August 29, 2018

Daniel P. Wolf
Executive Secretary
Minnesota Public Utilities Commission
121 7th Place East, Suite 350
St. Paul, Minnesota  55101-2147

RE: 2020-2034 UPPER MIDWEST RESOURCE PLAN
     AUGUST 28, 2018 WORKSHOP MATERIALS
     DOCKET NO. E002/RP-15-21

Dear Mr. Wolf:


We have electronically filed this document with the Commission, and copies have been served on the parties on the attached service list. Please contact Amber Hedlund at 612-337-2268 or amber.r.hedlund@xcelenergy.com or Bria Shea at (612) 330-6064 or bria.e.shea@xcelenergy.com if you have any questions regarding this filing.

Sincerely,

/s/

BRIA SHEA
DIRECTOR, REGULATORY AND STRATEGIC ANALYSIS

Enclosures
cc: Service list
Xcel Energy’s IRP Stakeholder Workshop 3: The Evolving Electric System—Part 2

August 28, 2018
Agenda

1:00 – 1:10 pm  Welcome, Agenda Review, and Overview of Stakeholder Process

1:10 – 1:30 pm  E3 (Energy and Environmental Economics, Inc.)
    – Arne Olson, E3, will discuss E3’s history in helping public and private-sector clients navigate the transition to a low-carbon economy as well as their role in supporting Xcel Energy’s 2020-2034 IRP.

1:30 – 2:15 pm  Minnesota’s Smarter Grid: Pathways Toward a Clean, Reliable and Affordable Transportation and Energy System
    – Chris Clack, Vibrant Clean Energy, will discuss their recently released report offering a pathway and analysis of how MN could transition to an energy system that is 80% decarbonized (from 2005 levels) by 2050.

2:15 – 3:00 pm  The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation
    – Jesse Jenkins, MIT PhD graduate, will discuss his recent work analyzing the opportunities and challenges presented by power system operations with renewable energy.

3:00 – 3:30 pm  Decarbonization Pathways from Other Jurisdictions
    – Arne Olson and Amber Mahone, E3, will discuss their analyses of deep decarbonization pathways and resource portfolio analysis in other jurisdictions.

3:30 – 4:00 pm  Open Q&A period for all three expert groups

4:00 pm  ADJOURN
Purpose of Vibrant Clean Energy, LLC:

- Reduce the cost of electricity and help transition 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;
- Increase the resiliency of the electricity market for uncertain futures;
- License WIS:dom optimization model and/or perform studies using the model;
- Ensure profits for energy companies with a modernized grid.
Utilize the WIS:dom optimization model to investigate the pathways available to Minnesota to decarbonize the economy by 80% by 2050;

- WIS:dom will model the **Minnesota electricity grid (along with the MISO and wider Eastern Interconnection)** with electrification of some other sectors taken into account under baseline (BAU) and decarbonized conditions.
- To decarbonize the economy by **80% by 2050**, the electricity sector must decarbonize by a minimum of **91%** (with the consideration of strong EE, electrification of space & water heating and transportation. Note these are all referenced back to **2005**. **Essentially, the MN electricity sector has a maximum of 4.5 mm T of CO₂ emissions allowed to reach goal.**
- The investigation will include portions that relate to the Xcel IRP at 2040.

Builds off two previous studies that VCE has performed in the MISO footprint:

Our Approach With WS:dom
WIS:dom Is a Synthesis Model

WIS:dom is the only (others should follow) combined capacity expansion and production cost model. It combines:

- Continental-scale (globally capable), spatially-determined co-optimization of transmission, generation and storage expansion while simultaneously determining the dispatch of these sub systems at 13-km or 3-km, hourly or 5-minutely resolution;

- Dispatch includes:
  - Individual unit commitments, start-up, shutdown profiles, and ramp constraints;
  - Transmission power flow, planning reserves, and operating reserves;
  - Weather forecasting and physics of weather engines;
  - Detailed hydro modeling;
  - High granularity for weather-dependent generation;
  - Existing generator and transmission asset attributes such as heat rates, line losses, power factor, variable costs, fixed costs, capital costs, fuel costs, etc.;

- Large spatial and temporal horizons;
- Policy and regulatory drivers such as PTC, ITC, RPS, etc.;
- Detailed investment periods (2-, 5-, or 10-year) out past 2050;
- **100 - 10,000x increased resolution** compared with nearest competitor for VRE, load, and conventional generator descriptions.
- Designed, operated and supported by small team.
<table>
<thead>
<tr>
<th>Input ID</th>
<th>Input Name</th>
<th>Existing</th>
<th>New</th>
</tr>
</thead>
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<td>1</td>
<td>Heat Rate</td>
<td>All Current Thermal Data</td>
<td>NREL ATB 2017 Value</td>
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<tr>
<td>2</td>
<td>Minimum Load</td>
<td>All Current Thermal Data</td>
<td>Fleet Average</td>
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<tr>
<td>3</td>
<td>Power Factors</td>
<td>All Current Generator Data</td>
<td>Fleet Average</td>
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<tr>
<td>4</td>
<td>Fuel Costs</td>
<td>All Current Thermal Data For Multiplier</td>
<td>NREL ATB 2017 Value</td>
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<td>Fixed O&amp;M Costs</td>
<td>All Current Generator Data</td>
<td>NREL ATB 2017 Value</td>
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<tr>
<td>6</td>
<td>Non-fuel Variable O&amp;M Costs</td>
<td>All Current Generator Data</td>
<td>NREL ATB 2017 Value</td>
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<td>7</td>
<td>Capital Costs</td>
<td>All Current Generator Data</td>
<td>NREL ATB 2017 Value</td>
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<td>8</td>
<td>Relicense / Repower Costs</td>
<td>All Existing Nuclear, Wind, and Solar Generators</td>
<td>45% for VRE, N/A for Nuclear</td>
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<td>Discount Rates</td>
<td>Uses Same Rate as &quot;New&quot;</td>
<td>5.87% Real</td>
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<td>10</td>
<td>Economic Lifetimes</td>
<td>All Current Generator Data</td>
<td>NREL ATB 2017 Value</td>
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<tr>
<td>11</td>
<td>Transmission Costs</td>
<td>Uses Same Cost As &quot;New&quot;</td>
<td>ABB / Blended Existing Costs</td>
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<tr>
<td>12</td>
<td>Transmission Topolgy</td>
<td>Current Above 69 kV Aggregated To Reduced Form</td>
<td>New Lines Allowed Within WISdom; constrained by user</td>
</tr>
<tr>
<td>13</td>
<td>Demand</td>
<td>Current Demand By Sector</td>
<td>Growth Estimates Provided By Sector By VCE</td>
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<tr>
<td>14</td>
<td>Weather / Power Data</td>
<td>N/A</td>
<td>One Year Of Hourly Power Data For Wind &amp; Solar Over El</td>
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<tr>
<td>15</td>
<td>Policy &amp; Regulations</td>
<td>Apply All Existing Policies &amp; Regulations</td>
<td>Input As Constraints On Future Scenarios</td>
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<td>16</td>
<td>Locational Multiplier</td>
<td>N/A</td>
<td>Black &amp; Veach / NREL Public Data Combined By VCE</td>
</tr>
</tbody>
</table>
Existing Supply-Side Technologies Considered

WIS:dom Estimated Installed Capacity For MISO

- Coal MW: 37.1%
- Combined Cycle MW: 15.7%
- Combustion Turbine MW: 6.1%
- Storage MW: 3.5%
- Nuclear MW: 1.2%
- Hydro MW: 1.2%
- Wind MW: 0.2%
- Offshore MW: 0.2%
- PV MW: 0.1%
- CSP MW: 0.1%
- Geothermal MW: 0.0%
- Other Natural Gas MW: 0.0%
- Other Plants MW: 0.0%
- Biomass MW: 0.0%
- Rooftop PV MW: 0.0%

info@vibrantcleanenergy.com
WIS:dom Contains Detailed Weather and Siting Datasets

Wind Power Resource at 80 m AGL (Capacity Factor)

Optimal Hub Heights For WIS:dom

Wind Siting Constraints For WIS:dom

info@vibrantcleanenergy.com
WIS:dom Contains Detailed Weather and Siting Datasets

Optimal Solar PV Type for WIS:dom

Utility PV Siting Constraints for WIS:dom

info@vibrantcleanenergy.com
Advanced Screening For Rooftop PV

Note: Logarithmic Color Scale

Maximum 2.5 W/m²
Minimum 2.5x10⁻⁵ W/m²
Electricity Demand Changes
Input Assumption
Decarbonization Electricity Demand in MN

Minneso\nta Decarbonization Case Annual Electricity Demand

Data provided by Synapse
Emissions From Outside Electricity in MN

Data provided by Synapse
**Scenarios Considered**

<table>
<thead>
<tr>
<th>ID</th>
<th>Scenario Name</th>
<th>Transmission Expansion</th>
<th>Emission Target</th>
<th>Electrification</th>
<th>MN Flexibility Level</th>
<th>EI Flexibility Level</th>
<th>NG Cost</th>
<th>Nuclear Retirement</th>
<th>DERs</th>
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<td>Baseline</td>
<td>Interstate &amp; Intrastate Allowed</td>
<td>Current Policies</td>
<td>EI Minimal</td>
<td>0% to 2.1% by 2050</td>
<td>0% to 2.1% by 2050</td>
<td>NREL ATB - Low</td>
<td>Follow License Schedule</td>
<td>No Lower Limit</td>
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<td>Baseline</td>
<td>Intrastate Allowed Only</td>
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<td>B1</td>
<td>MN Deep Decarbonization</td>
<td>Interstate &amp; Intrastate Allowed</td>
<td>MN 80% Economy Reduction</td>
<td>MN Extensive</td>
<td>0% to 20.8% by 2050</td>
<td>0% to 2.1% by 2050</td>
<td>NREL ATB - Low</td>
<td>Follow License Schedule</td>
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<td>MN Deep Decarbonization</td>
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<td>C1</td>
<td>High NG Cost</td>
<td>Interstate &amp; Intrastate Allowed</td>
<td>MN 84% Economy Reduction</td>
<td>MN Extensive</td>
<td>0% to 20.8% by 2050</td>
<td>0% to 2.1% by 2050</td>
<td>NREL ATB - Low</td>
<td>Follow License Schedule</td>
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<td>EI Decarbonizes with MN</td>
<td>Interstate &amp; Intrastate Allowed</td>
<td>EI 80% Economy Reduction</td>
<td>EI Extensive</td>
<td>0% to 20.8% by 2050</td>
<td>0% to 20.8% by 2050</td>
<td>NREL ATB - Low</td>
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<td>MN Deep Decarb. with Dominant DERs</td>
<td>Interstate &amp; Intrastate Allowed</td>
<td>MN 80% Economy Reduction</td>
<td>MN Extensive</td>
<td>0% to 32.3% by 2050</td>
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<td>50% from DERs</td>
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<td>MN Deep Decarb. with less Flexibility</td>
<td>Interstate &amp; Intrastate Allowed</td>
<td>MN 80% Economy Reduction</td>
<td>MN Extensive</td>
<td>0% to 5.2% by 2050</td>
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<td>Interstate &amp; Intrastate Allowed</td>
<td>MN 80% Economy Reduction</td>
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<td>Keep Online Through 2050</td>
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</table>

3 Scenarios do not decarbonize or electrify

8 Scenarios achieve 80% emissions reductions by 2050 compared with 2005

2 Scenarios completely decarbonize electricity sector
Main Conclusions
Based Upon Synthesis Results
**Major Conclusions**

- Minnesota has the potential to **reduce the cost of electricity for customers regardless of decarbonization portfolio**. The cost reduction **can be up to 2.8 ¢ / kWh** compared with 2017 average retail costs. If Minnesota chooses to fully decarbonize the electricity sector and perform heavy electrification the cost reduction compared with 2017 would be 1.4 ¢ / kWh. **The average decarbonization and electrification cost reduction is 2.3 ¢ / kWh.**

- Minnesota can completely decarbonize. Doing so along with the rest of the Eastern Interconnection raises the difficulty; however, Minnesota can still achieve its goals.

- Without action **emission reductions would cease by 2030**. Further, the asset choices would keep emissions high, or would be stranded if emission targets were enacted at a later date.

- The jobs within the electricity sector in Minnesota is robust under all scenarios. In particular, **with decarbonization and electrification jobs in the electricity sector rise dramatically.**

- If natural gas costs rise, and decarbonization is not chosen Minnesotans could face a cumulative **additional spend on electricity of approximately $15.6 billion by 2050.** Alternatively, decarbonization and electrification could save Minnesotans a cumulative **$15.9 to $51.4 billion by 2050.** That equates to an average household saving of $600 - $1,200 per year in energy costs.
Important Aside

System Cost Response to Varying Energy Share of Variable Renewables

- Wind
- Solar
- Wind and Solar

Nonlinear increase in system costs - even though the system has access to as much storage as it requires.
Retail Cost of Electricity By Scenario

WIS:dom Estimated Retail Cost of Electricity in Minnesota

- Zero Emissions
- EI & Local Decarb.
- 80% Decarb.
- Baseline

Retail Cost of Electricity ($ / MWh)

2015 2020 2025 2030 2035 2040 2045 2050
Decarbonization Becomes Clear After 2020

WIS:dom Estimated GHG Emissions By Scenario For Minnesota Economy

- Baseline w/ Tx
- Baseline w/o Tx
- Decarb w/ Tx
- Decarb w/o Tx
- Baseline + High Gas
- Decarb + High Gas
- 100% w/ Tx
- 100% w/o Tx
- E.I. Decarb
- Local Decarb
- Low-Flex Decarb
- Nuclear Relicensings
- Nuclear Retirements

GHG Emissions From Minnesota (mmT CO₂e)

2015 2020 2025 2030 2035 2040 2045 2050

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Decarbonization Becomes Clear After 2020

WIS:dom Estimated Carbon Intensity Of Electricity By Scenario For Minnesota

- Baseline w/ Tx
- Decarb w/ Tx
- Baseline + High Gas
- 100 w/ Tx
- E.I. Decarb
- Low-Flex Decarb
- Nuclear Relicensings
- Baseline w/o Tx
- Decarb w/o Tx
- Decarb + High Gas
- 100% w/o Tx
- Local Decarb
- Nuclear Retirements

Carbon Intensity of Electricity (g / kWh)

2015 2020 2025 2030 2035 2040 2045 2050

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Deeper Dive: MN Decarbonization
Eastern Interconnection Installed Capacity

WIS:dom Installed Capacities For The Eastern Interconnection

Installed Capacity (GW)

- 2017
- 2020
- 2025
- 2030
- 2035
- 2040
- 2045
- 2050

- Coal
- CCGT
- CT
- Nuclear
- Geo
- Hydro
- Storage
- Wind
- Offshore
- Roof PV
- Solar PV

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Minnesota Installed Capacity

MN Installed Capacity (MW)

- Coal
- NGCC
- NGCT
- Storage
- Nuclear
- Hydro
- Wind
- Offshore
- Rooftop PV
- Solar PV
- Geothermal

Installed Capacity (MW)

Year:
- 2017
- 2020
- 2025
- 2030
- 2035
- 2040
- 2045
- 2050

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Installed Interstate Transmission Capacity
Cumulative Emissions By State

WIS:dom Estimated El CO₂ Emissions By State (including imports and exports)

- 2017 - 2020
- 2021 - 2025
- 2026 - 2030
- 2031 - 2035
- 2036 - 2040
- 2041 - 2045
- 2046 - 2050

Carbon Dioxide Emissions (million metric tons)
Generation Share For Minnesota (Decarb)
Dispatch For Minnesota

Example Minnesota-wide Winter Economic Dispatch (2040)

Example Minnesota-wide Summer Economic Dispatch (2040)

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Deeper Dive:
El Decarbonization
Eastern Interconnection Installed Capacity

WIS:dom Installed Capacities For The Eastern Interconnection

VCE

Installed Capacity (GW)

2017 2020 2025 2030 2035 2040 2045 2050

Coal CCGT CT Nuclear Geo Hydro Storage Wind Offshore Roof PV Solar PV

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Installed Capacity (Geographic)
Installed Interstate Transmission Capacity

WIS:dom Interstate Transmission Capacity By Investment Period (MW)

Interstate Transmission Capacity (MW: -ve Export, +ve Import)

2017  2020  2025  2030  2035  2040  2045  2050

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Cumulative Emissions By State

WIS:dom Estimated El CO₂ Emissions By State (including imports and exports)

VCE

Carbon Dioxide Emissions (million metric tons)

States represented on the x-axis include:
- AL, AR, CA, CO, DE, FL, GA, HI, IA, ID, IL, IN, KS, KY, LA, ME, MI, MN, MO, MS, MT, NV, NH, NJ, NM, NY, NC, ND, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WV, WI, WY

Legend:
- 2017 - 2020
- 2021 - 2025
- 2026 - 2030
- 2031 - 2035
- 2036 - 2040
- 2041 - 2045
- 2046 - 2050

info@vibrantcleanenergy.com
Generation Share For Eastern Interconnection

Eastern Interconnection Generation Share For Each Investment Period

- 2017
- 2020
- 2025
- 2030
- 2040
- 2050

Legend:
- Coal
- NGCC
- NGCT
- Nuclear
- Hydro
- Wind
- Utility Solar PV
- Rooftop Solar PV
- Imports

info@vibrantcleanenergy.com
Dispatch For Eastern Interconnection

Example EI-wide Winter Economic Dispatch (2050)

Example EI-wide Summer Economic Dispatch (2050)
Thank You

Questions?

Full report found here:
http://www.vibrantcleanenergy.com/media/reports/

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CEO Vibrant Clean Energy, LLC

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E-mail: christopher@vibrantcleanenergy.com
Website: VibrantCleanEnergy.com
GETTING TO ZERO: DECARBONIZING ELECTRIC POWER

Jesse D. Jenkins, PhD
Institute for Data, Systems and Society and MIT Energy Initiative
Massachusetts Institute of Technology | jessedj@mit.edu
Resources


Getting to Zero

Global carbon intensity of energy

Electricity: the Linchpin

Data source: PNNL "Reference +80%" scenario in GGCAM USA Analysis of U.S. Electric Power Sector Transitions May 2017 performed for the United States Mid-Century Strategy for Deep Decarbonization
The Motivations

January 17, 2018

Renewable energy will be consistently cheaper than fossil fuels by 2020, report claims

January 13, 2018

Xcel Energy receives shockingly low bids for Colorado electricity from renewable sources

January 17, 2018

The Price of Solar Is Declining to Unprecedented Lows

August 27, 2016

Grid Batteries Are Poised to Become Cheaper Than Natural-Gas Plants in Minnesota

July 12, 2017

Forbes

Xcel Energy receives shockingly low bids for Colorado electricity from renewable sources

January 17, 2018

Renewable energy will be consistently cheaper than fossil fuels by 2020, report claims

January 13, 2018

The Price of Solar Is Declining to Unprecedented Lows

August 27, 2016

Grid Batteries Are Poised to Become Cheaper Than Natural-Gas Plants in Minnesota

July 12, 2017

Forbes
Wind, Solar & Battery Costs Plummet

Data Source: Wind and solar levelized costs from Lazard. Battery pack costs from Bloomberg New Energy Finance
Renewables are Keeping Pace…

...but Nuclear and CCS are Falling Behind

Nuclear energy

Carbon capture & storage

Source: Peters et al. (2017), “Key indicators to track current progress and future ambition of the Paris Agreement,” *Nature Climate Change* 7: 118-122
Santee Cooper, SCE&G pull plug on roughly $25 billion nuclear plants in South Carolina

June 29, 2017

Westinghouse Files for Bankruptcy, in Blow to Nuclear Power

March 29, 2017

Carbon Capture Suffers a Huge Setback as Kemper Plant Suspends Work

June 29, 2017
Do We Go All In?

Image Source: go100percent.org
A race to beat fossil fuels on cost…

A Flawed Model
A Race Against Declining Value

A Race Against Declining Value

Energy storage average system value ($/kWh installed) vs. CO₂ Emissions Rate Limit (g/kWh)

- 200
- 150
- 100
- 50

Energy storage power capacity (% of peak system demand)

- 0-10
- 10-20
- 20-30

2017 estimated Li-ion storage installed cost per kWh

~65-80 percent below 2017 costs

Declining Value: Three Key Mechanisms

1. Declining “fuel-saving” value (energy substitution)

2. Decreasing “capacity value” (capacity substitution)

3. Increasing “over-generation” (energy that must be stored or wasted when supply exceeds demand)

Additional factors: Increasing flexibility, ramping and reserve requirements, thermal plant cycling costs, transmission network costs
An Illustrative Example

Peak demand: 34 GW
Capacity factors
Wind: 28%
Solar: 24% (ac)
No storage in this example

Installed cost ($1,000 per kW-ac)

- Wind
- Solar
- Nuclear
- Gas

+$35/MWh
Wind Capacity Value: 9%

Solar Capacity Value: 4%

Clean Energy Share: 20%

Wind Energy Value: 100%

Solar Energy Value: 100%

Over-generation: 0%

Energy Graph:
- Nuclear
- Gas
- Wind
- Solar
- Demand
Net peak: September 8th 5pm

33 GW firm capacity needed

34 GW demand peak

Clean Energy Share: 20%
Wind Energy Value: 100%
Solar Energy Value: 100%
Wind Capacity Value: 9%
Solar Capacity Value: 4%
Over-generation: 0%
Clean Energy Share: 20%

33 GW firm capacity needed

34 GW demand peak

Clean Energy Share: 20%
Wind Energy Value: 100%
Solar Energy Value: 100%
Wind Capacity Value: 9%
Solar Capacity Value: 4%
Over-generation: 0%
Clean Energy Share: 20%
Over-generation: 3%

Wind Energy Value: 91%

Solar Energy Value: 77%

Wind Capacity Value: 9%

Solar Capacity Value: 4%

Net peak: September 8th 5pm

Clean Energy Share: 40%

32 GW firm capacity needed
Over-generation: 7%

Wind Capacity Value: 2%

Solar Capacity Value: 2%

Net peak: August 19th, 6pm

Clean Energy Share: 60%

Wind Energy Value: 72%

Solar Energy Value: 59%

31 GW firm capacity needed
Over-generation: 28%

Wind Capacity Value: 2%

Solar Capacity Value: 2%

Net peak: August 19th, 6pm

Clean Energy Share: 80%

Wind Energy Value: 25%

Solar Energy Value: 20%

30 GW firm capacity needed
Over-generation 11%

Wind Capacity Value 2%

Solar Capacity Value 2%

Net peak: August 19th 6pm

Clean Energy Share 80%

Wind Energy Value 43%

Solar Energy Value 34%

30 GW firm capacity needed
Clean Energy Share: 90%

Wind Energy Value: 43%

Solar Energy Value: 34%

Over-generation: 5%

Wind Capacity Value: 2%

Solar Capacity Value: 2%

Net peak: August 19th, 6pm

32 GW firm capacity needed
**“Fuel saving” variable renewables**
- Solar PV
- Solar thermal
- Wind energy
- Run-of-river hydro
- Solar thermal with storage
- Reservoir hydro

**“Fast burst” balancing resources**
- Energy storage
- Flexible demand (rescheduling)
- Demand response (price responsive curtailment)

**“Firm” low-carbon resources**
- Geothermal
- Nuclear
- Biogas
- Biomass
- “Flexible base”
- Gas or coal w/CCS
- “Firm cyclers”
One Possible Balanced Portfolio
1 g/kWh CO₂ emissions limit (99.9% decline)

- Fast Burst Resources
- Fuel Saving Resources
- Firm Low-carbon Resources ("Flexible Base")
Without Firm Low-Carbon Resources
1 g/kWh CO₂ emissions limit (99.9% decline)

Note 2x increase in y-axis scale

Fast Burst Resources

Fuel Saving Resources

Energy (GWh)
Southern System

Average cost of electricity ($/MWh)

CO₂ emissions limit (g/kWh)

Role of Firm Resources is Robust

Across nearly 1,000 cases spanning...

• A wide range of technology uncertainty;

• Two distinct regions with differing climate and renewable resource potential;

• Sensitivity cases including flexible demand, long-distance transmission, and long duration storage;

• Increasingly stringent CO$_2$ emissions limits.
In the near-term, wind, solar, batteries and natural gas can drive emissions reductions.
Fully decarbonizing electricity requires “firm” low-carbon substitutes for natural gas and retiring nuclear units.
Firm Low-Carbon Options

“Fuel saving” variable renewables

“Fast burst” balancing resources

“Firm” low-carbon resources

Reservoir hydro

Geothermal

Nuclear

Gas or coal w/CCS

Biogas

Biomass
Advanced Nuclear Reactors

Image: NuScale Energy
Carbon Capture and Storage
Batteries are no substitute for firm resources but rather play a distinct, complementary role as “fast burst” resources.
Pushing Renewables to the Limits

Solar PV
- Solar thermal
- Wind energy
- Run-of-river hydro
- Solar thermal with storage

“Fuel saving” variable renewables

“Fast burst” balancing resources
- Energy storage
- Flexible demand (rescheduling)
- Demand response (price responsive curtailment)

?
1. Continent-Scale Transmission
2. Demand Flexibility and Energy Efficiency
3. Extremely Cheap Wind, Solar, and Batteries
4. “Seasonal” Energy Storage
We Need Strategies Robust to Risk

continent-scale transmission
AND
highly flexible demand
AND
large efficiency gains
AND
cheap wind
AND
cheap solar
AND
cheap batteries
AND
seasonal storage

OR
affordable nuclear
OR
affordable CCS
OR
sustainable biomass
OR
generated geothermal
We Need Strategies Robust to Risk

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= 48% = 94%
Beware the “80-20” Mental Model

Wind & solar energy share (%) vs. CO₂ emissions limit (g/kWh)

Clean Electricity Resources
Within the Context of Economy-Wide Deep Decarbonization

August 28th, 2018
Xcel Energy Integrated Resource Planning Workshop
Minneapolis, Minnesota

Arne Olson, Senior Partner
Amber Mahone, Director
Tory Clark, Managing Consultant
Session 1: Intro to E3

- About E3
- E3 modeling approaches

Session 2: Low Carbon Case Studies and Lessons Learned

- Economy-wide decarbonization: California case study
- Optimal electricity portfolios: Pacific Northwest case study
- Electric reliability under high renewables: Southwestern utility case study
+ Session 1: Intro to E3
ABOUT E3
E3 is an industry-leading consultancy based in San Francisco

E3 serves as a thought-leader across a broad range of our practice areas

E3’s clients span the entire spectrum of electricity industry participants including utilities, ISOs, IPPs, developers, large users, regulators, and advocacy organizations
E3 Practice Areas

E3’s project scope and breadth is unmatched for a firm of its size

Distributed Resources & Retail Rates
Analyzes distributed energy resources, emphasizing their costs and benefits now and in the future.
Supports rate design and distribution system planning.

Asset Valuation & Large Users Services
Transaction support for buyers and sellers of energy assets and services
Uses proprietary in-house models and in-depth knowledge of public policy, regulation and market institutions

E3 has five defined working groups that create continual innovation from cutting edge projects and constant cross-fertilization of best practices across the groups

Planning
Develops and deploys proprietary tools to aid resource planners
Informs longer-term system planning and forecasting

Clean Energy
Provides market and policy analysis on clean energy technologies and climate change issues.
Includes comprehensive and long-term GHG analysis.

Market Analysis
Models wholesale energy markets both in isolation and as part of broader, more regional markets
Key insights to inform system operators and market participants
E3’s Clean Energy and Planning Practice

E3 consults extensively for utilities, developers, government agencies and environmental groups on clean energy issues. E3 PATHWAYS projects evaluate long-term, economy-wide energy scenarios, with a focus on electricity and natural gas.

**California PATHWAYS studies**
Analyzing strategies to meet 2030 & 2050 GHG targets (Air Resources Board, CA Energy Commission, Southern California Association of Govts.)

**New York 100% Renewable Energy**
Evaluating options to meet 100% renewable energy goal economy-wide with NYSERDA

**Oregon Market Approaches to Reducing GHGs**
Impact of current policies on Oregon’s GHG emissions and potential role of cap and trade, with OR DEQ

**Maryland PATHWAYS**
Analyzing impact of existing policies on GHG emissions in Maryland

**U.S. Deep Decarbonization Pathways for the DDPP**
Evaluated scenarios to meet 80% reduction in GHGs in the U.S. by 2050, part of the DDPP

**SCG Decarbonizing Gas Study**
Exploring the role of natural gas, biogas and hydrogen in long-term, low-carbon scenarios
E3 has worked with a wide range of clients to understand the challenges of renewable integration at high penetrations, including:

- **California ISO**: ongoing support for California ISO since 2010 LTPP
- **California PUC**: Key analytical support role for California IRP
- **California utilities**: landmark study of feasibility and implications of a 50% RPS goal
- **Sacramento Municipal Utilities District**: zero-carbon and 100% renewable portfolios in support of 2018 IRP process
- **Pacific Northwest**: Study of 80% GHG reductions and 100% RPS scenarios for a group of large public power utilities
- **Desert Southwest utility**: analysis of 80% clean energy and 50+% renewable scenarios
- **Hawaiian Electric Company**: Preferred Energy Supply Plan: 100% renewables by 2045
- **Canadian Maritimes**: analysis of low carbon portfolios for regulatory support
- **Western Electricity Coordinating Council**: West-wide flexibility and resource adequacy needs at high penetrations of wind and solar generation
E3 MODELING APPROACHES
Electricity sector must be considered within the context of economy-wide carbon abatement policies

- Many jurisdictions are considering high renewables as a means of reducing carbon emissions
- 20-40% of economy-wide emissions are from electricity
- Electric ratepayers cannot be responsible for all emissions reductions throughout the economy
- However the electricity sector can play a key role in leveraging decarbonization of other sectors

**Historical and Projected GHG Emissions for OR and WA**

**2013 CO2 Emissions for Oregon and Washington**

Sources: Report to the Legislature on Washington Greenhouse Gas Emissions Inventory: 2010 – 2013 (link); Oregon Greenhouse Gas In-boundary Inventory (link)
E3 has developed a three-model approach for deep decarbonization

**Analysis consists of three steps:**

1. Analysis of economy-wide GHG goals through 2050 using PATHWAYS
2. Optimal electricity system portfolio analysis using RESOLVE
3. Electricity sector resource adequacy analysis using RECAP

**Economy-wide GHG scenarios (PATHWAYS)**
- Evaluate alternative economy-wide scenarios for meeting 80% reduction in GHGs by 2050

**Electricity Sector Capacity Expansion and Dispatch (RESOLVE)**
- Evaluate least-cost portfolio of electricity generation, storage and capacity resources to meet demand

**Electricity Resource Adequacy Modeling (RECAP)**
- Evaluate reliability of electric energy and capacity availability over thousands of simulated weather years
High-level economy-wide GHG scenarios provide context for more detailed sectoral analysis.

More detailed, implementation analyses build from the core, economy-wide GHG reduction pathways.

PATHWAYS is increasingly being used in utility Integrated Resource Planning.
Xcel Energy retained E3 to perform independent modeling and analysis of the portfolio choices Xcel is facing

- The work will be carried out by E3 consultants using E3’s tools and expertise
- E3 will have full editorial control of the data inputs and models and will produce an independent report

E3 will work closely with Xcel Energy to ensure that the Upper Midwest system is modeled accurately

E3 will work with Xcel Energy to facilitate stakeholder access to the data and models to support a transparent analysis process
Key issues for Minnesota and Xcel Energy

+ What is the role of the electric sector in achieving Minnesota’s economy-wide decarbonization targets?
  - What level of electricity decarbonization is required?
  - What role could the electric sector play in reducing emissions in other sectors?

+ What mix of wind, solar and other resources results in lowest-cost electric sector GHG emissions abatement?
  - What is the potential role of Xcel’s nuclear plants in meeting long-run carbon goals for the Upper Midwest system?
  - What resources does Xcel Energy need to ensure electric reliability during peak load/low renewable production events?

+ What is the cost to Xcel Energy customers of meeting various policy goals, compared to a case without them?

+ How can Xcel Energy utilize the MISO market to achieve decarbonization goals at the lowest cost?
Session 2: Low-Carbon Case Studies and Lessons Learned
ECONOMY-WIDE
DECARBONIZATION
+ Economy-wide infrastructure-based GHG and energy analysis

- Captures “infrastructure inertia” reflecting lifetimes and vintages of buildings, vehicles, equipment
- Models physical energy flows within all sectors of the economy
- Allows for rapid comparison between user-defined scenarios

+ Scenarios test “what if” questions

- Reference or counterfactual scenario for consistent comparison in future years
- Multiple mitigation scenarios can be compared that each meet the same GHG emissions goal
We focus on four pillars of deep decarbonization, all requiring effort to achieve long-term energy and climate goals:

- **Energy efficiency & conservation**
- **Electrification**
- **Low-Carbon Fuels**
- **Reduce non-combustion emissions**

Graphs showing Reference, Bookend Ranges of Mitigation Cases, and CEC EPIC Scenario Results, 2018.
Lessons from California: Slow turnover of equipment means the energy system transformations must begin early

- Light duty vehicles have an average life of ~15 years, which means they will need an average of 2 replacements over the next 30 years
  
  - Even if we reach 100% of new sales as Zero Emission Vehicle alternatives, it will take significant time for existing gasoline vehicles to come off the road.
  
  - Delayed progress in sales could lead to costly programs to retire the existing fleet early (e.g. cash for clunkers programs).
Lessons from California:
Energy demand is increasingly met with low-carbon electricity, limited biofuels are used for hard-to-electrify end uses

+ Electricity increases due to electrification of transportation and buildings, all other fossil fuels decrease

+ Biomethane is used in this scenario to decarbonize industry, could be directed to renewable diesel to decarbonize trucking and off-road instead
Lessons from California:
Electrification of end-uses from other sectors will result in significantly higher electric loads

- Electrification of transportation, buildings and industry aids in decarbonization of the California economy
- Electric load may increase by 50% in 2050 relative to Current Policy Scenario

Existing and New Electricity Loads under California 80% GHG Reduction Scenario

<table>
<thead>
<tr>
<th>Year</th>
<th>Existing Loads</th>
<th>Transportation</th>
<th>Industry</th>
<th>Buildings</th>
<th>Other</th>
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<tr>
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<td>80</td>
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<td>500</td>
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Lessons from California: Electricity sector helps to decarbonize other sectors, through low-carbon electricity plus electrification

Deep decarbonization scenario results in direct GHG savings in the electricity sector of about 30 MMTCO₂ in 2050, compared to a 50% renewables scenario

The electricity sector enables an additional 80 MMTCO₂ of GHG savings in 2050 in other sectors, due to electrification in:

- Vehicles
- Buildings
- Industry
ELECTRICITY RESOURCE PORTFOLIO OPTIMIZATION
Decarbonization requires low-carbon electricity generation to become the principal source of primary energy

1. **Renewable**
   - **Hydroelectric:** flexible low-carbon resource that can help to balance wind and solar, resource limited
   - **Wind:** high quality resources in Midwest and West, intermittent availability
   - **Solar:** high quality resources across the West, intermittent availability
   - **Geothermal:** resource limited
   - **Biomass:** resource limited

2. **Nuclear**
   - **Conventional:** baseload low-carbon resource
   - **Small modular reactors:** potentially flexible low-carbon resource

3. **Fossil generation with carbon capture and storage (CCS)**
Efficient allocation of capital is the key to achieving decarbonization at the lowest cost.

- Power system is transitioning from one with significant fuel costs to one that is consists almost entirely of capital investments with no/low fuel costs.

- New planning approaches are needed to facilitate optimal allocation and utilization of highly capital-intensive investment.

**Hawaii Case Study**

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**E3 RESOLVE Model Approach**
E3’s RESOLVE model develops optimal portfolios for meeting power system and policy needs

**RESOLVE is an optimal capacity expansion model used in resource planning**

- Designed for high renewable systems
- Utilized in several jurisdictions including California, Hawaii and New York

**Selects combination of renewable and conventional resources to minimize operational and investment costs over time**

- Simulates operations of the electricity system including existing hydro and thermal generators
- Adds new resources as needed
- Complies with renewable energy and carbon policy targets
- Meets electricity system reliability needs

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<th>Resource Type</th>
<th>Examples of New Resource Options</th>
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<tr>
<td>Natural Gas Generation</td>
<td>- Simple cycle gas turbines</td>
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<tr>
<td></td>
<td>- Reciprocating engines</td>
</tr>
<tr>
<td></td>
<td>- Combined cycle gas turbines</td>
</tr>
<tr>
<td></td>
<td>- Repowered CCGTs</td>
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<tr>
<td>Renewable Generation</td>
<td>- Geothermal</td>
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<tr>
<td></td>
<td>- Hydro upgrades</td>
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<td></td>
<td>- Solar PV</td>
</tr>
<tr>
<td></td>
<td>- Wind</td>
</tr>
<tr>
<td>Energy Storage</td>
<td>- Batteries (&gt;1 hr)</td>
</tr>
<tr>
<td></td>
<td>- Pumped Storage (&gt;12 hr)</td>
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<tr>
<td>Energy Efficiency</td>
<td>- HVAC &amp; appliances</td>
</tr>
<tr>
<td></td>
<td>- Lighting</td>
</tr>
<tr>
<td>Demand Response</td>
<td>- Interruptible tariff (ag)</td>
</tr>
<tr>
<td></td>
<td>- DLC: space &amp; water heating (res)</td>
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</tbody>
</table>

Information about E3’s RESOLVE model can be found here: [https://www.ethree.com/tools/resolve-renewable-energy-solutions-model/](https://www.ethree.com/tools/resolve-renewable-energy-solutions-model/)
New Resources Added by 2050 (MW)

- 11,000 MW of new wind and solar power are added by 2050
- 7,000 MW of new natural gas generation needed for reliability

Annual Energy Production in 2050 (aMW)

- Primary source of carbon reductions is displacement of coal generation from portfolio
- Hydro generation still dominates
- Wind and solar generation replace coal
- Meets carbon goal at relatively low cost
Northwest Case Study: High RPS
Policy that focuses on renewables only such as a high RPS results in “overbuild” of renewables but does not reduce coal generation

New Resources Added by 2050 (MW)
- 23,000 MW of new wind and solar power are added by 2050
- 7,000 MW of new natural gas generation needed for reliability

Annual Energy Production in 2050 (aMW)
- Very large surpluses of wind and solar energy
- Coal generation continues to operate
- Much higher cost and does not meet goal

More than 3x renewables capacity is added to go from 30% to 50% RPS
Average curtailment increases from 5% for a 30% RPS to 9% for 50% RPS
Renewables displace gas first; coal begins to be displaced with higher renewables penetration
Northwest Case Study: No New Gas
Prohibition on new gas generation adds cost but does little to reduce carbon

- Very little change in wind and solar from the Reference Case
- 7,000 MW of pumped hydro and battery storage replaces gas
- Little change in wind and solar generation
- Coal generation continues to operate
- Storage does not produce energy!
Northwest Case Study: Cost & Emissions
Carbon Cap Cases

Note: Reference Case reflects current industry trends and state policies, including Oregon’s 50% RPS goal for IOUs and Washington’s 15% RPS for large utilities.
Northwest Case Study: Cost & Emissions
RPS Cases

Reduces emissions by **12 MMt** at an annual cost of **+$2.1 billion** by 2050

Note: Reference Case reflects current industry trends and state policies, including Oregon’s 50% RPS goal for IOUs and Washington’s 15% RPS for large utilities.
Northwest Case Study: Cost & Emissions
No New Gas Case

Reduces emissions by **2.0 MMT** at an annual cost of **$1.2 billion** by 2050

Note: Reference Case reflects current industry trends and state policies, including Oregon’s 50% RPS goal for IOUs and Washington’s 15% RPS for large utilities.
Northwest Case Study: Cost & Emissions
Original PGP Study + Additional Carbon Cap Scenarios

Additional reductions can be achieved beyond 80%, but at steeply increasing cost

Note: Reference Case reflects current industry trends and state policies, including Oregon’s 50% RPS goal for IOUs and Washington’s 15% RPS for large utilities.
Northwest Case Study: Loss of hydro/nuke
Replacing existing zero-carbon resources is expensive and may increase emissions.

Reference Case with Retirement:

- Existing resources replaced with gas
- Cost is $1.1 billion per year by 2050
- Carbon emissions increase by 5 million metric tons

80% Carbon Reduction Case with Retirement:

- 2,000 MW of existing resources replaced with 7,500 MW of new wind, solar and gas
- Total cost of meeting carbon goal increases by $1.6 billion per year by 2050
Northwest Case Study: Energy Storage

Battery storage is less effective in the hydro + wind heavy Northwest than in solar-dominated systems like California.

California can store surplus solar power with 4-6 hour grid batteries.

Northwest has surplus of wind and hydro generation that occurs day after day during high hydro years.

Spring Day In California

Spring Day in the Northwest

Power systems are a function of geography, and the least-cost solutions may be very different for different systems.
Northwest Case Study: Winter Peak
Gas generation still needed for reliability and is a good complement to hydro/wind/solar

Cold Winter Day under 80% Reduction

- **Pacific Northwest**: most challenging conditions system are multi-day cold snaps that occur during drought years

- **Wind and solar production** tends to be very low during these conditions, even under “100%” RPS

- Absent a technology breakthrough, gas generation appears to be needed for reliability

Energy from Zero-Carbon Resources

Without thermal generation, there is not enough energy to serve load during all hours
ELECTRIC SYSTEM RELIABILITY UNDER HIGH RENEWABLES
E3’s Renewable Energy Capacity Planning Model evaluates the adequacy of high-renewable systems

- Resource adequacy is a critical concern under high renewable and decarbonized systems
  - Renewable energy availability depends on the weather
  - Storage and Demand Response availability depends on many factors

- RECAP evaluates adequacy through time-sequential operations over thousands of simulated years
  - Captures thermal resource and transmission forced outages
  - Captures variable availability of renewables & correlations to load
  - Tracks hydro and storage state of charge

- Used as a check on reliability of RESOLVE portfolio and to add capacity if needed

Information about E3's RECAP model can be found here: https://www.ethree.com/tools/recap-renewable-energy-capacity-planning-model/
Loss-of-load events are infrequent and of short duration in a system with sufficient dispatchable generation

+ In a highly reliable system, loss-of-load events are infrequent and of short duration

+ Dispatch-limited resources like Demand Response and battery storage can provide significant value in reducing the frequency of loss-of-load events

Illustrative Results
Loss-of-load events are more severe in a system that is starved of dispatchable generation

In a system without sufficient dispatchable generation, loss-of-load events occur more frequently and have longer duration.

DR and battery storage alone cannot solve the problem.

Illustrative Results

Frequent events with more than 10 hours of lost load.
Example cold winter week with low solar/wind production causing lost load

Graphic shows a simulation of the system’s performance during a real winter storm event on December 18-22, 1978

Base system after retirements

Graph shows various energy sources and their contribution to the total supply during the week of December 18-22, 1978.
Example cold winter week with low solar/wind production causing lost load

Additional solar helps during the low solar days, but it does not avoid the lost load in the evenings after the storage discharge is exhausted.

Base system after retirements + 3000 MW of Solar PV
Example cold winter week with low solar/wind production causing lost load

Additional 4-hour storage helps during some evenings, but it quickly runs out of energy, especially during stormy days when it can’t charge during the day.

Base system after retirements + 2000 MW of 4-hour storage
Example cold winter week with low solar/wind production causing lost load

2,000 MW of 48-hour storage can bridge the multi-day energy shortage and avoid the lost load in this example week, but at significant cost.
The capacity contribution of wind, solar, storage and demand response declines with penetration

- Wind, solar, storage and demand response have dispatch limitations that restrict their contribution to system resource adequacy
- Limitations become important at higher penetrations

Wind, Solar ELCC in California

Wind ELCC in Winter Peaking System

Cumulative Storage ELCC in Summer Peaking System
CERTIFICATE OF SERVICE

I, Jim Erickson, hereby certify that I have this day served copies of the foregoing document on the attached lists of persons.

\( xx \) by depositing a true and correct copy thereof, properly enveloped with postage paid in the United States mail at Minneapolis, Minnesota

\( xx \) electronic filing

Docket No. E002/RP-15-21

Dated this 29\textsuperscript{th} day of August 2018

\( /s/ \)

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Regulatory Administrator
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<td>222 South Ninth St., Suite 825 Minneapolis, Minnesota 55402</td>
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