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PJM's clean electricity choices

Recommendations for an engineering concept definition study of the PJM system

The US National Academy advises us that "Emission reductions larger than about 80% (overall)… are required to approximately stabilize (atmospheric) CO_2 concentrations…"[1] In response, this recommendation is directed at a classic engineering concept definition study to clarify practical concepts for a zero-fossil-fuel electric power system for the PJM Interconnection.[2] The product of this study is a comparison of practical choices that can then become the factual basis for informed public discussion and policy making.

There is a useful analogy between this proposed study and the familiar Architect/Engineering phase of many public works projects. The executives set the goal (such as build a bridge); engineers quantify practical options (concept definition of high bridge, low bridge, drawbridge, and tunnels); stakeholders then choose which one to build (a political value choice). The value of a concept definition study is that the value choice can be based on trusted fact, not just on political advocacy.

THE GOAL

A large overall fossil-fuel reduction goal should not be uniformly allocated across all energy sectors: This would be like an across the board fiscal cut. An ultimate goal of a very large overall fossil-fuel reduction should be allocated to a zero-fossil-fuel requirement for electricity. This enables clean electricity to be leveraged to reduce fossil fuel use in other sectors through electrification (such as electric vehicles).

> *Goal - To characterize cost, performance and risk of alternative concepts for zero-fossil-fuel PJM power systems. The main value of a zero-fossil-fuel ultimate goal is that decision makers can avoid investments that interfere with achieving the goal.*

Biomass needs qualification as a renewable source. While biomass may be zero-fossil carbon, it is not clean with significant health and environmental impact.[3] Also, it is important to note that emergency and planning reserve may come from low emission fossil fuel sources such as natural gas generation. That reserve will not run normally but enjoys a very low capital cost per installed kW and will help keep electricity rates as low as practicable without compromising emission goals.

Even climate change skeptics should support this goal because it is inevitable. Fossil fuel resources are finite and have much higher value in applications such as aircraft fuel and chemical feedstocks. Schedule is a variable; a faster pace entails higher costs and higher risks than a slower pace. Whether the goal is to be achieved in 30, 50 or 100 years is a value choice that balances the cost and development risk of different concepts against environmental risk.

While the study will rank and score and provide recommendations, its primary purpose is not to recommend a "solution" but to quantify the cost, performance and risk of validated concepts in preparation for subsequent political value choices from these viable options. These concepts should be comprehensive, spanning the gamut between intermittent renewables and baseload nuclear power. The study would also clarify the need for improved data, critical item testing, prototype testing and development pathways.

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BACKGROUND

The first half of the 20th century saw vertically integrated electric utilities. These utilities had strong System Planning Groups responsible for inventing and developing the modern electric power system. These System Planning Groups had the technical expertise to identify esoteric technology and system challenges and to assemble and manage expert task forces for their resolution. As time passed, the technology and system concepts began to stabilize and these System Planning Groups began to atrophy. Engineers experienced with the development challenges of large-scale electric power systems have mostly retired in the second half of the 20th century. Today, the primary purpose of power system planning is to develop and maintain 20 year strategic plans for transmission upgrades, power plant siting and resource adequacy.

The overall loss of power system development skills was crystalized by the Public Utility Regulatory Policies Act (PURPA) of 1978.[4] Deregulation resulted in a dozen different Federal, State and utility agencies, each responsible for a different piece of the electric power system. While this management structure worked well during a period of relative stasis, it is inadequate under stress resulting from rapid and large scale change.

Today we are challenged by a new requirement for clean electric power systems. Since intermittent generators are not interchangeable with dispatchable[5] generators, whole system concepts need to be rethought. The current lack of development skills is confounded by the fact that there is no single entity responsible for overall power system development; for coordinating the complex interplay of technology integration, markets, and reliability. Today, utilities and RTOs are caretakers; they are expert in operating, upgrading and maintaining existing technology power systems. They do not have the broad skills or authority to develop new system concepts. The Nation also has earnest academics eagerly taking on the challenges of more complex technologies, but with little practical experience building and validating new systems. One consequence is that politicians are micromanaging through legislation. The result is that serious elementary mistakes are being made such as failing to recognize the high risks of migrating forwards incrementally vs the lower risk of working backwards from the ultimate goal.

State Governments need to assume responsibility for concept design of the PJM power system

PJM is a regional system spanning multiple States, and, clean energy system concepts would be unique to PJM's geophysical resources. PJM member State Governments are writing the checks, committing their ratepayers to large generation incentives using policy concepts like renewable portfolio standards; and all PJM ratepayers are subject to common costs. Since the investment decisions are being made at the State level and system concepts are regional in scope, it is in the best interest of the PJM States to partner and fund concept design studies. All the PJM States are in the same boat and it would be of mutual benefit for everyone to row in the same direction.

Prior investigations

Jenkins reviewed 30 recent (since 2014) studies on the "deep decarbonization" of the electric power sector.[6] This report provides a good bibliography and offers several conclusions:

1. Low cost dispatchable resources are an indispensable part of any low cost pathway
2. Relying on intermittent sources alone significantly increases cost and technical challenges
3. Stranded assets can be avoided by focusing on long term goals

The following studies are notable:

The Renewable Electricity Futures Study[7] was a large (110 author) US Department of Energy study published in 2012. Its purpose was to assess the technical feasibility of "high" levels of integration of commercially available renewable technology including biomass, geothermal, hydropower, solar, and wind. This study does not support a zero-fossil-fuel power grid with intermittent renewables. It is consistent with other studies suggesting that reliable systems with up to 50% intermittent renewables (requiring 50% reliable backup) can be supported before costs start escalating rapidly. While this study is a better example of a concept definition study it suffers from several difficulties:

- The goal – maximum renewables – is a political solution not a technology neutral performance goal.
- Renewable performance model validation is unconvincing
- While biomass may be zero fossil carbon it should not be a zero fossil-fuels candidate because of health and environmental impacts. Black carbon (soot) may have significant climate impacts.[8]
- Cost is not an explicit product of the study.

One example of the proposed system level concept definition study that includes both nuclear power and intermittent renewables is The Real Cost of Energy by The Ontario Society of Professional Engineers.[9] OSPE's summary (pp. 32, 33) is sound and useful. One difficulty is limited depth because this was a volunteer effort. To justify a one trillion dollar investment,[10] PJM's concept definition study should be more rigorous and detailed including PJM's specific resources, risk assessments, development needs and cost/technology forecasts.

A University of Delaware group published a study titled: Cost-minimized combinations of wind power, solar power and electrochemical storage, powering the grid up to 99.9%of the time.[11] This study is remarkable in that it showed that it is technically feasible for a high percentage (>90%) of PJM system electricity to come from wind and solar. But since storage costs are so high, the authors minimize total system cost by over-building wind and generating 3x the amount of electrical energy that is actually consumed; 2/3rds of the produced electric power is discarded. While theoretically feasible, the study seriously underestimated costs associated with building a practical system in this manner. (e.g. full peak capacity natural gas backup used for 8 hours per year).

A Stanford University group claims a "Low cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes."[12] This study speculates on how intermittent renewable technologies might fit together for a zero-carbon grid; though the poorly validated models and large number of unrealistic assumptions preclude this as a credible concept definition study.[13,14]

Bias reinforces the need for critical validation of performance models and cost estimates

Many published studies were directed not at objective comparison of choices, but at promoting specific solutions. Many wind performance models have unsubstantiated assumptions of wind-load independence and wind-wind independence for distant sites. The common result is over estimation of capacity factors and the benefits of geographic dispersal. Models need to be well anchored in empirical data.

Ontario Canada's experience provides a realistic beginning

Ontario's accomplishments are unprecedented. Over the past decade, Ontario[15] reduced grid emissions by 80% to 44 g(CO_2)/kWh (grams of CO_2 per kilowatt hour of electricity). By comparison, PJM emissions are 461 g and the Midwest Independent System Operator (predominantly coal) has emissions of 1043 g. The all-hydro grids like Scandinavia, and Quebec are the only large systems with lower CO_2 emissions. Ontario's current energy generation mix is 58% nuclear, 23% hydro, 10% natural gas and 9% wind/solar/biomass.[16] Ontario offers several important lessons.

- The key to very large emission reductions is zero-fossil-fuel base load, for Ontario this was nuclear and hydro. Ontario already had 23% hydro; they achieved an 80% reduction primarily by replacing coal with nuclear and natural gas.
- Solar has value only to the extent that it levels load.
- Too much solar and wind have no value on a zero-carbon system without seasonal storage.
- Ontario's achievement is not cheap, electricity rates have increased by 70% over the decade. Ontario currently has too much inappropriate capacity that produces significant amounts of zero-fossil-fuel electricity that must be exported at low prices or curtailed (wasted). More disciplined planning and system development would have significantly reduced cost.

SCOPE

An important aspect of the art of Concept Definition is the appropriate level of detail. The analysis needs enough detail to clarify and distinguish structure and to provide a factual basis for making value choices. Concept definition excludes detail which obscures fundamental relationships. Concept definition is a snapshot of a future from which value choices can be made. It excludes a plan for how to get there from what exists today.

No demand growth assumption

The time required to transition to a zero-fossil-fuel electric power system is an important value choice. This analysis and recommendations are substantially simplified by the assumption of no growth in electric power demand. The demand profile in future years is defined by the demand profile over the past 5 years. This assumption is consistent with the view that any increase in demand and new energy markets is offset by energy savings. Since the US and Canadian per capita energy consumption is about double that of other G7 nations, there is ample room for energy efficiency.[17]

Two electricity demand scales

Cost/performance/risk of zero fossil fuel electrical power systems should be estimated for two scales:

1) Clean electric generators satisfying 100% of today's electric power demand while maintaining system reliability against existing loads.
2) Clean electric generators displace 80% of primary fossil fuel consumption for large (80-90% overall (across the entire economy) fossil-fuel reduction. Scaling from national consumption patterns[18] suggest that this could increase today's electric power demand[19] by 4x. Technology and system innovations, such as using reactors for thermal heat, could significantly reduce this number.

Base data years 2012-2016

PJM publishes system hourly wind data beginning in 2012. Therefore the years 2012 through 2016 are the base years for wind. Demand can be adjusted to account for any additions to the PJM system during that 5-year period and any linear demand growth, if any, over that period. <u>It is absolutely essential that wind performance simulation preserve measured wind-load correlations</u>.

Inter-annual profiles of load and resource variability would be characterized by variability during that 5-year period. The adequacy of this assumption can be tested by exploring load data and meteorological data over the past 20 years.

Known technology and system concepts

Energy technology is an old and established field. The technologies visible today were all visible back during the last alternate energy boom in the 1970's. Advances in battery technology for example are likely to be incremental, 20-100% cost/performance improvement rather than revolutionary, 1,000-10,000%. All the battery chemistries are known and well researched. There simply is little opportunity for revolutionary new technology driven concepts. In contrast, there is opportunity for new system concepts like microgrids.

Rational planning is based on what is known and can be estimated with confidence today. It would include technologies and systems that have been prototyped sufficiently well to have high feasibility confidence and to be able to project volume production costs at scale. This would include technologies like certain nuclear reactors, wind turbines, solar PV and pumped hydro storage.

Other technologies and systems are potentially feasible but have specific questions that need to be demonstrated. Examples are fast neutron reactors and compressed air storage. These concepts can be included in concept design with the risks noted and recommendations made for engineering development. The same is true for new system concepts requiring lifestyle changes such as PEVs for grid scale storage.

It would exclude technologies without full scale prototypes or where serious feasibility questions exist. An example here is fusion, hot or cold.

Zero fossil fuel means zero

While the study goal is strictly a zero-fossil-fuel system, it is understood that practical systems may find it economic to employ minor amounts (<5%) of fossil fuel generators for some time especially for emergency and planning reserves as indicated earlier. Such a minor use of fossil fuel without carbon sequestration is permitted in this concept definition study.

Transmission architecture

Power transmission concepts can seriously complicate concept definition analysis. For the purpose of comparing base load and intermittent generators the copper plate assumption (no cost, no loss) is adequate for initial modeling efforts. However transmission costs can exceed generation costs under certain circumstances. Sufficient detail must eventually be incorporated to estimate transmission cost impact.

PJM's physical boundaries

The PJM Interconnection's roots go back to a 1927 power pool. The Federal Energy Regulatory Commission approved PJM as the nation's first Regional Transmission Operator (RTO) in 1997. PJMs primary function is to operate a competitive wholesale electricity market and manage the reliability of its transmission grid for its member electricity distribution companies. The adjacent map illustrates PJM's physical boundaries which are defined

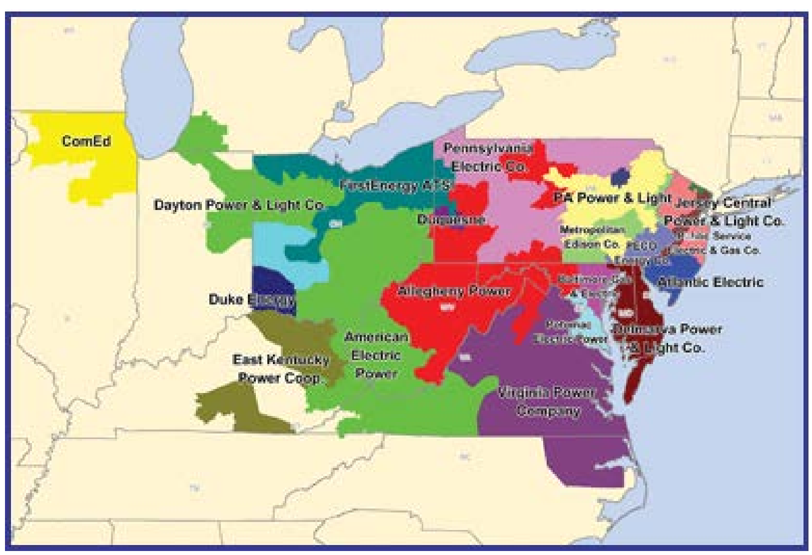

Figure 1 PJM map

by its component electricity distribution companies. The modeling effort will require defined boundary conditions preferably a closed boundary.

Consistent neutral bias

Practicing power system engineers tend to have a conservative risk adverse bias because the consequences of failure are severe. Today this bias is characteristic of nuclear power and legacy power system operations and planning.

In contrast alternate energy systems tend to be disruptive, every path needs to be explored, ideas should not be judged prematurely and there are as yet no serious consequences to failures because penetration is still low. Over time penetration will increase and failures will have more impact.

The objective of the PJM Concept Definition Study is to compare zero fossil-fuel system concepts. This comparison should be technology neutral. Models must be well validated and estimates well anchored in empirical data. Therefore the literature should not be taken at face value but should be critically reviewed for bias, adjusted where necessary and such adjustments noted.

METHOD

Engineers use a variety of methods to develop new systems depending on the type of problem. With a clear and stable ultimate goal, and expensive products with long product cycles, the appropriate method is a classic waterfall. After President Kennedy set the goal to put a man on the moon, NASA had the discipline to spend one year up front to get the concept right before they committed to a direction. This Apollo concept definition study is a main reason why America won the space race.

An alternative method, common in Silicon Valley, is agile development; rapid prototyping, build-it-sell-it-fix-it. Agile us useful when the goal is unclear as is the case with consumer products, human interface software, and the internet. With short cheap product cycles, it is easy to recover from mistakes. With long expensive product cycles, the risk of using agile development methods like the Renewable Portfolio Standard is that it may be impractical to recover from mistakes.

With zero-fossil-fuel as the clear and stable ultimate goal, the appropriate method for clean energy development is the classical waterfall; concept definition is the first phase.

Classical waterfall

The method is called a waterfall because it proceeds through a sequence of phases separated by major milestones. These milestones consist of a management review of progress to decide whether to proceed as planned, change direction, or to repeat the earlier stage.

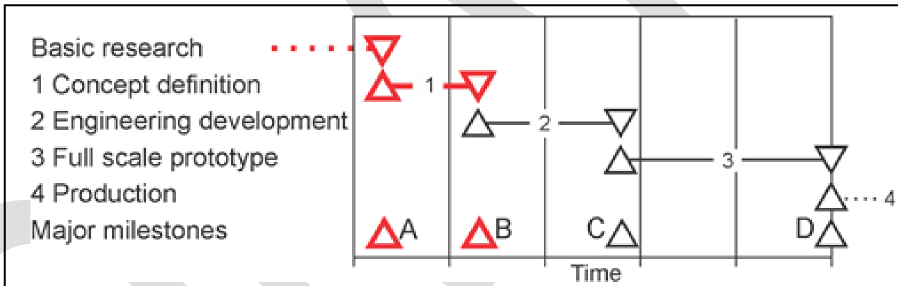

Figure 2 Classic Waterfall development

Clean energy today is at Milestone A. Phase 1, concept definition, systematically explores alternatives, feasible ways to achieve the goal. Concept Definition concludes with Milestone B where Stakeholders choose which concepts to develop. The product may be more than one concept to further develop. It may be useful to divide Concept Definition into sub phases such as cost limited planning followed by execution.

Phase 2, Engineering Development, (beyond the scope of this Concept Definition Study) consists of component design and testing to reduce risks identified during Phase 1. For example a Concept Definition phase conclusion might be that intermittent generators can economically contribute to a reliable zero carbon system only if they are matched with seasonal storage, thus necessitating a dispatchable combined technology. In that event, a priority Engineering Development task would be to attempt to develop seasonal storage technologies. Milestone C is a normally a decision to build full-scale system prototypes and map out a plan for migrating from the existing system to the goal system. Value choices are made at all major milestones; program efforts can be continued, terminated or re-directed at major milestones. Iteration can occur mainly between the major milestones as required.

Clean energy development is difficult because the system is unprecedented and technically complex. A management structure with roles and responsibilities aligned with the system does not exist. And there are many stakeholders with conflicting interests. The importance of the classic waterfall development model is that it identifies the development structure: phases and major decisions. Committing large resources to full-scale production (Milestone D) without first having a clear idea of ultimate goals (Milestone A); or a comprehensive analysis and comparison of alternatives (Milestones B); or evidence of proven technology (Milestone C); or evidence of cost effective systems (Milestone D); entails the risk of serious investment mistakes which may be economically unrecoverable.

Concept comparisons are the core of a successful Concept Definition study

A key conceptual comparison will be between systems that employ intermittent generators (wind and solar) with systems containing only clean base load generators (hydro, geothermal-electric, nuclear). Does mixing intermittent generators with clean base load generators offer any advantages. How much solar PV can be tolerated before it distorts the net demand profile? Do the two extreme concepts adequately define alternative conceptual choices (can mixing the two be characterized as independent subsystems)? Is there evidence that certain technologies will become stranded in zero fossil-fuel systems?

Concept definition work breakdown structure

The following tasks are envisioned as the basis for developing a more formal work breakdown structure (flow of tasks) for the Concept Definition study. Some tasks may involve full time teams; others may be part time individual contributors.

1.0 Intermittent generator system simulations - PJM concept definition will require original wind, solar and mixed system simulations. PJM has published hourly wind production data for the RTO system since 2012. Historical metered load data goes back for decades.

One simulation approach is to model wind and solar production by scaling real data, by assuming that additional wind turbines are added with the same geographic footprint is a sound conservative approach that reflects real world conditions. A primary advantage is that this approach correctly preserves wind-load correlations.

A second simulation method is to use one of several types of wind models to estimate a field of hub height wind, then use the manufacturer's power curve to estimate wind production. An advantage is that it is not necessary to assume the same geographic footprint. The disadvantage is that these models tend to ignore the realities or real world operations, disagreeing with data by as much as 50%. For example Budischak[20] modeled average annual PJM capacity factors of 42% while measured PJM wind capacity factors for 2011 to 2013 were in the range of 28%. The difference is likely due to real world limitations such as wake interference, imperfect siting, setup, tuning and operations. It is true that bigger better wind turbines will have higher capacity factors but this technology performance trend has been modest ~3% total over the past 15 years.[21]

A third factor (which still seems unsettled) is capacity credit usually defined as the amount of additional load that can be serviced by adding wind with no change in system reliability. One analysis[22,23] of 12 systems and 67 years of data from around the world indicates that capacity credit is a low single digits percentage of wind nameplate (if not zero). This conflicts with a wide range of numbers in the literature, generally in the 15-20% range. While capacity credit declines with penetration, this factor is sometimes ignored with large penetration studies

A fourth factor is the extent to which long distance transmission (e.g. connecting PJM and MISO) can improve wind capacity credit. There is evidence that the contribution is small.[24] The PJM Concept Definition study should be able to accurately quantify capacity credit.

2.0 Grid scale storage technologies forecast - While considerable effort has been directed at developing grid scale storage concepts, technologies are seriously constrained by chemical and physical realities. ARPA-E has funded a grid scale program for a number of years.[25] While that program seems to have reverted to short term storage, the feasibility of seasonal storage is needed for wind and solar to compete as a base load generator.

There are several concepts that have been proposed for seasonal electric storage. To what extent are these concepts practical for PJM?

1) Use the Great Lakes for pumped hydro storage[26]
2) Compressed Air Energy Storage (CAES).
3) Plugin Electric Vehicles (PEV) for voltage regulation and grid scale storage[27]
4) Fuel product ion and chemical storage using surplus electricity. This approach has merit both for a highly volatile net load from intermittent systems, and seasonal surplus on a system with base load generators.
5) Cycling hydroelectric assets allowing reservoir buildup during high intermittent generation

3.0 Nuclear power forecast -This task involves a critical review to identify nuclear fission technologies and viable long-term whole-system nuclear development paths. Assuming active development by DoE, which technologies are appropriate for deployment in the study period of 20-100 years and suitable for cost estimating? What risks need to be resolved by Engineering Development and full scale prototypes? What is the longer term (>100 year) potential of nuclear fission? Can it be assumed that disciplined development will result in passively safe nuclear products? How will radioactive waste disposal eventually be managed? Are new concepts emerging?[28]

4.0 Grid stability and transmission concepts[29] - Legacy grids and nuclear power concepts use synchronous generators. The power management systems, fault isolation and black start recovery strategies are all designed to exploit the electro mechanical properties of large synchronous generators. In contrast, wind turbines, PV collectors and batteries must be connected to the grid with power inverters. When renewables penetration is low, the system is still dominated by synchronous generators and relatively simple and inexpensive grid following inverters can be used for renewables connection. But as penetration increases, more sophisticated and expensive grid forming inverters will be necessary to avoid stability issues and difficulty with black restart. This is a technical issue that may require Engineering Development.

5.0 Independent performance model validation - PJM concept definition is an engineering study. Engineering models are extensively validated, well grounded in empirical data. The literature needs a critical review. This task, independent of 1.0 system simulations, recommends validation simulations to assure that capacity factor, capacity credit, and the potential impact of long distance transmission are accurately modeled.

6.0 Independent cost estimating - The main purpose of the CD study is to compare concepts. Hence the relative consistency of cost estimates is more important than absolute accuracy. To this end, estimates should assume the same cost of capital, consistent tax structures, no subsidies, realistic equipment longevity, consistent learning curve methodology, and the same degree of conservatism.

Validating cost estimates is difficult because there is not a lot of historical data for cost assessment and learning curves for new technologies and its subjectivity becomes vulnerable to bias. This is confounded by political pressures. One data source is the US Energy Information Administration (EIA)[30] which provides annual updates of generation cost. Difficulties with EIA numbers is that they seem to use equal life expectancy for all hardware and the onshore wind capacity factor jumped from 30% to 40% for no clear reason. Another frequently cited data source for new generation is Lazard.[31] The peer reviewed literature cannot be taken at face value. A significant effort by experienced cost estimators may need to go to raw data.

7.0 Environmental impact - PJM Concept Definition is conducted at two scales:

1) Existing power demand and profiles.
2) Scale up to displace 80% of fossil fuels across the economy.

For intermittent generators, environmental impact is a feasibility factor. Impact consists of the number of wind turbines, spacing, location candidates as well as the number and size of wind farms and solar PV fields; and the number and approximate location of nuclear plant clusters.

Substantially scaling up nuclear power will increase background levels of ionizing radiation. By how much will background levels rise and are there health physics consequences? To what extent is waste heat an environmental factor.[32]

8.0 Electricity market structure – PJM manages a competitive wholesale electricity market. Distribution utilities manage a regulated retail market to sell electricity to end users. Both markets have been designed for high variable cost, high emission systems. Markets compete the cost of energy ($ per kilowatt hour) with the goal of discouraging energy consumption. With a wholesale market that competes variable cost there is no incentive for capital investment which means no new generation. PJM has added a capital market to the existing energy market to account for this.

These markets need to change substantially as we migrate to clean generation with high up front capital cost but low variable cost. The importance of PJM's capital market and the ability to satisfy peak loads will increase. Retail incentives will change to incentivize the use of clean electricity to displace fossil fuel in markets that are currently non-electric. This transition needs to be though through. Ontario Canada is currently struggling with these questions.

9.0 Engineering Development requirements - Concept definition produces a list of technology options for Engineering Development. The purpose of Engineering Development is to reduce risk through further analysis, component development and testing, and laboratory scale prototypes to resolve questions that were raised during Concept Definition. While Engineering Development is beyond the scope of this proposal, other entities like equipment manufacturers and the US Department of Energy should be interested in those development needs.

GOVERNENCE FOR PJM CONCEPT DEFINITION STUDY

Existing management structures are proving inadequate for addressing the challenge of climate change. In the United States, State Governments need to step forward to establish trusted fact and conceptual choices because it is State Governments that are committing their people to paying clean energy bills. State governments need to do so responsibly.

Engineering best practices teach us that Waterfall Development (Fig. 2) is the low risk methodology for developing unprecedented systems with clear, stable ultimate goal such as zero-fossil-fuel electric power for PJM. Waterfall development identifies task phases, roles and responsibilities. The first step is classic concept definition, to clarify practical alternatives so that society can make informed choices.

The trusted study contractor

The popular debate over clean energy today is both highly politicized and ignorant of the realities of practical engineering and electric power system development. The necessary authority and skill sets are analogous to the strong power planning groups of the vertically integrated utilities of the first half of the 20^{th} century. These authorities and skill sets do not reside in any one organization today. The contractor needs to be trusted by the public as capable of assembling and managing expert teams. The contractor and its management processes also need to be regarded by the public as neutral, objective and transparent in developing and presenting the results of its analysis.

In the United States, a strong study contractor candidate is the National Academies of Science, Engineering and Medicine (NASEM).[33] The NASEM operating arm is the National Research council.[34] The NASEM component that would be responsible for conducting the PJM concept definition study is the Board on Energy and Environmental Systems.[35] NASEM's strong suits are public respect for its competence and neutrality, and the process experience of assembling and managing expert teams to solve problems. NASEMs weakness is inexperience with practical power system development processes. This weakness can be compensated by assembling teams who have that practical experience and process for transferring the results to the public policy arena.

Technical teams perform core analysis

In response to Steering Committee recommendations, NASEM will establish and support technical teams to perform the tasks identified in the METHOD section. Methodology will mximize video conferencing and virtual tools.

Stakeholder management group provides guidance on public relations

The role of stakeholders is to make value choices. Stakeholders are strong participants in the major program reviews (milestones) in Waterfall development (Fig.2). They may consist of members of different State agencies. The stakeholder team reaffirms the Goal and during milestone B decides whether the concept definition effort is complete and recommends or affirms recommendations for next steps.

The stakeholder team is the public face of the program. They communicate with various stakeholders and the public through meetings, press releases and town hall meetings much like stakeholder management teams in public works projects.

Technical steering committee

The role of the technical steering committee is to define the study tasks and a work breakdown structure in more detail than this document. They establish priorities to assure timely and relevant results. They also identify experts capable of executing these tasks. This team needs senior experts from wind, solar, nuclear, storage, modeling and simulations, cost estimating, climatology, environmental impact, operations (PJM), engineering development processes, and lessons learned from other clean energy concept development studies and jurisdictions that have already achieved an 80% or greater reduction in emissions.

Red team

The role of red teams is an independent review of progress, identifying strengths, weaknesses, and next steps from the perspective of technology, architecture and the view of various stakeholders.

The relationship with PJM

Since the scope of the PJM Concept Definition Study is the PJM system, PJM should be a major contributor, particularly with participation in and providing personnel resources for the technical teams and as a stakeholder. However PJM has governance conflicts that make it difficult to be the neutral study contractor.

PJM Interconnection is the world's largest regional transmission organization (RTO). It is responsible mainly to its member electricity distribution companies. These companies in turn are responsible to various State government agencies. PJM member States have different political views on climate change and measures needed to protect their citizens do so it is difficult at this time to develop a consensus. Concept definition needs a thorough review of all options so member states have real practical choices.

Partnership with other PJM States

Those PJM States with deep concerns about climate change should work together now, so the extension to long range planning would be relatively simple organizationally and politically. The action of any one State affects the whole PJM system, so it makes little sense for a single State to go it alone. Once a whole system concept plan is chosen by a majority of States, different States can implement compatible solutions at their own pace. In addition to sharing the concept definition study cost, participation adds authority to the results.

The proposed partnership may not include all PJM States. The concept definition study is a project; it has a beginning and an end. The relationship with non-participating PJM States is still to be defined; perhaps some sort of political understanding may be appropriate. Benefits of State participation would be mainly information gained by stakeholder teams enabling informed public policy.

The Relationship of the study with the Department of Energy (DoE) and ARPA-E

DoE and ARPA-E are Federal agencies with a national charter and goals that may not be neutral to this study. The scope of the PJM concept design study is regional. In contrast to both DoE and ARPA-E the National Academy of Science Engineering and Medicine (NASEM) charter is to be responsible to the needs of the sponsoring government agency. Hence, the NASEM is a better choice as the study contractor.

Cooperation with the DoE and ARPA-E is useful to the PJM concept design study. Cooperation adds authority and may share the cost and/or personnel resources. Insight to prior DoE work such as the Renewables Electricity Future Study[36] may provide insight and access to models and people. The nature of many Engineering Development tasks, the follow-on to Concept Design, is generic and may fall under DoE and ARPA-E charters. DoE and ARPA-E may be interested in participating in the Concept Design study to identify and prioritize Engineering Development tasks.

SUMMARY

Using known technology, the study objective is to compare cost, performance and risk of alternative system configurations; identify development needs priorities and practical timelines. There are two main aspects to performing this conceptual design study. The first is the development and comparison of conceptual designs themselves. The second is to do so in a way that encourages stakeholder buy in.

- PJM generation replacement cost is a trillion dollar decadal investments, mistakes are costly and recovery difficult. Risk is minimized by taking the time up front to discover the best approach.
- The ultimate goal of a zero-fossil-fuel electric power system should be confirmed and advertised. Zero fossil-fuel can be leveraged to lower emissions in other sectors.
- Partnering with other PJM States for the conceptual design of a zero-fossil-fuel PJM system encourages buy-in and common solutions.
- Contract the study to an organization with proven track record of solving problems by assembling and managing expert teams. NASEM is recommended.
- Develop management teams: a technical steering committee and a stakeholder management group.
- A primary goal is to illuminate the system implications and distinctions between clean intermittent generators and clean base load generators.
- Explore novel concepts for stakeholder engagement including the combination of traditional major program critical reviews, public commission hearings and social media.

REFERENCES & NOTES

[1] National Research Council, Climate Stabilization Targets, NRC Board on Atmospheric Sciences and Climate, 2011, p. 9, available at: https://www.nap.edu/download/12877

[2] PJM Interconnection is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia. See: http://www.pjm.com/

[3] Wang, Q., et al. Impact of biomass on urban air quality estimated by organic tracers, ScienceDirect 41:37, December 2007, pp. 8380-8390. Available at: http://www.sciencedirect.com/science/article/pii/S1352231007005766

[4] See: https://en.wikipedia.org/wiki/Public_Utility_Regulatory_Policies_Act

[5] Dispatchable generators are capable of being turned on and off on command. See: https://en.wikipedia.org/wiki/Dispatchable_generation

[6] Jenkins, J.D., Thernstrom, S., Deep decarbonization of the electric power sector; insights from recent literature, Energy Innovation Reform Project, March 2017, available at: http://innovationreform.org/wp-content/uploads/2017/03/EIRP-Deep-Decarb-Lit-Review-Jenkins-Thernstrom-March-2017.pdf

[7] Hand, M.M. et al. eds., National Renewable Energy Laboratory, Renewable Electricity Futures Study, NREL/TP-6A20-52409, 2012, available at: http://www.nrel.gov/analysis/re_futures/

[8] See: http://blogs.ei.columbia.edu/2016/03/22/the-damaging-effects-of-black-carbon/

[9] Ontario Society of Professional Engineers, The Real Cost of Energy: Energy Policy Presentation, November 2014, available at: https://www.ospe.on.ca/public/documents/presentations/real-cost-electrical-energy.pdf

[10] PJM generation replacement cost is ~$0.7 trillion. 2106 PJM capacity was 176 million kilowatts with estimated replacement cost of $4,000/kW. This number excludes transmission upgrades and technologies like storage, and the 4x scale up for 80% overall emission reduction, and upgrades of other sectors like electric vehicles..

[11] Budischak, C., et.al., Cost-minimized combinations of wind power, solar power and electrochemical storage, powering the grid up to 99.9%of the time, Journal of Power Sciences 225 pp. 60-74, 2013

[12] Jacobson, M, et al., Low cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes, PNAS 112:49, pp.15060-15065, 2015. Available at: http://www.pnas.org/content/112/49/15060

[13] Dams, R., Climate Scientists skeptical about Mark Z. Jacobson's 100% renewable energy "[lans," Atomic Insights, December 14, 2015, available at: http://atomicinsights.com/climate-scientists-skeptical-about-mark-z-jacobsons-wws-plans/

[14] Friedman, Alice, Jacobson and Delucchi energy dreams are irresponsible fairy tales, Energy skeptic, June 2, 2015, available at: http://atomicinsights.com/climate-scientists-skeptical-about-mark-z-jacobsons-wws-plans/

[15] IESO, Ontario Planning Outlook, September 1, 2016, available at: http://ieso.ca/Documents/OPO/Ontario-Planning-Outlook-September2016.pdf

[16] Ontario Planning Outlook; A technical report that provides a 10 year review and a 20 year outlook for Ontario's electricity system; September 2016, available at: http://ieso.ca/Pages/Ontario%27s-Power-System/Ontario-Planning-Outlook/default.aspx

[17] Wikipedia List of countries by energy consumption, primary source CIA World Fact book, available at: https://en.wikipedia.org/wiki/List_of_countries_by_electricity_consumption

[18] EIA, Primary Energy Consumption by Source and Sector, 2012, Monthly Energy Review (Jan 2014, tables 1.3, 2.1-2.6, available at: https://www.eia.gov/totalenergy/data/monthly/pdf/flow/primary_energy.pdf

[19] EIA, Primary Energy Consumption by source and sector, 2012, available at: https://www.eia.gov/totalenergy/data/monthly/pdf/flow/primary_energy.pdf

[20] ibid

[21] Wiser, R., et al. 2015 Wind Technologies Market Report, DoE, August 2016, figure 30, available at: http://www.nrel.gov/docs/fy16osti/66655.pdf

[22] Pavlak, A., Bothwell, C., Wind System Reliability and Capacity, Unpublished, October31, 2015, available at: www.pavlak.net/WSC.pdf

[23] Pavlak, A., Winsor, H., Wind System Reliability and Capacity, Power2014-32148, Proceedings of the 2014 Power Conference, July 28-31, 2014, Baltimore, available at: www.pavlak.net/WSR&C.pdf

[24] Smith, N. et al., Justification for long distance transmission, Proceedings of the ASME 2014 Power Conference POWER2014-32144, July 28-31, 2014, Baltimore, Maryland, USA, available at: www.futureofenergyinitiative.org/Pubs/LDT.pdf

[25] Arpa*e, GRIDS: Grid-Scale Rampable Intermittent Dis[patchable Storage, available at: https://arpa-e.energy.gov/?q=arpa-e-programs/grids

[26] Rhodes, C., Seasonal hydraulic energy storage, available at: http://www.xylenepower.com/Hydraulic%20Energy%20Storage.htm

[27] Herbert, C., Feasibility study foir grid scale storage, term paper ENMG691, 12-11, available at: ftp://www.futureofenergyinitiative.org/Pubs/Herbert-PEVs_ForGridScaleStorage_12-14-11.pdf

[28] Rhodes, C., The Ottensmeyer plan, available at: http://www.xylenepower.com/Ottensmeyer%20Plan.htm

[29] Kroposki, B., et.al., Achieving a 100% Renewable Grid, Operating Electric Power Systems with Extremely high Levels of Variable Renewable Energy, IEEE power & energy magazine, March/April 2017, pp 61-73

[30] Levelized cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2016, August 2016, available at: https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

[31] Lazard, Levelized Cost of Energy Analysis 10.0, December 23016, available at: https://www.lazard.com/perspective/levelized-cost-of-energy-analysis-100/

[32] Georgescu-Roegen, N. (1975) energy and economic myths. Southern Economic JournaL 41, 347-381 and Georgescu-Roegen, N. (1979). Energy analysis and economic valuation. Southern Economic Journal, 45, 1023-1058.

[33] National Academies home page: http://www.nationalacademies.org/

[34] National Research Council home page: http://www.nationalacademies.org/nasem/

[35] Board on Energy and Environmental Systems home page: http://sites.nationalacademies.org/deps/bees/

[36] Mai, T., Sandor D., Wiser, R., and Schneider, T., 2012, “Renewable Electricity Futures Study: Executive Summary,” NREL/TP-6A20-52409-ES., Golden CO: National Renewable Energy Laboratory.