Paving The Path to 100%

Path to 100%

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The world is moving quickly towards renewable energy as the new baseload, with many cities, states, provinces and utilities committing to 100% clean energy. However, in a world where electricity demand must be met around the clock, variable renewable energy sources are not always available. For example, the wind doesn't always blow, and the sun doesn't always shine. These variable resources don't work well with our current system of large, inflexible power plants that can take hours— or even days — to switch on and off. They were not built to keep up with fast-growing amounts of variable wind and solar energy.

These large traditional plants must stay on and emit carbon for reliability purposes, even when doing so is uneconomic. They are often kept online at partial loads to provide ramp capacity to compensate for solar and wind drop off periods.

At the other end of the extreme, there are already places — such as California and Germany — where the sun and wind sometimes generate more electricity than existing power systems can handle. This excess energy is called overgeneration, and is often wasted, or curtailed. In some cases, asset owners have to either give this excess energy away or pay utilities in other states or countries to take it.

Decision-makers must address the fact that the electricity system we have today was not built for a 100% renewable energy world. When it comes to making decisions about policy, technology, and investment, they need to choose options that help power systems evolve to accommodate ever greater amounts of energy provided by solar and wind. These choices must consider the consequent reduction in fossil-fuel use, and the need for flexibility rather than the traditional "baseload" or "peaking" resources.

To address the economic, scientific, and political challenges surrounding the decarbonization of electricity, Wärtsilä created the Path to 100% initiative. The Path to 100% brings together thought leaders and industry experts to discuss solutions, raise awareness, and discover operationally and financially realistic approaches to building a 100% renewable energy future — not just city by city, but across entire states and nations.

The following case studies demonstrate why it is beneficial to model different scenarios and capacities to find ways to optimize energy systems and future-proof assets with flexibility to integrate renewables and secure reliability as utilities transition from fossil fuels to renewables as a new baseload.

PNM Resources-New Mexico

PNM Resources, an investor-owned utility, is the largest electricity supplier in the state of New Mexico, with a peak load of approximately 2 GW and serving more than 500,000 customers. PNM's publicly available data shows a capacity mix reflective of US national averages. Like many utilities PNM had a legacy reliance on coal. In March 2019 the State of New Mexico passed the Energy Transition Act (ETA), which set goals of 80% and 100% carbon-free energy from investor owned utilities by 2030 and 2045 respectively. On Earth Day, April 22, 2019, PNM announced it would meet the 100% requirement by 2040, five years ahead of the Renewable Portfolio Standard (RPS) requirement.

The capacity mix of PNM is representative of the U.S. Utility Industry, and their aggressive renewable goals place them at the forefront of utilities willing to take on the challenge of 100% carbon-free. Therefore, PNM is a prime use case to explore questions relevant to the electric utility industry. Publicly available documents, such as Integrated Resource Plans, were used to create a model of PNM assets using PLEXOS™. The model was parameterized with new build capacity choices, fuel prices, load expectations, and other information needed to explore possible future trajectories of utilities like PNM. Future trajectories and costs were estimated using PLEXOS for long-term capacity expansion analyses in "chronological" mode and with hourly time resolution to capture the variability of wind and solar as well as the consequent flexibility needed. The modeling horizon was from 2020 to 2040.

Four scenarios were explored:

1. **Unconstrained** - the buildout was optimized to provide lowest cost over the horizon but without forcing RPS compliance
2. **100% Carbon-Free** - Full RPS compliance, new thermal allowed across the horizon but all thermal retired by 2040
3. **100% Carbon-Free no new thermal** - Full RPS compliance and only solar, wind and battery storage allowed for new-build capacity to replace retiring thermal
4. **100% Carbon-Neutral with Power-to-Gas (PtG)** - Replacing the "Carbon-Free" RPS requirement with allowance for some "Carbon-Neutral" power generation

In the C-Neutral with PtG scenario, excess renewable energy, or overgeneration, could be used to create synthetic carbon-neutral methane using electrolyzers for hydrogen, direct-air-capture of carbon, and a methanizer process to combine H2 and CO2 into CH4. The synthetic methane thus produced is "carbon-neutral", in that any CO2 released from combustion was initially taken from the air, resulting in no net increase in atmospheric CO2 levels.

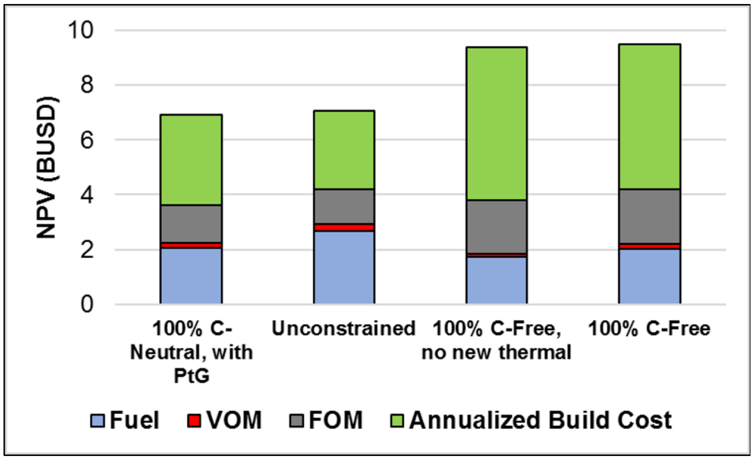

Figure X: Annual generation by resource type for 4 scenarios in the year 2040

Figure X shows the annual generation in 2040 by source for the four scenarios. The C-neutral with PtG had the largest proportion of load served by renewables, as the PtG process itself (a new load) absorbed overgeneration. This fourth scenario also had thermal generation serving load for reliability purposes using carbon-neutral synthetic gas. In comparison the two C-Free scenarios transferred considerable energy to short-duration battery storage, which served a greater proportion of load than the C-Free with PtG. The unconstrained scenario had the smallest energy needs as the additional load from either battery-storage or for PtG was simply uneconomic and not needed.

In terms of cost, Figure Y illustrates the expenses ranked from lowest to highest across the four scenarios, in terms of total NPV cost across the 20-year horizon. The 100% C-Neutral with PtG scenario was actually the lowest cost option, even slightly lower than the unconstrained case. The reason for this was the unconstrained case was not given the option of anything besides fossil-gas and was reliant on it throughout the horizon. Of note, the unconstrained case had 80% carbon-free generation in 2040, and thus the C-Free cases, both at significantly higher cost, demonstrate the cost of going from 80% carbon-free generation to 100% carbon-free using only solar, wind, nuclear and batteries. The higher cost of C-Free is due entirely to the overbuild of solar, wind and battery storage systems needed to meet RPS compliance. The cost-competitiveness of the C-neutral with PtG scenario illustrates that renewable fuels have promise in terms of maintaining reliability, avoiding costly overbuilds, and give utilities options to install flexible thermal at any time knowing they will never become a stranded asset and will be part of the 100% decarbonized future.

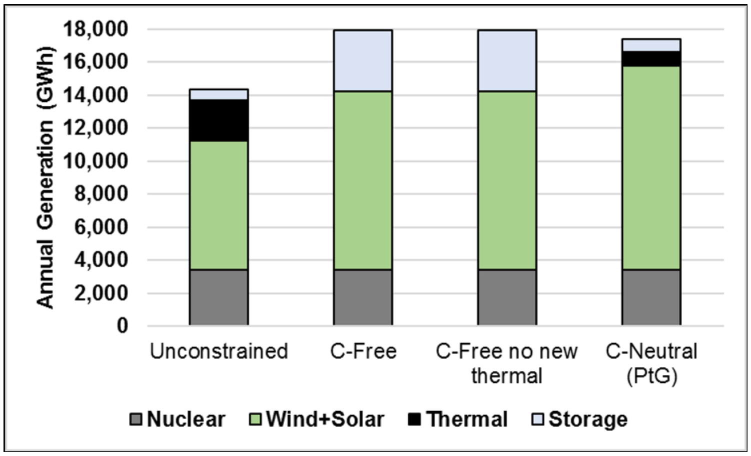

Figure Y: Costs ranked from smallest to largest across the four scenarios

Power-to-Gas

Flexible thermal generation is more efficient than traditional peaking assets and less expensive than traditional baseload assets, which can offer the ideal mix of cost and performance to attend to the volatility of high-renewable penetration. Power-to-gas (PtG) offers a way to absorb excess renewable energy and transform it to renewable fuels which can be stored indefinitely. These fuels can be then burned in flexible generation.

Power-to-gas (PtG) is defined as the process of using excess RES energy, MWh that would otherwise be curtailed, to produce renewable fuels. The first such fuel to consider is methane, produced through the power-to- methane, or PtM process. PtM produces carbon-neutral CH4 (methane) via a three-step process.

1. Direct Air Capture (DAC) of CO2 from the atmosphere as a source of carbon
2. Electrolysis of water as a source of hydrogen
3. Methanation to combine carbon and hydrogen into CH4

The final molecule, CH4 (methane) can be stored and transported in existing natural gas infrastructure and used in households, industries and power plants by any thermal technology that can burn natural gas. Carbon is recycled from air, so combustion of PtG methane is net-zero, or carbon-neutral, with no increase in atmospheric CO2 levels.

Power-to-Hydrogen

Power-to-hydrogen (PtH) is an alternate PtG pathway. Power-to-hydrogen requires only electrolysis, where electrolyzers use excess renewable energy to produce hydrogen (from water) for direct use as a fuel. Hydrogen production with PtH is less expensive than PtM and more efficient as there is no need for carbon DAC or methanation. In addition, hydrogen as a fuel is carbon free. Complexities arise as there is, unlike the existing infrastructure for methane, no comparable hydrogen infrastructure. Thermal power plants designed to burn methane typically cannot burn 100% hydrogen. Existing gas storage facilities, pipelines, compressor stations and distribution lines typically cannot handle 100% hydrogen without expensive upgrades, if not complete replacement. Still, hydrogen is an efficient and carbon-free alternative to renewable synthetic hydrocarbons and is worth investigating. Power plant technology manufacturers seem to understand this as many of them are in the process of developing technologies that are fueled by 100% hydrogen.

Why Power-to-Gas?

Fuel produced by PtG can be stored indefinitely and is the equivalent of fully charged “cells” in a Li-Ion battery storage system. Thermal power plants become the “inverters”, taking stored renewable energy and converting it to MWh. In power system operations renewable energy will serve the majority of load, traditional storage (e.g., batteries) will handle day to day balancing, and PtG coupled with the thermal fleet provides longer term balancing (e.g., seasonal) and reliability (e.g., generating MWh when unforeseen weather leads to days or weeks of little to no solar that cannot be managed with traditional, shorter term storage).

Traditional energy storage systems, ranging from Li-Ion batteries to pumped hydro, rarely exceed durations of 12 hours while seasonal weather-related events in renewable dominated systems can easily lead to far longer periods of diminished renewable outputs. Storage must cover the differences, and a diversified portfolio of storage optimized for different timescales is an optimal choice.

California

At present Californians pay some of the highest prices for electricity in the nation (Daniels, 2017). As California moves towards aggressive decarbonization, the state faces the challenge of doing so in the most cost-effective manner. As with any optimization problem, adding more choices, or degrees of freedom, often results in better solutions than those obtained with a narrower range of choices. The results for the Optimal Path and especially the introduction of PtG demonstrate this concept, as the Optimal Path allows the simulation to unlock the value of thermal capacity in a 100% carbon-neutral future.

In the Optimal Path scenario, excessive wind and solar electricity is used to power the direct air capture (DAC), electrolysis and methanation (collectively "PtM") for production of renewable methane, throughout the year. Production is maximized in mid-year when solar and wind outputs typically peak. Thermal generation using this carbon-neutral fuel is used mostly in the winter months (December through February) with some sporadic generation in late summer and fall. The renewable gas storage is charged with gas during spring and early summer to provide fuel for fall (Sept-October) and winter (Dec through Feb) carbon-neutral thermal generation.

The renewable capacity and PtG process are dimensioned so that enough carbon neutral fuel can be produced for Californian power system annual needs.

The PtM fuel storage need is approximately 15% of the total underground gas storage in California, or rather the existing storage capacity is 6.7 times greater than the fuel volumes needed for the Optimal Path. If the existing underground gas storage capacity in California was filled with renewable gas from the PtG process, the 32 GW x 240 hours would instead have a duration of 1,600 hours (67 days). There is potential for California to optimize stored gas volumes for reliability purposes. Similar can be envisioned for hydrogen, assuming hydrogen infrastructure is in place to move hydrogen from storage facilities to power plants.

Overall the combination of long-term renewable carbon neutral fuel storage coupled with thermal capacity has direct parallels with battery storage (Figure 9).

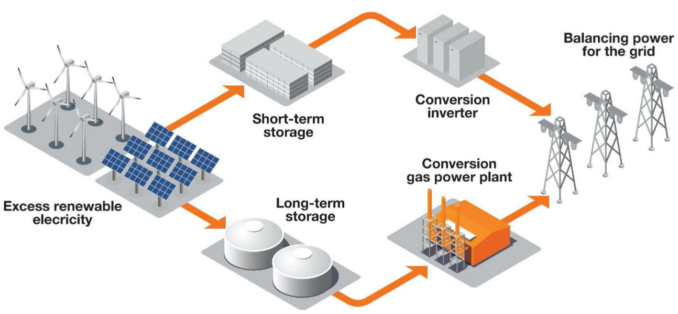

Figure 9: Renewable energy can be stored in short term batteries or converted to renewable PtG fuels for long term storage.

Planning Ahead:

Paving the path to 100% requires a plan which includes renewable, affordable and reliable storage and transition from fossil fuels to flexible generation. Furthermore, the plan should include ongoing transitions from flexible gas to synthetic renewable fuels. This option provides a solution for seasonal energy shifting as well as coverage of inclement weather scenarios, such as days to weeks of dramatic reduction in wind or solar output simply due to weather. The key then is to marry these renewable fuels to efficient and flexible generators capable of balancing volatile renewable energy sources. These generators have the ability to start multiple times per day, ranging from seconds to minutes from start to full load. Multiple starts can be done daily with no maintenance impact. Each unit can sustain minimum stable loads of 10%, making them ideal for balancing VREs in real time. Power plants can be built in modular blocks of approximately 10 to 20 MWs, for plants ranging in size from 10 MW to 500+ MW. Modularity also allows utilities to avoid "lumpy" investments. As these plants transition to renewable fuels, they will be part of the 100% renewable system instead of becoming stranded asset liabilities.