Contents

Context

Pathways to Decarbonization (PTD) identifies mitigation strategies that could reduce GHG emissions from NW power and economic sectors to zero by 2050. These strategies use CanESM2 climate change model projections of temperatures and precipitation. CanESM2 projections represent a warmer future temperature trajectory. Same climatic conditions are used in development of reference case. For each strategy tested, we report a description of strategy, reduction in GHG emissions by 2040 and 2050 and cumulative reductions in emissions between 2022 and 2050.

Two general categories of pathways or strategies were tested. First category includes strategies that need to be initiated by producers and supply-side of the economy such as cement, steel and electronic manufacturers, or agricultural products and livestock producers. This analysis attempts to quantify impact of increase in efficiency is these economic sectors. The second category are strategies that need to be initiated by consumers calling for reduced emissions in (buildings we live in, food we eat and clothing we wear).

Analysis of individual pathways are deterministic. Later in the resource planning analysis, done through Resource Portfolio Model (RPM) probabilistic deviations in loads are incorporated into the model. PTD Loads presented here are based on Frozen Efficiency scenario, where efficiency of enduses constant post 2021, except for strategies that include increasing technological efficiency. Also, impact of energy efficiency goals are not included in this analysis, at this time.

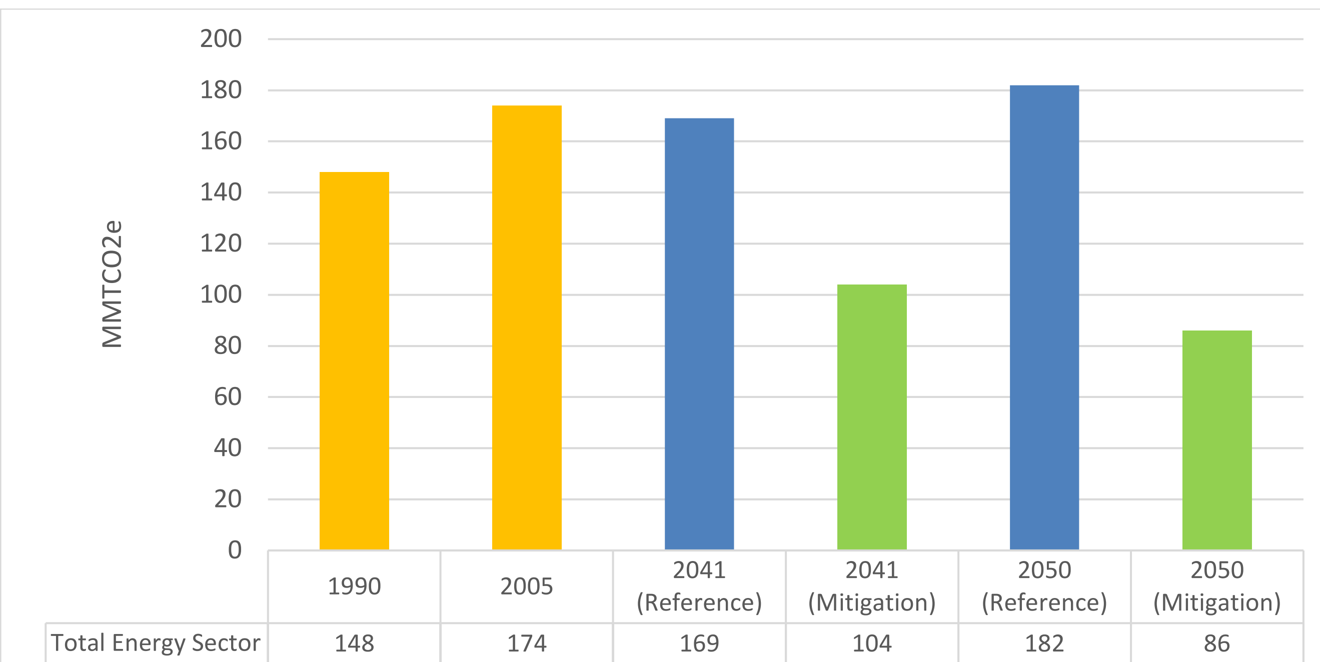
This analysis has NOT explicitly incorporated NW States demand side initiative to mitigate impact of increase in GHG emissions. Later in the analysis we have created PTD-Partial or Light to incorporate a set of soft targets for the states. Also not included, at this time, are economic impact and mitigation strategy initiatives under the new federal infrastructure investment act.

Overview

This report presents an overview of a roadmap to decarbonizing the Northwest economy. Implementing mitigation strategies outlined can reduce GHG emissions from the power sector as well as from transportation, industrial, and agricultural sectors. In developing the base or reference forecast for loads and emissions, we have used forecast of loads under climate change scenario CanESM2 with Frozen Efficiency starting in 2022. Conservation targets for the 2021 Power Plan are not incorporated into this analysis. State specific policies to reduce emissions were included to the extent known as of June 2021. However, because Idaho and Montana do not have stated decarbonization policies, unlike Washington and Oregon, our mitigation strategies may be considered optimistic for Idaho and Montana.

The goal of this work is to identify strategies that could lower emission levels to zero by 2050, as well as reducing cumulative emissions over the 2022 through 2050 period. First is a summary overview of the impact of mitigation strategies on loads and emissions for the power sector and followed by a discussion of non-energy sources and sinks of emissions.

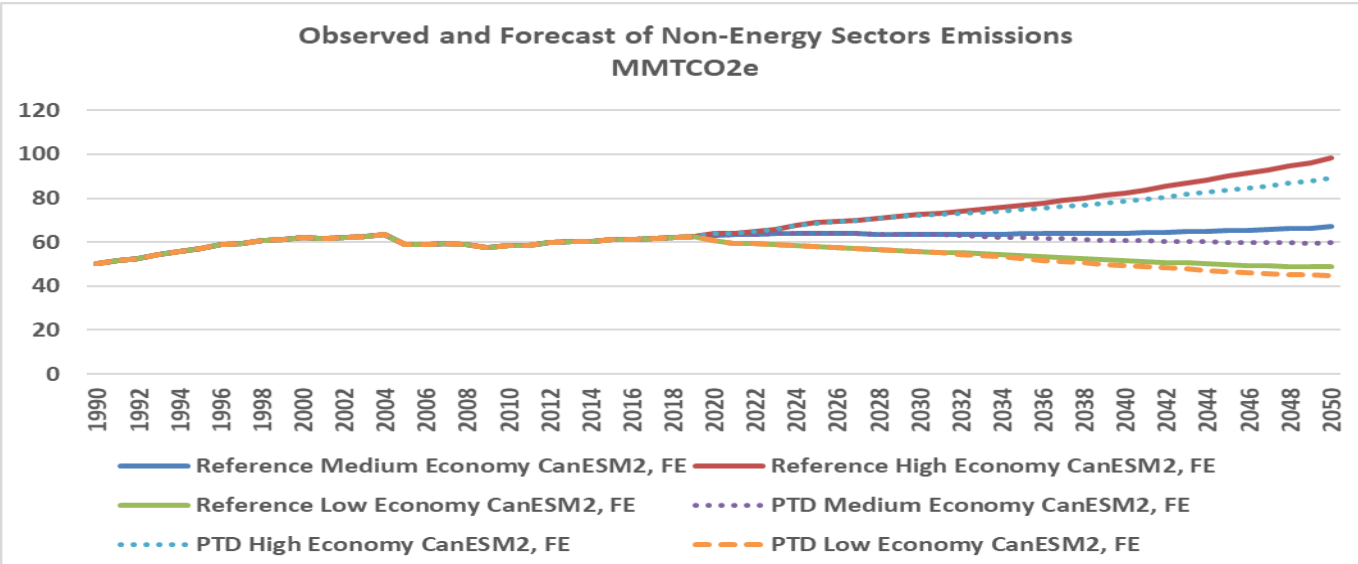
To start, the graph below shows that the region can reduce greenhouse gas (GHG) emissions from energy sectors (including electricity or natural gas used in transportation, buildings, industrial, as well as from electric utilities) from an anticipated total of 169 million metric tons of CO2 equivalent (MMTCO2e) in 2041 to about 104 MMTCO2e using strategies outlined later in the report. In the next three decades, emission levels that could have reached 182 MMTCO2e are lowered to 86 MMTCO2e. First column shows energy sectors emissions in 1990 (148 MMTCO2e), 2041 Reference shows level of emissions without mitigation strategies (169 MMTCO2e) and emissions after implementation of mitigation strategies region can reach 104 MMTCO2e. Extending the mitigation strategies to 2050, forecast shows that emission levels can be lowered from 183 to 86 MMTCO2e. Note that power sector is not 100% clean, even after all the mitigation strategies. Although this analysis shows that region can make great strides in reducing emissions coming from energy sector, the region will be far from a zero GHG-emission future.



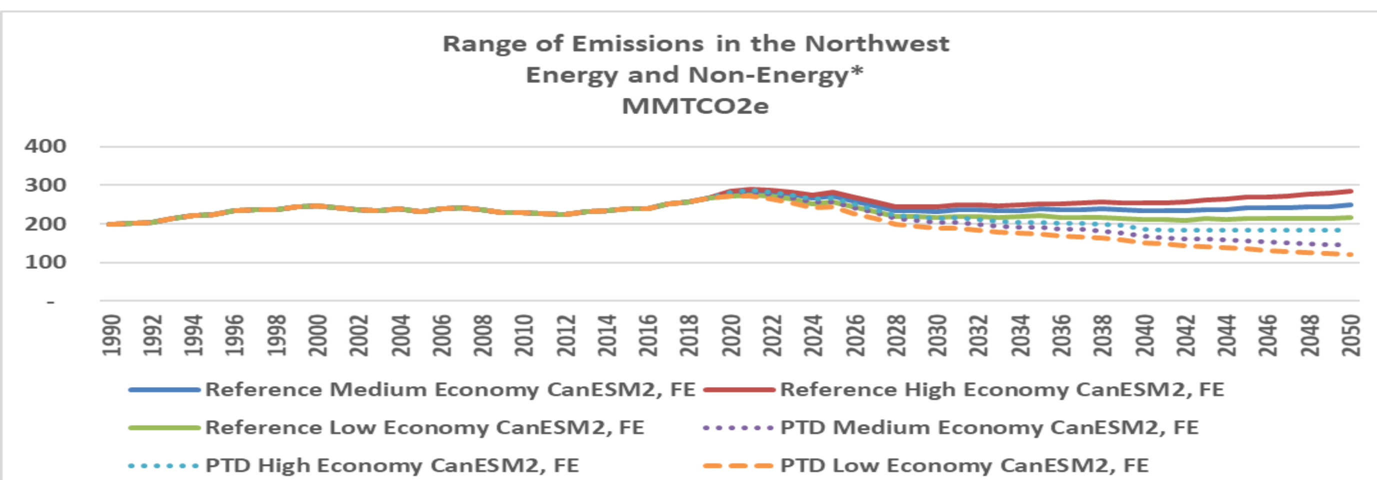
	1990	2005	2041 (Reference)	2041 (Mitigation)	2050 (Reference)	2050 (Mitigation)
Total Energy Sector	148	174	169	104	182	86

The above summary graph presents a partial picture of total emissions in the Northwest, as we need to add emissions from non-energy sectors (Transportation, Industrial, Agricultural sectors) to these totals. Graph below shows observed and forecast of range of emissions with ("PTD") and without ("Reference") mitigation for non-energy sectors of the region's economy.

Non-energy segments of the Northwest economy annually have generated between 54-63 MMTCO2e of GHGs in 1990 through 2018. It is forecast that without mitigation strategies, the level of emissions from non-energy sectors can reach 50-100 MMTCO2e in 2050 but emissions can be lowered to between 45 to 90 with mitigation strategies outlined in the report.



Combining energy and non-energy emissions provides a more complete picture of emission levels. Depending on the trajectory of future economy in the Northwest. The forecast shows emissions between 216-285 MMTCO2e in reference case, and between 121-185 after mitigation strategies (PTD). Note the range of emissions represents range of uncertainty in the future.



*excludes emissions from forest fires and emissions from man-made reservoirs.

To reach zero emissions by 2050, the region would need solutions to capture carbon and sequestrate it or use it. Decarbonization of the economy is possible but requires significant change in non-energy sources and sinks. Our analysis shows that the region would need to generate a sink of about 121-200 MMTCO2e by 2050 to reach a zero emission levels, depending on economic and climate change scenario. Table below shows emission levels observed in 1990 and 2050 emissions post mitigation. Note that this table is only considering the medium economic trajectory for one climate change model (global circulation model CanESM2) and it does not cover the full range of economic, climate change, and energy efficiency targets. The region would need to develop a carbon sink of about 100 MMTCO2e. The region also needs to pursue further decarbonization of power sector. If we assume that utilities can continue to decarbonize and increase generation efficiency at the same rate they are assumed to be able to do in 2022-2041, we estimate that energy sector emissions can be lowered by nearly 30 MMTCO2e by 2050. Note that emissions from forest fires were not part of inventories in 1990.

Reference Case- Medium Economic trajectory CanESM2, FE **Sources and Sinks MMTCO2E**	**1990**	**2050 PTD**	**2050 PTD Case with Additional Power Sector Improvements post 2042**
Energy*	148	90	63
Coal Mining & Abandoned Mines	2	0.4	0.4
Natural Gas and Oil Systems	3	0.3	0.3
Non-Energy			
Industrial Processes	11	5	5
Agriculture	25	20	20
Municipal Solid Waste	6	6	6
CH4 From Man-made Reservoirs	7	6.5	6.5
Emissions from Forest fires	-	13	13
Aggregate Sources	202	141	114
Aggregate Sinks** (needed to be net zero in 2050)	-101	-103	-114
Net Emission	101	38	0

*- Emission from power sector is not assumed to reach zero by 2050. Level of emissions from power sector are reflecting of current available technologies.
**- Sinks can include natural as well as carbon capture and sequestration and use technologies.

Cumulative Emissions

Although it is feasible to reduce GHG emissions in 2050 to zero, even with the mitigation strategies outlined, the region will be cumulatively adding between 2.4 to 4 billion metric tons of CO2e to the atmosphere during the period between 2022 and 2050. From 1990 through 2021 we estimate that region has emitted about 7,550 MMTCO2e. Without mitigation, the level of emissions under medium economic trajectory will be about the same as what region emitted in the historic period. The role and impact of cumulative emissions in raising global temperature is greater than reaching net-zero by a given year. So, although mitigation targets mapped out here could keep emissions to zero by 2050, global temperatures would continue to rise, due to cumulative additions. Table below shows levels of cumulative emissions under Baseline or Business as Usual, as well as cumulative emissions from energy sector after mitigation, and cumulative emissions with mitigation strategies from combined energy sector emissions and non-energy sector emissions.

CanESM2- Medium Economic growth- Frozen Efficiency*	**2022-2050 period Cumulative Emissions (Million Metric Tons CO2e)**
Baseline (Energy and Non-Energy Sources)	7,000
PTD case – Energy Sources only	4,000
PTD energy plus non-energy sources and sinks **	2,500

*- Does not include impact of energy efficiency.
**- Cumulative values shown here for Non-energy sources are projected to emit 1514 MMTCO2e prior to PTD and 1183 MMRCO2e after PTD.

Load Impact of Decarbonization Strategies

Focus of this scenario is to reduce GHG emissions. Many of these strategies, while reducing emissions, can increase demand for electricity significantly. Factors that impact growth in demand for electricity include general increase in economic activities as well as electrification strategies. As shown in the graph below, regional loads can increase substantially over the next 30 years, well above load increase due to economic growth, as the region decarbonizes its economy.

The following graphs and table show regional loads under various economic conditions and under decarbonization strategies. The three solid lines show loads prior to any mitigation. The dashed lines show loads after implementation of mitigation strategies. The mitigation strategies do not show their impact until early to mid-2030s. This is because many electrification strategies are slow to implement (e.g. water heating equipment electrify at time of replacement due to failure, not from early replacement).

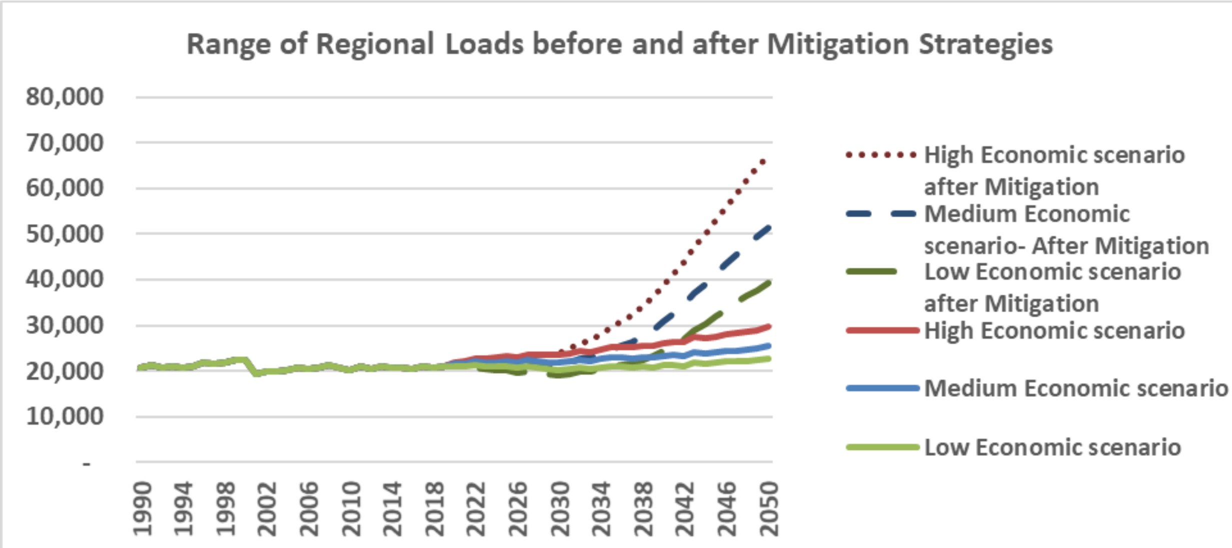


Table below shows current forecast of average load under a frozen efficiency for CanESM2 under the three economic trajectories, before and after mitigation. We expect loads under high economic trajectory to more than double by 2050. After mitigation, under all range of economic conditions, loads would double by 2050. It should be noted that these loads are forecasted for one climate change condition, CanESM2 and under frozen efficiency. Impact of energy efficiency is not netted out of these energy forecast.   Also, not included in this analysis, at this time, is electrical load impacts of Direct Carbon capture and Sequestration. Note that throughout this report ,we only discuss the impact of mitigation strategies on Energy and not peaks. Peak impacts are presented for the PTD partial at the System level.

Energy aMW	2022	2030	2035	2041	2050
Medium Economic scenario	22,093	21,881	23,043	23,523	25,503
High Economic scenario	22,729	23,559	25,278	26,519	29,618
Low Economic scenario	21,352	20,314	21,158	21,357	22,865
Medium Economic scenario- After Mitigation	21,601	21,134	24,796	32,679	51,446
High Economic scenario after Mitigation	22,264	23,900	29,489	41,220	67,232
Low Economic scenario after Mitigation	20,844	19,045	20,960	25,733	39,254

Regional and WECC-wide Implications of the Decarbonization Strategies.

Note that regional loads can increase to 300 percent of current system levels by year 2050. Average loads that have been in the 20,000-22,000 aMW range for the past 20 years would be increasing to 40,000 to 67,000 aMW. How the power system in the Northwest would reliably supply this amount of power needs much further analysis. If all of states outside the region follow similar decarbonization strategies, WECC would need to plan for a system more than three times the existing system. The power system would need to expand generation, transmission, and distribution infrastructures.

Summary of Findings

- Without mitigation strategies, the region is projected to emit over 7 Billion metric tons of GHGs over the next 30 years, roughly same as what region emitted in 1990-2021.
- Electrification could push loads to 300 percent the historic levels of around 20,000 aMW. Loads could increase to 67,000 aMW by 2050.
- The power sector alone, even under aggressive decarbonization strategies, cannot reach zero emissions by 2050.
- Improving efficiency of power system post 2042 needs to occur to lower emissions further. This can further reduce loads by an estimated 30 MMTCO2e by 2050.
- Mitigation strategies in the non-energy sector allow for major reduction in emissions.
- With mitigation strategies, cumulative GHG emissions from 2022 to 2025 are lowered to 4 billion metric tons CO2e.
- Freeing up agricultural, pastural lands, and urban and rural forest can significantly reduce emissions up to 2.5 billion metric tons.
- Initiatives to return land to nature would help create natural carbon sinks, increase biological diversity above and below ground, increase water storage capability of land and reduce implication of drought.

Synergy between Energy and Non-Energy Sectors and Mitigation Strategies

At first glance ,energy and non-energy mitigation strategies seem to be isolated from each other and mutually exclusive. However, further investigation reveals that there are great opportunities/ synergies between these two segments of the economy. What is done in the energy sector to decarbonize the system will impact non-energy sectors. What is needed to create carbon sinks can be helped with energy sector's investments. Let's take two cases: investments in renewable energy, and investments in energy efficiency.

Solar and Farming

Siting of renewable investments called for as part of decarbonization of power sector can help developing natural sinks by freeing up distressed land to be returned to nature. Fields of agri-voltaics/agri-solar can help create healthy land. A healthy land can support a more diverse eco-system and increase water and carbon storage of the land. Healthier land can also help improve health of the river systems. This can make things better for fish and wildlife. Integrated solar farms with grazing can support a wide range of other food and fiber growing activities and biodiversity outcomes, across horticulture, viticulture, as well as beekeeping.

But the improvements are not one-directional. A recent report from Oregon State University shows that installing solar panels on agricultural lands maximizes their efficiency because the efficiency of the panels decrease in hot temperatures and having cover-crops under the panels cool them and help increase solar power production.

Energy Efficiency and Carbon Sinks

Conservation or energy efficiency has been the cornerstone of energy strategies in the region. Over 7000 aMW of energy conserved has helped keep emissions from power plants lower than would have otherwise been. Benefits of conservation may include lower capacity requirements, higher resiliency in face of increased future risks from climate change, reduced emissions, and job creation. Years of experience in design, implementation, and evaluation of conservation programs has provided a wealth of information on how to develop new efficiency resources. This experience can be used in the new and challenging area of natural sinks. Markets for carbon offsets and credits can benefit from the conservation program learnings around rigorous baseline conditions for the new sinks, followed by well-defined monitoring and evaluation processes. As we have shown the region would need over 100 MMTCO2e of emissions captured and sequestrated in natural systems. To acquire this level of reduction would require significant investment in reviving pasture, farmlands, marginal lands, and new forests. By using the skill sets from energy efficiency, the region can make sure that incremental sinks are measurable, verifiable, and void of free-riders and misuse of public funds.

So, investments in energy efficiency not only reduces emission levels, they can also help in design and implementation of carbon sinks.

Policy adaptations for Decarbonization

Achieving decarbonization requires policy changes. As will be presented in the body of this report, many of the technological solutions to decarbonize the economy already exist, what is needed are human solutions to implement them. A few examples are highlighted here.

1. To reduce emissions from "Things We Make", governments and private sector investors need to create a level field for new green material to compete with traditional material. Building codes/standards and engineering designs need to be modified to allow green concrete or green steel to compete for infrastructure investments. Government can play a key role in allowing the low-carbon products to compete for market. If contracts and selection criteria are solely based on least cost, these new materials would not get a chance to grow. Environmental Product Declaration used by cement manufacturers, which is similar idea to food labeling, could go a long way in incorporating decarbonization value added from the new materials.
2. To reduce pressure on agricultural land and promote greater carbon sink and better health for the land, policies encouraging indoor agriculture could play a major role. Allowing indoor agriculture tailored to urban setting would further reduce footprint of agriculture.

Pathways to Decarbonization – more details

The key pillars of decarbonization of the Northwest energy and economy can be expressed in two general categories:

1. Demand side: energy efficiency, electrification, behavioral changes,
2. Supply side: renewables and hydrogen-based fuels, bioenergy, and carbon capture and use systems.

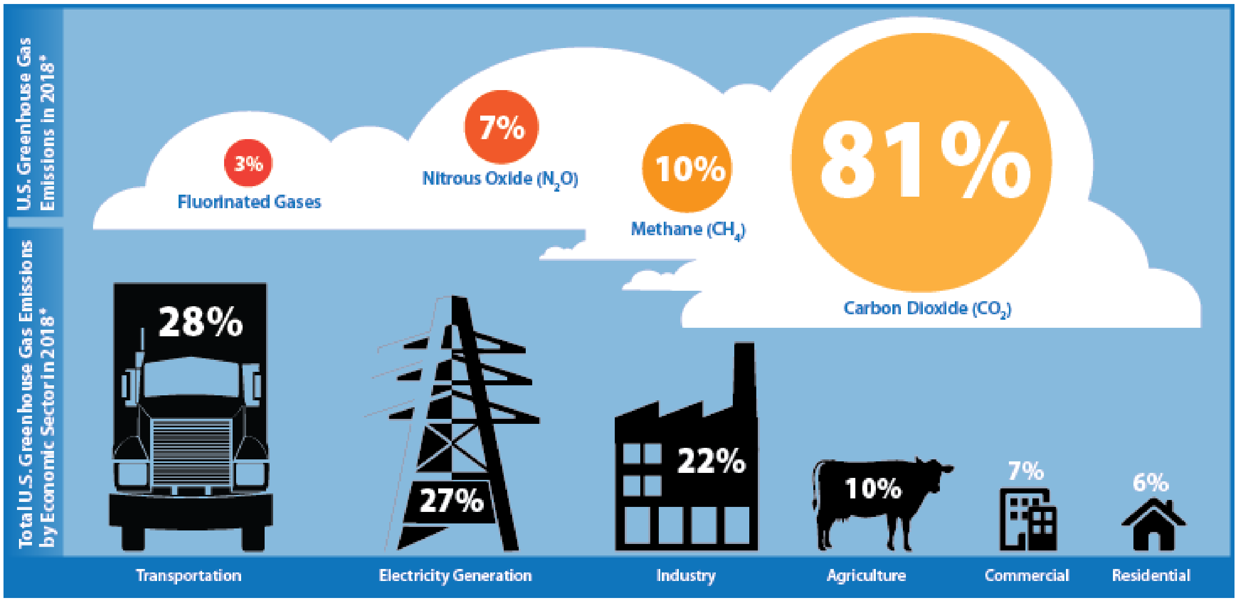
As we will show, it is feasible to decarbonize the regional energy system and economy over the next few decades. Here are the necessary steps.

1. Decarbonizing the energy/power system by using renewable sources of energy will take the region a long way toward decarbonization but will not be sufficient.
2. Non-energy sources of emissions need to reduce their contribution to GHG emissions significantly. There must be structural shifts in major industries that are heavy emitters. Burden of change is not solely on producers.
3. Consumers have a major role to play to reduce their consumption footprints. Reduced waste in what we eat, what we wear, how the buildings and roads are built and used, all are needed to reduce non-energy systems contribution to emissions.
4. Even after all these changes in behavior, reducing sources of emissions would not be enough to get the region to zero emissions by 2050. What is needed expansion of emission sinks to absorb emitted emissions. Sinks can be generated by focusing on rewilding the nature allowing it to capture more carbon in the soil.
5. With reductions in sources of emissions and increasing sinks for emissions, the region can reach zero emissions over the next three decades.

Where Are We Now?

In 2018, U.S. greenhouse gas emissions totaled 6,677 million metric tons of carbon dioxide equivalents, or 5,903 million metric tons of carbon dioxide equivalents after accounting for sequestration from the land sector. Greenhouse gas emissions in 2018 (after accounting for sequestration from the land sector) were 10.2 percent below 2005 levels.

According to 2018 report from EPA, see source below, CO2 emissions represent 81% of GHG emissions, followed by methane at 10% and nitrous oxide 7%. Fluorinated gases contribute about 3% of US GHG emissions. Cutting across sectors, 28% of emissions come from transportation, 27% from electricity generation, 22% from industrial production, 10% from Agricultural activities, 7% in commercial and 6% in residential buildings for other fuels uses (other than electricity). The Northwest represents about 4.8 percent of US emissions.



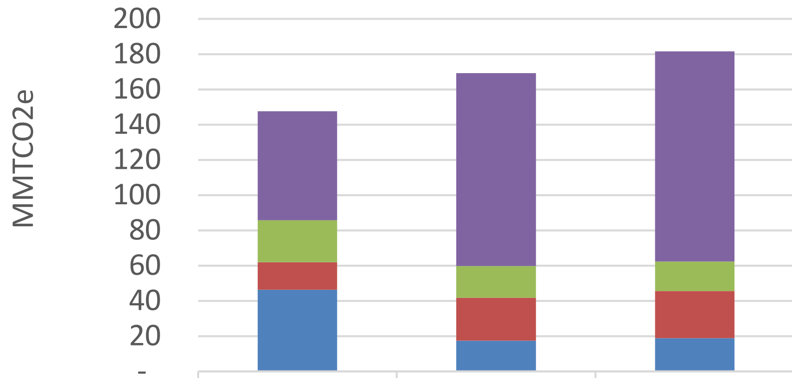
Source: U.S. EPA (2018)
https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018

2018	Emission Level MMTCO2e	Transport	Power Sector	Industry	Agriculture	Commercial Residential Buildings
Global	18,000	14%	35%	21%	24%	6%
USA	5,400	28%	27%	22%	10%	13%
Northwest	260	39%	28%	10%	14%	9%

Where Are We Heading?

To forecast level of regional GHG emissions, we used our reference case under medium economic conditions, under climate change scenario CanESM2 with frozen efficiency at 2022 levels. Review of energy sector emissions shows that in 1990 emission levels were around 148 million metric tons of CO2 equivalent (MMTCO2e). By 2041, absent any mitigation, emissions would increase to about 170 MMTCO2e. By 2050, forecast of emissions shows an increase to 182 MMTCO2e.

Transportation sector emissions dominate total emissions. Power generation that had a large share of emissions back in 1990 will be contributing less over time, as sources of power generation become predominately renewables and as coal plants are retired.



	1990	2041	2050
Transportation	62	109	119
Industrial, w/o Agric	24	18	17
Residential/Commercial	16	24	27
Electric Sector	46	17	19

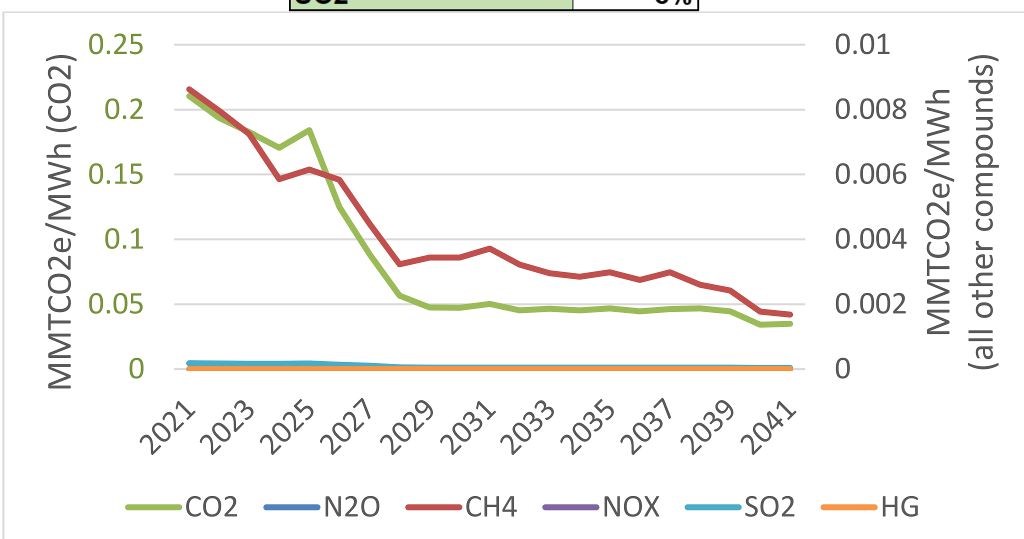
How can we Lower Emissions from Power Supply

Several supply side environments were tested by the Council's System Analysis team. For the PTD analysis, we assume that:

- All coal plants are retired by 2030.
- Bulk of new resource additions are solar and wind.
- Natural gas plants kept for system reliability.

Graph below depict changes in annual average emission rates for the power system in the Northwest, measured in MMTCO2/MWH. Average annual rates of CO2, CH4, NOx, and SOX emissions are expected to decline at 8-9% per year from 2022 through 2041. N_2O is declining at 5% per year. At this stage of analysis, post 2041 emission rates are held constant.

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



It should be noted that reducing emission from supply side can occur much faster than demand side as the demand side capital stock are replaced at a slower pace.

How Do We Lower Emissions from Demand Side Sectors?

To evaluate the impact of implementing different mitigation strategies, we started by preparing a list of potential strategies. Table below gives a brief overview of different demand-side categories. In general, strategies can be grouped into transportation, building efficiency, electrification, alternative green power sources, and distributed generation. Conservation in all its forms, fossil fuel or electricity, is expected to contribute to reducing the demand for power. Converting fossil fuels to electricity that is coming from a decarbonized power system is another logical step to reduce GHG emissions. Behind the meter generation through more rooftop solar and batteries can also contribute to reduction in emissions. It should be noted that the majority of solar power is assumed to be under utility control and dispatched rather than being rooftop installations.

Hydrogen (H2), with a green power source is another alternative fuel that was tested as a strategy in reducing emission. Green hydrogen applications for high temperature applications in the industrial sector is expected to capture about 20% of the hydrogen market by 2050. About 80% of green hydrogen is expected to be used in different modes of transportation, particularly in medium to heavy duty transportation.

	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		

Transportation System Strategies

Following is a brief listing of transportation strategies. We included the following “What If” mitigation strategies in transportation sector.

- All air travel has a 2% reduction in CO2 emissions per year starting in 2025
- New city buses sold in 2050 are 94% electric in Idaho & Montana and 100% electric in Oregon and Washington
- Corporate average fuel efficiency (CAFE) standards increase to 80 MPG by 2040 (from 25 MPG today)
- Forced early retirement of older passenger vehicles and light duty trucks
- Sales of heavy-duty vehicles (HDV) in 2050 are either 94% or 100% hydrogen or electric by 2050, depending on application
- Light-duty vehicles (LDV) are 100% electric by 2030 for Oregon and Washington, 2035 for Idaho, and 2040 for Montana
- Electric marine transport account for 50% of new vehicles sold in 2050

- Electric freight trains account for 50% of new vehicles sold in 2050
- Total vehicle miles traveled per capita reduces by 1% per year starting in 2020

Transportation Strategies Tested

Following table represents the mitigation strategies tested. Table includes baseline emissions and levels of reduction by strategy. Note that some strategies have minimal impact. In aggregate, these strategies can reduce emissions by 86 MMTCO2e by 2050 or about 47% of the baseline. Not only these strategies could reduce emissions in 2050 by over 47% of base or reference case. More importantly, these strategies also lower cumulative emissions by over 1,020 MMTCO2e in the period 2022-2050 over about 20% of cumulative emissions from reference case.

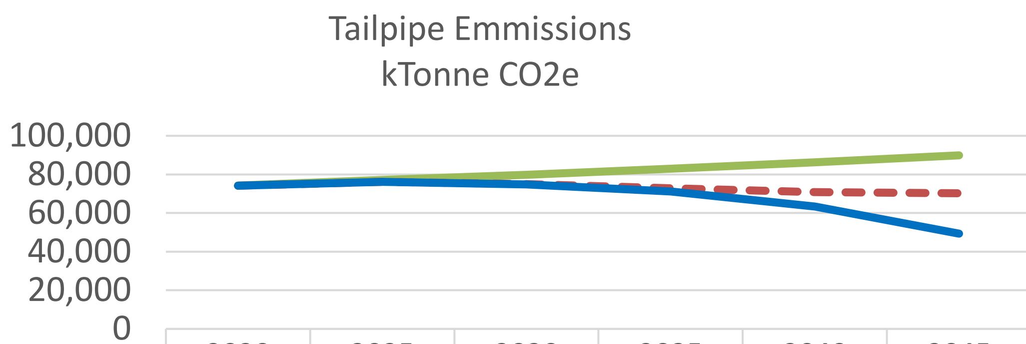
Included in the Combined Case	Transportation Mitigation Strategies	Change in Emissions by 2040	Change in Emissions by 2050	Cumulative Emissions 2022-2050 MMTCO2e	Cumulative Reduction in Emissions 2022-2050 MMTCO2e
	Baseline Emissions (energy Sectors (MMTCO2e)	169	182	5,206.2	
YES	Model International 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)	5,044.7	(161)
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)	5,197.2	(9)
NO	CAFE standards to increase to 100 MPG by 2050 from current 25 mpg	(3)	(5)	5,152.4	(54)
NO	CAFE standards to increase to 65 MPG by 2040 from current 25 mpg	(4)	(7)	5,131.1	(75)
YES	CAFE standards to increase to 80 MPG by 2040 from current 25 mpg	(4)	(7)	5,129.6	(77)
YES	Forced early retirement of older, inefficient gasoline & diesel fueled passenger vehicles and light duty trucks	(1)	(1)	5,182.1	(24)
YES	Set market share for HDV2 vehicles exogenously, 0.5% in 2026 increasing to 100% by 2050	(2)	(4)	5,166.4	(40)
YES	Set market share for HDV6 vehicles exogenously, 0.6% in 2026 increasing to 94% by 2050	(2)	(8)	5,158.1	(48)
YES	set market share for HDV8 vehicles exogenously, 0.6% in 2026 increasing to 94% by 2050	(3)	(13)	5,125.8	(80)
YES	Set market share for LDV vehicles exogenously. Starting in 2020 Market share 1-5% increasing to 100% by 2030, 2035, 2045 for Washington, Oregon, Idaho and Montana	(12)	(14)	4,975.5	(231)

YES	Increase electric marine so marginal market share so that it goes to 50% by 2050	(5)	(9)	5,217.3	11
YES	Increase new electric freight train market share so that it goes to 50% by 2050	(1)	(2)	5,096.8	(109)
YES	Reduce vehicle miles traveled per capita from 2020 levels by 1% per year	(11)	(13)	5,193.9	(12)
COMBINED CASE	Total for included strategies	(49)	(86)		**(1,020)**

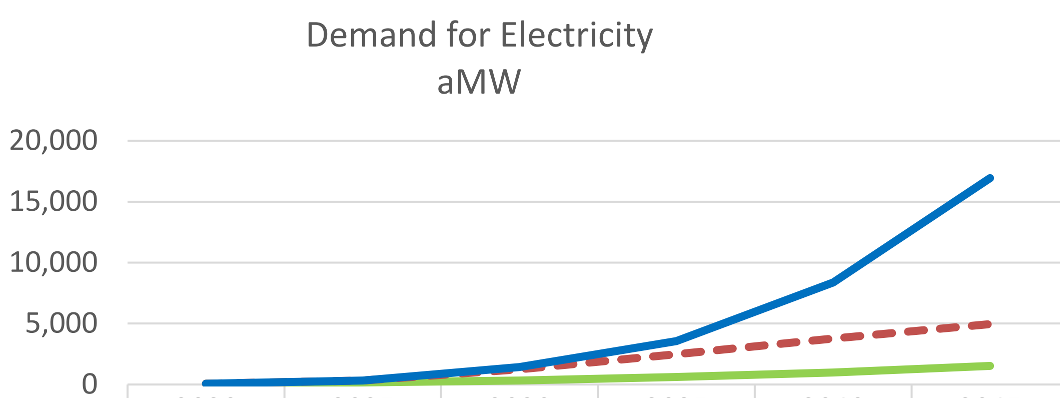
HDV2, 6 and 8 refer to different weigh classes for trucks moving freight.

Trade-off between Emissions and Electrical Loads

Electrification of transportation system will lower emissions but can raise loads. The following two figures show reduction in emissions with corresponding increase in loads. Although incorporating green hydrogen as a transportation fuel (H2T) can reduce emissions significantly, it can also increase demand for electricity.



	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



	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

Emission Reduction Impact of Increasing Building Efficiency Strategies

Increasing efficiency of energy use is expected to be a cornerstone of climate change mitigation strategies. The following types of energy efficiencies were tested. More detail on impacts is presented in the following table. These measures deal with increasing efficiency in structure of residential buildings. In the next set of strategies, we test increasing efficiency of appliances.

1. Increase efficiency of use for both electric and natural gas in new buildings
2. Increasing shell efficiency in manufactured housing (proposed federal standards)
3. Increasing shell efficiency in single family (update building codes on a 5-year cycle, 5% improvement per cycle)
4. Increasing shell efficiency in multi-family (update building codes on a 5-year cycle, 5% improvement per cycle)
5. Reduce size of new homes by 20% over the next 20 years (compared to base case)

In aggregate, the simulated strategies could lower emissions by about 25 MMTCO2e by 2050.

We also tested including the energy efficiency achievable technical potential in total. This curve reflects total potential for reducing loads. Although by 2050, the achievable technical potential for EE is over 10,000 aMW or about 40% of base case load, emissions decreased by only about 4%. The reason the emissions reduction is relatively low is that by 2050, the power system has very low emissions levels, so reduction in electric load does not significantly lower 2050 emissions. However, during 2022-2050 EE can reduce annual levels of emissions, by over 174 MMTCO2e. Combining the strategies shown below, can cumulatively reduce regional GHG emissions by over 442 MMTCO2e

Following table shows impact of efficiency measures tested. As expected, aggressive retrofit of appliances, removing more of existing appliances stock faster, has great impact on reducing emission levels. Some of the behavior changes, such as reduced size of new homes, can also reduce emission levels. Note that some of the strategies that were tested were not included in the combination case. Value of keeping these strategies is to highlight impact of strategy. For example, in the case of increasing lighting efficacy impact on emission was small so it was not included in the totals. But showing the value of the strategy is important to be able to size the impact.

Included in the Combined Case	Efficiency in Building	Change in Emissions by 2040	Change in Emissions by 2050	Cumulative Emissions 2022-2050 MMTCO2e	Cumulative Reduction in Emissions 2022-2050 MMTCO2e
	Baseline Emissions (energy Sectors (MMTCO2e)	169	182	5,206.2	
No	Increase lighting efficacy – at 5% per year instead of current 3% per year	(0.2)	(0.3)	5,200.4	(6)
Yes	More aggressive retrofit for appliances	(13.5)	(15.7)	4,941.3	(265)
Yes	Increasing shell efficiency in multifamily (update building codes on a 5-year cycle, 5% improvement per cycle)	(0.2)	(0.3)	5,200.7	(6)
Yes	Use proposed HUD standards for manufactured homes	(0.4)	(0.5)	5,197.2	(9)

Yes	Increasing shell efficiency in single family (update building codes on a 5-year cycle, 5% improvement per cycle)	(1.8)	(2.9)	5,164.8	(41)
Yes	Reduce size of new homes by 20% over the next 20 years (compared to base case)	(5.0)	(5.5)	5,084.4	(122)
No	Include EE achievable technical potential *	(6.0)	(7.3)	5,032.3	(174)
	Total for included strategies	(21)	(25)		(442)

*- Including the full technical potential as a strategy was tested. but not included in the totals.

Emission Reduction Impact of Fuel-Switching and Conversion Strategies

These next set of strategies depicts focus on fuel switching from fossil fuels to electric and from converting less efficient electric options to more efficient available technologies. This does not include the EE supply curves since most of these conversions are captured there. Converting zonal heating to heat pump will reduce emissions by about 7.5 MMTCO2e. Switching fossil fuels used for heating, cooking, and water heating to electric could lower emissions by about 19 MMTCO2e. It should be noted in our analysis, so far, all fuel switching, and conversions are happening at the time of natural replacement of equipment at the end of their life. This differ from strategies that mandate fuel switching or conversion at a pre-determined point in time. Our modeling approach allows for slower and smoother transition from fossil to electric technologies. Note that last strategy includes all non-electric demands- space heating, water heating, and cooking enduses- that are individually tested. that is the reason why we only included the last strategy in the Combined case.

Is this strategy included in the Combined Case	Fuel Switching	Change in Emissions by 2040	Change in Emissions by 2050	Cumulative Emissions 2022-2050 MMTCO2e	Cumulative Reduction in Emissions 2022-205 MMTCO2e
	Baseline Emissions (energy Sectors (MMTCO2e)	169	182	5,206	
NO	Requiring HP in place of zonal heating at end of life	(5.2)	(7.5)	5,097	(109)
NO	All other forms of Residential or commercial heating fuel use is shifted to electricity upon natural replacement	(7.1)	(10.6)	5,064	(138)
NO	Water heating shifted to electric resistance or heat pump	(1.4)	(2.0)	5,180	83
NO	Residential cooking fuel will shift from fossil fuel to electric	(0.8)	(1.2)	5,196	132
Yes	Moving all non-electric demands (wood, oil, natural gas, propane) to electric at end of equipment life in both residential and commercial sectors.	(14.8)	(19.4)	4,920	(261)
	Total for included strategies	(14.8)	(19.4)		(261)

Emission Reduction Impact Misc. Strategies Tested

The following strategies cover change in residential solar and battery installation. We allowed for additional battery storage so that more of rooftop solar energy can be stored. This strategy lowered emissions by about 5 MMTCO2e. Reducing cost of solar or increasing investment tax credits did not have significant impact in lowering emissions. Shifting high-temperature applications from fossil fuels to electricity then powering it by green hydrogen lowers emissions by about 5.6 MMTCO2e. However, increased H2 generation also raises the loads and thus increases emissions by about 4 MMTCO2e. Implementation of economy-wide consumer GHG pricing can reduce emissions by 1.9-3.8 MMTCO2e. In aggregate these strategies can lower emissions by about 10% by 2050. Cumulatively combined case strategies can lower emissions by 229 MMTCO2e between 2022-2050

- Increase ratio of battery to solar installation from one to one to five to one by 2050.
- Reduce cost curve for solar so by 2050 solar costs decrease by 75% compared to 2022.
- Increase and extend investment tax credits for residential solar installations
- Increased renewable natural gas penetration
- Industrial fuel demands shift to electric or hydrogen
- Add $50 tax per ton of CO2 equivalent emissions
- Add $100 tax per ton of CO2 equivalent emissions

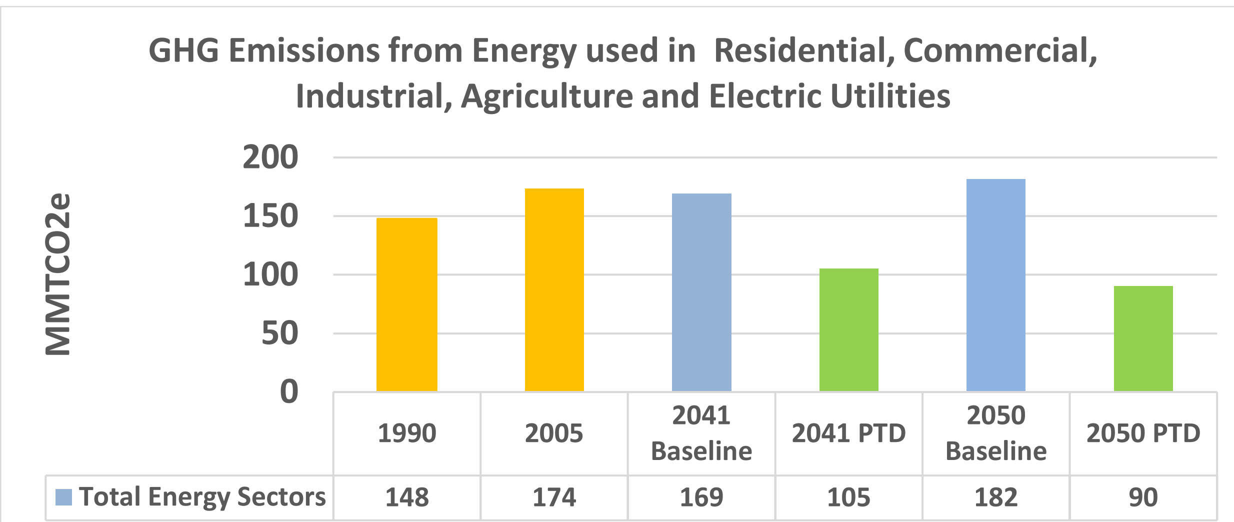
Strategy included in the Combined Case	Solar, RNG, Industrial and CO2 tax	Change in Emissions by 2040	Change in Emissions by 2050	Cumulative Emissions 2022-2050 MMTCO2e	Cumulative Reduction in Emissions 2022-2050 MMTCO2e
	Baseline Emissions (energy Sectors (MMTCO2e)	169	182	5,206	
YES	Increase ratio of battery to solar from 1 to 1 to one to five by 2050*	(2.1)	(4.8)	5,159	(47)
YES	Reduce cost curves for Solar so by 2050 costs are 75% lower compared to 2022	(0.2)	(0.1)	5,201	(5)
YES	Increase ITC for solar. ITC at 30%	(0.2)	(0.1)	5,200	(6)
YES	Increased RNG penetration as a replacement for natural gas fuel	(2.6)	(4.1)	5,141	(65)
YES	Shift industrial fossil fuel demand to electricity	(2.8)	(4.4)	5,156	(50)
YES	Shift industrial fossil demand to electricity then hydrogen	(3.5)	(5.6)	5,146	(61)
YES	Reflect increased electrical demand from H2 production	2.3	3.9	5,254	48

NO	Nominal $50/ton CO2e charge by 2050	(1.2)	(1.9)	5,179	(27)
YES	Nominal $100/ton CO2e charge by 2050	(2.0)	(3.5)	5,163	(43)
	Total for included strategies	(11)	(18.5)		(229)

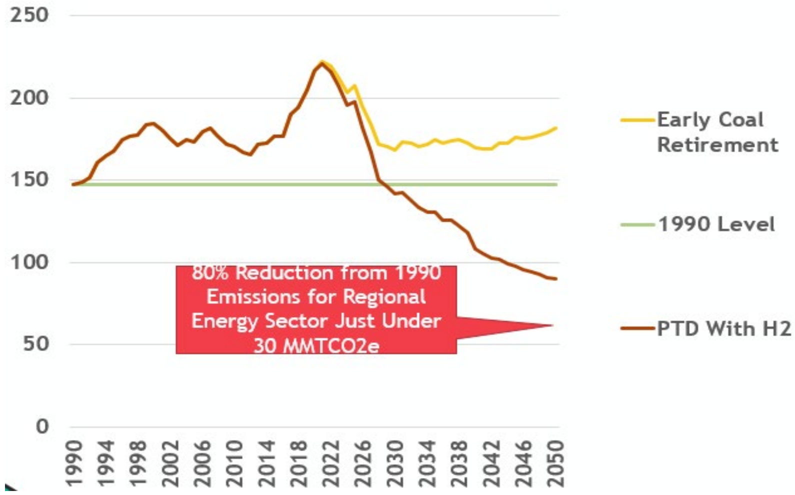
- Ration of 1 to 1 means solar and battery are sized to have a ratio of 1 to 1. One to 5 ratio means for every KW of solar capacity, Battery sized 5 times larger.

Emissions After Combined Mitigation Strategies

Aggregating mutually exclusive strategies in transportation, efficiency, and fuel switching in buildings and appliances, as well as the miscellaneous strategies can lower GHG emissions from energy use by about 50% of emissions absent these mitigation strategies. Base case emissions in 2050 estimated at 182 MMTCO2e can be lowered to 90 MMTCO2e.



To further reduce energy sectors emissions, a shift from electricity to green hydrogen may be needed. Our preliminary assessment shows that if H2 is incorporated into mitigation strategies, it can further reduce emissions by 30 MMTCO2e. The red box below indicates that more needs to be done to bring the emissions from power generation down by about 30 MMTCO2e. One option could be by bringing in green hydrogen generated by renewables that are curtailed or bringing in H2 from other locations outside the region.

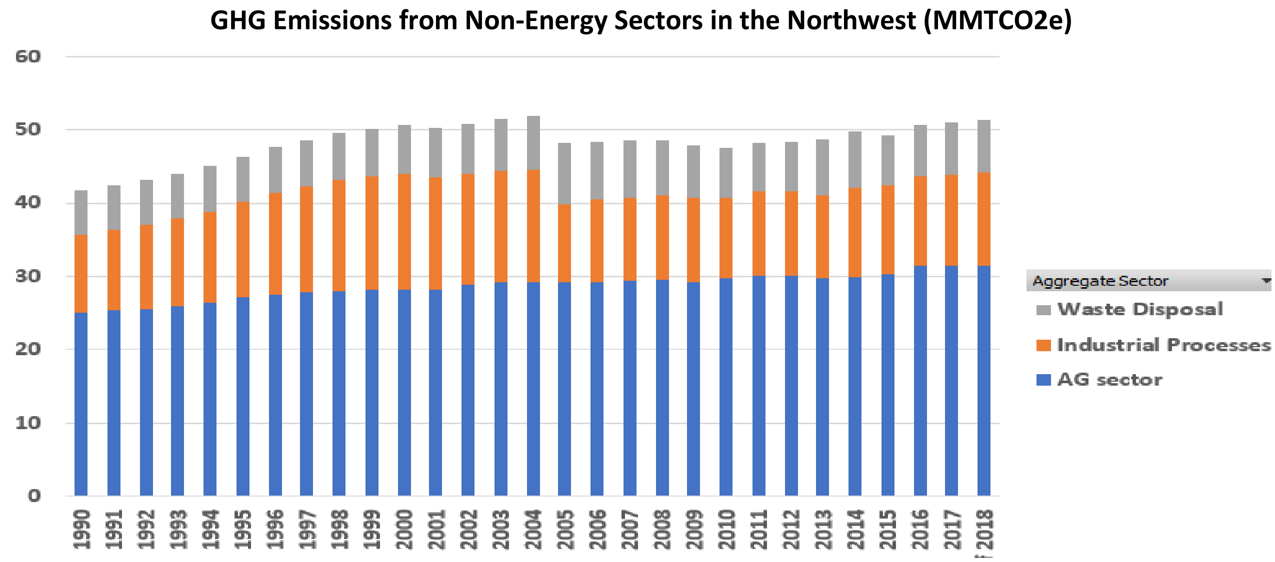


Finding: Decarbonizing Energy Systems is only part of the solution.

We need to look beyond energy systems. We need to incorporate non-energy sources of emissions.

Non-Energy Sources of GHG Emissions in the Northwest

In the following section we present estimated non-energy GHG sources in Northwest. We will be focusing on the non-energy sectors, as the energy sector emissions will be addressed separately. For this analysis, we used latest GHG inventory reports for each state. Three large market segments represent bulk of non-energy emissions: industrial and agricultural processes and waste disposal.



Agricultural sector dominates GHG emissions from non-energy sectors. In 1990, this sector is estimated to have emitted about 25 MMTCO2e; by 2018, emissions increased to about 32 MMTCO2e. This is equivalent to an average annual rate of increase of about 0.8%.

Industrial processes constitute second largest source of GHG emission among non-energy sources. Emissions increased from 10.6 MMTCO2e in 1990 to about 12.8 MMTCO2e in 2018. An increase of 2.2 MMTCO2 or about 20% increase since 1990. Emissions grow at 0.7% per year between 1990 and 2018.
Waste disposal emissions grow from 6.2 in 1990 to 7.1 by 2018, growing at annual rate of 0.5%.

MMTCO2e	Agriculture	Industrial Processes	Waste Disposal	Grand Total
1990	25.0	10.6	6.2	41.8
2018	31.5	12.8	7.1	51.4
Delta	6.46	2.20	0.98	9.63
AAGR	0.8%	0.7%	0.5%	0.7%

Mitigation strategies to reduce GHG Emissions from Non-Energy Segments of the Economy

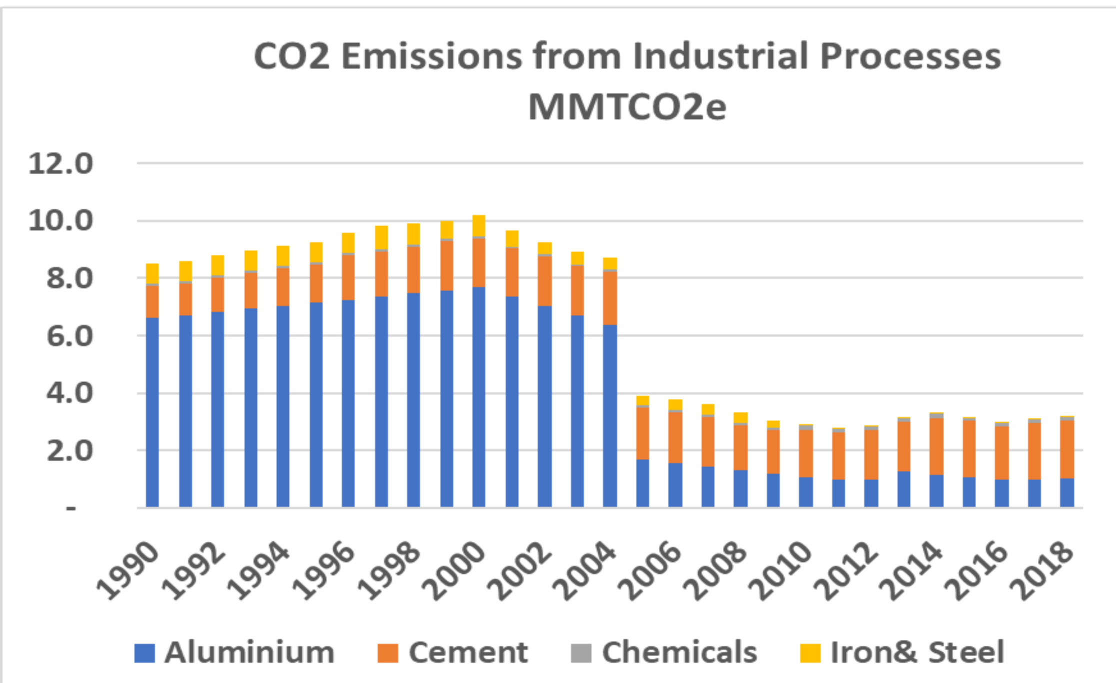
Each one of the three main non-energy segments of the economy would need its own unique set of strategies. Here we present an overview of the mitigation strategies and their impact.

Emissions from What We Make and Mitigation Strategies

The largest industrial emitter of CO2 in the region was the aluminum industry. With closure of the majority of these processing plants in 2000-2001 there was a significant decline in emissions, from about 6-7 MMTCO2e in 1990s to 2000s to less than 2 MMTCO2e after their closure. With the closure of the last aluminum smelting operations by 2020, emission from this industry has gone to zero.

Next largest industrial emitter was cement manufacturing with emissions ranging from 1 to 2 MMCO2e. Over the next few decades emissions from the cement manufacturing process is expected to decline, due to reduced commercial building activities forecasted prior to any mitigation. Other industrial sectors, chemicals and iron and steel are not expected to generate significant CO2 emissions.

Here, we are focusing on CO2 emissions, but it does not mean that industries do not emit other GHGs. As we will show, industries also emit CH4, N2O, SF6 and HFCs, that have a higher global warming potential than CO2.



CO2 Emissions (MMTCO2E)	1990	2022	2041	2050	Cumulative 2022-2050	2022-2050 AAGR
Industrial Sector	8.5	2.21	1.7	1.62	54.66	0.009%
Cement Manufacturing	1.1	2.04	1.52	1.40	49.01	-1.35%
Iron & Steel Production	0.7	0.03	0.03	0.04	0.91	0.93%

Aluminum	6.6	-	-	-	-	NA
Chemicals	0.1	0.14	0.17	0.19	4.75	1.11%

Aluminum Smelting Processes

The aluminum industry, till its demise, had some of the largest shares of CO2 emissions among industrial processes, and the Northwest was a player in global markets for aluminum. However, since early 2000s the Northwest has an increasingly smaller share of aluminum production. By 2022, all existing smelting plants are closed and do not represent a source for emissions, so we did not include any mitigation strategies for this industry.

Cement manufacturing

Reducing CO2 emissions while producing enough cement to meet demand for local and global demand will be challenging. International Energy Agency (IEA) identifies these key strategies to reduce emissions

- Fuel-switching from fossil fuels to cleaner options (solar, wind, hydro),
- Improving production efficiency,
- Reducing clinker-to-cement ratio (this is ratio of binding agents in concrete to cement)
- Reducing total demand for cement,
- Using advance technological innovations such as carbon capture and use or sequestration (in this case CO2 is stored in concrete).
- Changing from prescriptive standards to performance-based standards when design elements and specifications for buildings and infrastructure is set up.

MMTCO2e	2019	2022	2030	2035	2041	2050
Cement Manufacturing	2.02	2.04	1.87	1.68	1.52	1.40
Cement Manufacturing After Mitigation	2.02	2.00	1.53	1.21	0.91	0.59

Iron and Steel - Current Production Technologies

If the steel industry were a country, its carbon dioxide emissions would rank third in the world, below the US and above India. Aside from churning out 1.86 billion metric tons of steel last year, steelmakers generated over 3 billion tons of CO_2, corresponding to an astonishing 7–9% of all human-made greenhouse gas emissions, according to the World Steel Association. No other industrial material has a greater climate impact.

To help limit emissions, the steel industry will need to shrink its carbon footprint significantly. Some major steelmakers and start-ups have started investing in alternative technologies to make steel, mostly using green hydrogen or electrochemistry to reduce iron oxides to iron. Climate policies, around the globe that regulate CO_2 emissions, could incentivize other steelmakers to try these different routes for making steel.

With global steel demand expected to rise to 2.5 billion tons per year by 2050 (*Metals* 2020, DOI:10.3390/met10091117), that environmental burden is growing. Yet an analysis of the overall reduction in worldwide carbon emissions needed to limit global warming to a maximum of 2 °C above preindustrial levels—

the goal of the 2015 Paris climate agreement—suggests that the steel industry's annual emissions must fall to about 500 million tons of CO_2 by 2050 (*Metals* 2020, DOI: 10.3390/met10070972).

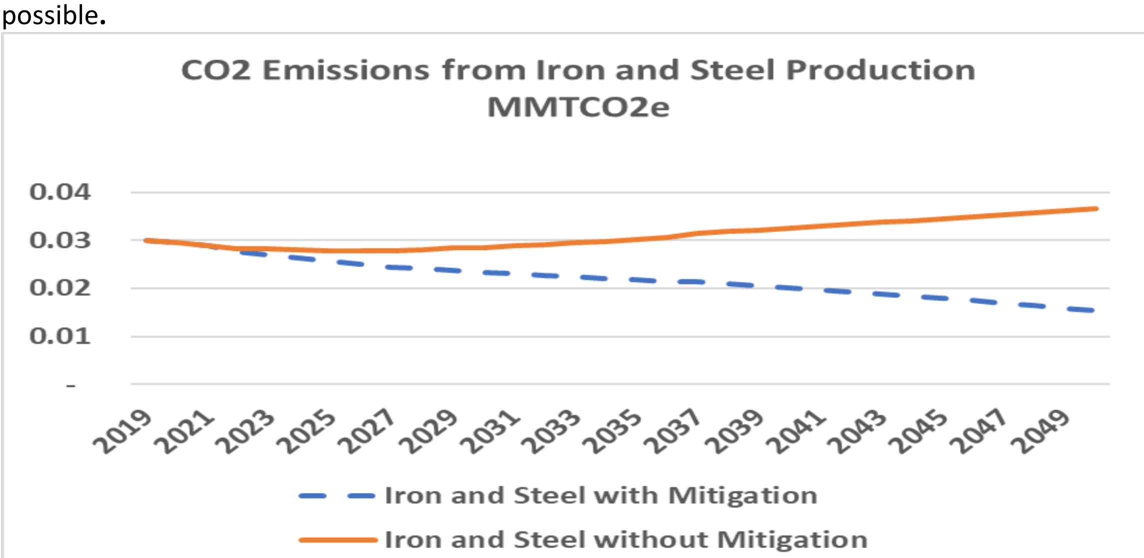
Although for this analysis, we investigated the iron and steel industry in the Northwest, because this product is a global commodity. Strategies outlined here would impact emissions regardless of where they occur. The Northwest by itself is not known as a major iron and steel producer. In addition to substantial emissions from combustion of fossil fuels for required heat, the process emissions from steel production (i.e., excluding fossil energy inputs) accounts for roughly 5 percent of global CO_2 emissions in recent years, mainly related to the coking coal used to reduce iron ore in blast furnaces (i.e., removing oxygen from raw Fe_2O_3).

Strategies to reduce emissions from Iron and Steel production.

Recycling: Already, more than half of the steel produced in the U.S. is via processing of scrap steel in Electric Arc Furnace (EAF). The electricity required to energize this process can be decarbonized and as such recycling avoids the process emissions associated with reducing raw iron ore. The main challenge to meeting more steel demand via this pathway are impurities such as tin, copper, nickel, molybdenum, chromium, and lead that may compromise the quality and integrity of such steel. With better sorting and product design (to facilitate separation of metals at the end of a product's life), recycled steel could meet 50-75 percent of global demand.

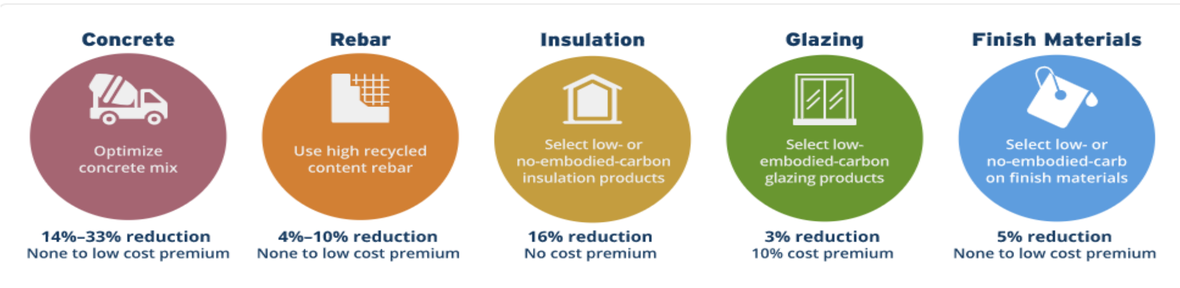
Hydrogen: Another option is to use renewable hydrogen as the reducing gas in the Direct Reduced Iron Electric Arc Furnace (DRIEAF) process. This pathway is increasingly of interest. Three Swedish companies (SSAB, LKAB and Vattenfall), are working with the Swedish Energy Agency in a joint venture to pilot this system (named HYBRIT).

For our analysis of mitigation strategies, we used IEA analysis that showed a 77% reduction in emissions is possible**.**



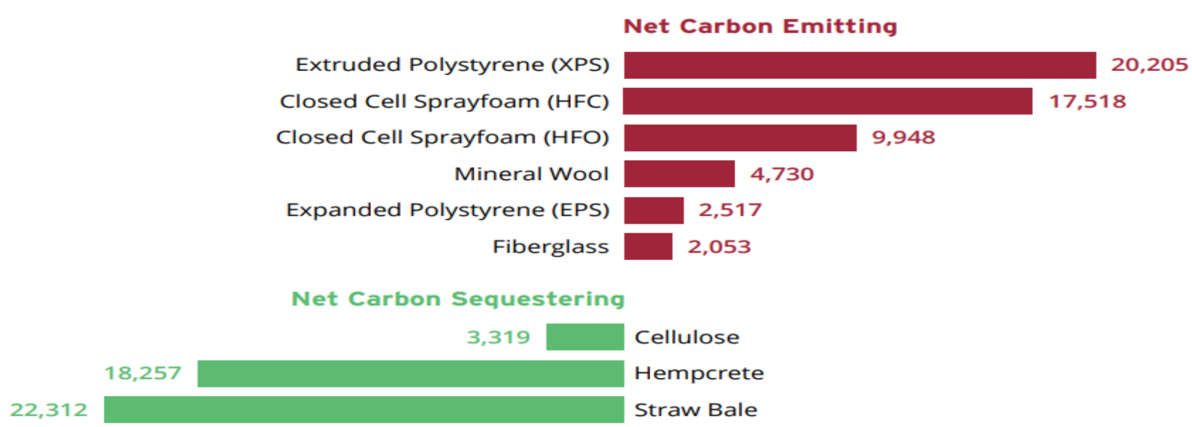
Reducing Embedded Emissions in Buildings

Iron, steel, and concrete constitute major materials used in modern buildings. According to a recent report from the Rocky Mountain Institute, buildings account for at least 39% of energy-related global carbon emissions on an annual basis. At least one-quarter of these emissions result from embodied carbon, or the carbon emissions associated with building materials and construction. RMI report, although based on comparison of three actual building projects in the Pacific Northwest, show that major reductions in embedded emissions can be achieved.



Insulation glazing and finished material was not covered in the earlier discussion about cement, iron and steel. These products can contribute significantly to lowering the embedded emissions in buildings. RMI report shows insulation material can be a significant contributor to a building's embodied carbon budget. Rigid or spray foam products have the greatest associated emissions, whereas biological-based materials (such as cellulose and cotton products) can contribute very little embodied carbon or even be considered as net carbon-sequestering products. The insulative capacity of a product, measured as thermal resistance, or R-value, varies between material type, with high values indicating higher performing insulation. Biological-based materials tend to have lower R-values than carbon-intensive materials and would require a thicker application of the product to achieve an equivalent level of performance. Exhibit 3 demonstrates the relative up-front embodied carbon emissions associated with various insulation materials.

Exhibit 3 **Embodied carbon of insulation materials (kg CO_2e)**

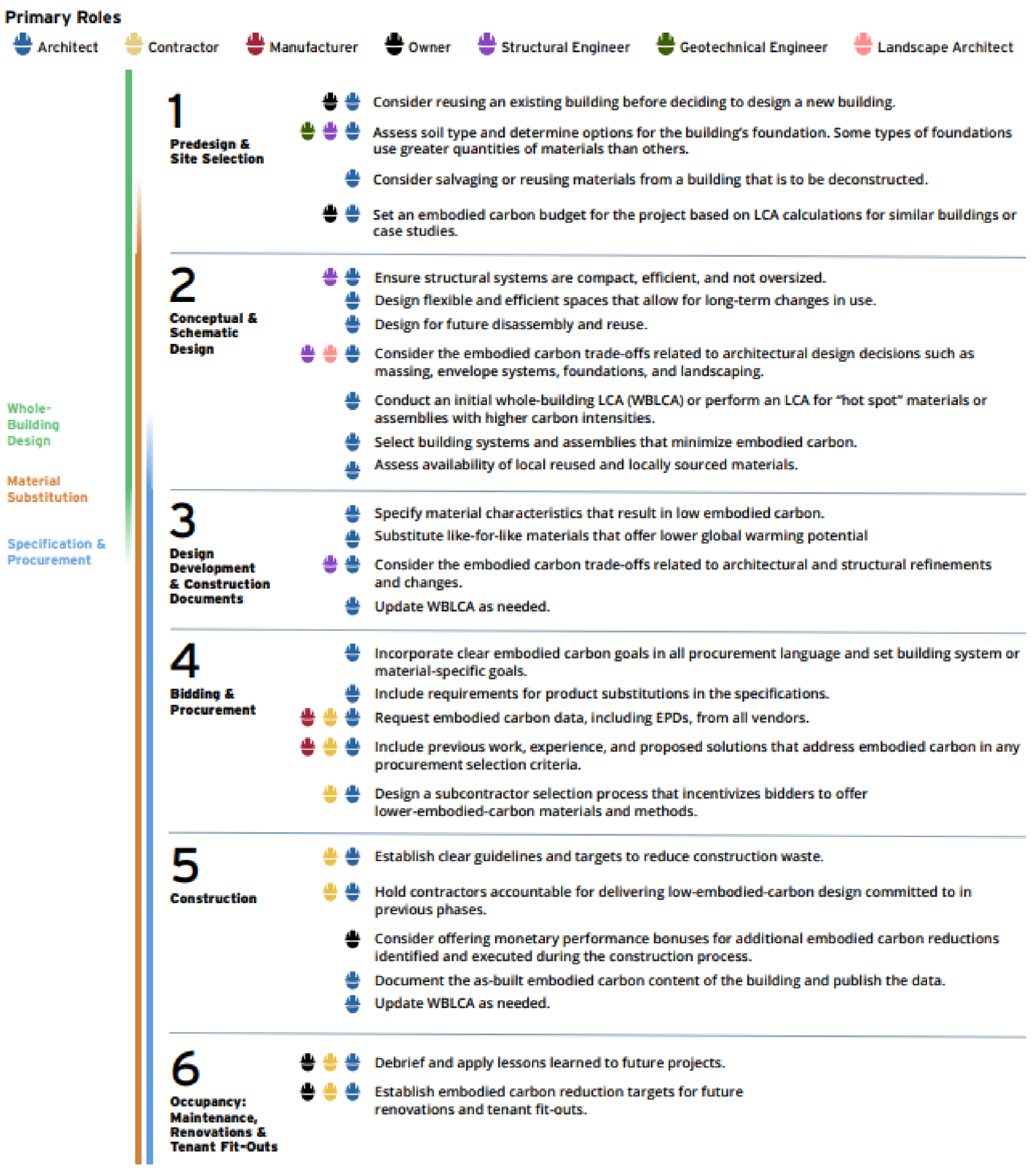


Note: The amount of CO_2e is based on R-20 at 234 m².

Source: Chris Magwood, *Opportunities for CO_2 Capture and Storage in Building Materials*, 10.13140/RG.2.2.32171.39208, 2019.

RMI report also identifies changes in architectural design, contractors, manufacturers, owners, structural engineers, and others that would help reduce embedded emissions in buildings.

Exhibit 4 **Strategies to reduce embodied carbon throughout the design and development process**

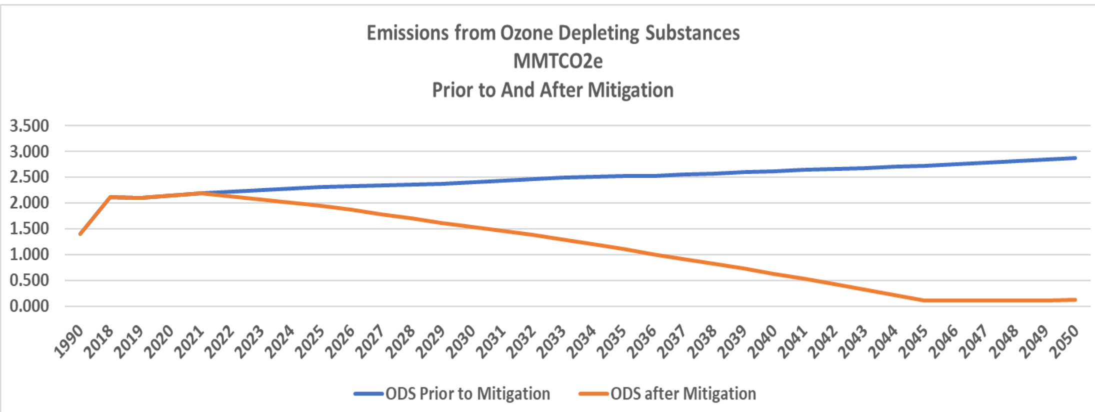


Source: Partially adapted from *Embodied Carbon Quick Guide: A Quick Reference Guide for Teams to Reduce their Project's Embodied Carbon*, International Living Future Institute, 2020.

RMI Report: https://rmi.org/insight/reducing-embodied-carbon-in-buildings?utm_medium=email&utm_source=spark&utm_content=spark&utm_campaign=2021_08_05

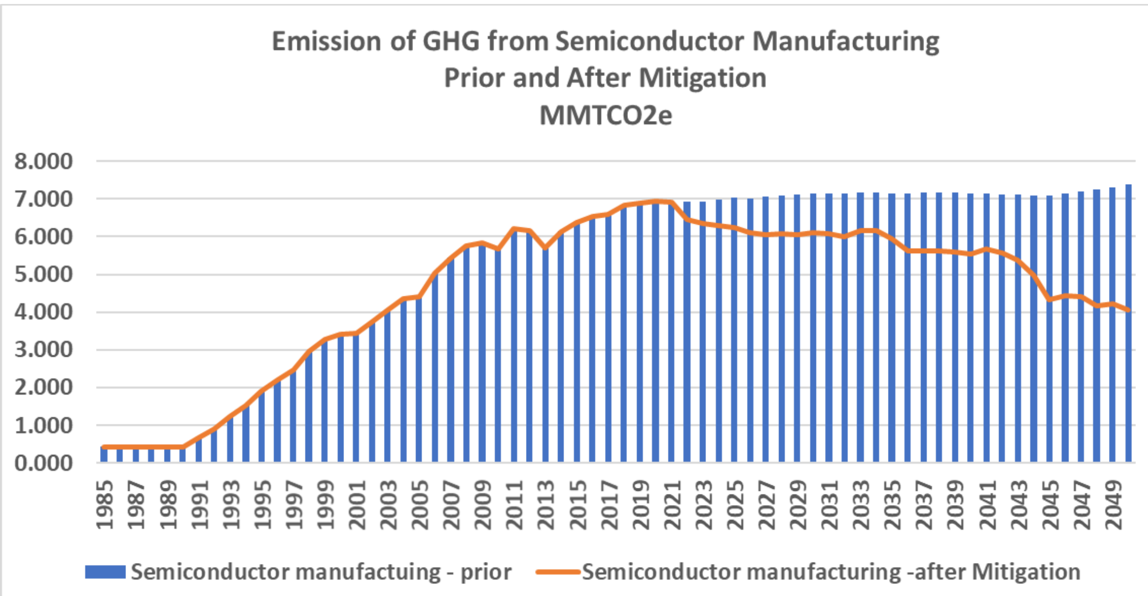
Emissions from Ozone Depleting Substances – ODS

Ozone Depleting Substances are another major category of industrial emissions. They do not come from an industrial process, but rather from the refrigerants themselves. Ozone Depleting Substances include: Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrobromoflurocarbons (HBFCs), halons, methyl bromide, carbon tetrachloride and methyl chloroform. HFC family of refrigerants were introduced as a way of combating release of CFCs that became known as causing ozone depletion. However, HFC gases have significantly higher impact as a GHG. HFCs are used extensively in refrigeration processes and in semiconductor manufacturing. Their use has been on the increase since 1990s. In the Northwest, their increased use changes emissions from roughly 1.4 MMTCO2e in 1990 to about 3 MMTCO2e by 2050, without mitigation steps. However, there are existing international agreements (2016 Kigali amendment to the Montreal protocol established a timeline for eliminating HFC gases. We presume US producers will abide by this agreement.



Semiconductor Industry

Semiconductor manufacturing processes use high global warming potential fluorinated compounds including perfluorocarbons (e.g., CF_4, C_2F_6 and C_3F_8), hydrofluorocarbons (CHF_3, CH_3F and CH_2F_2), nitrogen trifluoride (NF_3) and sulfur hexafluoride (SF_6). Semiconductor manufacturing processes also use fluorinated heat transfer fluids and nitrous oxide (N_2O).



Mitigation Strategies

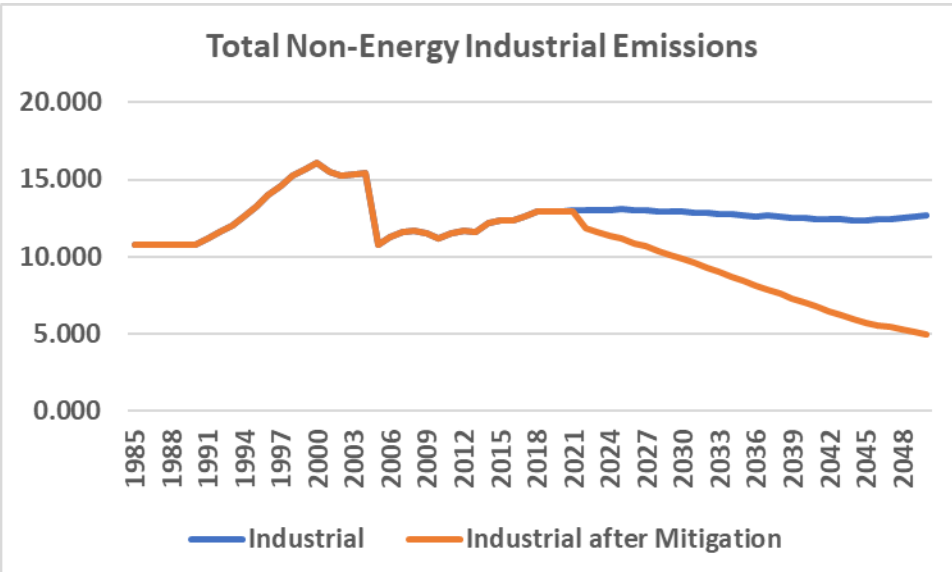
Many companies in semiconductor manufacturing have successfully identified, evaluated, and implemented a variety of technologies that protect the climate and improved production efficiencies. Solutions have been investigated and successfully implemented in the following key technological areas:

- Process improvements/source reduction
- Alternative chemicals
- Capture and beneficial reuse of fluorinated gases
- Destruction technologies for fluorinated gases

Between 2022 and 2050 emissions from this sector is expected to be reduced from about 7 MMTCO2e in 2022 to about 4 MMTCO2e by 2050. Cumulatively between 2022 and 2050, emissions would be reduced by about 22% from 207 MMTCO2e prior to mitigation to 161 MMTCO2e after mitigation.

Aggregate Emissions and Mitigation Strategies for Industrial Sector

Bringing together major sources of emissions from industrial processes, we estimate there are opportunities for reducing emissions from this segment of the economy. Cumulatively, without mitigation strategies, the total emissions would increase to over 600 MMTCO2e by 2050. After mitigation steps taken the emission levels can be cut by about 50% to about 305 MMTCO2e.



It should be noted that there are opportunities to lower emissions from all industrial sectors. We focused on a few emission-intensive industries.

Emissions from Foods We Eat and Mitigation Strategies to Reduce Emissions

Globally, food accounts for over 25% of global GHG. About 10% of national GHG emissions are from the agricultural sector. In fact, 50% of worlds habitable land is used for agriculture and 70% of global freshwater withdrawal are used for agriculture. Crop production accounts for 27% of food emissions. Land use and land use change accounts for 24% of food emissions (16% for livestock and 8% for human consumption).

Supply chains account for 18% of food emissions. Food processing (converting produce from the farm into final products), transport, packaging, and retail. There is little CO2 emission during food production.

Estimated Ag. Sector Emissions in the NW (MMTCO2e)	**1990**	**2041**	**2050**
CH4	28.0	27.8	28.9
Enteric Fermentation	15.8	14.7	15.6
Manure Management	12.3	13.0	13.4
N2O	3.6	3.4	3.5
Manure Management	0.1	0.1	0.1
Agricultural Soil Management	3.5	3.3	3.3

Table above shows source of emission for methane (CH4). Enteric fermentation production is expected to be reduced rather slowly as production increases. Globally, it is estimated that there are roughly a billion cattle raised for beef and dairy. Global methane emissions through enteric fermentation from this number of cattle is estimated at 2 billion tons of carbon dioxide or about 4 percent of global emissions (from "How to avoid climate disaster", page 117).

The cows that could help fight climate change

One of the strategies to reduce methane from enteric fermentation is to increase efficiency of beef production through better feed and better livestock management at local small farms.

One study by researchers at the University of California, Davis, estimated it might be possible to reduce global methane emissions from **cows by 15% by changing their diet.**

"Enteric methane (CH_4) generated in the gastrointestinal tract of ruminants represents the source of the greatest direct greenhouse gas (GHG) released from the livestock sector. We evaluated the global potential reduction of enteric CH_4 emissions released from dairy cattle through amendment of their traditional diets in 183 countries aggregated to 11 regions. Amending dairy cattle diets involves increasing the concentration of lipid (up to 6 %) and decreasing the concentration of fiber, without affecting the total gross energy intake (GEI). Enteric CH_4 emissions were calculated by using a mathematical model developed to include dietary intervention. In 2012, we found a global potential reduction of 15.7 % of enteric CH4 emissions from dairy cattle. The highest potential reduction per unit of milk produced occurs in Africa followed by South America and

Asia (55, 46 and 34 %, respectively). The amended diets proposed here, mostly affect the regions in which demand for animal source protein will be greatest in the future. Because lipid supplementation may result in an indirect effect on CH_4 and nitrous oxide (N_2O) emissions from manure management, they were also estimated. Methane emissions from manure management would decrease by 13 %, while N_2O emissions would increase by 21 % due to diet amendment. On balance, the total potential reduction of GHG emissions through diet amendment was 104 $MtCO_2eq$ annually. Moreover, amending diets would increase global milk production by 13 %. This study evaluated a global potential reduction of GHG emissions directly released from dairy cattle, however, future advancements dealing with the analysis of the upstream emissions associated to these diet changes are needed."
https://link.springer.com/article/10.1007/s10584-016-1686-1

Altering the diet eaten by cows, sheep and other livestock could reduce the amount of methane produced as microbes in their rumen break down plant materials. The more fiber a cow eats, the more methane it produces. By increasing efficiency in production, reducing demand for animal products, we can see a decrease in emissions of methane as well as reduced demand for grains as feedstock, less manure, less fertilizer, and better and more humane treatment of caged animals. Another strategy is to reduce consuming dairy and meat and instead choose a vegan diet. Yet, another strategy is to reduce food waste.

Strategies to Reduce Methane and N20 Emissions

Mitigation strategy options: Reduce GHG emissions 1% annually in 2022-2030, and 1.5% annually post 2031 using:

- Increase in Plant-Based food
- Reduce number of animals
- Reduce lands planted for feed
- Reduce water for irrigation
- Reduce manure/better manure management
- Switch from field to indoor leafy green produce, freeing outdoor acreage to return to nature.
- Increase land and water-based sinks

Beside smaller firms that work in alternative meat space (Beyond Meat and Impossible Food) the food giant Tyson in July 2021 introduced its alternative burger product to meet growing demand from customers that are seeking alternative to beef. Another development in alternative meat market is alternative chicken product that was introduced recently to the restaurant chain market.

Indoor/Vertical Agriculture as a Mitigation and Adaptation Strategy

Another strategy to reduce GHG emissions is to take the applicable agricultural products to grow indoors, powered with renewable power source. Recent literature search shows that:

- Greenhouse produced vegetables & leafy greens can be produced indoor efficiently.
- For leafy greens a 30,000 SQF facility can produce as much as 23 acres of outdoor facility.
- In the region, over 160,000 acres of outdoor farms grow vegetables and vegetables; nationally over 2.6 million acres.
- Large water savings
- Transportation cost savings – Close to market.
- Frees the farmland to return to nature to serve as a carbon sink.

Pursuing an indoor agriculture and multi-level indoor farming (powered by onsite solar installs) can reduce demand on agricultural land. These lands can then be freed up to return to nature, which in short time can recover from overuse and can regenerate its microbial life, support diverse fauna and flora, support insect and pollinator species, hold more water to combat drought, and reduce fertilizer intrusion into man-made reservoirs and river systems.

Estimating Potential Mitigation Strategies to Reduce Emissions from Food We Eat

There are literally thousands of peer reviewed research papers, blogs, documentaries focusing on different parts of the food supply chain. Each paper estimates the impact of different pathways to decarbonizing food we eat. From regenerative agriculture, to changing the diet of bovines, to changing human dietary habits, the research points to available options to reduce human impact on nature.

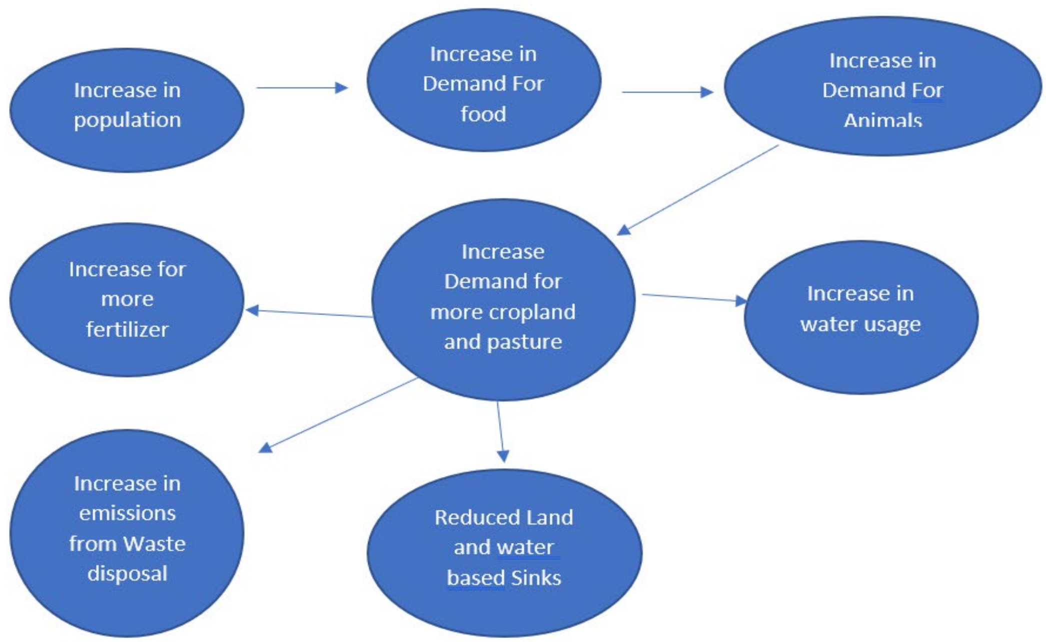
In this report, we took a simpler approach where over the next 30 years we assume that a 1-1.5% annual reduction in emissions across the food supply chain is feasible. Mitigation strategies to achieve this level of reduction includes some change in consumption behavior (using more plant-based foods), reducing the 40% waste, modifying diet of bovines to reduce methane emissions from burping. Growing more food in vertical, indoor farms under a controlled environment, which reduces water and fertilizer consumption. Producing more food locally to reduce transportation and refrigeration demand. We estimate emissions from food can be lowered from about 33 MMTCO2e to about 20 MMTCO2e.

It should be noted that most of these emissions are methane emissions that although have significant impact on climate, they have a much shorter lifetime and over a 10 to 20-year period are eliminated from the atmosphere.

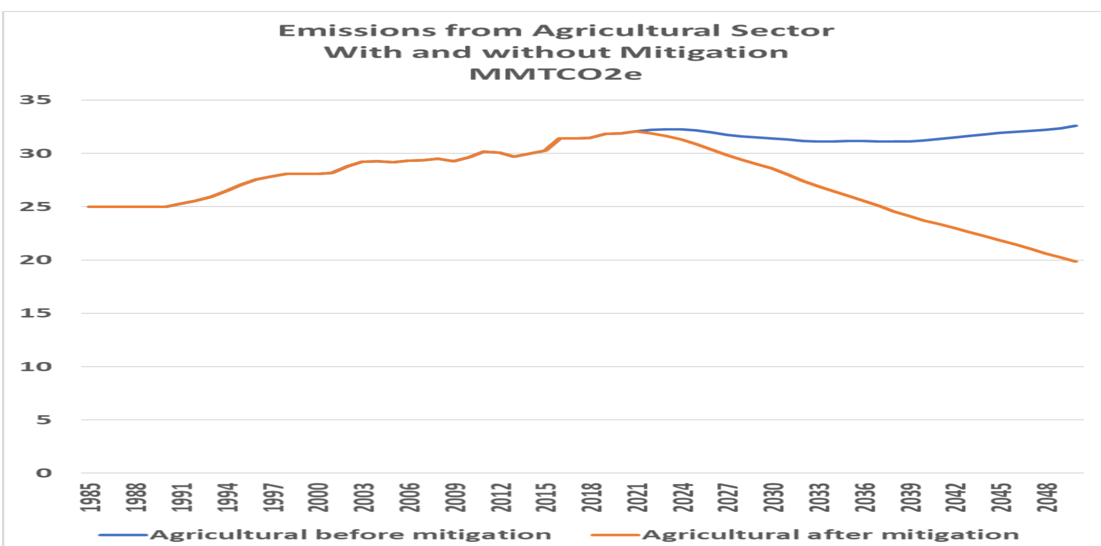
Food Web

Diagram below tracks dynamics of food production requirements. Starting with an increase in population leads increase in demand for animals. Meeting feeding needs of a growing animal population leads to increase in agricultural production and an increase in water and fertilizer usage. Crop and pastureland devoted to animal food production reduces capability of land to absorb carbon and rainwater. During and post-production, a large amount of food that is produced is wasted which leads to more methane emissions. This linear system of production, processing, and distribution and waste needs to change to a more cyclical and efficient production. The adage of reduce, reuse, recycle would go a long way in reducing emissions and allowing nature to recover.

Dynamics of Food Production, and Consumption



Note that emission from transportation of food is captured in another segment of the model, under freight.



Reduce Food Waste

Another strategy to reduce emissions is to reduce food waste. In Europe, industrial parts of Asia, and sub-Saharan Africa, more than 20% of food is simply thrown away, allowed to rot, or is otherwise wasted. In the United States it is a 40%. That is bad for the people who do not have enough to eat, bad for the economy, and bad for the climate. When wasted food rots, it produces enough methane to cause as much warming as 3.3 billion tons of carbon dioxide each year.

Education, environmental footprint food labeling, technologies to track amount of waste, along with change in behavior all can contribute to lowering the food-waste and GHG emissions from what we eat.

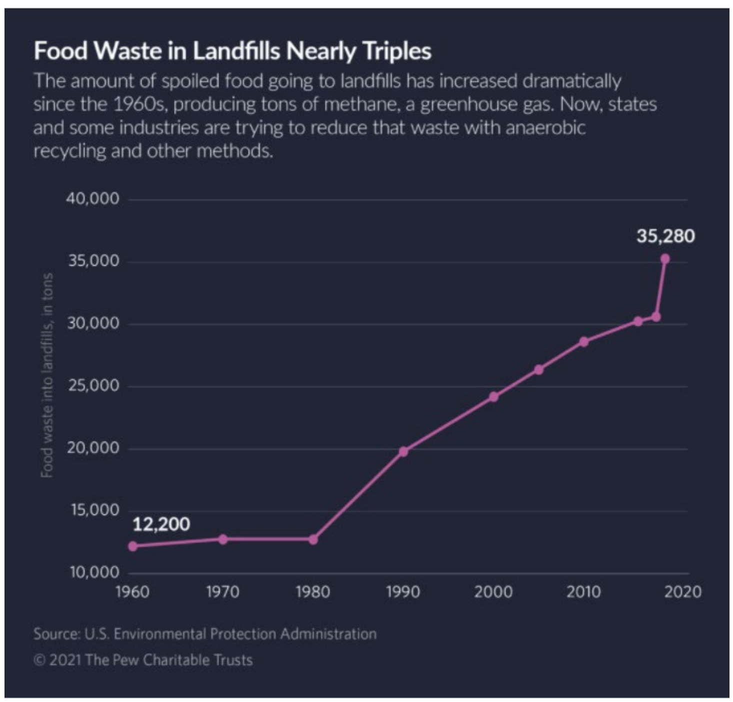
Roughly a third of the world's food is never eaten, which means land and resources used and greenhouse gases emitted in producing it were unnecessary. Interventions can reduce loss and waste, as food moves from farm to fork, thereby reducing overall demand.

More on how much food waste is there in the United States?

Following is an extract from USDA frequently asked questions:

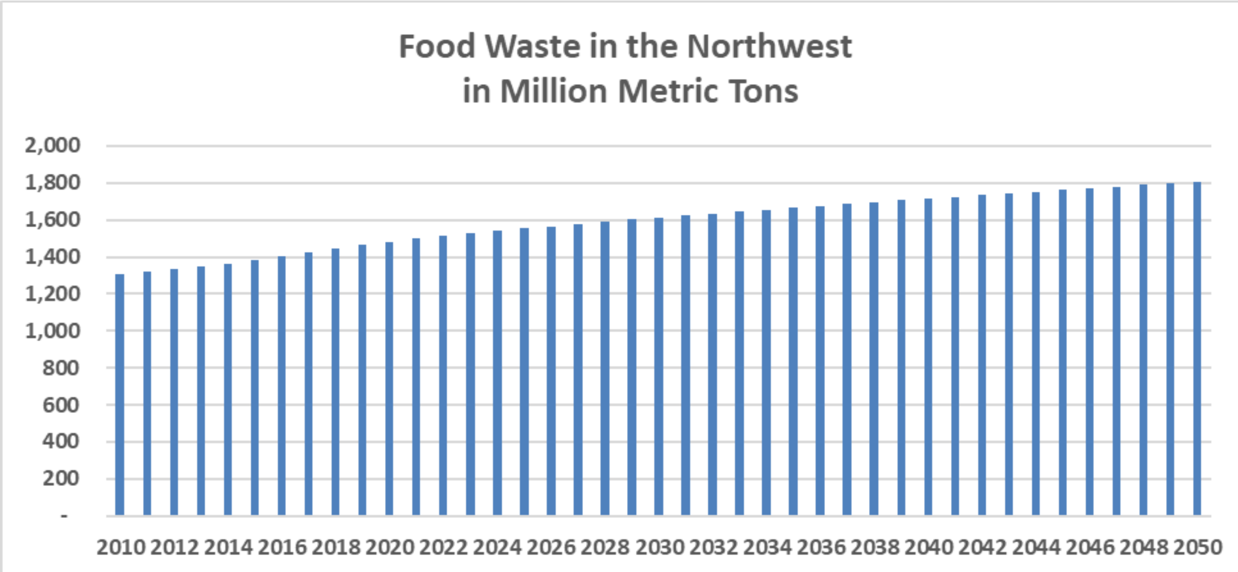
https://www.usda.gov/foodwaste/faqs

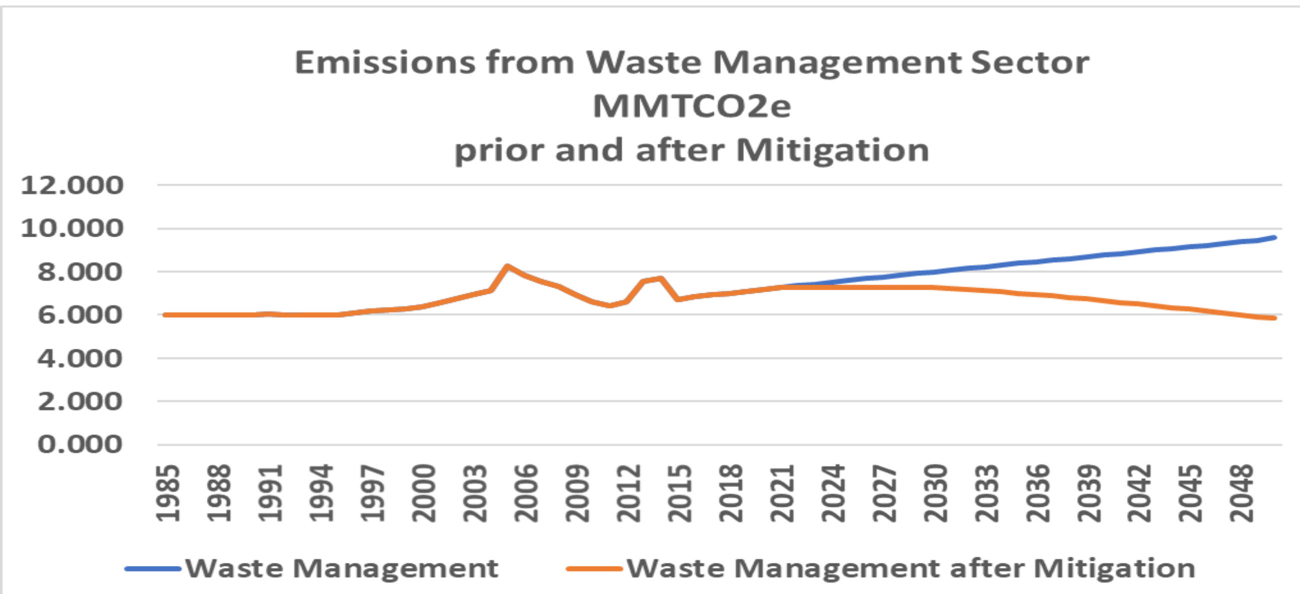
In the United States, food waste is estimated at between 30-40 percent of the food supply. This estimate, based on estimates from USDA's Economic Research Service of 31 percent food loss at the retail and consumer levels, corresponded to approximately 133 billion pounds and $161 billion worth of food in 2010. This amount of waste has far-reaching impacts on society. Wholesome food that could have helped feed families in need is sent to landfills. Land, water, labor, energy and other inputs are used in producing, processing, transporting, preparing, storing, and disposing of discarded food.



Estimated Food Waste in the Northwest

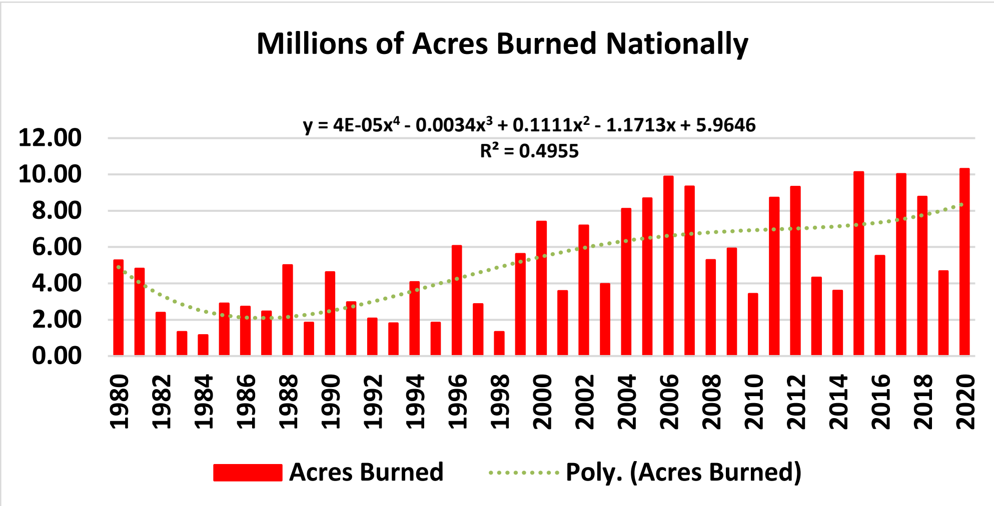
Using EPA's 2010 baseline estimate of 218.9 pounds of food waste per person sent for disposal, we estimate in the Northwest about 1.5 billion metric tons of food is wasted per year. If there are no future mitigation strategies to reduce food waste, by 2050 amount of food waste can reach over 1.8 billion metric tons.


Food Waste in the Northwest
in Million Metric Tons
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
-
2010 2012 2014 2016 2018 2020 2022 2024 2026 2028 2030 2032 2034 2036 2038 2040 2042 2044 2046 2048 2050


Emissions from Waste Management Sector
MMTCO2e
prior and after Mitigation
12.000
10.000
8.000
6.000
4.000
2.000
0.000
1985 1988 1991 1994 1997 2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030 2033 2036 2039 2042 2045 2048
Waste Management
Waste Management after Mitigation

Estimating Potential GHG Emissions due to Forest Fires

Nationally, the number and intensity of forest fires has increased over the past four decades. Number of acres burned has been on a gradual increase as the graph below shows.



Projections for Forest Fires in the Northwest with climate change

A warming climate will have profound effects on fire frequency, extent, and severity in the Pacific Northwest. Increased temperatures, decreased snowpack, and earlier snowmelt will likely lead to longer fire seasons, lower fuel moisture, higher likelihood of large fires, and greater area burned by wildfire. Existing literature shows that incidents of wildfires are related to growth in vegetation and undergrowth in spring, extreme summer temperatures, and precipitation in summer and winter.

We used a simplified econometric relationship between winter and spring precipitations, hot summer temperatures and GHG emitted from past forest fires. Climate change models provide daily temperature minimum and maximums as well as precipitation at a location. For our purpose, we used a simple linear equation where regional GHG emissions from forest fires is a function of three main variables.

1) Maximum summer temperature in the region
2) Summer river flows (at the Dalles)
3) Winter river flows (at the Dalles)

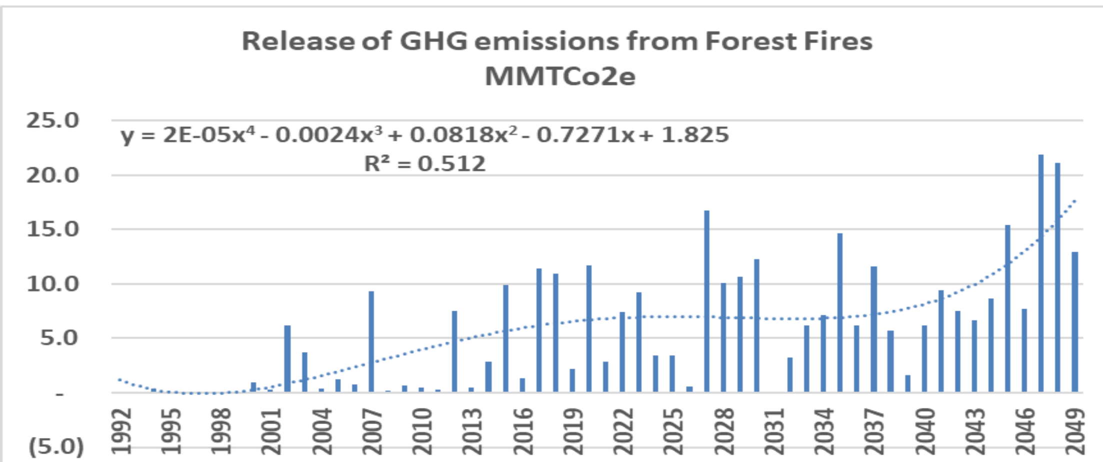
This structural form can explain 46% of historic variations in GHG emissions and all independent variables are stable and significant. Using this model, we can get a rough estimate of annual GHG emission for CanESM2. These estimated emission values are added to the inventory of non-energy emission sources.

Forest Fires, Smoke, Rain and Drought

Recent research on relationship between forest fires and rain points to a positive feedback loop where more fires may lead to less rain, that would lead to drought that could lead to more forest fire.s Research finds tiny particles in wildfire smoke affect the way droplets form in clouds, potentially resulting in less rain and

exacerbating dry conditions that fuel fires. The study's authors expected an increase in the number of water droplets forming in clouds because of wildfires, because more particles create more droplets. But the difference between smoky and clean clouds was bigger than expected, with smoky clouds hosting about five times the number of droplets than their clean counterparts. Smoky droplets were also half the size of pristine droplets. That size difference is what could stop the drops from falling. Because small droplets are less likely to grow and eventually fall out as rain, wildfires in the western U.S. could mean less rain during wildfire season, according to the new study published in the American Geophysical Union Journal *Geophysical Research Letters.* https://phys.org/news/2021-08-wildfire-western.html. Original research by:
Twohy, C. H., Toohey, D. W., Levin, E. J.T., DeMott, P. J., Rainwater, B., Garofalo, L. A., et al. (2021). Biomass burning smoke and its influence on clouds over the western U. S.
https://doi.org/10.1029/2021GL094224

In clouds that reach high into the atmosphere, adding more particles can invigorate the clouds and cause rain, but the opposite is true for lower-altitude cumulus clouds studied for the report. Previous work, unrelated to the present study, found similar changes in droplet size and concentration related to smoke in the Amazon, supporting the new findings.



Although estimated values shows increase in magnitude of future emissions from forest fires, given extent of the forest fires in 2021, this model underestimates size of future wildfires.

Fire Mitigation Strategies

Although we did not test any mitigation strategies for reducing emissions from forest fires, a recent report from a collaboration between different federal agencies and universities shows benefits from using Native American fire management techniques.

From proceedings of the National Academy of Sciences of the United States of America:

As residential development continues into flammable landscapes, wildfires increasingly threaten homes, lives, and livelihoods in the so-called “wildland–urban interface,” or WUI. Although this problem seems distinctly modern, Native American communities have lived in WUI contexts for centuries. When carefully considered, the past offers valuable lessons for coexisting with wildfire, climate change, and related challenges. Here we show that ancestors of Native Americans from Jemez Pueblo used ecologically savvy intensive burning and wood collection to make their ancient WUI resistant to climate *variability and extreme fire behavior. Learning from the past offers modern WUI communities more options for addressing contemporary fire challenges. Public/private–tribal partnerships for wood and fire management can offer paths forward to restore fire-resilient WUI communities.*

https://www.pnas.org/content/118/4/e2018733118

"The importance of traditional fire use and management practices for contemporary land managers in the American Southwest" Carol Raisha, Armando Gonza´lez-Caba´nb , Carol J. Condiec a USDA Forest Service, Rocky Mountain Research Station, Albuquerque, NM 87102-3497, USA b USDA Forest Service, Pacific Southwest Research Station, Riverside, CA 92507, USA c Quivira Research Associates, Albuquerque, NM 87106, USA https://www.fs.fed.us/rm/pubs_other/rmrs_2005_raish_c001.pdf

An adaptation strategy to reduce GHG emissions from forest fires is to quickly identify and stop spread of forest fires by use of more drones and increasing resources dedicated to firefighting. For example, by increasing federal and state investments in the number of aircrafts contracted for firefighting. Access to information from Pentagon's Fireguard drone images have proven to help firefighters locate new fires quickly and save lives. https://www.latimes.com/politics/story/2021-07-27/fireguard-expiration-congress-wildfires

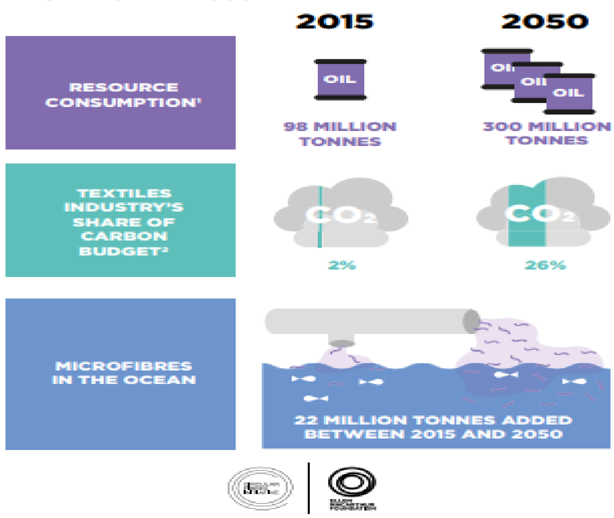
The Clothing We Wear

Another area that can help reduce GHG emissions and deserves attention is the clothing we wear. Globally clothing industry is a 1.3 trillion-dollar industry, employing more than 300 million people along the value chain. Global clothing production has more than doubled in the past 15 years. The current clothing system is extremely wasteful and polluting. Globally, the average number of times a garment is worn before it ceases to be used has decreased by 36% compared to 15 years ago. In United States, on average

According to industry reports:

- Since year 2000, demand for clothing articles increased from less than 50 billion to over 100 billion by 2015.
- Clothing utilization has declined steadily in the past 15 years.
- Textile industry relies heavily on non-renewable resources. 98% of material used every year are virgin material. 63% Plastic, 28 percent cotton and 11 percent other material.
- In 2015 GHG emissions from textile production totaled 1.2 billion tons of CO2 equivalent. More than those of all international flights and maritime shipping combined.
- 20% of industrial water pollution globally is attributable to the dyeing and treatment of textiles.
- If the negative impacts of the industry continues, by 2050, industry can use more than 26% of the carbon budget associated with a 2 degree C pathway.

FIGURE 4: THE NEGATIVE IMPACTS OF THE TEXTILES INDUSTRY ARE SET TO DRASTICALLY INCREASE BY 2050



1 Consumption of non-renewable resources of the textiles industry, including oil to produce synthetic fibres, fertilisers to grow cotton, and chemicals to produce, dye, and finish fibres and textiles

2 Carbon budget based on 2 degrees scenario

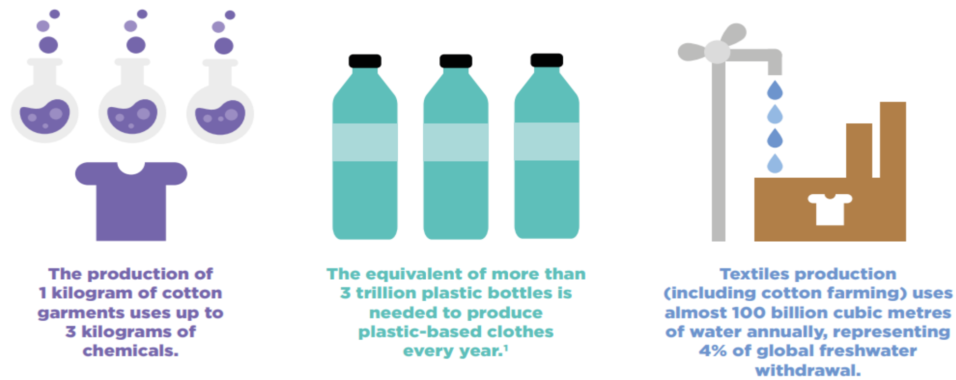
Source: Circular Fibres Initiative analysis – for details see Part I

Extract from the report: "A new Textile Economy: redesigning fashions future".

https://www.ellenmacarthurfoundation.org/assets/downloads/publications/A-New-Textiles-Economy_Full-Report_Updated_1-12-17.pdf

Raw material used in producing textiles take a great toll on environment. Figure below shows that to produce on kilogram of cotton, three kilograms of chemicals are used. Equivalent of over 3 trillion plastic bottles are used to produce plastic-based clothing every year. 4% of global freshwater, about 100 billion cubic meters, are used in textile production every year.

FIGURE 18: THE TEXTILES INDUSTRY USES SIGNIFICANT AMOUNTS OF RESOURCES



1 Based on an average weight of 10 gram of a 0.5 litres PET bottle

Source: KEMI, *Chemicals in textiles: Risks to human health and the environment* (2014), p.33; World Bank, AQUASTAT, and FAO, *Dataset: Annual freshwater withdrawals, total* (2014); Circular Fibres Initiative analysis

Analysis by McKinsey shows total GHG emissions for cotton production is about 86 MMTCO2e. Plastic-based fibers generate 530 MMTCO2e. including other fabric's emission, the total emissions from textile production is 1200 MMTCO2e.This represents about 7% of global GHG emissions.

To reduce emissions, the industry is working on developing alternatives to current take-make-dispose model for clothing and is focusing on creating a more circular clothing paradigm where clothes are produced using renewable resources.

Although industry efforts would go a long way in reducing GHG emissions and impact on water consumption, consumers have a major role to play in reducing the impacts of cotton by changing the way they care for clothing.

Some 70% of greenhouse gas (GHG) emissions associated with cotton clothing are at the consumer end, and not from growing cotton, transporting, or manufacturing clothing.

One way to dramatically reduce GHG emissions is to use cold-water laundry detergent. Contrary to popular perceptions, cold-water detergent is just as effective as hot water in the wash, and it can help to reduce energy from washing clothes by as much as 90%.

https://www.theguardian.com/sustainable-business/cotton-reduce-environmental-impact-consumer-behaviour

In our analysis of Pathways to Decarbonization, we did not quantify impact of mitigation strategies related to textile industry in the Northwest. But there is a vast opportunity for reducing GHG emissions by more prudent production, manufacturing, and consumption of textiles.

Emissions from Man-made Reservoirs

Below are excerpts from an upcoming peer reviewed paper published in *Global Biogeochemical Cycles May, 2021* under the title: "Year-2020 Global Distribution and Pathways of Reservoir Methane and Carbon Dioxide Emissions According to the Greenhouse Gas from Reservoirs (G-res) Model" by John A. Harrison, Yves T. Prairie, Sara Mercier-Blais, and Cynthia Soued
https://agupubs.onlinelibrary.wiley.com/action/doSearch?AllField=John+A.+Harrison%2C+Yves+T.+Prairie%2C+Sara+Mercier-Blais%2C+and+Cynthia+Soued&SeriesKey=19449224

By damming rivers, humans have created millions of reservoirs, which, collectively, constitute an important greenhouse gas source, especially for methane, a particularly potent greenhouse gas. Using observed relationships between reservoir characteristics and greenhouse gas emissions, we show that much more methane either bubbles out of reservoirs or is emitted just downstream from reservoirs than was previously known. This is important because it may be possible to reduce methane emissions from downstream of reservoirs by selectively withdrawing water from near the surface of reservoirs, which tends to be methane-poor, rather than from greater depths, where methane often accumulates. We also found that on a per-area basis reservoirs are a more potent source of greenhouse gases than previously recognized, and that the highest rates of emissions occur in the tropics and subtropics. Finally, we show that estimates of reservoir greenhouse gas emissionsare quite sensitive to climate-related factors like temperature.

"Collectively, reservoirs constitute a significant global source of C-based greenhouse gases (GHGs). Yet, global estimates of reservoir carbon dioxide (CO2) and methane (CH4) emissions remain uncertain, varying more than four-fold in recent analyses. Here we present results from a global application of the Greenhouse Gas from Reservoirs (G-res) model wherein we estimate per area and per-reservoir CO2 and CH4 fluxes, by specific flux pathway and in a spatially and temporally explicit manner, as a function of reservoir characteristics.

Discussion with Dr. John Harrison, lead author of this study puts annual emission from Northwest man-made reservoirs at about 6.5 MMTCO2E/YR. This figure has been added to non-energy source of emission in our analysis.

No mitigation strategy was tested for reducing emissions from manmade reservoirs**.**

Emission Sinks (Nature Based and Mechanical Solutions)

To reduce emission of GHG gases, in particular carbon dioxide there are different strategies being tested. these strategies can include

- Land/Forest Sinks
- Mechanical Carbon Capture and Use.

Can mitigation strategies, sketched in the earlier section, along with increased incremental capacity of natural and manmade carbon sinks reach a negative net emission? Before we investigate that, we need to know more about sinks.

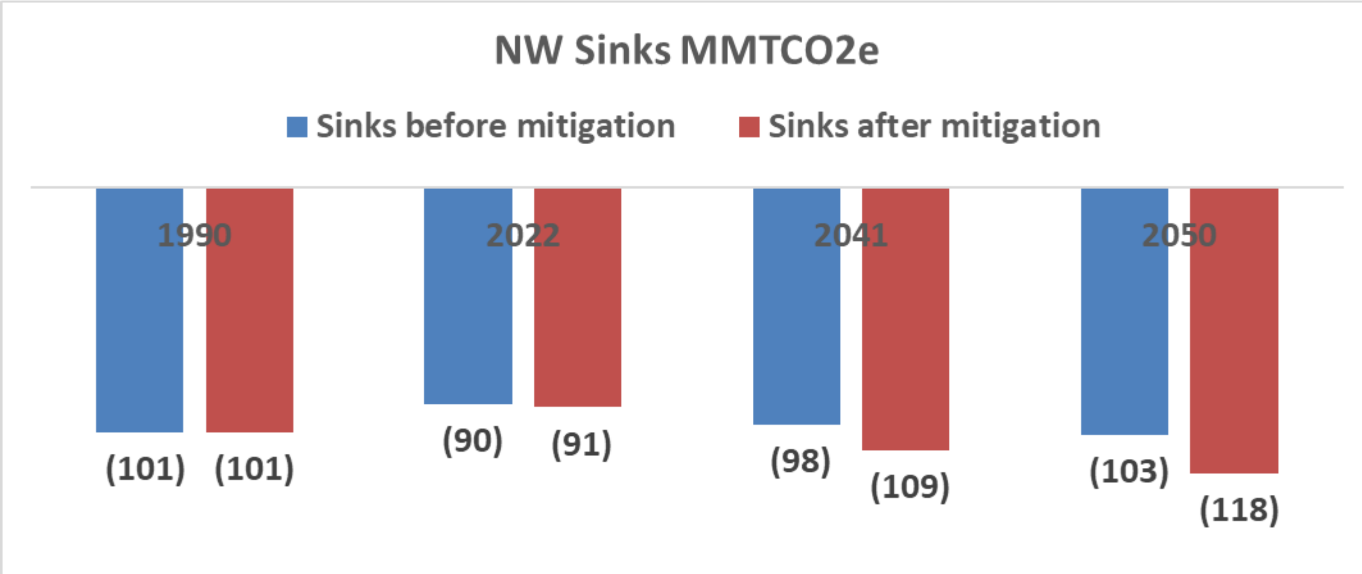
What are Sinks?

Land-Use and Land-Use Change and Forests are major natural 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 State Inventory Tool model to generate forecast of sinks for the NW. this model can be found here: https://www.epa.gov/statelocalenergy/state-inventory-and-projection-tool

We assumed LULUCF mitigation strategies can increase sinks in agricultural land, urban and rural forests. The LULUCF module calculates CO_2, CH, and NOx emissions from fertilization of settlement soils, carbon flux from forest management, urban trees, landfilled yard trimmings and food scraps, and agricultural soils.

We used EPA SIT model to generate sinks for the Northwest. Carbon is continuously cycled among ecosystem pools and the atmosphere as a result of biogeochemical processes in forests (e.g., photosynthesis, respiration, decomposition, and disturbances such as fires or pest outbreaks) and anthropogenic activities (e.g., harvesting, thinning, and replanting). As trees photosynthesize and grow, carbon is removed from the atmosphere and stored in living tree biomass. As trees die and otherwise deposit litter and debris on the forest floor, carbon is released to the atmosphere and is also transferred to the litter, dead wood, and soil pools by organisms that facilitate decomposition.

Using data from EPA SIT model we estimated that if in the Northwest more agricultural lands are returned to nature and allowed to build their inherent capacity to hold CO_2, we could expect a natural sink of about 118 MMTCO2e.



Nature Based Strategies to Increase Sinks

Rewilding is a strategy to help nature remain its ability to absorb carbon.

https://www.theguardian.com/environment/2020/oct/14/re-wild-to-mitigate-the-climate-crisis-urge-leading-scientists

Extract from the Guardian:

Restoring natural landscapes damaged by human exploitation can be one of the most effective and cheapest ways to combat the climate crisis while also boosting dwindling wildlife populations, a scientific study finds.

If a third of the planet's most degraded areas were restored, and protection was thrown around areas still in good condition, that would store carbon equating to half of all human caused greenhouse gas emissions since the industrial revolution.

The changes would prevent about 70% of predicted species extinctions, according to the research, which is published in the journal Nature.

Scientists from Brazil, Australia and Europe identified scores of places around the world where such interventions would be most effective, from tropical forests to coastal wetlands and upland peat. Many of them were in developing countries, but there were hotspots on every continent.

Only about 1% of the finance devoted to the global climate crisis goes to nature restoration, but the study found that such "nature-based solutions" were among the cheapest ways of absorbing and storing carbon dioxide from the atmosphere, the additional benefits being the protection of wildlife.

Restoring nature did not have to be at the expense of agriculture and food production, Strassburg said. "If restoration is not properly planned it could lead to a risk to agriculture and the food sector, but if done properly it can increase agricultural productivity. We can produce enough food for the world and restore 55% of our current farmland, with sustainable intensification of farming."

The study also says that planting trees, the "nature-based solution" that has received most support to date, is not always an appropriate way of preserving biodiversity and storing carbon. Peatlands, wetlands and savannahs also provide habitats for a wealth of unique species, and can store vast amounts of carbon when well looked after. Three-quarters of all vegetated land on the planet now bears a human imprint. But some scientists have a target of restoring 15% of ecosystems around the world.

The study focused on land, but the oceans also offer vast benefits linked to biodiversity and opportunities for absorbing carbon dioxide and mitigating climate change, said Richard Unsworth, senior lecturer in marine biology at Swansea University, and director of Project Seagrass, which restores vital marine habitats.

Unsworth said: "Marine habitat restoration is also vital for our planet and arguably more urgent given the rapid degradation and loss of marine ecosystems. We need restored ocean habitats such as seagrass and oysters to help promote biodiversity but also to help secure future food supply through fisheries and lock up carbon from our atmosphere."

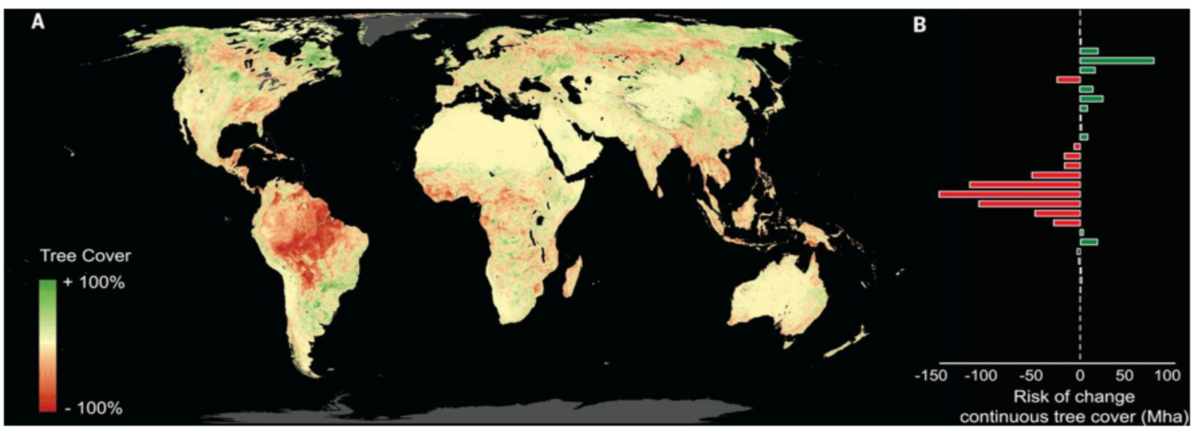
Here are some examples of rewilding: Extract from: https://www.rewildingbritain.org.uk/explore-rewilding/what-is-rewilding/examples-of-rewilding

- *Protecting, expanding, and connecting ancient woodlands to enable a diverse range of wildlife to establish and disperse, and increasing carbon storage*
- *Reducing high populations of grazing animals to help trees and other vegetation grow*
- *Removing fishing pressure and creating proper marine protection to stop dredging and bottom trawling so that sea life can recover and flourish*
- *Restoring wetlands and introducing beavers to boost biodiversity, store carbon and help flood prevention*
- *Bringing back missing species to plug crucial gaps in the ecosystem, and re-forge key relationships between species (for example, between predators and prey and scavengers)*
- *Restoring key marine ecosystems such as kelp forest, seagrass, and oyster beds to boost biodiversity, suck in carbon and get natural processes working*
- *Removing dams so that fish can move freely, and the forces of erosions and deposition can re-establish themselves*
- *Reconnecting rivers with floodplains, restoring their natural course to slow the flow, easing flooding, and creating habitats for fish and other aquatic and wetland wildlife*
- *Connecting habitats and providing wildlife bridges so wildlife can move and disperse naturally, helping them adapt to climate change and build resilience*
- *Setting aside large areas for nature so that nature can truly evolve on its own terms, maximizing biodiversity, carbon storage and essential eco benefits*

However, many of natural systems are extremely sensitive to changing temperatures, not to mention precipitation extremes and droughts. Using natural systems to increase natural sinks would be subject to climatic trends. A study by Jean-Francois Bastin, 2019 suggest a large mitigation potential for trees, it also shows how much tree cover might be lost by 2050 due to climate change itself.

> *"The restoration of trees remains among the most effective strategies for climate change mitigation. We mapped the global potential tree coverage to show that 4.4 billion hectares of canopy cover could exist under the current climate. Excluding existing trees and agricultural and urban areas, we found that there is room for an extra 0.9 billion hectares of canopy cover, which could store 205 gigatonnes of carbon in areas that would naturally support woodlands and forests. This highlights global tree restoration as one of the most effective carbon drawdown solutions to date. However, climate change will alter this potential tree coverage. We estimate that if we cannot deviate from the current trajectory, the global potential canopy cover may shrink by ~223 million hectares by 2050, with the vast majority of losses occurring in the tropics. Our results highlight the opportunity of climate change mitigation through global tree restoration but also the urgent need for action."*

https://science.sciencemag.org/content/365/6448/76



Jean-Francois Bastin et al. Science 2019;365:76-79

Science AAAS

Pathway to Decarbonization – Partial/Light

In this section we provide a brief description of a "partial or light" version of the full decarbonization by 2050 presented above. The PTD-light is the version of PTD that was used in PTD resource planning scenario.
In this version of PTD we focus on year 2041, which is the endpoint of the analysis for Council's 2021 Plan. To estimate PTD-Light loads we started with gathering recommended emission targets or goals from Council's State staff for Idaho, Montana (note these are not official state targets). Following targets were used in the PTD-Light analysis.

- Idaho Council staff recommendation: Power sector would be 100% clean by 2045. Transportation and non-power sectors would be 50% clean
- Montana Council staff recommendation: Power sector would be 90% clean by 2045 compared to 2010. Transportation and non-power sectors 50% clean by 2045.
- Targets for State of Oregon: 45% below 1990 by 2035 and 80% below 1990 by 2050.
- Targets for State of Washington: 45% below 1990 by 2030, 70% below 1990 by 2040, net zero by 2050

Estimates of State level mitigation targets by **2041**	Idaho	Montana	Oregon	Washington
Electric Sector (power)	83%	75%	67%	73%
Residential/Commercial	42%	42%	67%	73%
Industrial, w/o Agric	42%	42%	59%	73%
Transportation	42%	42%	59%	73%
Waste Management	42%	42%	59%	73%
Agriculture	42%	42%	59%	73%
Industrial Processes	42%	42%	59%	73%

Methodology for estimating Emission reduction targets and corresponding loads used a two-step process.

1. Calculate target emission reduction levels (MMTCO2e), using base year emissions and percent reduction targets.
2. Applied ratio of regional MWH average load to regional MMTCO2e of emission (Reference case MWH/MMTCO2e) from step 1.

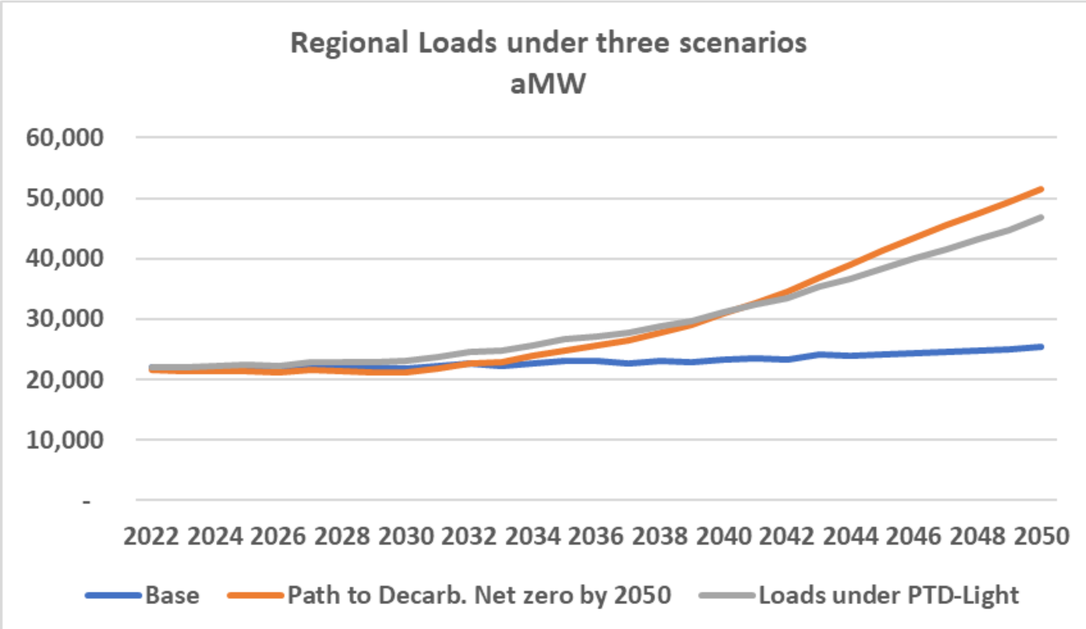
For Idaho: Staff recommendation for annual percent reduction targets were applied to Base emission forecast for that year then we apply ratio from step 2.

For Montana: Staff recommendation for annual percent reduction targets were applied to 2010 emissions, then apply ratio from step 2.

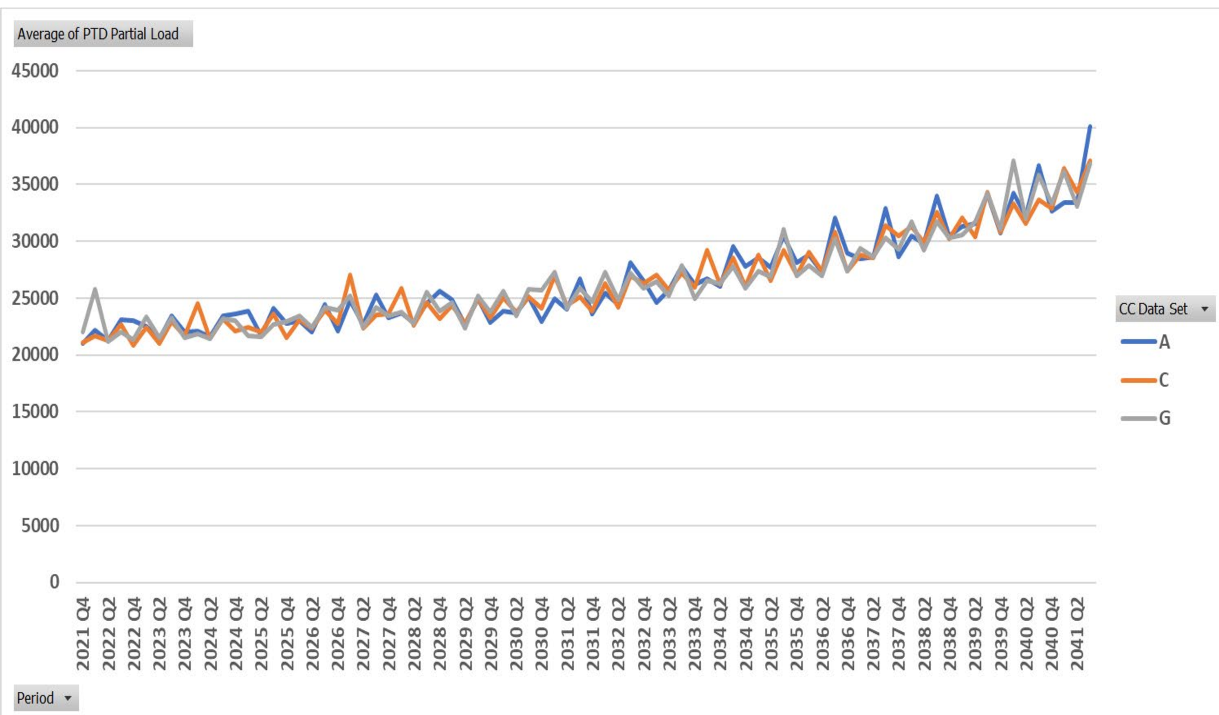
For Oregon: State percent reduction targets were applied to 1990 emissions, then apply ratio from step 2.

For Washington: State percent reduction targets were applied to1990 emissions, then applied ratio from step 2. Because state of Washington also required Net Zero by 2050, we replaced this calculated load with the load from our simulated loads Washington State with Net Zero by 2050.

Following graph shows a comparison of PTD light and PTD to the Reference case.
Note that by 2041 the loads from PTD are roughly same as loads from PTD light.

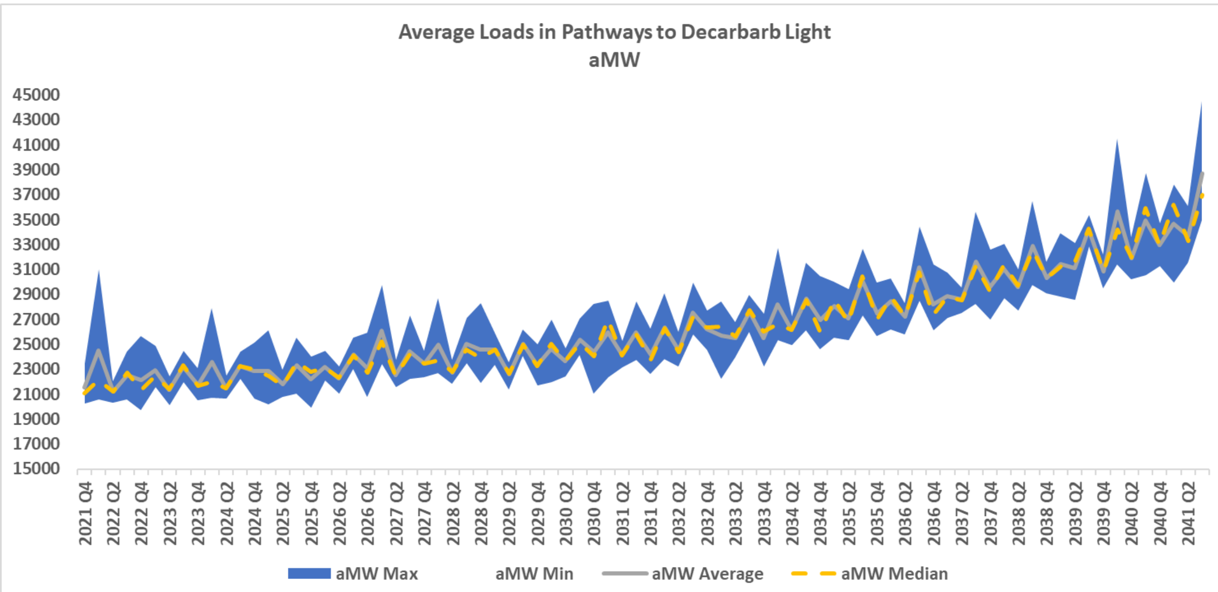


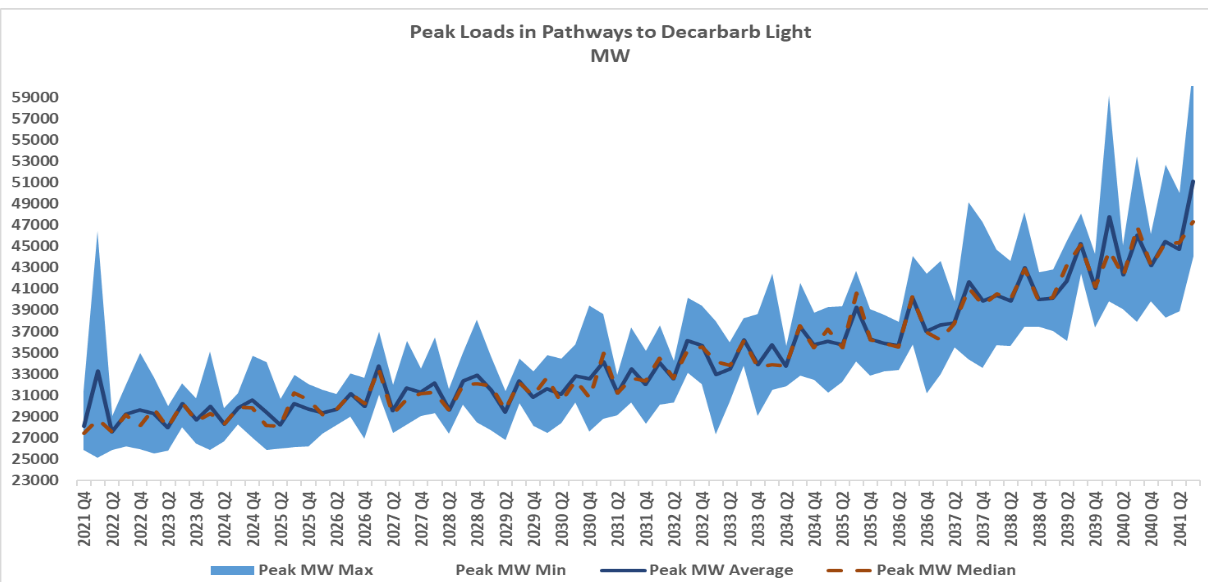
Following graph shows forecasted average load under the three climate change scenarios.



Loads Used in Resource Portfolio Model

Above loads should be considered as deterministic reference loads, as they are not subjected to various future uncertainties from climate change, economy, temperatures etc. Resource Portfolio Model (RPM) starts with these deterministic loads shown above and then creates range of departures from these loads. It is these RPM generated loads that are then are used for Resource Plan. In the section below, we present two graphs that show peak load, minimum and average load under the range of uncertainty mapped out in RPM. Note the wide range of swings in loads incorporated in the RPM.

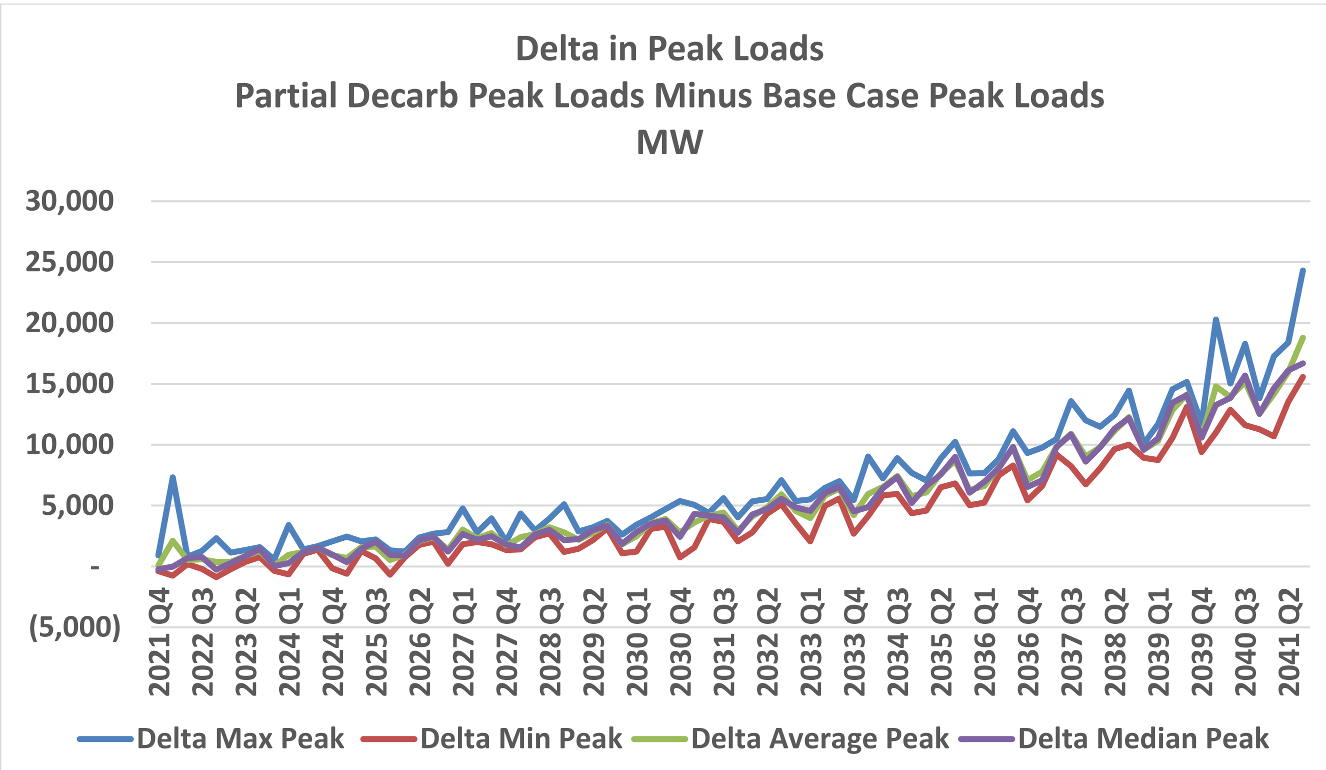




Q:\MJ\Demand Forecasting Model\8th Plan\Pathway to Decarb - Light\Partial PTD Load Futures.xlsx

Comparing RPM Loads under Pathways to Decarbonization (Partial/Light) and Base Case

As was mentioned earlier, the deterministic loads forecasts are subjected to future uncertainties. Resource Portfolio Model (RPM) takes the deterministic loads and introduces deviations from the deterministic forecast. It then uses load forecasts to optimize resource decisions. in the above section we showed two graphs depicting range of change in Pathways to Decarbonization- Partial. The following graphs show the summary of load deltas. Comparing loads in the partial pathway against Base case forecast of loads. as can be observed, magnitude of difference between the two peak loads increase substantially over the next 20 years. In the near terms (action plan period) peak loads under PTD Partial are simulated to be as much as 7,000 MW higher than Base Case. By the end of study period, peak loads can be as much as 25000 MW higher in the PTD partial case.



Risks to Climate Change Mitigation- Adaptations for a 3-4 degree C world

In the sections above we mapped out the technological innovations that producers and consumers need to undertake to reduce GHG footprint of NW power sector and economy. Reaching net-zero emissions by 2050 has been the stated goal of UN Framework Convention on Climate Change to keep the rise in global temperatures below 2 degrees. However, there is increasing evidence that this goal may be too optimistic and with the current trends 2-degree increase will be surpassed in the next 10 years and a more realistic figures put the increase at 3-4 degrees.

Mark New, Diana Liverman, Heike Schroder and Kevin Anderson in their 2010 report "Four degrees and beyond: the potential for a global temperature increase of four degrees and its implications https://royalsocietypublishing.org/doi/pdf/10.1098/rsta.2010.0303 reports that most analysts would agree that the current state of the UNFCCC process and other efforts to reduce greenhouse gases make the chances of keeping below 2◦C extremely slim, with 3◦C much more likely, and a real possibility of 4◦C, should more pessimistic analyses come to fruition. Research into flexible, staged approaches to adaptation that are robust to significant uncertainties is needed. We need to start designing the institutional framework that allows for integrated adaptation strategies, as well as both incremental and transformative adaptation, across sectors and across geographical scales. The modelling of future emissions pathways needs to work within a cumulative budget framework, rather than stabilization of concentrations in the atmosphere. This allows for incorporation of recent and concurrent emissions data, providing a realistic launch point for emissions profiles that fit the required budgets for a particular temperature target. Further, the cumulative budget approach allows for transparent discussion of how remaining emissions can be partitioned between nations.
Contemplating a world that is 4◦C warmer can seem like an exercise in hopelessness: accepting that we will not reduce greenhouse gases enough or in time and laying out a difficult future for many of the world's people, ecosystems, and regions.

Aug 9, 2021 (Reuters) - Global warming is dangerously close to spiraling out of control, a U.N. climate panel said in a landmark report Monday, warning the world is already certain to face further climate disruptions for decades, if not centuries, to come. https://www.reuters.com/business/environment/un-sounds-clarion-call-over-irreversible-climate-impacts-by-humans-2021-08-09/

The world is now on track to use up that budget in about a decade. With 2.4 trillion tons of climate-warming CO2 added to the atmosphere since the mid-1800s, the average global temperature has risen by 1.1C. That leaves 400 billion tons more that can be added before the carbon budget is blown. Global emissions currently total a little more than 40 billion tons a year.
https://www.reuters.com/business/environment/key-takeaways-un-climate-panels-report-2021-08-09/

The Economist paper, in its July 2021, provides the narrative for a world that must deal with 3 degrees of global warming, calling it quite plausible and truly disastrous.
https://www.economist.com/briefing/2021/07/24/three-degrees-of-global-warming-is-quite-plausible-and-truly-disastrous?itm_source=parsely-api

The Economist report documents many unprecedented heatwaves, wildfires and floods records throughout the world. This is what Earth looks like when, according to the latest data from the World Meteorological Organization, it is 1.1-1.3°C warmer than it was before the steam engine was invented. The Paris agreement of 2015 created a compact to limit global warming to "well below 2°C" above the pre-industrial, ideally seeing it rise no more than 1.5°C.

Paris targets were, and remain, both prudent and incredibly ambitious. A world which follows the policies that are actually in place right now would end up at 2.9°C, according to CAT (the UN Environment Programme, which tracks the gap between actual emissions and those that would deliver Paris Accord, provides a somewhat higher estimate). Almost everyone expects or hopes that policies will tighten up at least somewhat. But any reasonable assessment of the future must look at what may happen if they do not.

"In the 1990s, the concern was whether climate change was important enough to worry about. Governments never seriously pursued, the then possibly adequate, low-level mitigation. In the 2000s, climate was not important enough and the mitigation response was the central, while adaptation response was a bad word that corresponded to the unthinkable failure to mitigation. There was a failure to mitigate. The 2010s, in light of governmental and societal resistance to even limited mitigation responses, and in the realization of unavoidable significant climate change, adaptation response became an important consideration. There was only the storyline of imminent government mitigation policies and modest adaptation needs. Any other talk was deemed alarmist. Now in the 2020s, there has been very little action on either mitigation or adaptation. (Climate scientists: concept of net zero is a dangerous trap https://theconversation.com/climate-scientists-concept-of-net-zero-is-a-dangerous-trap Facing a future where temperatures may be well beyond 2 °C with highly consequential climate impacts, perhaps it is time to seriously address safeguard responses"

A more recent report released In July 2021 "Climate Risk and Response: Too Much and Too Little" presents evidence that global mitigation activities, so far, have been far from the level of intensity and seriousness it deserves. Finding and warnings from this study are echoed in the latest call for action issues by UN.

"The primary message of scientists and the UN is that ALL humanity simply HAS to immediately and dramatically reduce GHG emission. No matter how unrealistic that position has been since the first COP (Conference of the Parties) of 1992 in Rio de Janeiro, its repetition becomes more frantic each year. There is now an acceptance of the need for adaptation, but only to the limited extent of accommodating a 1.5 °C world. To a large degree, the actual elements of adaptation, or the more ambiguous resilience, remain largely academic studies. It is unacceptable to only acknowledge more than one successful outcome. Countries and governments have a moral obligation to prepare for the globally interconnected consequence of not adequately mitigating climate change. The delay in pursuing intense mitigation has consequences where adequate adaptation is no longer possible – either due to the extreme conditions or the neglect of aggressively pursuing adaptation solution while there still were resources to do so."

"There were numerous reported riots over COVID-19 restrictions despite extensive and obvious death rates. Countries struggled to protect the economic status-quo to the extent possible despite greater benefit in quickly bringing the pandemic under control. Country governments were unable to manage even the single logistics problem of vaccinations. Yet, the world anticipates that burdensome, complicated, adverse, and enduring climate mitigation will immediately and successfully take place."

Other key findings from the Climate Risk and Response report include:

"Human behavioral dynamics and socio-climatic feedback effects will make it improbable that temperatures can be kept below 3.5 C° – and this outcome is only possible if full global mitigation is maintained over decades, in the absence of earth-system tipping point responses.

Global governments do not have the ability to coordinate and complete the GHG transition to net-zero before 2065, although they can complete the carbon-fuel transition by 2057.

It is not possible to physically and socially produce the mitigation trajectory that the optimization studies of the GHG transition portray.

The GHG transition is a multi-generation problem. Fully executing even, the single-program approach ("renewably electrify everything") proposed herein will likely be politically problematic.

Socioeconomic impact uncertainty is more important than climate uncertainty for determining mitigation levels that trade off lives and economic costs.

All the mitigation activities produce economic multipliers that make the net cost to society and the economies, although large and impactful, much less than what the raw investment costs noted in other studies would suggest.

The long energy payback period of renewable-energy sources produces feedback effects that create the greatest hurdle for a successful GHG transition.

Climate is a threat multiplier and new technologies produce a confluence of threats that will interfere with climate mitigation efforts.

There will be inadequate mitigation and adaptation in the devastated developing countries. World governments will be forced to prioritize safeguard responses.

Even though it is rejected in this study, extreme geoengineering is inevitable, along with the counter-geoengineering conflicts it entails.

Realizable policy execution will make conditions better than they would otherwise be."

Each of above points are substantiated through the analyses presented in the report:
The report is on **The Climate Web – Crowd-Sourced Climate Intelligence** https://bra.in/3vB5Wa

Recently released IPCC6 report, indicates –compared to changes at 1.5° of global warming. The number of hot days and hot nights and the length, frequency, and or intensity of warm spells or heat waves will increase over most land areas." IPCC chapter 11.

"The frequency and intensity of hot extremes will continue to increase and those of cold extremes will continue to decrease, at both global and continental scales and in nearly all inhabited regions[1] with increasing global warming levels. *This will be the case even if global warming is stabilized at 1.5°C. Relative to present-day conditions, changes in the intensity of extremes would be at least double at 2°C, and quadruple at 3°C of global warming, compared to changes at 1.5°C of global warming. The number of hot days and hot nights and the length, frequency, and/or intensity of warm spells* *or heat waves will increase over most land areas (virtually certain). In most regions, future changes in the intensity of temperature extremes will very likely be proportional to changes in global warming, and up to 2–3 times larger (high confidence). The highest increase of temperature of hottest days is projected in some mid-latitude and semiarid regions, at about 1.5 time to twice the rate of global warming (high confidence). The highest increase of temperature of coldest days is projected in Arctic regions, at about three times the rate of global warming (high confidence). The frequency of hot temperature extreme events will very likely increase non-linearly with increasing global warming, with larger percentage increases for rarer events."*

"Heavy precipitation will generally become more frequent and more intense with additional global warming. At global warming levels of 4°C relative to the pre-industrial, very rare (e.g., 1 in 10 or more years) heavy precipitation events would become more frequent and more intense than in the recent past, on the global scale (virtually certain) and in all continents and AR6 regions. The increase in frequency and intensity is extremely likely for most continents and very likely for most AR6 regions. At the global scale, the intensification of heavy precipitation will follow the rate of increase in the maximum amount of moisture that the atmosphere can hold as it warms (high confidence), of about 7% per 1°C of global warming. The increase in the frequency of heavy precipitation events will accelerate with more warming and will be higher for rarer events (high confidence), with a likely doubling and tripling in the frequency of 10-year and 50-year events, respectively, compared to the recent past at 4°C of global warming. Increases in the intensity of extreme precipitation at regional scales will vary, depending on the amount of regional warming, changes in atmospheric circulation and storm dynamics (high confidence)". Chapter 11 of IPCC6 report.
https://www.ipcc.ch/report/ar6/wg1/#FullReport

While Pathways to Decarbonization maps out some of the strategies that are needed to reduce emission of GHGs in the Northwest, based on current finding from IPCC 6 and other reports discussing risks in getting to 1.5 degree by 2050, it may be prudent to in addition to mitigation strategies, region initiates transformational adaptation strategies in response to 3-4 degrees Celsius increase in global temperature.

Additional information

Details on regional and year-by-year emission and average load impact from strategies will be provided in a companion Excel workbook.

Companion workbook is currently located here.
https://nwcouncil.box.com/s/qmxxxmi0644vh5tx0faxosmyc040m0tz