THE FUTURE OF ENERGY INITIATIVE (FOEI)

The big picture perspective

Notes from FOEI for the Maryland RPS Study working group

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#1 - What is the purpose of the RPS?

Maryland's energy goals are inconsistent. The Greenhouse Gas Reduction Act (GGRA) should supersede the Renewable Portfolio Standard (RPS) because the GGRA is a technology neutral emission goal while the RPS mandates solutions without sound evidence.

Professional system development begins with sound goals. A sound goal specifies a performance level (what to do) not a technology (how to do it). Kennedy stated we will put a man on the moon in 10 years (what to do). The Apollo Moon Project was successful mainly because NASA had the discipline to spend one year up front to figure out the best way to achieve the goal. NASA decided that the low risk concept was a complicated lunar orbit rendezvous. At the time, astronauts had not joined two satellites in earth orbit, never mind lunar orbit. Nevertheless NASA made the correct decision and the rest is history. Likewise Maryland today needs the discipline to figure out how to build a reliable, sustainable, electric power system without fossil fuel.

Maryland's 2016 Greenhouse Gas Emissions Reduction Act requires a 40% overall reduction in greenhouse gas emissions by 2040. It also states {§ 2-1205(c)(3)} "*That plans shall be developed in recognition of the finding by the IPCC that developed countries will need to reduce greenhouse gas emissions by between 80% and 95% from 1990 levels by 2050*." This part of GGRA is a sound, technology agnostic, performance goal. Since some sectors like the chemical industry will be expensive to decarbonize the GGRA implies the need for nearly zero (<5%) emission electric power. The ultimate requirement is essential to avoid committing big long term investments to permanent structures that may be a reasonable way to reach an interim stage but interfere with the ultimate goal (reduce 80-95%).

In contrast to the GGRA, the 2017 Renewable Portfolio Standard requires 25% of retail electricity sales to come from specified generator technologies by 2020. The RPS is a technology mandate with no system goals. While wind and solar are certain to have some role in a post fossil fuel economy, that role is unclear. There is no competent evidence that renewables are a practical way to achieve the GGRA goal. Stakeholders have the right to choose any technology they want, to reject nuclear power or even to compromise goals; but a rational choice is based on the cost/performance/risk of trustworthy options. These options do not exist today; Maryland needs to do its homework.

Given a clear and stable GGRA goal (80-95% by 2050), the traditional low-risk development method is to first conduct a PJM Concept Definition Study (analogous to first year Apollo tradeoffs). Ignoring legacy constraints, the first question is: What will reliable power systems look like without fossil fuel? This concept definition study estimates the cost, performance and risk of electric power whole system alternatives as system emissions approach zero. Complexity and constraints are then added step by step to develop real system designs.

Based on the PJM Concept Definition Study, stakeholders then choose a path and a pace by balancing cost and risk. Most will find the choice to be obvious. Interim goals are not guesses but are derived from informed choices. This PJM Concept Definition Study becomes the basis for a Clean Electric Power Plan.

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The efficient professional method is Goal→Options→Choice. Stakeholders need to see trustworthy practical options, a PJM Concept Definition Study, before making large irrevocable investments.
Current investment must not interfere with the ultimate goal.

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#2 Household cost of 50% onshore wind

Since wind farms are not interchangeable with coal plants, the accurate method of estimating the cost of wind is to compare the cost of the whole system with wind minus the cost of the whole system without wind at equivalent levels of reliability. This approach correctly allocates indirect cost (idle backup, transmission, increased reserves) to wind.

The purpose of this memo is to develop a simple Rough Order of Magnitude (ROM) cost: a sanity check, a back-of-the-envelope estimate of magnitudes for the purpose of clarifying cost drivers. It includes important factors and ignores detail that can obscure fundamental relationships.

The ROM is based on published U.S. Department of Energy (EIA) levelized cost for onshore wind. Levelized cost is the sum of the annual operating cost plus the discounted capital investment (the equivalent annual mortgage payment). EIA's 2018 capacity weighted cost for onshore wind is $48/MWh (4.8 ¢/kWh). The ROM household cost is simply this cost times 50% of Maryland's total electricity consumption divided by the number of households.

Inherent in this perspective is that there is no "other guy" to help Maryland households pay the bill. Households cannot pass through costs and must pay the whole bill through standard of living adjustments. Tax credits, subsidies and indirect costs all come back to households through various paths. Other economic sectors such as government, industrial, and commercial users pass through their costs plus overhead to households in the form of higher charges. Households pay the whole bill.

ROM COST OF 50% MD WIND GENERATION

a	MD electricity consumption 2016 (MWh)	61,300,000
b	Annual wind production = 1/2 consumption (MWh)	30,700,000
c	Wind levelized cost @ $48/MWh ($/year)	$1,473,600,000
d	Number of MD households (census)	1,981,000
e	Wind annual cost risk per household	$744
f	Cost risk/household/month (no electricity sales) ($/mo)	**$62**
g	Overnight capital cost, CF=0.3	$21,900,000,000
h	Annual wind electric sales @ $35/MWh (row b*$35)	$1,074,500,000
i	Annual net cost (row c - row h)	$399,100,000
j	Net cost/household/month (cost risk - sales) ($/mo)	**$17**

This ROM estimate is that 50% onshore wind will increase Maryland household electric cost by $17 per month. This ROM assumes that all wind electric power produced is sold at PJM wholesale market prices ($35/MWh). The cost risk of $62/month is the bill that pays for wind regardless of whether or not electricity is sold, that is, even if the investment eventually becomes stranded. We note that beyond 50% wind generation costs increase much more rapidly than proportional due to curtailment.

Transition pace is important. $17/month is consistent with a gradual pace allowing existing power plants to gracefully retire. Forcing more generation on the grid than demand requires stresses existing power plants and increases household cost through shareholder ownership of distressed power plants.

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#3 - Overall risk assessments

Poor decisions can cause the clean energy transition to stall. Citizens rebel at high prices and refuse additional big investments. As a result, the transition gets stuck and the government entity becomes a long-term emitter.

The transition to a post fossil fuel economy is not simple or risk free. The type-for-t ype replacement cost of the existing US electric power system is approximately $5 trillion, $15,000 for every man/woman/child. Maryland's proportion based on GDP is about $200 billion. The total conversion of all energy sectors will be multiple times that amount. Long product cycles (50 years for power plants, 100 years for transmission) mean that serious mistakes can take a long time to repair.

Germany's Energiewende appears to have stalled with little carbon emission reduction. While Ontario Canada has successfully cleaned up their power grid , high electricity prices make it difficult to electrify other energy sectors. The "duck back" impact of solar PV on 10% of Oahu rooftops has forced Hawaii Electric Co. to limit connections. All 3 districts have either cancelled or constrained their RPS.

There are many ways to make poor decisions. Important lessons can be learned from a survey of other electric power systems (ISOs) around the world about their emission reduction programs. What are the successes and failures, lessons learned? As a minimum, this critical survey should include direct feedback from ISOs in Ontario, Hawaii, California, Germany, Denmark, Ireland, Australia and PJM...

- EMISSIONS - To what extent have these ISOs reduced CO_2 emissions? Have any ISOs achieved nearly zero (e.g. <40g(CO_2)/kWh) emissions? How? What do ISOs believe will be required to reduce system emissions to that level? What generation type is used to supply base-load in low emission ISO's?
- COSTS - What are total systems costs, both direct and indirect, of delivering electricity? What are electricity rates (without social costs and taxes)? Is electricity is being curtailed? By how much? How does curtailment depend on intermittent generator penetration?
- RELIABILITY - Have common-mode failures been experienced: extended periods of low wind, low sun, widespread storm damage, gas pipeline interruption? Have any ISOs received push-back from neighbors over backup demand? Have reliability compromises been experienced. Have reserve margins been increased? Has black start been a problem?
- POLICIES - What are ISO specific policy incentives for clean electricity? How effective are they? To what extent have incentives distorted markets? How effective is demand management? Can general guidelines be developed?
- MARKETS - Have incentives distorted markets? Do incentives raise costs to rate payers beyond the political entity imposing the incentives? How are capacity markets implemented? Does the ISO see a long term shift from energy to capacity based markets?

Risks can be identified and mitigated through disciplined planning. The purpose of the PJM Concept Definition Study is to clarify the cost/performance and risk of alternative whole system concepts as emissions approach zero. If the chosen goal is to reduce emissions by only 50% there are many technology options available. But the Greenhouse Gas Reduction Act implies the ultimate need for zero (<5%) emission electric power. This constrains the options. It is impractical for intermittent generators by themselves to meet this goal without seasonal storage.

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#4 – Stakeholders should demand feasible choices

Stakeholders are responsible for value choices; for choosing a path and a pace; for judging the relative importance of cost, performance and risk. Sound judgments require factual options. Stakeholders need to see how science and math constrains reliable electric power systems with little/no fossil fuel.

The low risk method for transitioning to sustainable energy is rational planning. Maryland's public works projects demonstrate the process; roles and responsibilities and the sequence of steps. An excellent example of the process is provided by the replacement of the Wilson Bridge.

1. Goal - The Executive role is to set the goal; everything flows from the stated purpose. For the Wilson Bridge, the Governors of Maryland and Virginia decided when replacement was necessary. For sustainable energy, Memo #1 argued that Maryland's 2016 Greenhouse Gas Emissions Reduction Act (GGRA) supersedes the RPS and any inconsistencies between the GGRA and the RPS should be resolved by the Executive.
2. Options – The Engineer role is to define feasible concepts. Professional Engineers agnostically apply science and math; indifferent to which technology is chosen so long as the choice is based on validated fact. The Wilson Bridge Concept Definition Study defined the cost/performance/risk of high bridge, low bridge, draw-bridge, and tunnel concepts. Likewise, for sustainable energy engineers need to define feasible electric power system configurations as emissions approach zero.
3. Choice – The Stakeholder's role is to demand factual options so they can rationally choose a path and a pace. While the Wilson Bridge engineers recommended a tunnel, stakeholders chose a drawbridge. $2.5 billion later we have a drawbridge. In contrast, sustainable energy does not yet have well defined power system choices. Around the world governments are guessing, betting on expensive solutions.

Intuition is a poor guide to the system impact of intermittent generators on electric power systems. Plug a wind turbine into a power grid with lots of fossil fuel generators and whenever the wind blows the grid operator can throttle back on the fossil fuel. The concept works great. But how does the system work without fossil fuel and prohibitively expensive seasonal storage? What technology starts/stops to backup wind? Ontario Canada found that the cheapest way to deliver reliable electricity to customers on a clean grid is to curtail (shut down) the wind when it produces energy out of alignment with load demand. This does not imply that wind has no value. Wind may have sustaining value as an intermittent generator for displacing fossil fuel in interruptible load markets such as fuel switching or hydrogen electrolysis.

Stakeholders should insist on factual options, a rigorous assessment of the cost/performance/risk of alternative system concepts as emissions approach zero. The PJM Concept Definition Study (§9.0, fig.5) illustrates such options and the types of results expected. Other investigators have asked the right question – how to get to zero? However, prior efforts have suffered from advocacy bias, inadequate model validation and inappropriate scope.

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Maryland can teach the world how to rationally develop sustainable energy systems by having the discipline to partner with other PJM States and do the requisite homework.

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#5 – The evolution of clean electric power markets

Clean generators change the cost basis of the electric power grid. The principle of aligning price with cost should cause electricity markets to evolve from energy markets (Watt-hours), to capacity markets (Watts) with further bifurcation into highly reliable markets and low cost interruptible load markets.

Fig. 1 shows the fixed and variable cost of different generation technologies (EIA). The fixed cost is the "mortgage payment" per million-watt-hours, a bill that must be paid regardless of how much electricity is consumed. Variable cost is primarily fuel cost and varies in proportion to the amount of electricity that is generated. Notice that all clean generators have little/no variable cost.

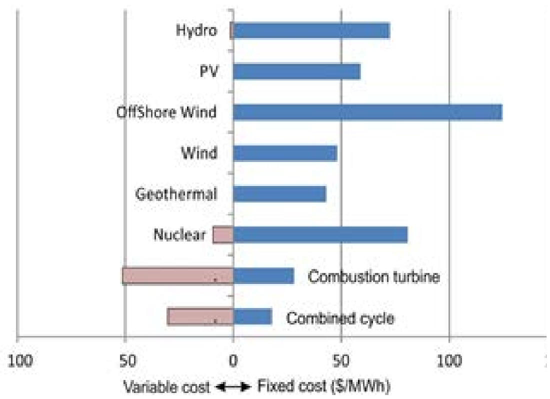

Figure 1 Fixed vs variable generation cost

Fig 2 shows the PJM2017 load with an annual peak demand of 146 GW. With clean generation capacity > 146 GW, the system can satisfy the high reliability load requirement. Since the variable cost is low, a system that can reliably satisfy peak load can also generate off-peak power at little additional cost. A second market will emerge for low cost clean power, available for displacing fossil fuel, subject to the constraint that the supplyer can interrupt power delivery.

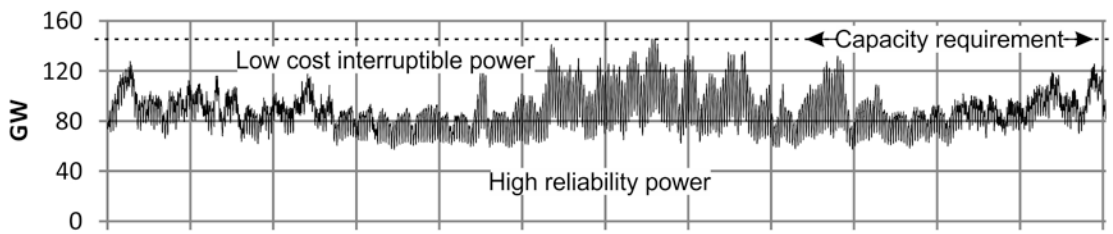

Figure 2 PJM load 2017

The objective of a wholesale market will be to reward generators for their ability to reliably deliver power during peak demand. Off peak, the market would be split into a high cost high reliability component and a low cost interruptible power component. On selling the power to the distribution utility, the wholesale market would add all fixed costs (transmission) to the high reliability component but not to the low cost interruptible power component.

The objective of the retail market would be to encourage consumers to level load and suppress peaks. Consumers requiring reliable power would be charged mainly on the basis of peak power consumption (kW) including fixed cost. Entrepreneurs with interruptible loads (fuel switching, hydrogen electrolysis, battery charging...) could contract to purchase electricity at a low price subject to the constraint that the electricity can be switched off/on by the supplier.

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The sequence is important. First design the system to determine cost structure, then design the market to align price with cost. These tentative ideas are expanded here.

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#6 – How to engineer a sustainable electric power system

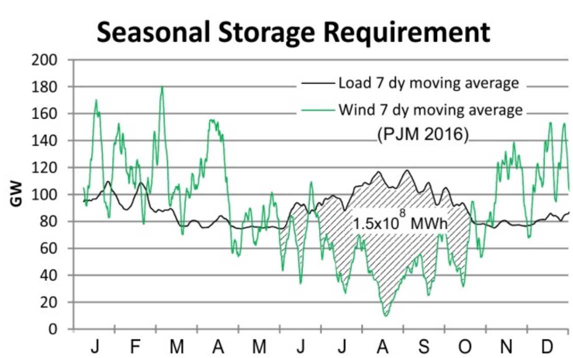
The professional development of an unprecedented system consists of three sequential steps:
1 Set the goal → 2 Define the options → 3 Choose one

RPS Memorandum #1 notes that Maryland does not have consistent clean energy goals. That Memo explains the requirement of a zero (or nearly zero) electric power system. A clear and stable goal is an essential constraint for rational system development.

Defining options is an engineering task. In building construction, this amounts to architectural sketches showing sizes, costs and the marketable features of different skyscraper configurations. In bridge building (eg. the Wilson bridge), engineers estimate the cost of meeting requirements with a high bridge, low bridge, drawbridge, and tunnel. For the Apollo Moon Project, engineers estimated mass associated with three options: 1- A big rocket launched form the surface of the earth to land on the moon then return; 2 – building a rocket in earth orbit, landing on the moon, then return; 3 – a lunar-orbit-rendezvous: earth surface to lunar orbit, drop an astronaut to the lunar surface, pick him up, and return to earth. What is impressive about Apollo is that NASA had the discipline to spend one year up front to clarify concepts before choosing. They made the correct choice and the rest is history.

For clean energy, concept definition starts with a blank sheet of paper and imagines what the world will look like without fossil fuel. Core carbon-free grid technologies are wind, solar, nuclear and storage. How do these concepts fit together in reliable affordable systems? Intermittency is a serious challenge to reliable system design because electricity generation from all generators of a particular technology type falls to zero at the same time. This happens every night for solar PV. Wind on the PJM system drops below 2% of nameplate capacity for a dozen hours per year, often during peak load.

Storage has been touted as a solution. For solar PV overnight storage flattens diurnal cycles, but it does not solve for the problem of sequential cloudy days. For wind, the adjacent figure shows that for PJM the storage requirement is seasonal and huge. Seasonal storage is theoretically possible but economically impractical. While intuition says that the wind is always blowing somewhere, a [2014 paper](#) combined wind production data from PJM and MISO (Midwest Independent System Operator) and found that wind production from the combined system still falls to almost zero.



Since peak loads determine the installed capacity requirement, it is important that models correctly portray the peaks and valleys; not just average production. Published models suppress volatility by assuming wind-load independence, and by spatial and temporal averaging. Only recently has enough good wind production data accumulated (5+ years) to rigorously validate models with real data.

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The next step in clean energy system development is a professional [PJM Concept Definition Study](#) to quantify the options as emissions approach zero.

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#7 – How large is the post fossil fuel transition?

It is important to have a sense of scale, of magnitudes. How big is the transition away from fossil fuel? Based on investment dollars, this transition is likely to be one of mankind's largest endeavors.

Joshua Rhodes estimates that the replacement cost of the US electric power grid infrastructure is about $5 trillion. The replacement cost assumes a type-for-type replacement of power plants, transmission and distribution lines, switchgear, substations and transformers. The estimate does not include wiring internal to buildings or electric meter interfaces.

The US Department of Energy's Energy Information Agency estimates total energy consumption by the US in 2017 as 97.7 Quads (quadrillion BTU) as shown in the adjacent figure. To arrive at a cost estimate for all energy sectors it is assumed that they are all electrified. That is the electricity sector replacement cost is scaled up on the basis of primary energy consumption; that the scaling factor is total primary energy consumption divided by electricity primary energy consumption (97.7/37.2 = 2.6).

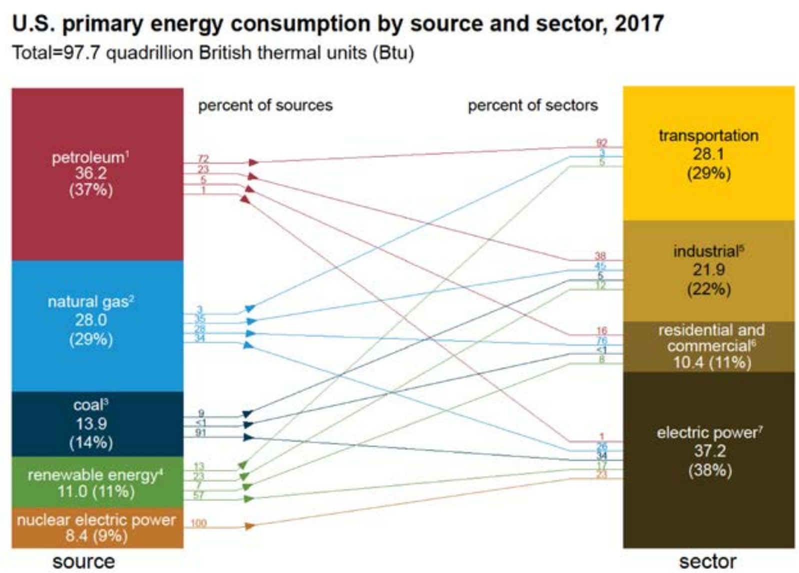

Figure 1 EIA US Energy Consumption

Total cost of transition away from fossil fuel is then estimated as:

$5T * 2.6 = $13T

Maryland's share, based on GDP scaling would be ~$200 billion.

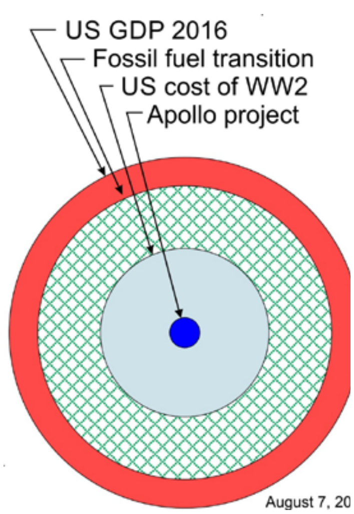

Figure 2 Scaled cost

$13T is conservative in that it excludes the cost to reconfigure the industrial and transportation sectors. Nevertheless, this is ~$40,000 for every man woman and child in the US. To put $13T in perspective, the adjacent figure compares the fossil fuel transition cost (green hatch) with the cost of other human endeavors scaled forward to todays' dollars using the Producer Price Index. The figure compares the relative cost of the total fossil fuel transition ($13 T); with the US cost of World War 2 ($4.3 T); and the Apollo Project ($0.14 T) and the US GDP for 2016 ($18.7 T). The fossil fuel transition is a huge endeavor and can cost substantially more than $13T if governments make serious mistakes.

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Be disciplined, do the homework and planning, and spread out the investment over time using replacement cost cycles

#8 – The PJM renewables scenario

The PJM load profile can be reliably satisfied by a system consisting of renewables plus natural gas generators. Key questions are: How much natural gas? Can the system eventually get to zero by continuing to add wind?

Professional engineers develop unprecedented systems by starting with a blank sheet of paper and with simple core concepts. Complexity is gradually added step by step. The core renewables concept is wind so start by looking at simple systems that consist of just wind plus natural gas.

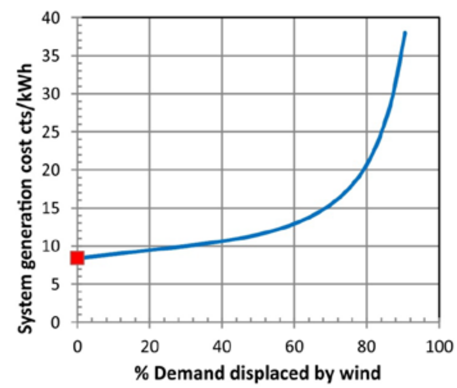

Figure 1 – Wind system cost

Fig. 1 shows the cost vs performance of a wind plus natural gas system for PJM. Details of how the figure was developed is detailed in §9 of the PJM Concept Definition Study proposal. The vertical axis shows the cost of the system generators, in cents per kWh. The horizontal axis shows wind penetration, the percent of annual demand that is satisfied by wind.

The red square represents an all-natural gas system. A new all natural gas system with no wind would cost about 8.5 cts/kWh. As wind turbines are added to the system, the % of demand displaced by wind increases and the generation system cost follows the blue curve. At low wind penetration, the curve slopes up to the right because, for the numbers used, the discounted capital cost of new wind turbines costs slightly more than the cost of saved natural gas. Most of the natural gas generators cannot be retired because it is needed to back up the wind turbines.

As wind penetration reaches 25% there are some hours (middle of the night, low load, high wind), when the wind electricity production exceeds demand. A few wind turbines need to be shut down (curtailed) for a few hours. As more wind turbines are added beyond 25%, more turbines need to be shut down and total installed capacity becomes less effective in displacing demand. At 50% displacement, curtailment becomes significant and the cost starts increasing rapidly. Wind cannot satisfy 100% of demand because all PJM wind production falls to zero for a few hours a year. If no wind turbines are generating electricity, all of the electricity must come from natural gas for those hours.

For this simple wind plus natural gas system, wind can reduce emissions by 50% before costs start increasing rapidly and cannot reach 100%. Standalone wind is not a reliable system.

But what about more complex systems with storage, solar, long distance transmission, geographic diversity, and offshore wind? It is theoretically feasible to build a reliable zero emission PJM system with seasonal storage. The question is at what lifecycle cost? Is the complex system economically practical? The answer to this question is one objective of the proposed PJM Concept Definition Study.

Fig 1 was developed from load and scaled wind production data. Scaling assumes that new wind turbines are located with the same foot-print as old wind turbines (or the exact location makes little difference). The other approach, common in the literature, is to model wind production starting with meteorological wind data and wind turbine power curves. Modeling is a sound approach provided that models are validated, rigorously shown to correctly reproduce empirical averages and curtailment.

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#9 The Nuclear fission scenarios

Visible nuclear power plants (Generation II technology) are large scale versions of reactors originally designed for ships and submarines. In the 1950's Adm. Rickover adapted a military reactor for commercial use at Shippingport PA. President Eisenhower declassified the technology and the utilities replicated designs to leverage the military investment. Some consequences of simply increasing the size of naval designs are that large cores are more susceptible to melt-down and pressurized-water cooling requires large structures to contain steam in the event of an accident.

Gen III reactors, available since CY2000, are an evolutionary improvement of Gen II designs: better fuel technology, thermal efficiency, passive safety systems and standardization. Gen IV reactors, currently under development, are the first generation designed and optimized for civilian requirements. They include such technologies as sodium cooled fast neutron reactors, high temperature gas reactors and thorium fuel cycles. Small modular reactors are factory built, either Gen III or Gen IV technology.

Sustainability – Gen II technology burns the fissile isotope U235 (0.7% of uranium ore). This is not sustainable as proven uranium reserves can power 100% of civilization's current needs for only a few decades if only 0.7% is used. Burning spent fuel in "fast neutron" reactors burns the remaining 99% and extends proven reserves to thousands of years. On civilization's time scales this is sustainable. Furthermore, there is enough uranium in sea water to power the planet indefinitely.

Safety – Public fear of radiation and nuclear reactors is at least partly irrational. While there have been worker deaths, no civilian deaths from radiation exposure at Three Mile Island, Chernobyl, or Fukushima have been clearly documented. Emotional trauma from evacuation has been a problem. Large number projections of ultimate death and cancer are based on the Linear No Threshold (LNT) assumption for biological damage. Improving research indicates that LNT may be too pessimistic at low radiation dose. New technology is less accident prone than old designs and the nuclear industry has an excellent safety record compared to other energy sources. Public perceptions can be expected to change with time, safe performance and new human generations.

Spent fuel disposal – Spent fuel from US Gen II reactors consists of 96% uranium, 3% fission products (elements with ~½ the molecular weight of uranium), and 1% actinides (new elements created by absorbing a neutron). Most fission products have a short half-life so letting the spent fuel cool to stable isotopes in a cask on the reactor site for 30 years is a sound strategy. The uranium and actinides can then be reprocessed to fuel fast neutron reactors. Also, there is a bill in Congress to allow reactor waste burial at New Mexico's Waste Isolation Pilot Plant.

Nuclear power system design –Ontario Canada successfully transitioned to 96% carbon free. One lesson is that nuclear is the low carbon work horse. Also the 6% of total consumption that was generated by wind is after 2/3 of the wind was curtailed or exported at discount prices. Defining PJM Options will require a PJM Concept Definition Study.

Nuclear	63%
Hydro	26%
Gas	4%
Renewables	7%

Ontario electricity mix 2017

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Nuclear fission has enormous development potential.

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#10 Lessons learned from other systems

Since the magnitude of a transition to clean electric power systems is so large (Memo #7), it is important to conduct a survey to better understand risk: What is working? What is failing? Why?

The main metric is the reduction in CO_2 emissions in grams per kilowatt-hour over the past decade. Also of interest is the absolute level of CO_2 emissions, cumulative investment over the past decade, current residential retail prices, grid reliability, technical issues, and policy effectiveness. At a minimum the survey should include the following systems:

- *Ontario* is the only grid that has successfully transitioned from 300g(CO_2)/kWh (CY 2000) to 21 gm(CO2)/kWh (CY 2017). Ontario is now 95% carbon free. How did they do it, what is the cost, and what are current challenges?
- *Germany* clean energy development has stalled. While they have 35% renewables, residential electricity rates are €0.38/kWh and ratepayers have refused additional big investments. What are Germany's choices going forward?
- *France* has had a predominately nuclear system since the 1970's. How effective has the additional wind generation in France been compared to France's nuclear program for continued CO_2 reduction?
- *Denmark* claims a 2017 record, generating 43.4% of its electricity from wind. The remainder from dispatchable backup, mainly fossil fuel. But to what extent do they rely on neighbor imports?
- *Scandinavia* (Sweden, Norway, and Finland) has primarily hydro power grids. What is the role of intermittent renewables and interties? How are they backed up?
- *California* has been a US leader and renewables test bed. Today they are seeking huge amounts of peaking energy imported from their neighbors. Is this practical? How successful are they in terms of emission levels and electricity prices. Can large users still get dependable supply?
- *Texas's* ERCOT is an experiment in energy-only markets. Is this market incentivizing adequate capacity? What is the long term reliability risk?
- *Hawaii* is islanded, but all power systems are bounded at some scale so important lessons can be learned from Hawaii. Solar has a penetration of ~9%. But Hawaii has stalled, the Public Utilities Commission ended their net metering program substantially slowing solar growth. What are the perceived options for the system to get to zero emissions?
- *Ireland* currently gets 24% of its electricity from wind and the backup is natural gas. Is this a limit from the perspective of residential prices?
- *Australia* had a September 2016 blackout followed by two others in December and February. While the root cause was storm damage to the transmission system, wind farm interfaces may have contributed to the cascade and the difficulty restarting. What are lessons learned?
- *Other* systems that may provide useful information are Quebec, Pacific Northwest, Brazil, Puerto Rico, developing nations ...

The survey is likely to conclude that, without a plan, the main risk is that the system development gets stuck. Electric power bills exceed ratepayer tolerance causing stakeholders to refuse additional large investments. Progress stalls and the system becomes an indefinite CO_2 emitter.

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#11 Transmission is not free

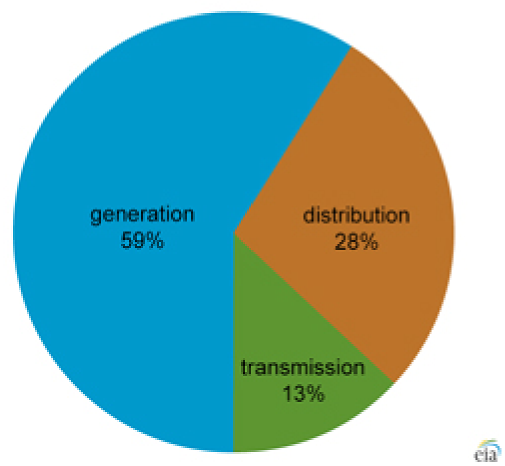
The pace by which renewables can be added to a system is limited by available transmission; no transmission, no new generation. Rooftop solar and distant wind & solar have different constraints.

There is no "free" transmission. The legacy electric power system is a "system" where each component is designed and sized to serve a purpose. A small amount of new generation can be added to the legacy system with only modest compromises in reliability and operations. Larger, distant installations would require costly time-consuming transmission upgrades during which few additional generators could be added.

PJM is highly transmission constrained. While PJM has three regions for locational marginal pricing, it is subdivided into 27 locational delivery areas based on transmission limitations.

PJM wind increased by 65% over the past 6 years to a total of 2.7% of the electricity generated on the PJM system in 2017. While the compound annual growth rate for wind was 9%, the total is still small with little impact on operations. It is difficult to determine the extent to which this growth is constrained by transmission because PJM keeps adding new territory. Eventually wind growth will slow then stall until new large scale transmission is built. The threshold at which new development stalls is unclear and requires a PJM Concept Definition Study.

Major components of the U.S. average price of electricity, 2017



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2018*, February 2018, Reference case, Table 8: Electrical supply, disposition, prices, and emissions

Rooftop solar with a few hours storage is co-located with user load and provides the system with capacity value. But cost effective penetration level is unknown, perhaps 5%. Below that solar penetration level the impact on long distance transmission would be minimal and would be compatible with legacy transmission.

Depending on location, grid scale ground mounted solar could create problems for both local distribution systems and long distance transmission. There has been land use opposition to this type of installation.

Wind energy from Appalachia and Midwestern states delivered to east coast load centers would require substantial new transmission lines. The cost of this transmission can exceed generation cost due to the magnitude of the power, long distances and low capacity factors. Political opposition to transmission passing through a state without benefiting that state would likely be intense. New transmission can take a decade or more to complete.

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The cost of a new technology is the difference between the cost of the whole system with and without the new technology. Rather than guessing at thresholds and growth rates, a rational approach would be to model a PJM renewables scenario as recommended in the PJM Concept Definition Study. This approach would quantify thresholds and costs. Growth rates would be a stakeholder choice.

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#12 – Maryland's role and responsibilities

Motivated by sea level rise, air pollution from Midwest fossil fuel plants and a passion for sustainability, Maryland is committing tens of billions of dollars to its RPS program (RPS Memo #5). This commitment imposes the responsibility to be professional; to base decisions on evidence and risk.

The modern electric power system was invented by vertically integrated electric power utilities. Employing strong multidisciplinary engineering teams, these utilities invented all aspects of the system from generation through transmission to consumption. By 1960 the system architecture stabilized, development skills atrophied, and the utilities became system operators. Systems grew in size. Physically larger systems are more efficient as many independent generators improve reliability and many loads smooth out the load curve. But utilities that span State boundaries are difficult to regulate.

PURPA (the Public Utility Regulatory Policies Act of 1978) broke up the vertically integrated electric utilities and imposed federal regulation. Around the world today, the electric power industry has many specialized players each with narrow responsibilities. The system integrators are gone. The resulting decentralized management structure works well so long as nothing changes:

- ISO – Independent system operator; responsible for operating the wholesale market
- RTO – Regional transmission operator; responsible for high voltage transmission infrastructure
- LSE – Load serving entities, responsible for operating the lower voltage local distribution systems
- Generators – Competitive commercial electricity generators
- High voltage transmission – A regulated monopoly
- PSC, FERC, NERC, DoE, NRC, ARPA-e, NREL, NSRB, professional associations ...

The introduction of intermittent wind and solar generators changes the power system architecture. Intermittent generators are not interchangeable with fossil fuel plants; the system still needs to deliver reliable power when there is no wind/sun. There is a need for new system concepts, a different interplay of generation, storage, backup, transmission, loads and market design. Wind has value when it can displace fossil fuel, but it has no value when the system has no fossil fuel. Who is responsible for overall coordination?

To make sound choices, stakeholders need to see whole system concepts for reliable affordable electric power without fossil fuel. How do renewable systems compare with nuclear systems? Is there a useful mix? How much does a little fossil fuel (say<10%) reduce system cost? There is no single organization responsible for addressing these overarching questions. Meanwhile Maryland is committing future ratepayers to pay $2.3 billion for 2 offshore wind farms and much more for its RPS. What needs to be done is clear; efficient, professional engineering development consists of three sequential steps:

Set the goal → explore the options → choose a path and pace

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Maryland's Greenhouse Gas Reduction Act recognizes the IPCC finding that emissions need to be reduced by 80-95% overall. Maryland needs to clearly state this as an ultimate goal along with the implication of (nearly) zero emission electric power. Furthermore, Maryland needs to lead a PJM Concept Definition Study so that its stakeholders can make rational system choices based on trustworthy factual options.

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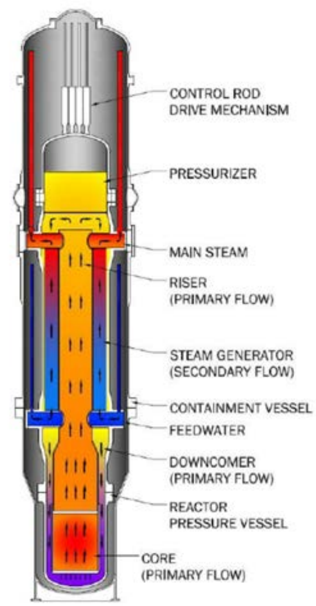
#13 Small Modular Reactor (SMR) value proposition

The driving force behind the SMR concept is the manufacturers' learning curve. Every time cumulative production doubles, unit cost drops by 15% (like Moore's Law). After first mover costs are overcome, SMRs have the potential to become the lowest cost source of reliable power.

SMRs are factory-built and truck-transportable nuclear fission power modules. They generate steam to drive turbines generating electricity. Their size is nominally 100 MWe, about 1/10 the size of commercial nuclear reactors and similar in size to reactors built to power ships and submarines. A commercial power plant might consist of a dozen modules. The value proposition is:

- Labor cost and risk is reduced through quality assured fabrication and testing in environmentally controlled factories rather than on-site fabrication.
- Smaller is simpler and safer when it comes to residual heat management. US Navy reactors have accumulated 5,700 reactor years of safe operations.
- Modular construction reduces financial risk and cost. Power plant capital investment can be staged; construction time is reduced.
- Standardized high volume fabrication reduces cost. With a 15% learning curve (in the aircraft industry cost is reduced by 15% every time cumulative production doubles) the cost of the 96th module should be 60% the cost of the first 12. This is a powerful trend. With proper cost control, these modules will become inexpensive.
- A power plant consisting of multiple modules has the flexibility to be sized to suit the location and power system requirements.
- SMRs can repower retired fossil fuel sites and independent micro grids. Advanced designs can be located near population centers so waste heat can be used for district heating.



NuScale (9' x 65')

Gen III reactors were introduced in the 1990's as evolutionary improvements to the 1970s Gen II designs. The first generation of SMRs will be smaller scale versions of Gen III. Downsizing proven architectures to truck transportable modules is relatively simple because it builds on decades of technology development, design and regulatory experience. NuScale is the SMR leader with NRC certification expected in 2021. NuScale's proposed first power plant consists of (12) 60 MWe modules and they estimate cost to be $3 billion ($4,200/kW). This first plant is scheduled to become operational at Idaho National Labs in 2026. Other Gen III SMR companies are Bechtel-BWXT, GE-Hitachi and Holtec.

Gen IV SMRs get interesting. Fast neutron reactors consume the actinides meaning there is little long-lived radioactive waste. Liquid metal cooled versions have no high pressure water, hence no risk of steam accidents. High-temperature gas-cooled reactors can be used for chemical and industrial applications. These reactors could be located near population centers and waste heat can be used for district heating further reducing system costs. There are many interesting variations for displacing fossil fuel in addition to electric power.

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While Gen IV reactors require more development time they also provide a sustainable path to meeting long range emission targets.

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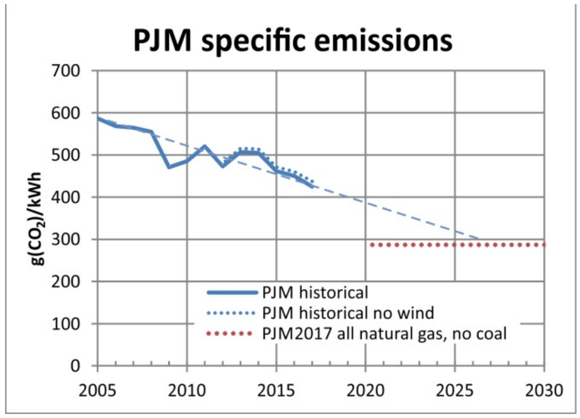
#14 PJM System transition

Physics and economics provide strong constraints on the transition of the electric power system to one with little fossil fuel. Big immediate emission reduction comes from continuing to replace coal with natural gas. Policy should be consistent with these constraints.

For over 10 years, the combina tion of environmental regulation plus cheap natural gas has been driving coal plants off the grid. The adjacent figure (historical data is from PJM) shows that this shift from coal to natural gas has caused a real decline in PJM carbon dioxide emissions (the solid blue line). Nationwide, electric power emissions follow a similar trend. If all the PJM coal plants were replaced by natural gas, the resulting PJM emissions would fall to about 290 g/kWh (the horizontal red dotted line). At the present 2.7% penetration, the contribution of wind to this decline has been small (about 8 g/kWh). The blue dots (above the solid blue line) indicate what emissions would have been without existing PJM wind.



Emission reduction from the replacement of coal by natural gas is a powerful, near term, economically driven trend. Policy can encourage this trend by supporting adequate pipeline expansion as well as temporarily supporting financially challenged nuclear plants. Closing nuclear plants would reverse this trend. Longer term, natural gas will play a reserve role for clean systems. Eventually natural gas would be replaced by a mixture of clean energy technologies.

Electricity prices might remain low for decades. The Energy Information Agency projects electricity demand growth to be low, < 1%/yr (less than GDP) through 2050. Eventually, electricity demand will increase as a result of exhausted efficiency measures and electrification of other energy sectors, such as transportation (electric vehicles). The EIA projects little demand growth for the next few decades. Also, barring a serious fracking accident, EIA projects natural gas prices to remain cheap (<1% growth) through 2050. Low growth and low natural gas prices mean that electricity prices will remain low.

During this gas era, markets cannot be relied upon for sound guidance. Memo #5 explains why wholesale markets will change as clean generators with high capital cost and low operating cost are added to the system. We also expect a second market to emerge for intermittent generators and interruptible load. Policy innovations will be necessary to incentivize the transition and control its pace. It is important to distinguish between temporary support to overcome first mover risk, and physical constraints such as intermittency (no-wind-no-sun-no-power) that require dispatchable generation to support grid reliability. A PJM Concept Definition Study would provide stakeholders with factual choices for choosing different system designs and alternative system architectures.

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Transition policy needs to be consistent with physical and economic constraints.

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