100% Clean By 2050: What does it look like?

Dr Christopher T M Clack
Vibrant Clean Energy, LLC

Energy Systems Integration Group
Spring Workshop: Virtual Meeting
March 2nd, 2021

Disclaimer:
This presentation has been prepared in good faith on the basis of information available at the date of publication. The analysis was produced by Vibrant Clean Energy, LLC. No guarantee or warranty of the analysis is applicable. Vibrant Clean Energy, LLC will not be held liable for any loss, damage, or cost incurred by using or relying on the information in this presentation.
Purpose of Vibrant Clean Energy, LLC:

- Reduce the cost of electricity and help evolve economies to near zero emissions;
- Co-optimize transmission, generation, storage, and distributed resources;
- Increase the understanding of how Variable Generation impacts and alters the electricity grid and model it more accurately;
- Agnostically determine the least-cost portfolio of generation that will remove emissions from the economy;
- Determine the optimal mix of VG and other resources for efficient energy sectors;
- Help direct the transition of heating and transportation to electrification;
- License WIS:dom® optimization model & data and/or perform studies using the model;
- Ensure profits for energy companies with a modernized grid;
- Assist clients unlock and understand the potential of high VRE scenarios, as well as zero emission pathways.
Motivation (Climate Requirements)

Mid Miocene (15-17 million years ago)

Historical Global Temperatures 4-5°C higher than today

Historical Temperature Analysis:
https://www.nature.com/articles/s41598-020-64743-5
Motivation (Energy Requirements)

This is equivalent to 29.4 PWh (29,400 TWh)

= 19.8 PWh

= 9.6 PWh
The Whole Economy Needs Clean Energy

- A. Wind
- B. Solar
- C. Natural gas/biomass/gyngas w/ capture
- D. Other centralized energy storage (e.g., thermal, batteries)
- E. Hydropower/pumped storage
- F. Compressed air energy storage
- G. Nuclear
- H. Hydrogen/synthetic gas
- I. Direct Air Capture
- J. Geologic storage
- K. Cement w/capture and all. Steel
- L. Biomass gas/liquids
- M. Synthetic gas/liquids
- N. Direct solar fuels
- O. Ammonia plant
- P. Electrolysis
- Q. Demand for highly-reliable electricity
- R. Demand for industrial materials
- S. Demand for aviation and long-distance shipping

CO₂

C₅H₁₀O₂

NH₃

H₂
Available Clean Generation Are Tied To Electricity

Low-marginal Cost Electricity Production Resources (kWh)

- Wind
- Solar
- Geothermal
- Nuclear
- Hydroelectric

Flexibility Resources (kWh → kW → kWh)

- Transmission
- Hybrid Resources (wind+solar+storage)
  - Storage (electricity+heat)
  - Electrification
  - Direct Air Capture
- Demand-side management
- Dispatchable Generation (SMR, EGS, H₂ CC, NGCC+CCS)
- Synthetic Fuel/Chemical Production (H₂, CH₄, NH₃)
- Peaking Generation (H₂ CT)
Demand For Electricity Will Necessarily Grow

- ZBF 2050 TWh with synthetic fuels & products (11 PWh)
- ZBF 2050 TWh with RCP4.5 climate change impacts (8.9 PWh)
- ZBF 2050 TWh without climate change impacts (7.8 PWh)

https://www.nrel.gov/analysis/electrification-futures.html
Demand Profiles & Stress Periods Will Change Over Time

* Before synthetic fuel production
Wind (a fuel of the future economy)
Solar PV (a fuel of the future economy)
We Need to Embrace & Design With Variability in Mind

* Preliminary VCE® 175-year resource dataset
Results from Zero By Fifty (ZBF)

Note: this is a possible pathway, not the pathway
Pollution and GHG Emissions

Economy-wide GHG emissions reduced by 65% from 2018 levels
Don’t build new gas except for replacing older versions

Build enormous amounts of wind, solar and storage

Prepare (R&D) and then deploy new technologies (nuclear, EGS, H2 turbines)

Keep GTs for reliability & emergencies

Annual Cost by 2050
~$410 billion
Alternative Installed Capacities (100% VRE+HVDC)

Double the Capacity Required

Capacity deployments exceed other scenario by 2040

All reliability provided by transmission and storage

Annual Cost by 2050
~$1,000 billion

WIS:dom Installed Capacities For The United States

info@vibrantcleanenergy.com
Wind and solar will produce greater than 50% of energy needs

Novel generation could supply up to 50%

Transmission & DACs can alter these trajectories

Limitations are space, materials, manufacturing & correlation effects
Alternative Generation Stack (100% VRE+HVDC)

Curtailment reaches 15% of demand

Much more generation to power storage and move around transmission system

Natural gas rises in the near term because of reliability issues
Deployments & Retirements

<table>
<thead>
<tr>
<th>MW</th>
<th>Coal</th>
<th>Natural Gas</th>
<th>Nuclear</th>
<th>Storage</th>
<th>Hydro</th>
<th>Wind</th>
<th>Solar</th>
<th>Other</th>
<th>Storage MWh</th>
<th>MaxLoad</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020 - 2035</td>
<td>-238,934</td>
<td>-125,885</td>
<td>17,565</td>
<td>105,709</td>
<td>5,783</td>
<td>491,724</td>
<td>345,984</td>
<td>59,498</td>
<td>730,293</td>
<td>125,775</td>
</tr>
<tr>
<td>2035 - 2050</td>
<td>-5,351</td>
<td>-343,709</td>
<td>371,772</td>
<td>260,184</td>
<td>1,292</td>
<td>427,727</td>
<td>408,515</td>
<td>65,348</td>
<td>3,548,550</td>
<td>397,096</td>
</tr>
</tbody>
</table>

Historical Average Net Installation Rate is 0.48 kW / s
# System Cost Components

<table>
<thead>
<tr>
<th>Year</th>
<th>Generation Fixed</th>
<th>Generation Variable</th>
<th>Distribution</th>
<th>Transmission</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>$161,879,856,147</td>
<td>$57,729,389,022</td>
<td>$81,199,860,452</td>
<td>$3,619,412,641</td>
<td>$74,038,326</td>
</tr>
<tr>
<td>2035</td>
<td>$150,096,807,234</td>
<td>$48,890,441,196</td>
<td>$93,866,444,801</td>
<td>$2,801,320,778</td>
<td>$805,489,602</td>
</tr>
<tr>
<td>2050</td>
<td>$260,746,105,578</td>
<td>$16,257,063,493</td>
<td>$126,995,746,572</td>
<td>$3,877,240,502</td>
<td>$1,523,886,680</td>
</tr>
</tbody>
</table>

## Retail Rates
- 2020 – 10.7¢/kWh
- 2035 – 7.6¢/kWh
- 2050 – 7.1¢/kWh

## Electricity GHG
- 2020 – 409.4 g/kWh
- 2035 – 118.2 g/kWh
- 2050 – 1.1 g/kWh

![Monthly Volatility of Marginal Energy Prices by Year](image-url)
Dealing with the worst weather and demand combinations

Minimum VRE contribution to meeting demand is 18% with a maximum is 93%

info@vibrantcleanenergy.com
Dispatch of Generation (2050)

Curtailment amounts to 1.33% of VRE production
Behavior of Storage (Diurnal & Seasonal)

Storage Behavior With System Strain (ZBF 2050)

Aggregate Hydrogen Production Demands (ZBF 2050)
Behavior of Storage (Diurnal & Seasonal)
Basic Checklist For Reaching Climate Goals

- Build additional **500 factories** for the production of wind turbines, blades and towers by 2025
- Build out the supply chain for solar PV **by five-fold**
- Build **13 Gigafactory scale battery plants** by 2035, with eight by 2030 and three by 2025
- **Rebuild the nuclear industry** for SMR and MSR production by 2030 and 2035, respectively
- Manufacturing facilities for **2000s level production of Natural Gas** (now with CCS)
- Facilitate manufacturing of transmission infrastructure at a level to **double that of China**
- **Modernize the distribution grids** to enable smart grids by 2030
- **Reinvent electricity markets** to enable DERs and fuel production across the continent by 2030
- **Create a hydrogen economy** and associated basic infrastructure by 2035
- Convert **all vehicle production to EVs by 2030** at the latest, preferably 2025
- Demand all **new buildings have ASHP and HPWH** for space and water heating by 2025
- **Convert** all water heaters and space heating to heat pumps by 2040
- All industry **must have CCS** or electricity alternatives by 2040
- Produce all ammonia for fertilizer through electricity and hydrogen by 2040
- Aviation and shipping must be **enabled by synthetic liquid fuels** by 2045
- **Retrain dislocated workers** with some of the millions of new jobs created
Thank You

Dr Christopher T M Clack
CEO Vibrant Clean Energy, LLC
Telephone: +1-720-668-6873
E-mail: christopher@vibrantcleanenergy.com
Website: VibrantCleanEnergy.com
Twitter: @DrChrisClack
Texas Energy Crisis (wind left on the table ~$4.8 billion in revenue)
Texas Energy Crisis (other regions could have helped)