Navajo Generating Station and Clean-Energy Alternatives: Options for Renewables

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National Renewable Energy Laboratory

Produced under direction of the U.S. Department of the Interior by the National Renewable Energy Laboratory (NREL) under Interagency Agreement R11PG30024 and Task No WFJ5.1000.

Technical Report
NREL/TP-6A20-54706
June 2012

Contract No. DE-AC36-08GO28308

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Cover Photos: (left to right) PIX 16416, PIX 17423, PIX 16560, PIX 17613, PIX 17436, PIX 17721

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1 Introduction

In January 2012, the National Renewable Energy Laboratory delivered to the Department of the Interior the first part of a study on Navajo Generating Station (Navajo GS) and the likely impacts of best available retrofit technology (BART) compliance options under the Clean Air Act's regional haze provisions. That document establishes a comprehensive baseline for the analysis of clean energy alternatives, and their ability to achieve benefits similar to those that Navajo GS currently provides.

This analysis is a supplement to NREL's January 2012 study. It provides a high level examination of several clean energy alternatives, using background established by the previous analysis. To be clear, this analysis is not intended to justify any particular BART outcome, nor is its purpose to support arguments for or against retiring Navajo GS. The factors addressed here are not likely to drive those threshold decisions in any case. However, if the ultimate outcome is retirement, then the task would be to identify a portfolio of generation resources that could provide the benefits Navajo GS is providing today. This analysis is an initial characterization of renewable energy options that would be available for a replacement portfolio, under a conceptual scenario in which the decision to retire the coal plant has already been made based on factors outside the ones addressed here.

None of the alternatives discussed in this analysis can happen quickly. It is assumed here that, if there were a decision to replace Navajo GS, the development of any alternative resource (or portfolio of resources) would occur at the end of a staged transition plan designed to reduce economic disruption. This glide path necessarily would most likely take several years and would need to take into account changes to the Navajo GS site lease, tribal development plans, coal supply contracts, the value of utility partners' investments in the coal plant that are not yet depreciated, and the outcomes of EPA rulemakings relating to air emissions. We assume that replacing the federal government's 24.3% ownership share of Navajo GS would be a cooperative responsibility of both the U.S. Bureau of Reclamation (USBR) and the Central Arizona Water Conservation District (CAWCD), and that at a minimum the replacement strategy must be sufficient to ensure that the Central Arizona Project (CAP) can economically meet all of its water delivery obligations.

1.1 Benefits

The January 2012 study described a wide and complex array of benefits provided by Navajo GS. Figure 1 provides a visual summary of those benefits. The aim of this supplement is to provide an initial assessment of alternative generating technologies, and to describe how each alternative's benefits are likely to qualitatively map to the array of benefits currently provided by Navajo GS.

Two types of benefits are unaffected by the choice of generating alternative, because they relate directly to retiring Navajo GS and not to the choice of alternatives. The first benefit involves health and other environmental factors that may be associated with shutting down the mine that supplies coal to Navajo GS. As discussed in the January 2012 study, there has been no detailed epidemiological study of the health impacts on the nearby

Navajo and Hopi communities. Nevertheless, the potential health and environmental improvements that may result from closing Navajo GS and the coal mine would not depend on whether the replacement power came from wind, solar, or any other non-coal resource.

Another type of benefit not shown in Figure 1 relates to the cost of power. No alternative—renewable or conventional—would cost less than Navajo GS as it currently operates. As detailed in the January 2012 report, most of the plant's capital costs have been depreciated, and its operating costs are among the lowest in the region. Therefore, the decision to seek alternatives would be driven by BART compliance, not by lower generating costs alone.

The task of screening alternatives on the basis of cost is reserved for Phase 2. Reliable cost estimates would require more specific guidance from the Department of the Interior with respect to siting constraints, timing, and other policy objectives. Independent determinations on such factors are beyond the scope of this analysis.

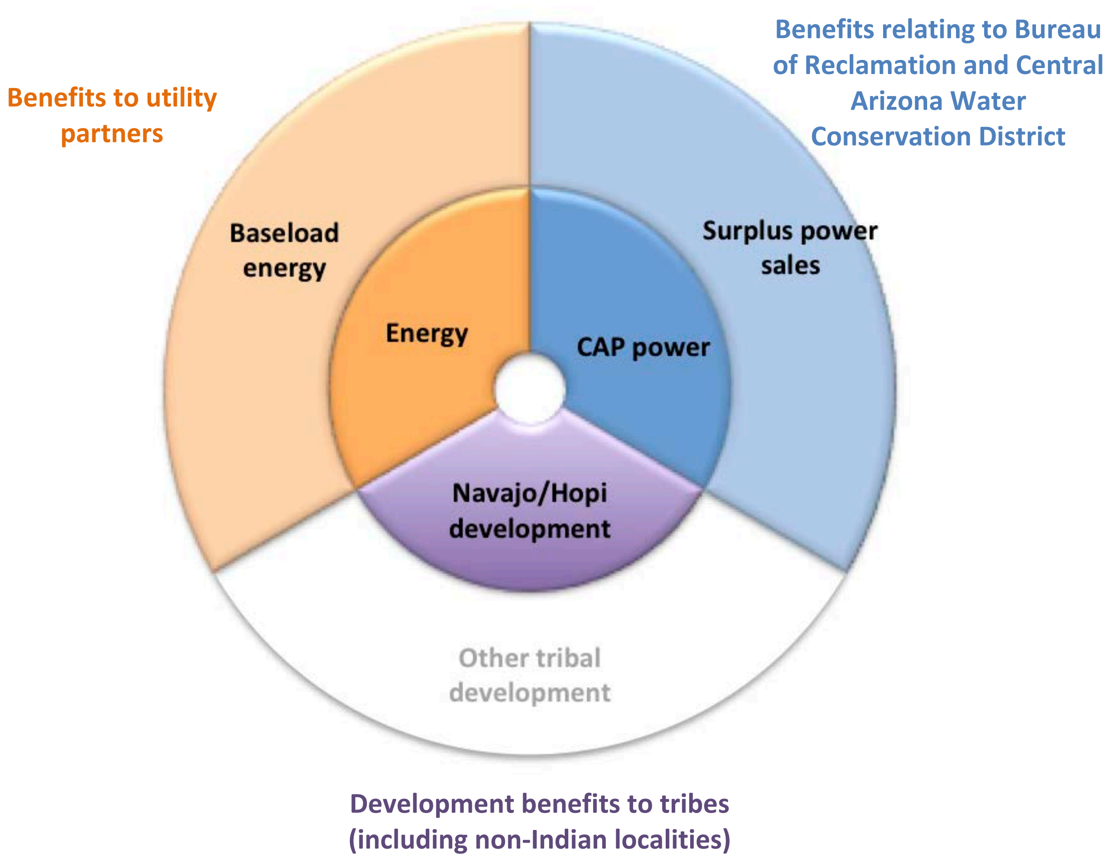


Figure 1. Qualitative relationship of major benefits currently provided by Navajo GS

Figure 1 is a qualitative depiction of the types of benefits currently provided by Navajo GS. They are grouped by beneficiary type, as described in the January 2012 report: USBR and CAWCD, the power plant's five utility partners, and tribes and localities who enjoy the development benefits of having the plant as part of their local economies. Note that the figure is not intended to imply any quantitative comparison of the benefits; that detailed analysis is reserved for Phase 2. The intent here is to identify the types of benefits provided by Navajo GS, and how alternatives would most likely map to that array of benefits.

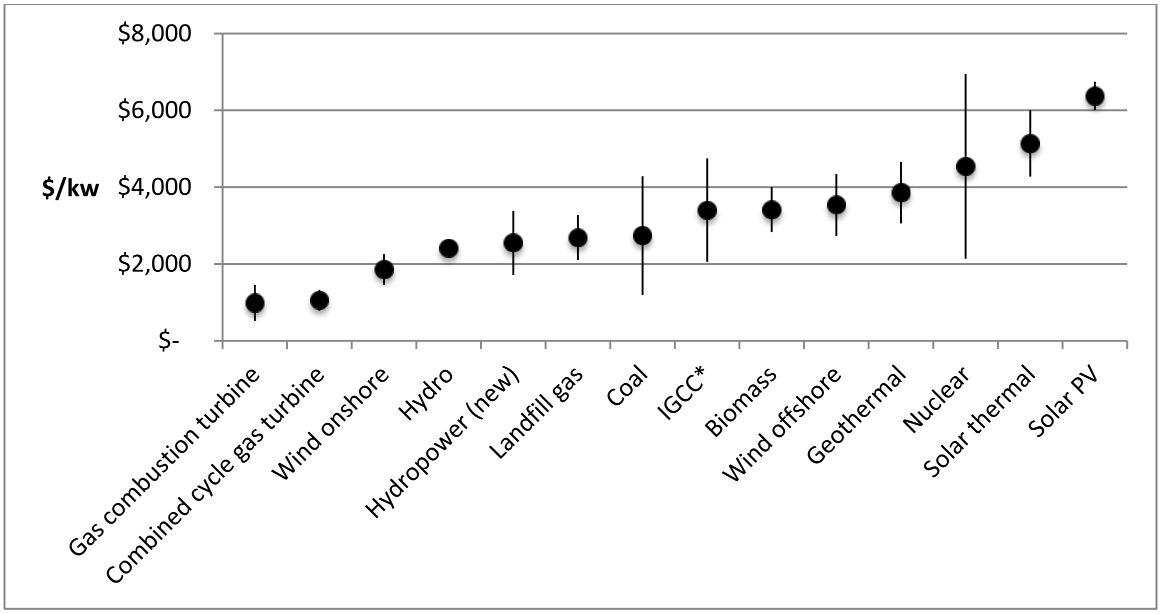
- For USBR and CAWCD, the primary benefit is providing power for the Central Arizona Project; related is the sale of surplus power to others as a source of revenue for the Lower Colorado River Basin Development Fund. We include in this type of benefit any tribal infrastructure project that is financed through the fund.
- For the utilities, the primary benefit is a supply of electricity to serve their retail customers. An added benefit to these utilities is the fact that Navajo GS is one of several sources of baseload power.
- Tribal and local development benefits primarily accrue to the Navajo and Hopi tribes, as well as to the city of Page, AZ. Some of the alternatives described here are found on other reservations. However, for this analysis we distinguish between benefits that historically have been limited to the Navajo and Hopi tribes, and future benefits that may extend to other Arizona tribes.

1.2 Cost

While a more precise analysis of cost is reserved for Phase 2, some elements affecting cost can be compared generally based on current data. Three primary factors shape an alternative's all-in cost: the fixed cost of the capital equipment and its installation (sometimes referred to as overnight costs), the variable cost of operating the plant (mostly the cost of fuel), and plant's productivity (commonly represented as the plant's capacity factor).[1] The perfect resource would have low capital costs, low variable costs, and a high capacity factor. Practically, any alternative involves a tradeoff with respect to at least one of these primary cost factors.

- Coal and nuclear plants have high capital and other fixed costs, but they also generate relatively more electricity over which those fixed costs can be spread. Per unit of electricity generated, the cost of coal is normally lower than the cost of natural gas.
- Natural gas plants have relatively low fixed costs, but their operating costs are affected by the price of natural gas, which can be volatile. Currently natural gas fuel costs are low—as of this writing, near $3 per mmBtu—but as recently as 2008 they were four times that level.

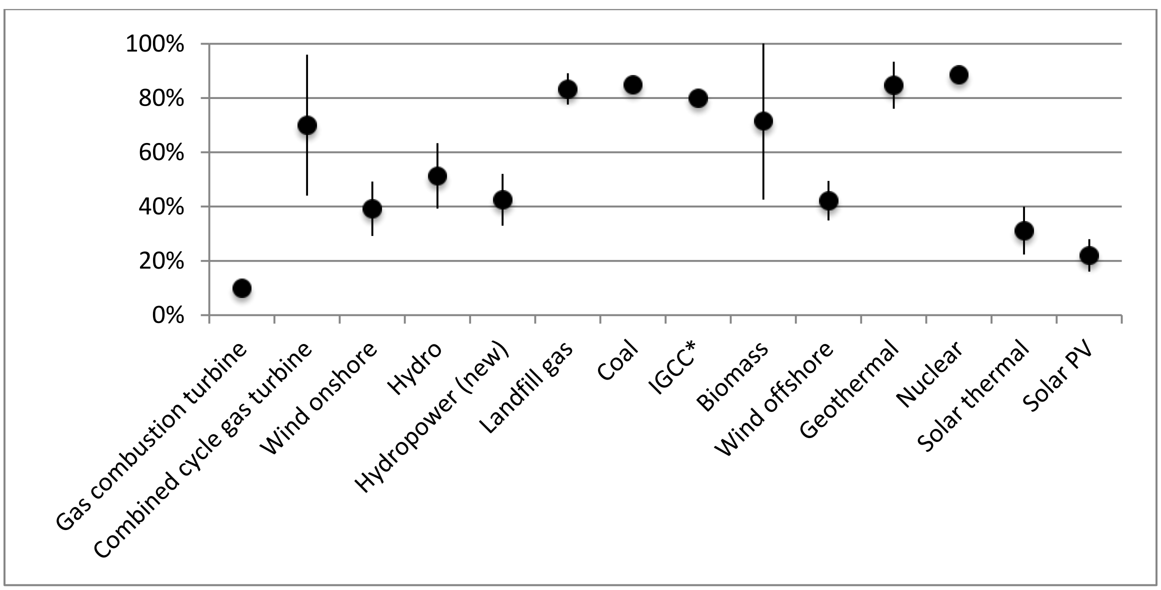
[1] A unit's capacity factor indicates how much of its capacity is used over a given period of time. A unit running at full capacity all the time has a capacity factor of 100%. It would have a 50% capacity factor if it ran at half capacity all the time, or if it ran at full capacity half the time and was idle half the time.



*Integrated gasification combined cycle

Figure 2. Comparison of capital costs in 2010 for various types of new generating units

(Compiled by NREL from various sources. Circles indicate average values; bars indicate averages plus and minus one standard deviation. For supporting data, see http://www.nrel.gov/analysis/tech_costs.html.)



*Integrated gasification combined cycle

Figure 3. Comparison of capacity factors for various types of new generating units

(Compiled by NREL from various sources. Circles indicate average values; bars indicate averages plus and minus one standard deviation. For supporting data, see http://www.nrel.gov/analysis/tech_costs.html.)

- Solar and wind power have negligible variable costs, but their capacity factors are low due to the variability of sunshine and wind. Capital costs for wind are relatively low. Capital costs for solar are higher, but have declined significantly in recent years due to technological improvements and excess supply in the world market.

Figure 2 provides a generic comparison of capital costs for various types of new generating units—renewable as well as nuclear and fossil fuels. The data are based on information as of 2010, and represent the plausible range of costs for each technology (adjusted for inflation to 2012 equivalent values). Since the time the numbers in this table were compiled, solar photovoltaic (PV) plant costs have continued to decline.

Capacity factors can significantly affect how the all-in cost of one alternative compares to another. Figure 3 compares the capacity factors of the technologies shown in Figure 2. Note, however, that capacity factors for renewable technologies are very site-specific even within Arizona, which is why a full comparative analysis of the all-in cost of alternatives is reserved for Phase 2.

1.3 Alternatives Other Than Renewables

Due to time and budget constraints, this overview sets aside for Phase 2 three potential alternatives: advanced coal with carbon capture and sequestration, modular nuclear, and natural gas. Their exclusion from this analysis is intended to be without prejudice to the merits of those options. All three can and should be examined in the next phase of this project. Focusing the present analysis on renewable energy alternatives enabled the study team to leverage off other work currently being done at NREL.

2 Framework and Analytical Assumptions

NREL's January 2012 report suggests a number of threshold issues that frame how to approach the question of alternatives.

- Is it necessary to find one single alternative that provides all the benefits that Navajo GS currently provides by itself?
- Should the federal government differentiate between the public interests (power for CAP, tribal economic development) and the utility interests that would be at stake in a post-Navajo GS world?
- Should the federal government continue to provide CAP with nearly all of its electricity from a single source?

More simply, solving the puzzle of Navajo GS alternatives begins by asking "alternatives to do what?" Without first deconstructing what a generating alternative (or a portfolio of alternatives) would need to accomplish, the analysis can quickly find itself on a circular path, such that the only "alternative" to Navajo GS is Navajo GS itself.

2.1 Size of the Puzzle

The January 2012 report supports the conclusion that finding alternatives to Navajo GS is not one single puzzle, but several overlapping puzzles. One is a 2,250-megawatt puzzle in which a large amount of generating capacity is centrally located. Navajo GS is the largest-capacity coal plant operating in the Western Interconnection, and it ranks fourth—behind only the Palo Verde and Diablo Canyon nuclear plants and the Grand Coulee hydroelectric plant—in terms of total electricity generated during a typical year.[2] Transmission infrastructure supporting it is commensurately large and designed to accommodate one single injection point on the grid. Operating such a large plant means significant local economic benefits in terms of employment, direct payments to local governments, and secondary economic impacts, in this case focused on the Navajo Nation, the Hopi Tribe, and the nearby community of Page, AZ.

At the same time, a Navajo GS alternative is also a 547-megawatt puzzle. This is the size of the federal government's share of the plant, which is dedicated to the operation of CAP. USBR is charged with managing this share of the plant in a manner consistent with federal policy. This share of the power is provided at cost to CAWCD, which was created to manage the delivery of CAP water to tribes, municipalities, agricultural users, and others. What CAP does not need out of this share is sold to other utilities. Revenues from surplus power sales flow into the Lower Colorado River Basin Development Fund, which among other things helps facilitate the terms of water rights settlements with several Arizona Indian tribes.

[2] Market data used in this analysis are compiled by the energy information service of SNL Financial LC. SNL Energy. http://www.snl.com

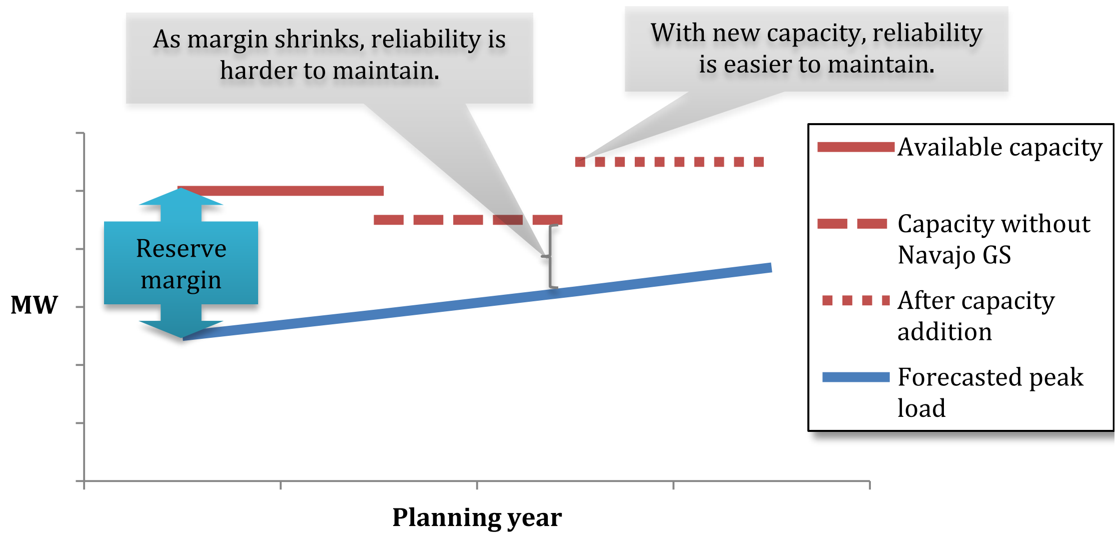


Figure 4. Conceptual illustration of reserve margin in utility planning

The 1,703 megawatts owned by the five utility partners constitute five separate reserve margin puzzles. For each utility, losing its share of Navajo GS will have some impact on its reserve margin and (depending on what it uses for replacement) its overall supply costs.

A utility's reserve margin is the total amount of capacity it has at its disposal in excess of its forecasted annual peak demand, as illustrated in Figure 4. A reserve margin that is too small means unexpected events such as a line outage or a generator failure are more likely to lead to a blackout or some other disturbance to service. Utilities in the West routinely project how they expect their reserve margins to change over time by forecasting load growth and factoring in planned retirements of old generators. The addition of new capacity is usually timed to prevent the utility's projected reserve margin from dwindling to a critical benchmark level.

Navajo GS constitutes between 3.5% and 7.6% of its utility partners' generation fleets. This is the amount of capacity each utility would need to replace with some alternative or another in the event that Navajo GS were no longer available. The timing would depend on when the utility's reserve margin (without Navajo GS) might fall below the minimum benchmark level.

2.2 Separating the Puzzles

The three types of benefits described above—benefits related to USBR and CAWCD, benefits related to tribal and local economic development, and benefits to the coal plant's utility partners—are not fundamentally linked, apart from the fact that one large facility currently provides them all. The value of baseload capacity depends on usage patterns where the electricity is consumed, not on where the power is generated. Similarly, the fact that Navajo GS is a baseload plant is not a necessary condition of the employment and economic benefits that accrue to the Navajo and Hopi tribes.

USBR and CAWCD do not require 2,250 megawatts of generating capacity for CAP and the Development Fund; they now meet those needs with only 547 megawatts. The Arizona Water Settlements Act does not restrict revenues from surplus power sales to baseload power only.

Utilities need baseload capacity, but they have operational flexibility with regard to where it is located; it need not be on the Navajo reservation. Indeed, Navajo GS came into existence because by the 1970s baseload generators no longer had to be geographically near the load they served. Technological advances in supercritical steam technologies in the 1960s enabled utilities to partner on large projects, such as Navajo GS, that could be optimally located anywhere in the region, and not necessarily on a utility's own network.

This analysis of alternatives will unbundle the array of current benefits and examine the alternatives with respect to:

- Options for clean energy generation on the Navajo or Hopi reservations (as well as on other Arizona tribal lands), but not constrained to 2,250 megawatts of baseload capacity
- Clean energy baseload options for the five partner utilities, but not constrained to 2,250 megawatts in one location and not limited geographically to the Navajo or Hopi reservations
- Clean energy options for operating CAP and providing revenues for the Development Fund, but not constrained to 2,250 megawatts of capacity and not limited geographically to the Navajo or Hopi reservations.

3 Assessment of Resource Options

This section provides a high-level overview of the renewable energy options relevant to the benefits currently provided by Navajo GS. The assessments that follow indicate where a given clean energy technology can be most productive; i.e, where a developer is likely to find the sunniest and windiest areas with the fewest physical obstacles to development.

Ownership structures are outside the scope of the factors assessed here. While we include assessments of how much solar power or wind power might be found on a reservation, the analysis does not consider whether the tribe itself owns the project. We assume here that the question of who owns a project will not appreciably change its cost or productivity.

Similarly, we make no assumption about whether the resource might be dedicated to providing CAP power, or how ownership might be structured to provide revenues into the Lower Colorado River Basin Development Fund. Those questions are more appropriately addressed once a preferred technological path has been identified.

State-level resource assessments draw on previous work conducted by NREL for the Western Renewable Energy Zone (WREZ) Initiative. The Western Governors' Association began the WREZ Initiative in 2008 with support from the Department of Energy.[3] In the first phase of the initiative, NREL conducted detailed screenings of wind, solar and geothermal resource potential across the entire Western Interconnection.

In addition, NREL conducted a geographic information system (GIS) analysis of renewable energy potential on all U.S. Indian reservations for DOE. This analysis draws on that work for its estimation of renewable potential available on tribal lands in Arizona.[4]

There are a number of other on-going planning efforts related to renewable energy development that may impact the siting, viability, and suitability of potential NGS generating alternatives. These efforts need to be considered in any Phase 2 analyses.

- The Bureau of Land Management's (BLM) is conducting a Programmatic Environmental Impact Statement (PEIS) for solar energy development in Arizona, California, Colorado, New Mexico, and Nevada. Included in the PEIS is BLM's plan to create up to 18 solar energy zones across the region, including three proposed zones in Arizona, two in California, and four in Nevada.
- The BLM is conducting a focused analysis for solar energy development in Arizona entitled the Restoration Design Energy Project (RDEP). The RDEP seeks to identify the best location for solar energy development in Arizona. This process is on-going,

[3] "Western Renewable Energy Zones – Phase 1 Report." (June 2009). Western Governors' Association. Accessed March 6, 2012 (WREZ Phase 1): http://www.westgov.org/component/joomdoc/doc_download/5-western-renewable-energy-zones--phase-1-report

[4] NREL. Unpublished analysis conducted for the DOE Tribal Energy Program.

and the draft EIS was released on February 17, 2012. USBR has successfully worked with BLM to include five potential solar energy sites located along the CAP for inclusion in the RDEP draft EIS.

- USBR is actively working to identify land it owns that is suitable for renewable energy development. Other potential USBR locations which could play into future NGS scenarios include several sites near Yuma, Arizona, as well as several potential locations along the All American Canal in Imperial County, CA.
- The Desert Renewable Energy Conservation Plan (DRECP) is a multi-agency, multi-year effort focused on identifying the best sites for renewable development in the Mohave Desert.
- The BLM Renewable Energy Program has more than 200 applications, totaling over 60,000 MW of potential projects in BLM lands in the west. As of December 2011, BLM has issued permit approvals for over 6,600 MW of renewable energy projects in the West. Several of these projects are already under construction. There are multiple proposed projects in Arizona, Nevada, and California.

3.1 Renewable Energy Credits

A renewable energy credit (REC) is an accounting device associated with one megawatt-hour (MWh) of electricity produced from renewable resources. It represents the value of the electricity's renewable energy attributes, separate from the electricity's work value. Unlike physical electricity that must be used in real time, RECs may be banked for use at a later time. A REC's economic value comes from its usefulness as a compliance mechanism for state renewable energy requirements, and from direct voluntary consumer demand for green power.

The generation alternatives examined here would have the ability to earn RECs.[5] How this would affect an alternative generation scenario would depend on the project's ownership structure, but in any case, RECs add a new element to potential scenarios for CAP power.

For example, a 100-megawatt PV installation near the Mark Willmer pumping station would generate in excess of 200,000 megawatt-hours per year, along with a corresponding number of RECs. If the project were structured so that the pumping station received the power and the RECs were sold separately to someone other than CAWCD, the revenues could amount to between $200,000 and $300,000 per year.[6]

[5] The Western Renewable Energy Generation Information System tracks and issues RECs for the electricity produced by wind, solar, and other eligible resources that have registered. More than 2,500 generators were registered with WREGIS as of March 2012: http://www.wregis.org

[6] In March 2012, the market price of RECs in California was between $0.98 and $1.50 per REC (SNL Energy). Although solar RECs trade at much higher prices in New England and the mid-Atlantic Coast area, currently the West has no separate market for solar RECs.

3.2 Solar

Arizona has some of the most productive solar potential in the United States. Because solar power increases in the morning and tapers off in the evening, it is generally better suited as a daily load following resource than as an around-the-clock baseload resource. Capital costs tend to be high—$5 to $6 per watt for dry-cooled concentrated solar power (CSP) systems and $3 to $5 per watt for PV, compared to $1 to $4 per watt for a new coal plant.[7] Since 2006, however, total installation costs for PV in Arizona have fallen by 14%.[8]

A standard measure of the quality of an area's solar potential is direct normal insolation (DNI), which indicates the average amount of sunlight falling on a typical square meter of ground during a given period of time. Higher DNI means more electricity can come from the same equipment. Figure 5 shows the degree to which more sunshine (as measured in DNI) translates into more energy generated. An area with an average annual DNI of 7.5 kilowatt-hours per square meter per day will yield about 7% more electricity than an area with DNI of 6.5.

Variable costs for solar are negligible, whereas fuel and other variable costs for Navajo GS are around $19 per MWh.[9] On the other hand, solar capacity factors are much lower than for Navajo GS. A CSP plant near Tucson can achieve a capacity factor of 30% (and up to 41% with thermal storage), as can a PV installation with single-axis tracking located near Tucson. By comparison, the Navajo GS capacity factor is typically 89%. A more precise comparison of overall costs (taking into account differences in capital costs, variable costs, and capacity factors) is not possible without knowing the specific options for siting, due to how differences in the quality of solar resources might affect a project's financial *pro forma*.

NREL has performed a number of screening analyses for solar resource in Arizona and other western states. The estimates of solar resource potential used here are taken from some of those prior screening analyses. Typically, the screening excludes uneven terrain such as hills and mountains. Solar collector fields typically require large, flat areas to keep development costs low. National parks, wilderness areas, and other areas where development is precluded by law are also screened out.

For this discussion, we distinguish between solar *capability* and solar *potential*. "Capability" refers to the land area capable of siting solar power. However, solar projects actually built within an expansive area of capability would likely not cover the entire area. A single project tends to be geographically dense within a limited footprint, and a larger area of capability would mean more choices for siting a project. "Potential" refers to the amount of capacity likely to be developed within a given area of capability.

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[7] "Utility-Scale Energy Technology Capital Costs." National Renewable Energy Laboratory. Accessed February 29, 2012: http://www.nrel.gov/analysis/tech_costs.html),

[8] State-specific summary data on PV costs are available via NREL's interactive Open PV tool. Accessed February 29, 2012: http://openpv.nrel.gov/visualization/index.php

[9] SNL Financial. Accessed February 29, 2012: http://www.snl.com

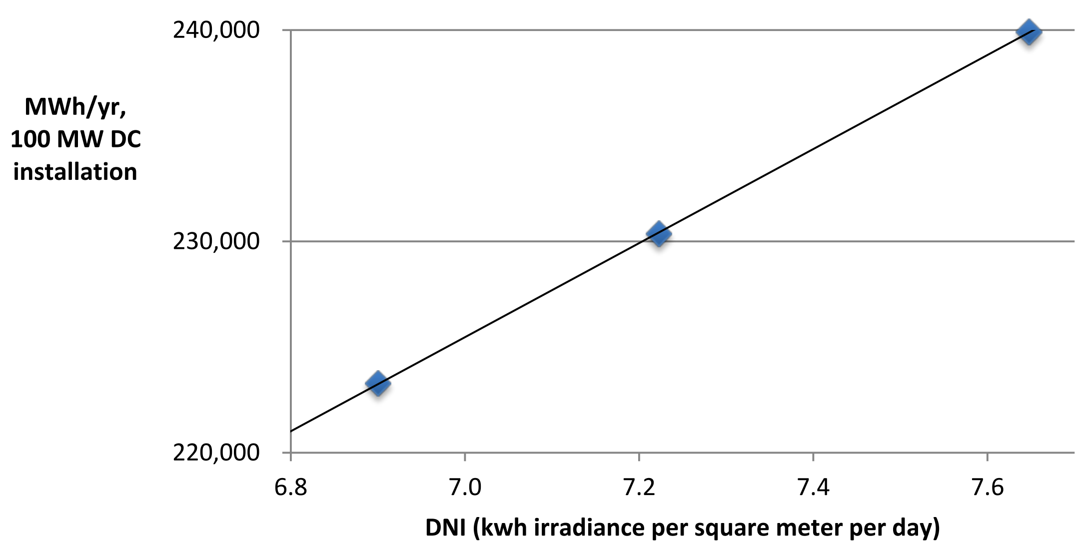

Figure 5. Relationship between DNI and electricity generated

[Line plot calculated using NREL's System Advisor Model (https://sam.nrel.gov/). Reference points are based on 100-megawatt PV systems near Phoenix (DNI 6.9), Tucson (DNI 7.2), and Daggett CA (DNI 7.6).]

3.2.1 Solar Energy Capability on Tribal Land

Nearly every Indian reservation in Arizona has areas with very high DNI. Some have conditions more suited to development, however, and these "best of the best" areas may hold a competitive edge with respect to siting a solar facility that can be cost effective.

Table 1 shows the quality and quantity of screened solar capability on Arizona reservations, ranked by DNI. The table suggests that a utility-scale PV installation would be about as productive on the Tohono O'odham Reservation as it would be on the Colorado River Reservation, but that the Tohono O'odham Reservation might offer roughly 10 times as many technically feasible siting options. The table indicates gross solar capability and does not take into account wildlife habitat or uniquely local constraints such as cultural resources, proximity to sacred sites, availability of roads, transmission access, or proximity to water. The estimates also do not reflect non-technical considerations that could affect the ability to find a purchaser for the power.

Table 1. Estimated Solar Capability on Arizona Indian Reservations

Reservation	Average annual DNI (kwh irradiance per square meter per day)	Estimated utility-scale capability (MW)[a]
Yavapai	7.30	4
Tohono O'odham	7.28	389,043
Colorado River	7.25	36,251
Hualapai	7.24	28,018
San Carlos	7.20	36,640
Maricopa (Ak-Chin)	7.19	3,747
Gila Bend	7.19	46
Hopi	7.17	142,607
Fort Mojave	7.17	4,100
San Xavier	7.14	10,211
Pascua Yaqui	7.13	125
Payson (Yavapai-Apache) Community	7.13	-
Gila River	7.11	53,573
Fort Yuma (Quechan)	7.10	5,847
Cocopah	7.07	1,038
Fort Apache	7.04	13,125
Havasupai	7.01	5,439
Fort McDowell	7.01	2,919
Camp Verde	6.99	49
Navajo	6.99	1,235,874
Salt River	6.98	7,090
Kaibab	6.92	9,564

[a] Areas with a terrain slope greater than 3% were screened out, as were areas such as wetlands, urban areas, water features, and protected federal lands. Remaining areas smaller than 1 km^2 were also screened out.

The Tohono O'odham Reservation has an estimated 389 gigawatts of solar capability with very high DNI. Currently Tucson Electric Power, one of the Navajo GS partners, plans to purchase power from a 35-megawatt PV facility on a site yet to be determined.[10] The reservation is also close to the CAP pumping stations upstream from Tucson. This proximity could reduce the cost of transmission upgrades for projects built to serve CAP directly. The Tohono O'odham Nation is also close to transmission connecting to the Palo Verde Hub, which would provide a path to the California market.

The Gila River Reservation has almost 54 gigawatts of capability close to the CAP pumping stations near Phoenix. The productivity potential of these resources is only

[10] Tilghman, C., UniSource Energy Director of Renewable Resources and Programs (29 March 2012). Email correspondence on file with author.

slightly less than those on the Tohono O'odham Reservation. DOE has awarded $210,000 to the Gila River Indian Communities to study the feasibility of commercial-scale solar and biomass generation for export.[11]

The Colorado River Reservation has some of the most productive solar capability and is just 10 miles from the largest CAP pumping station near Lake Havasu.

The Hopi and Navajo reservations also have significant solar capability. The Navajo Tribal Utility Authority (NTUA) is exploring the feasibility of large-scale solar, including possible development on a reclaimed portion of the Black Mesa coal mining complex.[12] One factor that might affect the cost of a project is the distance from the site to a transmission tie-in near the current Navajo GS site.

The San Carlos Apache Tribe has also received DOE funding to study the feasibility of solar generation on its reservation.[13]

3.2.2 State Potential

The WREZ Initiative estimated Arizona's developable export-quality solar potential to be around 20 gigawatts.[14] This estimate of potential is the result of significantly more rigorous screening than was applied to the estimates of solar capability on Indian reservations, however.

First, the WREZ analysis used a higher resource quality threshold, excluding areas where the DNI was less than 7.25 kwh irradiance per square meter per day. Second, the maximum slope screen was 2%, which was flatter and more restrictive than the 3% slope screen applied to the analysis of the reservations. The WREZ analysis applied the same land use exclusions, but then applied a density screen to the remaining areas to eliminate small, isolated resource pockets. This resulted in the solar resource areas shown in Figure 6, equivalent to 565 gigawatts of capability. Finally, the WREZ analysis mathematically discounted these remaining areas by 96.5% to approximate unknown development limitations and the amount of solar capacity that might actually happen.

Two solar energy zones (SEZs) under study by the Bureau of Land Management (BLM) are located in the Arizona West renewable energy zone hub (AZ_WE). One SEZ is located 40 miles from the largest CAP pumping station; the other is 30 miles from a pumping station west of Phoenix. These SEZs are on federally-owned land and are part of an initiative by the U.S. Department of the Interior to accelerate the development of renewable energy resources.

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[11] DOE Tribal Energy Program, http://energy.gov/downloads/tribal-energy-program-february-2012-award-project-descriptions.

[12] "Four Corners Sustainable Futures Initiative: Phase 1 Preliminary Report." (2011). Northern Arizona University. Accessed October 2011: http://www.fourcorners.nau.edu/docs/4Corners-WhitePaper.pdf

[13] DOE Tribal Energy Program.

[14] WREZ Phase 1, p. 23.

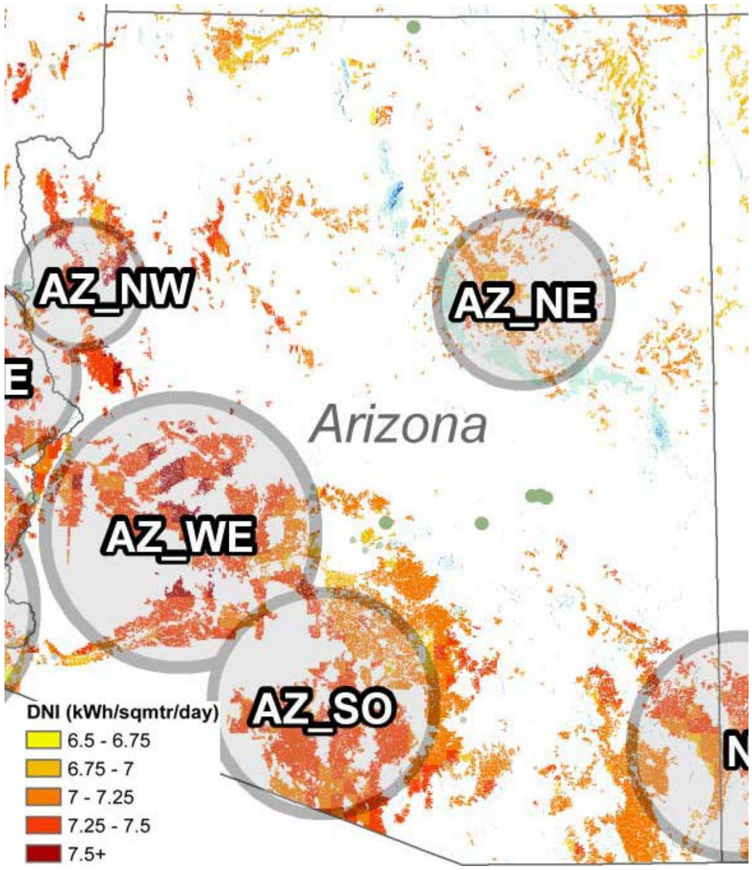


Figure 6. Renewable resources after WREZ screening

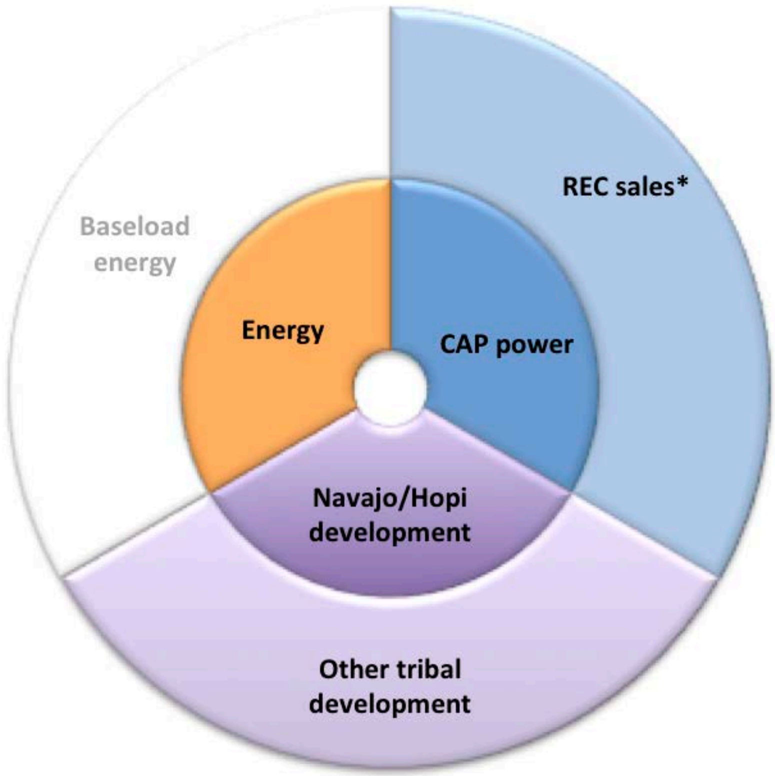
(Source: WREZ Phase 1 report. Circles indicate relative amount of a zone's potential energy; they do not indicate the zone's boundary.)

The southern Arizona WREZ hub (AZ_SO) includes significant portions of the Tohono O'odham Reservation. The northeast hub (AZ_NE) includes solar resources on the Hopi Reservation and the Navajo Reservation.

3.2.3 Summary

Solar power is Arizona's most abundant renewable energy alternative to Navajo GS. Most types of benefits currently provided by the coal plant can be met to some extent by solar power, specifically:

- Tribal economic development benefits related to siting projects on Indian reservations, possibly including but not limited to the Navajo Nation and Hopi Tribe
- Electricity to power CAP pumping stations
- Peak-period energy for the Navajo GS utility partners (although most of them can and are pursuing similar options independently).



*Depending on project ownership structure

Figure 7. Most likely benefit opportunities for solar

A benefit solar cannot easily provide is baseload capacity. While it is technically possible for CSP to provide some baseload energy with the addition of on-site thermal storage, doing so would entail significant additional cost. Solar Reserve's Crescent Dune project, for example, which is under construction near Tonopah, NV, will be the first commercial application of CSP with molten salt in the United States. Developers anticipate that this plant will be able to store energy for 10 to 15 hours and significantly reduce generation intermittency.[15]

Surplus power sales to others might also be difficult, unless project costs continue to decline significantly. At current costs, the purchase price that would be needed to recover a solar project's capital costs might be too high to attract buyers. Unbundling RECs and selling them separately from the power generated could potentially provide a revenue stream for the Development Fund.

3.3 Wind

While Arizona has some commercial-quality wind resource areas, they tend to be less productive than wind areas in neighboring New Mexico. Of the 3.7 gigawatts of screened wind potential that the WREZ initiative identified in Arizona, only 5% was Class 4 or

[15] SolarReserve, project developer. Press release. February 8, 2012: http://www.solarreserve.com/who-we-are/newsroom/

better. In comparison, New Mexico had an estimated 13 gigawatts that was Class 4 or better.[16]

Wind power is generally lower in cost than any other utility-scale renewable energy source. Capital costs are currently \$1 to \$2 per watt, somewhat lower than for coal but somewhat higher than for a natural gas unit. Wind power has no fuel cost, which reduces its overall cost relative to coal and natural gas even further.

Unlike coal, however, wind power is variable, and its output is generally uncontrollable. Forecasting can reduce the cost and the difficulty of managing wind's variability, and utilities have begun to incorporate wind forecasts into their day-ahead and real-time operations.[17]

Also unlike coal, wind power in most cases can earn RECs, which enhance project revenues.

3.3.1 Wind Energy Potential on Tribal Land

Of all the Arizona tribes, Navajo Nation has the largest and the most productive developable wind resource areas. NTUA is currently assessing major wind projects that, in all, could amount to more than 600 megawatts of wind power.

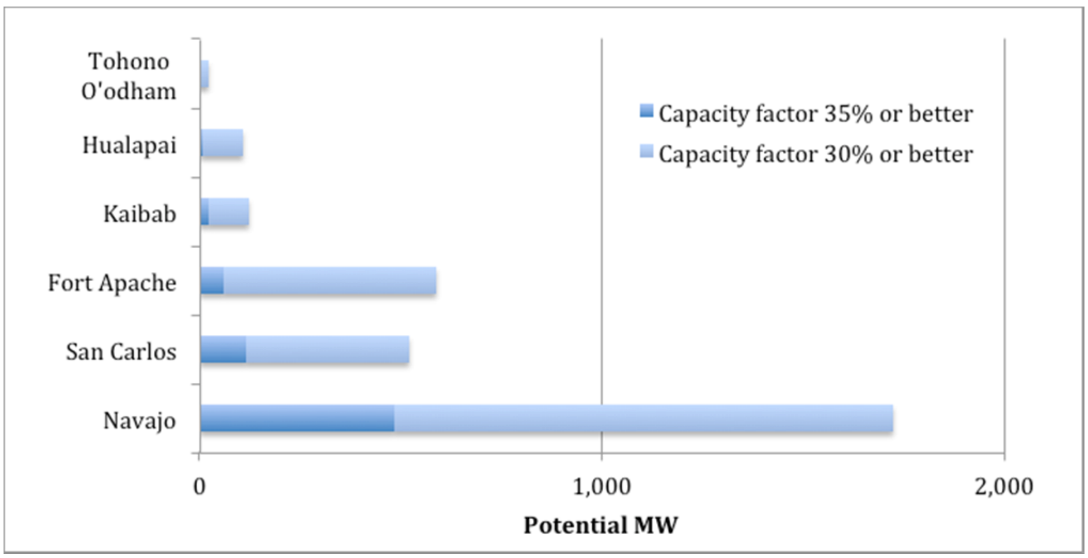


Figure 8. Screened wind resource potential on Arizona Indian reservations

Figure 8 shows the six reservations in Arizona with the largest amount of wind potential. The Navajo Reservation leads both in terms of quantity and quality. It has nearly 1.8 gigawatts of wind potential, 500 megawatts of which NREL estimates to have a potential capacity factor of 35% or higher.

[16] WREZ. The WREZ analysis estimated capacity factors of 32% and 36% for Class 3 and Class 4 wind areas.
[17] Rogers, J.; Porter, K. (March 2011). *Central Wind Power Forecasting Programs in North America By Regional Transmission Organizations and Electric Utilities: Revised Edition*, NREL/SR-5500-51263. Golden, CO: National Renewable Energy Laboratory.

A number of wind projects currently under development or study would provide some development benefits to Arizona tribes. On the Navajo Reservation, NTUA and Edison Mission Energy have partnered to build the 85-megawatt Boquillas Ranch wind farm.[18] The project is currently in the permitting phase. Navajo Nation is also studying a possible multi-resource site on a reclaimed portion of the Black Mesa coal mining complex. The Black Mesa project would include up to 250 megawatts of wind and solar power.

On the western side of the Grand Canyon, the Hualapai Tribe is conducting a feasibility study for a wind project of up to 150 megawatts.[19]

3.3.2 State Potential

In contrast to the rigorous screening used for Arizona's abundant and highly productive solar potential, the WREZ analysis applied more liberal criteria to assess the state's relatively limited wind resources. Most of the capability is in the north central part of the state, either near or on the Navajo reservation. Some wind capability exists in northwest Arizona.

The WREZ analysis estimates Arizona's export-quality wind resources at around 3.7 gigawatts.[20] Wind speed models based on turbines at a hub height of 50 meters estimate that most of this amount has a capacity factor of around 28%. Recent models of productivity for turbines at 80 meters and 100 meters hub height estimate annual capacity factors in northeast Arizona around 35%.

Arizona currently has about 230 megawatts of wind power operating in the northern part of the state. Eight other projects in planning or permitting would add another 1,800 megawatts, including a 500-megawatt project near Lake Mead in northwest Arizona.

[18] Salt River Project, *Navajo Tribal Utility Authority, Edison Mission Energy selected by SRP for new wind project in Coconino County*. Press release. July 27, 2011.
[19] DOE Tribal Energy Program. Presentation. October 2010. http://apps1.eere.energy.gov/tribalenergy/pdfs/17_hualapai.pdf
[20] The area that passed all the WREZ screens amounted to about 15 gigawatts. This amount was discounted by 75% to account for unknown limitations to development, and to estimate the amount that might actually be developed.

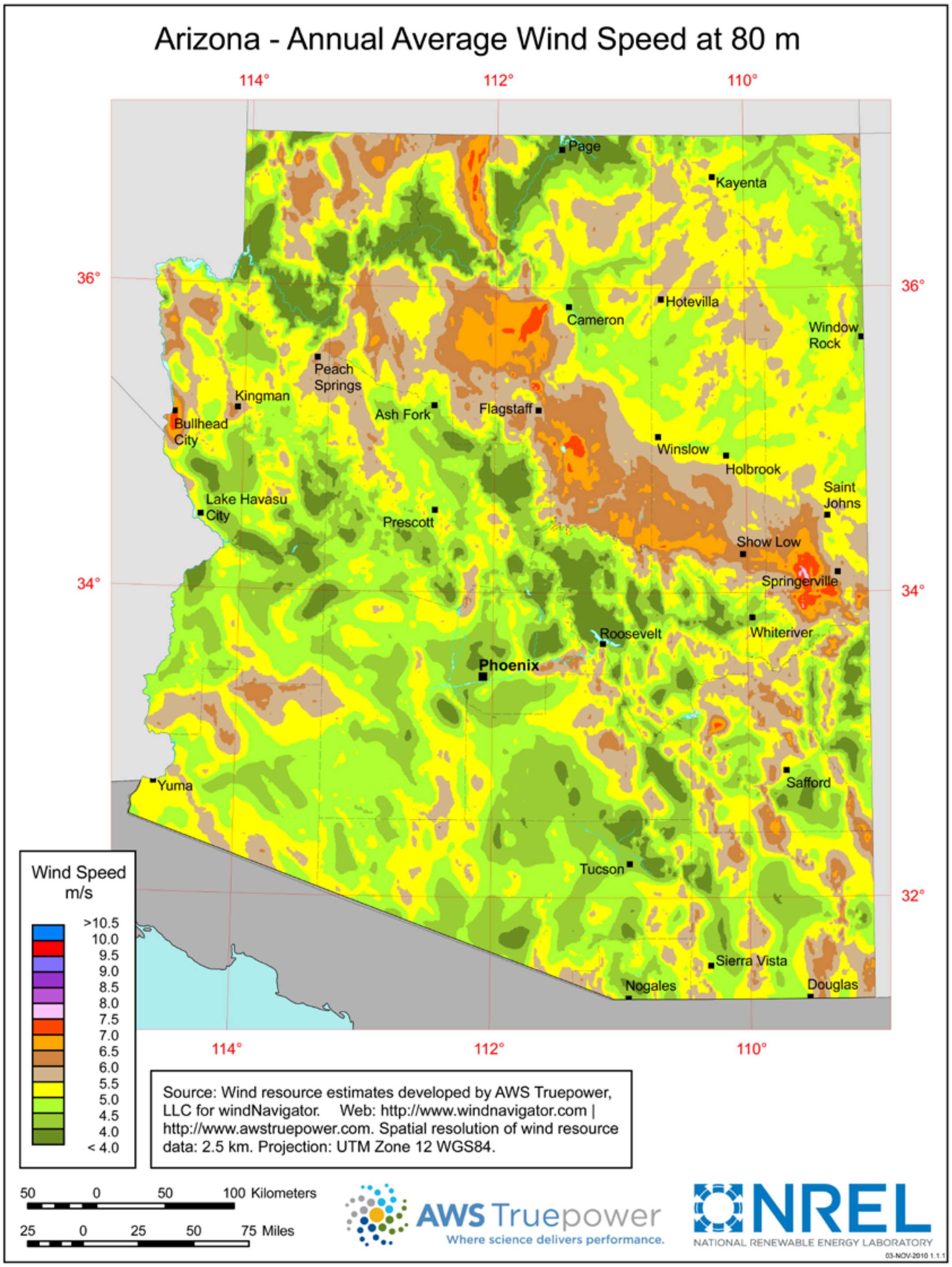


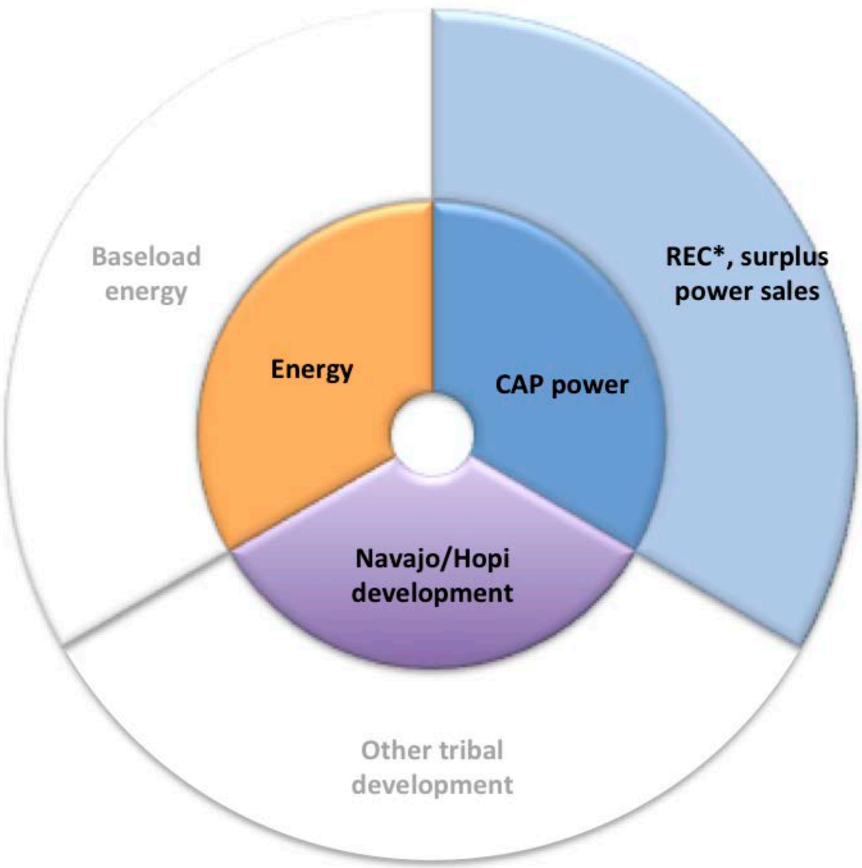
Figure 9. Average annual wind speed areas in Arizona at 80 meters hub height

3.3.3 Summary

Arizona wind power can provide a low-cost alternative to some power currently provided by Navajo GS. Because most of the state's best resources are in the northern part of the state, it is unlikely that wind could be developed economically near CAP pumping stations. Wind projects near the current site of Navajo GS could move power to CAP via transmission currently used to carry power from the coal plant.

Therefore, the type of benefits wind power could provide include:

- Economic development benefits to Navajo Nation (and possibly the Hopi Tribe) related to siting projects on tribal lands near Navajo GS, and some benefits for the Hualapi Tribe, but very little potential for similar benefits by other tribes
- Electricity to power CAP pumping stations via lines currently serving Navajo GS
- Low-cost renewable energy for sale to others
- Low-cost renewable energy for the Navajo GS utility partners (although most of them can and are pursuing similar options independently).



*Depending on project ownership structure

Figure 10. Most likely benefit opportunities for wind

3.4 Geothermal

Of all the Navajo GS owners, NV Energy has the greatest potential for using geothermal power as a baseload alternative. NV Energy is the utility serving most of Nevada, and the nation's most expansive geothermal resource play covers a large portion its network in northern Nevada, including some potential sites on tribal lands. Figure 11 shows the areas that are particularly favorable to geothermal power—areas where subsurface heat is relatively high at relatively shallow depth.

NV Energy's ownership position in Navajo GS is equivalent to 250 MW of baseload capacity, which historically has served Las Vegas and the rest of southern Nevada. A major transmission line currently under construction would, for the first time, provide southern Nevada access to northern Nevada's rich geothermal resources. With the new line, NV Energy could replace all of the baseload capacity it currently has at Navajo GS with geothermal power from northern Nevada.

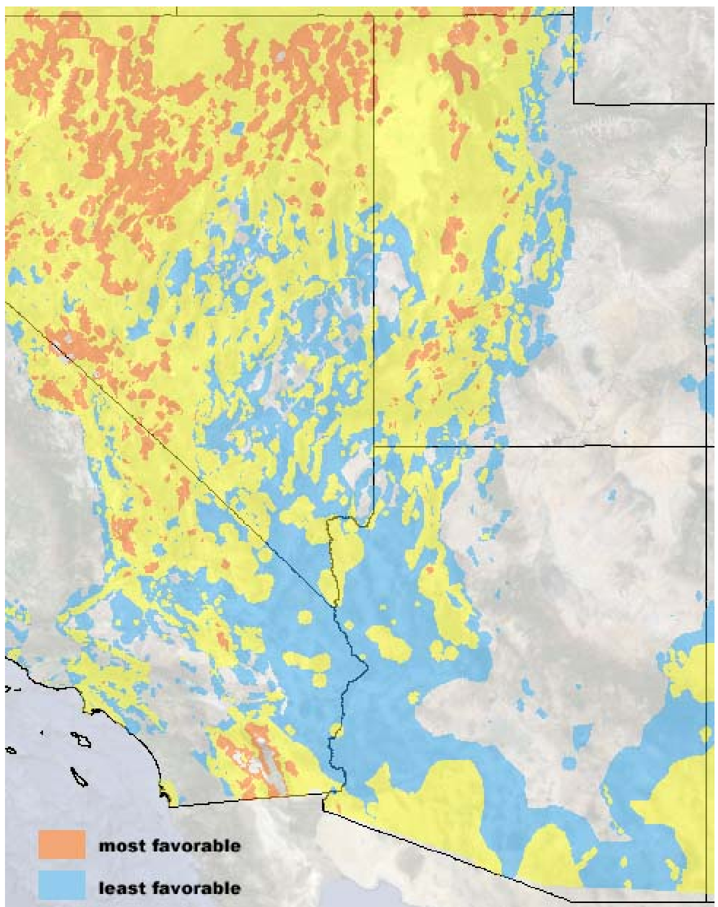


Figure 11. Geothermal favorability in the Southwest

(Source: U.S. Geological Survey, "Assessment of Moderate- and High-Temperature Geothermal Resources of the United States," 2008.)

Unlike wind or solar, geothermal power is well suited to be a baseload power resource. Many plants operating in northern Nevada and in California's Imperial Valley (another area with significant geothermal development) have capacity factors comparable to that of Navajo GS.[21]

Units tend to be small, however. Most operating in Nevada and California today are between 20 and 100 megawatts in nameplate capacity. NV Energy, for example, would need five 50-megawatt geothermal plants to replace the baseload power it currently gets from Navajo GS.

Currently Sierra Pacific Power (NV Energy's northern network) has about 346 megawatts of geothermal power operating, spread among more than a dozen individual plants. On a nameplate basis, this amounts to one-third of Sierra Pacific's baseload of about 1 gigawatt.[22] NV Energy's southern network (Nevada Power) has a baseload of around 2 gigawatts. The company has plans to retire by 2025 a coal plant of which it owns 50%, equivalent to 261 megawatts of baseload capacity.[23] NV Energy included 474 megawatts of geothermal capacity in Sierra Pacific's 2010 integrated resource plan, and by 2011 nearly three-quarters of that was in operation. Going beyond NV Energy's own resource planning, the Sierra Pacific transmission queue for interconnection requests includes 15 proposed geothermal projects, constituting more than 730 megawatts of capacity.

3.4.1 Geothermal Energy Potential in Arizona

Arizona itself lacks a significant base of proven geothermal resource potential. Geothermal favorability maps even suggest a "cool spot" below the Navajo and Hopi reservations that would limit development in the vicinity of Navajo GS and its transmission substation.

Nevertheless, Arizona utilities are currently seeking geothermal resources in California to complement the solar resources connecting to their own networks. The Imperial Valley, which already has transmission interconnections with Arizona near Yuma, has been an area of particular commercial interest. Salt River Project (SRP), the managing partner of Navajo GS, already purchases some geothermal power generated in the Imperial Valley.[24]

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[21] SNL Energy, database of electric generating units.

[22] Hurlbut, D., *Geothermal Energy and Interconnection: The Economics of Getting to Market*, NREL/TP-6A20-54192. Golden, CO: National Renewable Energy Laboratory.

[23] NV Energy. *Sierra Pacific Power Company Integrated Resource Plan*. (2010). Filing before the Public Utilities Commission of Nevada.

[24] Salt River Project, *SRP to purchase 49 MW of geothermal energy*. News release. Dec. 12, 2011. http://www.srpnet.com/newsroom/releases

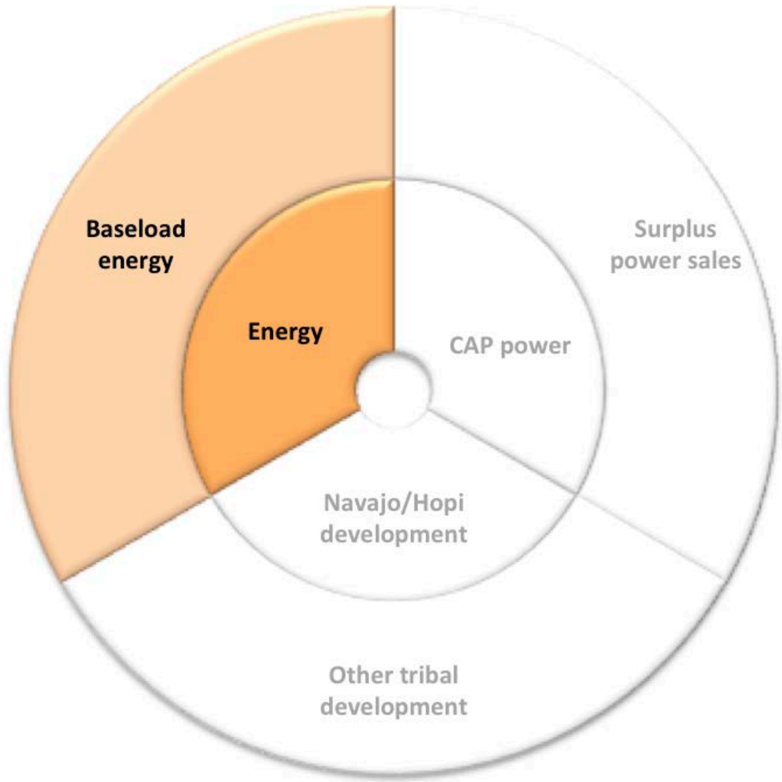


Figure 12. Most likely benefit opportunities for geothermal

3.4.2 Summary

Geothermal power could provide some of the baseload energy benefits that Navajo GS currently provides (Figure 12). NV Energy has sufficient geothermal resources in its own service territory to make up for the loss of its share of the coal plant. Knowing whether Nevada's geothermal resources could also serve load in Arizona, however, would require more detailed studies of network power flows that take into account the major transmission lines due to be completed in 2013.

Aside from NV Energy, other Navajo GS utility partners are independently pursuing deals to secure baseload geothermal power. For any partner, completely replacing its share of the coal plant with geothermal would require deals with many geothermal plants.

Because geothermal within the borders of Arizona is limited, it would not be able to provide the economic development benefits for Arizona tribes that Navajo GS currently provides.

3.5 Biomass and Small Hydro

Arizona's potential for generating electricity from biomass resources and small hydroelectric resources is limited, both statewide and on tribal lands. Table 2 shows the resource estimates for Arizona reservations based on NREL's GIS analysis. Note that the grand total for all reservations for biopower and hydropower is still just 7% of what Navajo GS generated in 2010.

The WREZ analysis estimated that Arizona could generate up to 2.4 million MWh per year through biopower. It also identified about 72 megawatts of small hydroelectric potential, which would produce about 347,000 MWh per year assuming a 55% capacity factor.

The interconnection-wide WREZ analysis treated biopower and small hydro as local rather than regional electric generating resources. Stakeholder discussions concluded that because these resources tend to be small and highly dispersed, they generally would not be competitive with larger wind and solar projects in a regional market for renewable power. Nevertheless, these resources could be a source of electricity for the communities in which they may be located. Those benefits are different from those provided by Navajo GS, however.

3.5.1 Summary

Biopower and small hydroelectric power cannot provide the same benefits as Navajo GS. They provide different types of benefits that are local rather than regional in nature.

Table 2. Biopower and Small Hydro Potential on Arizona Indian Reservations

	Biopower from Solid Residues[a] (MWh/yr)	Biopower from Gaseous Residues[b] (MWh/yr)	Hydropower Generation Potential (MWh/yr)
Camp Verde	26	1	-
Cocopah	1,161	25,403	-
Colorado River	17,814	34	106,505
Fort Apache	14,148	182	115,435
Fort McDowell	190	74,323	14,108
Fort Mojave	565	50	3,050
Gila Bend	1	-	-
Gila River	26,922	459	47,987
Havasupai	153	4	5,692
Hopi	745	62	1,860
Hualapai	580	16	897
Kaibab	14	4	452
Maricopa (Ak-Chin)	11,100	9	313
Navajo	103,018	1,755	369,000
Pascua Yaqui	415	10	-
Payson (Yavapai-Apache) Community	-	-	-
Salt River	3,495	59,395	17,910
San Carlos	12,211	76	49,442
San Xavier	575	293	2,638
Tohono O'odham	7,512	296	-
Yavapai	639	8	-
All Arizona reservations	201,284	162,382	735,289
Navajo GS net generation (2010)		16,429,593	

[a] Forest, crop, primary mill, and urban wood residues. Generation estimated assuming 1.1 MWh/bone dry ton of residue.

[b] Landfill and domestic wastewater residues. Generation estimated assuming 4.7 MWh/tonne of CH_4 produced by the residues.

3.6 The Renewable Portfolio

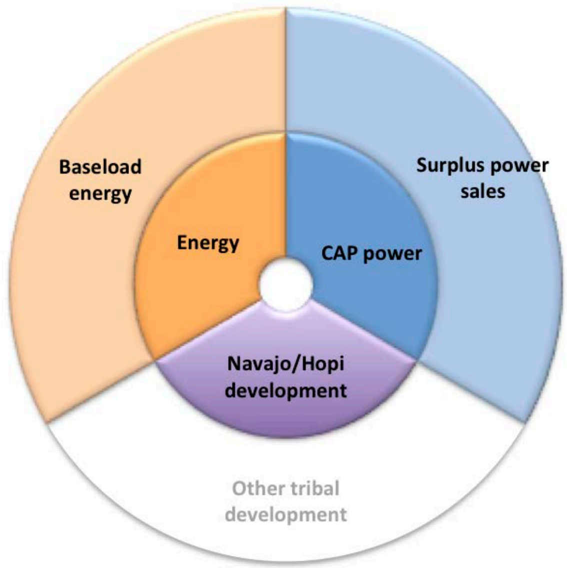
The foregoing discussion indicates that neither solar, wind, nor geothermal power alone can replace all the types benefits currently provided by Navajo GS. They might in aggregate, however. Figure 13 juxtaposes the resource-specific benefit graphics from Figure 7, Figure 10, and Figure 12. When considered together, they have the technical capability to cover the entire spectrum of current benefits, plus some tribal economic development benefits that the coal plant does not provide. A diversified renewable portfolio to provide some of CAP's power needs could expand tribal economic development benefits beyond the Navajo Nation and the Hopi Tribe to include tribes nearer to CAP pumping stations.

Whether a diversified renewable portfolio could match the amount of benefits in each category would depend on the number of projects developed, the economics of various options compared to other factors, and on the business arrangements linking them to the CAP and to the Development Fund.

With regard to the utility partners' benefits in particular, renewable energy alternatives to replace some or all of their Navajo GS shares might not require federal leadership. The utilities are already evaluating solar, wind, and geothermal resources that could address their portion of the puzzle at least in part.

What is unclear is whether a utility partner would respond to the retirement of Navajo GS—and, consequently, to the end of the partnership agreement—by incrementally increasing its renewable energy procurements by the amount of its ownership share. A utility's typical path forward would be to regard future capacity loss as an anticipated change in its reserve margin and to add new capacity on a least-cost basis. The factors guiding its procurement of renewable resources would probably not change. Therefore the total amount of renewables needed probably would not change if Navajo GS were no longer part of the generation fleet.

Types of benefits provided by Navajo GS

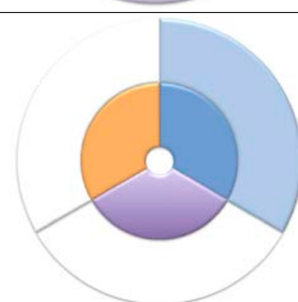


Solar:

- Energy (but not baseload energy)
- CAP power (possible REC sales to others)
- Tribal development, including tribes in addition to Navajo and Hopi

Wind:

- Energy (but not baseload energy)
- CAP power and possible market sales to others
- Tribal development, mostly Navajo



Geothermal (Nevada, Imperial Valley):

- Energy, including baseload energy
- Unlikely for CAP, market sales to others
- Unlikely for Arizona tribal development

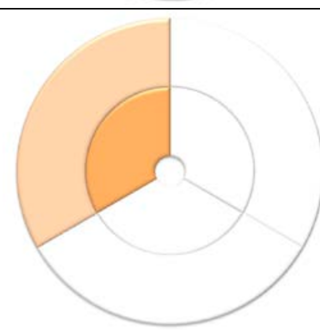


Figure 13. Comparison of likely benefits from solar, wind, and geothermal

4 Special Cases for Solar Alternatives

NREL has been engaged in separate analyses that relate to the question of clean energy alternatives to Navajo GS. Two of these analyses are summarized here as additional information. These are not necessarily recommended technologies, because such a recommendation would require more detailed analysis. They are included here for reference and for the reader's convenience, and include:

- Installation of concentrating solar power augmentation at one of the existing Navajo GS units
- On-site PVs to provide some of the power for CAP pumps.

4.1 Solar Augmentation at an Existing Navajo GS Unit

Concentrating solar power (CSP) differs from PV solar power in that CSP uses the sun's heat to drive a thermal power cycle. This reliance on thermal energy means CSP plants can be backed up with natural gas and can supply steam to augment fossil-fired power plants. Such "solar-augment" allows CSP to be combined with existing or new fossil power plants.

Solar-augment of a fossil power plant offers several advantages:

- It takes advantage of a pre-existing steam power block, electrical substation, and other ancillary equipment
- It takes advantage of pre-existing transmission and grid interconnection
- Location next to an existing power plant likely minimizes environmental and view-shed concerns
- Solar variability is mitigated by fossil fuel use.

These features combine to reduce some of the cost and risk associated with the solar project, and also may shorten project development timelines. As risk is reduced, indirect costs associated with financing costs and project contingencies may also decrease.

In 2009, the Electric Power Research Institute (EPRI) completed studies examining the best ways to integrate CSP steam into coal-fired and natural gas combined cycle (NGCC) power plants.[25] This work was followed by a joint NREL/EPRI study that examined the solar-augment potential of coal and gas plants in the United States.[26] Navajo GS was one of the plants included in the study.

[25] Libby, C. Project Manager (April 2010). *Solar Augmented Steam Cycles for Coal Plants: Conceptual Design Study*. Report 1018648. Work performed by Electric Power Research Institute, Palo Alto, CA. Libby, C. Project Manager (July 2009). *Solar Augmented Steam Cycles for Natural Gas Plant: Conceptual Design Study*. Report 1018645. Work performed by Electric Power Research Institute, Palo Alto, CA.

[26] Turchi, C.; Langle, N.; Bedilion, R.; Libby, C. (2011). *Solar-Augment Potential of U.S. Fossil-Fired Power Plants*. NREL/TP-5500-50597. Golden, CO: National Renewable Energy Laboratory. February 2011.

The potential to hybridize Navajo GS by augmenting the plant with solar-generated steam was evaluated following a procedure developed by NREL and EPRI. Qualitatively the plant is a good candidate for solar augment because of its attractive solar resource and the proximity of flat, vacant land. The protocol developed by NREL and EPRI seeks to maximize solar integration while maintaining high solar-use efficiency and the ability to run the power cycle with and without solar input. The best case integration of solar thermal energy utilizes power tower technology because of its better match to coal plant steam conditions.

For Navajo GS, developing the largest contiguous plot of suitable land near the plant would allow for a solar-augment potential of approximately 8% of annual energy generation of one of the 750 MW coal units, assuming the coal plant runs at a 90% capacity factor. The design-point solar contribution is as high as 26%. That is, a power tower with thermal storage could achieve up to 26% solar contribution, although this system would require roughly three times more land area than this analysis assumed would be available. The 8% annual and 26% design-point values are based on the use of molten salt power tower CSP technology. Parabolic troughs would have a lower solar-augment due to the lesser steam conditions provided by troughs.

This analysis was a high-level assessment based on properties that are typical for coal and CSP plants. A more detailed, site-specific analysis is necessary if development is to be considered.

Figure 14. Solar power tower

Source: NREL/PIX 02183

Figure 15. Solar parabolic trough

Source: NREL/PIX 16604

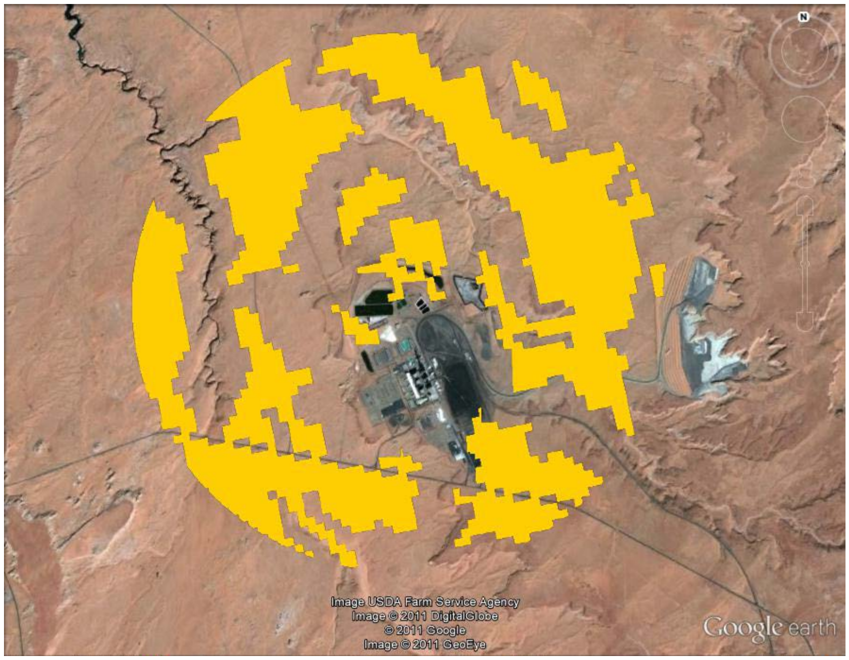


Figure 16. Satellite image of Navajo GS showing land potentially suitable for CSP development

4.1.1 Solar-Augment Results for Navajo GS

The limiting factor for the amount of solar-augment at Navajo GS depended on the CSP technology employed. For parabolic troughs, the maximum augment was limited by the ability of the steam cycle to accept relatively low-temperature steam. Turbine pressure rises as one incorporates lower quality steam and tries to offset the steam quality by increasing mass flow through the turbine to maintain plant output. This restriction limited the amount of solar steam that could be accepted by each unit. By the time the third unit was brought into play, the land area was exhausted, but it had nearly reached its steam turbine limit as well.

For power towers the limiting factor was land. The analysis only used the largest land parcel (1,220 acres). Integrating all solar energy from this land parcel into Unit 1 at Navajo GS would yield a 7.6% solar contribution to Unit 1 on an annual basis. The design point solar-energy contribution is as high as 26%; that is, when the solar field is a full power it can represent 26% of the energy output from Unit 1. The annual contribution is much lower because the capacity factor for the CSP plant is less than 30%, compared to the assumed coal capacity factor of 90%. The addition of thermal storage would increase the CSP capacity factor, but would also require additional land. Additional power tower solar could be integrated into Navajo GS if one chooses to construct multiple solar fields on different parcels of land. The solar plant could include thermal energy storage to increase the solar contribution of one coal unit or distribute the augment across all three coal units. Ultimately the amount of solar that could be integrated will be limited by the estimated 3,232 acres of suitable land within 3 km of the plant.

Table 3. Solar-Augment Results for Power Tower Technologies

Unit	Nameplate Capacity (MW)	Augment Potential (MWe)	Annual Solar Generation Contribution	Solar Use Efficiency	Limiting Factor
1	750	198.5	7.6%	35.4%	steam turbine
2	750	0	0.0%	-	land*
3	750	0	0.0%	-	land*

*Only the largest contiguous land parcel is used.
Values assume 90% fossil capacity factor and 26% CSP capacity factor.
Source: Turchi et al., 2011.

Table 4. Solar-Augment Results for Parabolic Trough Technologies

Unit	Nameplate Capacity (MW)	Augment Potential (MWe)	Annual Solar Generation Contribution	Solar Use Efficiency	Limiting Factor
1	750	55.8	2.1%	26.9%	steam turbine
2	750	55.8	2.1%	26.9%	steam turbine
3	750	46.7	1.8%	30.9%	land*

*Only the largest contiguous land parcel is used.
Values assume 90% fossil capacity factor and 26% CSP capacity factor.
Source: Turchi et al., 2011.

4.1.2 Summary

Adding solar-augment to one of the three units, while continuing to operate the other two as usual, would potentially preserve the same types of benefits currently provided by Navajo GS, all other factors held the same. Land availability may limit the relative degree to which solar-augment could contribute to a plant as large as Navajo GS.

An alternative scenario is that the other two units are retired, with USBR and CAWCD retaining a majority share of the remaining solar-augmented unit. In this case, the remaining benefits would include:

- Economic development benefits to Navajo Nation and the Hopi Tribe (but at a reduced level)
- Electricity to power CAP pumping stations
- Energy for sale to others, and possibly the additional sale of RECs
- Baseload power for any utility partner retaining a minority share of the solar-augmented unit.

It is possible that a solar-augmented coal unit could earn RECs calculated from the amount of solar energy used to generate power. Whether these RECs would have value would depend on state policies governing the types of resources eligible to meet renewable energy requirements.

4.2 On-Site Distributed Solar Power

NREL is currently conducting a study for USBR that examines the potential for using distributed PV to offset some of the power needed for water pumping stations along the CAP aqueduct. Distributed (or on-site) generation reduces the amount of power supplied from the transmission system, thereby eliminating long-distance line losses and reducing transmission-related costs. The methodology here assumes excess solar power would be sold, and that current electricity supplies would balance out variations in PV production so that pumping schedules were unchanged.

The pumping loads at Mark Willmer and Hassayampa Pumping Stations were selected for the analysis. Figure 17 shows the two stations in relation to the screened solar potential areas identified in the WREZ analysis. The Mark Willmer station is the largest on the CAP system, and is the point of withdrawal from the Colorado River. BLM's proposed Brenda solar energy zone is located 40 miles southeast of the station's withdrawal point. The much smaller Hassayampa station is about 30 miles northwest of Phoenix, and about 30 miles north of BLM's proposed Gillespie solar energy zone.

Figure 18 shows the average daily load profiles of the two stations. The average load in 2010 for Mark Willmer was around 180 megawatts, with a peak load of 287 megawatts. The total annual energy consumption is 1,572,621 MWh per year. Hassayampa's average load in 2010 was around 33 megawatts, with a peak load of 55 megawatts. The total annual energy consumption is 288,272 MWh per year.

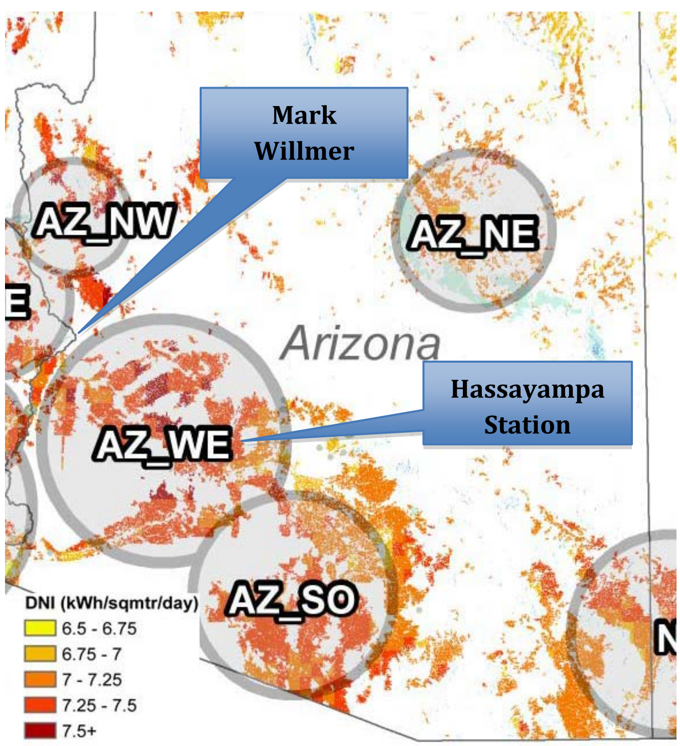


Figure 17. CAP pumping stations included in PV analysis

4.2.1 Methodology, Tools, and Assumptions

NREL used the software optimization tool HOMER[27] to model three different PV system sizes: 20, 50, and 100 megawatts. HOMER contemporaneously matched the hourly production of a solar PV system with the hourly demand of the pumping plant. The PV system is modeled as a horizontal continuous adjustment tracking system with a lifetime of 25 years. The HOMER model evaluates the opportunities from the perspective of the Bureau of Reclamation owning and operating the PV plant with capital and operating and maintenance (O&M) costs.

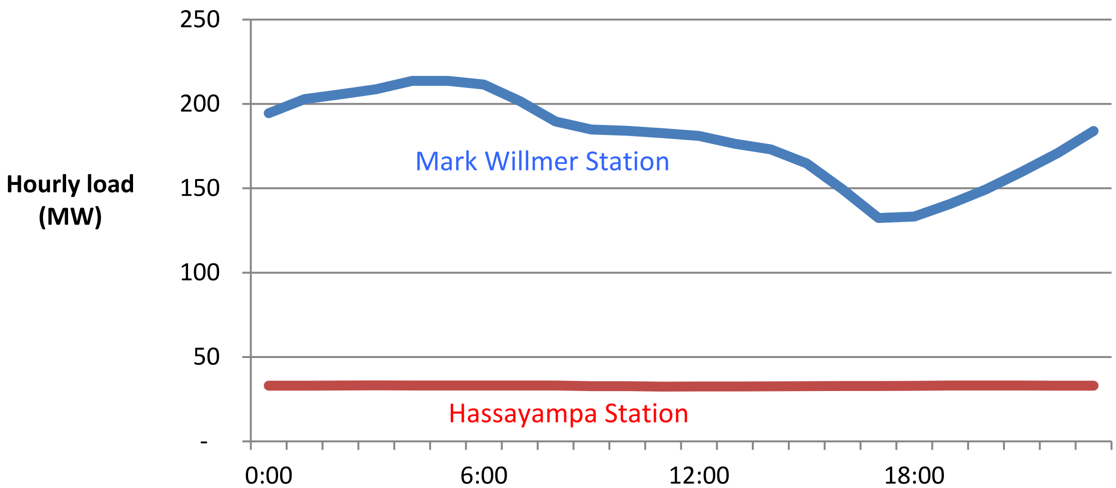


Figure 18. Average daily load profiles for Mark Willmer and Hassayampa pumping stations

The model used PV capital costs of $3 per watt and replacement costs of $2.50 per watt. O&M costs were assumed to be 0.1% of the capital cost every year. Economic calculations used a 6% annual real discount rate and a project lifetime of 25 years.

In the model, energy from the PV system offset the use of power from Navajo GS to meet pumping loads. We used CAP's cost of power from Navajo GS—$0.03 per kilowatt-hour—as the value of offset power. Excess production from the PV system that would be sold on the market as green power was valued at $0.10 per kilowatt-hour.

4.2.2 Results

A 100-megawatt PV system would provide 13% of Mark Willmer's annual energy needs and about 54% of Hassayampa's. A system of that size would yield some excess power at Hassayampa during the summer months. The estimated value of this excess, based on the assumptions used in the model, was around $3.2 million.

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[27] HOMER Energy LLC, Version 2.81. http://www.homerenergy.com/

However, the effective cost of a 100-megawatt PV system (levelizing capital and O&M costs to an equivalent cost per kilowatt-hour value) would have increased energy costs at both pumping stations. The model indicated that levelized costs would increase 23% at Mark Willmer and 41% at Hassayampa.

The analysis indicated that the economics are not favorable for PV as long as the cost of energy at the pumping stations is only $0.03/kWh. Power costs would have to increase to around $0.12/kWh before PV would be economical (assuming PV's capital costs were spread out over 25 years). Other factors that could affect economic viability in the future include further reductions in PV system costs, and an increase in the cost of power from Navajo GS.

The economics of integrating PV into the pumping stations located to the east of Hassayampa may be more favorable. Additional opportunities may be available for using PV during peak hours, thereby freeing up additional excess NGS power for possible sale during summer peak hours, when excess NGS power will have the highest market value.

4.2.3 Summary

On-site PV could provide power directly to CAP pumping stations. Near-site PV located on tribal lands would also provide economic development benefits to the tribe. The Mark Willmer station, for example, is just a few miles outside the Colorado River Reservation. However, the economics of a project probably would not be favorable under the conditions modeled in this analysis.

Benefits not addressed by this alternative would include:

- Economic development benefits to Navajo Nation and the Hopi Tribe
- Baseload power for any of the current utility partners.

5 Summary and Next Steps

Based on this preliminary screening, the following options should be evaluated in additional detail in Phase 2:

- Distributed wind and solar generation potential located across the Navajo and Hopi reservations, as well as the reservations of CAP water-using tribes
- Distributed wind and solar on non-tribal lands located throughout Arizona, Nevada, and California, including on lands owned by USBR, BLM, the Department of Defense, and private landowners
- Solar-augment at NGS, with possible tribal ownership or partial ownership of the CSP plant
- Geothermal from northern Nevada and from California's Imperial Valley
- Additional analysis of PV integration at CAP's pumping plants located east of Hassayampa, with an analysis of the potential to optimize PV use during summer peak hours, thereby freeing up additional NGS excess power for sale on the open market during peak hours
- Clean coal and CCS located on the Navajo/Hopi reservation
- Small, modular nuclear
- Natural gas generation.

The Phase 2 analysis should evaluate and compare the costs, benefits, and impacts of the various alternative generation scenarios against several alternative scenarios for Navajo GS, including:

- Baseline (business as usual) conditions
- Resulting plant operating and production costs from potential additional required control technologies from BART and MATS
- Shutdown scenario
- Intermediate solutions such as scaling back generation in one unit and/or shutting down one unit.

For each of the scenario comparisons, the Phase 2 analysis should compare impacts on jobs, emissions, CAP water costs, tribal benefits, visibility, public health, and other impacts and benefits associated with Navajo GS.