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To the Colorado Public Utilities Commission

Public comment of Arjun Makhijani on Case 24A-0442E, Just Transition Solicitation

2025-07-22

I have been doing technical and policy work on energy issues since 1970. I have a Ph.D. from the Department of Electrical Engineering and Computer Sciences, University of California, Berkeley. I have been a consultant on energy issues to utilities, including the Tennessee Valley Authority, the Lawrence Berkeley National Laboratory, the Edison Electric Institute, and several agencies of the United Nations.[1]

The orientation of my comments is similar to the testimony provided by David Schlissel in this case. Communities that have hosted fossil fuel plants should get a just transition and "deserve the support of PSCo's ratepayers and Colorado's taxpayers." [2] But this should not mean imprudent, unwarranted, or highly speculative expenditures that would burden ratepayers and/or create serious risks or compromise decarbonization goals. That characterization applies, in my view, to the expenditures requested relating to exploring a new nuclear plant to replace a coal-fired power plant in Pueblo. I recommend the Colorado Public Utilities Commission deny that request. Given the facts, it would be imprudent to grant it.

1. Nuclear power plant planning and construction performance, Round 1: 1950s to 1990s

In the first round of nuclear power, from the 1950s to the 1990s, about 120 reactors were commissioned and 83 that had commenced licensing activities with the NRC were cancelled. An additional one-and-a-half dozen or so were scrapped before any formal proceedings were begun. The overall success rate of commissioned to announced reactors was about 55 percent; if one takes into account only the 203 that began licensing proceedings, it was 59 percent.[3] All reactors planned or ordered after 1973 were cancelled. Costs spiraled.

[1] My CV is at https://ieer.org/wp/wp-content/uploads/2025/03/Arjun-Makhijani-Curriculum-Vita-updated-2025-03-31-1.pdf
[2] David Schlissel, Hearing Exhibit 1701, Case 24A-0442E, April 25, 2025.
[3] Licensing data are from Appendix A and B, NC Information Digest 2024-2025.

The combination of spiraling costs and cancellations, which included one of the largest bond defaults in US history, caused consternation even on Wall Street, as bluntly expressed in the February 11, 1985 issue of Forbes magazine:

> The failure of the U.S. nuclear power program ranks as *the largest managerial disaster in business history*, a disaster on a monumental scale. The utility industry has already invested $125 billion in nuclear power … only the blind, or the biased, can now think that most of the money has been well spent.[4]

2. Nuclear power plant planning and construction performance, Round 2: 2005 to 2024

Over-regulation and overly complex licensing were thought to be the reasons for the financial disasters of the first round. A simplified, one-step procedure was devised – a combined construction and operating license (COL). Standardized reactor designs would be certified in advance.

There was a proclamation of a "nuclear renaissance" in about 2001, but not much action. The term was operationalized with the passage of the Energy Policy Act of 2005, which included (among other things) provisions for loan guarantees and money to offset possible nuclear plant cost overruns. For the purpose of this analysis, I date its end in 2024, when Vogtle 4 came on line.

Wall Street refused to finance the nuclear renaissance, keeping the earlier "managerial disaster" in mind. The government offered loan guarantees. More importantly, for the four reactors for which construction began, ratepayers had to pay for them as part of their electricity bill, in advance and by law. They were given no guarantee that the reactors would be completed at reasonable cost, or even completed at all. This requirement to pay, known as Construction Work in Progress, was worse than a tax, for ratepayers risk getting nothing but financial pain and higher rates in return. In the case of Vogtle, where they were completed, they got higher rates.

Plans for 31 reactors were announced. As before, some did not make it to the license application stage. Of the 23 that started permitting processes, 21 were COL applications for reactors and 2 were early site permit applications. Four began construction. Two in South Carolina (Sumer Units 2 and 3) were cancelled after $9 billion in expenditures. The other two, Vogtle 3 and 4, were completed at a cost of about $36 billion compared to the starting estimate of $14 billion. They were about eight years late. Ratepayers paid and continue to pay dearly for that.

The completion success rate in the second round was just under 9 percent (2 out of 23) counting those that started the licensing/permitting processes. It was just 6 percent of the 31 that at were announced. This was a large deterioration of performance from the first round that was pronounced "the largest managerial disaster in business history."

[4] "Nuclear Follies," Forbes, 11 February 1985, italics added, quoted on the NCWARN website, https://www.ncwarn.org/2007/07/nuclear-power-worst-managerial-disaster/ This was a cover story. A photo of the cover can be seen at https://nukewatchinfo.org/wp-content/uploads/2019/10/FORBES-Cover-2-11-85.jpg

The total cost of the four completed or cancelled reactors was $45 billion. Several billion dollars more were likely spent on the others that remained paper projects. The total cost to society of the nuclear renaissance" was roughly $50 billion[5] for about 2,200 MW of capacity.

The decarbonization record between 2005 and when Vogtle 4 was commissioned in 2024 was dismal. New nuclear generated about 40 terawatt-hours; new solar and wind generated 120 times as much: 4,960 TWh.

3. Small Modular Reactors[6]

The move toward small modular reactors (SMRs) started at about the same time as the proclamation of a "nuclear renaissance." In 2001, Congress funded the Department of Energy study SMRs. The NuScale pressurized water reactor, at first sized at 45 MWe, seemed a promising one. The NRC opined in 2008 that the reactor would be certified by 2015. In fact, a certification application was only filed in 2016. NuScale received "Standard Design Approval" – a staff-level review approval – for the 77 MWe reactor it now wants to build in May 2025;[7] it has not yet received full design certification for this reactor.

A planned NuScale project was initially sized at 600 MW, with twelve 50 MW reactors. It was reduced to 462 MW, with six 77 MW reactors when there were not enough takers for the power. The project was cancelled after hundreds of millions of dollars of expenses. Costs had skyrocketed to $9.3 billion, about $20,000/kW. The project was still on paper when it was cancelled.

The skyrocketing cost of large reactors and the serious delays in commissioning led to greater emphasis on the SMR idea. Each reactor would be much smaller, making it less costly. But reactors are large for a reason – economies of scale. All other things being equal SMRs would cost more per kilowatt, making for even more expensive electricity. The core ideas that are supposed to make SMRs are work economically are that

[5] This includes roughly $5 billion for the non-starters. About $800 million was spent on a pair of reactors that came to nothing. It was a two-reactor project at the South Texas Project site , where two reactors had already been built and commissioned in Round 1. I have some personal knowledge of this project. I was involved in advising NGOs in San Antonio, Texas about cost and related issues. The city's municipal utility, CPS Energy, planned to own one of the reactors; the other would be owned by NRG. The initial official announced cost estimate for both reactors was $6 billion to 7 billion. I estimated the project cost at $12.1 billion to $17.5 billion. (See Arjun Makhijani, Assessing Nuclear Plant Capital Costs for the Two Proposed NRG Reactors at the South Texas Project Site, IEER, 2008, https://ieer.org/resource/economic-issues/assessing-nuclear-plant-capital/ . The official announced costs rose over time: to $9 billion, then $13 billion and then to over $18 billion. It all led to a lawsuit that was the effective end of the project. The COL process was terminated in 2018. CPS Energy wrote of $391.4 million dollars for this project. See David Hendricks, San Antonio Express-News, 26 February 2016, https://www.expressnews.com/business/local/article/CPS-Energy-writes-off-391-4-million-from-South-6852804.php . Assuming that NRG wrote off a similar amount, the cost of this failed two-reactor project, in round numbers, was about $800 million.

[6] Unless otherwise noted, this section is based on Arjun Makhijani and M.V. Ramana, Can small modular reactors help mitigate climate change?, Bulletin of the Atomic Scientists, 21 July 2021.

[7] NRC, Standard Design Approval for the NuScale Power Company, LLC US460 Power Plant Design, 29 May 2025, https://www.nrc.gov/docs/ML2512/ML25129A004.pdf

- mass manufacturing, with accompanying factory-based supply chains of standardized components, would enable assembly-line construction and relatively quick setup at the reactor site, overcoming the loss of economies of scale, and
- simplified design would reduce costs.

While these concepts seem attractive on paper, the practical problems are formidable, possibly insuperable. Consider, for example, the forbidding scale of the assembly-line and supply chains. Even if the cost of the 77 MW NuScale reactor could be brought down by almost a factor of three from the estimated $20,000/kW to $7,000/kW, each reactor would still cost well over $500 million. That is much more than the cost of the most expensive model of a Boeing Dreamliner.[8]

Large passenger aircraft have assembly-line type manufacture with complex supply chains. The rate of manufacture is several per month.[9] The assembly-lines and supply chains for SMRs such as NuScale would likely have to be comparable to have a hope of overcoming the loss of economies of scale. This was noted in rather graphic terms by the person in charge of a TVA SMR project, Dan Stout, in 2013:

> I don't want to pay for B&W's factory with automation to crank out repeatable parts. So that creates a contracting challenge… So as you scratch your head and puzzle how does this work, remember the math won't work on one unit. In fact our unit is most likely going to be, I'm going to use the word "cobbled together", it's going to be manufactured within existing facilities. But if B&W can get an order backlog of a hundred SMRs and they are going to start delivering them in China and India and, etc., then they'll be able to go get financing and build the building and have new stuff put in place to crank out these parts in a more automated manner.[10]

This assessment recognizes the scale of the supply chain required. Note that there are only two vendors of large commercial aircraft in the world. A comparable supply chain for SMRs is unlikely to materialize in the United States for many years. The plethora of designs being pursued will prolong the process and make it more difficult and complex. No SMR has been built in the United States, not even one that was "cobbled together." Even if a few SMRs are built in the next 10 to 15 years, it will be a period of industry sorting itself out. Costs in this period are likely to be very high. If history is any guide, most projects that have now been announced will likely be cancelled.

The there is the problem of recalls. Mass manufacturing makes the objects cheaper; it also makes them vulnerable to recalls because they tend to have common problems. This impacts even mature industries. Boeing Dreamliners and Boeing 737-Max planes have been recalled for serious safety issues, for instance. What will happen if serious safety issues point to the need to recall SMRs? How will that be done? How do you recall a radioactive reactor? What will happen to the electricity grid if there are hundreds of identical reactors? What will happen to the communities who depend on the jobs and the tax revenue, as recommended by the Pueblo Energy Solutions Advisory Committee?

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[8] Planenerd, https://planenerd.com/how-much-does-boeing-787-cost/ viewed on 18 July 2025.
[9] Kaspar Oestergaard, Airbus and Boeing Report May 2024 Commercial Aircraft Orders and Deliveries, June 21, 2024, https://flightplan.forecastinternational.com/2024/06/21/airbus-and-boeing-report-may-2024-commercial-aircraft-orders-and-deliveries/
[10] As quoted in Arjun Makhijani, Light Water Designs of Small Modular Reactors, IEER, 2013, p. 5. https://ieer.org/wp/wp-content/uploads/2013/08/SmallModularReactors.RevisedSept2013.pdf

This is not theoretical or only an analogy from the aircraft industry, though such considerations should have provoked serious analysis decades ago. But the issue is not even on the table. Let us consider the specific risk relating to the certification of the 50 MW NuScale SMR. It had three large asterisks noted in the certification document. Suffice it to note one of them here, relating to the steam generator.

In existing PWRs, the steam generator is outside the reactor. In the NuScale design it is inside the reactor vessel. In the NuScale reactor, the water heated by the reactor, which is at the bottom on the tall vessel rises vertically by natural convective force. It flows past a helical steam generator, in which water boils. The steam made in the helical coil goes to the turbine generator, where the electricity is produced. This simplifies the design and eliminates the pumps in the present PWR design.

But it has created a new issue. In the present design, the water that boils flows vertically in contact with massive closed coils in which the reactor water flows. Essentially the water boils in a large tank and turns to steam at the top. In the NuScale reactor it boils in the helical coils producing a sudden change of density, from the much denser water to low density steam. This step density change in a helical tube creates what are called "density wave oscillations" that can lead to metal fatigue and potentially failure. The NRC noted this in its design certification:[11]

> …NuScale Power has not demonstrated that the flow oscillations that are predicted to occur on the secondary side of the steam generators will not cause failure of the inlet flow restrictors. Structural and leakage integrity of the inlet flow restrictors in the steam generators is necessary to avoid damage to multiple steam generator tubes, caused directly by broken parts or indirectly by unexpected density wave oscillation loads. Damage to multiple steam generator tubes could disrupt natural circulation in the reactor coolant pathway and interfere with the decay heat removal system and the emergency core cooling system, which is relied upon to cool the reactor core in a NuScale power module. The failure of multiple steam generator tubes resulting from failure of an inlet flow restrictor has not been included within the scope of the NuScale accident analyses in DCA Part 2, Tier 2, Chapter 15. Therefore, the NRC concludes that NuScale Power has not demonstrated compliance with 10 CFR 52.47(a)(2)(iv) and appendix A to 10 CFR part 50, GDC 4 and GDC 31, relative to potential impacts on steam generator tube integrity from inlet flow restrictor failure.

The NRC granted design certification despite this potentially grave unresolved problem that could lead to catastrophic failure. In the event of such a failure, recalls would become a real issue. The NRC issued the certification despite the objection of the probabilistic risk assessment expert on its Advisory Committee on Reactor Safeguards, Dr. Vesna Dimitrijevic. She dissented, stating that "the steam generator integrity is *too significant of a safety issue* to not have received finality in the NuScale design certification."[12]

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[11] NRC, NuScale Small Modular Reactor Design Certification, Federal Register, 02/03/2023, https://www.federalregister.gov/documents/2023/01/19/2023-00729/nuscale-small-modular-reactor-design-certification

[12] Advisory Committee on Reactor Safeguards, "NuScale Area of Focus - Helical Tube Steam Generator Design," Nuclear Regulatory Commission, March 24, 2020, emphasis added. https://www.nrc.gov/docs/ML2009/ML20091G387.pdf

4. Conclusions

The disastrous financial historical performance of the industry in the first round only got worse in the second, where it concerns large reactors. SMRs are currently batting .000, nearly 25 years after Congress first appropriated money to study the issue and 17 years after the NRC's optimistic projection regarding certification of the NuScale reactor by 2015.

New designs create new risks, even for the well-established light water reactor concept, as discussed above. High estimated costs are already the norm, even at the ground floor of the proposed projects. For instance, the 345 MWe Terrapower sodium cooled reactor is estimated at $4 billion[13], or over $11,000/kW. Seven-and-a-half decades of effort and inflation-adjusted global expenditures of $100 *billion* have failed to commercialize the sodium-cooled design.

The supply chains and assembly lines required to lower costs are highly unlikely to materialize in the United States for in the coming decade (or more), especially given the approach being taken to SMRs – too many designs and too little sorting. Financial considerations of scale, clearly indicated by the aircraft industry, point to one or at most two supply chains, even if the industry takes off.

Recalls will be an ever present risk. If regulatory vigilance is relaxed, those risks will rise.

I do not know if the Pueblo community has considered the prospect that even if a project is authorized, it may not be completed. The landscape is littered with failed projects, whose main results were higher rates, unemployed construction workers, and zero tax dollars for the community. Those risks are greater with SMRs in my view.

Whether the community has considered the risks are not, it is obligatory for the Colorado Public Utilities Commission to do so. Providing PSCo with even modest funds would create hopes and political pressures for a full project. That would be unwarranted and highly risky. In light of the facts, it would be imprudent.

While not the purpose of my testimony, I should note in closing that the notion that solar and wind cannot be the basis of a decarbonized electricity system without nuclear or fossil fuel plants with CCS is not correct. I spent the better part of four years, with substantial staff support, examining whether Maryland could have a fully decarbonized, reliable, affordable electricity system with only solar, wind and a very small amount of existing hydro (2 percent) as the primary energy sources. The project included hour-by-hour modeling, full electrification of road transport and heating. It modeled solar, wind, existing hydro, battery storage, demand response, and hydrogen produced with electricity that would otherwise be curtailed.[14] The following were the results:

- For 68 percent of the hours in the year, the entire load was met without the use of storage.
- Storage, amounting to 5.5 hours of annual average load, increased that to 96 percent.

[13] Pallavi Madhiraju, "Bill Gates-backed TerraPower rakes in $650m to build first advanced Natrium reactor in Wyoming," Energy Industry News, https://business-news-today.com/bill-gates-backed-terrapower-rakes-in-650m-to-build-first-advanced-natrium-reactor-in-wyoming/

[14] Arjun Makhijani, Prosperous, Renewable Maryland: Roadmap for a Healthy, Economical, and Equitable Energy Future, IEER, 2016, https://ieer.org/resource/energy-issues/prosperous-renewable-maryland-2016/

- Demand response, shifting some loads within 24 hours, added two percent.
- The remainder required fuel cell peaking capacity using the hydrogen produced with surplus wind and solar. Low-cost light duty fuel cells can be used for peaking since the duty cycle would be similar to or even lighter than most passenger vehicles

The modeling did not include vehicle-to-grid (V2G) or seasonal thermal storage, both of which would improve the system. I do not expect the Commission to accept my conclusion. But I do think it is its imperative for the Commission to make its own serious effort on this matter as well. It should not accept the view that solar and wind without nuclear cannot be the foundation of a decarbonized electricity system.

Thank you for your consideration of these comments. I would be happy to answer questions, should you have any. Please send them to arjun@ieer.org.