UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION
BEFORE THE SECRETARY OF THE COMMISSION

In the Matter of:	)	
	)	
UNION ELECTRIC CO.	)	Docket No. 50-483-LR
	)	
(Callaway Plant Unit 1)	)	

DECLARATION OF DR. ARJUN MAKHIJANI IN SUPPORT OF MISSOURI COALITION FOR THE ENVIRONMENT'S HEARING REQUEST REGARDING CALLAWAY LICENSE RENEWAL APPLICATION

I, Arjun Makhijani, declare as follows:

1. Introduction and Statement of Qualifications

1.1 I am President of the Institute for Energy and Environmental Research ("IEER") in Takoma Park, Maryland. Under my direction, IEER produces technical studies on a wide range of energy and environmental issues to provide advocacy groups and policy makers with sound scientific information and analyses as applied to environmental and health protection and for the purpose of promoting the understanding and democratization of science. A copy of my curriculum vita is attached.

1.2 I am qualified by training and experience as an expert in the fields of plasma physics, electrical engineering, nuclear engineering, the health effects of radiation, radioactive waste management and disposal (including spent fuel), estimation of source terms from nuclear facilities, risk assessment, energy-related technology and policy issues, and the relative costs and benefits of nuclear energy and other energy sources. I have conducted numerous studies and written extensively regarding investment planning in the electricity sector, the comparative costs of nuclear power plants and other energy sources, the safety of nuclear power, and the health effects of and risks of exposure to ionizing radiation.

1.3 I am author or co-author of several studies regarding the economics of nuclear energy and other energy technologies. In 1971, I was the principal author of the first ever study of the energy efficiency potential of the U.S. economy, *An Assessment of Energy and Materials Utilization in the U.S.A.* I am the author of *Carbon-Free and Nuclear-Free*, published in 2007, which demonstrated the technical and economic feasibility of a fully renewable energy economy in the United States by about 2050 and of a study published in 2010 showing how Utah could have a renewable energy economy by 2050, *eUtah: A Renewable Energy Roadmap*. I am also a co-author of *Renewable Minnesota: A Technical and Economic Analysis of a 100% Renewable Energy-Based Electricity Sector for Minnesota* (Institute for Energy and Environmental

Research, Takoma Park, Maryland, 2012), and of *Investment Planning in the Energy Sector* (Lawrence Berkeley Laboratory, Berkeley, 1976).

1.4 I am author or co-author of several books and articles regarding the health and safety risks of nuclear power in comparison to other energy technologies, including *The Nuclear Power Deception: U.S. Nuclear Mythology from Electricity "Too Cheap to Meter" to "Inherently Safe' Reactors"* (Apex Press, New York, 1999, co-author, Scott Saleska); *Securing the Energy Future of the United States: Oil, Nuclear and Electricity Vulnerabilities and a Post-September 11, 2001 Roadmap for Action* (Institute for Energy and Environmental Research, Takoma Park, Maryland, December 2001); "Atomic Myths, Radioactive Realities: Why nuclear power is a poor way to meet energy needs," *Journal of Land, Resources, & Environmental Law,* v. 24, no. 1 at 61-72 (2004) (presented at the Eighth Annual Wallace Stegner Center Symposium, entitled "Nuclear West: Legacy and Future" at the University of Utah S.J. Quinney College of Law); *Assessing Nuclear Plant Capital Costs for the Two Proposed NRG Reactors at the South Texas Project Site* prepared in 2008 on behalf of the SEED Coalition); *Science for the Vulnerable: Setting Radiation and Multiple Exposure Environmental Health Standards to Protect Those Most at Risk* (Institute for Energy and Environmental Research, Takoma Park, Maryland, 2006); *Nuclear Wastelands: A Global Guide to Nuclear Weapons Production and Its Health and Environmental Effects* (MIT Press, Cambridge, 1995 and 2000). I have also written or co-authored numerous other reports and articles on the health effects and risks of radiation.

1.5. I am a co-author of a report reviewing the official post-Fukushima safety evaluation reports by Electricité de France and AREVA, published in February 2012, entitled *Sûreté nucléaire en France post-Fukushima :Analyse critique des Évaluations complémentaires de sûreté (ECS) menées sur les installations nucléaires françaises après Fukushima* (Institute for Energy and Environmental Research, Takoma Park, Maryland, and WISE-Paris, Paris) (title in English: *Post-Fukushima Nuclear Safety in France: Analysis of the Complementary Safety Assessments (CSAs) Prepared About French Nuclear Facilities* – a summary in English is available).

1.6 I have been retained as a consultant on energy issues, including energy efficiency, demand projections, renewable energy technologies, and investment planning by electric utilities, research institutions, NGOs, U.S. government agencies, and international agencies. My clients have included the Tennessee Valley Authority, the Edison Electric Institute, Lawrence Berkeley National Laboratory, and several agencies of the United Nations.

1.7 I am generally familiar with materials from the press, the Japanese government, the Tokyo Electric Power Company, the French government safety authorities, and the U.S. Nuclear Regulatory Commission ("NRC") regarding the Fukushima Daiichi ("Fukushima") accident and its potential implications for the safety and environmental protection of U.S. reactors. I have also read *Recommendations for Enhancing Reactor Safety in the 21st Century: The Near-Term Task Force Review of Insights from the Fukushima Dai-chi Accident*, July 12, 2011 (the "Task Force Review"),[1] published by the NRC. After the Fukushima accident began on March 11, 2011, I was one of the first experts in the United States to call attention to the dangers and

[1] NRC 2011 Task Force. A bibliography is attached.

potential consequences of spent fuel accidents. The analysis was written on March 13 and first issued on March 14, 2011.[2]

1.8 I am familiar with the environmental report prepared by Union Electric Co. in support of its application to the U.S. Nuclear Regulatory Commission ("NRC") for renewal of the Callaway reactor operating license. Union Electric is a "a subsidiary of Ameren Corporation and doing business as Ameren Missouri (Ameren) operates Callaway Unit 1 near Fulton in Callaway County, Missouri."[3] These entities are referred to below as Ameren.

1.9 A copy of my curriculum vita is attached.

2. Purpose of My Declaration

2.1 The purpose of my declaration is to explain the basis for my opinion that Ameren did not address renewable alternative energy sources in the Environmental Report for Callaway in a reasonable and technically sound way. In particular, Ameren should have examined wind energy operating in the MISO grid and compared it to nuclear operating in the grid, taking into account the specific patterns of unavailability of each, including unplanned outages. This source of energy is currently available and sufficient to entirely replace the energy to be generated by Callaway during the license renewal term. In addition, I will explain the ways in which the assumptions upon which Ameren relied in rejecting the wind alternative are factually, technically, and conceptually flawed. Ameren has unreasonably examined wind and other renewable alternatives to nuclear license extension as if Ameren were an electrical island separate from the Midwest Independent Transmission System Operator (MISO) grid. All Ameren generating stations, including Callaway, operate as part of the grid. In addition, Ameren's assumption that storage or full standby fossil fuel replacement capacity would be needed for wind to reliably replace Callaway energy is incorrect. Neither is needed today and will not be needed even as renewables expand under the present renewable mandates in the MISO system. Finally, Ameren incorrectly assumes that energy from Callaway will be constantly available during the license term while wind power is "intermittent." In reality, however, all power stations have planned and unplanned outages during which the grid fills in. Callaway and other nuclear reactors have experienced many unplanned outages. A proper apples-to-apples comparison requires that Ameren analyze the patterns of unavailability of nuclear, including the many recent long unplanned outages in Germany, Japan, and the United States as well as its own outages, which have grown more frequent and long in recent years. In that context, it should examine the role of the grid in providing supply during the unplanned outages of nuclear and the variability of wind. Therefore, under any scenario, all electricity generation energy sources must be considered in the context of the grid. In the case of Ameren, this is the MISO service area.

3. Inadequacies of Ameren's consideration of nuclear reactor outages

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[2] Makhijani 2011-03

[3] Ameren Environmental Report 2011, Chapter 1, p. 6.

3.1 Ameren's analysis of nuclear energy and its renewable alternatives is factually, technically, and conceptually flawed and inadequate. Ameren has ignored the unplanned outages of nuclear and the need for nuclear power to be part of a grid so that continuous loads are not interrupted. At the same time, Ameren has examined renewable alternatives to nuclear license extension as if Ameren were an electrical island separate from the MISO grid. Thus, wind power is evaluated with or without storage – all to be built by Ameren itself to replace Callaway. This is a technically incorrect framework in which to evaluate renewable energy as a replacement for nuclear generation from Callaway. The option of renewable energy combined with sales and purchases from the grid can reliably replace Callaway nuclear generation. We will first consider the unplanned outages as they relate to nuclear, notably the many that have occurred in the recent past, and then consider how a technically correct comparison with alternatives to it needs to be done. The underlying point is that both nuclear and renewable sources have times of unplanned unavailability when loads must still be met and therefore whether either can supply continuous loads needs to be considered in the context of the grid. In the case of Ameren, this is the MISO service area.

3.2 In 2012, the Nuclear Regulatory Commission in its decisions rejecting renewable energy sources as alternatives to relicensing of nuclear power plants has made two decisions based on the notion that the alternatives to nuclear should meet the requirement of baseload generation and be demonstrably available in the period prior to nuclear license expiry. For instance, in the Davis-Besse case, the Commission rejected the contention on renewables as follows:

> "All in all, however, we agree with FirstEnergy that the Petitioners have failed to lay a foundation for their claim that wind, solar, and energy storage – in any combination – could satisfy the baseload demand in the region of interest by 2017 [date of current license expiration]."[4]

3.3 No single power plant can meet continuous loads for decades, which is the time period covered by the license extension. Electricity generating devices are periodically closed for maintenance, and in the case of nuclear power plants, also for refueling. In addition, all power plants, including nuclear power plants, have unplanned outages. During planned and unplanned outages, the electric system reliability requirements are met by other generating devices on the same grid or by demand control or some combination of the two. The patterns of availability and unavailability are different for different generating devices. Wind and renewables vary from hour to hour and even within minutes and seconds. Nuclear provides more steady power when it is online but can be out for months or even years as recent events have shown. A statistical analysis is required to make an apples-to-apples comparison of nuclear with renewables. This, of course means that we must have the data on outages especially unplanned outages for nuclear and on what the needs of load balancing are for intermittent renewables at various levels of integration into the grid. Nuclear power has had its share of unplanned outages in decades past, but the problem has become more acute since much has changed in the last few years, especially since the Fukushima Daiichi accident that started on March 11, 2011

[4] NRC CLI-12-08 (Davis-Besse), p. 10

3.4 The July 16, 2007, earthquake at the Kashiwazaki-Kariwa (KK) plant in western Japan, did not damage the essential systems of the seven reactors at the KK nuclear plant, though there was some spillage of radioactive waste. The reactors were all shut nonetheless. The first did not reopen until December 28, 2009. By early 2011 there were four operating reactors at the KK plant. At the Kashiwazaki-Kariwa (KK) nuclear plant, it took more than two years for the first of the seven reactors to be fully re-connected to the grid. Three of the seven units were still shut as of November 2, 2011, more than four years after the earthquake. The dates of first approval for commercial operation after the 2007 earthquake were as follows:

- Unit 7: December 28, 2009[5]
- Unit 6: January 19, 2010[6]
- Unit 1: August 4, 2010[7]
- Unit 5: February 18, 2011[8]]

As of March 26, 2012, all units at Kashiwazaki Kariwa were again shut.[9]

3.5 In September 2009, Crystal River Unit 3 in Florida was shut for refueling and steam generator replacement. In the process a delamination, or gap, was discovered between the inner and outer concrete shells of the containment structure. The problem was created as a result of the hole that was cut into the containment building to install the steam generators inside it. The reactor has had an extended unplanned outage for major repairs since near the end of 2009. Progress Energy expects the reactor to be back on line in 2014 – for an unplanned outage of more than four years.[10]

3.6. The effects of the Fukushima disaster on the reliability of nuclear power and on its ability to supply baseload power have been profound. They have reached far beyond the six reactors at the site. Since March 11, 2011, the reactors in Japan have been progressively shut, as they were closed for maintenance or stress tests. Under normal circumstances, these reactors would have been routinely restarted after planned outages of a few weeks. But after Fukushima, the reactors could not be restarted without local government authorization, which has not been forthcoming. As a result, all but one of the 54 nuclear power reactors in Japan are in a long, indeterminate unplanned outage that no nuclear or utility official foresaw on or before March 10, 2011, so far as the public record indicates. One reactor at the KK plant was operating until March 26, 2012,

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[5] It took several starts and restarts between May and December, but Unit 7 was officially approved for commercial operation on December 28, 2009. (TEPCO 2009-12-28) Units 1 and 7 were shut for regular inspections in August 2011. (TEPCO 2011-08-06 9am and TEPCO 2011-08-23 9am). Japanese rules require periodic shutdowns for inspection every 13 months. As of November 2, 2011, two units at the Kashiwazaki-Kariwa plant were operating; throughout Japan eleven of the 54 commercial reactors were operating. (JAIF 2011). As discussed below in paragraph 3.6 only one of commercial nuclear power reactor was operating as of April 18, 2012.

[6] TEPCO 2010-01-21

[7] TEPCO 2010-08-05

[8] TEPCO 2011-02-24

[9] Reuters 2012

[10] NRC Crystal River 2012

when it was shut down, reportedly for "planned maintenance." But like the other reactors in Japan, there is no restart date. As of 18 April 2012, all but one of Japan's 54 reactors have been shut in what has become an unplanned an unforeseen prolonged outage. The last operating reactor, Tomari Unit 3 of the Hokkaido Electric, is due for a planned maintenance outage on May 5, 2012. Even if some or most of Japan's reactors are restarted at some time in the future, the fact remains that 47 reactors in Japan (that is leaving aside the one now operating and the six at Fukushima Daiichi) have suffered a prolonged unplanned outage that might well become permanent in some, many, or all cases. Both boiling water and pressurized water reactors have been closed.

3.7 Events in other countries have confirmed that nuclear power has a problem of unreliability and long or permanent unforeseen outages on a significant scale. Most notably, in the wake of Fukushima, the German government decided to temporarily close down eight of Germany's 17 nuclear power reactors for safety reasons, not because they were experiencing problems themselves at that point, but because they were among the oldest reactors in the German nuclear power system. On May 30, 2011, the government announced a planned phaseout of all 17 by the end of the 2022. The plants that were already closed at that date were not to be reopened.[11] While Germany had made a decision to phase out nuclear power over the coming decades, the shutdown of these specific reactors was not planned for the year 2011. Hence their closure was an unplanned and, so far as can be determined at present, it will be permanent.

3.8 The Fort Calhoun reactor was shut down for a planned refueling outage in April 2011. But it has yet to restart. It was put into a cold shut down stage on June 17, 2011, in anticipation of a severe flood, which did affect the plant. Allowing for a two-month normal planned refueling outage, the Fort Calhoun reactor has now had an unplanned outage of about ten months; there is as no restart date as of April 18, 2012.[12]

3.9 On August 23, 2011, there was a 5.8 magnitude earthquake with its epicenter near the town of Mineral, Virginia,[13] about ten miles from the North Anna nuclear power plant. Even though there was no damage to the reactor or generating facilities, the plant had to be shut down for inspections, as had been the case with the KK nuclear plant in Japan in 2007. The North Anna Unit 1 was restarted and reached full power on November 18, 2011; Unit 2 reached full power on November 27, 2011. Unit 2 was listed as defueled or refueling from September 19, 2011, to a few days before restarting.[14] However, since Unit 1 was closed for inspection due to the earthquake, it is reasonable to surmise that Unit 2 would also have had an outage until November independent of the refueling outage.

[11] World Nuclear Association 2012. See also BBC 2011 which gives the date of the temporary shutdown as March 15, 2011, and the permanent shutdown as May 30, 2011.
[12] NRC Fort Calhoun 2012
[13] USGS 2011
[14] NRC 2011-08-24, NRC 2011-09-17, NRC 2011-09-18, NRC 2011-09-19, NRC 2011-11-18, NRC 2011-11-23, and NRC 2011-27

3.10 Unit 2 of the San Onofre Nuclear Generator Station was shut for a planned refueling outage on January 9, 2012. On January 31, Unit 3 was shut after a leak was discovered from steam generator tubes. Subsequently unexpected wear was discovered in the tubes in the new steam generators that had been installed very recently (between late 2009 and early 2011).[15] The reactors remain in a prolonged unplanned outage with no restart date. It is unlikely that they will be restarted until the cause(s) of the unexpected wear have been found. Gregory Jaczko, the Chairman of the NRC wrote on March 13, 2012, that the "root cause of the tube leak has not yet been determined."[16]

3.11 When the above facts are put together, we can see that 67 light water reactors,[17] including both pressurized and boiling water reactors have suffered prolonged unplanned outages in recent years, almost all of them in the approximately 13 months since March 11, 2011. They have jeopardized the power supply in the second largest economy in the world, Japan, which has had to resort to extraordinary conservation and emergency generation measures. Should the outage at San Onofre continue through the summer, the same may be necessary in Southern California.

3.12 The extended unplanned outages at 67 reactors – more than 18 percent of the all the commercial light water power reactors in the world[18] have had prolonged unplanned outages in 2011 and 2012 – point up the fact that nuclear reactors cannot *a priori* be regarded as baseload sources that can supply baseload electricity for two or more decades. These facts need to be taken into account in the consideration of alternatives. We might put in another way. In light of the facts of the extended unplanned outages for a variety of reasons, including at reactors that have no identified safety defects (other than generic issues associated with them or with their siting) as well as those that do, the requirement that alternatives should clear a hurdle that nuclear power can no longer clear is unreasonable.

3.13 While Callaway is not part of the list above in terms of prolonged outages since the Fukushima accident, it has had many unplanned outages since it entered service in 1984. For instance, in December 2008, Callaway had two forced outages, one lasting 39.8 hours and the other for 209.8 hours – which is well over one week. It had forced outages of 219 hours in October 1995, of 237 hours in April-May 1988, and 296.3 hours in March-April 1985. Callaway has also had forced outages during the summer. For instance, it had a 17.9 hour outage, which ended on August 17, 1995. The longest outages occurred in the middle of 2006. There were two: one of about 18 days and the other of about 46 days. In all Callaway had 39 forced outages

[15] NRC News 2012 San Onofre
[16] Jaczko 2012
[17] The total of 67 is made up of 53 reactors in Japan, 8 in Germany, 2 in California, 1 in Nebraska, 1 in Florida, and 2 in Virginia. This figure would be 66 if we did not count the refueling time for one of the North Anna units. Sixty five of these reactors are still in outage mode (temporary or permanent) as of April 18, 2012.
[18] There were 361 light water reactors connected to the grid worldwide at the end of 2010. (IAEA 2011, Table 2 (p. 12))

document by David Lochbaum of the Union of Concerned Scientists, of durations ranging from a few hours to about one-and-half months over the course of its operation.[19]

3.14 The data on Callaway outages in the Lochbaum compilation is complete up to the end of 1995 and from November 1, 1999 to June 2010. Despite this gap, the data indicate what David Lochbaum of the Union of Concerned Scientists, has called the "bathtub effect" – that is a higher frequency of forced outages in the initial break-in period, a dramatic drop in a middle operating period and rising forced outages later in licensed life. This analysis is based on the raw data compiled by David Lochbaum. Between October 1984, when it was first connected to the grid and the end of 1990, Callaway had an average of 3.2 forced outages per year. From the start of 1991 to the end of 1995, Callaway had an average of just 0.6 outages per year and from November 1999 to the end of 2004 the average was only one outage (for an average of 0.24 outages per year). The rate rose again from the start of 2005 to June 2010 (when the Lochbaum compilation ends) to an average of 2.2 per year. These outage rates do not include planned refueling outages or short outages during restart after refueling.

3.15 The length of the Callaway forced outages has also roughly followed the bathtub curve. In the first two years, it was about 5.1 days per outage, dropping to 2.4 days per outage in the next four years, to 2.2 days per outage[20] in the middle period from 1991 to 1995. The data compilation is not complete between the start of 1996 and the end of October 1999. The single outage between November 1999 and the end of 2004 lasted about one day. The time per outage rose sharply to about 10 days in the period from the start of 2005 to mid-2010.

3.16 Fulton, Missouri, where Callaway is located, is in Central earthquake zone as defined by the new NRC-EPRI seismic study.[21] Indeed, Fulton, Missouri is close to the New Madrid earthquake zone. In announcing the study the NRC noted that "[t]he new seismic model will be used by nuclear power plants in the central and eastern United States for these re-evaluations, *in addition to being used for licensing of new nuclear facilities.*"[22] The NRC announcement also stated that the results of the study "indicate that estimates of the seismic hazard have increased with respect to some operating nuclear plant sites in the Central and Eastern United States" and that "sample calculations indicate that *the largest predicted ground motions could occur in the vicinity of repeated large magnitude earthquake sources, such as New Madrid, Mo., and Charleston, S.C.*"[23] We recognize that the seismic hazard evaluation will occur separately from the license extension process. The point here is to note that Callaway could have an earthquake about the same order as its design basis. There have been two nuclear power plants since 2007 (KK and North Anna) that have had prolonged unplanned outages due to earthquakes near or slightly exceeding their design bases, even though in both cases there was no major damage to the reactors.

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[19] Lochbaum 2012. Data in this compilation are not complete for the period from the start of 1996 to the end of October 1999.

[20] This average is dominated by a single 219 hour outage in October 1995. Omitting this event gives an average outage time of about 1.2 days.

[21] EPRI-DOE-NRC 2012

[22] NRC News 2012 Seismic Model, italics added.

[23] NRC News 2012 Seismic Model, italics added.

4. Inadequacies in Ameren's Discussion of Wind Alternative

4.1 Ameren has assumed that zero capacity credit should be allocated to renewables:

> Ameren has considered evaluating wind or solar power in combination with fossil fueled generation as alternatives. However, because of the intermittent nature of wind and solar power in the region, such combinations would require building fossil fueled plants with the full 1200 MWe capacity to replace Callaway Unit 1 when the solar or wind power is unavailable, as well as the solar and wind powered replacement units. *As a result, this option would incur the full construction impacts associated with building a 1200 MWe baseload coal or gas-fired plant, as well as the full construction impacts associated with building 1200 MWe of solar or wind powered units*.[24]

4.2 We recognize of course that wind is intermittent; yet it is not entirely unpredictable. Day-ahead and hour-ahead forecasts can be and are being made. The vast amount of wind capacity installed in the United States, more than 40,000 megawatts is operated on the basis of such forecasts. More refined techniques of installing measuring devices at the turbines themselves can be used to improve forecasts. While the variability of wind energy is not reduced in this way, the ability to forecast it and hence dispatchability of wind energy is increased.

4.3 Making an assessment of the capacity value of wind energy is largely a statistical matter, just as it is with nuclear or coal or gas,[25] Though the specific statistical considerations are different. As noted in paragraphs 3.13 to 3.15 above, Callaway has had many unplanned outages since it entered service in 1984 lasting from hours to one-and-a-half months. Moreover, the average length of the outages since 2005 is almost five times greater than in the 1991-2004 period. And as discussed in Section 3 above, worldwide 67 light water commercial nuclear power reactors – over 18 percent of the world's total – have suffered long unplanned outages during 2011 and 2012. This total includes six reactors in the United States, four of which remain shut. Wind does not have this technology-wide vulnerability. Instead it is the factor of wind variability that must be taken into account as noted in the prior paragraph. Therefore, for any energy source, it is a matter of assessing the probability of unforeseen unavailability of installed generating capacity and of taking into account the specific characteristics of unavailability of each source. Overall, the availability values and patterns are different but the principles are not when one tries to assess the capacity value of any type of generation. In some cases, utilities may rely on their own generation resources to make up the lost capacity, in others they may resort to purchased power. They may also use a combination of their own generation and purchased power. The specific choices would depend on the circumstances of the outage and the location of the various resources in the grid. But in all these cases, utilities rely on the grid during their times of unavailability to maintain electricity service to consumers.

[24] Ameren Environmental Report 2011, Chapter 7, p. 6
[25] NREL 2005 and Milligan and Parsons 1997 for instance.

4.4 There is a considerable literature on the capacity value of wind energy.[26] The PJM regional interconnection has, for instance, allocated a 20 percent capacity value to new wind projects to be replaced as data are gathered in succeeding years for the average value between 3 p.m. and 7 p.m. of wind capacity factor during the summer period (June 1 to August 31).[27]

4.5 Within MISO, where Ameren is located, the grid operator has developed a sophisticated method of allocating a capacity value to wind. A recent MISO report shows a figure that estimates the capacity value of wind as the degree of wind penetration in the MISO grid changes.[28] This figure illustrates that (i) the capacity value of wind in the MISO system in 2012 was just under 15 percent. It also shows that wind capacity value will tend to decline as penetration increases. As noted above, in 2011 wind capacity is just under 10 percent of the MISO total. If wind penetration were 30 percent of the total, MISO estimates that the capacity value of wind would be about 10 percent. However, since the total amount of installed capacity would be 30 gigawatts, the total wind capacity value in the MISO system would be about 3 gigawatts, which is two-and-half times the nameplate net capacity of Callaway.

4.6 Further, as discussed in Section 3, nuclear can no longer be considered to have a capacity value at or close to its nameplate value since the industry in the West is plagued with unplanned outages for a variety of reasons. The Fort Calhoun reactor in the neighboring state of Nebraska provides a graphic example that the problem of prolonged unplanned outages that need to be taken into account when comparing the capacity value of wind (and renewables in general) and nuclear. Moreover, since Callaway operates within the MISO system, the capacity credit for wind determined by MISO is the most important figure of merit, much less the zero capacity value assigned to wind by Ameren in its Environmental Report. Interestingly Ameren is aware that MISO grants capacity credit for wind and cites a figure of 8 percent in its Integrated Resource Plan for 2011.[29]

4.7 In sum, the assignment of zero capacity value to wind and solar energy by Ameren is technically incorrect and even contradicts some of its own literature. The Effective Load Carrying Capacity (ELCC) of wind needs to be evaluated in the context of considering renewable alternative. This ELCC of wind should be compared to the ELCC of nuclear that takes appropriate account of the extended unplanned outages that currently afflict the nuclear power industry and notably light water reactors.

4.8 Wind energy is commercial today. It is a large scale industry in the United States and the world. Table 1 shows the growth of wind capacity in the MISO system since 2007. As can be seen almost 8,000 MW were added during the 2007-2011 period (inclusive). Nationally, the installed capacity of wind energy was nearly 47,000 MW at the end of 2011.[30]

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[26] As the penetration of solar increases, the same methods can be applied to solar and to combinations of wind and solar.
[27] NREL 2005, p. 15
[28] MISO 2012, Figure 3.2 (p. 20)
[29] Ameren IRP 2011, Chapter 5, p. 33
[30] AWEA 2012

Table 1: Wind capacity in the MISO region, in MW

MISO Wind Capacity	Additions	Cumulative
2007	1350	2462
2008	2399	4861
2009	2764	7625
2010	976	8601
2011	1,768	10,369

(Source: MISO 2012 Growth)

4.9 There are ample renewable energy resources, including very high quality wind energy resources, available in Missouri and the rest of the Midwest Independent System Operation region. Table 2 shows the wind potential at the best sites (with more than 40 percent capacity factor) in some of the states that are partly or fully in the MISO region.

Table 2: Wind energy potential of some states fully or mainly in MISO only for sites with capacity factor greater than 40 percent, at 100 meters

State	Installed Capacity[3] (MW)	Annual Generation (GWh)
Illinois	78,691	286,858
Indiana	29,754	109,526
Iowa	466,297	1,890,360
Minnesota	369,909	1,457,950
Missouri	58,815	215,946
North Dakota	756,497	3,180,710
South Dakota	833,893	3,508,870
Total	2,593,857	10,650,220

(Source: NREL and AWS Truepower 2011)

4.10 Compared to generation in hundreds of thousands or millions of gigawatt-hours, Callaway generates less than 10,000 gigawatt hours.[31] Ameren could easily build or contract for replacement capacity in the MISO region that has high geographic diversity and high capacity factor. In fact, it is normal for utilities to not build wind generation themselves but to sign purchased power agreements with third parties for the production of a certain amount of capacity. In fact, Ameren has recently contracted to purchase 102 MW of wind from an Iowa wind farm over 15 years in this way.[32] About 2,300 MW of wind of the average (high quality)

[31] In its IRP, Ameren has recognized that the available wind resources are greatly in excess of its electricity requirements. (Ameren IRP 2011, Chapter 5, p. 35)

[32] Ameren Corp. Form 10-K 2012, p. 13

resources shown in Table 2 would entirely replace Callaway generation.[33] This less than 0.1 percent the available high quality (over 40 percent capacity factor) wind power in the states listed above in Table 2. A larger capacity, about 2,900 MW, would be needed if the capacity factor were a more typical 37.5 percent.

4.11 Since the wind generation that would replace Callaway would be in the MISO region, it would be injected into that grid. Ameren does not need to install storage capacity if it replaces Callaway nuclear generation with wind, since both sources would operate reliably for the foreseeable future under presently set renewable targets. Large scale storage is not required until wind has exceeded 20 percent of the generation in the grid.[34] We discuss this issue in more detail in the paragraphs below.

4.12 Missouri has a renewable energy standard for its investor-owned utilities of 15 percent by the year 2021. There are examples of electricity systems operating reliably at levels of wind penetration higher than that. For instance, Denmark supplies about 18 percent of its electricity requirements using wind without major storage facilities. In 2009 it imported and exported amounts equal to about 30 percent its total electricity consumption.[35] And Denmark has no large-scale storage facilities.[36]

4.13 In 2007, in *Carbon-Free Nuclear Free,* I wrote that wind storage currently was not necessary because reserve capacity could be supplied in other ways. In particular, large amounts of wind energy could be integrated into the grid reliably given that natural gas capacity was available. That circumstance prevails today generally in the United States and in the specific instance of Ameren Missouri, which is a part of the MISO transmission grid system – see 4.17 and 4.18 below. Ameren exchanges power within this system today and plans to continue to do so. This has been reaffirmed with a specific analysis the National Renewable Energy Laboratory that concluded that storage is not needed until wind generation of was 20 percent of the total supply in a grid:

> The increasing role of variable renewable sources (such as wind and solar) in the grid has prompted concerns about grid reliability and raised the question of how much these resources can contribute before enabling technologies such as energy storage are *needed*. Fundamentally, this question is overly simplistic. In reality, the question is an economic issue: It involves the integration costs of variable generation and the amount of various storage or other enabling technologies that are economically viable in a future with high penetrations of VG [Variable Generation]. **To date, integration studies of wind to about 20% on an energy basis have found that the grid can accommodate a substantial increase in VG**

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[33] We assume a 90% average capacity factor for Callaway. The average capacity factor of the resources in Table 2 is 46.9%.
[34] Further, as discussed below, there is pumped hydro storage in the MISO system today.
[35] IEA 2009
[36] Westenhaus 2010

without the need for energy storage, but it will require changes in operational practices, such as sharing of generation resources and loads over larger areas**.**[37]

4.14 Ameren has misrepresented the issue of storage as being linked to solar and wind alone. In fact, when storage is introduced into an electricity system, it is into a grid and it would be used (as pumped hydro facilities are today) to balance the entire system and not just solar and/or wind. This has been pointed out by the National Renewable Energy Laboratory:

> Energy storage will best be used as a resource for the overall power system. It is not cost effective or efficient to couple energy storage resources exclusively to individual wind plants. *It is the net system load that needs to be balanced, not an individual load or generation source in isolation.* Attempting to balance an individual load or generation source is a suboptimal solution to the power system balancing needs. Hydropower and energy storage capacity are valuable resources that should be used to balance the system, not just the wind capacity. During this present stage of wind power integration and growth, wind simply adds to the existing opportunities for energy storage.
>
> **Is Energy Storage Needed?**
>
> *At present levels of wind penetration on the electrical grid, storage has not been a priority consideration*. But eventually, as a system resource and not exclusively due to wind or other renewable resource capacity additions, the nation's electrical grid will benefit from energy storage technologies. Essentially, the power system already has storage in the form of hydroelectric reservoirs, gas pipelines, gas storage facilities, and coal piles that can provide energy when needed. [38]

4.15 Missouri's renewable portfolio standard only requires 15 percent renewable energy by 2021. [39] Other states in MISO generally have more or less stringent requirements ranging from very low (Iowa -- 105 MW, a total that has already been accomplished) to 10 percent by 2015 for North Dakota, and Michigan, to 25 percent by 2025 for Minnesota.. Moreover, not all the load in these states is covered by renewable energy requirements. For instance, the fraction of the load covered is less than half in Illinois, about half in Minnesota, 70 percent in Missouri, and 100 percent in Michigan.[40] Based on present RPS requirements, overall intermittent renewable integration into the MISO grid would remain well below 20 percent for a decade or more, which means that new storage would not be needed until at least that time frame. Moreover, as we will see below, that large scale storage is available in the MISO service area and that Ameren has greatly exaggerated the difficulties of siting underground compressed air storage facilities. Thus,

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[37] Denholm et al. 2010, p. 46, italics in the original, bold added.
[38] NREL 2011, bold in the original, italics added.
[39] Ameren Corp. Form 10-K 2012, p. 13 for Ameren. The requirement applies to investor-owned utilities, like Ameren. (See DSIRE 2012 Missouri)
[40] DSIRE 2012 RPS Data. DSIRE (Database of State Incentives for Renewable Energy maintains and updates a list of renewable portfolio standards requirements around the United States. See also its state-by-state descriptions at DSIRE 2012 States.

dismissal of wind on the basis of CAES siting difficulties is incorrect in the context of the parameters set by the Commission that Callaway relicensing and its alternatives should be considered in the context of commercial availability before the license expiry date (at the latest).

4.16 Wind variability will demand different transactions with the grid than nuclear unavailability. Specifically, in general, nuclear is either completely available or not available at all. Wind varies from hour to hour and day to day. Since wind would replace the entire Callaway generation on an annual basis, the required capacity would be about 2,300 MW (or more if the average quality of resources were lower than that shown in Table 2). Hence, some of the time, wind generation would be at a rate much greater than the 1,190 MW capacity of Callaway; at other times it would be much less. During times of short fall, typically fast responding resources, notably natural gas and hydro would provide the necessary response.[41]

4.17 Table 3 shows that the natural gas capacity in five Midwestern states, three states of which wholly or mainly in the MISO region. Missouri is largely outside that region, though the Ameren service area is in it. The weighted average capacity factor for natural gas generation in these five states in 2010 was just 8.1 percent. An increase in average capacity utilization of just over 3 percent to 11.4 percent in these five states would generate enough electricity to replace Callaway generation. There is clearly more than enough excess generating capacity in the MISO system to allow for the needed transactions to be made to keep power supply reliable if wind generation fully replaces Callaway generation on an annual basis.

Table 3: Natural gas fired electricity generation capacity utilization in five Midwestern states in 2010

	Illinois	Indiana	Iowa	Minnesota	Wisconsin
Natural Gas Capacity (MW)	13,771	5,766	2,299	4,936	6,110
Natural Gas Generation (MWh)	5,723,733	6,474,986	1,312,195	4,340,847	5,496,814
Capacity Factor	5%	13%	7%	10%	10%

Source: EIA State Profiles 2010, Tables 4 and 5 for each state shown.

4.18 We recognize, of course, that some natural gas resources are used only for short periods, notably to maintain supply and an adequate margin of reserve capacity (called "capacity margin" or "reserve margin"). This reserve margin is generally in the 12 to 15 percent range for any particular utility though it may be higher in a region with a high proportion of renewables. The MISO requirement for the capacity margin for the entire region was 17.4 percent but the actual capacity margin in 2010 was 23.3 percent.[42] The Electric Power Annual projects this to remain at or above 17.4 percent until 2015 inclusive.[43] Hence, there is also a surplus of capacity in the MISO service area even at the time of peak load. This is before any capacity credit is taken for

[41] Demand response and efficiency could also provide part of the response, but they have not been analyzed here and are not necessary components of the alternative considered here.
[42] MISO 2011, Table 1-1 (p. 2)
[43] Electric Power Annual 2010, Table 4.3.B

2,300 MW or more of wind capacity or account is taken of the hydropower capacity and pumped hydro storage capacity already available in the MISO service area.

4.19 Wind energy has essentially no air pollutant emissions and requires no water for its operation. Since wind energy would be entirely replacing the annual generation of Callaway, the air pollution impacts of the change would be expected to be small to nil, though we note that the routine releases of radioactive tritium to the air from Callaway would be eliminated.[44] Since wind generation requires no cooling water, essentially all of the water pollution impacts of Callaway as well as the consumption of millions of gallons of water per day, would also be eliminated. Finally, wind energy is also less dangerous than nuclear power reactors: replacing Callaway generation with wind would eliminate the risk of catastrophic accidents such as Fukushima.

4.20 The facts above show that Callaway can be replaced with wind energy with technology that is commercially available now. Replacement wind power is available in ample supply and on a commercial basis. Ameren can build wind farms itself. It also has the option of signing a long-term purchased power agreement for a third party to supply it with wind energy. In fact, Ameren itself purchased 102 MW of wind in 2009 for a period of 15 years from a wind farm located in Iowa. There is no hurdle to increasing that amount to the capacity needed to replace Callaway generation. When this wind is injected into the grid, it can serve the customers of Ameren in Missouri with the same reliability as it serves its customers today for the foreseeable future. Ameren has not argued that its wind capacity today compromises reliability. There is no technical basis to argue that replacing Callaway with wind would be qualitatively different since the total planned renewable capacity in the MISO system in the coming years will not require storage facilities to maintain reliability. Further, nuclear power also relies on the grid during unplanned and planned outages to keep power supply reliable for its customers. Ameren gives no analysis of the Effective Load Carrying Capacity (ELCC) of nuclear in the context of unplanned outages. It also implicitly assumes that supply will be available from the grid to fill in the power supply needs during such outages. At the same time, Ameren assigns no capacity credit to wind, assumes that 100 percent standby fossil fuel capacity will be needed, or that storage will have to be built to compensate for the variability of wind.[45] These problems have created an apples-to-oranges comparison that is technically unsound. In sum, Ameren needs to compare wind plus grid with nuclear plus grid. This is especially important, given the recent history of large numbers of extended unplanned outages of commercial light water reactors. It is not at all a given that Callaway would supply electricity to the grid over a long period with a reliability comparable to wind combined with power exchange with the MISO grid.

5. Ameren's Incorrect and Inadequate Analysis of Wind Storage

[44] Callaway, like other light water reactors, emits tritium in the form of water vapor to the atmosphere. In 2004, for instance, it emitted 38 curies. (IEER 2009)

[45] "However, a 600-MW [pumped hydro] facility would provide roughly half of the storage capacity needed for a facility the size of Callaway Unit 1. Additional storage capacity would need to be developed and other suitable sites, if they exist." Ameren Environmental Report 2011, Chapter 7, p. 17.

5.1 Ameren has inadequately analyzed the issue of storage in general and of compressed air energy storage (CAES) in particular; it has also made an erroneous claim about CAES. I will address the erroneous claim first.

5.2 Ameren claims that the environmental impact of CAES will be similar to natural gas power plants:

> Also, CAES systems generate electrical power by supplying heated compressed air to combustion turbines. So their air quality impacts would be similar to the impacts of a gas-fired power plant. Ameren has determined that due to technical and environmental issues, and the limited availability of suitable sites, use of energy storage mechanisms to provide baseload wind generation is not a reasonable alternative for a facility the size of Callaway Unit 1.[46]

5.3 Ameren's statement quoted in the prior paragraph is incorrect. The air quality impacts from CAES per kilowatt-hour delivered are far lower than a natural gas plant. The amount of natural gas needed to operate a wind plus CAES system in baseload mode is only about 1,000 Btu per kilowatt hour of the total electricity output[47] compared to six or seven times that much for a combined cycle plant and ten times or more that amount for a single stage natural gas turbine. This is because most of the wind energy is supplied directly to the load and requires no storage and hence no natural gas for heating compressed air. Only the part that is stored as compressed air needs some natural gas. The overall result is that natural gas consumption per unit of electricity supplied is quite low. This means that the environmental impact of wind plus CAES in a baseload mode would be just one-sixth to one-seventh of a combined cycle power plant and even less when compared to a single stage gas turbine plant. Ameren should completely reevaluate its assessment of the environmental impacts of CAES with wind.

5.4 Ameren claims that there are difficulties in siting CAES storage facilities. However, Ameren failed to discuss the fact that there are large numbers of underground compressed natural gas storage facilities in the United States that are essential to the reliable distribution of that fuel to consumers. Among other types of storage, natural gas can be and is stored in aquifers where the compressed gas above a certain pressure forms a large bubble. Trillions of cubic feet of natural gas are stored in underground facilities around the United States, including in aquifers. Aquifer storage is particularly common in the Midwest.[48] Figure 1 shows the locations of compressed natural gas facilities in the United States as of 2004. Compressed air can be stored in aquifers in the same way as natural gas.[49] (These facilities are in addition to the large-scale compressed air storage facilities that have been operating in Germany and the United States for decades in a peak-shaving context, which Ameren did discuss.[50]) Given that many compressed

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[46] Ameren Environmental Report 2011, Chapter 7, p. 17
[47] NREL 2006 Figure 5
[48] EIA 2004
[49] The storage pressures may, of course, be different.
[50] Ameren Environmental Report 2011, Chapter 7, p. 17. Ameren states that the German and U.S. CAES facilities "are peak shaving facilities that do not provide baseload power." However,

natural gas storage facilities exist, including dozens in the MISO region, and that two large-scale CAES facilities have operated for decades providing peak-shaving services, it is incorrect to say, as Ameren has done, that CAES is an "immature" technology.[51] Ameren has greatly exaggerated the difficulties of siting underground storage facilities. Ameren's conclusion that there is a "limited availability of suitable sites" is not well-founded, given that there are dozens of compressed natural gas storage sites in the MISO region, including many aquifer storage sites. At a minimum, a realistic evaluation of CAES requires an evaluation of underground compressed natural gas storage siting, including aquifers, and the implications of that evaluation for CAES siting in the MISO service area.

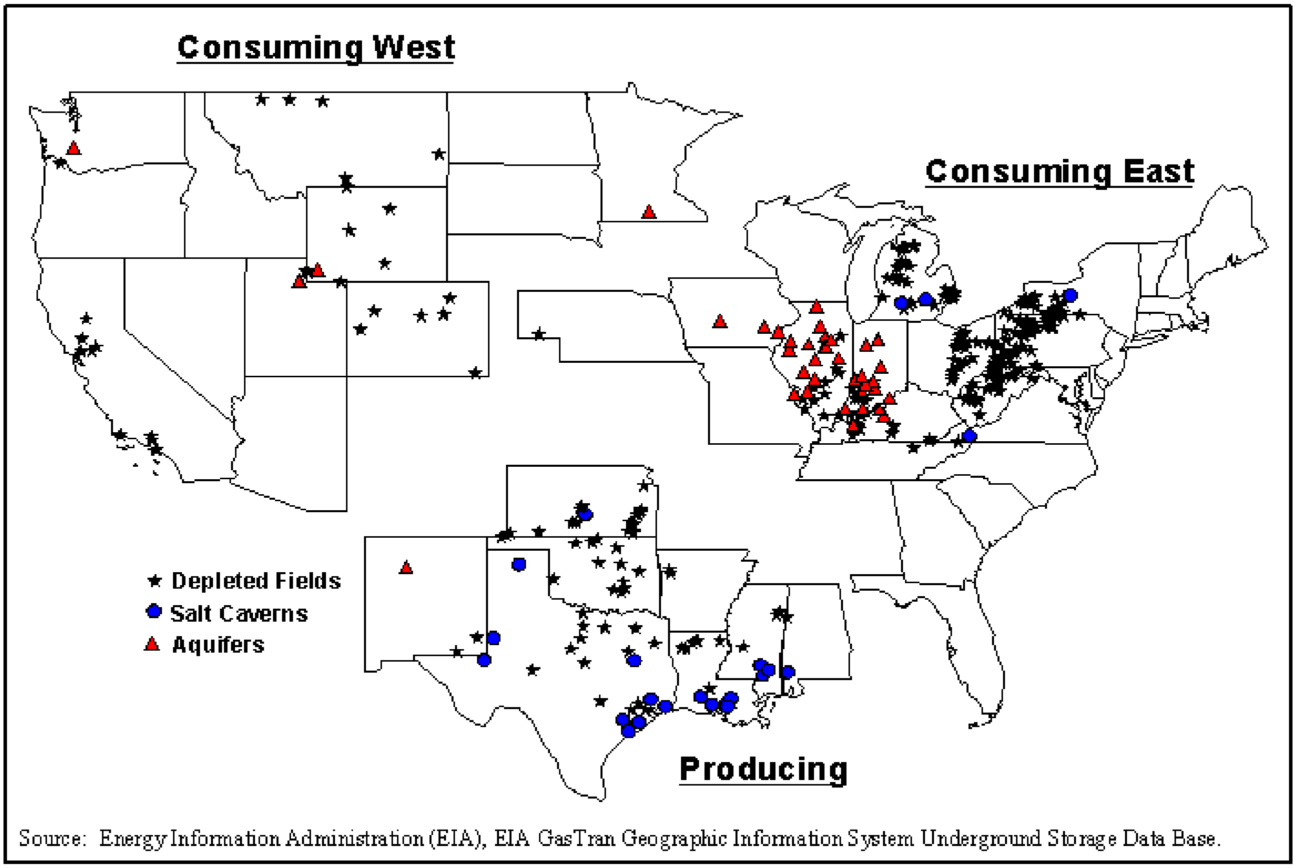

Figure 1: Underground Natural Gas Storage Facilities in the Lower 48 States (Source EIA 2004)

5.5 Ameren also does not provide some relevant facts about or an adequate analysis of pumped hydro storage. For instance, the Environmental Report does not discuss the fact the

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it is never the function of CAES facilities or any other storage facilities to provide baseload power. This criticism of CAES by Ameren indicates a basic misunderstanding of the role of storage, which, as noted in paragraphs 4.29 and 4.30 operates in the context of the entire grid to provide balancing services. Peak-shaving is one type of service that CAES can provide. It can also provide balancing services in the context of high penetration of wind and solar in a grid service area, just as gas turbines, hydropower, and combined cycle plants would do it at low and medium levels of penetration.

[51] Ameren Environmental Report 2011, Chapter 7, p. 17

2,500 MW of pumped hydro capacity is already registered in the MISO region.[52] It has also ignored the fact that the Federal Energy Regulatory Commission has given preliminary approval to 3,200 MW of pumped storage within the MISO service area.[53] Together, the existing facilities and facilities with preliminary permits amount to 5,700 MW in the MISO service region. Ameren both ignored these realities and stressed the difficulties and impacts of siting new pumped hydro facilities on its own as if Callaway operated outside of the grid.[54] These factual and analytical omissions provide further evidence that Ameren's analysis of storage is incomplete and inadequate and did not take account of available relevant facts.

6. Conclusions

6.1 As summarized above in Section 2, Ameren did not address renewable alternative energy sources in the Environmental Report for Callaway in a reasonable and technically sound way. In particular, Ameren should have examined wind energy operating in the MISO grid and compared it to nuclear operating in the grid, taking into account the specific patterns of unavailability of each, including unplanned outages. This source of energy is currently available and sufficient to entirely replace the energy to be generated by Callaway during the license renewal term. In addition, the assumptions upon which Ameren relied in rejecting the wind alternative are factually, technically, and conceptually flawed. Ameren has unreasonably examined wind and other renewable alternatives to nuclear license extension as if Ameren were an electrical island separate from the Midwest Independent Transmission System Operator (MISO) grid. All Ameren generating stations, including Callaway, operate as part of the grid. In addition, Ameren's assumption that storage or full standby fossil fuel replacement capacity would be needed for wind to reliably replace Callaway energy is incorrect. Neither is needed today and will not be needed even as renewables expand under the present renewable mandates in the MISO system. Finally, Ameren incorrectly assumes that energy from Callaway will be constantly available during the license term while wind power is "intermittent." In reality, however, all power stations have planned and unplanned outages during which the grid fills in. Callaway and other nuclear reactors have experienced many unplanned outages. A proper apples-to-apples comparison requires that Ameren analyze the patterns of unavailability of nuclear, including the many recent long unplanned outages in Germany, Japan, and the United States as well as its own outages, which have grown more frequent and long in recent years. In that context, it should examine the role of the grid in providing supply during the unplanned outages of nuclear and the variability of wind. Therefore, under any scenario, all electricity generation energy sources must be considered in the context of the grid. In the case of Ameren, this is the MISO service area.

I affirm that the above facts are true and correct to the best of my knowledge and that analysis in this declaration represents my best professional judgment.

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[52] MISO Energy Storage 2011, p. vi. There are more than 16,000 MW of pumped hydro storage installed in the United States. (FERC 2012)

[53] FERC Preliminary Permits 2012

[54] Ameren Environmental Report 2011, Chapter 7, p. 17.

Arjun Makhijani

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