Northwest **Power** and
**Conservation** Council



April 27, 2021

**MEMORANDUM**

**TO:** **Council Members**

**FROM:** **Massoud Jourabchi, Steven Simmons**

**SUBJECT:** **Paths to Decarbonization Scenario Discussion**

## BACKGROUND:

Presenters: Massoud Jourabchi, Steven Simmons

Summary: The Paths to Decarbonization Scenario is an investigation into the extent to which greenhouse gas emissions can reduced from the entire Northwest Economy by the year 2050.

Numerous reduction strategies in transportation, building and appliance efficiency, fuel switching, carbon taxes and green hydrogen were tested. Each strategy was tested individually and when appropriate; combined with other strategies.

Strategies were also tested for reducing non-energy sources of emissions in the industrial, agricultural, and other sectors. The potential of greenhouse gas sinks to lower carbon intensities was also tested.

A new forecast scenario was developed for transportation to reflect recent policy and industry trends indicating the potential for a more aggressive move to electric vehicles in the light duty vehicle space. Hydrogen use was also modeled as an alternative fuel for transportation. Hydrogen fuel cell technology may provide a viable alternative to diesel powered long-haul freight trucking, which could result in significant demand growth for electricity from electrolysis hydrogen production while lowering emissions.

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Relevance: Analysis of methods to reduce greenhouse gas emissions is of key interest to the region

Workplan: A.1 Develop and analyze scenarios analysis for the Power Plan

Background:

More Info: Scenarios
https://www.nwcouncil.org/sites/default/files/2020_02_p2.pdf

https://www.nwcouncil.org/news/exploring-key-power-supply-questions-through-scenario-analysis

Overview of Hydrogen -
https://www.nwcouncil.org/sites/default/files/2021_01_p2.pdf

# Path to Decarbonization Scenario

Massoud Jourabchi
Steven Simmons
May 4, 2021

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NORTHWEST
POWER PLAN
FOR A SECURE & AFFORDABLE
ENERGY FUTURE

# Introduction

To combat climate change - the states of Oregon and Washington have set goals and limits on future greenhouse gas emissions from their respective states

Oregon

45 % below 1990 levels by 2035

80 % below 1990 levels by 2050

Washington

45 % below 1990 levels by 2030

70 % below 1990 levels by 2040

95 % below 1990 levels by 2050 and net zero emissions

For the 2021 Power Plan – in order to form a more comprehensive understanding of expected regional emissions - we expanded our forecasting out past the power sector to include the use of fuels for transportation, the home, the business and industry

The Paths to Decarbonization Scenario is an investigation into methods that can reduce greenhouse gas emissions from the **entire economy** – both energy related & non-energy related

# Today's Agenda

1. Discussion of the Transportation Forecast – $H_2T$
   Steven Simmons

2. Discussion of the Path to Decarbonization
   Massoud Jourabchi

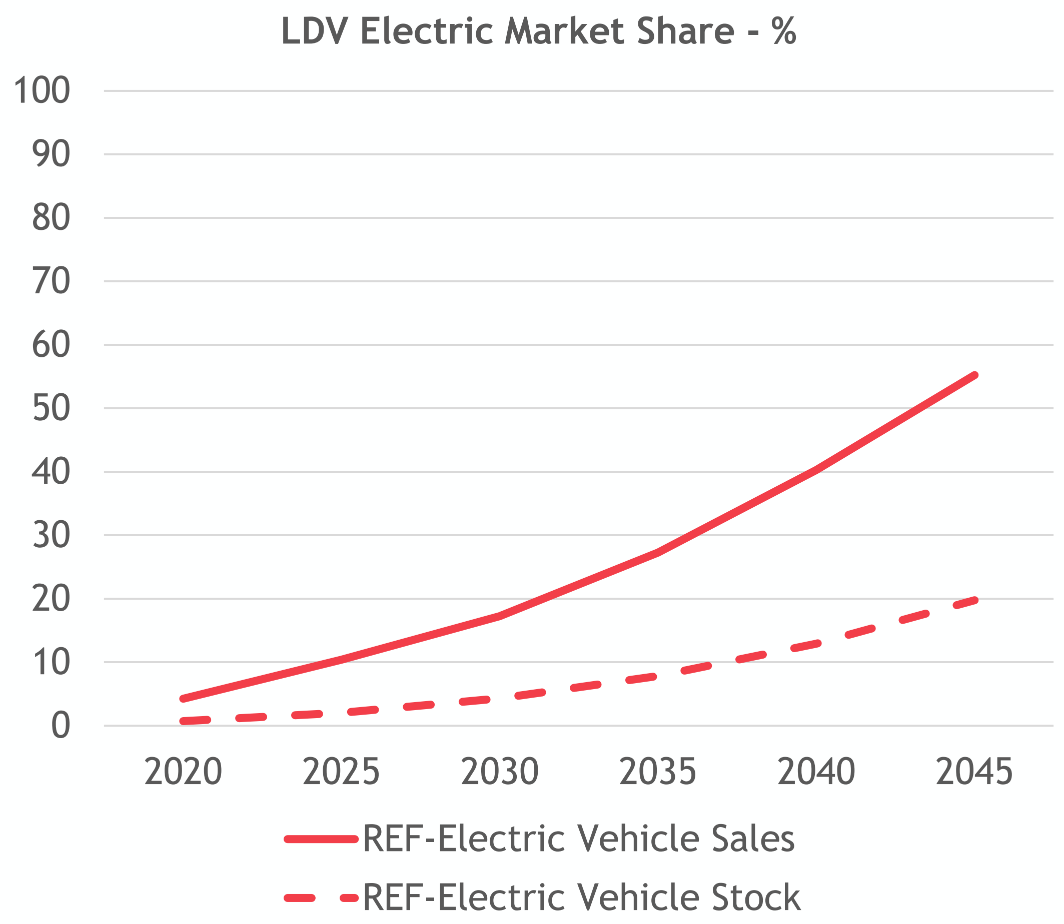
# Hydrogen & Transportation Forecast ($H_2T$)

Steven Simmons

May 4, 2021

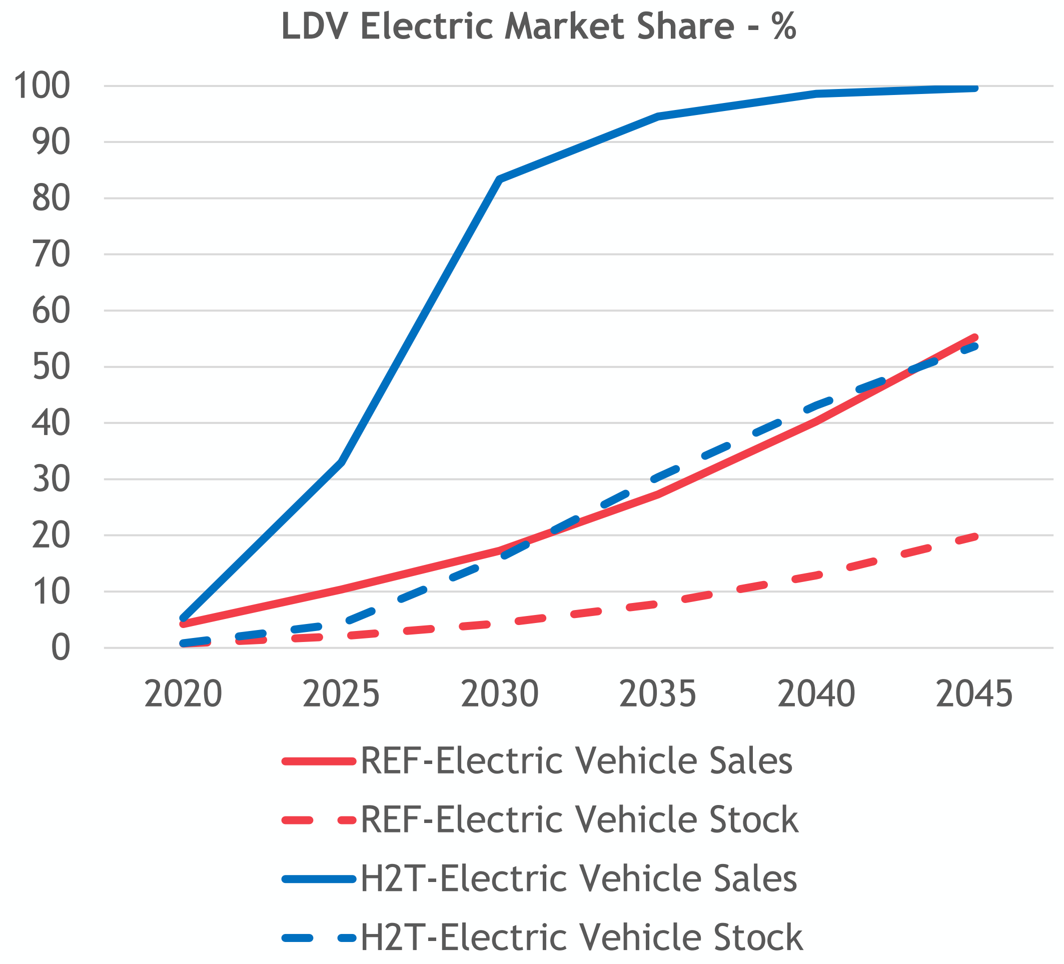
# Reference Case for Transportation - REF

- Focused on electrification of the Light Duty Vehicle (LDV) space over time
- Results in modest growth in demand for electricity
- Emissions in the LDV space decline by 14 % from 2020 to 2045 even though vehicle miles traveled increases by 31 %
- Freight Trucks (HDV) begin to standout as the dominant emitter



# Hydrogen & Transportation Case – $H_2T$

- Remains consistent with REF Case in terms of transportation requirements and modes i.e. miles traveled the same, ton-miles freight the same, no switching between train/marine/HDV
- Force a faster turn to Electric in LDV space (recent policy & industry trends)
- Move some light commercial delivery trucks to electric, more buses to electric
- Move to Hydrogen Fuel Cell for HDV – medium and large freight trucks
- New demand for electricity from Hydrogen production via Electrolysis and delivery

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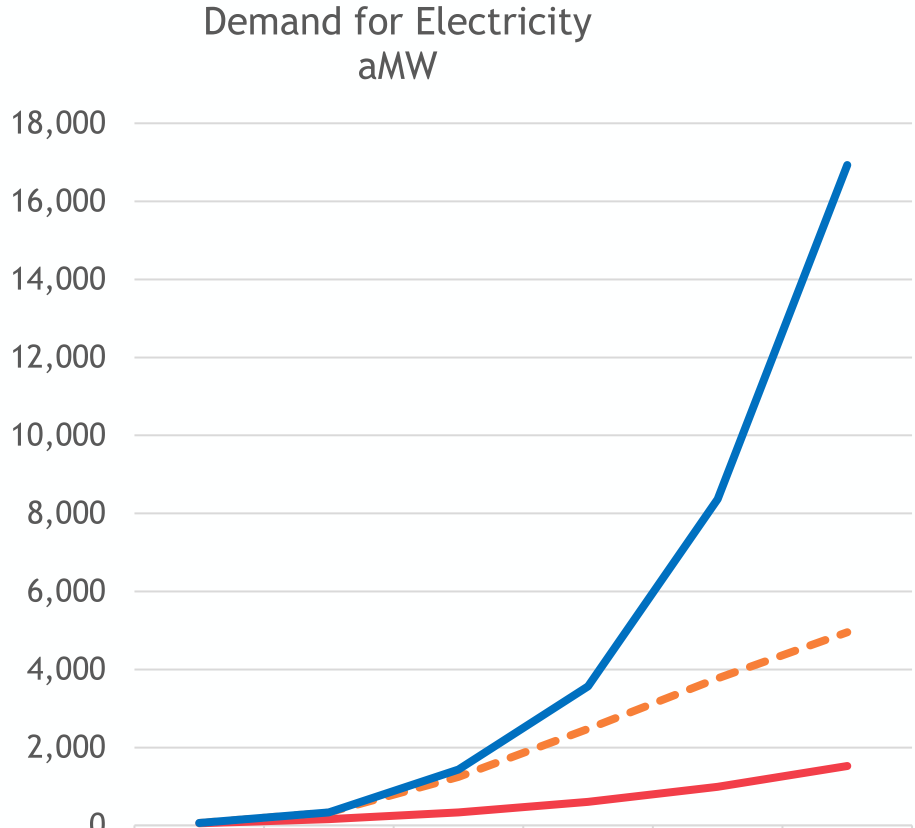
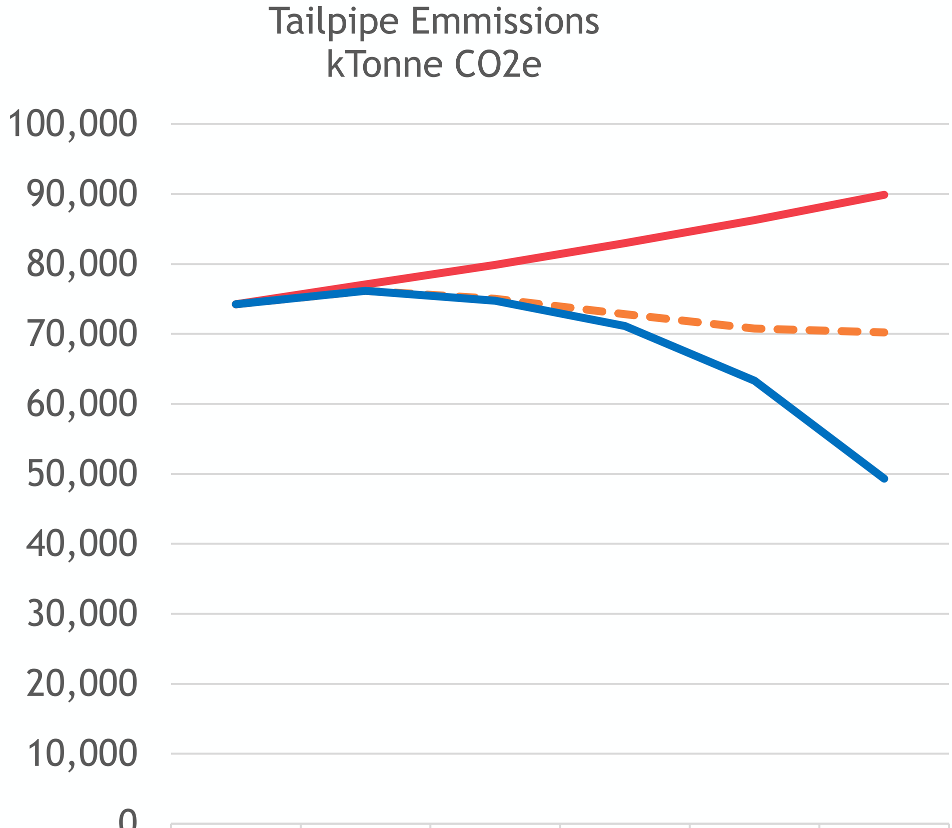
ELEC Only – electrification changes only – no $H_2$

# Results

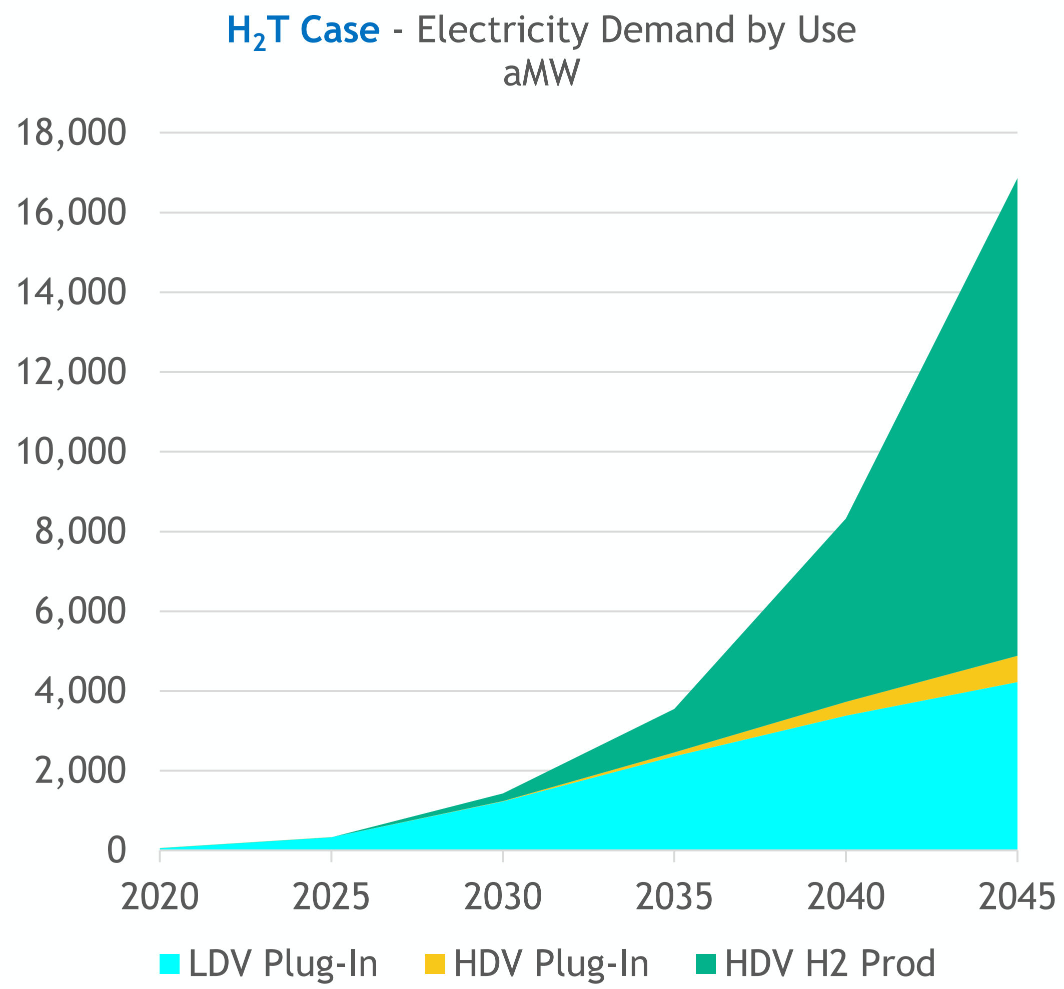


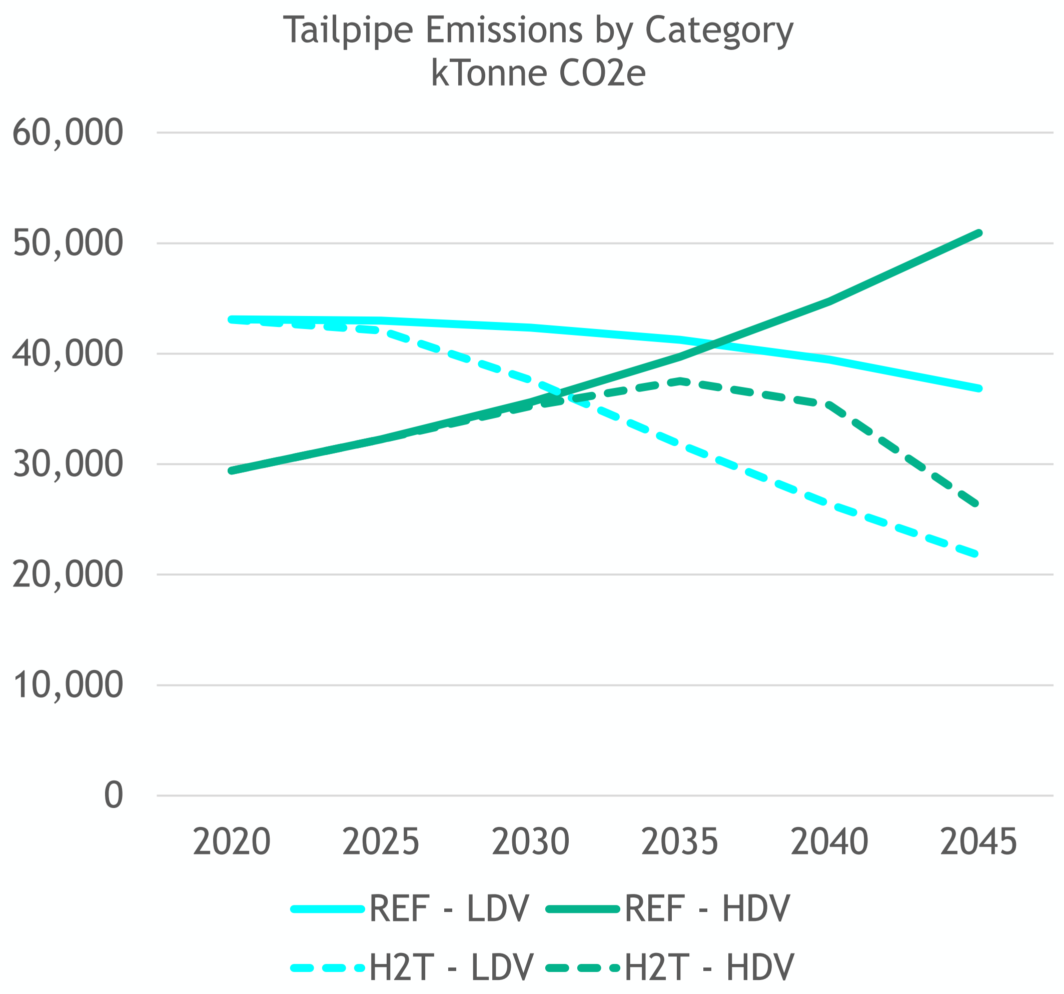

| | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 |
|---|---|---|---|---|---|---|
| REF | 60 | 161 | 336 | 603 | 993 | 1,524 |
| ELEC Only | 63 | 332 | 1,246 | 2,475 | 3,771 | 4,954 |
| H2T | 63 | 332 | 1,436 | 3,570 | 8,367 | 16,934 |




| | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 |
|---|---|---|---|---|---|---|
| REF | 74,257 | 77,084 | 79,874 | 82,964 | 86,256 | 89,879 |
| ELEC Only | 74,232 | 76,156 | 75,034 | 72,803 | 70,756 | 70,240 |
| H2T | 74,232 | 76,156 | 74,750 | 71,112 | 63,325 | 49,332 |

# More Results

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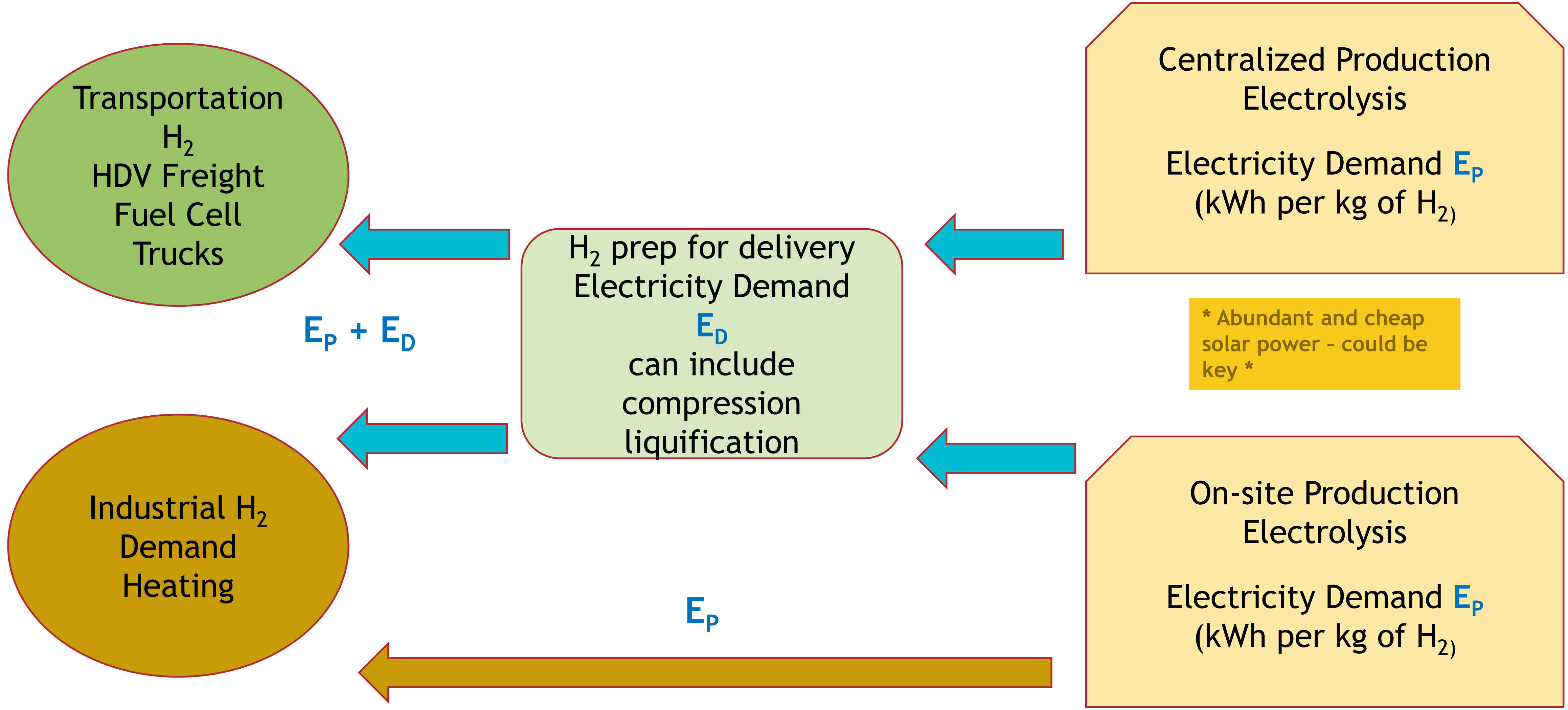
Transportation
$H_2$
HDV Freight
Fuel Cell
Trucks
$E_P + E_D$
Industrial $H_2$
Demand
Heating
$H_2$ prep for delivery
Electricity Demand
$E_D$
can include
compression
liquification
$E_P$
Centralized Production
Electrolysis
Electricity Demand $E_P$
(kWh per kg of $H_2$)
* Abundant and cheap solar power - could be key *
On-site Production
Electrolysis
Electricity Demand $E_P$
(kWh per kg of $H_2$)

# Quick Summary of $H_2T$
# Roadway Modes of Transportation

1. Kept requirements and modes consistent with REF Transportation Case
2. Earlier move to electric vehicle in LDV space, and gradual move to Hydrogen Fuel Cell in HDV freight space
3. Much lower emissions
4. Much less consumption of petrol products – gasoline and diesel
5. Much more demand for Electricity

# Pathways to Decarbonization

## Possible Strategies and Outcomes

Massoud Jourabchi

Steve Simmons

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# What are Pathways that can significantly Reduce (GHG) Emissions from NW economy?

The primary focus is on reducing the energy-related emissions from:

- Use of fossil fuels in the Residential, Commercial, Industrial and Transportation, agricultural Sectors
- Electric Generation Systems

- Secondary focus is on reducing emissions from rest of the economy. The non-energy sectors, that provide the food we eat and things we make.
- Third area of focus is on Sinks for GHG emissions in land, forest.
-

| Examples from end-use sectors (not a comprehensive list) | 1 | 2 | 3.a | 3b. | 3c. |
|---|---|---|---|---|---|
| | More efficient use of fossil fuels (natural gas, oil) | Conversion to Electricity | Green hydrogen H2 | More efficient use of electricity | More distributed generation |
| Residential | Conservation | Various end-uses | | Conservation | Rooftop PV |
| Commercial | Conservation | Various end-uses | | Conservation | Rooftop PV |
| Industrial | Conservation | Various end-uses | High temp applications | Conservation | Rooftop PV |
| Transportation | Higher MPG standards | Battery Electric Vehicles | Heavy Duty Vehicles/Marine | | |

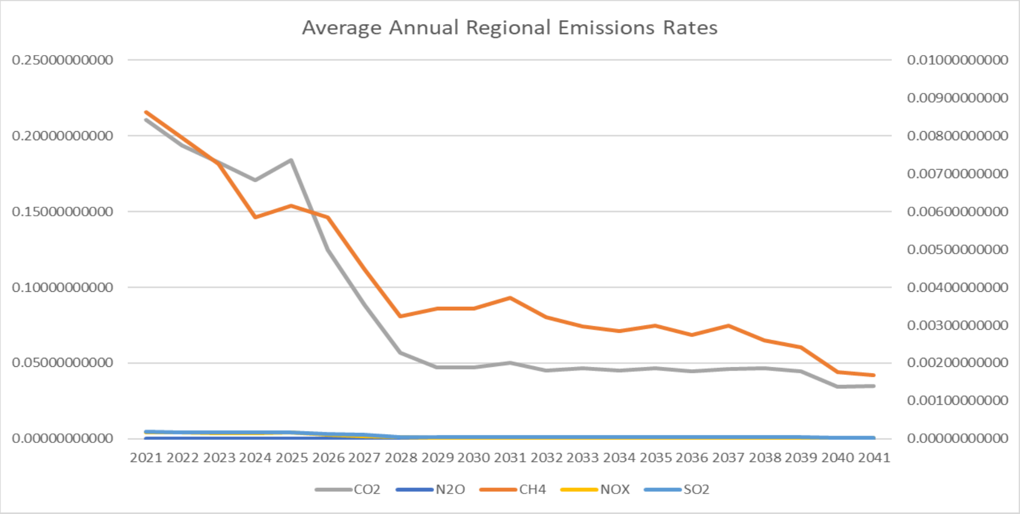
| Examples from the Gas and Electric Systems (not a comprehensive list) | 4a. Greater mix of non-emitting or low emitting supply | 4b. Early retirement of high emitting supply | 4c. Cleaner fuel delivery systems |
|---|---|---|---|
| Electricity Generation System | Utility scale solar, wind geothermal, storage, and emerging techs | Coal plants, inefficient natural gas plants | Reduce upstream Methane emissions to the power plant delivery point |
| Natural Gas System | Renewable Natural Gas (RNG) | | Reduce upstream Methane emissions to all delivery points |

# Methodology for GHG reduction Strategies

- After establishing a baseline or reference forecast . A number emission reduction strategies were evaluated.
- Each strategy was tested individually, then a subset were combined into a combined scenario.
- Yearly emissions from energy sector (electric power and fossil fuels) were calculated using emission rates from Aurora, and forecast of loads from long-term model (E2020).
- Economywide, non-energy sources and sinks are then combined with energy related emissions.
- Economywide Net Emissions were calculated for the region/state.

# Key Exogenous Input – Emission Coefficients from Power Sector

- 2022-2041 Emission Coefficients for 6 pollutants are from Coal Retirement scenario.
- **Average Regional Emissions Rate (tons/MWh)**




Reduction in emission coefficients

| 2022-2041 | AAGR |
|---|---|
| N2O | -5% |
| CH4 | -8% |
| CO2 | -9% |
| NOX | -9% |
| SO2 | -8% |

Post 2041 emissions are kept at the 2041 levels.
We will test cases with declining emission coefficients for 2042-2050.

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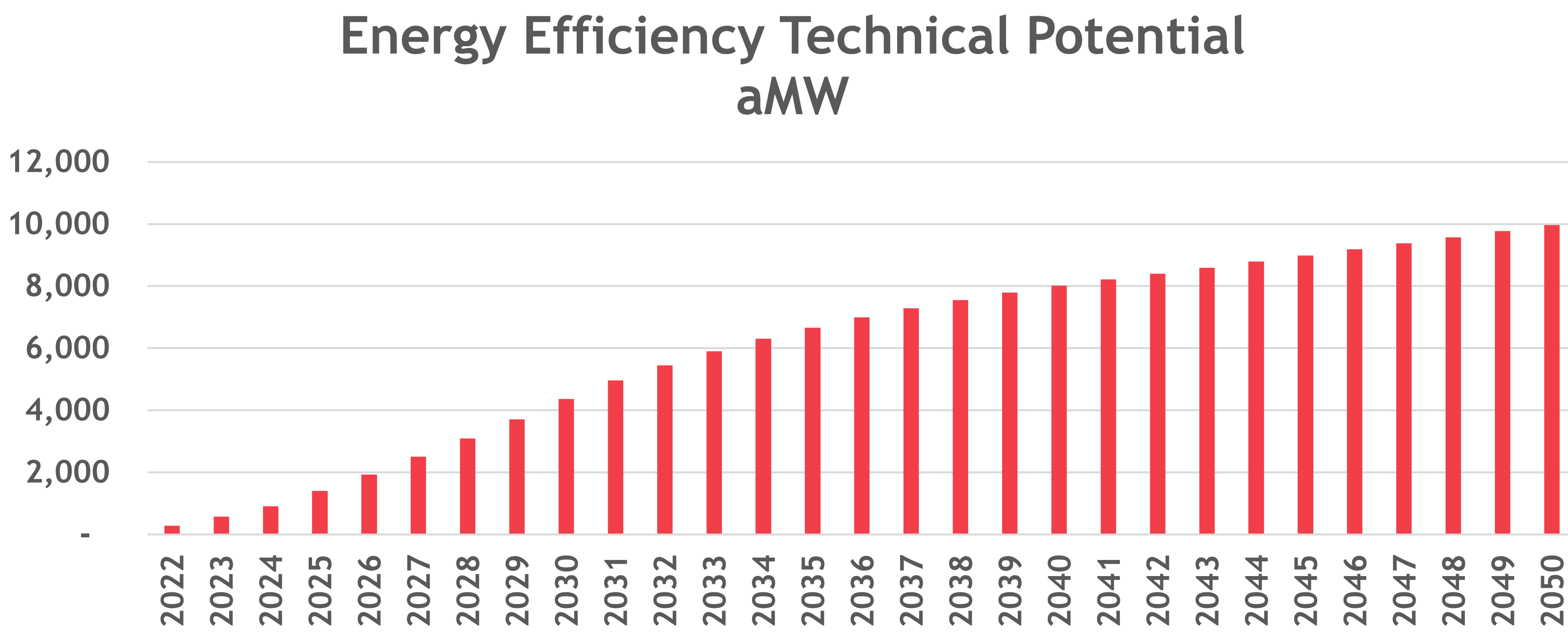
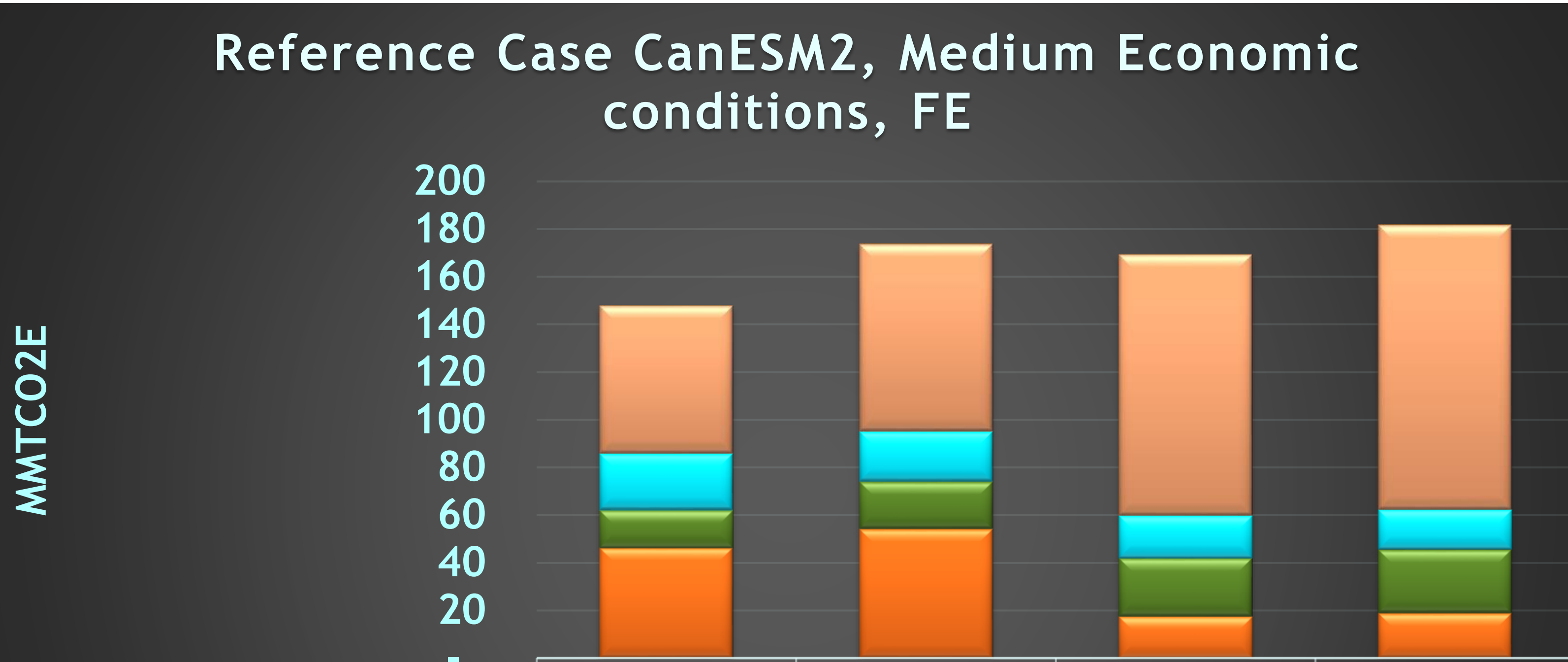
# EE Targets




As a strategy we netting out all of EE technical potential from loads. Although loads go down by over 10,000 aMW by 2050 (from about 25,000 aMW to 15,000 aMW) GHG emissions in 2050 decrease by about 7 MMTCO2e. Proportionally speaking loads go down by 40% but emissions go down by 4%. Much less than expected. Reason being power system has very low emissions by 2050, so reduction in load does not significantly lower emissions.

# Reference Case Energy System GHG Emissions Prior to mitigation Strategies




| | 1990 | 2005 | 2041 | 2050 |
|---|---|---|---|---|
| Transportation | 62 | 78 | 109 | 119 |
| Industrial, w/o Agric | 24 | 21 | 18 | 17 |
| Residential/Commercial | 16 | 20 | 24 | 27 |
| Electric Sector | 46 | 54 | 17 | 19 |

| Is this strategy included in the Combined Case | Transportation Mitigation Strategies | change by 2040 | change by 2050 |
|---|---|---|---|
| | Baseline (MMTCO2e) | 169 | 182 |
| YES | Model International Standards required a 2% per year reduction in CO2 emissions for all Air travel (starting in 2025) and Ocean Freight (starting in 2028) | (9) | (14) |
| YES | Set market share for electric BUS exogenously, 0.1% in 2020 growing to 94% in Idaho and Montana by 2050 and 100% for Oregon and Washington | (0.5) | (1) |
| NO | CAFÉ standards to increase to 100 MPG by 2050 from current 25 mpg | (3) | (5) |
| NO | CAFÉ standards to increase to 65 MPG by 2040 from current 25 mpg | (4) | (7) |
| YES | CAFÉ standards to increase to 80 MPG by 2040 from current 25 mpg | (4) | (7) |
| YES | Forced early retirement of older, inefficient gasoline & diesel fueled passenger vehicles and light duty trucks | (1) | (1) |
| YES | set market share for HDV2 vehicles exogenously, 0.5% in 2026 increasing to 100% by 2050 | (2) | (4) |
| YES | set market share for HDV6 vehicles exogenously, 0.6% in 2026 increasing to 94% by 2050 | (2) | (8) |
| YES | set market share for HDV8 vehicles exogenously, 0.6% in 2026 increasing to 94% by 2050 | (3) | (13) |
| YES | Set market share for LDV vehicles exogenously set. Starting in 2020 Market share 1-5% increasing to 100% by 2030, 2035, 2045 for Washington, Oregon, Idaho and Montana | (12) | (14) |
| YES | Increase Electric marine so marginal market share so that it goes to 50% by 2050 | (5) | (9) |
| YES | Increase Electric Freight Train marginal market share so that it goes to 50% by 2050 | (1) | (2) |
| YES | Reduce VMT per capita from 2020 levels by 1% per year | (11) | (13) |
| | Total for included strategies | (49) | (86) |

# Emission Reduction Impact of Efficiency Strategies

| Is this strategy included in the Combined Case | Efficiency in Building | Change by 2041 | change by 2050 |
|---|---|---|---|
| | Baseline (MMTCO2e) | 169.2 | 181.6 |
| NO | Increase Max. efficiency of residential lighting and appliance standards every 5 years by 5% | (15.0) | (23.5) |
| NO | Increase efficiency of residential lighting and appliance standards every 5 years by 10% | (7.8) | (12.7) |
| NO | Increase lighting efficacy – at 5% per year instead of current 3% per year | (0.2) | (0.3) |
| YES | More Aggressive retrofit for Appliances | (13.5) | (15.7) |
| NO | Increasing shell efficiency in multifamily (update building codes on a 5-year cycle, 5% improvement per cycle) | (0.2) | (0.3) |
| NO | Use proposed HUD standards for manufactured homes | (0.4) | (0.5) |
| NO | Increasing shell efficiency in single family (update building codes on a 5-year cycle, 5% improvement per cycle) | (1.8) | (2.9) |
| NO | Reduce size of new homes by 20% over the next 20 years (compared to base case) | (5.0) | (5.5) |
| Yes | Include EE Technical Potential | (6.0) | (7.3) |
| | Total for included strategies | (20) | (23) |

# Emission Reduction Impact of Fuel-Switching and Conversion Strategies

| Is this strategy included in the Combined Case | Fuel Switching/conversions | Change by 2041 | change by 2050 |
|---|---|---|---|
| | Baseline | 169 | 182 |
| NO | Baseboard heating would be converted to heat pump upon replacement | (0.1) | (0.2) |
| NO | Requiring HP in place of zonal heating at end of life | (5.2) | (7.5) |
| NO | All other forms of heating fuel use is shifted to electricity upon natural replacement | (7.1) | (10.6) |
| NO | Water heating will be shifted to electric and heat pump | (1.4) | (2.0) |
| NO | Residential Cooking fuel will shift from fossil fuel to Electric. | (0.8) | (1.2) |
| NO | Moving all non-electric demands (wood, oil, natural gas, propane) to electric at end of equipment life in both residential sectors. | (14.8) | (19.4) |
| | Total for included strategies | - | - |

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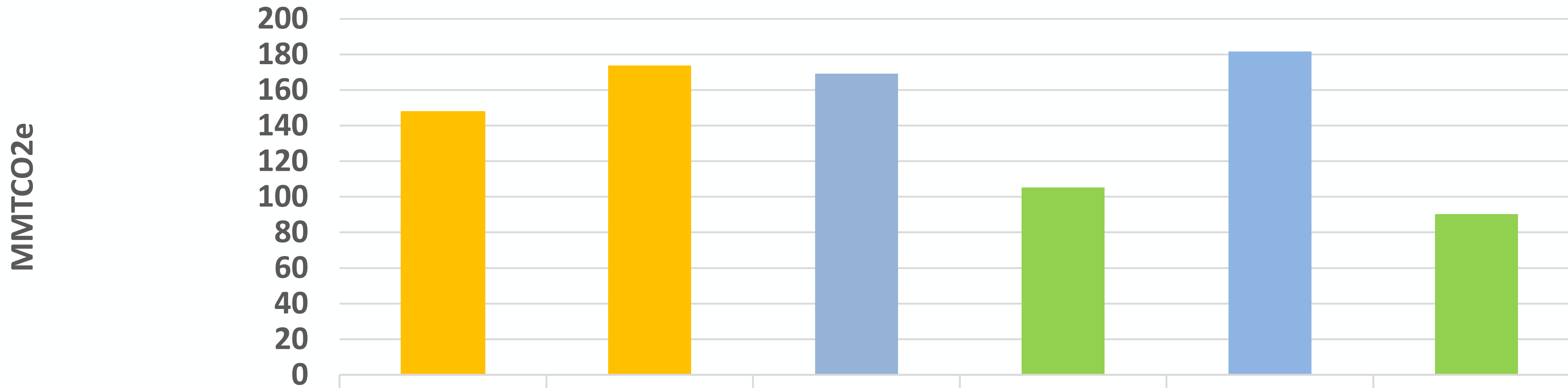
# Emission Reduction Impact Misc. Strategies Tested

| Is this strategy included in the Combined Case | Solar, RNG, Industrial and CO2 tax | Change by 2041 | change by 2050 |
|---|---|---|---|
| | Baseline (MMTCO2e) | 169.2 | 181.6 |
| YES | Increase ratio of battery to solar from 1 to 1 to one to five by 2050 | (2.1) | (4.8) |
| YES | Reduce cost curves for Solar so by 2050 costs are 75% lower compared to 2022 | (0.2) | (0.1) |
| YES | Increase ITC for solar. ITC at 30% | (0.2) | (0.1) |
| YES | Increased RNG penetration as a replacement for natural gas fuel | (2.6) | (4.1) |
| YES | shift industrial fossil fuel demand to electricity | (2.8) | (4.4) |
| YES | shift industrial fossil demand to electricity then Hydrogen | (3.5) | (5.6) |
| YES | reflect increased electrical demand from H2 production | 2.3 | 3.9 |
| NO | Nominal $50/ton eCO2 charge by 2050 | (1.2) | (1.9) |
| YES | Nominal $100/ton eCO2 charge by 2050 | (2.0) | (3.5) |
| | Total for included strategies | (11.04) | (18.52) |

# In Combinations above Strategies Could lower GHG Emissions from Residential, Commercial, Industrial, Agriculture and Electric Utilities from 182 to 90 MMTCO2e in 2050

GHG Emissions from Energy used in Residential, Commercial, Industrial, Agriculture and Electric Utilities

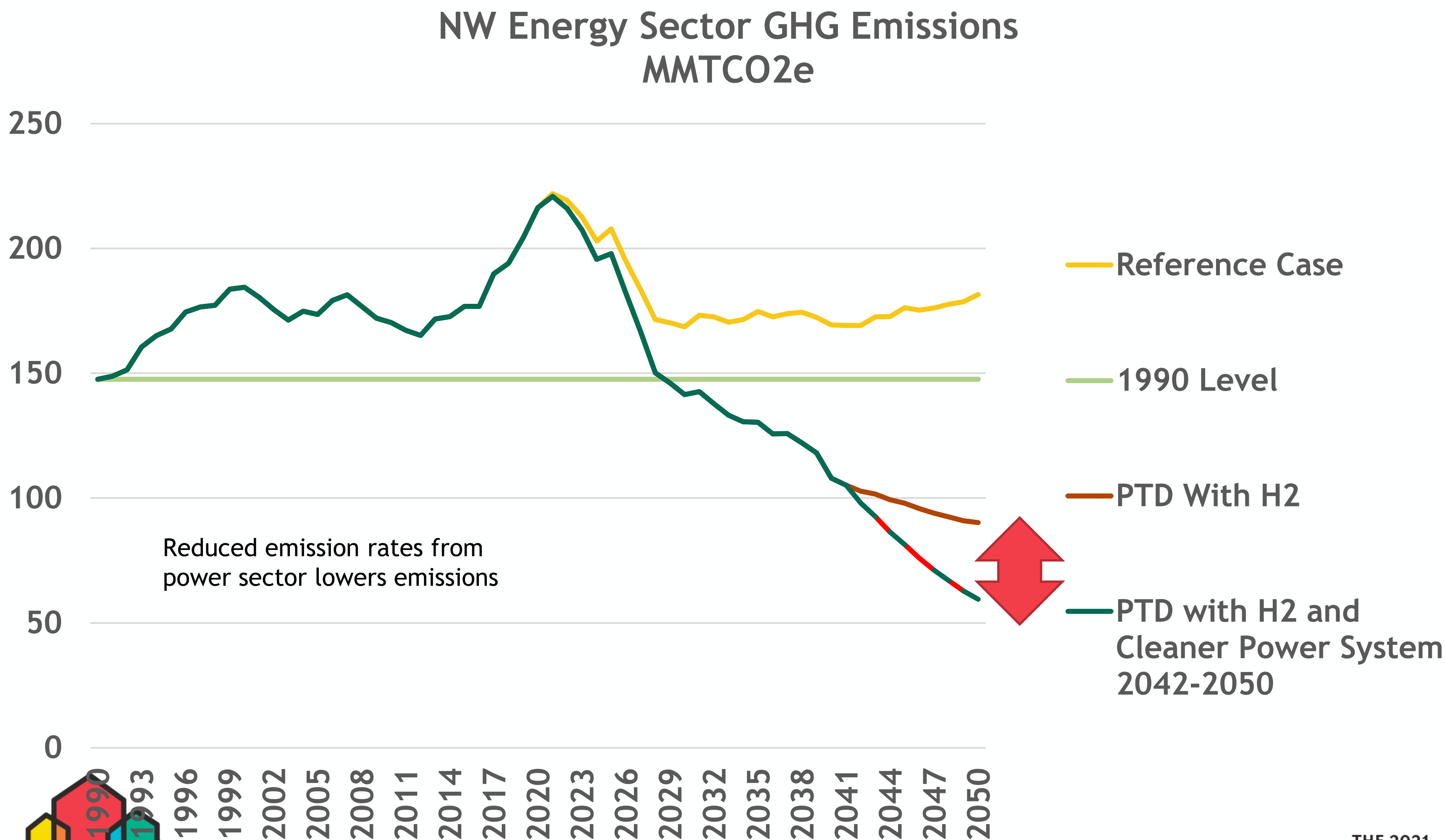



| | 1990 | 2005 | 2041 Ref. | 2041 Combination #14 | 2050 Ref | 2050 Combination # 14 |
|---|---|---|---|---|---|---|
| Total Energy Sectors | 148 | 174 | 169 | 105 | 182 | 90 |

# Can we further reduce Regional GHG Emissions from energy sector?

- Some Options
    1. If power system can continue to decarbonize at the same rate as 2035-2041 then emissions from power sector can be reduced by 30 MMTCO2e by 2050.
    2. Incorporating H2 into the supply mix lowers GHG emissions in 2050 by 14 MMTCO2e. Increasing efficiency of H2 production. post 2041 will further reduce emissions.
    3. Test different combination of strategies- by more aggressive conversion strategies and front-loading EE.
    4. Direct Carbon Capture and Use applications

# Option1- Cleaner Power System (2042-2050) Can Further Reduce Emissions from Energy Sector by over 30 MMTCO2e

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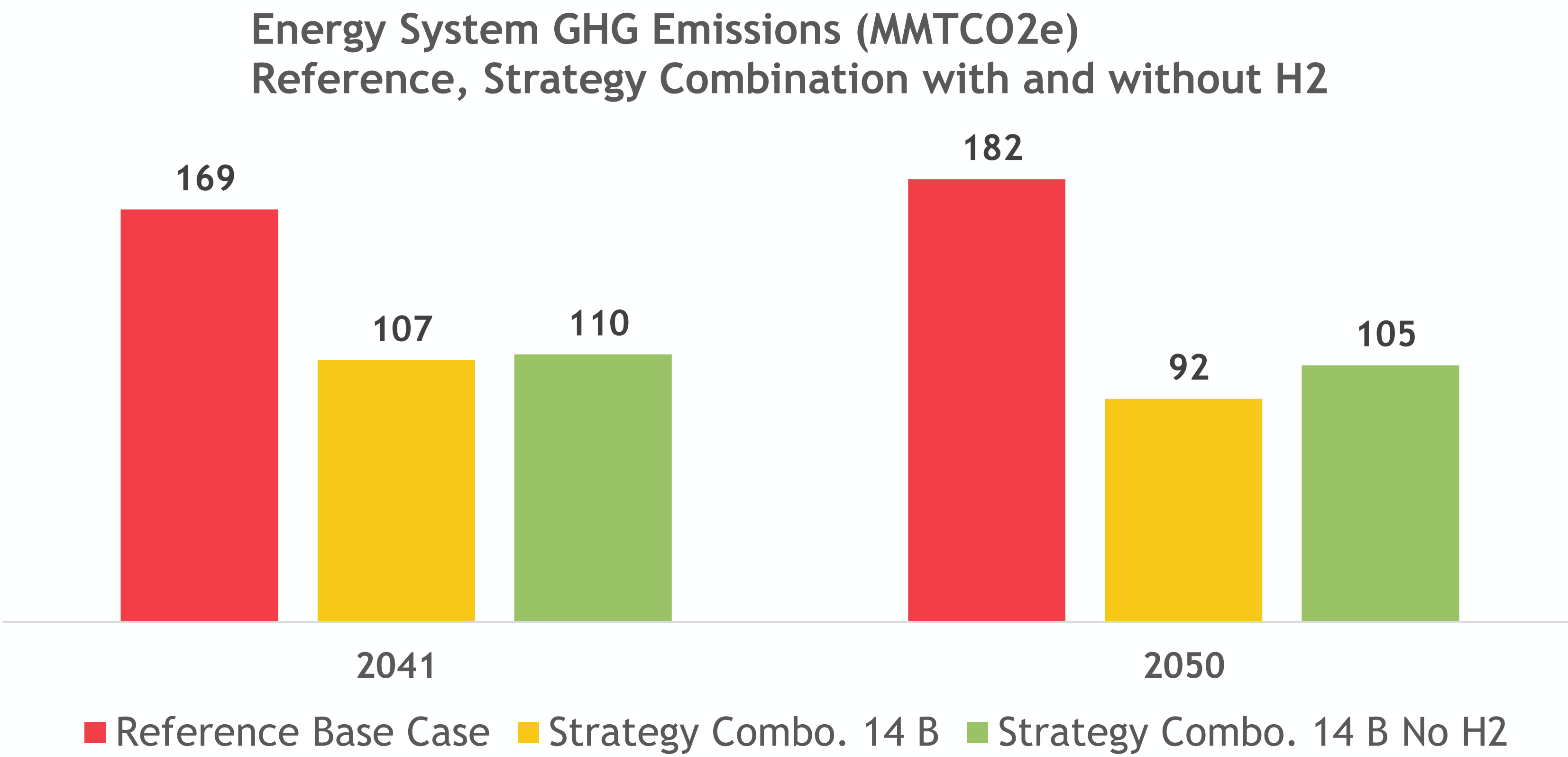
# Option 2:
# H2 Production adds 34,000 aMW to Regional Load but by 2050 it can reduce emissions by 13 MMTCO2e




**Do we have enough excess generation/curtailed renewable to meet H2 needs?**

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# Non-Energy Sector Emissions

- These sectors include, all non-energy related processes that emit greenhouse gases.
- Major categories include:
  - Industrial Processes
  - Agricultural and Dairy Processes
  - Waste disposal- solid and waste water processes
- Also included:
  - Emissions from forest fires
  - Emissions from man-made reservoirs
- We track and project emission levels by subsector and gas using EPA/State Inventory Tool  Model.

# Source of Economy-wide Sources & Sinks

| | |
|---|---|
| Energy | |
| | CO2 from Fossil Fuel Combustion- From Council Models |
| | Stationary Combustion (N2O, Ch4 from Council LTM) |
| | Mobile Combustion ( from Council LTM) |
| | Coal Mining & Abandoned Mines |
| | Natural Gas and Oil Systems ( from Council RNG analysis) |
| Industrial Processes (from Council LTM) | |
| Agriculture (from SIT model) | |
| | Enteric Fermentation |
| | Manure Management |
| | Rice Cultivation |
| | Agricultural Soil Management |
| | Liming |
| | Urea |
| | Burning of Agricultural Crop Waste |
| Waste (From SIT model) | |
| | Municipal Solid Waste |
| | Wastewater |
| Forest Fire (From council analysis) | |
| Man-made reservoirs (WSU/IPCC) | |

## Sinks

Net Forest Carbon Flux

Urban Trees

Landfilled Yard Trimmings and Food Scraps

Agricultural Soil Carbon Flux

## Industrial Processes Sources of Emissions

| | |
|---|---|
| Carbon Dioxide Emissions | |
| | Cement Manufacture |
| | Lime Manufacture |
| | Limestone and Dolomite Use |
| | Soda Ash |
| | Aluminum Production, CO2 |
| | Iron & Steel Production |
| | Ammonia Production |
| | Urea Consumption |
| Nitrous Oxide Emissions | |
| | Nitric Acid Production |
| | Adipic Acid Production |
| HFC, PFC, SF6 and NF3 Emissions | |
| | ODS Substitutes |
| | Semiconductor Manufacturing |
| | Magnesium Production |
| | Electric Power Transmission and Distribution Systems |
| | HCFC-22 Production |
| | Aluminum Production, PFCs |

# Industrial Sector is projected to emit 35 MMTCO2e by in 2050.
# Industrial emissions growing at between 1.3 to 2.3 annually, depending on the industry

| Emissions (MMTCO2E) | 1990 | 2022 | 2041 | 2050 | Cumulative 2022-2050 | 2022-2050 AAGR |
|---|---|---|---|---|---|---|
| Carbon Dioxide Emissions | 3.5 | 7.3 | 10.4 | 12.0 | 278 | 1.8% |
| Cement Manufacturing | 0.5 | 2.6 | 3.6 | 4.1 | 97 | 1.7% |
| Iron & Steel Production | 0.0 | 2.9 | 4.6 | 5.4 | 121 | 2.3% |
| | | | | | | |
| HFC, PFC, NF3, and SF6 Emissions | 3.9 | 16.1 | 22.2 | 23.0 | 612 | 1.3% |
| ODS Substitutes | 0.0 | 12.1 | 16.6 | 16.6 | 463 | 1.2% |
| Semiconductor Manufacturing | 0.5 | 3.4 | 5.2 | 6.0 | 137 | 2.1% |
| Total Emissions from all industrial sectors | 7.4 | 23.5 | 32.5 | 35.0 | 890 | 1.5% |

ODS: Ozone Depleting Substitutes

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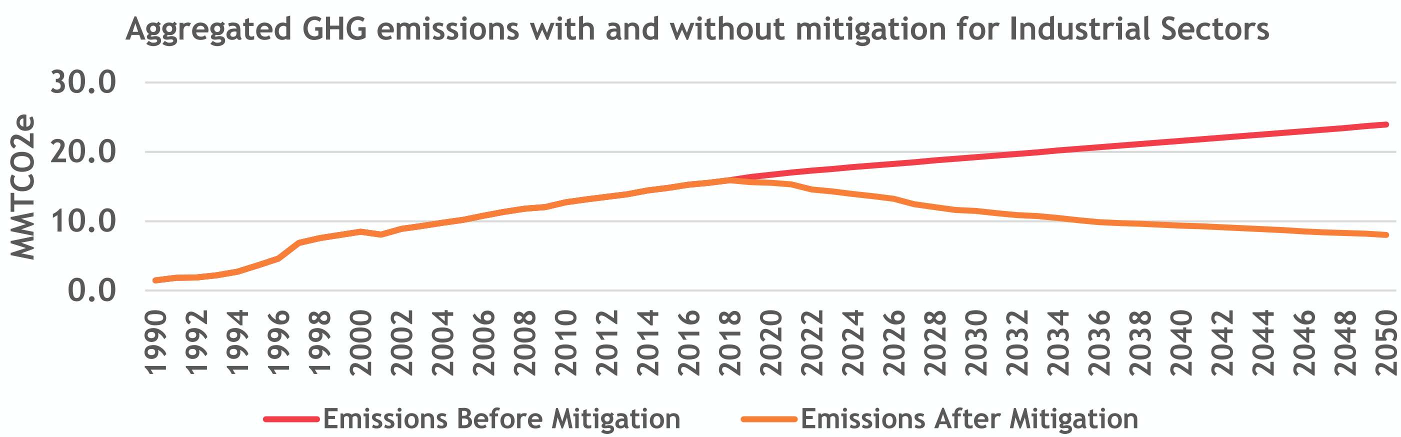
# Mitigation Strategies for Non-Energy Sectors

- Things we make
  - Cement, (2% annually post 2022)
  - Iron & Steel (4% annually post 2022),
  - Semiconductor Manufacturing ( 1% annually post 2022),
  - Replacement of Ozone Depleting Substances (4% annually post 2022)




| Cumulative Emissions 2022-2050 MMTCO2e | Before Mitigation | After Mitigation | % reduction- By 2050 |
|---|---|---|---|
| Cement | 97 | 59 | 39% |
| Iron and Steel | 95 | 61 | 36% |
| Semiconductors | 137 | 106 | 22% |
| Ozone Depleting Substance Substitutes | 249 | 64 | 74% |
| Lime manufacturing | 21 | 15 | 25% |
| Sum of above | 598 | 305 | 49% |

# GHG Emissions from Agriculture and Dairy in the NW

Major categories of GHG emissions from agricultural and Dairy businesses, are CH4 and N2). As population grows, so do emissions. By 2050, over 61 MMTCO2 emissions are expected, absence any mitigation strategies. A growth 75% growth over 1990 levels and 77% growth over 2022.

| MMTCO2E | 1990 | 2022 | 2041 | 2050 |
|---|---|---|---|---|
| **CH4** | **20.1** | **26.5** | **32.5** | **37.2** |
| Enteric Fermentation | 14.2 | 18.6 | 24.9 | 30.3 |
| Manure Management | 1.1 | 3.5 | 3.6 | 3.6 |
| Rice Cultivation | - | - | - | - |
| Waste | 4.2 | 3.7 | 3.1 | 2.3 |
| Wastewater | 0.6 | 0.8 | 0.9 | 0.9 |
| **N2O** | **15.4** | **20.6** | **22.5** | **23.3** |
| Manure Management | 0.4 | 0.7 | 0.7 | 0.8 |
| Agricultural Soil Management | 14.9 | 19.9 | 21.7 | 22.5 |
| **Total (MMTCO2e)** | **35** | **47** | **55** | **61** |

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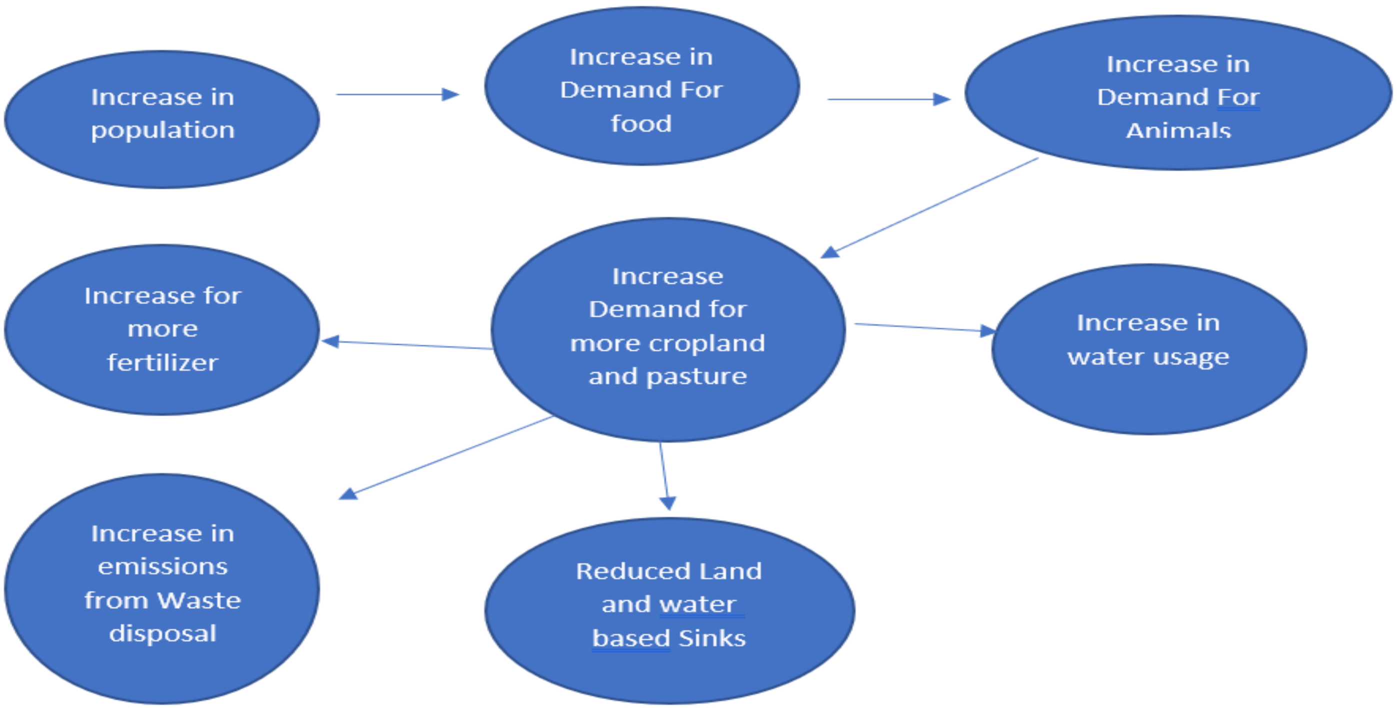
# Foods We Eat
## Strategies to Reduce Methane and N20 Emissions

Meat is still what is for dinner, But:
Following Mitigation (1% annual reduction post 2022, 1.5% annually post 2031)

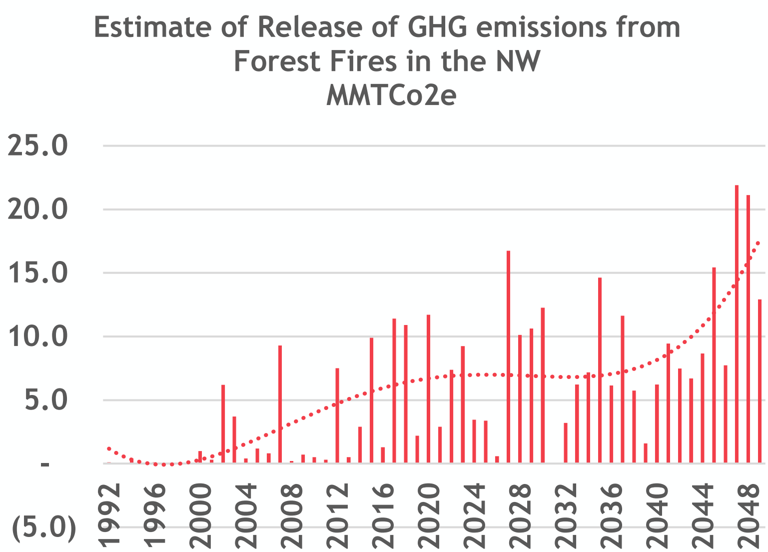
- Increase in Plant-Base Food
- Reduced number of animals
- Reduced lands planted for feed
- Reduced water for irrigation
- Reduced manure/better manure management
- Increased land and water based sinks

Can help reduce GHG emissions



# Additional Sources of Emission

- Two additional sources of emissions
  - Forest Fires
  - Man-made reservoirs



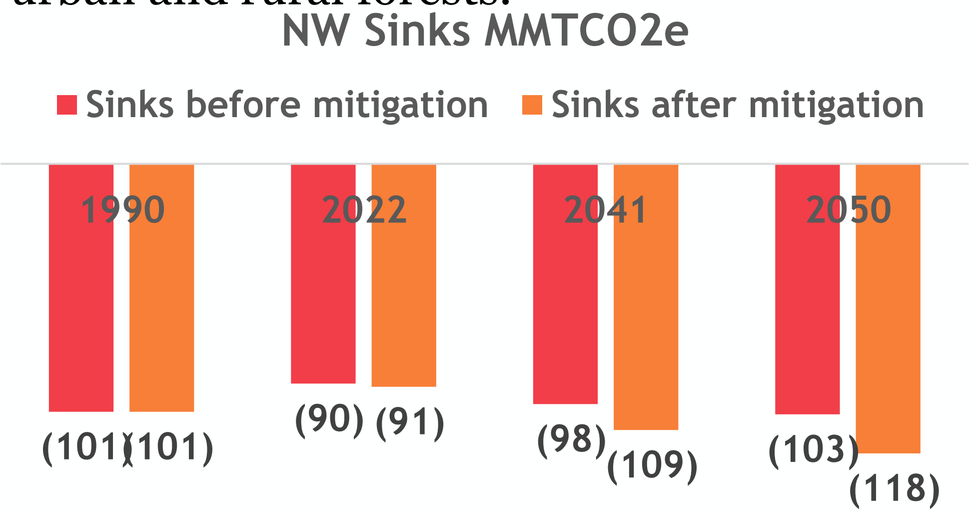

- Forest fire emissions are estimated using econometric relationships. Emission vary based on temperature and precipitation.

- Annual emission from Northwest man-make reservoirs estimated at about 6.5 MMTCO2E/YR.

**Source research for reservoir emission:**
**Year-2020 Global Distribution and Pathways of Reservoir Methane and Carbon Dioxide Emissions According to the Greenhouse Gas from Reservoirs (G-res) Model -**
John A. Harrison, Yves T. Prairie, Sara Mercier-Blais, and Cynthia Soued

# Sinks (Land-Use and Land-Use Change and Forests) are major contributor to reducing GHG emissions

- LULUCF sector is a net "sink" of emissions in the US (e.g., more greenhouse gas emissions are sequestered than emitted from land use activities).
- Although LULUCF in the United States can be considered as a sink for emissions, this sink has declined by 9% since 1990.
- We used default values in EPA SIT model to generate forecast of sinks for the NW.
- We assumed LULUCF mitigation strategies can increase sinks in agricultural land, urban and rural forests.



# Mitigation strategies on Sources and increased sinks, makes is possible to have a negative Net Emission

| MMTCO2E | 1990 | 2050 PTD | 2050 PTD Case* |
|---|---|---|---|
| Energy | 148 | 90 | 63 |
| Coal Mining & Abandoned Mines | 2 | 0.4 | 0.4 |
| Natural Gas and Oil Systems | 3 | 0.3 | 0.3 |
| Industrial Processes | 7 | 35 | 9 |
| Agriculture | 32 | 41 | 24 |
| Municipal Solid Waste | 4 | 2 | 1 |
| CH4 From Reserviours | 7 | 6.5 | 6.5 |
| Emissions from Foreast fires | - | 13 | 13 |
| Aggregate Sources | 203 | 189 | 118 |
| Aggregate Sinks | (101) | (103) | (118) |
| Net Emissions | 101 | 86 | (1) |
| *- Includes further reduction in emission coefficients in power sector POST 2041 | | | |

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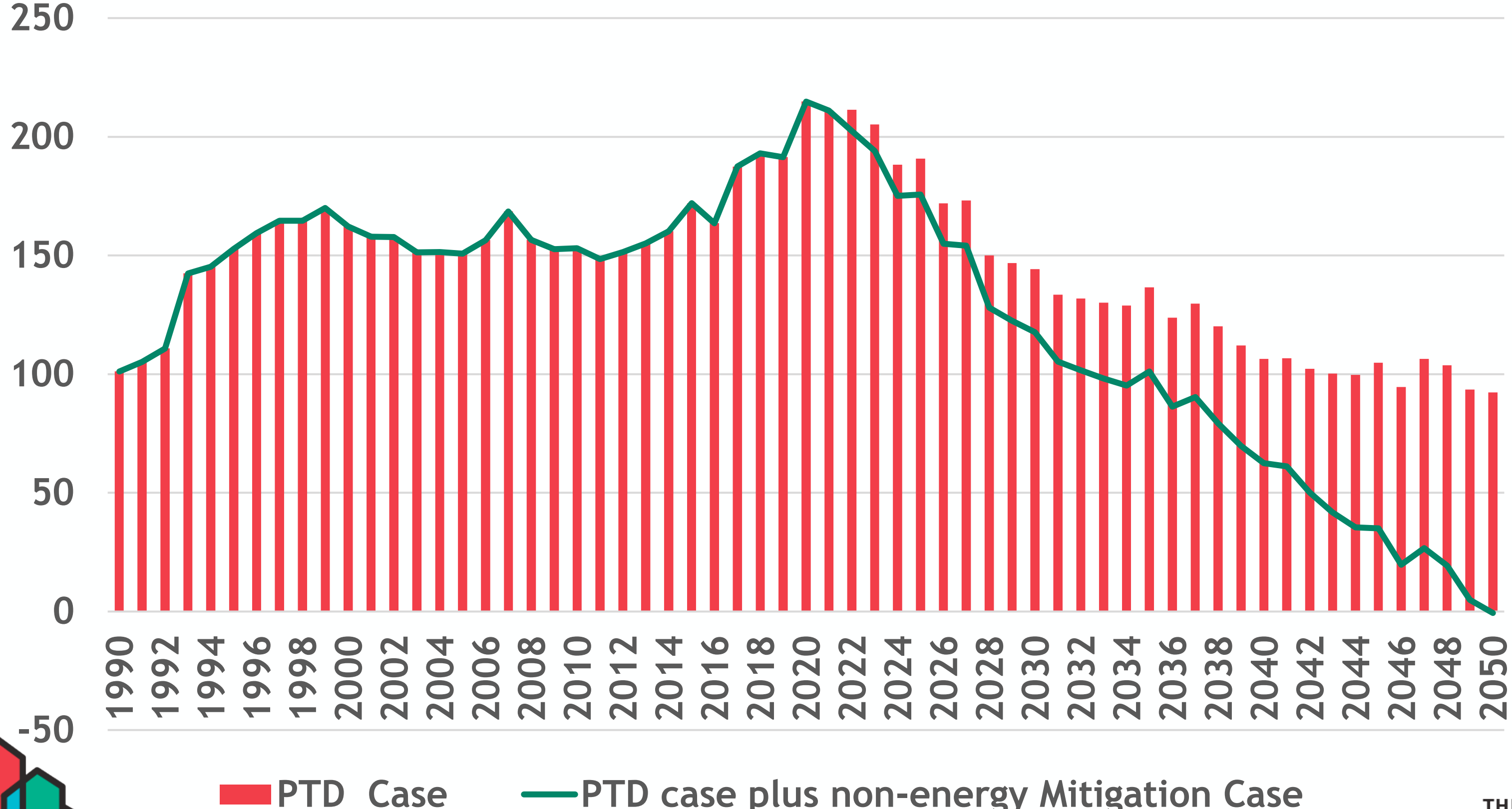
# Pathways to Decarbonize Economy of NW can Produce Negative Emissions

Comparison of Net Emissions in the PTD case and PTD plus Non-Energy Mitigation Strategies MMCO2e

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# Although it is feasible to reduce GHG emissions in 2050 to less than zero
# Cumulatively region will be adding between 4 to 2.4 billion metric tons of CO2e to the atmosphere between 2022-2050

| Cumulative MMTCO2 Emissions | 2022-2050<br>Billions of Metric Tons CO2e |
|---|---|
| Baseline/Reference | 7 |
| PTD case | 4 |
| PTD plus non-energy sources and sinks | 2.5 |
| | |

# Summary

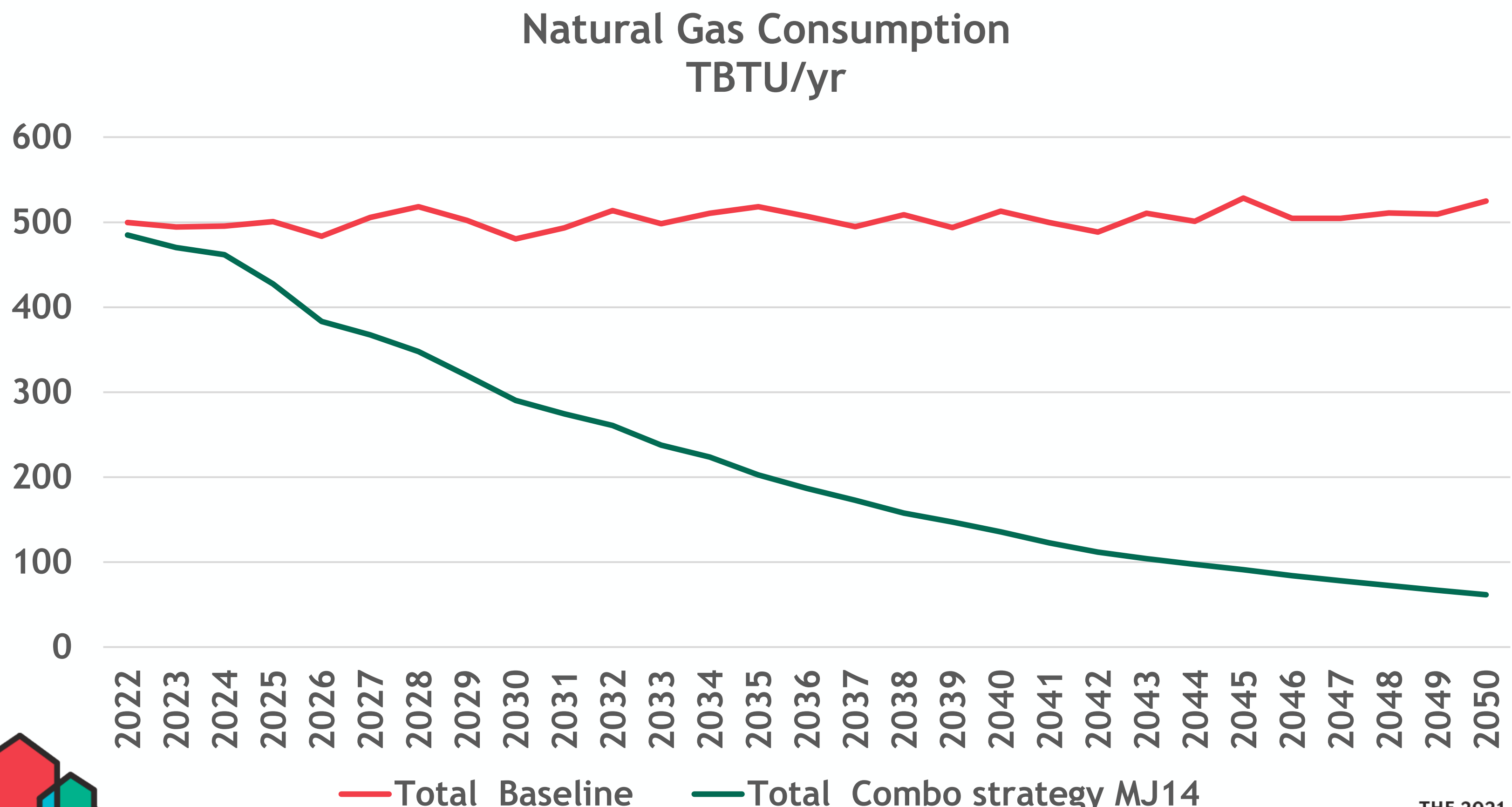
- Without mitigation strategies, region is projected to emitting over 7 Billion metric tons of GHGs.
- PTD loads increase to 57,000 aMW by 2050, compared to 25,000 in the reference case.
- Power sector alone, even under aggressive set decarbonization strategies cannot reach zero emissions by 2050.
- Improving efficiency of power system post 2042, can lower emissions by 30 MMTCO2e.
- Netting out EE supply curve from loads, did not reduce emissions significantly, because emission coefficients for power system are declining rapidly.
- Adding hydrogen will add load but lowers emissions.
- We tested and incorporate a set non-energy sources and sinks. This allowed testing economy-wide decarbonization strategies of things we make and eat.
- Mitigation strategies in the non-energy sector allowed for major reduction in emissions.
- With mitigation strategies, cumulative GHG emissions are lowered to 4 Billion metric tons.
- Improving agricultural, pastural lands and urban and rural forest help significantly in increasing GHG sink,

# NEXT STEPS

- Incorporate feedback from this meeting
- Expand the analysis across economic and climate change scenarios.
- Present current finding to Demand Forecast Advisory Committee, in a near future.
- Complete documentation for PTD scenario.

# Questions

# Natural Gas Consumption (Excludes Electric Utility Demand)

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