Arizona Clean Energy Vision—100% by 2040

Richard C. Powell, Science Foundation Arizona
and
Richard J. Wiener, Research Corporation for Science Advancement

I. Rationale for Clean Energy

Energy is the foundation of every modern society; yet we seem to pit one form of energy against another. What we need is a balanced approach that is sustainable. What if – over the next 30 years – Arizona could develop its solar, wind and other energy resource potential so that it was the equivalent of Saudi Arabia energy-wise? What if those energy sources catalyzed entire new industries and created a virtual circle of sustainable economic growth Arizona? What if Arizona energy, exported around North America, became the source of revenue to fund an outstanding K--12 system and great colleges and universities as well as a new generation of much needed infrastructure? The better question might be "why not"?
– William C. Harris, President and CEO, Science Foundation Arizona

Currently there is no clear vision for the future of energy in Arizona similar to those developed by other states such as Texas, New Mexico and California. The purpose of the *Arizona Clean Energy Vision—100% by 2040* is to start the dialog which could lead to such a vision for market-based economic development based on cleaner electricity, and demonstrate that it is wholly achievable and economically viable. Arizona has the resources, including the United States' greatest potential for solar energy, to move ahead of sister states, which are already moving ambitiously to increase their production of electricity from wind and solar. Arizona has set a goal of 15% renewable energy production by 2025. The vision outlined in this paper embraces an aggressive aspirational goal of transitioning to 100% clean energy production by 2040.

Forty percent of energy in the United States goes to producing electricity, and the technology to produce electricity cleanly, from non-fossil fuel sources, is well developed and quickly improving. Arizona has more than sufficient resources to produce 100% of its electricity with minimal use of fossil fuels. A bold, visionary transformation to cleaner energy, coupled with business-friendly market-based approaches, would create sustainable jobs, attract new, high wage industries from around the world, and make the state an even more attractive place to live, work and visit. One-hundred percent clean electricity production would greatly reduce demand for precious water resources in Arizona, because clean energy production requires vastly less water than the same amount of energy produced from fossil fuel power plants, which require cooling and waste heat disposal. Development of its solar resources would allow Arizona to become a major exporter of energy, which would greatly benefit the state's economy as global energy resources grow scarcer.

One regional response to growing energy demands might be to increase the use of fossil fuels such as coal and natural gas, which currently are relatively cheap. But the great risk to this approach is that it may be unsustainable even in the short term. Demand will rise for fuels to replace oil, mainly used in transport, and which, as we all know, has seen extreme price volatility ranging from $35 to 140/bbl in the last 2 years with a doubling of the price during a major worldwide recession only in the last 12 months. This is not the pricing pattern of a commodity in robust supply and serves as a warning signal to our economy. Natural gas, mainly from unconventional sources such as coal and shale, appears to be plentiful for the time period discussed here, but it may be subject to much greater demand if used as an alternative to oil in the transportation sector. Additional international treaties and federal laws may cap or tax emissions of carbon dioxide from coal and natural gas. Fossil fuel power plants exacerbate severe water shortages in arid regions. The cost of energy in a global economy is influenced by each of these, and many other, factors. Fossil fuel may well become prohibitively expensive, maybe even in the near future. Expanding fossil fuel infrastructure for electricity production in a region that isn't a major producer of fossil fuel is a high-risk bet.

An alternative, proactive approach to the coming energy crisis is to develop Arizona's energy resources. In our view, Arizona should consider an energy future counting primarily on its own resources, and exporting our energy surplus, because our resource base provides a competitive economic advantage in projected pricing stability of electricity. If *Arizona Clean Energy Vision—100% by 2040* is realized, the state will increase its energy independence, immunize itself against volatility of fossil fuel prices, conserve its precious water resources, and become a model for sustainable economic growth. Arizona will prosper while many other regions of the nation and world struggle economically in an era of volatile pricing of energy resources.

II. Clean Energy Plan

Clearly any such transition will occur in phases and there is much work to be done, especially in terms of transitioning to new energy sources as the current power-generating infrastructure ages to obsolesence during the time frame considered here. Of special concern to us is finding a way to achieve reasonable progress towards the goal envisioned here, including a way for market-based solutions to improve the economic benefit derived by the Hopi and Navajo nations out of energy generation today, while transitioning towards a cleaner energy future. We do not presume to have all the answers, but we propose a two-phase plan be considered. The first phase will count primarily on solar and wind energy development to meet all new energy demand in Arizona since technical maturity and economic viability are rapidly narrowing the competitive advantage currently enjoyed by conventional generating sources. The 2009 Arizona legislation -- which provides tax incentives for solar companies -- is an excellent first step in the regulatory reform needed to implement a transition to a clean energy future. The second phase will focus on the replacement of our current aging energy infrastructure as it becomes obsolete. The second phase should consider the inclusion of a new generation of nuclear power, since Arizona has substantial supplies of uranium, equivalent perhaps to the entire energy content of the Alaskan North Slope. However, the rest of this article will focus on what can be done in Phase 1.

The plan for achieving Phase 1 of the vision of 100% clean electricity production for Arizona by 2040 is summarized in Figure 1, showing the electrical requirements for a typical summer day in Arizona. This plan represents a vision for Arizona to become a clean energy state, where virtually all the load is met by clean, carbon-free technologies. Arizona resources will produce renewable energy for home and business consumption as well as export energy to neighboring states. In addition to meeting the electrical energy

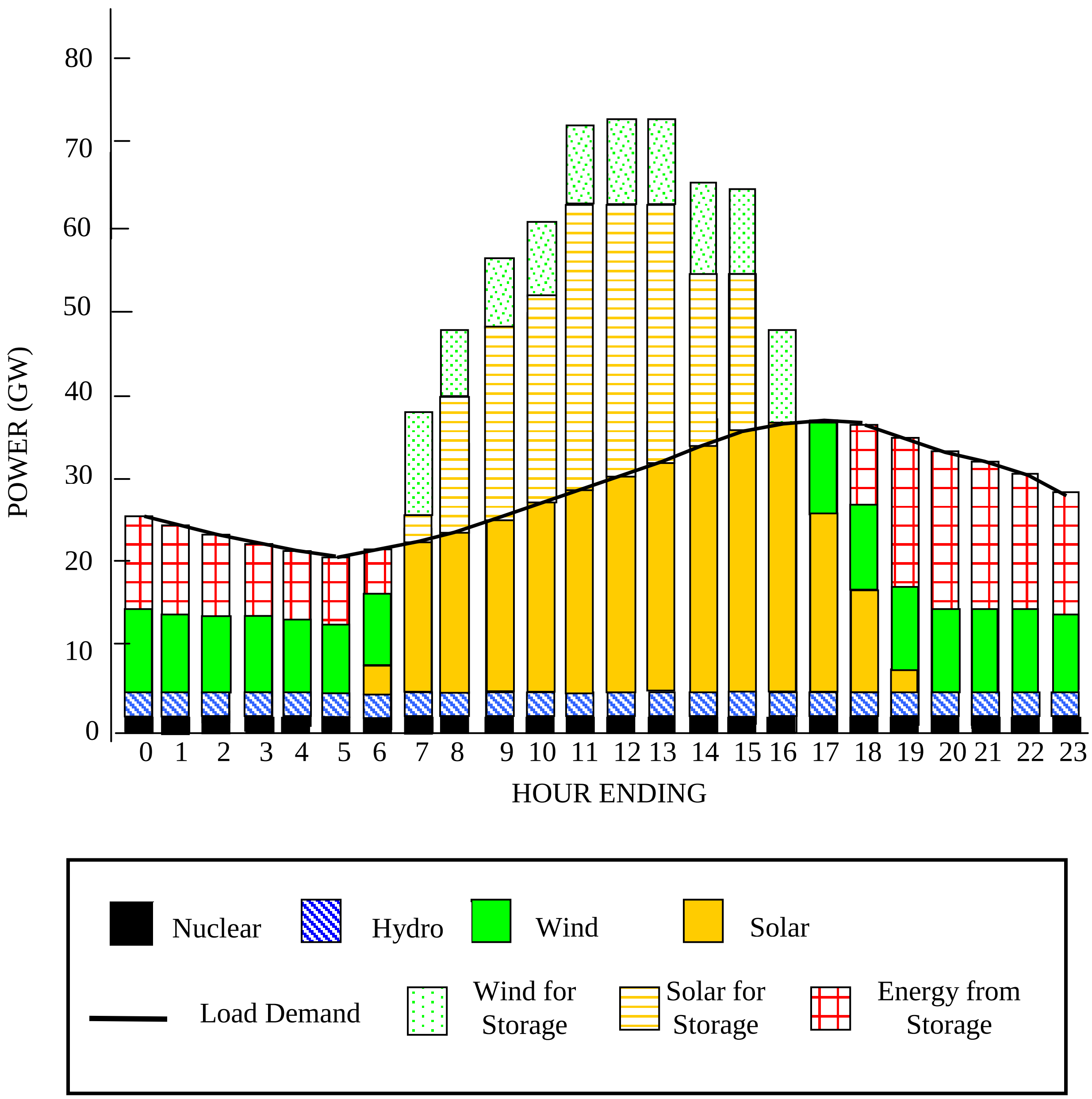

FIGURE 1: ARIZONA CLEAN ENERGY PLAN
(100% Clean Energy by 2040)

needs of the state, renewable and advanced technologies will be employed such that the peak power demand can be met reliably, and that satisfactory flexible, rapidly responding generating resources are available to assure system reliability. These include new, cost-effective, energy storage technologies and other strategies to provide ancillary services.

The plan is based on the projected increase in peak power demand predicted by several studies (*Arizona Solar Electric Roadmap Study*, Arizona Department of Commerce, Phoenix, 2007; *Arizona Renewable Energy Assessment*, Black and Veatch, 2008). They project an increase of the peak load from about 19 GW today to the value of 38 GW peak load by 2025. We recognize that these growth projections are uncertain and may be high given current views of Arizona's economy. However, these are the best available numbers today and the state will surely reach this level of electrical demand by 2040. Also we believe the the move to plug in electric vehicles (GM, Ford and others have new models coming within 2 years) may in fact increase the demand for electricity at a yet-to-be-determined rate, but likely to at least offset any decline in projected base load due to lower growth of real estate development as Arizona's primary economic engine. Any excess energy that is produced can be sold to generate revenues for the state. It is assumed that the diurnal variation in power demand will be similar to what state utility companies now experience. The curve used here (shown by the solid line) represents the high demand period of the year.

Current electricity generation in Arizona (Energy Information Administration numbers) comes from about 32% coal-fired power plants, 37% natural gas, 4% hydroelectric, and 27% nuclear power with petroleum, solar and wind together providing much less than 1%. The new plan assumes the use of all forms of available sources of clean energy. The current assesment of geothermal energy potential in Arizona is very low, about 0.45 GW, so it will not play a significant role in the Plan and its contribution is too small to be seen in the figure. Electricity generation from low temperature geothermal sources may be viable, but there is little active research and engineering being done in this direction at present in Arizona.

Biofuels have been shown to have enormous potential for use in aircraft and automobiles, but with current technology there is not enough biofuel capacity to make it useful as a primary source for burning in electrical power plants. However, there is a need for some dispatchable, responsive generation that is capable of covering the ramping and ancillary services each hour. Renewable energy generated by biomass fuel could be useful for this.

The major sources of power in this plan are nuclear, hydro-electric, wind and solar energy. Arizona's current share of the power production of the Palo Verde nuclear reactors is about 2 GW. It would certainly be possible to expand this facility in order to generate a significant increase in nuclear power. However, this would be expensive and require a significant amount of time for permitting and construction, certainly more than

10 years and perhaps as long as 20 years. Moreover, nuclear power is high in water usage; Palo Verde uses 65 million gallons of water daily. Therefore, phase 1 of the plan discussed here assumes that the amount of nuclear power usable in Arizona will remain constant at 2 GW. This is shown as a constant base amount in Figure 1. If future economics and water availability favor expanding nuclear power generation, the increased nuclear power could add to the base power supply shown in Figure 1.

The amount of hydroelectric power usable in Arizona is currently about 3 GW. There is a potential for slightly increasing the production of hydroelectricity in the state, but gaining public approval for building additional dams would be difficult. Local micro-hydro systems are being considered that may help reduce the power demand to a small degree. However, realistically, the plan assumes that contribution of hydroelectricity to meet Arizona's power demand will remain constant at 3 GW as shown in Figure 1.

Studies of wind potential by the National Renewal Energy Laboratory (*NREL Data Base*) and Northern Arizona University (*Arizona Wind Energy Assessment* [NAU Arizona Wind Working Group, 2007] have shown that the installed capacity of wind energy in Arizona is 10.9 GW. This assumes the use of 80 m hubs only on land with high enough average wind velocities to make wind energy financially viable. The plan presented here recommends intallation of all of this 10.9 GW capacity. With the diurnal variation of Arizona winds, this will allow the load demand to be met or exceeded for 11 hours a day with the excess generation stored and used to mitigate intermittency. The cost of wind is currently competitive with that of coal and natural gas, and it is unlikely to increase nearly as dramatically over the next several decades as the cost of these fossil fuels.

There is enough solar potential in Arizona to provide all of the power the state needs plus a large amount for exporting. The plan assumes a peak generation of only 60 GW from solar, which is more than the amount needed to meet the projected load demand plus the additional amount for long-term energy storage. The variation of solar power during the day that is shown in Figure 1 is typical of photovoltaic generation with two-axis tracking.

Figure 1 shows that there are 10 hours of the day during which the energy generation exceeds the demand. This is critical to producing a reliable source of electrical power using renewable resources that are intermittent. It demonstrates the importance of long-term energy storage. The excess energy produced can be stored and used to generate power when needed at night or on cloudy or calm days.

Several types of energy storage methods have been developed. Batteries have been a traditional method. However, for the capacity of energy storage required on the scale of a power plant, the number of batteries required would be very expensive, and maintanence and disposal of depleted batteries a major problem. Other techniques -- such as thermal storage, compressed air storage, and pumped hydro storage -- are all viable in terms of cost and capacity. Some solar power technologies generate excess heat. This thermal energy can be stored in materials such as molten salts and used to generate power at the end of the day. Longer-term storage for use overnight or on days when primary sources (sun and wind) are not producing enough energy can be achieved by pumped hydro or compressed air energy storage though the efficiency of the latter type of system needs to be improved dramatically for economic viability. Such research is underway at Arizona universities. In the meantime, natural gas back up generating capacity can be deployed in integrated systems along with the solar and wind capacity anticipated here to insure uninterruptible power generation and/or to lower the cost of excess generating capacity used for storage purposes only.

This plan shows that Arizona has the resources to be energy independent and free from the pollution generated by burning carbon fuel for generating electricity. The electricity demand and the solar and wind generation capacities vary during the year. Figure 1 for a hot summer day shows the most stringent demand for electrical power. During winter months the total demand and the mix of solar versus wind power will be different. The plan is not unique. For example, it would be possible to generate all the power that will be needed by solar energy alone. However, diversifying the sources of power generation provides a hedge against any problem that might occur with one specific power source. Compared to solar energy, wind power generation is a mature technology and currently less expensive. Thus it makes sense to build more wind power while allowing the development of solar technology to mature and decrease in price.

No distinction has been made in this plan between solar-thermal and solar-photovoltaic technologies or between distributed solar and solar grid power generation plants. The crucial point is to use the sun's energy instead of burning fossil fuel to generate our power needs. However, it is important to note that there is not enough capacity for distributed solar alone to meet projected demand. There will be a need for producing grid power, while distributed sources will help in leveling off the growth in demand for grid power. Thus, the plan assumes that solar power generation will be a mixture of distributed and grid-based solar. For the latter it is assumed there will be a mixture of technologies, including solar-thermal trough and heat engine technologies as well as concentrated and flat-panel photovoltaics. This diversification helps smooth out the fluctuations due to atmospheric conditions.

Another important point for solar power installations in the desert is water usage. Typical solar-thermal technologies, like fossil fuel and nuclear power plants, require evaporative cooling, which is water intensive. Although the use of effluent water can mitigate this problem, solar-photovoltaic power generation and solar-heat engine technologies, like wind power, have the major advantage of not needing evaporative cooling and therefore using very little water.

III. Implementation of Phase 1

Implementing this plan requires the construction of 10.9 GW of peak wind power and 60 GW of peak solar generation with some thermal storage capabilities. In addition, major energy storage facilities (compressed air or pumped hydro) capable of producing about 18 GW of peak power must be constructed. It is estimated that about 15% of this construction will occur in implementing Phase 1 (the first 10 years of this plan) as discussed in a subsequent paper. The exact mix of thermal storage and long-term storage techniques will depend on the mix of solar-thermal versus solar-photovoltaic technology used for primary generation. Also the power lines and grid infrastructure must be built. Current installed cost for wind power is close to $1/W. Technology breakthroughs should bring the cost of solar down to this level within the next 5 years. Facilities for compressed air and pumped hydro energy storage cost about half this amount. Thus, a rough cost estimate for implementing the first phase of this plan is about $9 B spent over the next 10 years. To this must be added the cost of transmission and infrastructure development and improvement. This will not be easy to accomplish in this short timeframe, but once constructed this infrastructure will provide real and long-lasting value to the citizens of Arizona. The cost of generating and transmitting power (including annualized cost of capital, operations maintenance, land, storage and transmission) by conventional means is estimated to average 8¢/kW-hr by 2020 whereas power from wind and hydro are projected to be only 4¢/kW-hr (M.Z. Jacobson and M.A. Delucchi, "A Path to Sustainable Energy by 2030," *Scientific American*, November 2009, p. 58). Again, solar power is currently higher than this but its cost should decrease to grid parity before 2020. The more-efficient, cheaper, clean electrical power should be a good investment even without a carbon tax.

One issue that must be addressed quickly is the need to dedicate land to power generation and storage facilities. The plan will require a mixture of state, federal, tribal and private lands. Land use always involves choices. It is important that power requirements rise to the top of the priority list for land use if we are to expand both wind and solar installations. For example, studies by the National Renewable Energy Laboratory estimate that Arizona has 12,613 mi^2 suitable for solar energy usage, giving the state a solar capacity of 1,742 GW, or about 29 times the amount being called for in this plan. This number is a low estimate. It assumes "best" land that is defined as having no primary use today, no slope greater than 1%, and is not "sensitive" to environmental or other issues. A less restrictive definition would significantly increase the amount of land potentially available for solar power generation. In addition, the solar capacity quoted in this study is based on current solar-thermal concentrator technology. Concentrator photovoltaic solar generation technology currently under development has the potential of generating almost 3 times the amount of electricity per acre of land compared to solar-thermal trough technology. Thus new solar technology will require less land for the same amount of elecricity.

NREL studies have identified 2,180.8 km^2 of land that can be used for wind power in Arizona. This includes only land that is not sensitive to environmental issues and has strong enough winds to make wind power financially viable. Using the typical number for wind power generation of 5 MW/km^2 gives the 10.9 GW capacity assumed in this clean energy vision.

After land is identified for power generation or storage, it is important to have in place fast-track procedures for permitting, so it will not take an unreasonable amount of time to build new power facilities. Procedures for mitigating environmental impact and other sensitive issues should be developed for the state and provided to potential power providers and developers. Other states are already working to accomplish this goal.

Although the cost of wind power is currently close to being on par with the cost of fossil fuel power, current solar power technology is 3 to 5 times higher. Thus achieving technology breakthroughs in the next few years is critically important to bringing down the cost of solar power and making it possible to implement this plan. It is vitally important that the state supports the research and development necessary to produce technology breakthroughs to lower the cost of solar energy, especially in the promising technology of concentrated photovoltaics and efficient flat-panel photovoltaics. There is an additional need to support the research, planning and development of thermal storage techniques, compressed air storage facilities, and areas where pumped hydro storage can be used. Grid infrastructure and management techniques must be developed. The University of Arizona and Arizona State University both have strong research programs in solar energy, and Northern Arizona University has a major research effort in wind power.

Science Foundation Arizona, a public-private partnership for advancing high-tech economic development in the state, is helping to fund several important university/industry collaborative research projects focused on decreasing the cost of solar power. For example, one project involves combining a unique, cost-effective solar concentrator design developed at UA with a new multi-junction photovoltaic cell developed at ASU that has the potential of producing $1/W electricity with extremely low water usage in the next few years. Research Corporation for Science Advancement (RCSA), a private foundation located in Tucson, has recently initiated a program to fund research on more efficient photovoltaic devices. According to its president, Jim Gentile, "RCSA is currently exploring new ways to encourage research in photovoltaic energy conversion. Such research must be multi-disciplinary and enhance dialog beyond individual fields of knowledge and inquiry. Only then can we enable scientists to share and consider ideas that will be innovative enough to work. We believe that private foundations can complement the federal government's far greater, and absolutely essential, funding." These two organizations strongly support the vision for Arizona clean energy articulated here.

Currently there is a strong push to utilize more natural gas, both as a fuel for transportation and to generate electricity. This view is driven by the discovery of new supplies of gas that have driven down the cost. This might be a good intermediate step since natural gas has a lower carbon footprint than coal or oil. However, gas fired power plants for electricity still utilize water for evaporative cooling and still generate pollution, and natural gas may experience significant price volatility as global demand increases. Thus natural gas is not a primary part of our clean electricity vision for the future, although it could be useful for backup needs in combination with pumped hydro or compressed air energy storage.

Much of what needs to be done to fulfill this vision is described in the AERO *Solar Task Force Report* (2008). Now what is required is a broad-based dialog leading to a unified commitment of the people of Arizona, political and business leaders, and utility companies to move this plan into reality. The vision described here can be accomplished if we encourage development of solar, wind, geothermal, energy efficiency, and demand response technologies through support of research and implementation of these technologies. We also must support the development of grid infrastructure and management techniques, including smart grid and demand responsive load. From a practical point of view, the implementation of this plan will have to be done step by step. For example, the first step might be to consider building only renewable energy generation systems when the demand for additional power exceeds current generation capacity. This will get us halfway to the final goal. Perhaps the next step could be replacing existing coal-fired power plants with natural gas plants. These fossil fuel plants could be phased out entirely as more solar and wind generation facilities are built. Defining the exact pathway to achieving the goal requires a thorough economic analysis, land use analysis, and water use analysis.

Implementing this plan will have a significant, positive impact on economic development in the state, including rural areas. Now is the time to utilize the great natural resources of Arizona to solve the daunting economic and social problems that need to be overcome for the future wellbeing of the state. Now is the time to discuss, refine and then implement the *Arizona Clean Energy Vision—100% by 2040*. This paper is a call to action to the people of Arizona to move forward with this plan. Science Foundation Arizona and Research Corporation for Science Advancement stand ready to foster dialog with all interested parties to this end.