EEES on their campuses. Arizona State University is in the process of installing 10 MW of solar, and plans to have deployed 11 MW by the end of 2011, which would make it by far the most "solarized" campus in America. The University of Arizona plans to install at least 2 MW of solar as part of their climate action plan.[49] And all campuses have a focus on energy efficiency and green building. Northern Arizona University has become a leader in green building as one means to support its renewable energy and energy efficiency goals.[50]

## The Future of Electricity in Arizona—Potential Scenarios

### The Base Case: RES and EEES

In the rest of this chapter, we assume that the RES and the EEES serve as the "floor" for clean energy, and that the total amount of clean energy, including Arizona's nuclear supplies, will stand at 57% in the year 2025. Under this "business as usual" scenario, hundreds of thousands of Arizonans will participate in some direct way through the utilities' efforts to meet RES and EEES targets, e.g., through incentives to add solar to their homes or incentives or rebates to make their homes and businesses more energy efficient. Many more Arizonans will become part of the utilities' decision, pursuant to the EEES, to roll out behavioral energy-efficiency programs, in which consumers learn directly from the utility, in the form of a direct mailing or email message, how much energy they use relative to their neighbors. It is likely that tens of thousands of Arizonans will elect to become a part of the utilities' efforts to conduct "direct load control," a kind of demand response energy efficiency program, in which the utilities will have the ability to turn down residents' air conditioners during certain times of the day (e.g., peak load), with the customer's permission. (See "smart meters" in the glossary for further explanation.) Hundreds of businesses will sign up to be a part of commercial demand response programs, in which they are paid a fee to turn off their electricity at peak times of the day, thereby reducing the amount of power utility companies must generate at the most expensive times to generate power, e.g., during the hottest part of a summer's day. (See also "peak load" in the glossary.)

While the RES and EEES are being deployed, the ACC and the utilities have incentives to become much more aggressive in integrating the cost of negative externalities (see glossary) associated with inefficiencies and non-renewable energy sources into the cost of all of their resources. Given the increased focus on and demand for a cleaner energy future, technologies that are cleaner and use less water will have a greater likelihood of being chosen by the utilities for deployment over dirtier, more water-intensive technologies. It is expected that the true "costs" associated with fossil fuels, indeed all energy sources, will be increasingly factored into the price of the electricity from each source.

Implementation of the EEES will allow Arizona utilities to defer the construction of any new base load power plants until 2030, which will save Arizona ratepayers $9 billion.[51] Under the RES, utilities will need to construct or purchase 2,500 MW of renewable energy. This means that very little traditional utility power plant infrastructure will be constructed in Arizona over the next two decades; most new electricity generators installed in the state will be renewable energy facilities, such as solar or wind farms, with the possible deployment of one additional peaking gas plant at each major utility between now and 2030.

## Possibility of Accelerated Change in Arizona's Energy Future

While the RES and EEES standards provide a floor for new renewable development, it is possible that renewable electricity generation could accelerate faster than these standards require. Some of the factors that could contribute to such a scenario include: (1) solar prices continue to fall, reaching grid parity (see glossary) more quickly than currently anticipated; (2) energy efficiency becomes widely available through financing and other mechanisms that allow homeowners to significantly and more easily afford the up-front costs of efficiency measures (see Chapter 5); (3) energy storage becomes commercialized and is used to allow homeowners to store energy from their distributed systems on-site, through the evening hours; and (4) a robust build-out of the transmission system in the Western Interconnection occurs, creating a true Western marketplace for energy sold by utility-scale solar and wind developers.

Two other significant and uncertain variables to consider when examining future energy scenarios are the rate of smart grid technology (see glossary) adoption among Arizona households and businesses and the rate of electric vehicle adoption. The shift away from gasoline for transportation in favor of electricity could have especially significant ramifications for the states' consumers and utilities; further, the rapid deployment of devices that assist homeowners in controlling and understanding their electricity usage remotely will drive electricity sales downward, further saving ratepayers money and reducing environmental emissions. In Arizona's future, these two factors could cancel one another out, or one could become more dominant, either increasing the amount of electricity needed (electric vehicles) or decreasing it (smart grid).

## Pace of Grid Parity for Solar

Under a moderate transition scenario, solar will reach grid parity by the year 2020, i.e., solar energy will cost roughly the same as other sources of electricity at times of peak energy use during the day (see the glossary for further explanation of grid parity). This pace of change will give Arizona utilities and consumers time to adjust to the reality that utilities will become part of a wider web of providers of electricity services, rather than remaining the monopoly providers of last resort they are today. Gradually, an increasing number of neighborhoods will go from "minority solar" neighborhoods to "majority solar" neighborhoods. This changeover will be slow enough that the number of and types of solar technologies deployed on rooftops will be multi-various, and utilities will not experience excessive intermittency issues associated with solar rooftops.

Large-scale solar and wind projects will continue to experience difficulty securing logistically suitable locations and financially viable power purchase agreements in Arizona and across the West, as utilities and states struggle to build new transmission lines necessary to deliver renewable energy to large load centers like Los Angeles, San Diego, Phoenix, Las Vegas, and San Francisco. Political barriers will remain the greatest problem in this area, as each state pursues a "go your own way" approach to transmission and renewable energy, believing that doing so will lead to an increase in jobs in their own backyard. While potentially misguided, there are strong incentives for political leaders to reject building interstate transmission when the perception is that doing so will facilitate renewable energy projects in other states, rather than their own. Other political questions, such as concerns of local residents about land use change or the environmental impacts of projects, will continue to exist around large wind and solar farms and renewable energy transmission projects.

The pace of the change to a new energy economy will be gradual enough under this scenario to give utilities the time and space to decide whether they want to join in a transition to renewable energy and incorporate it in meaningful ways into their business plans. It is likely, for instance, that the list of solar installers offering services to homeowners will include APS and TEP, albeit with strict controls levered on their operations by regulators who do not wish to see large monopolies use their advantages to reduce competition among smaller installers.

### Rise of the Smart Grid

Another factor to consider in discussing the future of electricity in Arizona is the degree to which Arizona develops its smart grid capabilities, especially with regard to the widespread automation and integration of household energy use and appliances into consumer-controlled Internet application (apps). Smart grid is a broad term that is used to describe everything from upgrades to the nation's transmission grid to applications that will make it easier for consumers to control their energy environment at home and at work, among other things. A number of large national and multinational companies have recently announced their intention to enter the smart grid arena, joining a cadre of smaller companies already working on building applications that will allow consumers to see in real time the amount of energy they are using and receive tips for ways to reduce energy costs at any given time of the day; to access their thermostats from their smart phones; and to turn appliances on and off from their desktops at work. Other businesses are working on smart grid technologies that will support rapidly evolving and adaptable energy strategies, including diverse mixes of utility-scale and distributed generation, changing energy sources and distribution capabilities, and increased grid efficiency, stability, and security. If the smart grid expands rapidly due to customer demand, energy efficiency savings could actually exceed the requirements of even the most dramatic Energy Efficiency Standards, such as Arizona's EEES.

Even as consumers gain more control over their home energy infrastructure and energy data, their ability to cut down on their utility bills may rely on decisions made by state public utility commissions regarding rate structures and increased access to data (i.e. information) on their energy consumption. For instance, in most states, companies that would provide these services have difficulty doing so because monopoly utilities currently control customer energy data and have the exclusive right and obligation to serve the customers. As companies increasingly seek access "inside the home" to provide smart grid services, the traditional monopoly utility structure may need to be reconsidered. This is taking place in a number of venues. Additionally, key decisions will have to be made by state and federal regulators about who "owns" the data collected by smart meters. While there are certainly privacy and national security issues that will have to be addressed as part of this conversation, increasingly, consumers are likely to demand—and receive—access to information regarding their own energy usage patterns.

### Rise of the Electric Vehicle

An additional consideration in thinking about energy futures is the arrival of electric vehicles, which could reduce the state's dependence transportation fossil fuels. At the same time, large numbers of these vehicles would also significantly increase demand for electricity. Electric vehicles may also provide a new "storage capacity" for electric power if their batteries can be used as either part of an individual home's "power system" or within the larger grid network. This concept is known as "Vehicle to Grid (V2G)" and is being studied in California, Arizona, and other states. For example, Phoenix has been chosen as a "test city" for the Nissan Leaf and accompanying electric vehicle charging stations. Rollout of these electric vehicles began earlier this year. At least one Arizona utility appears to recognize the potential for electric vehicles to appeal to consumers and has requested permission from the ACC to build and operate some of its own charging stations. This and other utilities are just beginning to consider the implications of home and business electric vehicle charging, including the possibility that extremely rapid adoption of electric vehicles in a specific neighborhood could cause overloads on electricity substations that were not sized to accommodate both the electricity needs of existing homes and newly added garage-based vehicle charging stations.

Under a high electric vehicle adoption scenario, at least some of the electricity savings associated with the state's aggressive EEES would be restored, increasing the utilities' load growth profile over what it would have been under the EEES. Because it is impossible to know exactly how quickly—or even whether —electric vehicles will take off in the United States, and in Arizona more specifically, it is difficult to quantify exactly what electricity use in the transportation sector will mean for the state's overall electricity portfolio. If storage, which would make renewable energy a 24/7 power source, is not perfected by the time electric vehicles become popular, it could lead to an increase in carbon dioxide emissions from power generation, as more electricity is demanded for fueling vehicles. However, it is equally possible that renewable energy, coupled with even more aggressive energy efficiency measures, could supply the increase in electricity needed by the electric vehicle market.

While it is impossible to know with certainty which of these scenarios will evolve, and on what timetable, it is highly likely that the way power is delivered and used in Arizona and the rest of the West will change dramatically over the next two decades. The rapid increase in interest in solar as a source of energy, decreases in its cost, as well as increased awareness that energy efficiency (or energy that we never have to produce) is the cheapest form of electricity available, and the pressing need to address air quality concerns in Arizona—all point strongly toward important changes in the electricity sector that deserve significant public deliberation.

## The Future of Nuclear Generation in Arizona

Arizona's energy future will likely involve the continued operation of the Palo Verde Nuclear Generating Station west of Phoenix. As described earlier in this report, Palo Verde provides electricity to more than 4 million people in the Southwest, and accounts for 35% of the electricity produced in Arizona. (See Chapter 3). APS, Palo Verde's operator, recently successfully negotiated with the federal Nuclear Regulatory Commission for an extension of the Palo Verde license, meaning that the plant has permission to run at full capacity until 2045.[52]

Whether there will be a need to build additional nuclear power plants in Arizona will depend on several financial, social, and technical factors, though under the projections of the ACC and Arizona's utility industry, there will be no need for new nuclear power until at least 2030. According to a study conducted on behalf of the ACC, Arizona's ambitious EEES will obviate the need for any new base load power plants in Arizona until 2030, meaning that as long as the EEES are met, or exceeded, the utilities will not need to build any additional nuclear power plants until 2030.[53] Additionally, it is possible that given the long timescale of the EEES and RES, the markets will develop technologies in the interim that reduce or even eliminate the need for new nuclear power indefinitely.

However, in the event that this does not occur, and assuming the Southwest's population continues to grow, in the year 2030 Arizona utilities could require additional base load power resources. This base load is unlikely to provided be coal-fired electricity, given recent rulemakings by the Environmental Protection Agency that will make coal fired electricity increasingly expensive to operate (see Chapter 7). Thus, any new base load power plants are more likely to be either natural gas or nuclear plants. Once built, nuclear power is regarded as a cost effective resource that is capable of providing power during the hottest summer months—a time when utilities do not want to be on what are known as the "spot markets". The spot market is the market for power that utilities access when their own power plants fall short of their customers' needs, and which can be very volatile, and more expensive when power demands in the Southwest are high. However, new nuclear power plants can be very costly to construct, requiring steep rate increases in the early years of a plant's construction in order for the utility to be able to proceed with building the plants and avoid detrimental financial actions. More specifically, because capital costs are high for nuclear, smaller utilities generally have difficulty financing the construction without significant capital partners, and without risking bond downgrades during the construction and capital outlay process.

Additionally, nuclear power has continued to be controversial for a variety of reasons, including that some neighborhoods object to nearby power plants, in particular nuclear plants, which store nuclear waste on site. The federal government has so far failed to create a centralized federal repository for nuclear waste and, as a result, most nuclear waste is stored on-site at nuclear power plants where the waste is produced. These storage issues took on greater urgency in the public's mind after the Fukushima nuclear power plant disaster in Japan (see Chapter 8), and will likely persist into the future.

Finally, nuclear power plants cooled by traditional means use significantly more water per megawatt-hour produced than any other conventional means of generation (see Chapter 6),[54] and utilities will have to confront how to procure those water resources in an arid environment like Arizona.[55] Hybrid cooling for nuclear is possible and could lower water-use requirements. The siting of new nuclear power plants in the Southwest will include not only questions of proximity to population centers, but also questions regarding the use of local groundwater or surface water resources, assuming effluent is not available. Whether a reliable source of water will be available to a future nuclear power plant will be further complicated by the possibility of drought and the stress such droughts would place on water supplies to nuclear power plants.[56]

## Notes

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13 Salt River Project. Palo Verde Generating Station. Retrieved from http://www.srpnet.com/about/stations/paloverde.aspx

14 Energy Information Administration. (2010). Arizona Energy Overview. Retrieved from http://www.eia.gov/state/state-energy-profiles.cfm?sid=AZ.

15 Energy Information Administration – Arizona Energy Data, http://www.eia.gov/state/state-energy-profiles-data.cfm?sid=AZ (follow hyperlink to “Reserves and Supply”).

16 Energy Information Administration. (2011). Arizona Energy Analysis. Retrieved from. http://www.eia.gov/state/state-energy-profiles-analysis.cfm?sid=AZ

17 Bureau of Reclamation Lower Colorado Dams Office. Retrieved from http://www.usbr.gov/lc/hooverdam/lcdo.html. (follow “Davis Dam, Hoover Dam, or Parker Dam” hyperlink).

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20 Salt River Project. Dry Lake Wind Power Project. Retrieved from http://www.srpnet.com/about/stations/drylakewind.aspx.

21 Abengoa Solar. Solana Generating Station. Retrieved from http://www.abengoasolar.com/corp/web/en/our_projects/solana/.

22 Arizona’s public utilities commission, the Arizona Corporation Commission (ACC), is a five-member body, consisting of Commissioners who are elected statewide to four-year terms. Unlike most other states, the Commission in Arizona is not appointed by the governor, and is a constitutional body, with its ratemaking and regulatory powers set out in the Arizona Constitution.

23 The SPS was established as part of the Electric Competition Rules adopted December 26, 1996. See R14-2-1618.

24 Renewable Energy Standard and Tariff, Ariz. Admin. Code §§ R14-2-1801 to 1816 (2007).

25 The RES has been unsuccessfully challenged in the courts by the Goldwater Institute, which asserted that the Commission lacked the constitutional authority to enact a renewable energy standard. The Commission and others countered that, in fact, the Commission did have both constitutional as well as statutory authority to enact the rules. In Miller v. the Arizona Corporation Commission, Superior Court Judge Joesph Heilman upheld the Commission’s RES rules; that decision was followed by an Arizona Court of Appeals decision in April 2011 authored by Judge Margaret Downie, affirming the Superior Court’s favorable ruling regarding the Commission’s authority to enact the RES. The Goldwater Institute has appealed the Court of Appeals decision to the Arizona Supreme Court, where the case sits today awaiting the determination of the Supreme Court on whether it will hear the appeal.

26 Ariz. Admin. Code § R14-2-1804 (2007).

27 Ariz. Admin. Code § R14-2-1805 (2007).

28 Ariz. Admin. Code § R14-2-1805(D) (2007).

29 Arizona Net Metering Rule, Ariz. Admin. Code §§ R14-2-2301 to 2308 (2009).

30 Ariz. Admin. Code § R14-2-2306 (2009).

31 Ariz. Admin. Code § R14-2-2303 (2009).

32 Total connected load refers to the total amount of electricity that would be used at a given occupied structure if all of the electrical applications (such as appliances, outlets, etc.) were in use at once. Allowing 125% of a home’s total connected load to be net metered allows a homeowner to upsize their solar system, which is often more cost-effective.

33 Ariz. Admin. Code § R14-2-2302(13)(d) (2009).

34 Ariz. Admin. Code § R14-2-1808 (2007).

35 See ACC Decision No. 72022 adopting the 2011 APS RES Implementation Plan, Docket No. E-01345A-10-0166.

36 Salt River Project. Sustainable Portfolio Principles. Retrieved from http://www.srpnet.com/environment/sustainability/ Sustainable Principals.aspx.

37 Arizona Public Service. (2010). 2010 Renewable Energy Standard Compliance, Report. Retrieved from http://www.aps.com/_files/solarRenewable/2010RESComplianceFiling.pdf.

38 Database of State Incentives for Renewables and Efficiency. Arizona Electric Energy Efficiency Standards. Retrieved from http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=AZ27R&re=1&ee=1.

39 Whether or not nuclear energy is considered “clean” has been subjected to an extensive and long-running debate. Some believe that because nuclear energy cannot be produced without the concomitant production and storage of spent nuclear fuel rods, in addition to other negative externalities, it cannot be categorized as “clean.” We do not seek to resolve this dispute in this document.

40 Public Interest Research Group (2005).. Renewing Arizona Economy: The Clean Energy Path to Jobs and Economic Growth. Retrieved from http://www.policyarchive.org/handle/10207/5146.

41 Ibid.

42 These calculations were conducted by Ray Williamson, a member of the Arizona Corporation Commission staff and the principle staff architect of the RES. According to Williamson, this is the level of renewable energy produced under the RES, assuming that solar comprised the bulk of the renewable energy used to meet the RES, a likely bet in Arizona.

43 City of Tucson Solar site. Online at http://cms3.tucsonaz.gov/energy/solarintucson.

44 Pima County One Stop Solar site. Online at http://www.solaronestopaz.org/AboutUs.aspx.

45 Flagstaff Sustainability Program, (2010). Online at http://flagstaff.az.gov/DocumentView.aspx?DID=9371.

46 LaMonica, M. (Jan. 2010). Solar driven Stirling engines get to work. CNET. Retrieved from http://news.cnet.com/8301-11128_3-10439709-54.html?tag=mncol;title.

47 City of Phoenix. Green Buildings and Energy. Online at http://phoenix.gov/greenphoenix/sustainability/summary/green.html.

48 City of Gila Bend Solar Web Page. Online at http://www.gilabendaz.org/SolarPlants.html.

49 University of Arizona. (2010). University of Arizona Climate Action Plan, 2010. Retrieved from http://www.fm.arizona.edu/documents/Sustainability/UA%20Climate%20Action%20Response%20v2.pdf.

50 McLaren, B. Northern Arizona University. Creating a Culture of Sustainability. Retrieved from http://green.nau.edu/docs/NAU_Sustainability_powerpoint.pdf.

51 Lawrence Berkeley National Laboratory. Decoupling Assessment for the Arizona Corporation Commission. June, 2010.

52 Ryan Randazzo, "Palo Verde Nuclear Generating Station Gets 20-Year Extension," Arizona Republic, Apr. 22, 2011, available at http://www.azcentral.com/business/articles/2011/04/22/20110422palo-verde-20-year-extension.html.

53 See report by the Lawrence Berkeley National Laboratory on Decoupling for the Arizona Corporation Commission.

54 It is relevant to note that the Palo Verde Nuclear Generating Station currently utilizes effluent and not groundwater; however, the operators of the plant, APS and SRP, recently negotiated for an extension to 2048 of their effluent agreements with the cities that provide it, and because effluent, like groundwater, has become increasingly scarce and valuable, the cost of the effluent to APS and its customers rose significantly.

55 Nuclear power plants generally use approximately 500 to 1,100 gallons of water per megawatt hour.

56 Drought conditions in the Southeast nearly forced the shutdown of several nuclear power plants in that region (and did necessitate the brief closure of one plant in Alabama) in January, 2008. See http://www.accessnorthga.com/detail.php?n=206119.

# Chapter 11: **Transportation Fuels from Solar Energy**

*Gary Dirks*

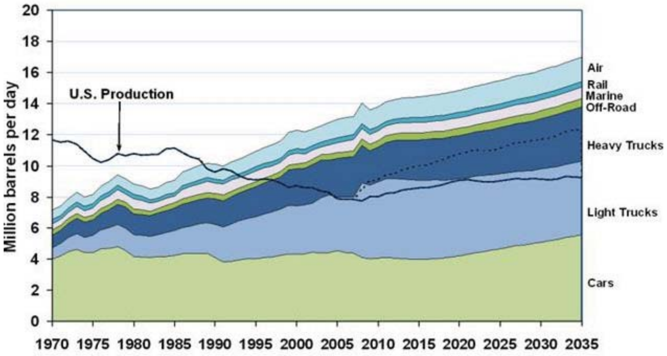
## Overview

- Oil remains overwhelmingly the source of transportation fuels, and this will not change soon or easily.
- Security of supply is of increasing concern as reserves are concentrated in fewer countries.
- Every president since Richard Nixon has set goals to reduce dependence on foreign oil. None have been met.
- Arizona is exposed to the same security concerns as the rest of the nation.
- There are new technologies on the horizon that might enable Arizona to both increase its supply security and provide fuel to the nation, all based on solar energy.

## A Brief Overview of Global Oil Production

Oil powers the transportation sector in the United States and around the world. Though details vary from country to countr—for example, some use more gasoline and some more diesel—all rely on oil as the primary feedstock for hydrocarbon fuels. Because the United States consumes far more oil than it produces and has for many years (see Figure 1), the U.S. faces a security risk from the disruption of crude supplies. This risk has increased over time.

**FIGURE 1** | U.S. Oil Production and Fuel Consumption by Sector 2010 to 2035 is Forecasted



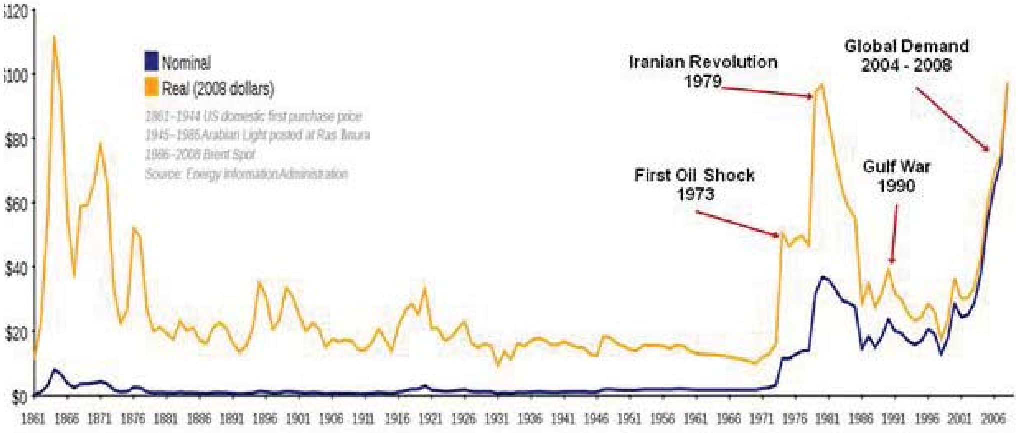
Source: International Energy Agency

The risk is reflected most noticeably in oil price volatility (see Figure 2), but it is also reflected in international U.S. diplomatic and military postures. Thus, in April 1986, Vice President George H.W. Bush traveled to Saudi Arabia with a stern warning. Record low oil prices of $10 per barrel threatened the U.S. oil industry and U.S. national security. If prices did not rise, he warned, perhaps a U.S. tariff on imported oil would do the job. More recently, at the urging of the International Energy Agency, the Organization for Economic Co-Operation and Development (OECD) countrie—including the United States—began to release oil from the strategic oil reserve. This action was taken in response to the decision by the Organization of Petroleum Exporting Countries (OPEC), which controlled more than 80% of the world's crude oil reserves in 2010, to hold oil production levels constant and thus allow prices to rise in the face of strong demand. This was the first time that the global strategic reserves, and the U.S. reserve in particular, were used to affect oil price due to an immediate risk to economic activity.

Every president since Richard Nixon has recognized the vulnerability of the United States to dependence on foreign oil and has set targets for increasing domestic supplies of oil and reducing imports (see Figure 3). None of the targets have been achieved.

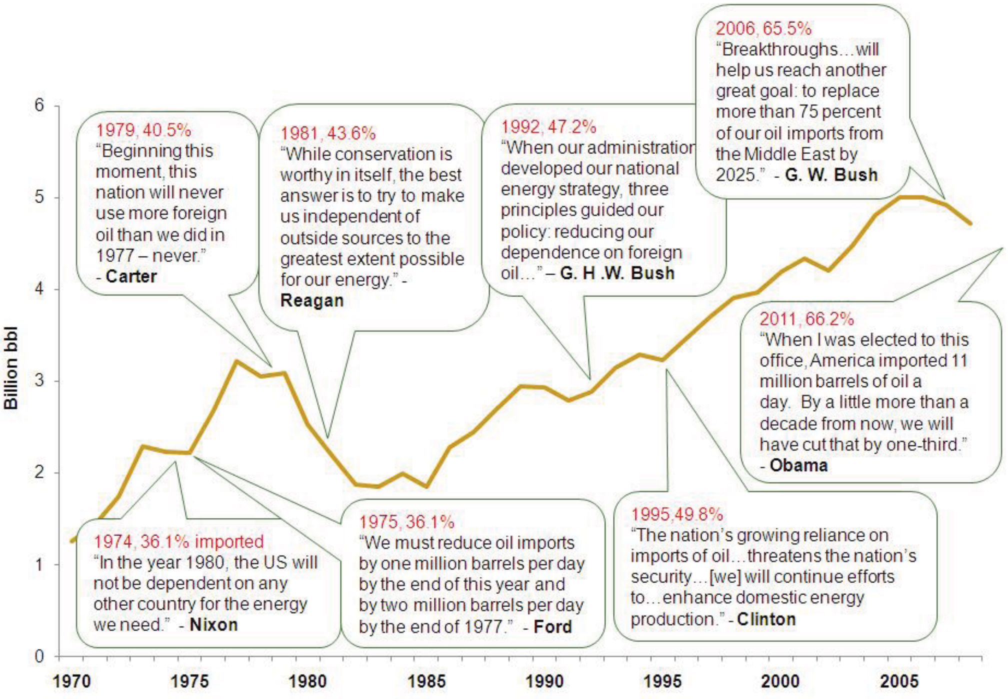
The security risk has intensified as oil reserves have become more concentrated in fewer and fewer countries. Though the United States and Canada are among the top 12 holders of oil reserves, the largest reserves are in the Middle East and Africa. Saudi Arabia has the single largest reserves, and Iran, Iraq, Kuwait, United Arab Emirates, Libya, and Nigeria are all among the top 12. Russia, Kazakhstan, and Venezuela complete with the leading reserve holders.

**FIGURE 2** | Real (inflation adjusted dollars) and Nominal (current dollars) Price of Oil



Source: Energy Information Agency[1]

**FIGURE 3** | Annual U.S. Oil Imports in Billions of Barrels



1979, 40.5%
"Beginning this moment, this nation will never use more foreign oil than we did in 1977 – never." - **Carter**

1981, 43.6%
"While conservation is worthy in itself, the best answer is to try to make us independent of outside sources to the greatest extent possible for our energy." - **Reagan**

1992, 47.2%
"When our administration developed our national energy strategy, three principles guided our policy: reducing our dependence on foreign oil…" – **G. H .W. Bush**

2006, 65.5%
"Breakthroughs…will help us reach another great goal: to replace more than 75 percent of our oil imports from the Middle East by 2025." - **G. W. Bush**

2011, 66.2%
"When I was elected to this office, America imported 11 million barrels of oil a day. By a little more than a decade from now, we will have cut that by one-third." - **Obama**

1974, 36.1% imported
"In the year 1980, the US will not be dependent on any other country for the energy we need." - **Nixon**

1975, 36.1%
"We must reduce oil imports by one million barrels per day by the end of this year and by two million barrels per day by the end of 1977." - **Ford**

1995,49.8%
"The nation's growing reliance on imports of oil…threatens the nation's security…[we] will continue efforts to…enhance domestic energy production." - **Clinton**

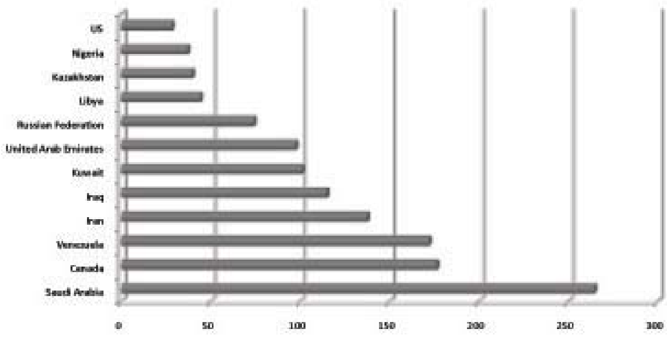
Source: Energy Information Agency

Importantly, with the exception of the United States and Canada, the reserves of all countries are controlled by state companies and are managed as national strategic assets. Foreign companies have little access to and even less control over investment decisions in these countries. Investment decision-making is important not only because new supply needs to meet growing demand, but also because it needs to make up for the natural decline in production from older fields. The decline is large, as can be seen in Figure 5. The dark blue shows the output in 2035 that can be expected from fields that are producing today. In order to meet the demand for transportation fuels in 2035, new fields need to be found and developed that fill in the light blue, about 45 million barrels per day or about half of current demand and nearly 85% of current crude oil production.

In effect, the security of oil supplies to importing countries, like the United States, Japan, China, and all of the Eurozone, depends on the investment decisions made by the large oil reserve holders. While investment by the large U.S. and European oil companies are helpful, they cannot offset a lack of investment in the countries that produce a lot of oil. Irrespective of the social or political differences that the United States may have with these countries, or the political and economic instabilities that these countries may face, the United States is utterly dependent on their will and ability to continue to invest in a timely and sufficient manner to maintain supply security.

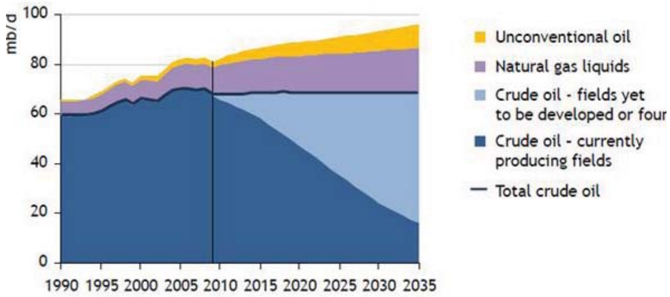
The stability of the oil markets depends on reliable supply. In fact, price becomes volatile and can spike if just the excess production capacity gets low. The cause of the 2008 oil price spike remains controversial, but certainly concern about growing demand and low excess capacity contributed to market fears of tight supply.

**FIGURE 4** | Proven Oil Reserves in Billions of Barrels



Source: BP Energy Statistics 2009[2]

**FIGURE 5** | Oil Supply Sources to 2035



Source: Fatih Birol, World Energy Outlook 2010 and Renewables[3]

A possible exception to this otherwise difficult story is the growing potential for natural gas vehicles. Natural gas vehicles (NGVs) are either fueled exclusively with natural gas (dedicated NGVs) or are capable of natural gas and gasoline fueling (bi-fuel NGVs). The fuel may be compressed in high-pressure fuel cylinders to produce liquefied natural gas. The latter have the advantage that the fuel is a liquid, and much more can be carried in the same space than for compressed fuel.

The driving range of natural gas vehicles generally is less than that of comparable gasoline- and diesel-fueled vehicles because of the lower energy content of natural gas. Extra storage tanks can increase range, but the additional weight may displace payload capacity. NGV horsepower, acceleration, and cruise speed are comparable with those of an equivalent conventionally-fueled vehicle, and, compared with vehicles fueled with conventional diesel and gasoline, NGVs can produce significantly lower amounts of harmful emissions.

Though natural gas taxis, buses, and trucks are not new, they are a small percentage of the U.S. vehicle fleet. Less than 1% of the natural gas consumed in the United States used is for transportation, and in 2009 there were only 117,000 compressed natural gas and liquefied natural gas vehicles on the road in the United States. This may change. As is discussed in the next section, the development of production technology that enables energy companies to produce natural gas economically from shale may fundamentally reshape the natural gas industry. There is the possibility that the United States may enjoy both high-volume and low-cost natural gas. The availability and low cost of natural gas will likely spur vehicle manufacturers to produce vehicles to take advantage of the new fuel option.

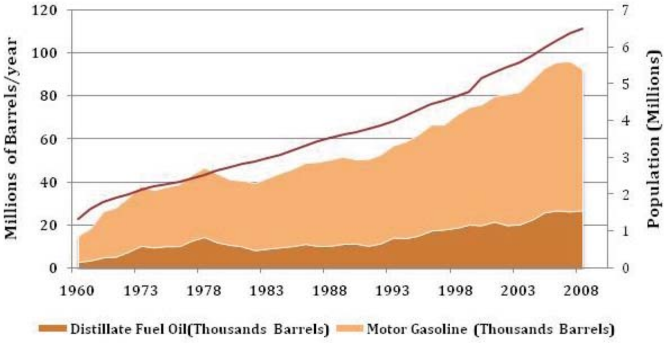
## Transportation Fuel in Arizona

Today Arizona is fully exposed to the international markets for security of supply. The state imports all of its transportation fuel. This situation is neither especially surprising nor alarming. For refining to be attractive, favorable crude oil supply, distribution logistics, and very large capital investment all must be available. Arizona has no crude oil and a relatively low population density. A refinery of any size would by necessity need to import crude oil and export products. At least until recently these conditions have not prevailed, and Arizona does not have a large fuel refinery. Fuel security and supply are covered in Chapters 2 and 9.

Arizona's demand for transportation fuel has grown in parallel with population growth (see Figure 6), except in the case of two major periods of economic downturn, from 1978-1982, after the Middle East oil shocks and the Iranian revolution, and in the economic collapse of 2007-2008. In 2008, Arizona consumed more than 90 million barrels of gasoline and distillate fuel, or nearly 4 billion gallons. According to the Energy Information Agency (EIA), the cost of supplying Arizona's transportation fuel was $13.5 billion (see Figure 7).

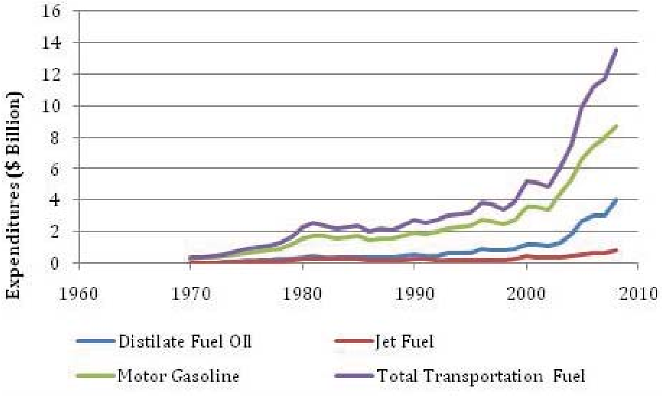
The bulk of this money leaves the state.[6] A 2006 study of motor gasoline showed that 86% of expenditures left the state. As all petroleum products are imported, the ratio is likely to be about the same for petroleum products today. This would suggest that nearly $12 billion dollars leave the state for transportation fuel. Finding a profitable way to produce fuels within the state would generate substantial revenues for the state economy.

**FIGURE 6** | Motor Fuel Demand and Population Growth



Source: Energy Information Agency[4]

**FIGURE 7** | Arizona Expenditures on Transportation Fuel



Source: Energy Information Agency[5]

**FIGURE 8** | Monthly Average Regular Gasoline Price for Arizona and the U.S.

Source: Gasbuddy.com[7]

In spite of impressions to the contrary, however, gasoline and transportation fuels are cheap, especially in Arizona where gasoline prices tend to be lower than the national average, as shown in Figure 8. The low price makes deployment of new technology challenging. Arizona's challenge is made more difficult by its lack of resources for producing fuel. It has neither oil nor natural gas, although there is some coal and biomass in the form of agricultural waste and forestry waste. There is also lots of sunlight. Alternative fuel sources will be considered next.

## New Fuel Sources

The nation needs options for reducing dependence on foreign oil. A number of technologies could offer a way forward. Hydrogen as a fuel, compressed natural gas, and electric vehicles have all gained some interest, as have various forms of non-petroleum hydrocarbon fuels. Hydrocarbon fuels resulting from the conversion of coal or natural gas to liquid fuels, biofuels, or various forms of fuel made from direct conversion of sunlight to liquid fuel are all examples of options for making fuels from sources other than petroleum.

**FIGURE 9** | Mandated Volumes of Renewable Fuel (Billions of gallons) under The Energy Policy Act of 2005 (U.S. Congress 2005)

| Mandate Year | Volume (billions of gallons) |
|---|---|
| 2006 | 4.0 |
| 2007 | 4.7 |
| 2008 | 5.4 |
| 2009 | 6.1 |
| 2010 | 6.8 |
| 2011 | 7.4 |
| 2012 | 7.5 |

Production of fuels that are compatible with existing transportation fuels—fuels that can be used in existing engines, otherwise known as “drop-in” fuel—has been a focus of scientific and engineering research for nearly 100 years. Hitler’s Germany deployed a process still in use today to convert coal to liquid fuels—the very same process advanced by South Africa during the apartheid oil embargo.

The United States has explored a range of pathways. A major step for the United States came with the passage of The Energy Tax Act of 1978, which provided for a 40 cent per gallon tax exemption for production of bioethanol for fuel. The Synthetic Fuels Corporation was established in 1980 under the Synthetic Fuels Corporation Act, creating a financial bridge for the development and construction of commercial synthetic fuel manufacturing plants based on converting coal or natural gas to transportation fuels. Both of these acts were in response to the oil shocks of the 1970s. More recently, The Energy Policy Act of 2005 established targets for biofuels in the U.S. fuel supply (see Figure 9) and The Energy Independence Act of 2007 extended them. However, performance against these targets has been poor. For three consecutive years, the U.S. Environmental Protection Agency has reduced the targets. The new targets for 2012 are given in Figure 10.

In order to understand hydrocarbon fuels, it is important to recognize the extraordinary investment required both in the supply and distribution of these fuels and also in the equipment for consuming them. Changing to completely new fuels will involve investing trillions of dollars worldwide and would take many years to accomplish. In the meantime, drop-in fuels that can be used in existing engines would create, at minimum, a bridge to new fuels of the future and, potentially, a sustainable, long-term alternative.

**FIGURE 10** | The New EPA Target Proposed Volumes for 2012 Biofuels in the US Fuel Supply. (Environmental Protection Agency)[8]

| | Target Volume | Percent of Total Fuel Requirement |
|---|---|---|
| Cellulosic Biofuel | 3.45 - 12.9 Mill Gal | 0.002 - 0.010% |
| Biomass-Based Diesel | 1.0 Bill Gal | 0.91% |
| Advanced Biofuel | 2.0 Bill Gal | 1.21% |
| Renewable Fuel | 15.2 Bill Gal | 9.21% |

## An Economic Opportunity for Arizona?

There are two paths to developing synthetic drop-in fuels. One of these two routes makes use of fossil carbon (i.e., coal or natural gas) as the starting resource; the other makes use of solar energy as the starting resource. In 2009, Arizona produced 7.5 million tons of coal and imported 13.4 million tons for power production.[9] Estimates of the size of Arizona's coal reserves vary widely. According to the U.S. Geological Survey, studies from the 1950s of the Arizona Black Mesa coalfield estimated that Arizona had approximately 21 billion tons of coal reserves.[10] The EIA estimated that in 1992 Arizona had 102 million tons of demonstrated underground coal reserves and 135 million tons of demonstrated surface coal reserves, for a total of 237 million tons of demonstrated coal reserves. Further, in 1992, there were 51 million tons of total recoverable underground coal reserves and 106 million tons of surface coal reserves, for a total of 157 million tons of recoverable coal reserves. There is currently no coal underground mining in the state, only surface mining.[11] Current estimates of the quantity of coal reserves in Arizona are withheld to avoid disclosure of individual company data, which means that it is unclear just how much coal is currently available for mining.

Arizona's reserve base is not ideal for producing liquids from coal, a process that requires large-scale production to be economically viable. Sasol, Ltd., one of the leading suppliers of alternative fuel technologies, uses a number of criteria for locating a coal-to-liquids plant including:

- access to large reserves of low-cost gasifiable coal (approximately 2 to 4 billion tons) at the proposed location for the Coal-to-Liquids facility;
- a Coal-to-Liquids plant should preferably be based on 'stranded coal,' which is coal that cannot easily be used in other ways;

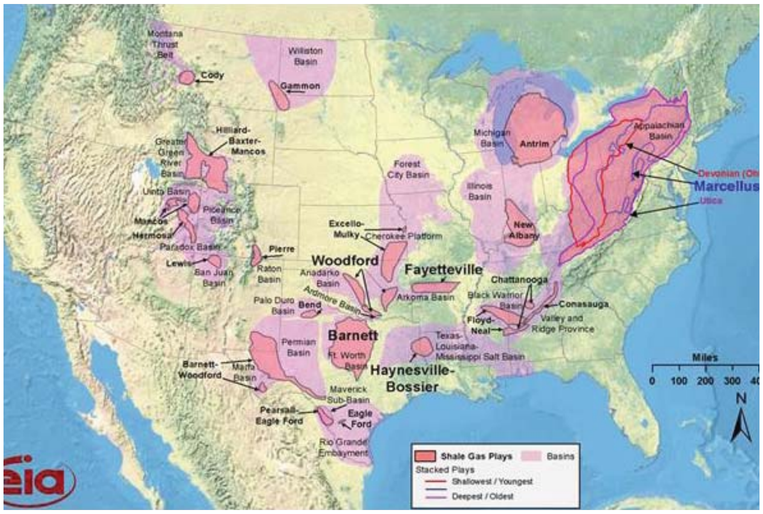
Arizona's coal reserves are too low for a competitive facility. Further, the coal is not stranded; it is currently serving electric utilities in several locations.

A second option using fossil carbon to convert to natural gas to liquid fuel (a process called GTL) is using Fischer-Tropsch technology. GTL has historically been used by locations with poor access to crude supplies, but it has also been used as an option when abundant and under-commercialized natural gas reserves are available. The substantial costs associated with GTL (for example, the Sasol plant in Qatar cost over $1 billion to construct) means that abundant gas feedstock and low gas prices are prerequisites for the construction of a plant.

Arizona, again, is not well positioned for GTL. It has no supply of natural gas, and, in particular, no shale gas (see Figure 11). To support a new industry, all the gas would have to be imported. The cost of building the infrastructure and purchasing the gas is likely prohibitive, though no analysis has been done.

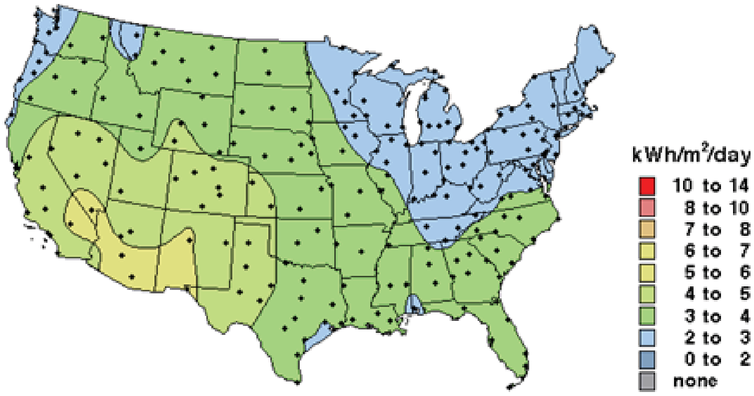
In what follows, the focus will be on just those fuel conversion options that are particularly reliant on solar energy, specifically biofuels and direct conversion of sunlight to fuels. These choices were made not because the others lack merit; in fact, most of them are good avenues to pursue (although any option based on fossil resources will have no impact on reducing carbon emissions). Rather, Arizona is one of very few locations in the world that could consider developing a fuels industry based on conversion of sunlight to fuel either with living organisms or through artificial processes. Arizona is unique because it has extraordinary sunshine and sufficient land and water resources to support a large industry of national if not international consequence.

**FIGURE 11** | Shale Gas in the Lower 48 States



Source: EIA[12]

**FIGURE 12** | Intensity of Sunshine in the Lower 48 States
kWh/m2/day= kilowatt-hours per square meter per day



Source: National Renewable Energy Laboratory[14]

As shown in Figure 12, Arizona enjoys abundant sunlight. The density of sunlight is among the highest in the country and the world. By comparison, a gallon of gasoline contains the equivalent of 35 kWh of energy. Thus, every 6-7 square meters of land in Arizona (about the size of a small room) receives the solar energy equivalent of a gallon of gasoline every day. Of course, no process can capture 100% of this energy, and therein lies the challenge of finding economically efficient ways to capture the energy of the sun and convert it into fuel.

## Biofuel

Even though Arizona's climate ranges from arid to desert over much of the state, plant-based biofuels are an option for the state. A 2008 report estimated the amount of forest biomass supply in Arizona.[13] They estimated that Arizona could produce 53,313 dry tons of forest biomass per year at $10/ton or at maximum 2 million tons at $100 per ton roadside. Using a gasification technology in development that can produce about a barrel of liquid fuel from a ton of biomass, forest waste could produce between 50,000 and 2 million barrels of biofuel per year. (In comparison, Arizona used a total of 90 million barrels of fuel per year in 2008.) Due to the high cost of the biomass feedstock alone, it seems unlikely that the upper end of the estimate (i.e., 2 million barrels) would be economically viable.

An alternative to forest and agricultural waste is algae, which are aquatic photosynthetic organisms. In the production of vegetable oils, for example, algae can be tens or even hundreds of times more productive than common oil crops (see Figure 13). This difference in productivity arises in part from the inherent energy efficiency of the organisms, but also, in part, because they make few of the structural materials that plants need to support themselves. Consequently, they can divert their energy to making oils and proteins and to reproduction.

Algae are also remarkably diverse organisms. No one knows how many different species of algae and related species exist, but the number is certainly in the millions. They grow in the oceans, in brackish water and in freshwater. They can grow across a wide range of temperatures and in the presence of many contaminants. This versatility means that scientists and engineers have a large inventory of species to select from when considering commercial opportunities. Algae today are grown for natural coloring, protein supplement, and nutraceuticals (i.e., therapeutic dietary supplements or foods). Increasingly, they are grown for fuel, but this is more challenging. A global effort is underway to develop strains of algae and processes and equipment to grow for fuel. Here in Arizona, research efforts are underway in universities, as well as in companies that are producing equipment and growing algae for fuel. All this activity is motivated by the potential for Arizona to play a leading role in the future of algae-based fuel.

**FIGURE 13** | Comparison of Oil Yields From Biomass Feedstocks

| Crop | Oil Yield (Gallons/Acre/Yr) |
|---|---|
| Soybean | 48 |
| Camelina | 62 |
| Sunflower | 102 |
| Jatropha | 202 |
| Oil Palm | 635 |
| Algae | 1,000 - 6,500 |

Source: DOE[15]

The process for growing algae and producing fuel is outlined in Figure 14. In addition to water and sunlight, algae require nutrients, like nitrogen and phosphorous, to grow. Waste water can provide these nutrients. The algae also need carbon dioxide, which can be provided by the flue gas from power plants or any furnace burning fossil fuels. The algae are farmed in closed bioreactors, which are closed plastic containers that prevent exposure to the contaminants in the air, or in open ponds. In the most common method of making fuels, the algae are harvested by filtration ,and water is removed. The algae are then dried and the oil extracted. The extracted oil is then further refined into fuel. The residual material is rich in protein and carbohydrates and has value as a co-product. This process is practiced widely in research facilities and start-up companies. It is unfortunately expensive—too expensive for making these fuels cost-competitive with oil.

The cost challenges have not dampened enthusiasm for the technology. The federal government, through the Department of Energy (DOE), the National Science Foundation, the Department of Defense, the National Aeronautics and Space Administration, and the U.S. Department of Agriculture, has provided funding to research teams across the country to reduce the cost of producing algae-based fuels, to make them attractive alternatives to crude oil. To make a difference in Arizona's demand for oil products, or even make Arizona an exporter of fuel, however, it would require algae cultivation on a grand scale. The DOE National Algal Biofuels Technology Roadmap anticipates productivity in the range of 4,000-6,000 gallons of oil per acre per year. Arizona consumes about 100 million barrels of fuel or about 4.2 billion gallons each year. At the DOE target productivity, meeting Arizona's requirements would take between 700,000 and 1 million acres. This land commitment is on the order of 40 miles square (i.e., 1,024,000 miles)—not inconsequential, in fact, on the same scale as harvested agriculture land in the state.[16]

**FIGURE 14** | Process of Growing Algae for Fuel. ASU Laboratory for Algae Research and Biotechnology

**FIGURE 15** | Open Pond Bioreactors. Laboratory for Algae Research and Biotechnology (LARB)

Water is a potential limitation for growing algae in Arizona. There are two basic types of bioreactor systems for growing algae: the open pond system (see Figure 15) and closed bioreactors (see Figure 16). Both consume water. In open ponds there is evaporation from the surface of the ponds, as much as an inch-per-day in the summer. In contrast, closed reactors need to be cooled and evaporative cooling is the lowest cost way to cool. The actual water consumption turns out to be similar for both systems. Fortunately, the diversity of algae means that they will grow in waters of a wide range of composition. Species can be found that grow in very salty waters and waters of high or low acidity. As a result, we do not need to plan for high quality water resources to grow algae; they can even be grown on wastewater. Arizona has supplies of wastewater often laden with nutrients that can brought into service.

Algae-based technologies are not quite to the point where they can be deployed profitably on a large scale for making fuel, but much research across the world is underway. As the technology matures, Arizona is well-placed to benefit.

## Fuels from Sunlight

In addition to growing biofuels, there is a suite of technologies that can make fuel directly from sunlight, carbon dioxide, and water. Some make use of principles similar to photosynthesis in plants, but others are totally different. Two technologies are of particular relevance to Arizona. One makes use of high temperatures to make fuel precursors from water and carbon dioxide. The other generates electricity first and then uses the electricity to make fuel precursors and fuels.

The first approach, called 'thermochemical cycling' makes use of mirrors to create temperatures as high as 1,500 degrees Celsius (see Figure 17).

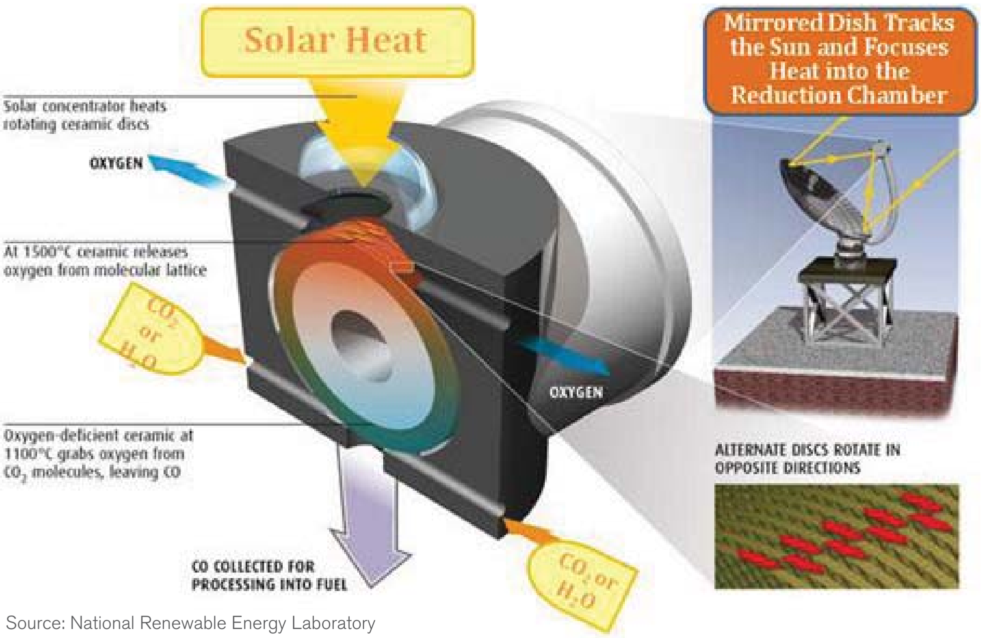
Sandia National Laboratories in New Mexico is the U.S. leader in this technology. At the National Solar Thermal Test Facility in New Mexico, the Sunshine-to-Petrol project has developed the

**FIGURE 16** | Closed bioreactors. LARB

**FIGURE 17** | Parabolic Mirrors

Photo courtesy of Stirling Energy Systems (SES)

**FIGURE 18** | Sandia National Laboratories Sunshine-to-Petrol Reactor Design



Source: National Renewable Energy Laboratory

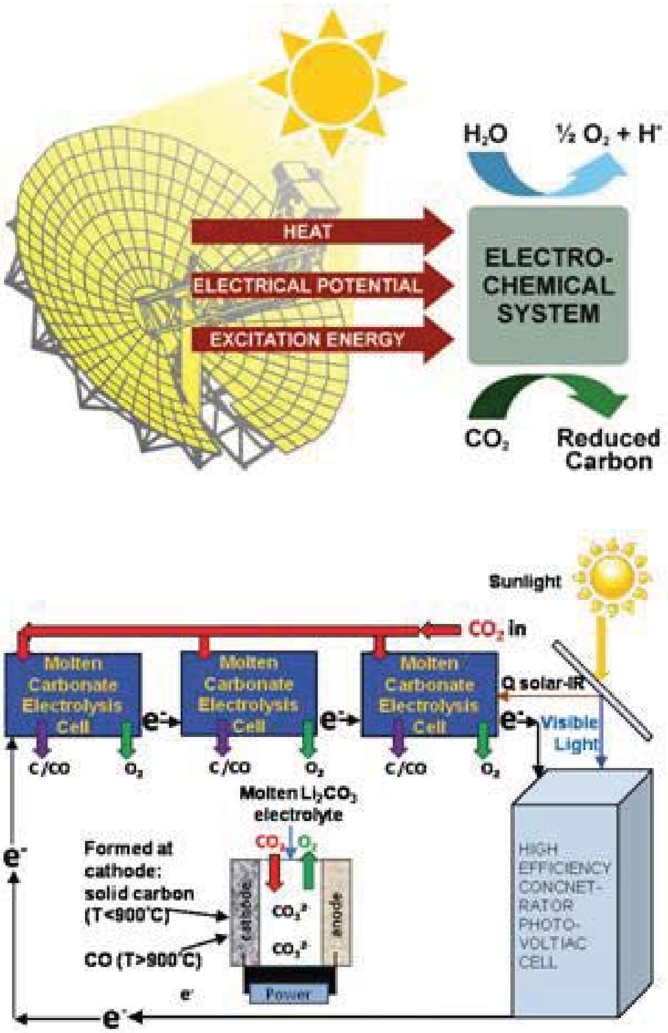
materials and reactor designs for a practical system for producing fuels (see Figure 18). This technology makes use of the very high temperatures that can be achieved by using mirrors to focus the sun's rays on a small area. In operation, a reactive material is exposed to the sunlight where temperatures reach about 1,500 degrees C and then cycled to a dark zone where the temperature is about 700 degrees C. Under these conditions carbon dioxide can be converted to carbon monoxide, and water can be converted to hydrogen or synthesis gas, which is easily converted to liquid fuel. This thermo-chemical cycling technology is much more efficient than algae, and the land area required for this technology will be correspondingly less. Water will also be required to make fuel with this technology, but water consumption in the reactor is not large and there is little water loss from other steps. It is much more efficient in the use of water than algae-based biofuels.

The Sandia project remains in the developmental stage, but the Sandia team expects to have demonstrated the design concept by the end of this year. Economic assessment of the current design shows that fuel at $5 per gallon is possible. Today, this price is high, but within a decade when the technology is fully deployable it may very well be competitive.

The second approach is called electrochemical reduction (see Figure 19). This technology has at its core the reduction of carbon dioxide. Various different approaches are in different stages of development. One approach based on breakthroughs at Princeton University and commercialized by the company, Liquid Light, makes use of special catalysts to convert carbon dioxide to fuel molecules. A second approach involves high temperature electrochemical reduction to make synthesis gas. In this approach electrochemical reduction is carried out at high temperature. One of these technologies developed at George Washington University called STEP (Solar Thermal Electrochemical Photo) uses a molten metal oxide at about 900 degrees C for efficient operation.

Both of these technologies begin by generating electricity using standard photovoltaic panels or concentrating solar devices. The electricity is then used to make fuels and their precursors. Like the thermochemical cycling technology, both of these approaches should be much more efficient than algae. Consequently, they will use less land than algae. Also, like thermochemical cycling, they will use less water. These technologies are at an early stage of development, and credible information about their cost has yet to be made available in public sources. Nevertheless, each are based on new insights that, when fully developed, could lead to commercially viable technologies.

**FIGURE 19** | Electrochemical Reduction and STEP



Source: Stuart Licht

Arizona research teams are engaged in aspects of the science necessary for developing viable technologies of the type described here. Both Arizona State University and the University of Arizona have large algae research programs, and they are each members of large national consortia funded by DOE. In addition, an Arizona State University team has a grant from DOE for a novel technology that eliminates most of the steps required to release and recover fuel molecules from cyanobacteria, an organism similar to algae. This latter team involves researchers from both the university and private businesses. Several entrepreneurial businesses have started in the state that produce equipment, do engineering, and even grow algae for commercial purposes.

Arizona is leading the work for direct conversion of sunlight to fuel. Roger Angel, the Director of the Steward Observatory Mirror Laboratory at the University of Arizona, is developing new, very low cost mirror technology for producing low-cost electricity using high-efficiency solar cells. A startup company, RENhu, is commercializing this technology. Low-cost electrons are, of course, critical for electrochemical reduction of carbon dioxide to fuels. The same mirrors may also support the thermochemical cycling approach to making fuels by focusing the sunlight to create the very high temperatures required for this process. Similarly, Arizona State University is a leader in the science of high performance solar cells. This research is aimed at producing low-cost photovoltaic cells with efficiencies of 50% or higher.

Today, making fuels from sunlight, either directly or with micro-organisms, is not commercially attractive. The costs remain too high. The science and engineering is developing rapidly, and affordable technologies for developing fuels from sunlight may be available within a decade. There is an opportunity now for Arizona to plan for this future. With its exceptional sun and open landscape, Arizona will be a natural choice for solar-to-fuels deployment. The opportunity now is to consider what steps need to be taken to direct business to locations that are suitable for deploying their technologies, but also are sensitive to other uses or expectations for the land. There is an opportunity to establish policies that will make Arizona attractive to these businesses. Most importantly, there is an opportunity for Arizona to position itself as a leader in creating a scientific and industrial ecosystem that will lead to the benefits of an in-state fuels industry and the jobs that come with it.

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# Chapter 12:
# A Green Silicon Valley in Arizona —Innovation Clusters for Economic Success

*Bill Brandt*

## Overview

- Companies and their associated supply chains grow faster in business clusters.
- Creating early demand and providing finance for scaling up an industry is critical for the success of clusters.
- Arizona has the potential to develop business clusters in the following areas:
    - Solar manufacturing
    - Smart grid (with embedded renewables)
    - Energy efficient buildings
    - Energy from microalgae

## Key Elements for Innovation Clusters and Economic Success

Long-standing and newly emerging energy challenges are creating opportunities for technological innovation. The challenges span a wide range, from global resource availability and energy needs in developing markets to growing demand for energy security and economic competitiveness in the United States. Arizona could be a leader in meeting some of these challenges by supporting innovation clusters.

This chapter explores Arizona's potential future as a major global hub for energy technology innovation and business success. The analysis is accomplished in three parts: first, a structure of key elements needed for successful "cluster" development is presented and specific scenarios for developing energy clusters is identified; second, clean technology opportunities in Arizona are examined; third, examples of clusters that show promise for development in Arizona are outlined.

### Structural Element Requirements for Clusters

- **Building on regional strengths:** Experience suggests that building on a region's economic strengths is an often highly effective strategy for economic development.[1] Arizona is recognized as a business-friendly state. The state has also become more adept at structuring policy frameworks and diverse incentives to attract "foundational" companies that can spur further growth. First Solar and Suntech are examples of foundational companies that have been important in creating a solar manufacturing cluster in the Valley. In addition to attractive economic incentives, Arizona has well-regarded solar research expertise. For example, Suntech's decision to locate a manufacturing facility in the Phoenix area was partially influenced by the proximity and access to the resources of Arizona State University. In addition, Arizona universities also provide a growing pool of skilled future employees.

- **Linking local to global:** Local demand provides start-ups with opportunities to create, test, and develop ideas. This local demand then provides the revenues for scale-up, thereby creating a global industry and supply chain. For example, the Netherlands has been the hub of the global flower trade since pioneering the industry in the seventeenth century. The Dutch floriculture cluster is an example of a successful economic model that works in a globalized market despite the fact that lower cost competitors exist outside of the Netherlands. A similar scenario, where a skilled industry succeeds despite lower-cost competitors, might apply to emerging, innovative global energy companies. In general, a sustained competitive advantage can be developed through consistent innovation and cost management techniques based on a virtuous circle of business, research and policy interactions. While industries can lead the clusters, it is important to note that, to be successful, these clusters must also include important institutions such as universities, standard setting agencies, trade associations and training, education, technical support, and a sophisticated supply chain.[2]

  Arizona's abundance of sunshine, land availability, and the prevalence of major metropolitan areas are among its key advantages for creating clusters in clean energy. In many ways, location, local conditions, and positive feedback from business, government, and institutions provide the impetus for cluster growth. According to Marco, et al., "Far from being placeless, the economy and economic change is place-based."[3] The real economy is location-based and is not 'flat' or evenly networked globally, but, instead, it is concentrated in particular places. For instance, approximately 64% of current 'clean' economy jobs in the United States and 75% of new job growth between 2003 and 2010 occurred the 100 largest U.S. metro areas.[4] The links between cities and regional infrastructure, therefore, are crucial to providing a critical mass of economic activity to foster the development of clusters. If a region is adopting new technologies, then this will create activity that fosters local businesses and professional expertise. International business strategist, Michael Porter, describes the interconnection between the local and global in cluster-formation by stating, "Clusters are not unique; however, they are highly typical—and therein lies a paradox: the enduring competitive advantages in a global economy lie increasingly in local things—knowledge, relationships, motivation—that distant rivals cannot match."[5]

- **Supporting market-driven conversations:** Clusters often are formed around conversations between companies or their customers, and, as a result, both entities share a similar 'competitive space.' These conversations typically focus on common problems in the sector, such as insufficient skilled labor or opportunities that arise from linking and leveraging existing assets.[6] As more companies join the conversation, they create an emerging and synergistic network. For example, in the clean energy sector, between 2003 and 2010, cluster-based businesses grew at a rate of 1.4% points faster each year when compared with non-clustered (isolated) establishments.[7]

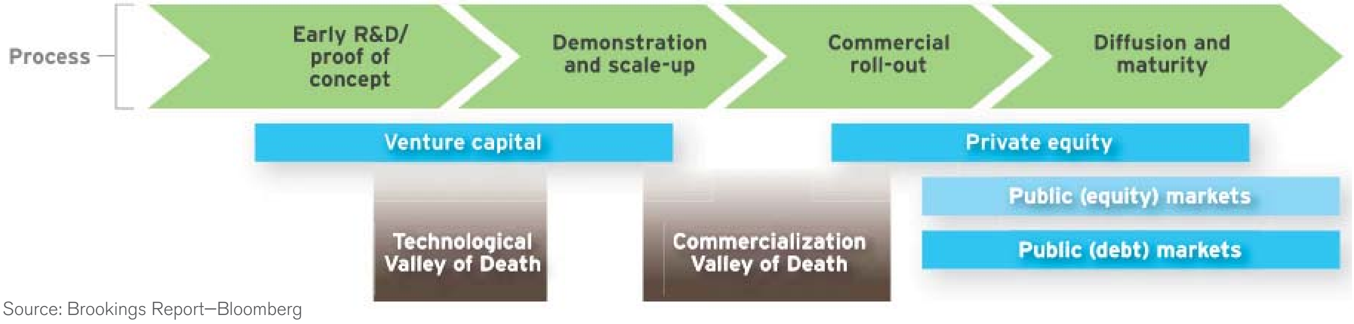
- **Developing critical mass and anchor investments:** Successful clusters are often privately led and publically supported.[8] There are, however, examples of key anchor investments, which when pooled can accelerate the collaboration process between inventors, entrepreneurs, researchers, and financiers, all of whom are focused on meeting a market challenge. Critical mass is not just about the number of collaborators, but also the appropriate diversity of players. Innovation, for instance, may be driven by bringing together skilled labor and university expertise for pilot projects that can be scaled-up by industry via open test bed ventures. Clusters can also receive support in terms of physical facilities, such as incubators, accelerators, and research centers. They may also receive soft money or funding for investments in talent, entrepreneurship support and education, marketing and branding, and other innovation supports.[9]

## Strategies for Supporting Energy Innovation Clusters

There are two strategies critical to supporting clusters for energy innovation. First, local market demand must be stimulated; often this occurs through market-informed policymaking. This is accomplished, for example, through establishing new standards (e.g., Arizona's Renewable Energy Standards, see Chapter 10) or government procurement policies that are specifically focused on clean energy standards. These policies help create local demand. As a result, clusters with steady local or regional domestic demand are able to create the opportunities needed for firms to invest, scale-up, and lower their manufacturing costs.

The second strategy is to develop just-in-time finance capacity for funding scale-up in clean energy businesses. Substantial financing is critical for energy businesses, which are often required to develop new technologies that require large up-front capital expenditures. While significant attention has been directed toward financing early technology demonstration projects, often new energy industries do not have a clear financing plan for advancing beyond the initial phase. The result is a series of what industry experts call "valley of death" (in other words, business failure in between research and development and technology demonstration or between technology demonstration and commercial roll-out) as illustrated in Figure 1. Few sources of finance exist for building initial pilot plants and for scaling up advanced manufacturing facilities. Moreover, the financing situation for new companies is made more difficult as a result of the uncertainty and disruption in federal funding initiatives, many of which are scheduled to end in 2011.

**FIGURE 1** | Multiple Finance Gaps Complicate the Scale-Up of New Industries

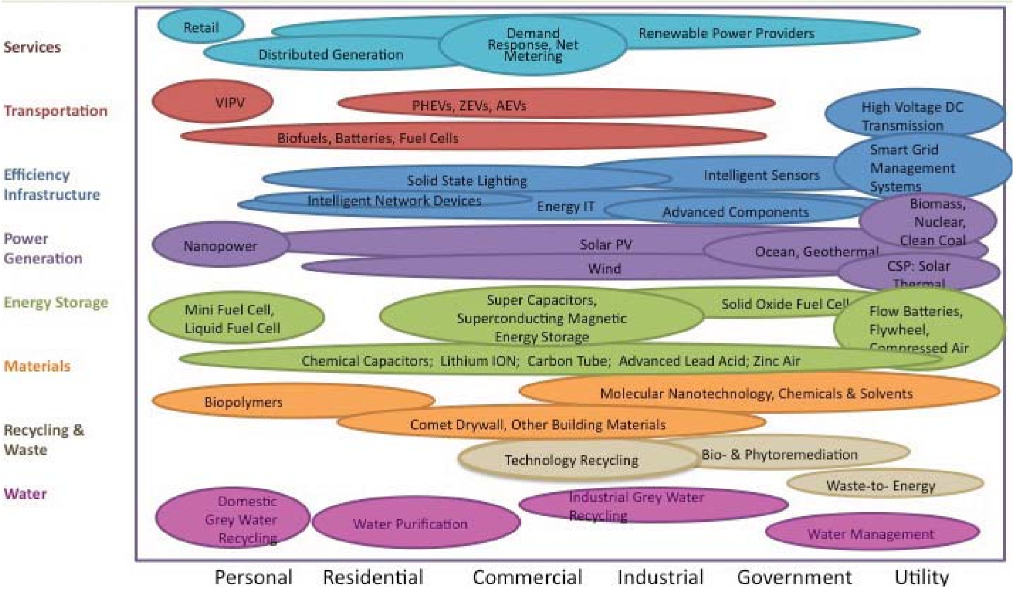


Source: Brookings Report—Bloomberg

## Timing and Opportunities for Clean Energy Clusters in Arizona

In spite of the serious 'headwinds' that often exist for clean energy economic development, as discussed earlier, Arizona is well-positioned for a clean energy ecosystem. The right combination of demand stimulus along with world-class scientific minds, venture and finance capital, and supportive government policies can generate new energy opportunities. This leads to new jobs. Dow Chemical Company CEO, Andrew Liveris, wrote recently, "A renaissance is within reach. If Americans are the ones who design and build the new [clean economy] technologies, it will re-energize commerce in the United States, creating, without a doubt, millions of high-paying jobs."[10] The clean economy that Liveris is referring to would be diverse and include a wide range of traditional industries. Figure 2 illustrates the breadth of opportunity as well as the complexity of clean energy and clean technologies.

**FIGURE 2** | Clean Energy Cluster Landscape[11]

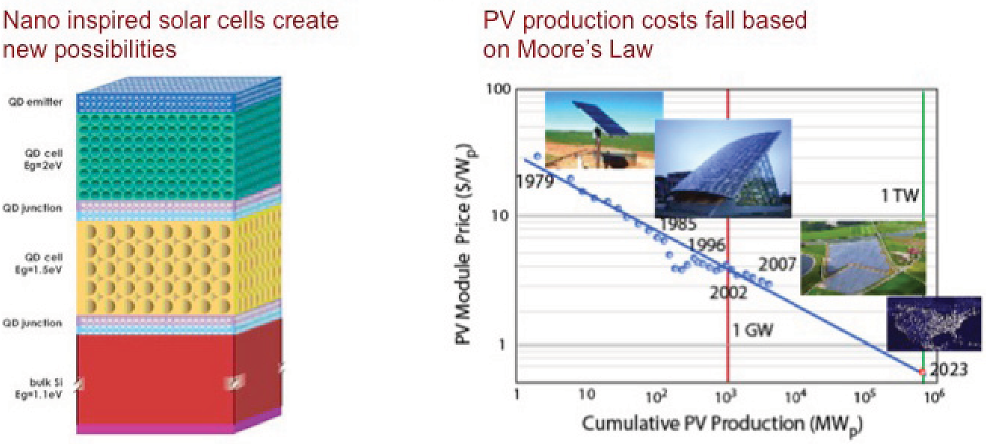


Source: Tom Cain

Currently, across the United States, clean technology is still largely a niche industry, and this is unlikely to change overnight. To make these industries more mainstream, however, policy makers and regulators can help by creating a favorable investment climate focused on stimulating demand and creating financial capacity to fund scale-up. In Arizona the following factors are seen as critical to promoting business opportunities for the future:

- The cost of solar panels continues to decline with changes in the technology and manufacturing experience. The cost of energy generated from solar photovoltaic panels is already approaching grid parity (see glossary), which may create a tipping point in demand for solar PV system installations.
- The integration of different energy conversion processes with new technologies creates the possibility of more efficient clean energy systems. The National Science Foundation's recent research grant awarded to ASU for developing an Engineering Research Center (ERC) focused on new solar photovoltaics (PV) technology is a reflection of new and emerging concepts for clean technology. The ERC's vision is to revolutionize energy systems by taking advantage of economies of scale and cost reductions in PV while integrating semiconductors, nanotechnology, optics, electrochemical, and biochemical processes (see Figure 3).

**FIGURE 3** | An Integrated Systems Approach to Developing Transformative Renewable Energy Technologies



- The projected growth of electric cars may spur other technological infrastructure, such as solar-powered charging stations. For example, Ecotality is creating hubs in Phoenix and Tucson as part of a $230 million project in cooperation with the U.S. Department of Energy to install 14,000 charging devices in six states. The project is designed to increase infrastructure for electric vehicles (e.g., battery charging stations) to allow drivers to take longer trips.[12]

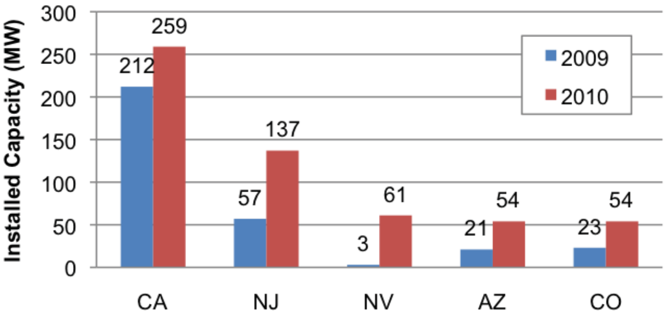
## Potential Arizona Clusters

### Solar Manufacturing

Arizona has among the best solar energy resources in the United States, but this fact alone is insufficient to earn the title of 'Solar Silicon Valley'. Arizona is one of 29 states, including Washington, D.C. and Puerto Rico that has a Renewable Portfolio Standard (RPS), and it is one of the most stringent in the country.[13] The Arizona RPS (or the RES, Renewable Energy Standard, as it is called elsewhere in this report) requires that by 2025, utility companies must get 15% of their electricity generation from renewable sources, and 30% of this must be met through distributed generation (e.g., rooftop solar panels). Half of this target is to come from residential applications of solar panels and half from non-residential applications. This is anticipated to create demand for solar installations from both homeowners and businesses. The rest of the RPS requirement is projected to come from large-scale renewable-energy projects (e.g., concentrating solar power plants).[14] (See Chapter 10.) Therefore, this policy has created demand for both distributed and utility power generation technologies.

The growth in demand stemming from the RPS has changed the dynamics of the solar industry. In 2007, only four states had installed over 10 MW of PV, but by 2010, 16 states had reached this level of installed capacity. Five states, including Arizona have now installed over 50 MW each (see Figure 4).

**FIGURE 4** | Installed PV Capacity Increase Between 2009 and 2010 in the U.S. States with the Most Solar PV Capacity[16]



CA= California, NJ= New Jersey, NV= Nevada,
AZ= Arizona, CO= Colorado

Source: Solar Energy Industries Association

Installations in Arizona grew 157% between 2009 and 2010.[15]

2010 emerged as a banner year for domestic manufacturing of upstream PV components as production increased substantially year-after-year (Table 1). There was strong global demand, growing 139% from 7.1 GW to 17 GW in 2010, Domestic demand grew by 67% to 878 MW in 2010.

**TABLE 1** | Growth Rate of Production of Critical PV Building Components

| Component | Production | Growth Rate (Y-O-Y) |
|---|---|---|
| Wafers | 624 MW | 97% Growth |
| Cells | 1,058 MW | 81% Growth |
| Modules | 1,205 MW | 52% Growth |

There are more than 2,000 companies in the U.S. solar value chain, a great many of which are located in California due to its leadership position in solar PV deployment. However, Arizona's aggressive Renewable Energy Tax Incentive Program creates one of the most competitive tax environments for renewable energy headquarters and manufacturers in the country. This program's success resulted in Business Facilities Magazine naming Arizona the country's "solar capital" in 2010. The program has attracted 11 companies, creating 6,359 jobs, resulting in $1.832 billion in investment in the Greater Phoenix region (see Table 2).

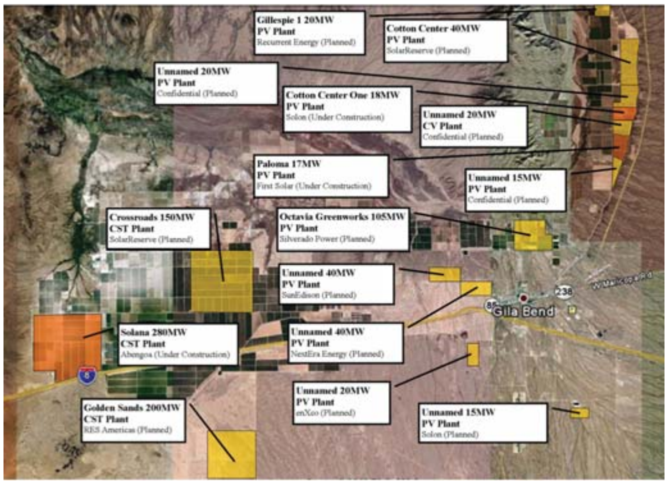
Arizona illustrates how a state's strategic initiative to create demand, along with appropriate incentives provided to businesses, can create opportunities not only for companies but also for local cities. For example, the city of Gila Bend has taken an active role in seeking ways to market green electrons based on its high sunlight and geographic position. It has reduced the time for issuing permits to new power plants from nearly two years to just four weeks. Today, Gila Bend has several projects under construction with an anticipated

**TABLE 2** | Jobs Created and Local Investments Made by Businesses Since the Passage of Arizona's Renewable Energy Tax Incentive Program at Full Implementation[17]

| Company | Project Type | Location | Jobs | Investment | Date |
|---|---|---|---|---|---|
| **Suntech** | Manufacturing | Goodyear | 150 | $14M | Oct. 2010 |
| **Tower Automotive** | Manufacturing | Goodyear | 182 | $50.6M | Apr. 2010 |
| **Linamar** | Manufacturing | Glendale | 52 | $3.5M | Jul. 2010 |
| **Rioglass** | Manufacturing | Surprise | 109 | $50M | Aug. 2010 |
| **Alpha Energies** | Headquarters | Phoenix | 57 | $5.1M | Feb. 2010 |
| **PowerOne** | Manufacturing | Phoenix | 350 | $11M | Jan. 2010 |
| **Faist** | Manufacturing | Phoenix | 45 | $5M | Jan. 2011 |
| **Gestamp** | Manufacturing | Surprise | 164 | $57M | Feb. 2011 |
| **First Solar** | Manufacturing | Mesa | 4,800 | $1,600M | Mar. 2011 |
| **Fluidic** | Manufacturing | Maricopa County | 400 | $16M | Apr. 2011 |
| **Satin Gobain** | Manufacturing | Goodyear | 50 | $20M | Jun. 2011 |
| **Total** | | | 6,359 | $1.832B | |

total capacity in excess of 5,000 MW (estimate based on land availability) (see Figure 5). With an infrastructure of four substations and the Entegra combined cycle gas-powered generation plant, several green power options are available. Gila Bend is also actively working to find solutions to improve transmission line infrastructure, which is essential if Arizona is to reach its full potential as a supplier of 'green' electrons to the electric power grid.

**FIGURE 5** | Solar Energy Projects Supported by Local Gila Bend Energy Initiatives



Challenges and opportunities for growing the existing solar industry cluster include:

- Identifying changes to the utility operations and regulation model that would accelerate demand.
- Establishing framework(s) that will permit renewable energy development on a financially sustainable basis.
- Considering changes to federal and state policy initiatives to ensure a maximum positive impact on the market.

## Smart Grid

There is increasing recognition that we often have smart machines and smart people but a rather 'dumb' power grid (see glossary under 'the grid' and 'smart grid'). An analogy may be drawn between today's power grid operation and the flow of water through a series of different pipes: if the right pipes are in place, great. If not, the costs of "new plumbing" can be significant and possibly prohibitive. However, with today's rapidly evolving energy needs, including novel power technologies, changing markets, and the growing need for increased efficiency, a "smarter," more adaptive grid is required. Indeed, developing this smart grid is not only critical to energy security and efficacy, but also to global economic competitiveness.

Arizona is a unique testing ground for smart grid technology development because it is a central player in transmission across the Southwest and a potential link to the Midwest and East. Additionally, Arizona has ongoing research efforts in this area, with a unique focus on supporting both centralized and distributed energy technologies. Arizona, therefore, has intellectual muscle that can support future economic research and product development.

Challenges and opportunities for promoting a smart grid include:

- The current grid loses one to three electrons for each produced due to moving power over long distances.
- The current grid is inflexible for many distributed or "low voltage" energy systems such as rooftop wind and solar.
- The current grid is not flexible in terms of delivering power to shifting populations or shifting energy demands (e.g., delivering power to new suburbs or at times of day when it is not usually demanded in large quantities).

- The current grid is not well built to link electricity with mobile sources, such as electric vehicles.
- The current grid is old and was not built with up-keep and adaptation in mind (i.e., it costs a lot to maintain and is not easily adaptable to change).
- The current grid is not well-suited to the needs of growing economies in the rest of world (e.g., in developing countries where we expect to see 90% population growth in the next 20 years).

## Energy Efficient Buildings

In July 2010, Arizona began the implementation of an Electric Energy Efficiency Standards (EERS) to save 22% on energy by 2020. Under the standard, Arizona utilities are now required to reach 20% cumulative annual energy savings by 2020, and this includes a credit for demand response of up to 2%. Arizona's building industry could become a center for an 'energy efficient building innovation cluster'. Arizona has a development culture, an excellent building base, and plenty of sun. Solar will play an important role and could have an impact on smart girds and peaking power (see glossary) management. Building retrofit opportunities, the smart use of waste heat, and reducing peak heating and cooling loads among other things have the potential to create an Arizona hub for technology innovation. In addition, green energy efficient buildings and parking facilities generate solar electrons for use in electric vehicles. An additional advantage arises as charging car batteries during the sunniest times of day creates a way of storing solar-generated electricity, energy which can be later used for transportation long after the sun has set.

**FIGURE 6** | The Phoenix Convention Center incorporates energy-efficiency design in order to achieve 20% energy savings from lighting and HVAC controls technologies and water savings from low-flow urinals, dual-flush water closets, and low-flow lavatories (saving 1.9 million gallons per day). Building and construction recycling efforts diverted over 84% (3,100 tons) of material away from the landfill.[18]

Energy efficiency is not a new industry, so creating a cluster will require the creation of demand plus the right combination of policy, freeware, demonstration projects and incentives to gain traction. As an illustration of the impact of metro-area influence on 'green buildings', 73% of the nation's LEED-certified (see glossary) green buildings stand in the nation's top 100 metro areas. Arizona is one of several states that requires all new state buildings to be LEED certified, and at the local level, municipalities, such as Tucson and Scottsdale, were among the first in the nation to establish green building programs. These programs have become models. Engagement of Arizona's universities and other institutions will be crucial to attracting more support and participants in a green building innovation hub. The convention and hospitality industry can also play a role in creating visibility for Arizona's green building cluster (Figure 6).

Opportunities in the green building sector include:

- Reducing peak energy use
    - Electric lighting and day lighting
    - Window coverings and low-emissivity (or low-e) windows
    - Insulation
- Efficient equipment
    - HVAC (see glossary)
    - Energy Star (see glossary) appliances and compact fluorescent lights
- New and applied technologies
    - Waste heat to cooling
    - Smart energy management systems
- Renewable resources
    - Solar thermal (hot water)
    - Solar electric (photovoltaic systems)

While the energy-efficient building cluster is strategically attractive, implementation requires good policy initiatives to create a market from a fragmented series of submarkets. Training and, in particular, financing for clean energy investments may not be easily developed. This will require extraordinary vision and leadership in implementation.

## Microalgae Based Fuels

Arizona has the potential to develop an industry centered around using microorganisms to produce fuels and specialty chemicals. Algae and cyanobacteria capture the energy from sunlight and convert it into lipids, alkanes, alcohols, and general biomass. Microbial electrochemical cells convert the biomass into valuable forms of energy and recover the nutrients. Algae are also good at absorbing $C0_2$, with the objective of creating a carbon neutral system. Early work at the Intel Corporation has shown that algae can grow using $CO_2$ from their fabrication plant, and this could be a step toward developing an industry around recycled $CO_2$.

At ASU's Polytechnic campus, The Arizona Center for Algae Technology and Innovation (AzCATI) is opening an open test bed for algae-based fuel systems this fall. The open test bed is available to small and large companies for testing photo bioreactors, harvesting equipment, and oil and product separation systems (See Figure 7).

**FIGURE 7** | The Diverse Efforts Required for Solar-to-Fuels Innovation and Development Using Algae is Shown

Arizona can play a significant role as a regional test bed at the national level for third-generation technologies using microorganism products including biofuels. There are more than 100, mostly small companies, globally, developing algal biofuels, as well as several U.S. Department of Energy-funded R&D consortia and pilot projects, including a 300-acre algae demonstration farm in New Mexico. The commercialization of third-generation biofuels from micro-algae is still dependent upon technological breakthroughs on several key challenges including:

- Low-cost photo bioreactors
- Protection of contamination from other microorganisms
- Harvesting the algae from the water
- Processing the algae into useable chemical components
- Refining algae products into diesel or gasoline

## Energy and the Armed Forces

Due to increased U.S. reliance on foreign energy supplies and energy crises, such as the oil crisis in the 1970s, the United States Armed Forces have been actively exploring energy and power solutions, including distributed and renewable energy, for over 40 years. As early as the Nixon administration, energy and related environmental issues were translated into specific policy directives for our nation's armed forces. From requirements for energy efficiency and "greener" energy to decreasing loss of life through enhanced security of operational supply chains in combat arenas, the Armed Forces is pursuing a secure, defensible and, sustainable suite of energy/power options—all with a grand "net zero" overall goal.[19] Future plans even include a U.S. naval strike group deployed using renewable and bio-based fuels by 2016,[20] as well as specific requirements for United States bases here and abroad.

Arizona, is already focusing on serving the nation's national security needs, possessing major academic research and teaching centers focusing on energy and security innovation as well as significant testing and training sites and facilities (i.e., the National Guard at Papago). Arizona could be well-positioned for an economic and technology development cluster in this area.

Opportunities include:

- Novel mobile energy sources in different sizes
- Defensible and robust distributed energy systems
- Deployable energy systems for specific short term and longer term "in the field" needs such as MASH (mobile army surgical hospital) units, individual power supplies or increasingly large and "permanent" refugee centers
- Energy sources for mobile vehicles
- New energy storage technologies

## Conclusion

Most of the nation's clean economy jobs reside within the largest metropolitan areas. Arizona has options because of its resource base and major metropolitan regions. It can improve its competitive position by making policy decisions that support cluster development, making anchor investments that enhance collaborations, and creating a supportive environment for financing.

### Notes

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# Energy Units of Measurement 101

Throughout the report, a variety of units are used to describe a quality of power or fuel. The information below should aid the reader in interpreting these units.

## Measures of Power

**Watt (W):** A Watt is a measure of the *rate* at which a power plant generates energy or an appliance uses energy. A Watt is thus a measure of energy used per second or energy generated per second. For example, standard incandescent light bulbs are 60-Watt bulbs; this means they use 60 units of energy each second. A 30-Watt bulb would use half that much energy each second. The size, or capacity, of power plants is also described using Watts. For example, typical solar panels on a rooftop might generate 3000 Watts or 3000 units of energy per second. 1000 Watts is the same as 1 kilowatt or 1 kW. One million Watts is the same as 1 megawatt or 1 MW.

## Measures of Energy

**Watt-hour (Wh):** A Watt-hour is a measure of energy. It is used to keep track of the *amount* of energy that is used over a period of time. It is computed by multiplying the number of Watts for a device by the number of hours that it runs. For example, if a 100-Watt light bulb is turned on for one hour, it would consume 100 Watt-hours (Wh) of electricity. If it is turned on for two hours, it will consume 200 Watt-hours of electricity. 1000 Wh is the same as 1 kWh. Each month, your electricity bill tells you how much energy you used, typically measured in kWh. The price of electricity is also measured in cents per kWh.

**British Thermal Unit (BTU or Btu):** A British Thermal Unit is another measure of energy. In other words, it measures the same thing as Watt-hours, but using a different scale (just like Fahrenheit and Celsius are both measures of temperature, using different scales). BTU is usually used to measure the energy in heat, while Watt-hours are used to measure the energy in electricity, but they are interchangeable. Literally, 1 BTU is the amount of heat needed to raise the temperature of a pound of water one degree Fahrenheit at sea level. According to the California Energy Commission, it takes 2,000 BTU to make a pot of coffee. According to the Energy Information Administration (EIA), a gallon of gasoline equals 124,238 BTU. For comparison, one Watt-hour is about 3.41214 BTU. (A third measure of energy, called a Joule, is often used to measure the energy content of fuels. One BTU is the same as 1054 Joules.)

## Measures of the Amount of Fuels

**Barrels (crude oil/petroleum):** One barrel of oil is equal to about 42 gallons of liquid. The barrel is often used to measure crude oil, which must later be refined into useful petroleum products like gasoline and diesel for vehicles and propane to heat homes. According to the Texas Oil and Gas Association, a barrel of crude oil typically yields 19.5 gallons of gasoline.

**Gallons (gasoline/petroleum):** This familiar unit is often used to measure the quantity of gasoline that consumers use to fuel their vehicles. A gallon of gasoline is the same amount of liquid as a gallon of milk.

**Cubic Feet (cf) (natural gas):** Natural gas is measured in cubic feet. A cubic foot is the volume of a cube that measures one foot on each side. According to the Energy Information Administration, the United States consumed 22 trillion cubic feet of natural gas in 2010.

**Tons (coal):** Coal is typically measured in tons. A ton is about 2,000 pounds. According to the Energy Information Administration, the United States consumed 1.4 billion tons of coal in 2009.

## Measuring Water

**Acre feet (AF):** One acre foot of water equals 325,851 gallons. It is the amount of water it takes to cover one acre of land with one foot of water. The average family of four in the United States uses about 1 AF of water in one year.

### Understanding Unit Conversions

The units below are a shorthand for measuring large quantities of energy or power without using a lot of zeros. You can think of these conversions as monetary quantities. When you start adding lots of zeros (e.g., $1,000,000,000 for one billion dollars) it gets confusing. The prefixes below are used to concisely describe measures of energy:

**1 Watt (W)**

**Kilowatt (kW)** = 1,000 (one thousand) watts

**Megawatt (MW)** = 1,000,000 (one million) watts

**Gigawatt (GW)** = 1,000,000,000 (one billion) watts

**Terawatt (TW)** = 1,000,000,000,000 (one trillion) watts (Globally, humans used 15 TW of energy in 2008)

The same conversions apply to Watt-hours.

**1 Watt-hour (Wh)**

**1 Kilowatt-hour (kWh)** = 1,000 (one thousand) watt-hours

**1 Megawatt-hour (MWh)** = 1,000,000 (one million) watt-hours

**1 Gigawatt-hour (GWh)** = 1,000,000,000 (one billion) watt-hours

**1 Terawatt-hour (TWh)** = 1,000,000,000,000 (one trillion) watt-hours

# Glossary of Organizations and Terms

**Arizona Commerce Authority (ACA):** The Arizona Commerce Authority is a new organization in the Arizona government (formerly, the Arizona Department of Commerce) that recruits quality companies and jobs to Arizona, including energy-related companies. It also promotes the expansion of Arizona's existing companies.

**Arizona Corporation Commission (ACC or 'the Commission'):** The constitutionally-established Arizona Corporation Commission consists of five commissioners who regulate utilities in the state, including energy utilities. The ACC develops energy regulations and also rules on contested matters, such as where new power plants or new transmission lines can be built. Among other duties, the ACC regulates rate increases and the quality of service provided by utility companies, with a mandate to protect the public interest. It also established the Renewable Energy Standard in 2006. All states have public utility commissions that perform these functions. Arizona is one of only thirteen states, however, that choose public utility commissioners by popular election.

**Arizona Public Service (APS):** APS is the largest utility company in Arizona, serving more than one million customers in northern and central Arizona, including Phoenix. As a subsidiary of the Pinnacle West Capital Corporation, it is an investor-owned utility and the Arizona Corporation Commission regulates it.

**Balance of Systems (BOS) and installation costs:** Balance of Systems costs are the additional costs of solar photovoltaic (PV) systems other than the solar panel itself. These costs include, e.g., the costs for wiring, switches, inverters, support racks, etc. Installation costs are the costs required to transport the panels from the factory to your house and for workers to install them on your house. (See Chapter 3.)

**Base load:** An electric power 'load' is the amount of electricity being used by a utility's consumers at any given point in time. Think of it as putting a weight on a scale: when you add weight to the scale, you load the scale down. If people turn on a lot of lights, they add to the load on the electricity grid. If they turn off a lot of lights, they reduce the load on the system. A simple definition of base load is the minimum amount of electricity load that is being used all of the time. For example, consumers typically use more electricity during the day than at night. So, the nighttime level of use would be the minimum amount of electricity used or, roughly, the base load. Base load power plants are those plants used to meet base load demand, such as coal-fired and nuclear power plants. They produce energy at a constant rate and typically provide cheaper electricity than other power plants. (See also "peak load.")

**Biofuels:** Biofuels are liquid fuels that are produced from biomass, or plant materials, such as corn, wood, or switchgrass. (See Chapters 10 and 12 for a discussion of biofuels made from algae.)

**Bureau of Land Management (BLM):** The Bureau of Land Management is a federal agency that manages some federal lands. Some of these lands are available for lease to energy companies for mining or power plants, including solar and wind power plants.

**California Energy Commission:** The California Energy Commission is California's primary energy policy and planning agency. Among other duties, it licenses power plants over 50 MW. It is somewhat similar to the Arizona Corporation Commission.

**Carbon dioxide ($CO_2$):** Carbon dioxide is one of the gases that make up the atmosphere. The amount of it in the atmosphere is growing as a result of people burning fossil fuels, either from automobile engines or coal-fired or natural gas-fired power plants. Plants absorb it to grow. It is also the substance used to make dry ice. Carbon dioxide is the most important greenhouse gas that humans release into the atmosphere. (See also "fossil fuels" and "greenhouse gases.")

**Capacity factor:** A power plant's capacity factor describes how much electricity it actually produces versus how much it could produce. If a plant is capable of producing 100 MW but is only used to produce 70 MW, then it is operating at a 70% capacity factor.

**Carbon capture and storage (CCS):** Carbon capture and storage is a process of capturing carbon dioxide emissions from fossil-fuel burning power plants and injecting it under the earth's surface. The goal is to reduce carbon dioxide emissions into the atmosphere that contribute to climate change by storing them underground instead.

**Central Arizona Project (CAP):** Completed in 1993, the Central Arizona Project is a 336-mile long canal that transports water from the Colorado River near Lake Havasu City to central and southern Arizona (i.e., Pima, Pinal, and Maricopa counties). The water is used by cities, including Phoenix, Mesa, and Scottsdale, by agricultural users, and by Native American communities.

**Coal-fired power plant:** Coal is the most abundant fossil fuel produced in the United States. Most coal is used for electricity generation. Coal-fired plants burn coal to heat water and turn it into steam, which then turns a turbine to generate electricity. According to the Energy Information Administration, a pound of coal supplies enough electricity to power ten 100-watt light bulbs for an hour. The Navajo Generating Station is a 2,280 MW coal-fired power plant on the Navajo Nation, near Page, Arizona, and is the largest coal-fired power plant in Arizona. (See Chapter 7.)

**Combined heat and power (CHP) generating facilities:** CHP plants burn fuel to drive a turbine to generate electricity. Unlike in a traditional power plant, the leftover heat from this process is then captured and used for space and water heating in buildings. The leftover heat that is not of high enough quality to heat buildings is captured to generate even more electricity. The heat may also be used for air conditioning. This kind of facility is more efficient than a traditional power plant because it uses a larger fraction of the total energy generated.

**Concentrating solar power (CSP)/solar thermal:** Sunlight can be captured and turned into electricity either using heat or light. Concentrating solar power plants or solar thermal power plants use heat, whereas photovoltaic solar panels use light. This heat powers a generator or moves a turbine to produce electricity. The electricity generation process is similar to fossil-fuel power plant, except the sun's heat is used rather than heat from burning fossil fuels. Types of CSP plants include solar power tower plants, solar trough plants, and Stirling engines. (See also "photovoltaic".)

**Demand-side management:** Demand-side management refers to a variety of initiatives taken to reduce the amount of electricity that consumers use or demand. Often, the goal of demand-side management programs is to reduce the amount of electricity used at the times of day when consumers use the most electricity (e.g., the hottest hours of the day). Examples may include investment in energy efficiency appliances and home weather stripping. It is also used to refer to new techniques that are being considered by utilities that would involve smart devices that automatically shut off or lower their energy use during periods when electricity demand is the highest (See Chapter 5.)

**Decoupling:** Decoupling would change the way utility companies are compensated for investments in technology. Currently, utilities can only incorporate new investments in technology into the consumer price of electricity if these investments are needed to meet growing electricity demand. Decoupling would allow utilities to incorporate investments in energy efficiency technologies into the rate they charge consumers. (See Chapter 5.)

**Department of Energy:** The U.S. Department of Energy is a department in the federal government whose mission is to advance energy technology and promote energy innovation in the United States. It manages a number of national laboratories, such as Sandia National Laboratories and Los Alamos National Laboratory in New Mexico. It also works to advance a variety of fossil fuel, nuclear, renewable, and energy efficiency technologies through basic research and policies to spur energy innovation, like loan guarantees and grants.

**Distributed generation (DG):** Distributed generation refers to the generation of electricity in small amounts in lots of places, e.g., by people with solar panels on their rooftops. Currently, electricity generation is mostly centralized, meaning that relatively large power plants generate almost all of our electricity, which is then transmitted through transmission lines to people's homes and businesses. Consumers pay utility companies to provide them with this service. A distributed generation system would rely on small sources of energy generation located where the energy is used, in which consumers generate some or all of their own power. Examples include rooftop solar panels and small wind turbines.

**Dry-cooling:** (Also called air-cooling). Power plants generate a lot of heat (e.g., to produce steam to drive turbines; see "coal-fired power plants"). Most power plants use water for cooling to offset this heat. In contrast, dry-cooled plants use air for their cooling. For example, they may use air-cooled condensers to convert steam back into water. This approach is generally more expensive than using water for cooling, but it can save a lot of water. (See also "thermoelectric power plants." For more on water and energy, see Chapter 6.)

**End-users/end-use:** End-users are the customers who consume the energy generated and may include residential, industrial, and commercial users. End-uses of energy are the ways in which energy is ultimately consumed, such as washing dishes, driving to work, watching television, or manufacturing a product.

**Energy conservation:** Conserving energy simply means to use less of it. Consumers can conserve energy through a variety of means including adjusting the thermostat, turning off or unplugging lights and appliances when not in use, and adopting energy efficiency measures. (See Chapter 5.)

**Electric cooperatives:** Some rural areas in Arizona get their power from electric cooperatives rather than traditional utility companies. A co-op is a nonprofit entity whose membership consists of the customers themselves, rather than stockholders. These customers share in the benefits and risks of operating the cooperative and vote on the cooperative's board members. Cooperatives, in all other respects, act like any other utility. Examples include the Sulphur Springs Valley Electric Cooperative, the Trico Electric Cooperative, and the Navopache Electric Cooperative.

**Energy efficiency:** Efficient energy use, or energy efficiency, aims to reduce the amount of energy it takes to provide a particular good or service. Examples of energy efficiency measures include improving home insulation, line drying clothing, installing compact fluorescent light bulbs or LED bulbs, and buying more appliances and electronics that use less energy. (See Chapter 5.)

**Electric Energy Efficiency Standards:** See "Energy Efficiency Resource Standards."

**Energy Efficiency Resource Standards (EERS):** Energy efficiency resource standards require utilities to lower their total electricity sales by improving energy efficiency. Arizona's version of EERS was approved by the Arizona Corporation Commission in 2010. They are called the Electric Energy Efficiency Standards (EEES) and cover large investor-owned utilities regulated by the ACC.

**Electricity generation:** The process by which power plants (e.g., nuclear, coal-fired, natural gas) or other sources of energy produce, or generate, electricity. The amount of electricity generated is usually described in kilowatt hours (kWh) or megawatt hours (MWh).

**Energy intensity:** The concept of energy intensity describes the amount of energy it takes to achieve a task, like pumping water. Tasks that require more energy to get the same result are said to have higher energy intensity. Likewise, if energy intensity is declining, that means that the same task is now being accomplished with less energy. A common use of energy intensity is to talk about how much energy is required to produce a dollar of gross domestic product (GDP). Countries can be compared, for example, to see which produces more economic wealth for the same amount of energy input. Among wealthy countries, the US generally does poorly on this measure, using more energy to produce the same amount of wealth. This is partly because the US is large and therefore has high transportation requirements and partly because energy costs in the US are relatively low, creating few incentives to find more energy efficient processes.

**Energy Information Administration (EIA):** The U.S. Energy Information Administration collects and publishes statistical information and conducts analyses of energy markets, supply, production, price, and consumption. The agency provides information at the state and national levels, along with some international analyses. This information is available online at http://www.eia.gov/. Much of the data for this report comes from EIA.

**Energy Star:** Energy Star is a federal government-backed program that helps businesses and individuals adopt more energy efficient products and practices. The Energy Star labeling system seeks to help consumers identify more energy efficient household products. (See Chapter 5.)

**Environmental Project Agency (EPA):** The EPA is an agency within the federal government tasked with protecting human health and the environment. The EPA develops and enforces regulations, funds research, studies environmental issues, educates people on health and the environment, forms partnership groups, and publishes information.

**External costs:** Also called externalities, external costs are the environmental and social costs of production that are not reflected in the price of a product or service. Pollution is an example of an external cost of some energy production. The use of water by energy production is also an external cost. (See Chapter 8.)

**Federal Energy Regulatory Commission (FERC):** The U.S. Federal Energy Regulatory Commission, or FERC, is an independent agency that regulates the interstate transmission of natural gas, oil, and electricity. FERC also regulates natural gas and hydropower projects.

**Fixed costs:** Fixed costs are expenses that a business must cover regardless of how much of a product or service they sell. They can be contrasted with variable costs that change depending on how much they sell. For example, to sell electricity, a utility must build a power plant to produce the electricity. This is a fixed cost. On the other hand, fuel costs are a variable cost. If you want to produce more electricity you have to buy more fuel; vice-versa, if you want to produce less electricity, you buy less fuel. Often a utility's fixed costs are charged to consumers through a flat, monthly electricity service charge.

**Fossil fuels/fossil fuel generation:** Fossil fuels are fuels formed by the decomposition of dead organisms over millions of years. The main sources are petroleum, coal, and natural gas. They are considered non-renewable because once depleted they take millions of years to form again and therefore are used much faster than they can be replenished. Electricity is generated from fossil fuels, such as coal and natural gas, by burning the fuel to heat water into steam that drives a turbine.

**HVAC:** HVAC is an abbreviation describing a building's heating, ventilation, and air-conditioning system.

**Geothermal energy:** Geothermal energy taps into the hot water and steam deep inside the earth. This geothermal power can be harnessed in individual households through geothermal heat pumps or through a heat exchanger, which uses heat from the water to heat buildings. Geothermal energy can also be used to generate electricity in a power plant.

**Greenhouse gases (GHGs):** These gases act as a shield that traps heat in the Earth's atmosphere as part of the greenhouse effect. Examples of greenhouse gases (GHGs) include water vapor, carbon dioxide, methane, and nitrous oxide. Concentrations of some of these greenhouses gases in the atmosphere have increased over the past century due to human activities, including the burning of fossil fuels.

**The grid:** Electricity is generated in power plants. Power then travels from these power plants to consumers via the electricity grid. The grid consists of transmission lines that carry power from the power plant to power substations near towns, where it is then distributed via power lines to houses and businesses. (See Chapter 1.)

**Grid parity:** Renewable energy is typically more expensive than the average cost of electricity produced in the current electrical power grid system. Grid parity is the point at which an alternative energy source, like solar or wind power, becomes nearly the same price as the current price of electricity produced by the power grid. (See Chapter 3.)

**Hydropower:** Hydropower plants generate electricity through the harnessing the energy from falling water to drive a turbine and generator. Glen Canyon and Hoover dams are examples of hydropower plants in our region.

**Investor-owned utilities:** Utilities fall into several categories. Investor-owned utilities are owned by private investors, either as a privately held company or through the stock market. APS is an investor-owned utility. Other utilities are publically owned, like SRP, which means that a government owns them. In some places, for example, cities own electric utilities, called municipal utilities. Other utilities are cooperatives (see "electric cooperatives"). Various categories of utilities are regulated differently.

**Kinder Morgan (KM):** Kinder Morgan is a company that operates the petroleum pipelines serving Tucson and Phoenix. They transport gasoline, diesel, and jet fuel. (See Chapter 9.)

**LEED-certified:** The U.S. Green Building Council developed the Leadership in Energy and Environmental Design (LEED) building certification in 1998. The guidelines required to achieve this certification aim to, for example, reduce the energy and water usage of buildings, reduce construction waste, and encourage the use of recycled building materials. The certification system increases in stringency from certified, silver, gold, to platinum.

**Levelized cost of energy (LCOE):** Projected costs for new power plants are usually compared for alternative technologies in terms of the "levelized cost of energy" (LCOE). LCOE takes into account the entire cost of producing electricity from a facility, including construction, fuel, operating, and decommissioning expenses. Calculating LCOE often requires making a number of assumptions; therefore, LCOE may significantly differ across studies. (See Chapter 8.)

**Liquefied petroleum gas (LPG):** Liquefied petroleum gas, or LPG, is used for vehicle fuel, for heating, and as a refrigerant.

**Load:** The electric power load is the amount of energy used by a utility's customers at any given point of time. Attempts to reduce the amount of electricity demanded through energy efficiency, conservation, or other means is often called load reduction or demand reduction.

**Morenci Water and Electric Company:** Morenci Water and Electric Company is Arizona's fifth largest electric utility company.

**Natural gas power plant:** Natural gas is used to generate electricity in a variety of ways. Examples include a steam turbine; a gas turbine; and a combined-cycle unit, which uses both a gas turbine and a steam unit. The largest natural gas power plant in Arizona is the Gila River Power Station, which is a combined-cycle 2,200 MW plant in the town of Gila Bend, 70 miles SW of Phoenix.

**Net metering:** If a house has solar panels on it and produces more electricity than the household uses, the remaining energy can be put onto the electricity grid. Net metering occurs when utilities pay households for this extra energy put on the grid. Arizona's net metering standard requires utilities to credit consumers with rooftop solar power systems for any electricity they produce that exceeds their usage. These electricity credits accumulate monthly, and customers are paid annually for any excess credit remaining.

**Nuclear power plant:** Nuclear power plants are fueled by uranium. Heat is generated through nuclear fission, in which uranium atoms are split apart, releasing energy. This heat is then used to drive a turbine that produces electricity. Arizona's only nuclear power plant is the Palo Verde Generating Station, which is the largest nuclear power plant in the country.

**Peak load:** An electric power 'load' is the amount of electricity being used by a utility's consumers at any given point in time. Think of it as putting a weight on a scale: when you add weight to the scale, you load the scale down. If people turn on a lot of lights, they add to the load on the electricity grid. If they turn off a lot of lights, they reduce the load on the system. Peak load is the time of day when consumers demand the most electricity. For example, in the Arizona summer, demand is generally highest between 1 p.m. and 8 p.m., when a large quantity of air conditioning is used. In the winter, peak hours are generally early in the morning when it is chilly and people are getting ready for work, and from 5 p.m. to 9 p.m. when consumers return home from work, turn up the heat, cook dinner, and switch on the TV and other appliances. Peaking power plants, or "peaker" plants, provide the additional power needed during peak demand and typically produce more expensive electricity than base load power plants. (See also "base load.")

**Photovoltaic (PV):** Sunlight can be captured and turned into electricity either using heat or light. Photovoltaic solar panels capture light and convert it directly into electricity using a process that physicists call the "photoelectric effect." When light hits the panel, it knocks electrons loose, which allows them to flow through the material. Solar panels are often made out of materials called semiconductors, like silicon. Solar PV panels are often placed on the roofs of residential homes, on the roofs of commercial buildings, or on desert lands. (See also "concentrating solar power".)

**Pipelines:** Pipelines are crucial infrastructure for transporting fuels, such as crude oil and natural gas, over long distances. They are typically steel or plastic tubes that are often buried but are sometimes elevated, like with portions of the Trans-Alaskan oil pipeline. (See Chapter 9 for more information on the pipeline infrastructure serving Arizona.)

**Refinery:** In order to be turned into useful products, crude oil, which is the oil that is extracted directly from the ground, must be sent to a factory called a refinery that separates it into useful petroleum products like gasoline and diesel for vehicles and propane to heat homes. Refineries also provide petroleum for various consumer products like crayons, deodorant, and tires.

**Renewable Portfolio Standard (RPS):** A Renewable Portfolio Standard, or Renewable Electricity Standard (RES), is a regulation that obligates utilities to generate a certain percentage of electricity from renewable sources. Twenty-nine U.S. states and the District of Columbia and Puerto Rico have Renewable Portfolio Standards. The Arizona Renewable Energy Standard requires electric utilities regulated by the Arizona Corporation Commissions to produce or buy 15% of their total electricity from renewable energy sources by the year 2025. (See Chapter 10.)

**Renewable resources:** Renewable energy comes from resources that are constantly replenished. Some disagreement exists about which sources count as renewable, but some typical examples include hydroelectric, geothermal, solar, tide, wind, and water.

**Salt River Project (SRP):** The Salt River Project includes the Salt River Project Agricultural Improvement and Power District, which is a municipal electrical utility serving the Phoenix metropolitan area, and the Salt River Valley Water Users' Association, which is a utility cooperative providing water for central Arizona. The Power District is a publically owned utility and is the second-largest utility in the state of Arizona, providing power for 934,000 retail customers. As a public utility, it is not regulated by the Arizona Corporation Commission.

**Smart grid:** The smart grid is a proposed plan to develop a more efficient power grid. The smart grid plan aims to upgrade old and inefficient transmission and distribution infrastructure, improving financial and environmental performance and reducing black outs.

**Smart meters:** Smart meters allow customers and utility companies to see how much power is being consumed at any point in time. Since the price of electricity varies throughout the day, this allows the utility to offer alternate pricing programs that charge customers different rates at different times of day. Customers can potentially save on their bill by shifting their electricity uses to times of the day when electricity is cheaper. Some smart meter pricing programs allow consumers to choose to allow the utility company to remotely adjust their household's energy use by adjusting their thermostats, for example.

**Solarize:** To solarize means to add solar panels to the rooftop of a house or business.

**Southwest Gas Corporation (SWG):** SWG is an investor-owned utility that provides natural gas to approximately 1.8 million customers, 986,000 of whom are located in Arizona. SWG serves 81% of Arizona's residential customers, 72% of the commercial customers, and almost 93% of the industrial customers.

**Stirling engine:** Dish sterling engines are large dishes made up of mirrors, which reflect sunlight onto a canister of hydrogen gas and an engine attached to the center of the dish. The sunlight heats up this hydrogen gas, which expands to push a piston that turns a gear shaft to crank a generator, which produces electricity.

**Synthetic "drop-in" fuels:** Synthetic fuels, also called synfuels, are fuels that are chemically engineered from coal, natural gas, shale oil, or biomass. Drop-in fuels can be used in existing automobiles in place of gasoline. (See Chapter 11.)

**Thermoelectric power plants:** Most power plants are thermoelectric power plants (exceptions include photovoltaic and wind). Thermoelectric power plants use heat to turn water into steam, which drives a steam turbine to generate electricity. This steam is then cooled, which turns it back into water, and the process is repeated. Some of the water evaporates and must be replaced. (See also "dry cooling." See Chapter 6 for a complete discussion of energy and water.)

**Transmission/transmission line:** Transmission lines are large steel towers, typically with three large wires strung between them. They carry extremely high voltage power over long distances, typically up to 300 miles, from sometimes remote power plants to power substations near towns for distribution to households and businesses.

**Tucson Electric Power (TEP):** Tucson Electric Power is the third-largest Arizona utility company, serving southern Arizona, including Tucson. As a subsidiary of UniSource Energy, it is an investor-owned utility and is therefore regulated by the Arizona Corporation Commission.

**UNS Electric, Inc:** UNS Electric, Inc. is Arizona's fourth largest utility company.

**Utility-scale solar power:** Utility-scale or large-scale solar power comes from concentrating solar power plants and large fields of photovoltaic panels. This may be contrasted with individual solar panels on rooftops. (See also "concentrating solar power.")

**Variable costs:** See "fixed costs."

**Water intensity:** The concept of water intensity describes the amount of water it takes to achieve a task, like generating energy. A declining water intensity would indicate that the same amount of energy is produced using less water. (See also "energy intensity." See Chapter 6.)

**Wind power:** Producing power from wind is accomplished by capturing kinetic energy or the energy of motion from flowing air through the blades of a wind turbine. This runs a wind-electric turbine by spinning a shaft to power a generator, which produces electricity.


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