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July 27, 2021

Oregon Public Utility Commission
Attn: Filing Center
P.O. Box 1088
Salem, OR 97308-1088

RE: UM 2178 Natural Gas Fact Finding Per EO 20-04

Attention: Filing Center

Enclosed for filing is Cascade Natural Gas Corporation's (Cascade or Company) Supplemental Comments regarding scenario's and sensitivities in the Climate Protection Plan Fact Finding Document. This filing includes Appendix A, which is referenced in the original Scenario and Sensitivity Comments filed on July 26, 2021.

If there are any questions regarding this request, please contact me at (509) 734-4593 or via email at Michael.Parvinen@cngc.com or Brian Robertson at (509) 734-4546 or via email at Brian.Robertson@cngc.com.

Sincerely,
CASCADE NATURAL GAS CORPORATION
/s/ Michael Parvinen
Michael Parvinen
Director, Regulatory Affairs

Analysis of Oregon's Cap-and-Reduce Program GHG Emissions Reductions

Provided to:

Avista Corporation and Cascade Natural Gas Corporation

Provided by:

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May 24, 2021

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Disclaimer

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This memo describes modeling that Guidehouse conducted to understand how the adoption of different greenhouse gas emissions reduction technologies could affect statewide emissions in Oregon. The analysis presented does not examine health or economic impacts of program policies, the banking or trading of compliance instruments, or the purchase of alternative compliance instruments such as Community Climate Investment credits.

Guidehouse

Guidehouse is a leading global provider of consulting services to the public and commercial markets with broad capabilities in management, technology, and risk consulting. We help clients address their toughest challenges with a focus on markets and clients facing transformational change, technology-driven innovation, and significant regulatory pressure. Across a range of advisory, consulting, outsourcing, and technology/analytics services, we help clients create scalable, innovative solutions that prepare them for future growth and success. Headquartered in Washington DC, the company has more than 7,000 professionals in more than 50 locations. Guidehouse is led by seasoned professionals with proven and diverse expertise in traditional and emerging technologies, markets and agenda-setting issues driving national and global economies. For more information, please visit: www.guidehouse.com.

Executive Summary

In response to Governor Brown's Executive Order 20-04, the Oregon Department of Environmental Quality (DEQ) has engaged stakeholders and the public in the development of a cap-and-reduce program to regulate greenhouse gas (GHG) emissions from gas utilities, fuel providers, and industry sources. The DEQ has stated three goals for the cap-and-reduce program: to reduce GHG emissions, to contain costs, and to promote equity. This analysis focuses on the first of the program's three goals: the GHG emissions reductions mandated by EO 20-04. This memo describes the methodology and results of Guidehouse's independent modeling (under contract to Avista and Cascade) to understand the economywide energy and emissions impacts of the proposed program.

Background

The DEQ and its contractor use modeling tools to forecast the impacts that a cap-and-reduce program may have on GHG emissions, public health, and the economy. The DEQ has modeled a Reference Case that forecasts future conditions based on existing regulations prior to adoption of a cap-and-reduce program. The DEQ has also modeled program options in three policy scenarios and compared the scenario outcomes to the Reference Case to inform its rulemaking. DEQ's contractor presented summary assumptions and results of this modeling activity to DEQ's Rulemaking Advisory Committee (RAC) in a series of meetings since January 2021.

Among other RAC stakeholders, Avista and Cascade have raised questions about the transparency of DEQ's modeling analysis. Additional concerns have surfaced regarding DEQ's focus on a collection of compliance pathways centered on electrification while not sufficiently considering resource adequacy concerns and emerging hydrogen technologies. Stakeholders are also concerned that:

- The DEQ has been slow to provide the records and assumptions underlying its analysis
- The DEQ's default approach to GHG reductions would shift emissions from regulated sources (stationary sources, gas utilities, and fuel suppliers) to sources not regulated by DEQ (electric generators)
- DEQ's scenario results do not account for emissions leakage to the electric sector that result from electrification of the heating and transportation sectors

The body of this memo describes these concerns in more detail.

Independent Modeling

Avista and Cascade contracted with Guidehouse to develop a transparent model that examines the economywide energy use and emissions impacts of the proposed cap-and-reduce program. This analysis is not intended to serve a as substitute for DEQ's analysis, but rather to provide a transparent and system-wide view of GHG reduction scenarios to assist RAC members in their rulemaking efforts. Guidehouse used publicly available data to develop a Guidehouse Reference Case forecast, which assumes that policies in place on January 2021 remain in force and no new policies are implemented to reduce GHG emissions. On May 20, 2021, the DEQ provided details about its model in response to a public records request made by the Northwest Gas Association on April 8. Guidehouse examined the information provided by DEQ and confirmed that key assumptions and results for the Guidehouse and DEQ Reference Cases are aligned. Guidehouse used its Reference Case as the basis for modeling policy scenarios in a manner similar to DEQ's modeling, but with greater consideration of the impacts that a cap-and-reduce program would have on emissions from sectors beyond the regulatory purview of DEQ.

Guidehouse modeled the emissions outcomes of the three policy scenarios presented by DEQ and one additional policy scenario developed by Avista & Cascade that is focused on low carbon gas deployment. Each scenario is defined by a GHG emissions reduction target and an array of GHG reduction interventions that are deployed to reduce GHG emissions. Table 1 summarizes the GHG reduction technologies assumed in each of the four scenarios. The Guidehouse model introduces these emissions reduction technologies as interventions to the Guidehouse Reference Case, and the model calculates the collective energy and emissions impacts of each scenario's technology mix. For this analysis, Guidehouse assumed an electric generation mix matching the High Renewable WECC Future forecast presented in Portland General Electric's *Integrated Resource Plan 2019*. This forecast assumes a high penetration of renewables at levels exceeding current renewable portfolio standards (RPS), as well as some amount of gas-fired generation to maintain system reliability and meet peaking needs.

Table 1. Policy Scenario Summary

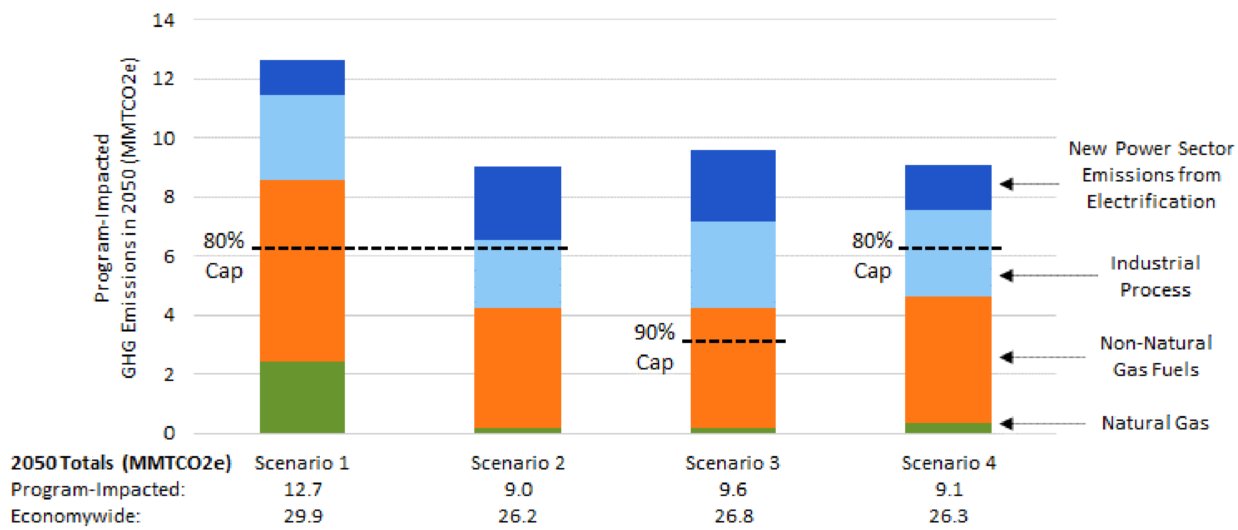
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4 (developed by Avista & Cascade)**
GHG emission cap	80% by 2050	80% by 2050	90% by 2050	80% by 2050
Trading allowance	Allows trading	Limited trading	Allows trading	Allows trading
Alternative compliance instrument allowance	Up to 25%	Up to 5%	Up to 25%	Up to 25%
Includes hydrogen (H_2) technology	No	No	No	H_2-enriched natural gas (HENG), and industrial H_2
Renewable natural gas (RNG) portion of gas supply	Moderate	High	High	High
Energy efficiency improvements in all sectors	High	High	High	High
Electrification of building heat and hot Water	Moderate	High	High	Low
Electrification of industrial processes	Moderate	High	High	Moderate

Figure 1 presents the 2050 GHG emissions outcomes of the four scenarios modeled in this analysis, and it includes incremental electric sector emissions data that has not been provided in DEQ's analysis. The dark blue bars on the chart show the increase in annual GHG emissions from the electric sector resulting from the program's electrification activities. Figure 2 presents the portion of total 2050 energy use from each fuel type for the four scenarios considered. These figures illustrate that:

- Policy scenarios that include high levels of end use electrification (e.g., scenarios 2 and 3) will have high levels of emissions leakage (2.4 MMTCO2e/year) to the electric sector.
- Policy scenario 1 results in the highest 2050 emissions, in part because it has a moderate level of RNG adoption and does not consider technologies such as hydrogen.

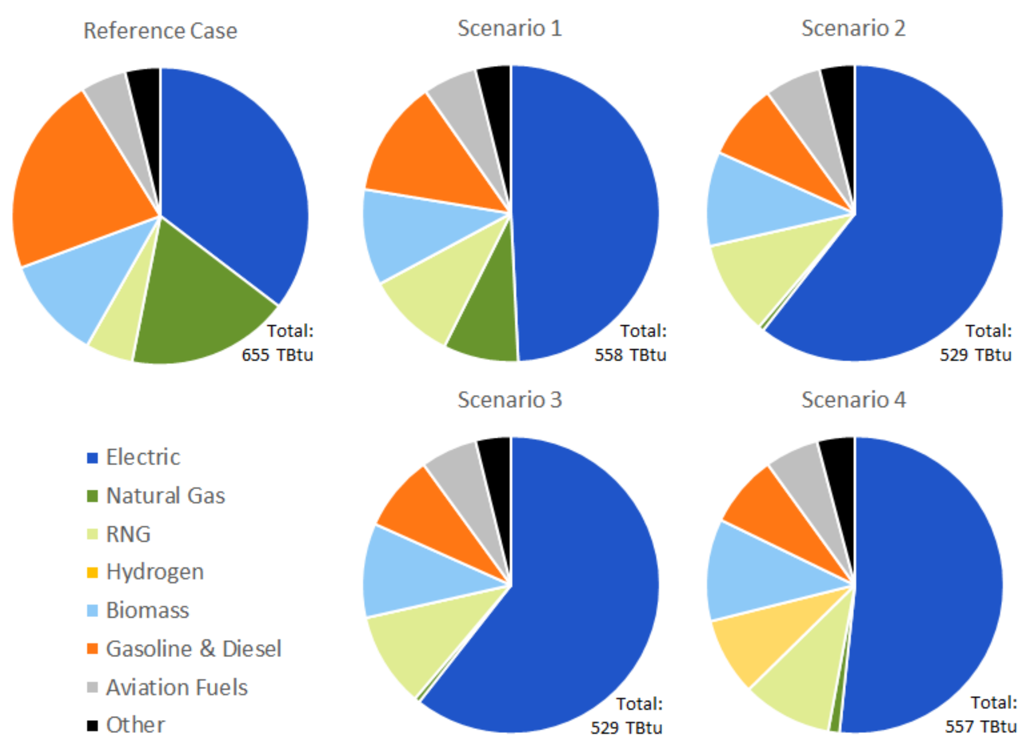
- Through application of low carbon gas technologies and limited electrification, policy scenario 4 provides a high level of GHG reductions with low emissions leakage.
- Of the scenarios considered, policy scenario 4 provides GHG reductions comparable to scenario 2 and provides the lowest economywide emissions intensity, in terms of total emissions per total energy use.

Figure 1. Projected 2050 GHG Emissions Affected by Cap-and-Reduce Program, for Four Policy Scenarios



Source: Guidehouse analysis

Figure 2. Total 2050 Energy Use by Source, for Four Policy Scenarios



Source: Guidehouse analysis

Conclusions and Recommendations

The fourth policy scenario that Guidehouse modeled emphasized the delivery of low carbon gas through deployment of RNG and hydrogen technology. This low-carbon gas scenario delivers GHG reductions comparable to the high electrification modeled in Scenario 2. Guidehouse has previously analyzed and reported how the gas system contributes to US energy system resilience.[1] In a decarbonized future, gas networks would continue to support the reliability and resiliency of Oregon's broader energy system by transporting and distributing low carbon gas and hydrogen.

- **Recommendation:** The DEQ should develop and present to the RAC a scenario in which emerging low carbon fuel technologies are used to deliver GHG emissions reduction with minimal impacts to the electric sector. DEQ's analysis of policy alternatives should consider the reliability and resilience benefits of maintaining diverse energy delivery systems, including the gas network.

In contrast to DEQ's presentation of policy scenario results, Guidehouse found that scenarios with high levels of electrification do not eliminate GHG emissions from Oregon's economy unless Oregon's power sector fully decarbonizes the electricity supplied to its customers. The DEQ's policy scenarios do not meet the intended goal of reducing overall GHG emissions to the levels mandated by EO 20-04. Rather, the DEQ's scenarios effectively shift GHG emissions from one group (within DEQ's purview) to another group (outside of DEQ's purview) resulting in net reductions system-wide which do not meet the mandates by EO 20-04.[2]

- **Recommendation:** To adequately inform the RAC's decision-making, the scenario results presented by DEQ should describe the economywide emissions impacts of the proposed cap-and-reduce program.

Meeting the statewide goals of EO 20-04 will require emissions reduction from sectors outside the proposed scope of the cap-and-reduce program. The proposed Community Climate Investment (CCI) program provides an avenue for investment in GHG reductions strategies in these sectors. There are opportunities for interventions to reduce GHG emissions in the non-energy residential, commercial, and agricultural sectors of the economy, for instance through improved wastewater management, refrigerant handling, and conservation tillage.

- **Recommendation:** Alternative compliance mechanisms such as CCIs should encourage innovation from regulated sectors and incentivize a broad range of approaches. Funds from a CCI program should be invested in direct emissions reductions so that there is a clear linkage between inputs (funding) and outputs (GHG reductions) under a single regulator.

For further detail on this analysis and resulting recommendations, please read on in the following memo below.

[1] American Gas Foundation (2021). "Building a Resilient Energy Future: How the Gas System Contributes to US Energy System Resilience" Available at: https://gasfoundation.org/2021/01/13/building-a-resilient-energy-future/

[2] It is important to understand that DEQ's charter does not allow it to regulate electric utilities.

1. Introduction

Governor Brown's Executive Order 20-04 directs the Oregon Department of Environmental Quality (DEQ) to cap and reduce emissions from transportation fuels, from other liquid and gaseous fuels, and from large stationary sources of greenhouse gas (GHG) emissions.[3] In response to EO 20-04, the DEQ has engaged stakeholders and the public in the development of a cap-and-reduce program. The DEQ has stated three goals of the cap-and-reduce program: to achieve significant GHG reductions, to contain costs, and to promote equity.[4] This memo describes the methodology and results of Guidehouse's independent modeling (under contract to Avista and Cascade) to understand the economywide energy and emissions impacts of the proposed program. This analysis focuses on the first of the program's three goals: the GHG emissions reductions mandated by EO 20-04.

DEQ's Modeling Efforts to Date

The DEQ convened a rulemaking advisory committee (RAC) to provide diverse perspectives on policy proposals including fiscal, environmental justice, public health, and economic impacts. At the RAC's second meeting on February 17, 2021, DEQ's contractor presented the Reference Case results, projecting emissions from different sectors through 2050 in the absence of a cap-and-reduce program. DEQ's contractor presented initial greenhouse gas (GHG) emissions results from three policy scenarios at the third RAC meeting (March 18, 2021) and presented revised emissions results at the fourth RAC meeting (April 22, 2021). DEQ's policy scenario presentations showed emissions from entities that would be regulated under the cap-and-reduce program; but DEQ's results do not show how the program's activities could affect emissions from sectors outside of the program, such as the electric sector. DEQ has also stated that their modeling does not consider emerging GHG reduction technologies such as carbon capture and sequestration or hydrogen technologies.

RAC Stakeholder Questions

Among other RAC stakeholders, Avista and Cascade have raised questions about the transparency of DEQ's modeling analysis and the DEQ's focus on electrification in its modeled policy scenarios. Specifically, stakeholders have noted that:

- On April 8, the Northwest Gas Association requested that DEQ share its analytical assumptions, which are critical to providing meaningful and substantive input into RAC discussions, and the DEQ did not respond to this request until May 20, 2021.
- The electrification of building heat and transportation end uses would increase emissions from electric generation unless the power sector greatly reduces its emissions intensity.
- The DEQ's policy scenario results (as presented to the RAC) do not account for emissions that would be transferred to the electric sector due to electrification.
- The DEQ appears to consider electrification as the default approach that a CCI program would use to reduce GHG emissions.

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[3] Office of the Governor of the State of Oregon (2020). "Executive Order No. 20-04." Available at: https://www.oregon.gov/gov/Documents/executive_orders/eo_20-04.pdf

[4] Oregon Department of Environmental Quality (2021). "Oregon Climate Protection Program: Rulemaking Advisory Committee Meeting 1." p.25. Available at: https://www.oregon.gov/deq/Regulations/rulemaking/RuleDocuments/ghgcr2021rac1slides.pdf

Avista and Cascade have stated that they believe an overemphasis on electrification as the primary decarbonization solution will result in leakage[5] or displaced emissions from the natural gas and other fuels sectors to the electric generation sector. As a result, electrification-focused policies risk falling short of delivering economywide emissions reductions in the ways presented by DEQ's modeling results.

To date, DEQ has not presented scenario results regarding the amount of emissions leakage from regulated entities to the electric sector. This memo provides a thorough view of economywide emissions to understand the program's potential impact on emissions from regulated entities and emissions from sectors outside of the program's scope.

Independent Statewide Emissions Modeling

Avista and Cascade contracted with Guidehouse to develop a transparent model that examines the economywide energy use and emissions impacts of five potential outcomes for Oregon:

- A Reference Case forecast of emissions in the absence of a cap-and-reduce program
- The three policy scenarios developed and presented by DEQ
- A fourth policy scenario that allows deployment of hydrogen technologies in the form of hydrogen-enriched natural gas (HENG) and supply of industrial green hydrogen

This modeling effort intends to understand how the adoption of different GHG reduction technologies could affect economywide emissions in Oregon. Taking an economywide perspective of emissions enables consideration of the emissions impacts to sectors such as power generation, which are outside the scope of the proposed program. The analysis presented here does not examine health or economic impacts of program policies, the banking or trading of compliance instruments, or the purchase of alternative compliance instruments such as CCI credits. These points are important considerations that policy makers should consider in addition to the emissions analysis presented here.

2. Methodology

Guidehouse created an independent model to forecast the energy use and emissions associated with the Reference Case and policy scenarios, using technology assumptions presented by the DEQ and its contractor. These assumptions include Oregon-specific, Oregon-adjacent, and Federal policies that impact the future energy mix, energy landscape, and emission sources, including utility programs.[6] Guidehouse's economywide energy and emissions model forecasts changes in energy consumption through 2050 across all sectors of the economy, by fuel type and by end use. The model accounts for energy used upstream to generate electricity and energy used downstream by customers. Figure 3 provides a schematic of Guidehouse's energy and emissions model.

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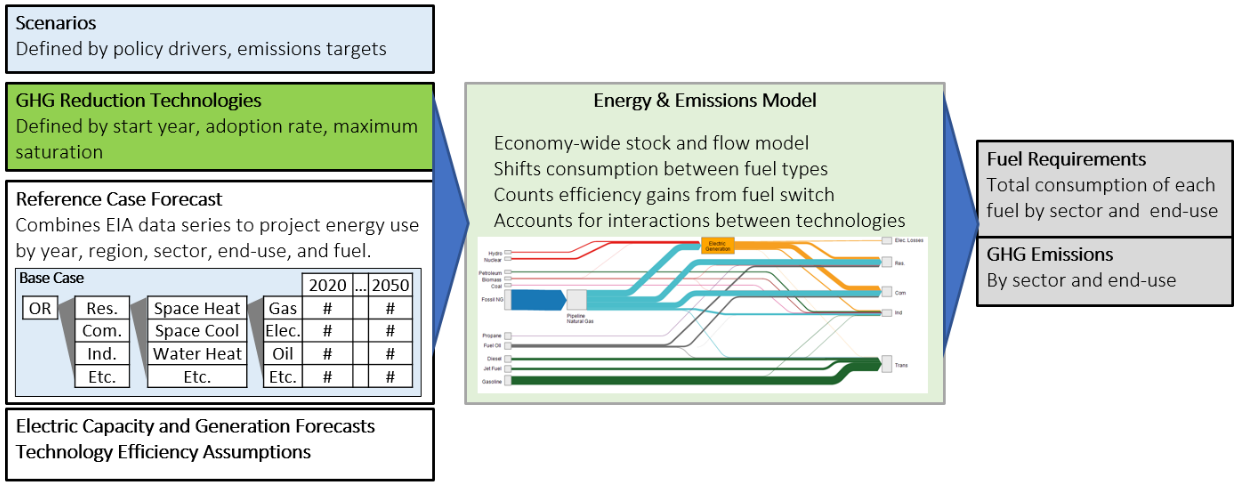
[5] The DEQ has defined leakage as the shifting of emissions or business to outside of Oregon or outside the scope of the program's regulation. https://www.oregon.gov/deq/Regulations/rulemaking/RuleDocuments/ghgcr2021KeyTerms.pdf

[6] The DEQ's assumptions regarding adoption of GHG emissions technologies are provided in a presentation titled, "Modeling Study: Assumptions and Background," available at: https://www.oregon.gov/deq/Regulations/rulemaking/RuleDocuments/ghgcrModAssumptions.pdf

Figure 3. Schematic of Guidehouse Energy and Emissions Model



Reference Case Methodology

Guidehouse used publicly available data to develop a Guidehouse Reference Case forecast, which assumes that policies in place on January 2021 remain in force and no new policies are implemented to reduce GHG emissions. The Reference Case begins with 2018 energy consumption data by sector and by fuel, reported by the US Energy Information Administration's (EIA's) State Energy Data System (SEDS).

Guidehouse referenced the EIA's *Annual Energy Outlook (AEO) 2021* forecasts for the Pacific region to project energy consumption by sector and by fuel type through 2050. For the residential and commercial sectors, Guidehouse estimated the amount of energy consumed for different end uses (e.g., space heating, water heating) based on end use consumption estimates in EIA's Residential Energy Consumption Survey (RECS) and EIA's Commercial Building Energy Consumption Survey (CBECS).

For the power generation sector, Guidehouse estimated the electric generation mix using the High Renewable WECC Future forecast described in Portland General Electric's *Integrated Resource Plan* (IRP).[7] The High Renewable WECC Future forecast approximates a world with high penetration of renewables at levels exceeding current renewable portfolio standards (RPS) and some amount of gas-fired generation to maintain system reliability and meet peaking needs.

Policy Scenario Methodology

Guidehouse modeled the emissions outcomes of the three policy scenarios presented by DEQ and one additional policy scenario focused on low carbon gas deployment. Each scenario is defined by a GHG emissions reduction target and an array of GHG reduction interventions that are deployed to reduce GHG emissions. Guidehouse's model introduces these emissions reduction technologies as deviations from the Guidehouse Reference Case. The model calculates the collective energy and emissions impacts of each scenario's technology bundle.

[7] Portland General Electric. *Integrated Resource Plan 2019*. p.77. Available at: https://portlandgeneral.com/about/who-we-are/resource-planning/

On May 20, 2021, the DEQ provided details about its model in response to a public records request made by the Northwest Gas Association on April 8. The modeling assumptions shared by DEQ prior to May 20 did not include precise figures describing the adoption of different GHG reduction technologies.[8] Guidehouse examined the data files provided by DEQ on May 20th and developed policy scenario assumptions to replicate the policy scenarios used in the DEQ contractor's model as best as possible.[9] Table 2 summarizes these assumptions.

Appendices to this memo include a list of referenced data sources and further modeling details.

Table 2. Policy Scenario Assumptions

	Scenario 1	Scenario 2	Scenario 3	Scenario 4 (developed by Avista & Cascade)
Policy Scenario Definition				
GHG Cap	80% by 2050	80% by 2050	90% by 2050	80% by 2050
Trading allowance	Allows trading	Limited trading	Allows trading	Allows trading
CCI use allowed	Up to 25%	Up to 5%	Up to 25%	Up to 25%
Includes hydrogen tech?	No	No	No	Yes
GHG Reduction Technologies				
Building Heat Electrification	Moderate (38% of load)	High (61% of load)	High (61% of load)	Low (17% of load)
Building Hot Water Electrification	Moderate (39% of load)	High (52% of load)	High (52% of load)	Low (26% of load)
Efficiency Improvements over Reference Case	10% load reduction	10% load reduction	10% load reduction	10% load reduction
Cooking Electrification	60% of gas load	90% of gas load	90% of gas load	60% of gas load
Transport Electrification Beyond SB1044	52% of remaining LDVs	76% of remaining LDVs	76% of remaining LDVs	76% of remaining LDVs
RNG Supply	54 bcf/year, equivalent to 75% of statewide RNG potential			
	54% of gas supply	95% of gas supply	95% of gas supply	84% of gas supply
Hydrogen-enriched Natural Gas (HENG)	None	None	None	5% of gas supply by energy
Industrial Process Electrification	15% of gas load	63% of gas load	63% of gas load	15% of gas load
Industrial Local Green Hydrogen	None	None	None	75% of gas energy

[8] Oregon DEQ. "Modeling Study: Assumptions and Background." Available at: https://www.oregon.gov/deq/Regulations/rulemaking/RuleDocuments/ghgcrModAssumptions.pdf
[9] The assumptions in Table 2 may be refined upon further examination and clarification of the data files provided by DEQ on May 20, 2021.

3. Modeling Results

This section details the results of Guidehouse's modeling of a Reference Case and four policy scenarios.

Reference Case Modeling Results

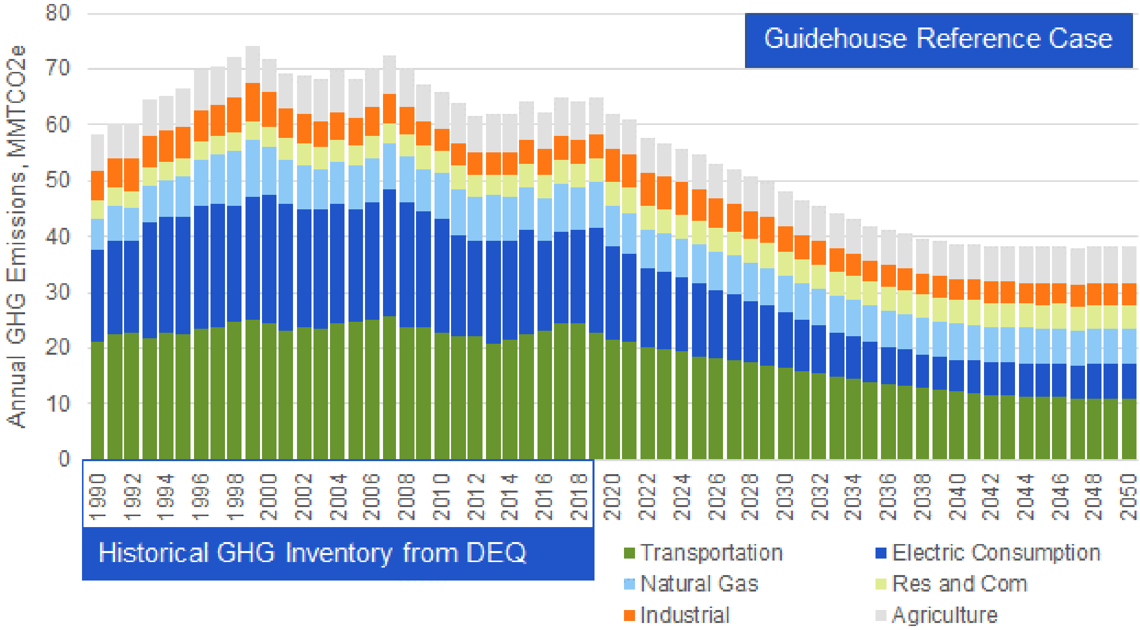
Guidehouse modeled a Reference Case that forecasts future emissions based on regulations in force as of March 2021, including regulations with future compliance dates. The Guidehouse team aligned historical emissions estimates prior to 2019 with emissions estimates published by the DEQ.[10] Figure 4 presents emissions forecasts through 2050 for the Guidehouse and DEQ Reference Cases. The following trends are evident:

- Transport emissions decrease due to requirements of the Oregon Clean Fuels Program, increased stringency of federal CAFE standards, and Senate Bill (SB) 1044 requirements for zero emissions vehicle adoption.
- Natural gas emissions decrease due to RNG adoption requirements in SB 98 and utility-driven improvements to energy efficiency (referenced from IRP plans).
- Industrial emissions decrease due to US AIM Act requirements for reduced emissions of hydrofluorocarbons (HFCs).
- Electric sector emissions decrease due to increased generation from renewable sources and utility-driven improvements to energy efficiency (referenced from IRP plans). Electric sector emissions increase in later years due to vehicle electrification.
- Emissions from residential, commercial, and agriculture sectors remain stable.

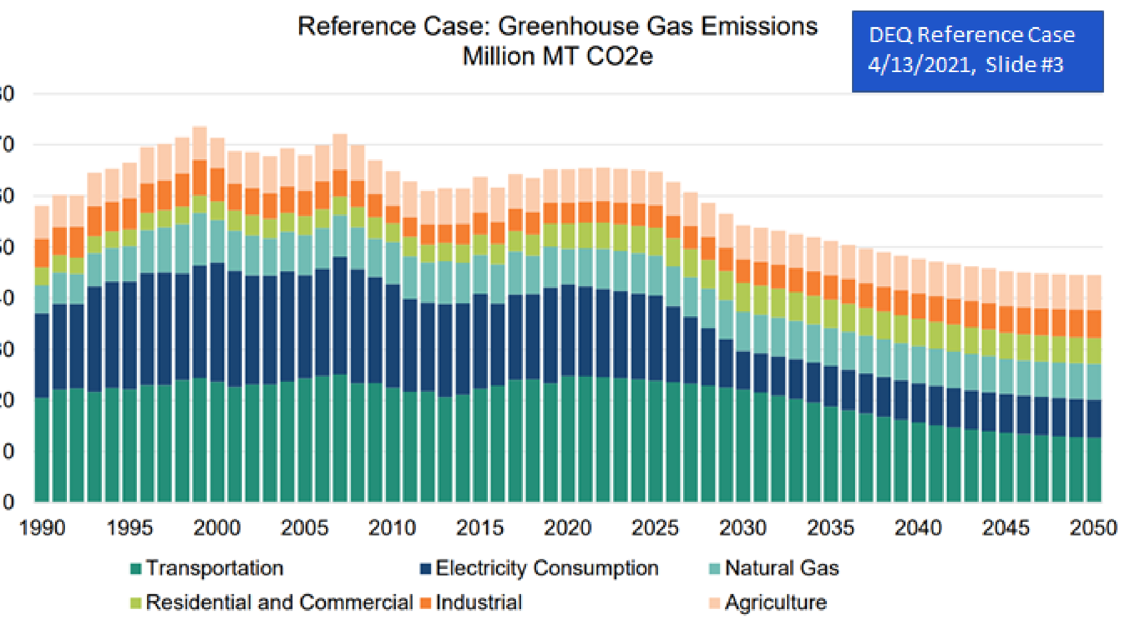
These trends and the proportional decrease in emissions over time are similar to the DEQ Reference Case results presented at the third RAC meeting, which Figure 4 replicates. This comparison illustrates that the fundamental assumptions of Guidehouse's model are aligned with DEQ's model.

[10] Oregon Dept. of Environmental Quality (DEQ). "Oregon Greenhouse Gas Sector-Based Inventory Data." Available at: https://www.oregon.gov/deq/aq/programs/Pages/GHG-Inventory.aspx

Figure 4. Guidehouse and DEQ Forecasts of Reference Case Greenhouse Gas Emissions,[11] MMTCO2e



Source: Guidehouse analysis



Source: Oregon Department of Environmental Quality

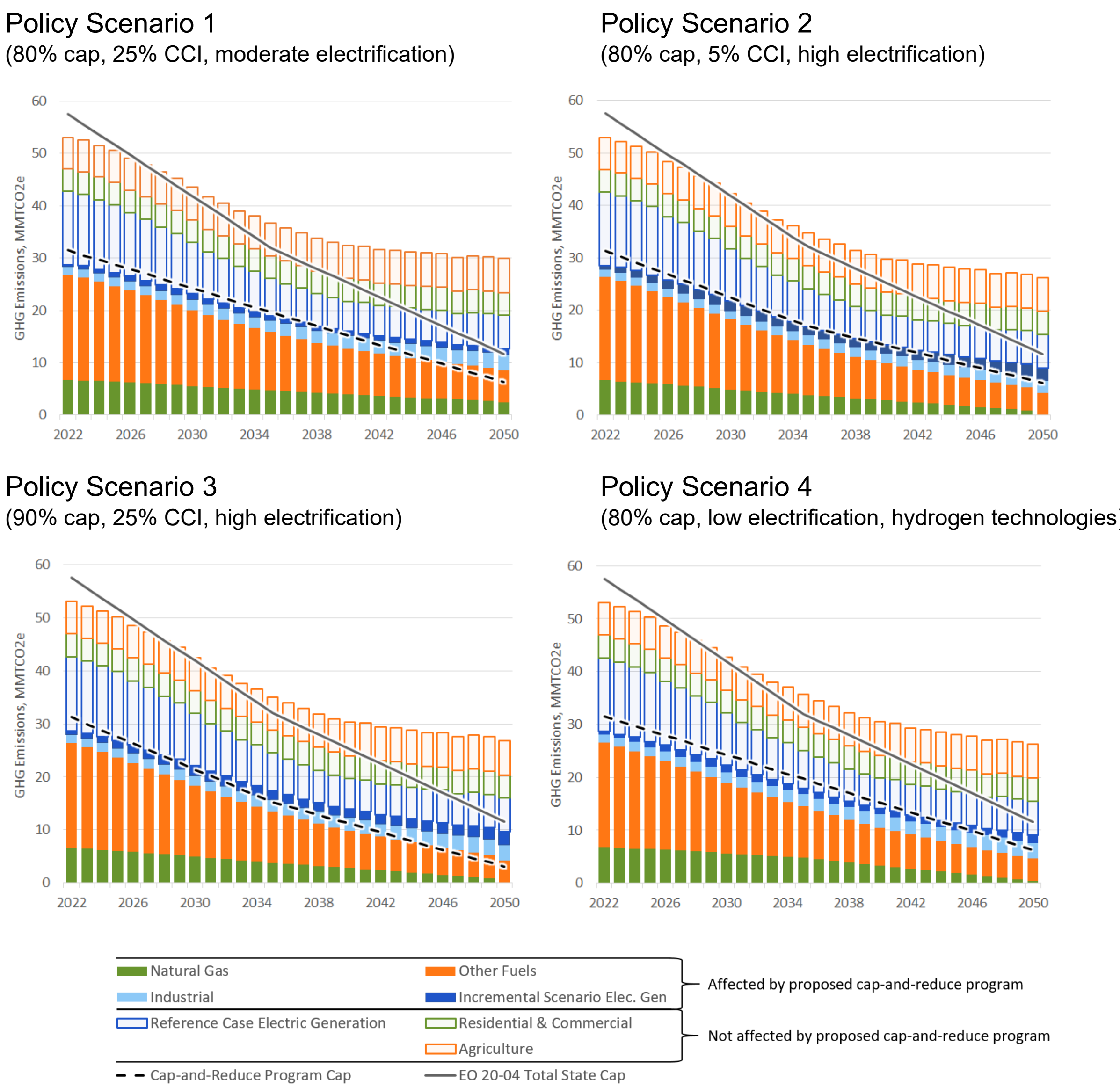
[11] Consumption of electricity and natural gas from all sectors are included in the "Electric Consumption" and "Natural Gas" categories. The "Industrial" category represents process emissions. The "Residential and Commercial" category represents emissions from delivered fuels, landfills, wastewater, and other non-energy sources.

Policy Scenario Modeling Results

Guidehouse modeled the emissions outcomes of four policy scenarios (Figure 5). In Figure 5, solid bars represent GHG emissions affected by the cap-and-reduce program. The program will directly regulate gas utilities (green bars), non-natural gas fuel suppliers (orange), and industrial emitters (light blue). Although the program will not regulate the electric sector, the electrification measures implemented to meet the program's requirements will increase electricity consumption and lead to an incremental increase in electric sector emissions (dark blue bars).

The hollow bars in Figure 5 represent GHG emissions that will not be affected by the cap-and-reduce program. These include non-energy emissions from the residential and commercial sectors (hollow green, i.e., wastewater, landfills, refrigerants), from agricultural activity (hollow orange), and from electric generation unaffected by the program (hollow blue). The dashed lines represent the GHG limits for activities covered by the cap-and-reduce program; the solid lines represent statewide GHG emissions limits prescribed by EO 20-04.

Figure 5. GHG Emissions Forecasts for Four Policy Scenarios



Note: Guidehouse’s modeling assumes that Oregon’s electric generation mix evolves as shown in Figure 6. Regardless of cap-and-reduce program activities, Oregon’s average electric emissions factor is projected to decrease due to the retirement of coal generating facilities and the installation of new renewable capacity, from 0.54 lbs CO_2/kWh in 2022 to 0.21 lbs CO_2/kWh for 2040-2050.
Source: Guidehouse analysis

Although none of the policy scenarios achieve the statewide emissions targets (solid line) established by EO 20-04, there are differences between the scenarios; stakeholders need to understand the potential outcomes and the relationships that drive them. Several findings are evident from the policy scenario results in Figure 5:

- In all four scenarios, the 2050 actual GHG emissions from regulated sectors exceed the program’s GHG emissions cap. Depending on the program design, regulated entities may be allowed to use flexibility mechanisms such as emissions banking and alternative compliance instruments to meet the cap. In scenarios 2 and 4, 2050 emissions are only slightly above the emissions cap, and flexibility mechanisms may yield net emissions below the cap. However, the 2050 emissions in scenarios 1 and 3 are far above the program cap, and flexibility mechanisms may not be sufficient to meet the cap.

- The electrification activities modeled in policy scenarios 2 and 3 will reduce GHG emissions from gas utilities to almost zero. However, as the solid blue bars in Figure 5 illustrate, these emissions are not fully eliminated from the economy. Instead, the electrification activities effectively displace emissions from the gas sector to the electric sector, which is outside the scope of the cap-and-reduce program.
- Policy scenario 3 has a high emissions target of 90% reduction by 2050 and, as the DEQ noted in presentations at the third and fourth RAC meetings, it is unlikely that the GHG reduction technologies being considered can achieve a 90% target.
- In policy scenario 4, GHG emissions from gas utilities are reduced to almost zero using a combination of electrification and low carbon fuels such as renewable natural gas (RNG) and hydrogen. Scenario 4 represents an additional compliance pathway that allows utilities to eliminate GHG emissions with minimal impact to electric generation emissions.

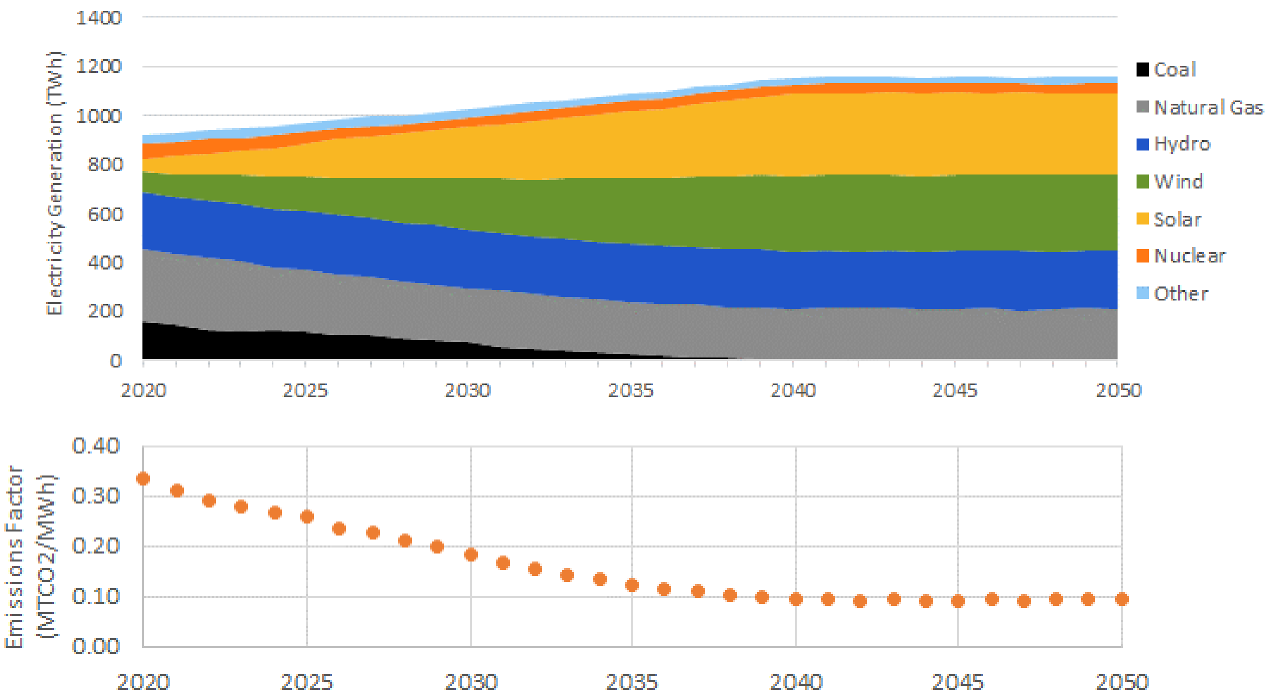
While the non-energy emissions (agriculture, wastewater) remain relatively stable in this analysis, new policies may be developed to reduce these emissions in the future. However, even if all non-energy emissions were eliminated, policy scenario 1 would not meet the statewide goals set by EO 20-04.

Electric Sector Emissions

The emissions forecasts depicted in Figure 5 are highly sensitive to assumptions regarding the electric sector generation mix in future years. For this analysis, Guidehouse took an optimistic view of how the power sector will decarbonize, using the High Renewable WECC Future forecast described in Portland General Electric's IRP and illustrated in Figure 6.[12] The High Renewable WECC Future forecast assumes a high penetration of renewables at levels exceeding current RPS and some amount of gas-fired generation to maintain system reliability and meet peaking needs. In this forecast, increased generation from renewable sources leads the electric generation emissions factor (in tons of carbon per MWh) to drop by over 60% by 2050.

[12] Portland General Electric. *Integrated Resource Plan 2019.* p.77. Available at: https://portlandgeneral.com/about/who-we-are/resource-planning/

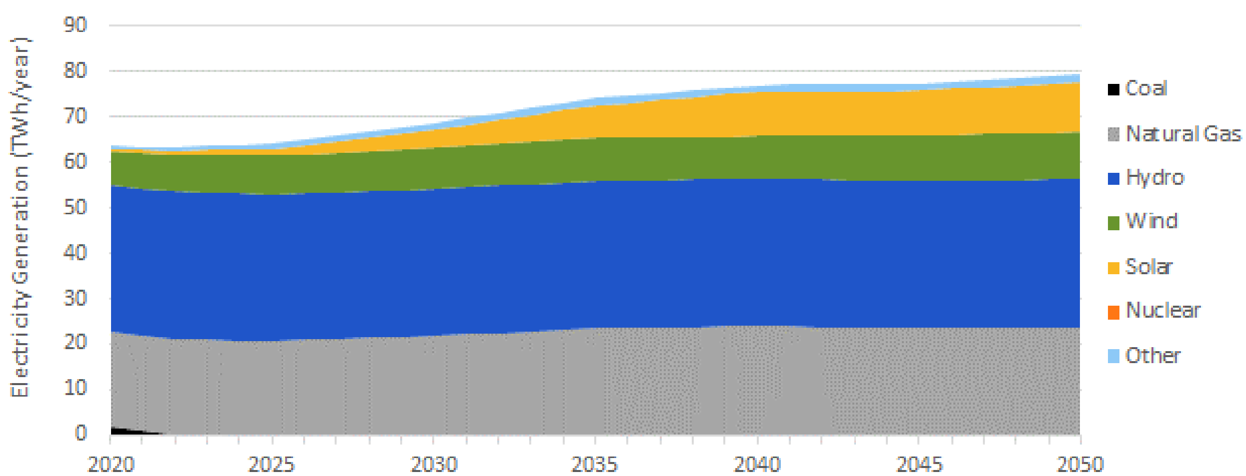
Figure 6. Electric Generation Mix and Emissions Factor Forecast, WECC High Renewables Case



Source: Electric Generation from Portland General Electric IRP 2019. Emissions Factor from Guidehouse analysis.

Compared to the WECC High Renewables case, the generation forecast used in the DEQ's modeling (Figure 7) shows greater reliance on fossil fuel generation in later forecast years.[13] If Guidehouse conducted this analysis using the DEQ's electric generation forecast, then the analysis would show an even greater amount of emissions displaced to the electric sector.

Figure 7. Electric Generation Mix Forecast, DEQ Reference Case

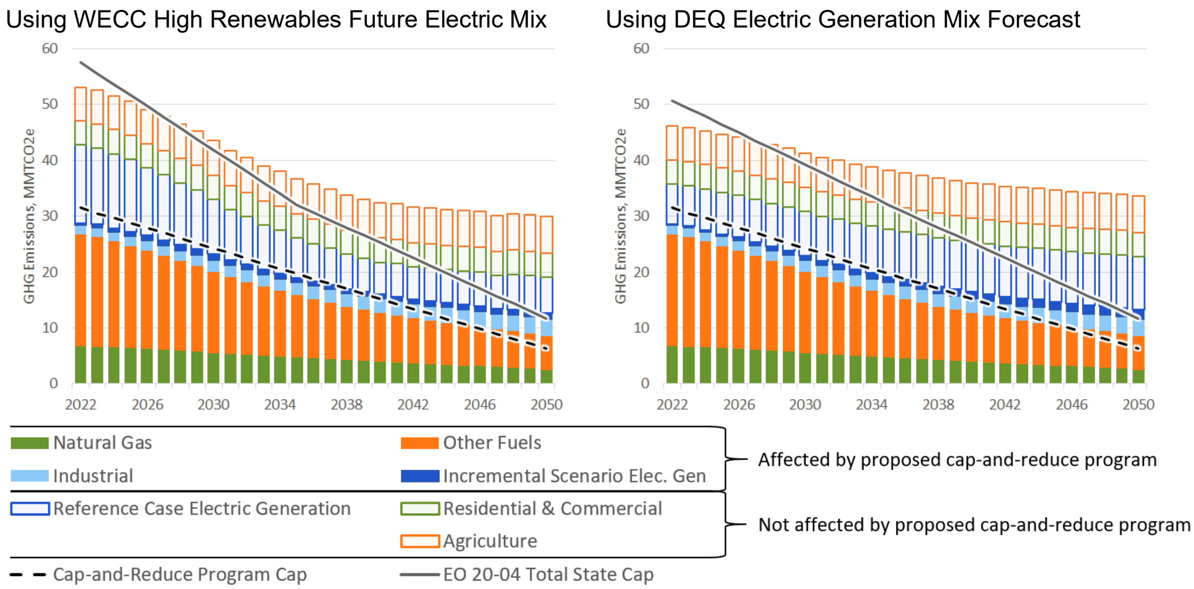


Source: DEQ

[13] Oregon Department of Environmental Quality. Filename "DEQ-ICF-GHGanalysis-2021.04.22.xlsx" sheet name "Power Sector Detail Projections."

Figure 8 compares the results of policy scenario 1 as it was modeled (with the WECC High Renewables forecast) to an alternative outcome using the DEQ Reference Case forecast.

Figure 8. GHG Emissions Results of Policy Scenario 1 Using Two Generation Mix Forecasts



Source:Guidehouse analysis

This comparison of results using different electric generation forecasts indicates the following:

- Compared to the DEQ's forecast, the Guidehouse model assumes a higher penetration of zero emissions renewable generation.
- If fuel-fired electric generation continues to provide 30% of Oregon's electric power (as in the DEQ Reference Case), then electrification activities will lead to even greater emissions leakage from the cap-and-reduce program to the electric sector.

Guidehouse notes that Oregon is currently considering legislation to increase its clean energy standards to further decarbonize the electric power sector. If adopted, Oregon's House Bill 3180 would increase the state's RPS to 90% by 2035, and 100% by 2050. Implementation of the requirements in HB 3180 would results in lower emissions leakage from the cap-and-reduce program in later years of the forecast period.

4. Conclusions and Recommendations

The fourth policy scenario that Guidehouse modeled emphasized the delivery of low carbon gas through deployment of hydrogen technology, and it resulted in the greatest reduction in economywide GHG emissions. Guidehouse has previously analyzed and reported how the gas system contributes to US energy system resilience.[14] In a decarbonized future, gas networks would continue to support the reliability and resiliency of Oregon's broader energy system by transporting and distributing low carbon gas and hydrogen.

[14] American Gas Foundation (2021). "Building a Resilient Energy Future: How the Gas System Contributes to US Energy System Resilience" Available at: https://gasfoundation.org/2021/01/13/building-a-resilient-energy-future/

- **Recommendation:** The DEQ should develop and present to the RAC a scenario in which emerging low carbon fuel technologies are used to deliver GHG emissions reduction with minimal impacts to the electric sector. DEQ’s analysis of policy alternatives should consider the reliability and resilience benefits of maintaining diverse energy delivery systems, including the gas network.

In contrast to DEQ’s presentation of policy scenario results, Guidehouse found that scenarios with high levels of electrification do not eliminate GHG emissions from Oregon’s economy unless Oregon’s power sector fully decarbonizes the electricity supplied to its customers. The DEQ’s policy scenarios do not meet the intended goal of reducing overall GHG emissions to the levels mandated by EO 20-04. Rather, the DEQ’s scenarios effectively shift GHG emissions from one group (within their purview) to another group (outside of DEQ’s purview) resulting in net reductions system-wide which do not meet the mandates by EO 20-04.[15]

- **Recommendation:** To adequately inform the RAC’s decision-making, the scenario results presented by DEQ should describe the economywide emissions impacts of the proposed cap-and-reduce program.

Meeting the statewide goals of EO 20-04 will require emissions reduction from sectors outside the proposed scope of the cap-and-reduce program. The proposed Community Climate Investment (CCI) program provides an avenue for investment in GHG reductions strategies in these sectors. There are opportunities for interventions to reduce GHG emissions in the non-energy residential, commercial, and agricultural sectors of the economy, for instance through improved wastewater management, refrigerant handling, and conservation tillage.

- **Recommendation:** Alternative compliance mechanisms such as CCIs should encourage innovation from regulated sectors and incentivize a broad range of approaches. Funds from a CCI program should be invested in direct emissions reductions so that there is a clear linkage between inputs (funding) and outputs (GHG reductions) under a single regulator (DEQ).

Guidehouse recognizes that this statewide emissions analysis may raise additional questions and recommendations beyond those outlined above. We welcome the opportunity to discuss and refine this analysis with the DEQ and RAC members.

[15] It is important to understand that DEQ’s charter does not allow it to regulate nor consider electric utilities and therefore they are prohibited/inhibited by their charter to produce a system-wide/holistic approach to GHG reductions.

Appendix A: Data Sources Used

Table 3 lists the main data sources referenced in Guidehouse's modeling of the Reference Case and policy scenarios. The table contains hyperlinks to the source data and describes how data from each source was used. Table 3 also notes which data sources were also referenced in the DEQ's modeling, based on information provided by DEQ.

Table 3. Referenced Data Sources

Source Consulted	Nature of Use	Sector	Used by DEQ?
Oregon Greenhouse Gas Sector-Based Inventory	To obtain OR's historic emissions by sector (1990-2018)	All	Yes
EIA State Energy Data System (SEDS)	To obtain baseline energy use in OR by fuel type and sector	All	Yes
EIA Annual Energy Outlook (AEO)	To obtain % change in fuel use each year from SEDS baseline for Reference Case to 2050 – used Northwest Power Pool	All	Yes
NREL Electrification Futures Study	To inform the level of end use electrification assumed to occur by 2050	All	Yes
Integrated Resource Plans for Avista, Cascade, NW Natural, Pacificorp, Portland General Electric, and Puget Sound Energy	Compared load forecasts to EIA AEO forecasts; gathered projected savings from energy efficiency measures	All	Yes
EIA Residential Energy Consumption Survey (RECS)	To calculate % energy consumption by fuel type and end use in the Pacific Region	Residential	Not stated
EIA Commercial Buildings Energy Consumption Survey (CBECS)	To calculate % energy consumption by fuel type and end use in the Pacific Region	Commercial	Not stated
Argonne National Laboratory's VISION 2020 Model	To inform growth projections of state vehicle registrations	Transportation	Yes
EIA State Electricity Profiles	To obtain OR's generation mix, present day, in-line with Electricity Mix in Oregon	Electricity	Not stated directly
EPA SIT Agriculture Module	To affirm historical emissions numbers from DEQ GHG inventory	Agriculture	Yes
EPA SIT Projections Tool	Default settings used to obtain projection data for Reference Case to 2050	Agriculture	Yes

Source Consulted	Nature of Use	Sector	Used by DEQ?
McKinsey & Company (2018) "Decarbonization of industrial sectors: the next frontier"	Informed the portion of industrial energy consumption that may be replaced by hydrogen fuel	Industrial	Yes
ICF (2019), "Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment"	Provides statewide potential RNG production capacity	Natural Gas	Yes

Appendix B: Sector- and Technology-Specific Methodology

This appendix describes the methodology and assumptions for individual sectors and technologies in the energy and emissions model.

Residential and Commercial Electrification

In 2018, 40% of homes in Oregon used fossil fuels as their primary heating source, well below the US average of 57%.[16] Technologies available today can be used to fully electrify the heating and hot water needs of Oregon’s buildings. However, the electrification of end uses served by fuels will shift consumption and GHG emissions to the electric sector and will require substantial expenditures by consumers to purchase and install electric heating equipment. Guidehouse tested whether a more selective approach to building electrification can meet the cap-and-reduce program’s targets with a lesser degree of electrification.

Guidehouse focused on three technologies to electrify buildings’ heating needs:

- **Electric air-source heat pumps** (ASHPs) provide space heating and space cooling by using electricity to move heat from the outdoor space to the indoor space and vice versa. Recent advances in cold climate ASHP technology make it possible to use heat pumps for space heating when outdoor ambient temperatures are as low as -13ºF.[17] With these systems, most buildings in Oregon could feasibly electrify their heating needs, albeit with high installation costs.

- **Heat pump water heaters** (HPWHs) use electricity to transfer heat from ambient air to a stored water tank and are an energy efficient alternative to electric resistance water heaters and fuel-fired water heaters. The adoption of HPWHs has been limited by a variety of factors, including cost, product availability, and installation constraints. Guidehouse projects that the market for HPWHs will overcome these barriers and that many Oregon buildings will use HPWH technology for water heating by 2050.

- **Electric cooking equipment** is capable of displacing conventional fuel-fired cooking equipment. In the Pacific West region (including Oregon), about 23% natural gas consumed by commercial buildings is used for cooking purposes.[18]

Fuel-fired appliances and electric appliances have inherently different energy efficiency ratings. When modeling electrification interventions, Guidehouse accounted for the changes in energy efficiency. Guidehouse also assumed that equipment energy efficiency improves over time, due to replacement of older less efficient appliances and to improvements in appliance technology. Table 4 presents Guidehouse’s assumptions regarding the efficiency of different end uses and energy sources at the start and end years of the modeling period. These values reflect the

[16] US Energy Information Administration (2021). “State Profile and Energy Estimates: Oregon.” Available at: https://www.eia.gov/state/data.php?sid=OR#ConsumptionExpenditures

[17] A sample of heat pump products capable of continuous operation at -13ºF include Daikin’s Aurora, Mitsubishi’s Hyper-Heat, Fujitsu’s Halcyon, and Lennox’s MLA product lines.
https://daikincomfort.com/go/aurora/
https://www.mitsubishicomfort.com/benefits/hyper-heating
https://www.fujitsugeneral.com/us/residential/technology/xlth-low-temp-heating.html
https://www.lennox.com/products/heating-cooling/mini-split-systems/mla

[18] EIA (2012). Commercial Buildings Energy Consumption Survey. Table E7. Natural gas consumption and conditional energy intensities by end use. Available at: https://www.eia.gov/consumption/commercial/data/2012/c&e/pdf/e7.pdf

assumption that non-condensing gas-fired equipment will gradually be replaced by high-efficiency condensing gas equipment and that electric resistance heating will gradually be replaced by electric heat pumps.

Table 4. Energy Efficiency Assumptions by Sector, End Use, and Energy Source

Sector and End Use	Energy Source	2020	2050
Residential Space Heat	Electric	128%	260%
	Natural Gas	82%	88%
Residential Water Heat	Electric	150%	330%
	Natural Gas	58%	73%
Commercial Space Heat	Electric	161%	360%
	Natural Gas	83%	88%
Commercial Water Heat	Electric	150%	332%
	Natural Gas	59%	75%

Source:Guidehouse analysis

Energy Efficiency Measures

Energy efficiency can reduce energy-related carbon emissions by decreasing the amount of energy consumption needed to accomplish a given task (e.g., heat a home, transport cargo, etc.). Our analysis assumes that some amount of energy efficiency will be deployed in the Reference Case, as utilities continue their rebate programs, building codes improve over time, and federal automobile efficiency standards become more stringent. The Reference Case for this analysis is based on the EIA's *Annual Energy Outlook 2021*, and the EIA provides estimates of energy intensity by sector and end use in 2020 and 2050.[19] Guidehouse's analysis uses EIA's proportional change in energy intensity as a proxy for energy efficiency improvement in the Reference Case.

The measures included in the Guidehouse model assume that efficiency measures implemented in the policy scenario cases could achieve greater efficiency reductions that those included in the Reference Case. Guidehouse referenced projected reductions in energy loads from the IRPs published by electric and gas utilities operating in Oregon. Each utility's IRP stated that energy efficiency would impact overall load growth over the IRP period, though the magnitude of energy efficiency reductions was different for each utility.

The DEQ stated its assumption for energy efficiency by stating, "[the] achieved technical potential energy efficiency [is] based on Oregon Energy Trust methods and results as presented in utility IRPs."[20] Guidehouse believes that this approach will overestimate the emissions savings from energy efficiency measures, since the technical potential counts all available efficiency measures regardless of cost. Guidehouse instead recommends using of the "achievable" emissions reduction from utility IRP filings.

[19] EIA (2021). *Annual Energy Outlook 2021 with projections to 2050: Chart library*. pp. 9, 33, 42-43, 48. Available at: https://www.eia.gov/outlooks/aeo/pdf/00%20AEO2021%20Chart%20Library.pdf
[20] Oregon DEQ. "Oregon Climate Protection Program: Modeling Study on Program Options." p.24. Available at: https://www.oregon.gov/deq/Regulations/rulemaking/RuleDocuments/ghgcrModAssumptions.pdf

Transportation Sector Modeling

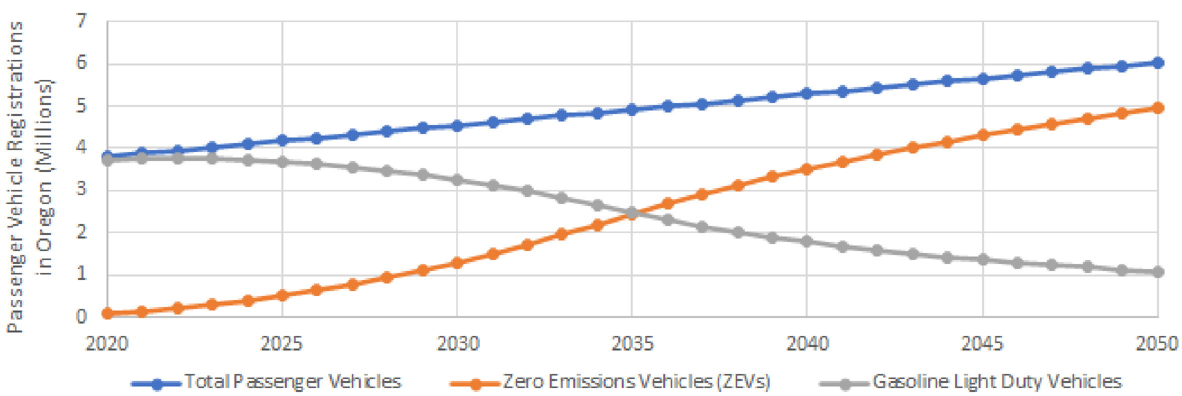
The Guidehouse Reference Case for transportation sector emissions is based on Oregon's current transportation sector energy use from EIA SEDS and on the EIA's *Annual Energy Outlook* projections of transportation sector growth in the Pacific region. Guidehouse adapted the EIA's outlook to account for local laws and regulations including Oregon's SB 1044 and Oregon's Clean Fuels Program.

Vehicle Electrification

Oregon's SB 1044 sets targets for zero emissions vehicle (ZEV) adoption in the state.[21] Per SB 1044, Oregon must target the registration of 250,000 ZEVs by 2025, and ZEVs should account for 25% of total vehicle registrations in Oregon by 2030. To model the expected impacts of SB 1044 on the transportation sector's energy consumption, Guidehouse assumed the targets in SB 1044 are met.

Guidehouse forecast the growth in total state passenger vehicle registrations based on trends observed in Oregon's historical vehicle registrations[22] and nationwide forecasts included in Argonne National Laboratory's VISION model.[23] Guidehouse used a stock turnover calculation to estimate how the shares of ZEV and gasoline-powered passenger vehicles changes over time through 2050. Based on these forecasts, the energy and emissions model includes a fuel switching calculation to estimate the amount of energy use that shifts from gasoline to electricity, accounting for the difference in energy efficiency of gasoline- and electric-powered vehicle types.

Figure 9. Forecast of Oregon Passenger Vehicle Registrations by Fuel Type in Guidehouse Reference Case



Source:Guidehouse analysis

[21] Oregon State Legislature (2019). "SB 1044 Enrolled." Available at: https://olis.oregonlegislature.gov/liz/2019R1/Downloads/MeasureDocument/SB1044/Enrolled
[22] Oregon Department of Transportation (2020). "Oregon DMV Vehicle Registration Statistics." Available at: https://www.oregon.gov/odot/DMV/Pages/News/vehicle_stats.aspx
[23] Argonne National Lab (2020). "VISION Model." Available at: https://www.anl.gov/es/vision-model

Clean Fuels Program

Oregon's Clean Fuels Program requires reduction in the carbon intensity of gasoline and diesel beginning in 2015.[24] Guidehouse modeled the effects of this program as adjustments to the emissions factors for gasoline and diesel fuels over time, using emissions factors provided by the DEQ, as Table 5 lists.

Table 5. Oregon Clean Fuel Standards for Gasoline and Diesel Fuels

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025 and beyond
Percent Reduction from 2015 Baseline (%)	0.25	0.50	1.00	1.50	2.50	3.50	5.00	6.50	8.00	10.00
Gasoline Emissions Factor (gCO2e/MJ)	98.37	98.13	97.66	96.59	95.61	94.63	93.15	91.68	90.21	88.25
Diesel Emissions Factor (gCO_2e/MJ)	99.39	99.14	98.61	97.26	96.27	95.29	93.81	92.32	90.84	88.87

Source: Oregon DEQ

Transportation Sector Efficiency

Guidehouse also assumed that transportation sector efficiency may be improved so that transportation energy loads decrease relative to the Guidehouse Reference Case. The catchall assumption for transportation efficiency includes measures such as improvements to urban planning, traffic management, and public transit, though the analysis did not model these opportunities individually.

Renewable Natural Gas

RNG is a gaseous fuel with lower carbon intensity and similar operational and performance characteristics to natural gas, and RNG can reduce GHG emissions in applications that use natural gas and other fossil fuels. RNG reduces systemwide GHG emissions by avoiding the release of methane into the atmosphere from the natural breakdown of organic materials. Combusted natural gas has a much lower carbon intensity than pure methane when released to the atmosphere; eliminating methane emissions provides the majority of avoided GHG emissions. The specific carbon intensity of RNG is a complex calculation that depends on feedstock, production technology, and location, among other factors.

RNG or biomethane can be produced through several production technologies, including landfill gas collection, anaerobic digestion, and thermal gasification systems. Common RNG feedstocks include landfill gases, livestock waste, food waste, agricultural residues, and woody biomass. RNG facilities can use the produced gas onsite for electricity generation, boiler heating, and transportation refueling, or facilities can inject the RNG into the natural gas grid for use by gas utility customers. When distributed to these end use customers, RNG can reduce the GHG emissions of gas appliances in buildings, gas-fired combined heat and power systems at

[24] Oregon Department of Environmental Quality. "Oregon Clean Fuels Program Overview." Available at: https://www.oregon.gov/deq/ghgp/cfp/Pages/CFP-Overview.aspx

industrial sites, or through compressed natural gas vehicle fleets. RNG is a valuable low carbon resource for applications that are difficult or expensive to electrify.

Table 6 highlights the RNG production potentials for each feedstock assumed for Oregon, along with the applicable emissions rates. In recent years, RNG development has increased in support of federal and state decarbonization goals in the transportation and gas utility sectors. Oregon has an estimated in-state RNG production technical potential of roughly 27.7 trillion Btu per year from available landfill, animal manure, wastewater treatment, and food waste resources through anaerobic digestion technologies. In future years, thermal gasification production technologies could increase in-state RNG technical potential by about 44.8 trillion Btu per year using available agricultural residues, forest residue, municipal solid waste resources, and energy crops. In 2018, Oregon consumed 271 trillion Btu of natural gas.[25] Our analysis assumes that the state's total natural gas consumption will decline over time due to efficiency improvements and electrification measures, while the state's total RNG potential will remain stable.

As the final column of Table 6 illustrates, the emissions factor of RNG can vary depending on the source of the gas, since some sources capture greenhouse gases that would otherwise be vented to the atmosphere. Guidehouse adopted the assumption used in DEQ's modeling that RNG is a zero emissions fuel source.

Table 6. Estimated RNG Production Potential and Emissions Rates for Oregon

Process	Feedstock	Potential (Trillion Btu/Year)				Emissions Rate (lbs CO_2e per MMBtu)**
		Low	High	Average High-Technical	Technical	
Anaerobic Digestion	Landfill gas	6.24	10.19	12.80	15.41	21.0
	Animal manure	1.96	3.93	5.23	6.54	-124.0
	Water resource recovery facilities	0.29	0.41	0.72	1.03	16.6
	Food waste	0.14	0.25	2.47	4.70	-9.9
Thermal Gasification	Agricultural waste	1.06	2.65	7.34	12.03	12.3
	Forestry and forest product residue	2.16	4.32	7.70	11.08	10.4
	Energy crops	0.00	0.00	0.00	0.00	9.7
	Municipal solid waste	1.16	8.66	15.18	21.70	6.4
	Total	**13.02**	**30.41**	**51.45**	**72.48**	

** Emissions rates are based on relevant Low Carbon Fuel Standard projects; data available at: https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities

Source: Low, High, and Technical potentials from ICF (2019), "Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment." The ICF report claims that the provided potentials are conservative, so Guidehouse calculated an average of the High and Technical cases from ICF (2019).

[25] US Energy Information Administration. State Energy Data System, Table C1. Available at: https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_sum/html/sum_btu_1.html&sid=OR

Hydrogen-Enriched Natural Gas (HENG)

In sectors currently using natural gas and other fossil fuels, hydrogen offers another low carbon gas solution to reduce GHG emissions. Hydrogen can be produced through electrolysis using dedicated renewable generation or curtailed renewable generation systems (power-to-gas or green hydrogen) and through natural gas reformation with carbon capture (blue hydrogen). It can be blended into existing natural gas pipelines using HENG. If implemented with low concentrations, this strategy appears to be viable without increasing risks in end use devices (such as household appliances and heating equipment), overall public safety, or the durability and integrity of the existing natural gas pipeline network. Guidehouse research and interviews with heating technology experts indicate that hydrogen may be blended with natural gas at a maximum concentration of 15% hydrogen by volume, which could displace about 5% of natural gas supplied in HENG pipelines.[26,27] HENG technology is unlikely to be available beyond the pilot scale until 2030.

The Guidehouse energy and emissions model assumes in policy scenario 4 that utilities begin blending hydrogen in the gas supply in 2035 and that hydrogen has displaced 5% of natural gas deliveries by 2050. Blending hydrogen into delivered gas has the effect of reducing the emissions factor of delivered gas by about 5%.

Industrial Sector Process Emissions

The Guidehouse model estimates two values for industrial sector GHG emissions: (1) the total GHG emissions from all industrial activity in Oregon, and (2) the total GHG emissions from industrial activity that would be regulated by the cap-and-reduce program.

In the Reference Case forecast, total industrial GHG emissions from all industrial activity is referenced from forecasts provided by the US Environmental Protection Agency's State Inventory Tool (SIT).[28] The SIT model reports CO_2, N_2O, and other emissions based on historical industry activity and forecasts of industrial growth through 2050. The SIT tool was last updated prior to passage of the US AIM Act, which requires an 85% reduction in hydrofluorocarbon (HFC) emissions by 2035. To reflect the impact of the AIM Act, the Guidehouse model assumes a linear reduction in HFC emissions beginning with 0% HFC reduction in 2021 and ramping to 85% HFC reduction in 2035.

In the policy scenario forecasts, consideration of industrial GHG emissions is limited to facilities that would be regulated under a cap-and-reduce program. During RAC meetings, the DEQ has stated that the cap-and-reduce program's regulations of industrial emissions will likely be limited to stationary sources producing over 25,000 $MTCO_2e$ of process-related GHG emissions per year. The DEQ reports GHG emissions from facilities holding air quality permits,[29] but these reports do not separate process emissions from emissions due to combustion of natural gas and delivered fuels. Thus, from the data publicly available, Guidehouse was unable to validate the DEQ's estimates of industrial process emissions from facilities that would be regulated by

[26] GRTgaz et al. (2019). "Technical and economic conditions for injecting hydrogen into natural gas networks." Available at: http://www.grtgaz.com/fileadmin/plaquettes/en/2019/Technical-economic-conditions-for-injecting-hydrogen-into-natural-gas-networks-report2019.pdf
[27] Melaina, Antonio and Penev (2013). "Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues." Available at: https://www.nrel.gov/docs/fy13osti/51995.pdf
[28] Available at: https://www.epa.gov/statelocalenergy/state-inventory-and-projection-tool
[29] See: https://www.oregon.gov/deq/aq/programs/Pages/GHG-Emissions.aspx

the program. Because of this limitation, Guidehouse used values for regulated industrial process emissions as reported in DEQ's presentation of initial results from DEQ's modeling study.[30]

Industrial Local Green Hydrogen

Green hydrogen is a term used to describe hydrogen that is separated from water and converted to a viable fuel source through a renewables-powered electrolysis process. Recent studies that have demonstrated the feasibility of using green hydrogen in the steel industry[31] and the cement-making process.[32] Separate from the HENG strategy described previously, hydrogen may be delivered to customers through dedicated distribution systems designed for 100% hydrogen gas, known as hydrogen clusters or districts. For policy scenario 4, Guidehouse's energy and emissions model calculates the impacts associated with switching a portion of the industrial sector's energy consumption from pipeline gas sources to locally produced hydrogen. Assumptions regarding the amount of industrial energy consumption that may be replaced by hydrogen were informed by a third-party analysis of industrial sector decarbonization.[33]

30 Available at: https://www.oregon.gov/deq/Regulations/rulemaking/RuleDocuments/ghgcrRefPolResults.pdf
31 See, for instance, Hybrit Steel in Sweden, at: http://www.hybritdevelopment.com/ ;
Voestalpine Hydrogen Production Facility in Austria, at: https://www.voestalpine.com/group/en/media/press-releases/2019-11-11-h2future-worlds-largest-green-hydrogen-pilot-facility-successfully-commences-operation/ ;
Thyssenkrupp Steel Europe's partnership for green hydrogen production, at: https://www.thyssenkrupp.com/en/newsroom/press-releases/pressdetailpage/green-hydrogen-for-steel-production--rwe-and-thyssenkrupp-plan-partnership-82841 ;
32 Doyle, Amanda (2019). "Producing cement using electrolysis". Available at: https://www.thechemicalengineer.com/news/producing-cement-using-electrolysis/
33 McKinsey & Company (2018). "Decarbonization of industrial sectors: the next frontier" Available at: https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/how%20industry%20can%20move%20toward%20a%20low%20carbon%20future/decarbonization-of-industrial-sectors-the-next-frontier.pdf