DEPARTMENT OF ECOLOGY
State of Washington

Washington State Climate Commitment Act

Summary of market modeling and analysis of the proposed Cap and Invest Program

FINAL

Economic and market modeling and analysis conducted by Vivid Economics for the Washington Department of Ecology

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Executive Summary

This draft report summarizes the market modeling and economic analysis of the Cap and Invest program performed by Vivid Economics for the Washington Department of Ecology. The report explains the modeling conducted across a set of scenarios and sensitivities. The outputs of the modeling are allowance prices, compliance costs, and emissions profiles under those scenarios. Vivid Economics provided this modeling as an independent expert and was not involved in decisions regarding rulemaking.

Washington State's Climate Commitment Act (RCW 70A.65) sets out a provision for a Cap and Invest Program to be established in 2023. The Cap and Invest Program represents a form of carbon pricing. The cap establishes a fixed supply of emissions allowances, each of which represents the right to emit a metric ton of carbon dioxide equivalent.[1] These allowances are partly auctioned, and partly distributed at no cost to covered entities in the program. Covered entities must surrender allowances equivalent to their emissions in each four-year compliance period. Covered entities and other market participants may trade allowances with each other in a secondary market, at a price determined by market forces. This results in an incentive for covered entities to reduce their emissions.

The program rules have been proposed by the Department of Ecology. On May 16, 2022, Ecology proposed 173-446 WAC (the "proposed rules," "program rules," or "proposed program rules") to implement the requirements of RCW 70A.65. These rules describe the proposed design of the program by Ecology. It states that the program will begin operation in 2023, covering approximately 75% of existing statewide greenhouse gas (or GHG) emissions. The program aims to reduce covered emissions, which start at a 'program baseline' of 68MMT CO_2e, estimated from the historical average between 2015-2019.[2] The cap trajectory is set in line with emissions targets under RCW 70A.45.020, which requires Washington to reduce statewide emissions 45% by 2030, 70% by 2040, and 95% by 2050 (relative to 1990 levels).

This report summarizes the results of the economic and market analysis of the program. During the analysis, several iterations of modelling and specific parameters were run, in line with Ecology's feedback and requirements. The modeling analysis aims to provide policymakers and other stakeholders an understanding of potential allowance prices and emissions trajectories under different scenarios. This ensures that the rulemaking process and public comment period are informed by robust evidence.

Insights from modeling should be considered as one part of a broader array of evidence. While the model is calibrated against the latest information and sources currently available, modeling necessitates simplifying assumptions and results should be interpreted with this in mind. The main areas of uncertainty include the future speed of technology adoption, scope and extent of other climate-related (complementary) policies, and market

[1] Carbon dioxide equivalent, denoted as CO_2e, is a unit of measurement to standardize the climate effects of various greenhouse gases based on their global warming potential, indexed to carbon dioxide. The unit is used throughout this report as the Cap and Invest Program covers a range of greenhouse gases.

[2] The unit MMT CO_2e refers to million metric ton of carbon dioxide equivalent.

behavior. A sensitivity analysis to examine the impact of these assumptions on modeling results has been conducted and is summarized in Section 3.

Three key scenarios were modeled to understand the system:

- **Linking scenario.** This represents a scenario where all market participants expect linkage with the California – Quebec market from 2025 onwards.
- **Frontloading scenario.**[3] This represents the current proposed rules by Ecology where Allowance Price Containment Reserve allowances (APCR)[4] from 2023-2030 are placed into the APCR at the beginning of 2023. All market participants expect the Washington system to continue to stand alone with no future linkage to the California – Quebec market.
- **No Linking or Frontloading scenario:** This scenario is based on an earlier version of the rules drafted for Chapter 173-446 WAC. It contains no frontloading of APCR Allowances and no expectation of a link to the California – Quebec market.

In a 'Linking scenario' where market participants expect linkage with the California – Quebec market in 2025, modeled allowance prices start at $41 per MT CO_2e in 2023.[5,6] Linking would imply interchangeability of allowances. Given that the size of the California – Quebec market is about five times larger than Washington in terms of annual emissions, allowance prices in a linked system would likely track California – Quebec prices. Market expectations of linkage would therefore bring Washington's prices closer to the California – Quebec market even prior to the linkage occurring. California – Quebec prices are currently $29 per MT CO_2e as of May 2022 and have in past years tracked the price floor which will be $19.5 per MT CO_2e in 2023.[7]

Modeled allowance prices for the program rules proposed by Ecology ('Frontloading scenario'), in the absence of linking expectations, start at $58 per MT CO_2e in 2023. The 'Frontloading scenario' reflects the current rulemaking by Ecology across all key aspects of the proposed program rules. In this scenario, the APCR contains a frontloaded supply: APCR allowances from 2023-2030 are placed into the reserve in 2023. The scenario also assumes Washington is a standalone system and market participants do not expect future linkage with any other carbon markets. Modeled prices in the scenario rise gradually from $58 per MT CO_2e in 2023 to $100 per MT CO_2e in 2030. Such increase in modeled prices is mainly driven by the declining program cap, which nearly halves emissions between 2023 and 2030.

If market participants are uncertain regarding the likelihood of linking with the California – Quebec market, this could see resulting prices somewhere between the

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[3] The word 'frontloading' is used in this report for the purposes of clarity and consistency in describing scenarios. It is not a term of art, and nor does it carry any technical, economic, or legal significance.

[4] The APCR aims to lower prices by increasing supply in the market when certain price thresholds are met. A share of allowances is placed into a two-tiered APCR, which releases allowances via APCR auctions when prices reach the respective price trigger levels for each tier.

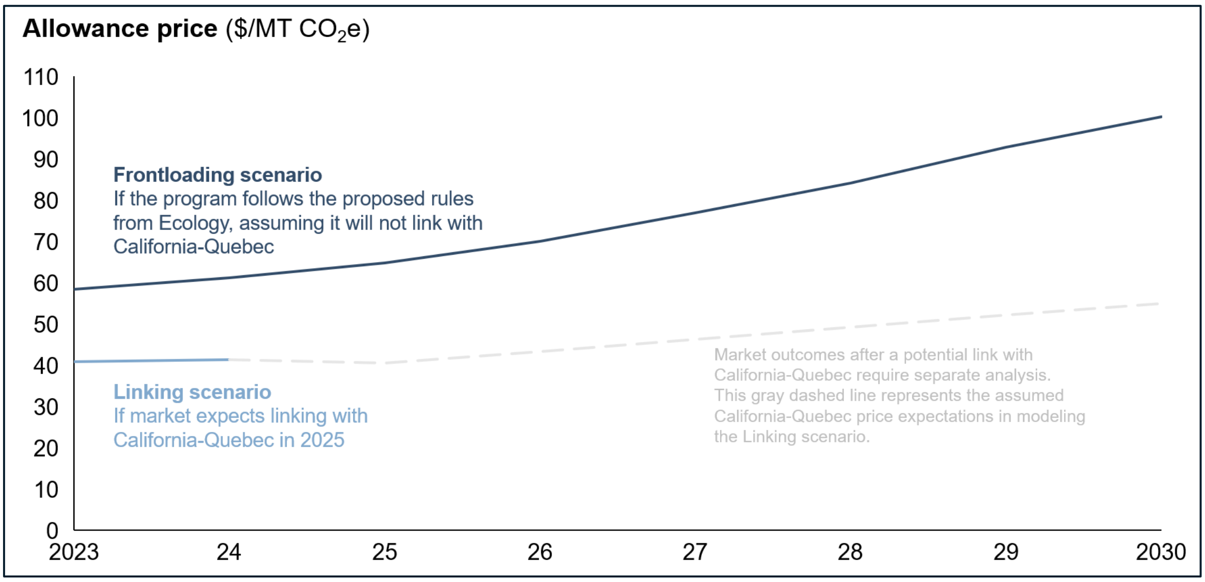
[5] All prices in this report are expressed in real 2021 US Dollars.
Unless specifically stated otherwise, allowance prices presented in this report are outputs of the Vivid Economics Compliance Carbon Markets Model.

[6] The unit MT CO_2e refers to a metric ton of carbon dioxide equivalent.

[7] Price information from California Air Resources Board, Summary of California-Quebec Joint Auction Settlement Prices and Results, May 2022, these California prices are real 2022 Dollars

Linking and Frontloading scenarios. While the Linking scenario assumes that the market fully expects linking with the California – Quebec market in 2025, the Frontloading scenario assumes the market expects no linking in the future. Therefore, if market expectations regarding linking are in between the two assumptions, initial allowance prices would likely lie between two scenarios. The modelled allowance prices for the two scenarios are shown in Exhibit 1.

Exhibit 1: Modeled allowance prices under the Linking scenario and Frontloading scenario.[8]



In a scenario containing No Linking or Frontloading allowance prices would start at $68 per MT CO_2e in 2023. This scenario is identical to the Frontloading scenario, except that there are fewer available allowances in the APCR in 2023. Due to the lower supply of allowances, modeled prices are higher for the initial years.

In all modeled scenarios, the average cost of allowances for some covered entities is likely to be lower than the modeled allowance price due to the use of offsets and no-cost allowances. The program allows covered entities to use offsets to meet part of their compliance obligations (up to 8% in the first compliance period and 6% thereafter). As offsets typically trade at a discount to emissions allowances, this is likely to reduce the effective compliance cost.[9] Furthermore, no-cost allowances would initially cover most emissions from electric utilities, natural gas suppliers and emissions-intensive trade-exposed (EITE) industries. This could keep average compliance costs under $20 per MT CO_2e for these sectors in the first compliance period under the Frontloading scenario. While no-cost allowance allocations reduce the cost impact, entities still face an incentive to decarbonize. If they decarbonize faster than the benchmark reduction, they can sell any excess no-cost allowances on the secondary market at the prevailing market price.

Modeling results suggest that cumulative emissions would stay within the total program allowance budget. By design, the Cap and Invest Program limits the cumulative emissions via the cap on emission allowances. Under this framework, annual emissions may

[8] Source: Vivid Economics analysis

[9] Evidence from the California market suggests that offsets may trade at a slight discount to allowances.

overshoot the annual cap in certain years, which is compensated by undershooting the annual cap in other years. Cumulative emissions would remain under the cap unless a significant amount of price ceiling units, which are additional to the cap, were released. [10] In the Frontloading scenario, modeled emissions decline at approximately 7% per year from 57 MMT CO_2e in 2023 to 34 MMT CO_2e in 2030. In the early 2030s modeled emissions are higher than the cap. This occurs because in the 2020s, modeled emissions are below the cap and unused allowances from these years are banked for surrendering at a later time. In the linking scenario, modeled emissions are 0.6MMT CO_2e higher than the Frontloading scenario in 2023, reflecting limited differences in short term emissions reductions between the two scenarios.

[10] According to the program rules, price ceiling units are released in situations where compliance entities are unable to purchase sufficient allowances to meet their compliance obligations. In this circumstance Ecology will sell price ceiling units at the ceiling price directly to the entities up to the number of compliance instruments the entities need to satisfy that year's compliance obligation. These units can only be purchased by compliance entities and must be surrendered for compliance purposes in the year that they are sold. In this circumstance cumulative emissions could be larger than the cumulative cap due to the creation of the new price ceiling units.

1. Introduction

1.1 Context of this study

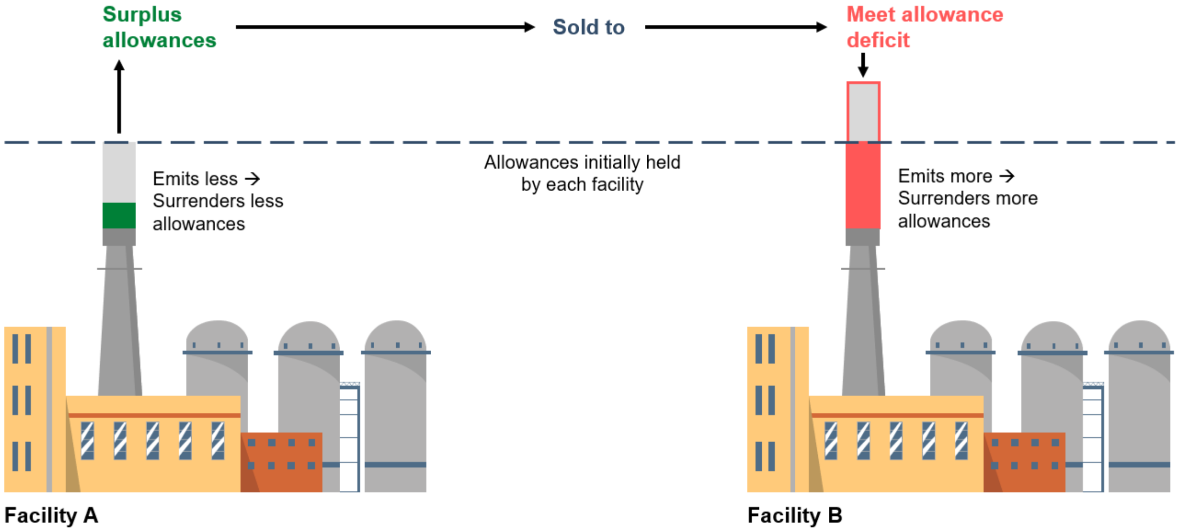
Washington State's climate targets aim to nearly halve statewide greenhouse gas emissions by 2030. Under the targets set out in RCW 70A.45.020, Washington is required to reduce statewide emissions 45% by 2030, 70% by 2040, and 95% by 2050 relative to 1990 levels.[11] Achieving these targets would imply reducing statewide emissions to 50MMT CO_2e by 2030 and 5MMT CO_2e by 2050.

In 2021, the Washington Legislature passed the Climate Commitment Act (CCA), which requires the Department of Ecology to set up a Cap and Invest Program to help achieve the statewide emissions targets. As codified in RCW 70A.65, the CCA directs Ecology to develop rules to implement a cap on carbon emissions, including mechanisms for the sale and tracking of tradable emissions allowances, along with compliance and accountability measures. Ecology is required to adopt program rules to achieve the share of reductions by covered entities necessary to achieve targets established in RCW 70A.45.020. The CCA also directs Ecology to design allowance auctions to allow for linkage to similar programs in other jurisdictions to the extent possible.

The Cap and Invest Program represents a form of carbon pricing, which places a cap on the total emissions from covered sectors. The cap determines a fixed supply of emissions allowances, each of which represents the right to emit a metric ton of carbon dioxide equivalent. These allowances are auctioned or distributed to covered entities in the program, who must surrender allowances for their emissions during a compliance period. Covered entities may buy or sell these allowances on a secondary market. The cost of allowances provides an incentive to reduce emissions, and the cap trajectory limits cumulative emissions in the future. Exhibit 2 provides a simplified illustration of the program, indicating how two covered entities may trade allowances with each other, with their total emissions ultimately bounded by the cap.

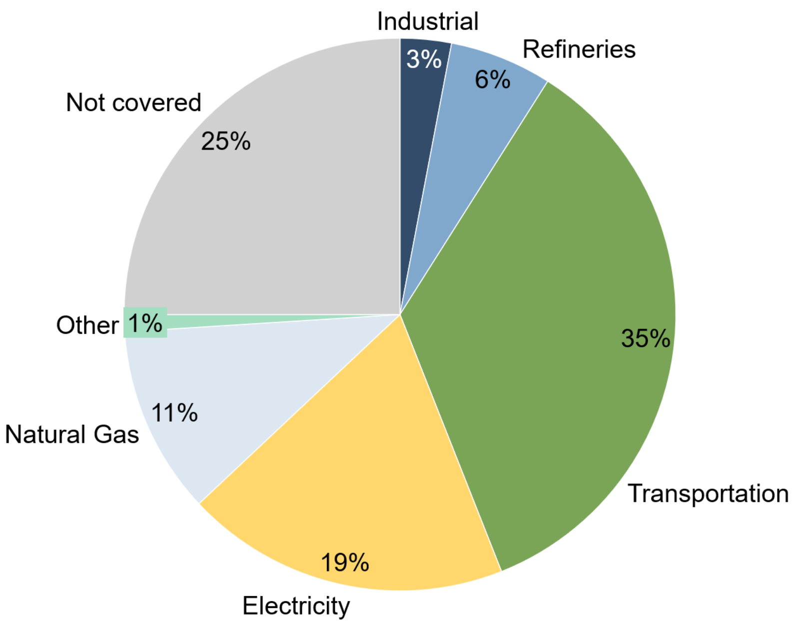
[11] Link to RCW 70A.45.020: Greenhouse gas emissions reductions

Exhibit 2 Simplified illustration of the Cap and Invest Program [12]



The Cap and Invest Program covers sectors representing approximately 75% of statewide emissions. As shown in Exhibit 3, these sectors include transport (35% of statewide GHG emissions), industrial and refinery facilities (9%), electricity (19%), and the use of natural gas and other fuels in buildings (12%). As of May 2022, the total program baseline emission is estimated at 68MMT CO_2e (2015-2019 annual average).

Exhibit 3 Washington statewide greenhouse gas emissions (2018) and sectoral coverage by the program [13]



This study aims to assess potential price and emissions pathways under the proposed rules for the Cap and Invest Program. Vivid Economics, commissioned by the Department of Ecology, provided economic modeling of the emissions allowance market.

[12] Source: Vivid Economics
[13] Source: Washington State Department of Ecology

The main analytical outputs are potential price and emissions pathways in the system, as well as how different program rules, technology, and behavioral factors could influence market dynamics. This work informs the Department of Ecology in its decision-making regarding the proposed Climate Commitment Act Program rule (Chapter 173-446 WAC). Vivid Economics acted as an independent expert and was not involved in decisions regarding rulemaking.

This report summarizes the key findings from the modeling analysis and provides further detail on underlying methodology. Section 2 presents result from the main analytical scenarios: the Linking scenario, Frontloading scenario and the No Frontloading or Linking scenario. Section 3 presents results from the additional sensitivity tests performed to investigate the impact of different modeling assumptions across policy, technology, and market behavior. Section 4 provides a technical description of the modeling methodology and underlying assumptions.

1.2 Key program specifications relevant for this study

The modeling analysis draws on the latest program rules proposed by Ecology so that the results are directly relevant for the rulemaking process. The analysis assumes a total program baseline of 68 MMT CO_2e, which is an estimate of historical annual emissions from covered entities between 2015 and 2019. Accordingly, the annual program allowance budget (or "cap") begins in 2023 at 93% of the program baseline, or 63 MMT CO_2e. The cap is also assumed to decline at 7% per year (relative to the program baseline) through to 2030, 1.9% per year during 2031-2042, and 2.5% per year thereafter according to the proposed program rules by Ecology. The analysis is also consistent with provisions regarding no-cost allowances and the use of offsets.

The modeling analysis explicitly represents the three price containment measures in the program:[14] [15]

- **Price ceiling** – Covered entities can purchase any number of allowances they need for compliance at the price-ceiling price. Hence, the market price for allowances will not exceed this ceiling. In line with the proposed program rules, the analysis assumes a price ceiling starting at $71 per MT CO_2e in 2023, growing at 5% per year, consistent with current rules in the California – Quebec market.[16]
- **Auction floor price** – No allowances will be sold at auctions at a price below the price floor. When they are not purchased for multiple auctions, the unsold allowances are put into the Emission Containment Reserve (ECR).[17] The analysis assumes that the auction

[14] Assumptions for containment measures were provided by Washington State Department of Ecology.
[15] The trigger values, for APCR reserves, price ceiling, and auction floor price, presented in this report are based on the 2022 California price mechanism trigger prices and are rebased into 2021 dollars. The use of different inflation indexes to calculate the 2021 dollar values may result in minor differences relative to what is presented in this report.
[16] All prices in this report are expressed in real 2021 US Dollars.
[17] Allowances in the ECR are released when there are new covered entities entering the program. As the modeling analysis assumes no new entrants in the system, these allowances are effectively removed from market supply.

floor price starts at $19 per MT CO_2e in 2023 and increases at 5% per year, consistent with the current rules in the California – Quebec market.

- **Allowance Price Containment Reserve (APCR)** – The analysis assumes that 5% of the annual cap is placed into a two-tiered APCR, which releases allowances via APCR sales when prices reach the respective price trigger levels for each tier, (hereafter known as APCR1 and APCR2 price triggers).[18]

The proposed rule involves 'frontloading' the APCR allowances between 2023 and 2030 and making them available in 2023 if necessary. In other words, there is a bigger buffer of allowances within the APCR at the start of the program, which could be released earlier in the first two compliance periods if allowance prices reach the respective APCR thresholds. The analysis assumes that the APCR1 and ACPR2 trigger prices start at $46 per MT CO_2e and $59 per MT CO_2e respectively in 2023 and increase at 5% per year.

1.3 Guidance on interpreting results

Modeling results should be considered as a part of a larger evidence base. While significant efforts have been made to identify the most robust assumptions, there is a degree of unavoidable uncertainty across different policy, technology, and market behavioral factors. The following assumptions should be borne in mind when interpreting modeling outputs:

1. **Electricity sector:** Modeled electricity sector emissions are anchored by targets set out in the Clean Energy Transformation Act (or CETA). Carbon prices do not induce additional electricity sector abatement because the electricity sector's modelled reductions match CETA's ambitious decarbonization targets.[19]
2. **Business As Usual (BAU) emissions:** The model assumes a set of sectoral growth assumptions which relate to the underlying economic activity. These are inherently uncertain as they depend on economic growth and other future policy choices. The assumptions used for the modeling are outlined in section 4.2.2.
3. **No linking expectations:** Unless otherwise stated, modeled scenarios assume all market participants expect Washington to permanently remain as a standalone system without linking with any other emissions trading systems.
4. **Technology costs and adoption frictions:** The model is calibrated with the latest information, but these factors are inherently uncertain and depend on future technology availability and performance. The details of the assumptions used are outlined in section 4.2.2.
5. **Forward looking behavior:** The model incorporates realistic behavioral factors amongst market participants, such as having a limited planning horizon and making investment decisions based on some foresight on carbon prices.

[18] A further 2% of the cap and 0.33% of the cap is placed into the Emissions Containment Reserve and Voluntary Renewable Energy Reserve respectively each year. In effect, excluding the allowances placed into all three reserves, the annual supply of allowances would be equivalent to 92.67% of the cap.

[19] Electric utilities are modelled to receive no-cost allowances that cover the cost burden associated with the emissions from the electricity that they deliver under CETA implementation plans.

The impact of these assumptions is described in further detail alongside sensitivity tests in Section 3. Further details on modeling methodology and assumptions are provided in Section 4.

2. Key results

This section presents modeling results across the three main scenarios:

- **The 'Linking' scenario assumes the market expects a potential linkage with the California – Quebec market to occur from 2025.** Modeled prices in the linking scenario span only 2023 and 2024. Modeling market outcomes after the hypothetical 2025 linkage would require separate analysis of the market fundamentals in California and Quebec. However, prices after linkage are expected to converge to California – Quebec prices due to the significantly larger size of that market.
- **The 'Frontloading' scenario is consistent with Ecology's proposed program rules, including the frontloading of APCR allowances**. The Frontloading scenario is based on a calibration using the best available information for technology costs, sectoral activity, and market behavior. The scenario reflects Ecology's proposed rule contents, including the cap trajectory, volume of reserve allowances and how 2023-2030 APCR allowances are frontloaded to 2023 (see details in Section 1.2). It assumes that the market behaves as if Washington will always remain a standalone market.
- **A 'No Linking or Frontloading' scenario is also modeled:** This scenario is based on an earlier version of the rules drafted for Chapter 173-446 WAC, it is identical to the frontloading scenario, except that allowances are distributed equally to each year between 2023 and 2030 in the APCR rather than being frontloaded.

Modeled allowance prices for 2023 are $41 in the Linking scenario, $58 in Frontloading scenario, and $68 in the No Linking or Frontloading scenario.[20] The differences in assumptions and main results are summarized below in Table 1. The three scenarios are described in more detail in sections 2.1, 2.2, and 2.3.

Table 1: Key modeling scenarios and results

	Linking scenario	Frontloading scenario	No Linking or Frontloading scenario
Description	Market participants fully expect a link with the California – Quebec market in 2025.	Program rules as per latest proposal from Ecology, including the cap trajectory, auction rules, and frontloading of APCR allowances. Calibration of covered sectors using best available information.	Identical to Frontloading scenario except that APCR allowances are distributed to each year between 2023 and 2030 rather than all being available in 2023.
Modeled prices	2023: $41 per MT CO_2e	2023: $58 per MT CO_2e 2023-2026 average: $64 per MT CO_2e 2027-2030 average: $89 per MT CO_2e	2023: $68 2023-2026 average: $71 2027-2030 average: $86
Modeled emissions	2023: 58 MMT CO_2e	2023: 57 MMT CO_2e 2030: 34 MMT CO_2e	2023: 57 MMT CO2e 2030: 34 MMT CO2e

[20] All prices in this report are expressed in real 2021 US Dollars.

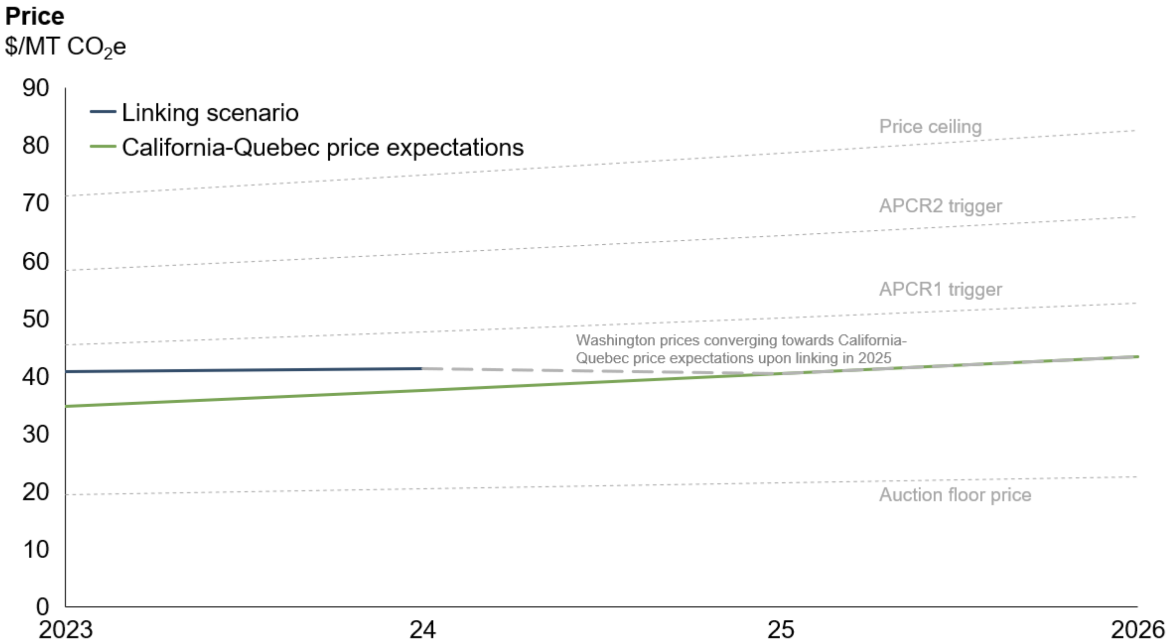
2.1 Linking scenario

The modeled allowance price under the Linking scenario is at $41 per MT CO_2e in 2023 as market expectations of linking with the Californica-Quebec market reduce the perceived scarcity of allowances. The Linking scenario assumes that market participants expect a link with the California – Quebec market in the year 2025. Linking would imply that allowances from the two systems become interchangeable for compliance purposes. This necessarily equalizes the prices across the two systems. As California – Quebec is a much larger system than Washington, allowance prices in Washington might trade at prices closer to California – Quebec levels even prior to linking due to market participants' forward price expectations. The frontloading of APCR allowances does not influence results in this scenario as the APCR is not triggered in 2023 and 2024.

Modeled prices in the Linking scenario are relatively close to the California – Quebec price expectations assumed in the analysis. It should be noted that allowance prices under market expectations of linking are sensitive to California – Quebec price expectations (assumption indicated by the green line in Exhibit 4), as well as the anticipated timing of linking. As market expectations are difficult to predict and heavily influence allowance prices, further sensitivity tests are presented in Section 3 to examine how modeled prices differ under alternative types of market expectations regarding a potential link with the California – Quebec market.

Prices and emissions after a potential linkage with California – Quebec are not modeled as part of this study. A detailed analysis of long-term prices and emissions under a linked system would require calibration of the market fundamentals in both California and Quebec, which lies outside the scope of this work.

Exhibit 4: Modeled allowance prices in 2023-2024 under the Linking scenario [21]



[21] Source: Vivid Economics analysis

2.2 Frontloading scenario

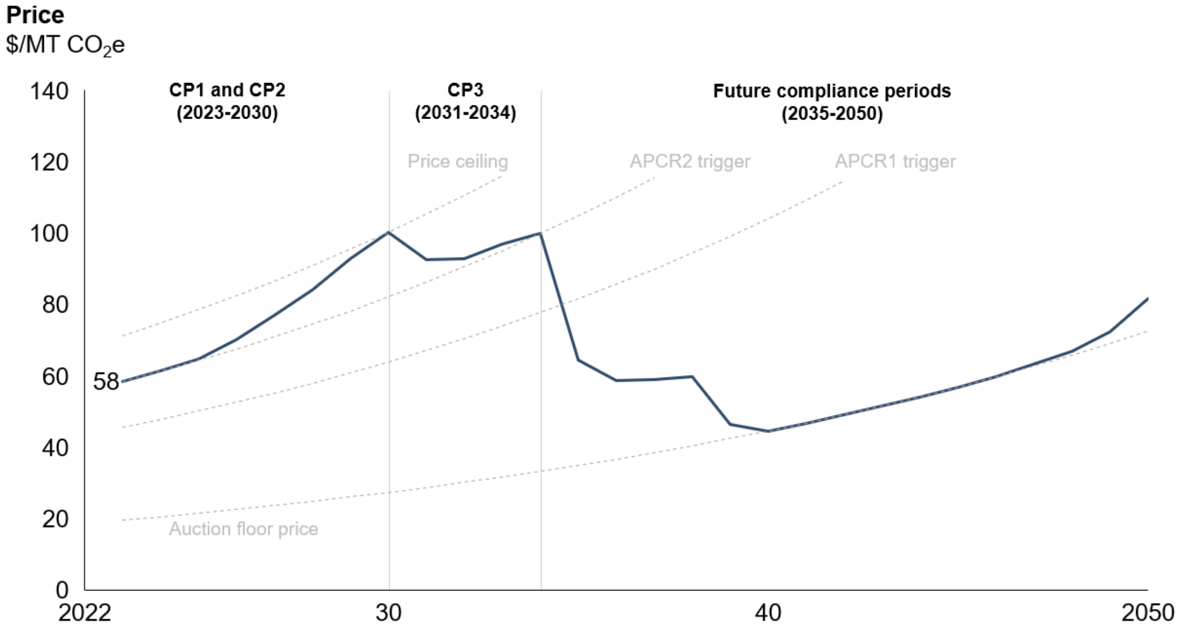
2.2.1 Modeled prices

Modeled allowance prices in the Frontloading scenario begin at $58 per MT CO_2e in 2023 and rise to $100 per MT CO_2e in 2030. The modeled price trajectory exhibits three distinct phases, as shown in Exhibit 5:

1. **In the first two compliance periods (2023-2030), modeled prices increase on average at 8% per year, primarily due to the 7% annual decline in the cap.** The cap decline reduces the annual program allowance budget from 63MMTCO_2e in 2023 to 30MMTCO_2e in 2030 (inclusive of allowances held in reserves). As the pace of emissions reductions is slower than the reduction in allowance supply, allowances become increasingly scarce in the market and the price increases over time. Initial modeled prices are kept closely to the APCR2 threshold up until 2025 as the APCR2 auctions prevent prices from exceeding the threshold. The APCR is depleted after 2025 and so prices rise after this point.
2. **In the third compliance period (2031-2034), modeled prices stabilize in the range of $90-100 per MT CO_2e.** Although allowances are still relatively scarce, the upward pressure on prices is reduced because the cap declines at 1.9% per year (compared to 7% per year from 2023-2030). Meanwhile, the adoption of key abatement technologies such as electric vehicles and electric heating becomes widespread, narrowing the gap between emissions and the cap. This contributes to the slowdown in the growth of modeled prices.
3. **From 2035 onwards, modeled prices decline towards the auction floor price.**[22] In this period, the cap declines at a relatively slower pace of 1.9% to 2.5% per year. At the same time, more low carbon technologies become cheaper and readily available over time. Towards the 2040s, the electricity sector is largely decarbonized according to CETA requirements of achieving 100% clean electricity consumption by 2045. This explains the relatively low price for allowances compared to previous periods.

[22] Modeled prices exhibit kinks between compliance periods (in 2034 and 2038) because market participants are unable to ‘borrow’ allowances, i.e., meet their current compliance obligations using allowances issued in future compliance periods. This is a model artifact driven by simplifying assumptions and should not be overinterpreted.

Exhibit 5: Modeled allowance prices in the Frontloading scenario exhibit three distinct phases[23]

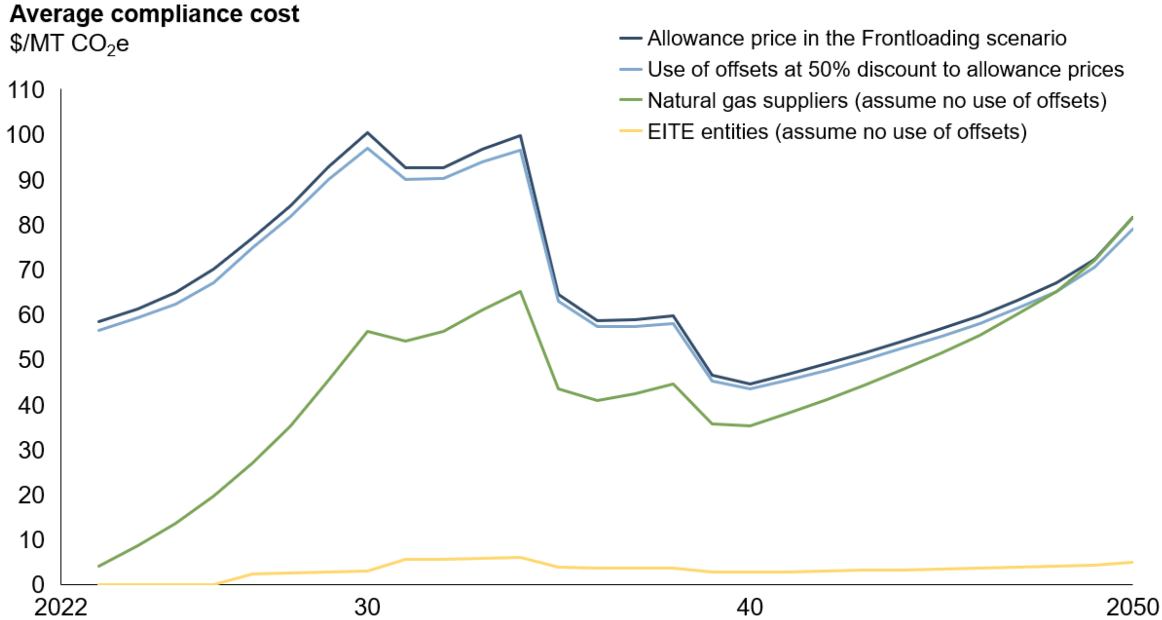


2.2.2 Average compliance costs

The average compliance cost for some covered entities may be lower than the modeled allowance prices due to the use of offsets and no-cost allowances. The proposed rule by Ecology permits a limited use of offsets for covered entities and distributes no-cost allowances for covered entities in some sectors. Estimates of average compliance costs for covered entities are illustrated in Exhibit 6, derived from modeled prices under the Frontloading scenario.

[23] Source: Vivid Economics analysis

Exhibit 6: The use of offsets and no-cost allowances could reduce average compliance costs [24]



Offsets typically trade at a price lower than allowances, meaning the use of offsets reduces the average compliance cost. This effect is limited as covered entities can only meet up to a maximum of 8% of compliance obligations through offsets in the first compliance period, and up to a maximum of 6% thereafter. The light blue line in Exhibit 6 indicates the average compliance cost for an entity that uses offsets at the maximum limit under the Frontloading scenario, assuming offsets are priced at half the cost of allowances.

Sectors that receive no-cost allowances covering a large share of their emissions face relatively low average compliance costs. As per the proposed rule, natural gas suppliers receive 93% no-cost allowances in 2023, gradually decreasing to 44% in 2030. Average compliance costs would initially begin at $5 per MT CO_2e, rising to $53 per MT CO_2e by 2030. EITE entities receive no-cost allowances to cover 100% of their emissions in the first compliance period, and subsequently 97% and 94% in the second and third compliance periods.[25] Therefore, they face a relatively low average compliance cost, which remains under $10 per MT CO_2e throughout the model horizon. Electric utilities are allocated no-cost allowances to cover 100% of their projected emissions throughout the program, which should effectively remove the compliance cost burden. Therefore electric utilities are not shown in Exhibit 6.[26]

Although some covered entities are protected from the cost impact through no-cost allowances, they still face an incentive to decarbonize. If they decarbonize faster, firms can sell any excess no-cost allowances they receive on the secondary market at the prevailing market price.

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[24] Source: Vivid Economics analysis

[25] No-cost allowances are distributed to covered entities to mitigate the cost impact. The number of no-cost allowances given to each entity is based on the allocation baseline determined by Ecology. The modeling analysis also assumes that the rules on no-cost allowances continue after the third compliance period.

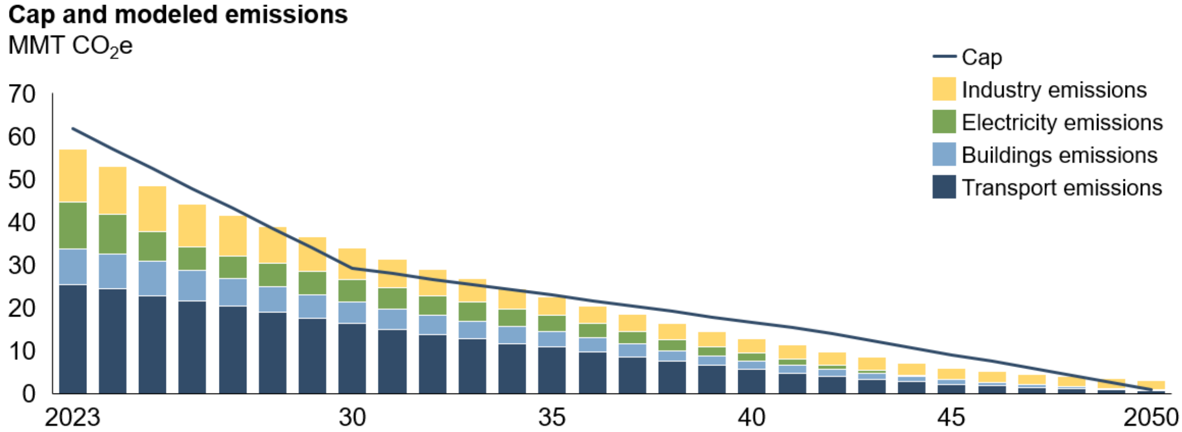
[26] Decarbonization of the electricity sector is driven by CETA regulations. See Section 4.3 for details on the electricity sector.

2.2.3 Modeled emissions

Cumulative emissions are projected to stay under the cap throughout the program. The cap determines the number of allowances supplied to the market, which then limits the volume of total emissions from covered sectors under the program. In principle, cumulative emissions can only exceed the cap if a significant number of price ceiling units are released to the market. This is a key feature of the Cap and Invest Program which ensures that the desired emissions reductions are achieved over the long term.

Annual emissions under the program are projected to be 57MMT CO_2e in 2023 and decline 40% by 2030, reaching 34MMT CO_2e. As shown in Exhibit 7, electricity emissions decline proportionately faster than other sectors, with modeled emissions dropping from 11MMT CO2e in 2023 to 5MMT CO2e by 2030 (52% reduction). This is driven by the assumed progress under the Clean Energy Transformation Act (CETA), which requires utilities to phase out coal by 2025 and secure 80% of their electricity from carbon-free sources by 2030. Meanwhile, the transport sector contributes to the largest absolute emissions reductions by 2030 because it is the largest emitting sector, and the adoption of electric vehicles could accelerate in the near term.

Exhibit 7: Cap trajectory and modeled emissions in the Frontloading Scenario [27]



Key results on modeled emissions	
2030 emissions – total	34 MMT CO_2e (-40% from 2023)
2030 emissions – industry	7 MMT CO_2e (-40% from 2023)
2030 emissions – transport	16 MMT CO_2e (-36% from 2023)
2030 emissions – electricity	5 MMT CO_2e (-39% from 2023)
2030 emissions – power	5 MMT CO_2e (-52% from 2023)

Covered entities are likely to bank allowances to reduce costs over time, which means that annual emissions will overshoot or undershoot the cap in certain years (despite cumulative emissions remaining below the cap). As the cap declines at a relatively faster rate in the first two compliance periods (7% per year) compared to subsequent periods (1.9%-2.5% per year), the market supply of allowances might be relatively scarce towards 2030. Intertemporal optimization from market participants means that the supply of allowances could exceed annual emissions in the first compliance period, such that allowances could be banked and surrendered in the second or third compliance period

[27] Source: Vivid Economics analysis

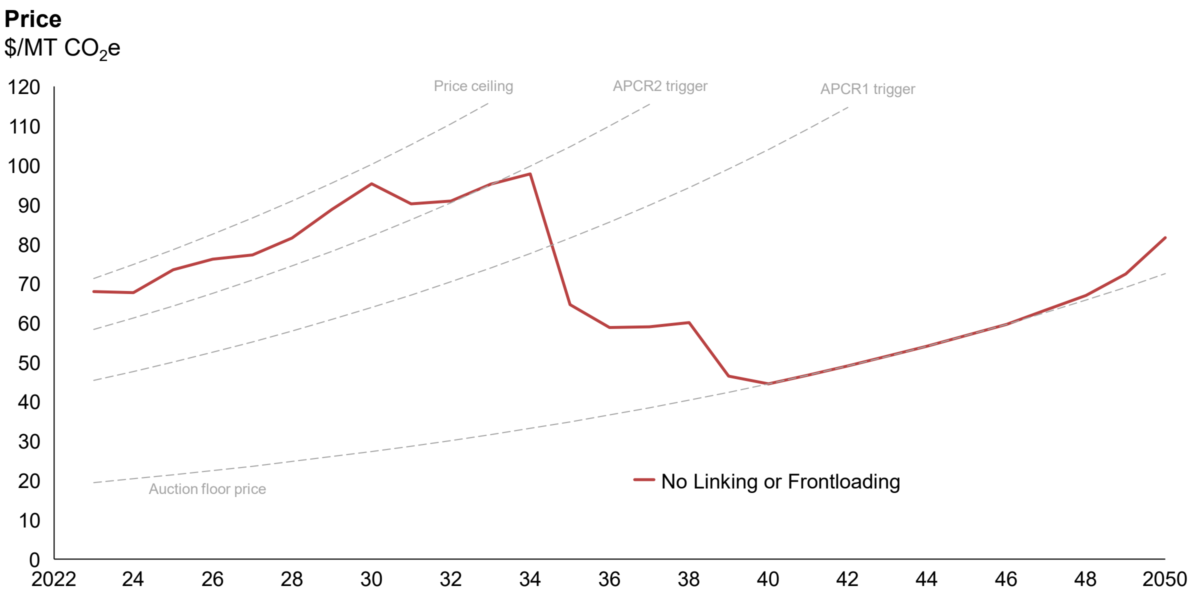
instead. The use of banked allowances for compliance obligations could mean that annual emissions overshoot the cap around 2030, compensated by undershooting the cap in later years, as shown in Exhibit 7.

2.3 No Linking or Frontloading scenario

2.3.1 Modeled prices

Modeled allowance price in the No Linking or Frontloading scenario begin at $68 in 2023 and rise to $95 in 2030. The modeled price trajectory exhibits the same three phases, that are present in the Frontloading scenario and described in section 2.2. Since it has no frontloading of allowances into the APCR, this scenario has a lower supply of allowances in 2023, which leads to higher initial carbon prices. In the 2030s, prices are very similar to the Frontloading scenario since the supply of allowances is the same.

Exhibit 8 Modeled allowance prices in the No Linking or Frontloading scenario [28]



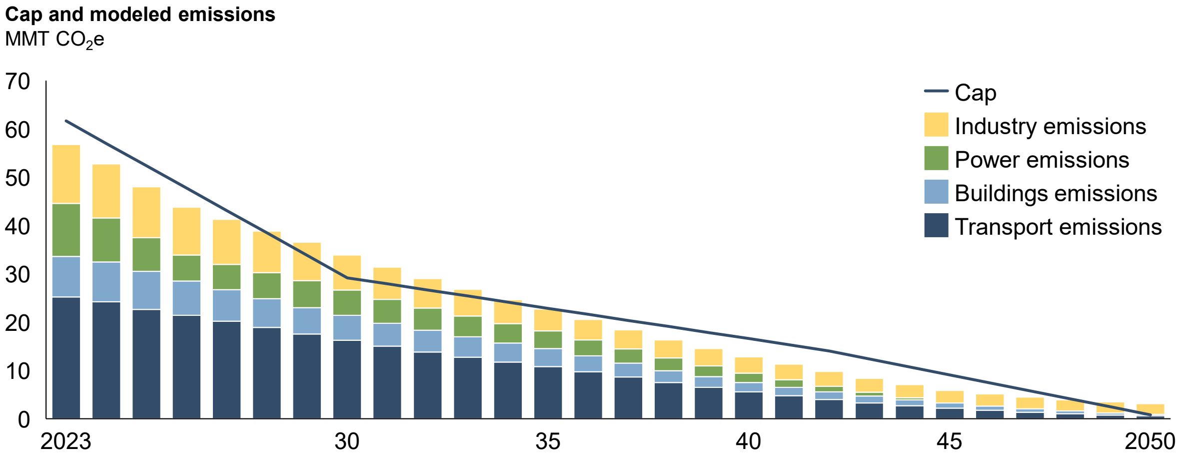
2.3.2 Modeled emissions

Annual emissions under the program are projected to be 57MMT CO_2e in 2023 and decline 40% by 2030, reaching 34MMT CO_2e. The No Linking or Frontloading scenario emissions are shown in Exhibit 9. As with the Frontloading scenario electricity emissions decline proportionately faster than other sectors, with modeled emissions dropping from 11MMT CO2e in 2023 to 5MMT CO2e by 2030 (52% reduction). Meanwhile, similarly to the Frontloading scenario the transport sector contributes to the largest absolute emissions reductions by 2030 because it is the largest emitting sector. Due to the higher allowance prices relative to the Frontloading scenario the cumulative emissions between 2023 and

[28] Source: Vivid Economics Analysis

2030 are 0.3% lower in the no Linking or Frontloading scenario than in the Frontloading scenario.

Exhibit 9 Cap trajectory and modeled emissions in the No Linking or Frontloading Scenario [29]



Key results on modeled emissions	
2030 emissions – total	34 MMT CO_2e (-40% from 2023)
2030 emissions – industry	7 MMT CO_2e (-40% from 2023)
2030 emissions – transport	16 MMT CO_2e (-36% from 2023)
2030 emissions – buildings	5 MMT CO_2e (-39% from 2023)
2030 emissions – power	5 MMT CO_2e (-52% from 2023)

[29] Source: Vivid Economics analysis

3. Sensitivity analysis

Modeling results depend on input assumptions around program specification, complementary policies, market behavior, and technology adoption pathways. Modeling of complex markets necessitate simplifying assumptions to capture key market attributes. There is inherent uncertainty in those assumptions. This section presents a series of sensitivity tests in addition to the key results in the previous section to evaluate the variability of modeling results with respect to uncertain factors.

The sensitivity analysis involves testing alternative input assumptions against a baseline configuration. The baseline configuration used in this case is the No Linking or Frontloading scenario, presented in section 2. Sensitivity tests in the subsequent sections identify the impact of different assumptions relative to this baseline scenario.

This section presents results from the sensitivity analysis, organized around four categories of uncertainty:

- **Program specification** scenarios evaluate how modeling results depend on program rules, such as frontloading of APCR allowances, price control mechanisms, or linking with the California and Quebec system (Section 3.1). These assumptions and scenario designs were provided by Ecology.
- **Complementary policy** scenarios evaluate how modeling results depend on assumptions related to sector-specific policies that reduce emissions independent of the Cap and Invest Program, such as the Clean Fuel Standard, the Clean Vehicles Program, and the Clean Energy Transformation Act (Section 3.2)
- **Market behavior** scenarios evaluate how modeling results depend on assumptions regarding the way covered entities and non-covered entities, which may include the financial sector, buy and sell allowances (Section 3.3)
- **Technology pathway** scenarios consider the impacts of assumptions regarding the speed of adopting low carbon technologies (Section 3.4)

These sensitivity tests focus on inputs with the greatest potential to influence modeling results. Table 2 describes the full range of model inputs and assumptions required by the model, alongside a qualitative indication of their impact on modeling results.

Table 2: List of key model inputs and assumptions

	Model assumptions	Default assumption under the baseline, No Linking or Frontloading, configuration	Potential impact on modeled price results
Program specification	Frontloading of supply	No frontloading of APCR allowances *(This differs from the proposed program rules)*	Higher
	Market expectation of linking	Standalone system in Washington. Market expectations consistent with no linking	Higher
	Price containment mechanisms	Aligned with California – Quebec price floor, price ceiling and APCR trigger prices	Higher
	No-cost allowances	Based on proposed program rules	Lower
	Use of offsets	Based on proposed program rules	NA
Complementary policy	Assumed policies	Includes CETA regulations but excludes the proposed rules for Clean Vehicle Program and Clean Fuel Standard	Medium
Market behavior	Banking horizon	Default assumption of 4 years	Medium
	Non-covered entity demand	Demand sensitivity and hurdle rates calibrated to yield plausible market behavior	Medium
	Interest rates	Calibrated to sector borrowing cost, adjusted for risk and behavioral factors	Medium
	Abatement horizon	Calibrated to sector depending on asset lifetimes and consumer behavior	Medium
	Short run elasticities	Based on academic literature estimates	Lower
	Long run elasticities	Based on academic literature estimates	Lower
Technology pathway	Technology adoption inertia	Calibrated to sector	Higher
	Electricity sector emissions	Scaling using CTAM consumption-based electricity sector emissions trajectory	Medium
	Baseline activity growth	Washington-specific sources, refined by expert analysis and input from Ecology staff	Medium
	Abatement technology costs	In-house database	Medium
	Technology uptake constraints	Aligned to literature estimates, refined based on discussions with Ecology	Lower

* Sensitivity analysis discussed in detail for items shaded in blue

3.1 Program specification scenarios

The program specification scenarios examine how modeling results depend on the design of the Cap and Invest Program. This is particularly relevant to provide an understanding of the effects of different design features of the program. The sensitivity analysis involves adjusting assumptions around how many APCR allowances are frontloaded, the type of market expectations around linking with the California – Quebec market, and the presence of price containment mechanisms. These assumptions and scenario designs were provided by Ecology.

3.1.1 APCR frontloading

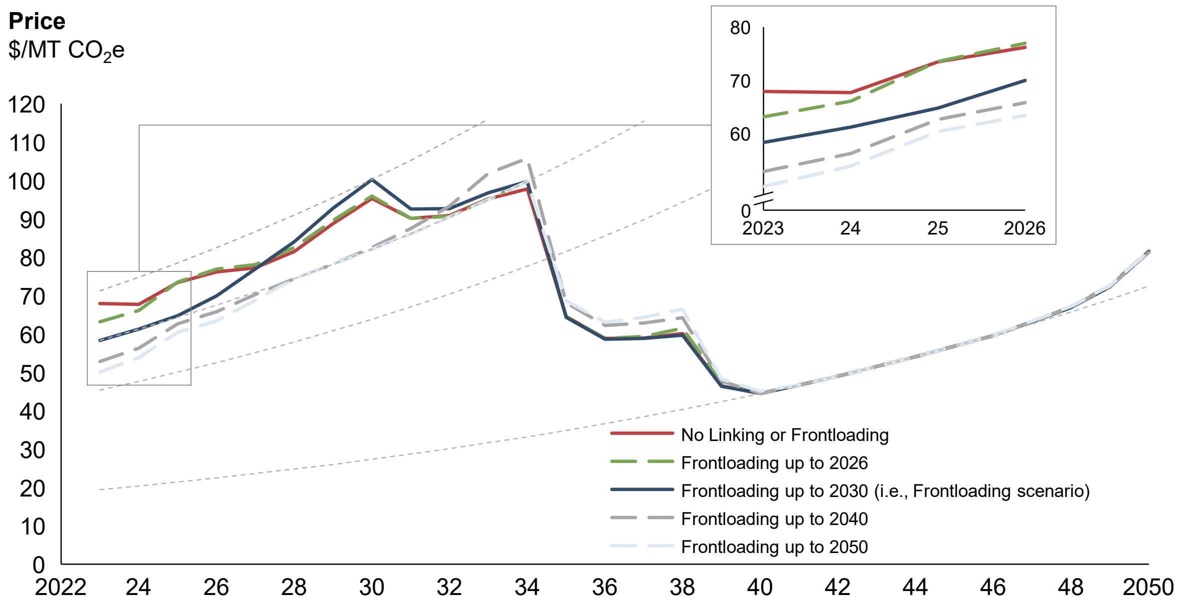
The proposed program rules by Ecology involve frontloading APCR allowances. As explained in Section 1, the rules earmark 5% of the cap for the APCR. Rather than placing these allowances into the reserve at a uniform schedule each year, the allowances earmarked for the APCR between 2023-2030 are frontloaded and placed into the APCR in 2023. In effect, more allowances are made available to the market early on if APCR trigger prices are reached in the initial years of the program. This also implies that in later years there might be no allowances left in the APCR for further releases, if the APCR is depleted before 2030.

Given the importance of this program design, the following sensitivity tests investigate the impact of alternative frontloading specifications. Exhibit 10 presents modeled prices from five alternative scenarios:

1. No frontloading – This is equivalent to the 'No Linking or Frontloading' scenario described in Section 3.
2. Frontloading up to 2026 – All APCR allowances in **2023-26** put into 2023 APCR
3. Frontloading up to 2030 – All APCR allowances in **2023-30** put into 2023 APCR, which is consistent with the proposed program rules by Ecology and equivalent to the Frontloading scenario described in Section 2.1
4. Frontloading up to 2040 – All APCR allowances **2023-40** put into 2023 APCR
5. Frontloading up to 2050 – All APCR allowances **2023-50** put into 2023 APCR

Frontloading of APCR allowances reduces 2023 modeled prices between $5-$18 per MT CO_2e relative to the No Linking or Frontloading scenario, depending on the extent of frontloading. Prices in all five scenarios exceed the APCR1 trigger in 2023, and the first three scenarios also reach the APCR2 trigger, leading to corresponding APCR sales. The frontloading of APCR allowances means that the number of allowances available for APCR auctions in 2023 is greater than it otherwise would be under the No Linking or Frontloading scenario. In other words, frontloading of APCR allowances increases the effective supply of allowances in the market, reducing allowance prices particularly in the first compliance period. As shown in Exhibit 10, the greater the amount of frontloading, the larger the price difference relative to the No Linking or Frontloading scenario. In the extreme case of frontloading up to 2050, prices are $18 per MT CO_2e lower than the No Linking or Frontloading scenario and $8 per MT CO_2e lower than the Frontloading scenario (which frontloads up to 2030).

Exhibit 10: Additional frontloading reduces modeled prices in the first compliance period [30]



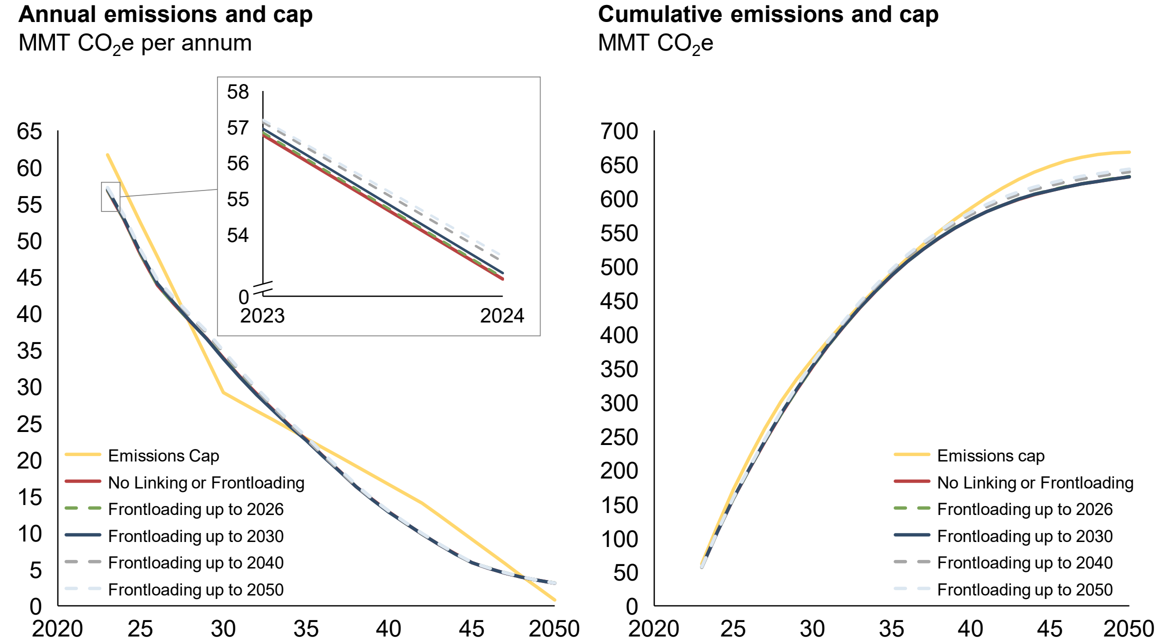
Frontloading of APCR allowances has a more muted effect on modeled prices after 2034. This is partly because of the auction floor price, which is reached after 2040 and acts as a lower limit on allowance prices across all five scenarios shown in Exhibit 10. Furthermore, modeled prices across these scenarios fall below the APCR1 trigger from 2034 onwards, which means that there may not be any APCR sales after 2034. Therefore, frontloading of APCR allowances has a limited impact on modeled prices in the longer term.

Frontloading of APCR allowances also has a more limited impact on modeled emissions. Although the frontloading of APCR allowances shifts the supply of allowances towards the initial years of the program, annual emissions across the different frontloading scenarios are at most 1 MMT CO_2e higher than the No Linking or Frontloading scenario, as shown in Exhibit 11. This is because decisions to adopt low carbon technologies are often investment decisions that cover a long-term horizon, such as replacing a fleet with electric vehicles or upgrading an industrial boiler. The differences in modeled prices in the near term (2023-2026) across the scenarios shown in Exhibit 10 does not lead to significant differences in price signals for such investments. The extra supply of allowances through the frontloading of APCR allowances are mainly purchased and banked in the initial years of the program for use in later years.

Regardless of frontloading, overall emissions reductions will achieve the total emissions reductions set out by the program. The overall target for statewide emissions reductions is represented by the quantity of allowances under the cap, which includes the allowances in the APCR. Thus, shifting the distribution of APCR allowances from later years in the program into earlier years does not change the long-term total of the cap.

[30] Source: Vivid Economics analysis

Exhibit 11 Frontloading of APCR allowances has limited impact on modeled emissions [31]



3.1.2 Market expectations of linking

Market expectations of linking with the California – Quebec market could affect allowance prices in Washington, depending on the expected timing of linking and price expectations for the California – Quebec market. In the event of linking the two systems, allowances would become interchangeable for compliance purposes for Washington covered entities. The resulting price is likely to track that of the California – Quebec market because it is much larger than Washington in terms of annual emissions. Therefore, the main driver for allowance prices in Washington prior to linking could be market expectations of how and when the linking occurs. Given the potential impact of linking and the inherent uncertainty in market expectations, this section examines how modeling results depend on two key assumptions: the time at which the link is expected to occur, and the expected future price trajectory under the California – Quebec market. Analysis of this scenario involves specifying alternative market expectations relative to the Linking scenario presented in Section 2.2.

Modeled prices for Washington start at a higher level if market participants expect linking to occur later. Market expectations for the California – Quebec market likely represent some increasing price trajectory (illustrated by the dashed light blue line in Exhibit 12). A later link would imply a higher price in the linking year. Conversely, an earlier link would imply a lower price in the linking year. The Linking scenario is based on the default assumption that the market expects a link in 2025, which brings initial modeled prices to a level relatively close to the California – Quebec market, at $41 per MT CO_2e in 2023. By contrast, if linking is expected to occur in 2030, such expectations have a weaker effect on modeled prices in 2023, resulting in a higher modeled price of $58 per MT CO_2e in 2023.

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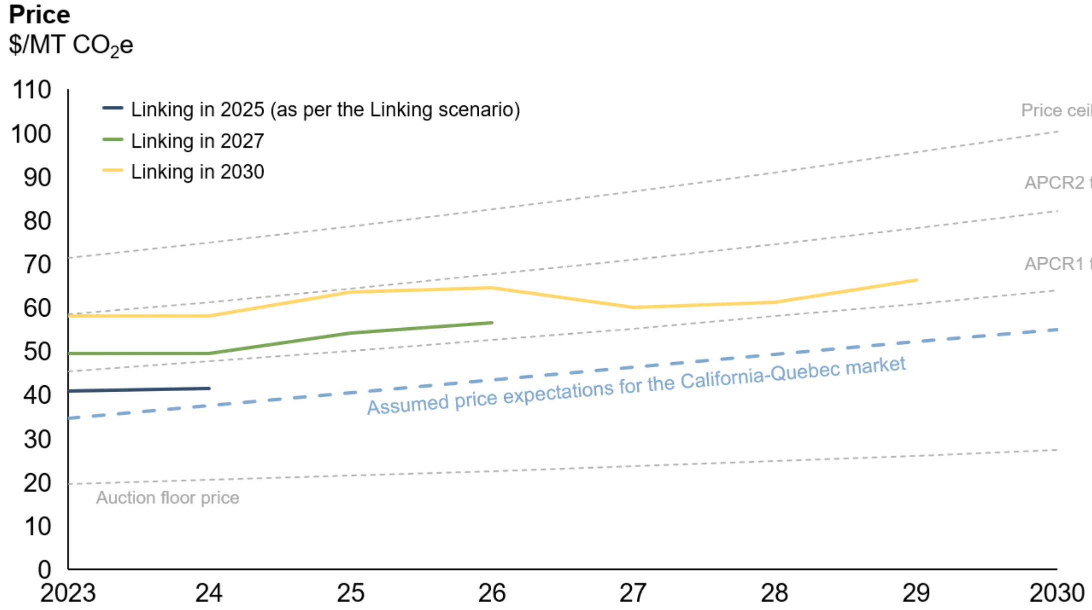
[31] Source: Vivid Economics analysis

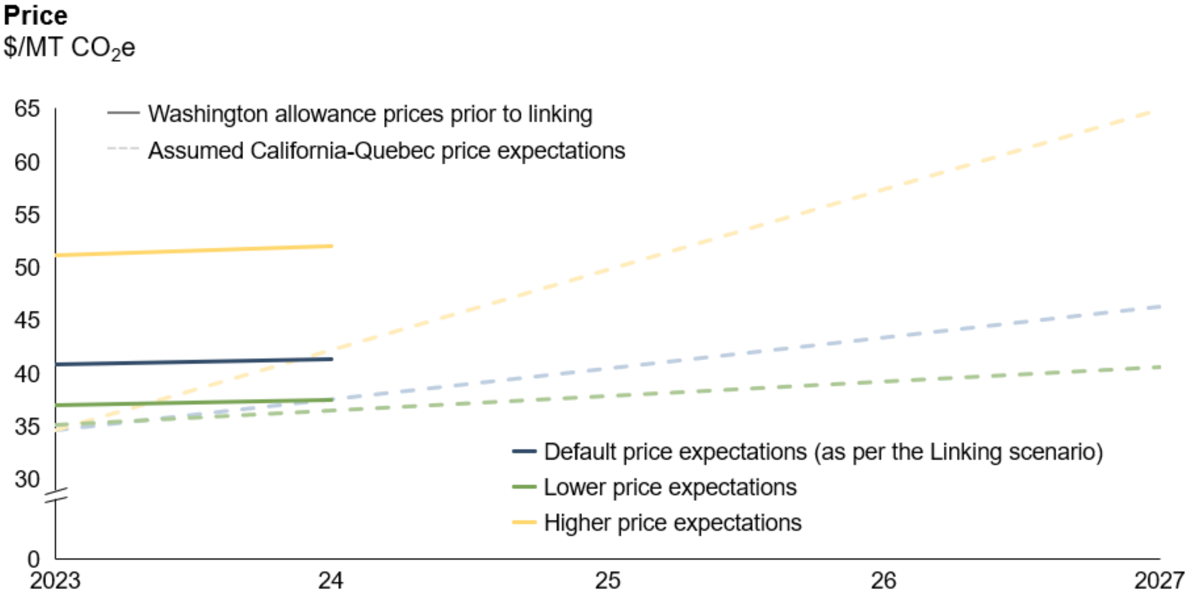
Exhibit 12: The Linking scenario is sensitive to market expectations for the timing of linking [32]



Modeled prices are also sensitive to assumptions of price expectations for the California – Quebec market. Price expectations for the California – Quebec market could affect the perceived value of Washington allowances prior to linking. The default assumption under the Linking scenario is a California – Quebec price expectation that starts at $34 per MT CO_2e in 2023 and rises towards $46 per MT CO_2e in 2027, as shown as the dashed blue line in Exhibit 13. If price expectations increase more quickly, such as reaching $65 per MT CO_2e by 2027 (dashed yellow line), the modeled price for Washington in 2023 starts at $51 per MT CO_2e in 2023. Conversely, if such price expectations increase more slowly, reaching only $41 per MT CO_2e by 2027, the modeled price for Washington in 2023 is $37 per MT CO_2e.

[32] Source: Vivid Economics analysis

Exhibit 13: The Linking scenario is sensitive to California – Quebec price expectations [33]



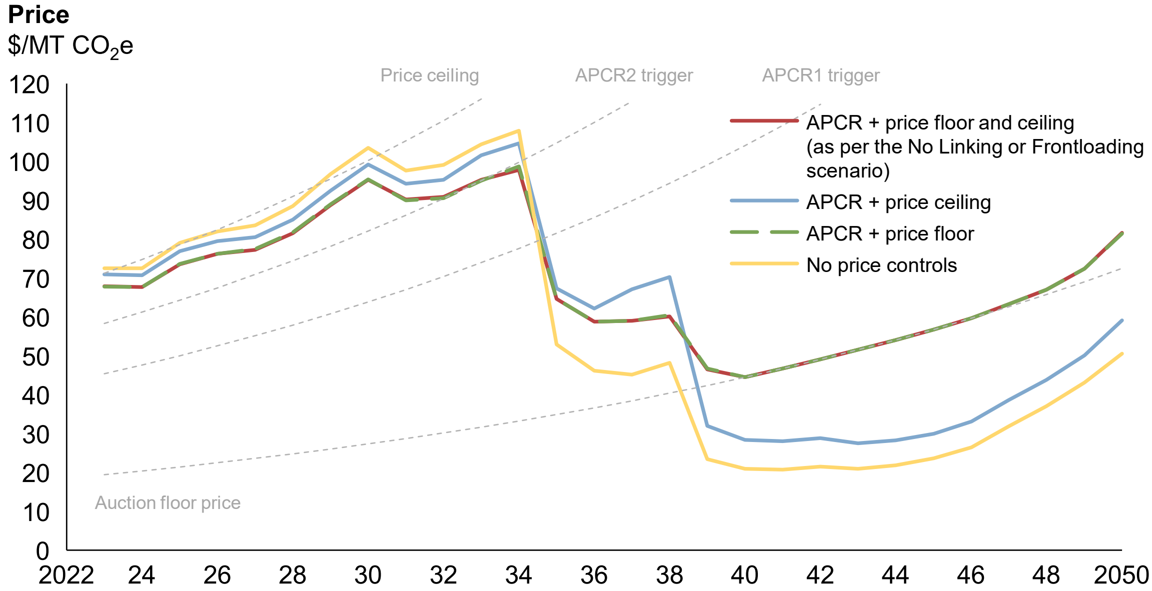
3.1.3 Price containment mechanisms

Price containment mechanisms affect the modeling results by limiting the movement of allowance prices over time. As introduced in Section 1.2, the proposed program rules include three price containment mechanisms: a price ceiling, an auction price floor and a two-tiered allowance price containment reserve (APCR). These mechanisms influence allowance prices by either expanding or restricting the supply of allowances at certain price levels. The following sensitivity analysis illustrates the effect of the different price containment mechanisms on modeling results by introducing them sequentially relative to a 'No price control' scenario where all three mechanisms are absent. For this analysis the trigger prices for the price containment mechanism are assumed to be the same as those in the draft rule, which are consistent with the California price mechanism prices. The four scenarios presented in Exhibit 14 include:

1. **No price controls** – All price containment mechanisms are absent. APCR allowances are assumed to be released via auctions every year
2. **APCR + price ceiling** – Only the APCR and price ceiling are included
3. **APCR + price floor** – Only the APCR and price floor are included
4. **APCR + price floor and ceiling** – All price containment mechanisms included, equivalent to the baseline configuration, i.e., the No Linking or Frontloading scenario

[33] Source: Vivid Economics analysis

Exhibit 14 Price containment mechanisms limit the movement of modeled prices [34]



In the absence of price containment mechanisms, modeled prices are higher in the first three compliance periods (2023-2034) and lower for the rest of the program phase. As represented by the yellow line in Exhibit 14, the lack of a price ceiling meant that prices could reach a higher level up to 2034, and the lack of an auction floor price allow prices to fall to lower levels subsequently.

Introducing the APCR reduces modeled prices in the first three compliance periods. Comparing the yellow line (no price controls) and light blue line (APCR + price ceiling), modeled prices are $2-4 per MT CO_2e lower in the latter scenario.[35] This is because the higher allowance prices from 2035 onwards feed into the expectations of covered entities, which may decide to adopt low carbon technologies slightly earlier given the higher cost of emitting in the future. The accelerated decarbonization under the latter scenario reduces the demand for allowances and therefore lowers the modeled prices in the first three compliance periods.

The APCR results in increased modeled prices from 2035 onwards because the allowances that are placed into the APCR represent a reduction in supply compared to the no price controls scenario. This effect can be best understood in Exhibit 14 by again comparing the yellow line (no price controls) and light blue line (APCR + price ceiling). Introducing the APCR means that 5% of the cap is withheld from supply when the price is below the APCR triggers (because if prices are below the triggers, these allowances are not released into the market). As modeled prices stay below the APCR trigger levels after 2034 under the scenario without any price controls, introducing the APCR restricts the supply of allowances, increasing modeled prices from 2035 onwards.

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[34] Source: Vivid Economics analysis

[35] Although the APCR + price ceiling scenario also includes a price ceiling, the difference in price between the scenarios is due to the APCR, because modeled prices do not reach the price ceiling in the APCR + price ceiling scenario.

Introducing the price floor increases modeled prices in the 2040s. In the 'no price controls' scenario, modeled prices are below the auction price floor from 2040 onwards. Therefore, the introduction of the auction price floor will effectively reduce auction supply until the market price reaches the price floor. The introduction of a price floor also reduces modeled prices in the first three compliance periods slightly because covered entities would decarbonize faster due to higher allowance prices in the 2040s.

Introducing the price ceiling when modeled prices are already below the ceiling level has no impact on modeled prices. This is evident from comparing the dashed green line (APCR + price floor) with the red line (APCR + price floor and price ceiling) in Exhibit 14, which overlap because the price ceiling is not binding and does not affect the supply of allowances.

3.2 Complementary policy scenarios

Complementary policy scenarios investigate how modeling results depend on the assumed impact of other climate-related policies. Complementary policies refer to regulations and policies that drive emissions reductions but are separate to the Cap and Invest Program. If such policies create emissions reductions additional to the carbon price from the Cap and Invest Program, then they lower the emissions reductions amount required to meet the cap, thereby lowering allowance prices. The sensitivity analysis focuses on complementary policies in the transportation and electricity sector respectively.

3.2.1 Transportation sector

The sensitivity analysis considers an alternative scenario which covers two major policies in the transportation sector:

- **Clean Vehicles Program (CVP).**[36] In November 2021, Ecology adopted new vehicle emissions standards consistent with the zero emissions vehicles program in California, which will take effect in 2024. In January 2022, Ecology further announced the start of rulemaking to adopt new vehicle emission standards. This rule would increase zero emission vehicle sales of passenger cars, light-duty trucks, and medium-duty vehicles to 100% starting in 2035. It would also require cleaner, less polluting heavy-duty engines.
- **Clean Fuel Standard (CFS).** [37] The Clean Fuel Standard requires fuel suppliers to gradually reduce the carbon intensity of transportation fuels to 20% below 2017 levels by 2038. The rulemaking was announced by Ecology in July 2021, and the rule may be adopted later in 2022.

The proposed rules for these two programs are excluded from the baseline configuration for other scenarios as they are not yet final.

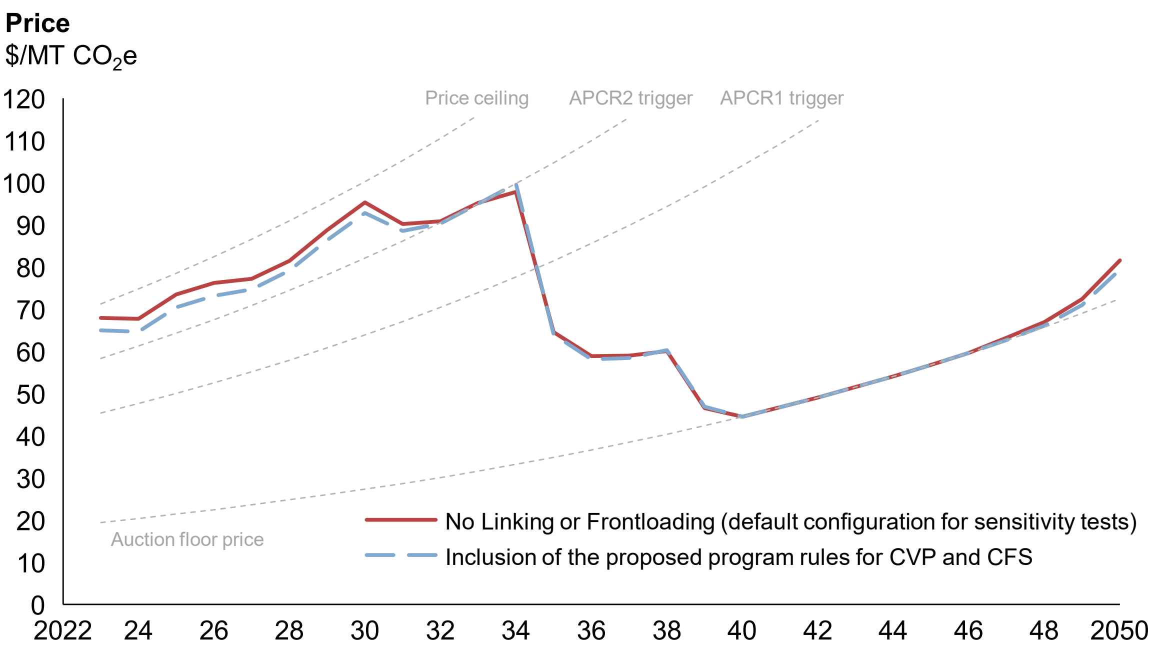
Modeled prices accounting for CVP and CFS program rules are $2-3 per MT CO_2e lower in the 2020s compared against the No Linking or Frontloading scenario baseline. This is illustrated in Exhibit 15. The policies could accelerate emissions reductions

[36] Link to the existing Clean Vehicles Program rules and latest rulemaking announced in January 2022

[37] Link to the rulemaking for the Clean Fuel Standard

in the transportation sector by lowering the emissions intensity of road transport. This reduces the demand for emissions allowances from fuel suppliers and therefore lowers the modeled prices for allowances. Overall, the effect on modeled prices is muted because significant emissions reductions in addition to those from the complementary policies are still required.

Exhibit 15: Modeled prices are lower with the introduction of complementary policies [38]



3.2.2 Electricity sector

The default calibration in the modeling analysis is consistent with the Clean Energy Transformation Act (CETA). The CETA requires electric utilities to phase out coal-fired electricity from their state portfolios by 2025. By 2030, their portfolios must be greenhouse gas emissions neutral. The law commits Washington to an electricity supply free of greenhouse gas emissions by 2045. The default assumption across all scenarios in this report so far is consistent with this ambitious trajectory. The electricity sector emissions are directly derived from projections by Ecology, which represent the expected decarbonization trajectory under CETA.[39]

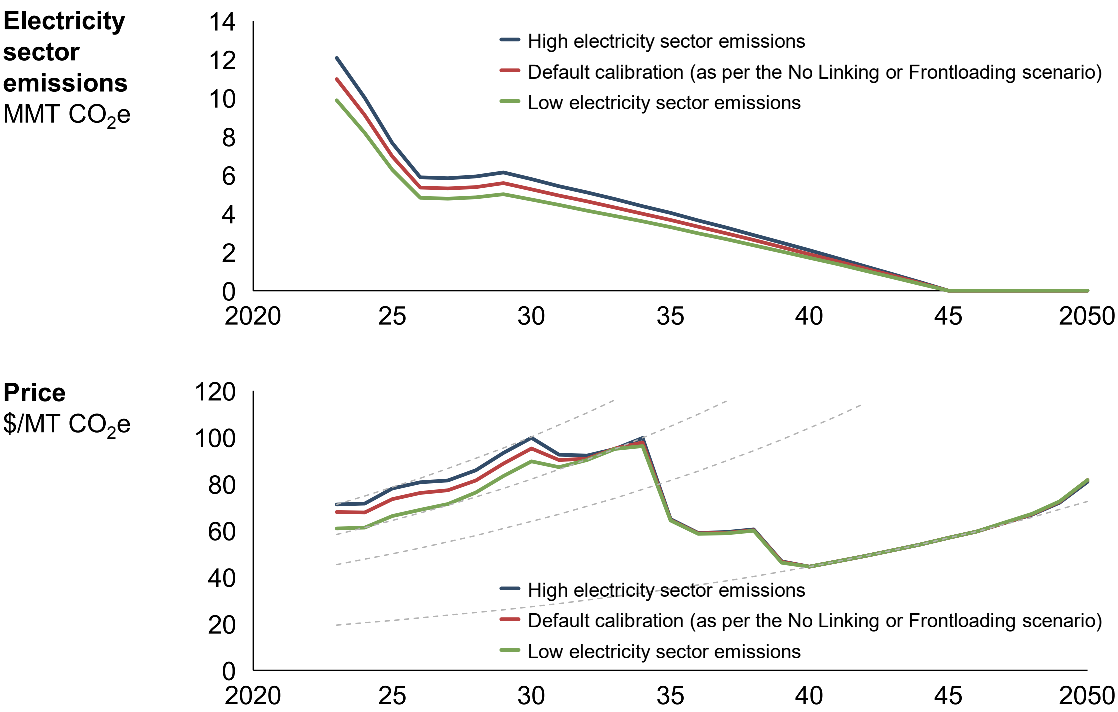
The modeling approach assumes that CETA is the key driver for decarbonization of the electricity sector. Electric utilities are allocated no-cost allowances to cover their cost burden in the Cap and Invest Program. Although the opportunity to auction their no-cost allowances creates an incentive to decarbonize faster than CETA implementation requirements, the program rules mandate that electric utilities pass the economic benefits from auctioning unused no-cost allowances through to ratepayers. This means there is limited economic incentive to abate beyond the CETA trajectory. Utilities may still decarbonize faster than the CETA trajectory, but this is not captured in the model.

[38] Source: Vivid Economics analysis
[39] See details on this approach in Section 4.2.2.

The sensitivity analysis examines the impact of alternative outcomes under the Clean Energy Transformation Act (CETA). This is relevant for the study because the growth of electricity consumption and future capacity mix remains uncertain even under CETA, and because of the simplified modeling approach for electricity sector decarbonization. The analysis includes two scenarios to quantify the impact if electricity sector decarbonization proceeds faster or slower than expected, relative to the default calibration.

A 10% higher rate of electricity sector decarbonization leads modeled prices to be $7 per MT CO_2e lower in 2023. As shown in Exhibit 16, the accelerated decarbonization of the electricity sector means that the demand for allowances will be lower, reducing the scarcity of allowances and leading to lower prices relative to results under the default calibration. Conversely, a 10% lower rate of electricity decarbonization result in $3 per MT CO_2e higher modeled prices in 2023. The modeled prices across these scenarios converge towards 2034 because the differences in electricity sector emissions become counteracted by corresponding differences in the supply of allowances, determined by the APCR and the auction floor price.

Exhibit 16: Modeled prices depending on the trajectory of electricity sector emissions [40]



3.3 Uncertainty in market behavior

Modeling results further depend on assumptions regarding market behavior, which pertain to how market participants buy and sell allowances. This is an important aspect to the modeling approach because it affects the demand for allowances and the way market demand responds to intertemporal prices differences. The sensitivity tests include:

[40] Source: Vivid Economics analysis

- **Banking horizon** – The number of years for which a covered entity plans for when purchasing and banking allowances.
- **Non-covered entity behavior** – The rate of return ("hurdle rate") at which most non-covered participants will enter the market, and the extent to which their demand responds ("sensitivity") to the expected rate of return of holding allowances.

3.3.1 Banking horizon

Under the default calibration used in the No Linking or Frontloading scenario, covered entities are assumed to plan four years ahead in their banking decisions. This means that covered entities in 2023 fully recognize their compliance obligations within the first compliance period from 2023 to 2026. The default assumption for the banking horizon is chosen as four years to match the length of a compliance period.

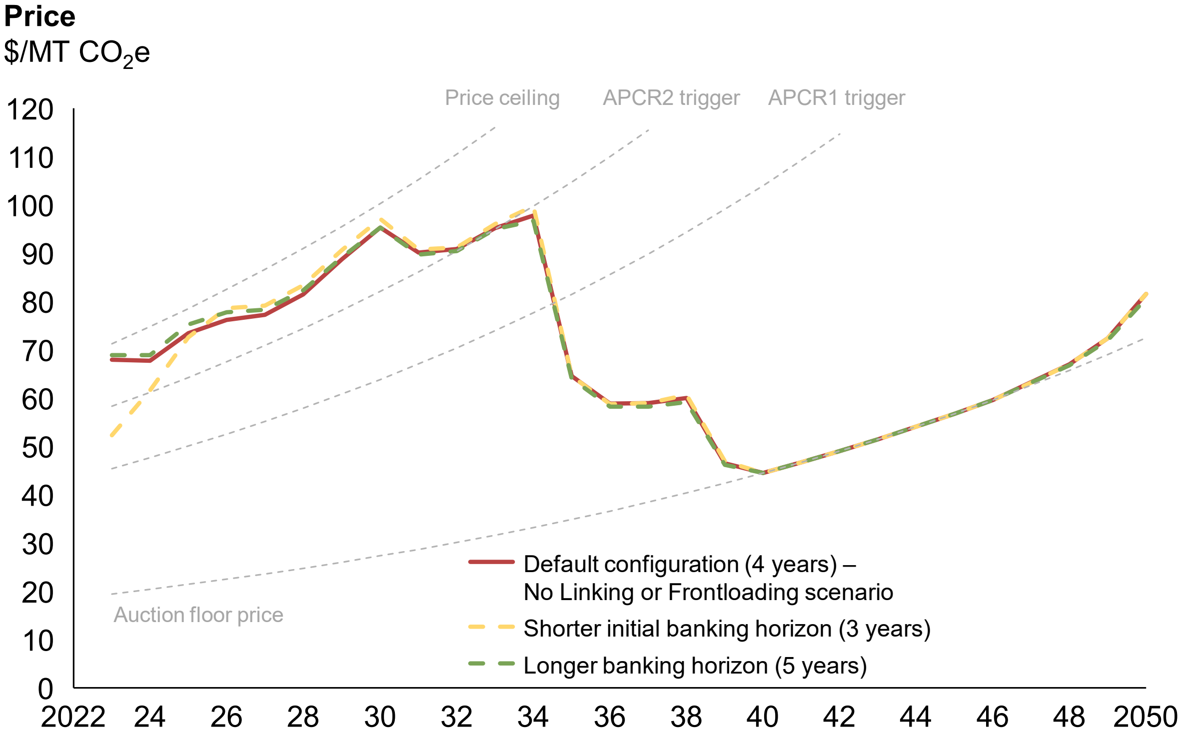
Reducing the initial banking horizon from four to three years reduces the modeled price for 2023 by $16 per MT CO_2e, because covered entities do not recognize their compliance obligations at the end of the compliance period in 2026. With a limited initial banking horizon of 3 years, covered entities in 2023 only plan to purchase enough allowances to cover 30% of their emissions between 2023 and 2025, due to the schedule for meeting compliance obligations in the program rule.[41] In effect, covered entities in 2023 do not recognize the full extent of the scarcity of allowances by the end of 2026. Under this assumption, the banking demand for allowances in 2023 is much lower and therefore reduces prices relative to the No Linking or Frontloading scenario, as shown in Exhibit 17. However, such a short banking horizon is less plausible in practice because evidence suggests that covered entities tend to consider their full compliance obligations within a compliance period.[42]

By contrast, increasing the banking horizon from four to five years has a limited effect on modeled prices. When the banking horizon is increased beyond four years, covered entities' perception of their total compliance obligations within the near term are unaffected, and so their demand for allowances and prices are not significantly changed.

[41] The proposed program rule states that compliance obligations are 30% of annual emissions for the first three years of a compliance period. In the fourth year, obligations cover 100% of all emissions during the compliance period.

[42] For example, the auction patterns in the California cap-and-trade system indicate that covered entities plan and purchase allowances in advance of the compliance deadline in the final year of the compliance period.

Exhibit 17: Modeled prices under different banking horizons [43]



3.3.2 Non-covered entity behavior

The model includes demand from non-covered entities who buy and sell allowances depending on their price expectations. This represents all participants in the market who do not have compliance obligations and includes participation from the financial sector. The following sensitivity tests investigate two model parameters which regulate the behavior of these agents, namely the hurdle rate and the price sensitivity of their demand.

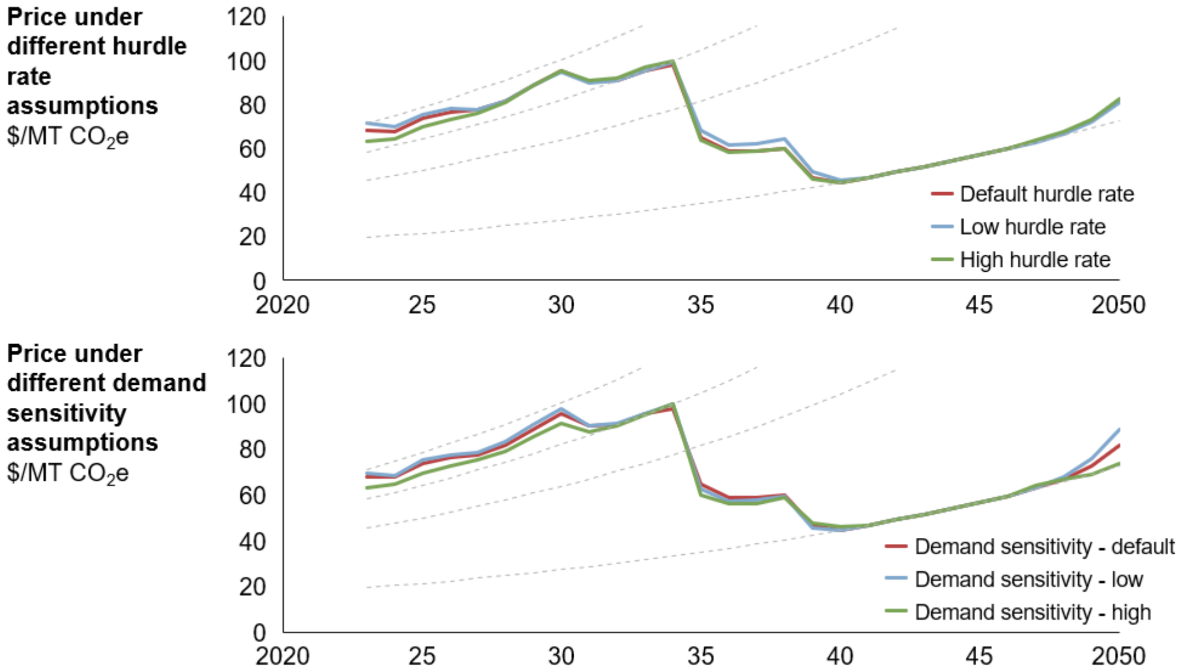
Alternative hurdle rate assumptions have less than \$5 per MT CO_2e impact on modeled prices in 2023, with the effect diminishing over time. As shown in the upper panel of Exhibit 18, a higher hurdle rate results in allowance prices that are \$5 per MT CO_2e lower because it decreases the initial demand for allowances from non-covered entities. Conversely, a lower hurdle rate implies larger initial demand from the non-covered entities, resulting in marginally higher allowance prices, with initial prices \$3 per MT CO_2e higher than in the No Linking or Frontloading scenario. The effect diminishes over time because the hurdle rate mainly affects the size of non-covered entity holdings, rather than the net demand from the non-covered entities each year.

Non-covered entity demand sensitivity to prices has a similarly limited impact on modeled prices. The sensitivity is a technical assumption in the model that relates to the strength of arbitrage, which capitalizes on intertemporal price differences and smooths out the price trajectory over time. By extension, the sensitivity parameter determines the size of non-covered entity holdings at a given expected rate of return. If the expected rate of return is below the hurdle rate, a higher sensitivity parameter would result in a lower demand for

[43] Source: Vivid Economics analysis

allowances from the non-covered entities, and vice versa. This is shown in the lower panel of Exhibit 18, where alternative assumptions on demand sensitivity have less than $4 per MT CO_2e impact on modeled prices.

Exhibit 18: Modeled prices under different non-covered entity behavior assumptions [44]



3.4 Uncertainty in technology pathways

The availability of and ability to deploy decarbonization technology in the coming decades is uncertain. Technology deployment rates depend on the cost of switching to low carbon technologies, future carbon prices, and other non-financial frictions to technology adoption. For example, the rate of switching of internal combustion engine cars to electric vehicles will depend not only on their relative costs, but also on the infrastructure development of charging stations, supply chains impacting the availability of new vehicles, and consumer perceptions around the suitability of electric vehicles for their travel needs. These frictions need to be understood and accounted for to understand the speed of technology deployment.

The sensitivity analysis focuses on the transport sector because this sector accounts for nearly 45% of covered emissions and has a relatively high technology switching friction. The default calibration of the transportation sector was chosen to represent a plausible pathway of electric vehicle adoption in the future.[45] Sensitivities are then chosen to represent scenarios with lower and higher rates of transport decarbonization as compared to the default calibration. In the scenario with faster transport decarbonization, emissions associated with passenger vehicles are 10% lower by 2030 relative to the default calibration (the No Linking or Frontloading scenario). For example, this could represent a scenario where there is an accelerated rollout of charging stations which reduces the ‘range anxiety’

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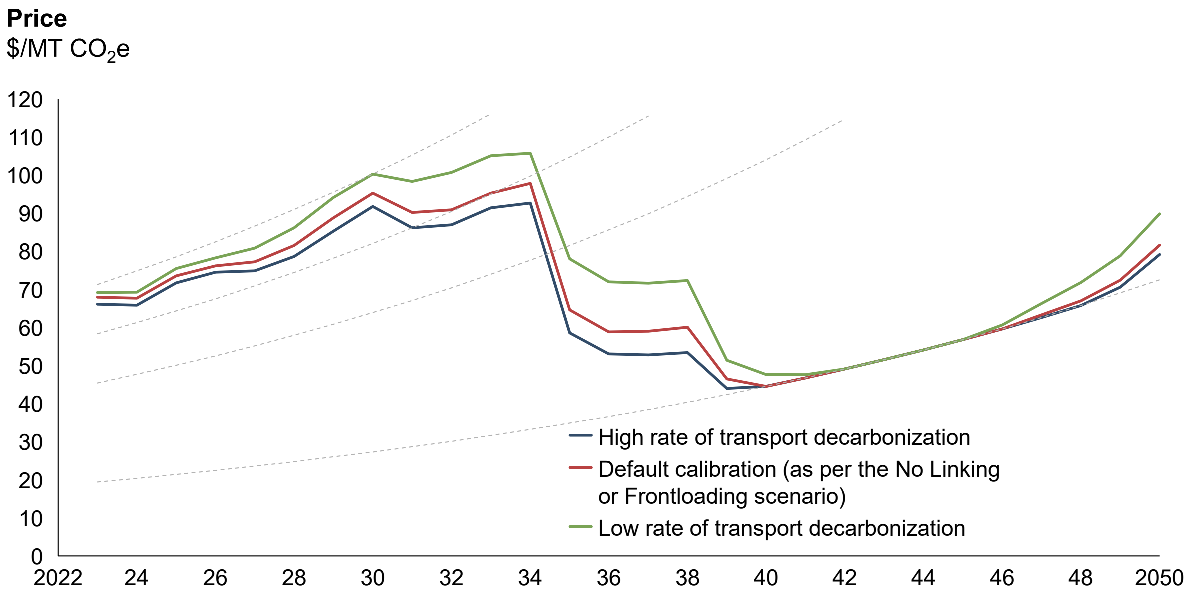
[44] Source: Vivid Economics analysis

[45] Under the default calibration of technology adoption frictions, adoption of electric vehicles (including hybrids) reach 41% of the total passenger vehicle stock by 2030.

associated with driving electric vehicles. By contrast, the scenario with slower transport decarbonization has 8% greater emissions from passenger vehicles in 2030 when compared against the default calibration.

When technology adoption friction is lowered, decarbonization of transport is faster and the resulting modeled prices are lower. Modeled prices from the sensitivity tests are displayed in Exhibit 19. The increased availability of low-cost abatement in the transport sector means that lower carbon prices are required to shift the sector towards greater adoption of electric vehicles, reducing the modeled price for 2030 by $4 per MT CO_2e. Conversely, when adoption friction is higher, decarbonization of transport is slower and carbon prices are higher, increasing the modeled price in 2030 by $5 per MT CO_2e.

Exhibit 19: Modeled prices in different transport decarbonization scenarios [46]



[46] Source: Vivid Economics analysis

4. Modeling methodology

The modeling was conducted using the Compliance Carbon Market Model (or CCMM) developed by Vivid Economics. The model allows for an explicit and granular representation of emission trading systems such as Washington's Cap and Invest Program. This section gives a general overview of the model (Section 4.1) and details the assumptions for modeling the Cap and Invest Program (Section 4.2).

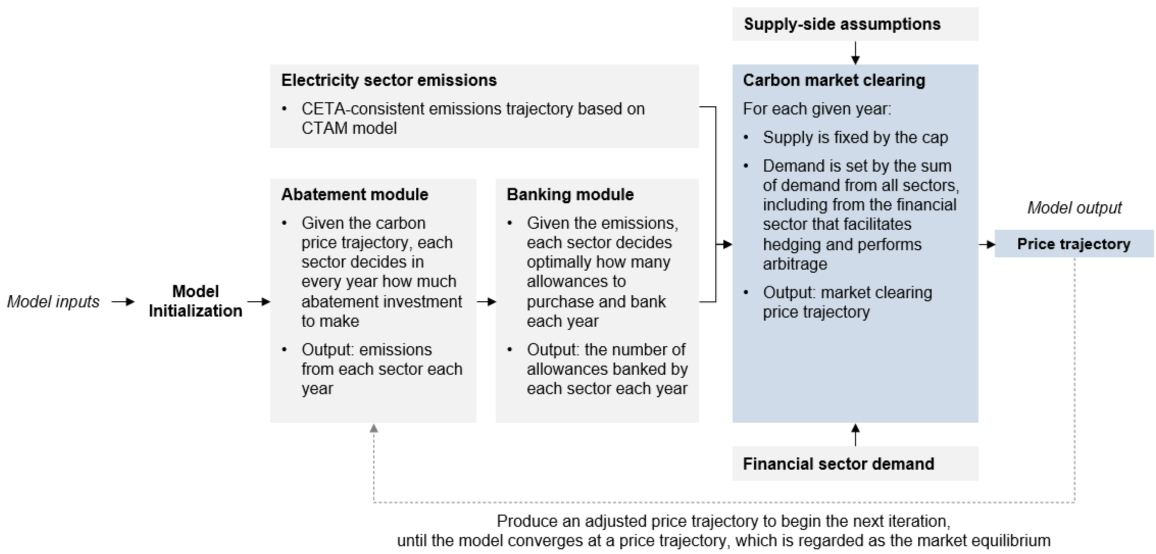
4.1 Model overview

The CCMM is an agent-based model that solves for the market equilibrium price under emissions trading systems. This section sets out the model structure (Section 4.1.1), the characteristics of agents (Section 4.1.2), and finally the model limitations (Section 4.1.3).

4.1.1 Model structure

CCMM is an agent-based, modular, and iterative model. Agent-based models allow explicit representation of the market behavior of different types of agents, providing a more realistic outcome compared to a model which uses total system optimization. The model uses a modular setup, which calculates the allowance demand from different agents endogenously before entering the market clearing module to solve for market equilibrium prices that equate supply and demand (see Exhibit 20). This means that allowance demands from different sectors are not model assumptions, but part of the model solution. CCMM utilizes an iterative approach to solve for the final market clearing prices. An iterative approach is needed because market participants' expectations of future carbon prices affect their abatement and banking decisions, and these decisions in turn affect total demand for allowances and subsequently market clearing prices.

Exhibit 20: Schematic of model structure



4.1.2 Model agents

There are three types of agents in the model:

- **Covered entities outside of the electricity sector.** This refers to market participants in the industry and transportation sectors, and the use of natural gas and other fuels in buildings. Each subsector (e.g., Petroleum Refineries) is represented as a unique agent in the model. Each agent has specific attributes and market behaviors depending on the input assumptions, such as technology costs, interest rates, and planning horizon. When faced with a carbon price trajectory, an agent invests in abatement technologies to minimize the total cost of compliance up to their investment planning horizon, and bank adequate allowances for their compliance obligations.
- **Covered entities in the electricity sector.** Electricity sector emissions enter the model as a fixed exogenous input due to the assumption that decarbonization is driven by CETA regulations and that carbon prices do not induce additional abatement in this sector. Section 4.2.2 provides further detail on this assumption.
- **Non-covered entities that participate in the market.** These entities do not have compliance obligations and participate in the market voluntarily, typically as investors. Their behavior in the model is driven by input assumptions such as a desired rate of return and demand sensitivity parameter. These entities may take either a long or a short position on the market depending on their expectation of allowance prices. The size of their market positions depends on the rate of return for holding allowances.

Agents in the model behave with imperfect foresight. Agents in the model only consider future carbon prices that are within their investment planning horizon for abatement decisions and banking horizon for compliance and banking decisions. This short-sightedness of agents means that they are not fully rational in their decisions, however the agents are assumed to have exact knowledge of the carbon price trajectory within their abatement and investment horizons.

4.1.3 Limitations of CCMM

The main limitations of the model are:

- **Annual granularity of model inputs and outputs.** In practice, auctions in the Cap and Invest Program occur four times a year while trading is continuous on the secondary market. As with many other commodities, carbon prices can see significant short-term variations. However, this model abstracts away from short-term variations and provides only an average annual price based on market fundamentals.
- **No full linking of two compliance carbon markets.** While the model is designed to explicitly model compliance carbon markets, modeling the linking of two independent emission trading systems is a much more complicated exercise and requires extensive calibration outside the scope of this study. The linking scenarios presented in this report are modeled via a simplifying assumption that because Washington is a much smaller market, allowances will track prices in California – Quebec once linked.

4.2 Washington-specific assumptions

This section details the assumptions contained within the modelling approach for the Cap and Invest Program. Section 4.2.1 details assumptions impacting the supply of allowances, while Section 4.2.2 sets out the assumptions impacting the demand for allowances.

4.2.1 Supply side assumptions

Supply slide assumptions are aligned with the Cap and Invest Program using information and program rules provided by Ecology. Key aspects related to the supply of allowances include the program coverage, the level and trajectory of the cap, and various rules related to the distribution of allowances and compliance schedules. Table 3 summarizes the supply side assumptions in the analysis, which are aligned with the current rulemaking from Ecology.

Table 3: Supply side assumptions for the model [47]

Assumption	Details
Total program baseline	67.9 MMT CO2e (2015-2019 estimated average emissions)
Program coverage	Washington's cap-and-invest program includes four main sectors, electricity, industry, transportation, and the use of natural gas and other fuels in buildings.
Reserves	Reserves are created with 5% of the cap allocated into the allowance price containment reserve (APCR), split evenly across two tiers, 2% of the cap is allocated into the emissions containment reserve (ECR) and 0.33% of the cap allocated into the voluntary renewable energy reserve (VRER).
Banking	Banking across compliance periods is allowed, which means holding allowances from one year to the next without surrendering them is permitted. Borrowing from future compliance periods is prohibited, this means entities cannot use allowances from future compliance periods to meet their compliance obligations in the present period.
Compliance obligations	A covered entity's compliance obligation consists of compliance obligations every year and compliance obligations every 4 years. A covered entity has an annual compliance obligation of 30% of their annual emissions for the first three years of a compliance period. In the fourth year of a compliance period, covered entities must surrender allowances to cover 100% of their emissions from that year, as well as allowances to cover 70% of annual emissions for the preceding three years. At that point allowances to cover all emissions from the four-year compliance period have been surrendered.

[47] These assumptions were provided by Washington State Department of Ecology

4.2.2 Demand-side assumptions and sources

Demand side assumptions relate to how covered emissions and other sources of allowance demand are modeled. This section explains the assumptions made in calibrating the market demand under the Cap and Invest Program. These include baseline emissions, electricity sector emissions, complementary policies, technology costs, market behavior, and demand elasticities.

4.2.2.1 Baseline emissions

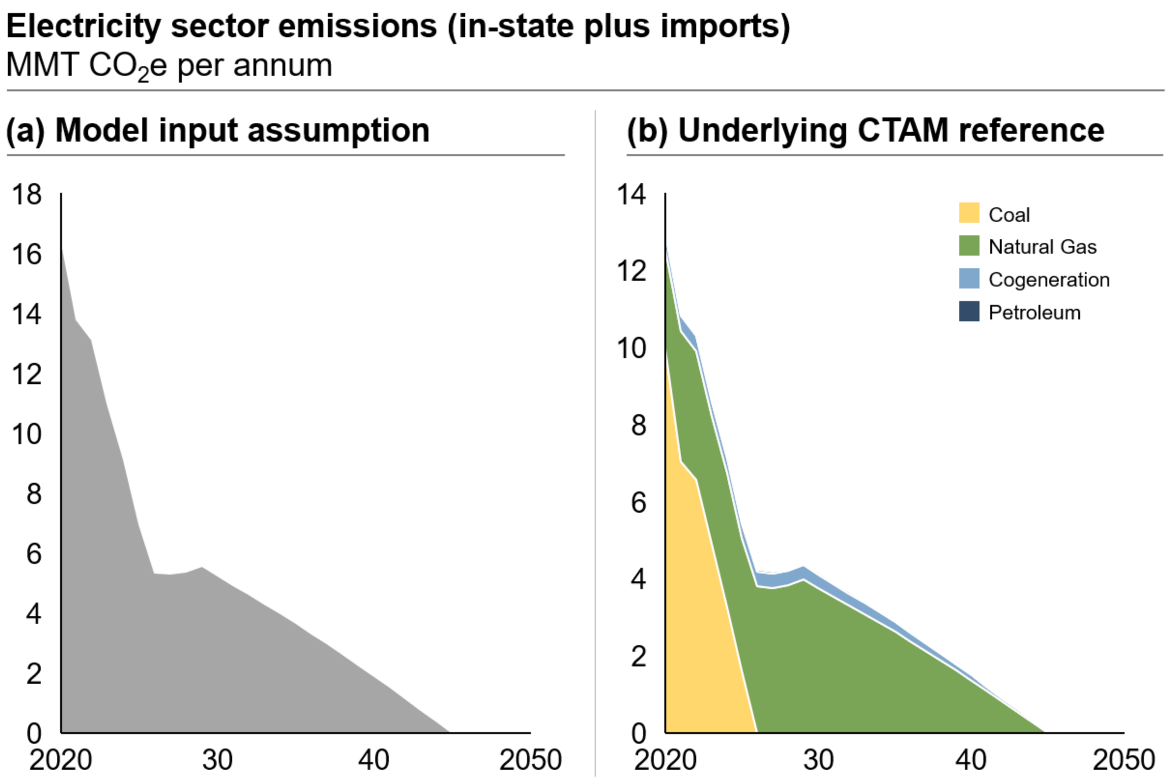
The model assumes a baseline activity trajectory for each agent. This is typically expressed in unit production or final demand, such as in metric tonnes of steel produced and vehicle-miles traveled. Baseline activity levels evolve over time based on factors such as population growth, economic growth, and changes in modes of transport.

Baseline activity growth assumptions are refined by local and sectoral experts to represent the specifics of the energy and industrial systems in Washington. This is based on an extensive calibration process for each sector, validating an in-house projection against third party sources and local experts. Key sources of reference include the 2021 State Energy Strategy. This validation process also improves on assumptions related to the initial technology mix, such as how steel is currently produced in Washington or how many electric vehicles have been sold in recent years. Activity growth in the transport sector also assumes changes in modes of transport away from passenger cars and towards public and active transport, which is consistent with policies in Washington such as the light rail system expansion in Seattle.

4.2.2.2 Electricity sector emissions

Electricity sector emissions are an exogenous input to the model and are aligned with projections under the Clean Energy Transformation Act (CETA). The electricity sector decarbonization trajectory shown in panel (a) of Exhibit 21 is fed into the model. This emissions trajectory starts in 2020 with the latest baseline estimate from Ecology of 16.5MMT CO2. The future trajectory is then extrapolated using the CETA-consistent projection from the CTAM v4.2 model published by the Department of Commerce. This projection includes emissions associated with in-state generation and imports. As this is derived in line with CETA, the assumption is consistent with a coal phase out after 2025, gas making up 20% of the generation mix in 2030, and achieving 100% clean electricity by 2045.

Exhibit 21: Electricity sector decarbonization pathways[48]



4.2.2.3 Emissions impact of complementary policies

The impact of the Clean Vehicles Program (CVP) and Clean Fuel Standard (CFS) policies on emissions are included as part of the sensitivity analysis. As described in Section 3.2.1, the CVP mandates increasing sales of zero emissions vehicles, while the CFS requires fuel suppliers to gradually reduce the carbon intensity of transportation fuels to 20% below 2017 levels by 2038. The model accounts for the CVP by setting a minimum constraint on the number of zero emissions vehicles sold in each year in a way that is consistent with the proposed rules for CVP. As for the CFS, the model incorporates biofuel blending in a way that is consistent with separate work commissioned by Ecology to assess the impacts of the clean fuel standard on vehicle emissions.

4.2.2.4 Technology costs and inertia

Technology cost assumptions in the model are taken from an extensive in-house database. The data includes the capital expenditure, operating expenditure, fuel costs and emissions intensity associated with over a hundred different technologies in the covered sectors. The database is regularly updated via expert input, public sources, and direct engagement with industry.

Technology adoption inertia is assumed to account for non-measurable costs and switching friction. The inertia parameter accounts for natural stock turnover rates and for hidden costs or frictions which may slow down the adoption of low carbon technologies. These parameters were applied to reflect that there are limits to how quickly a technology

[48] Underlying CTAM reference provided by Washington State Department of Ecology

can be deployed even if deploying it is economically favorable. These limits can represent fuel or resource constraints, such as the availability of carbon dioxide transport and storage infrastructure that is required for carbon capture projects, as well as behavioral factors such as the inconvenience to homeowners of replacing heating systems or the reluctance to use electric vehicles due to range anxiety and other concerns. The inertia parameter is calibrated for each sector such that resulting technology uptake patterns are consistent with the views of sectoral experts and broadly comparable to projections in the literature.

4.2.2.5 Market behavior

A banking horizon parameter was chosen to represent the limited foresight of covered entities in purchasing and banking allowances. This assumption was implemented because evidence from other jurisdictions, including the EU Emissions Trading System, suggests that firms behave with limited foresight.[49] The model assumes by default a foresight parameter of 4 years, implying that covered entities would consider the full compliance period in purchasing and banking allowances.

The abatement decision of each agent depends on the assumed investment horizon and interest rates. The model assumes a sector-specific investment horizon that is calibrated to the typical asset lifetimes of those investments, ranging from about 10 years for a passenger vehicle to over 30 years for an industrial facility. The model also assumes sector-specific interest rates consistent with borrowing costs. These were adjusted for risk and behavioral factors, especially for consumer segments where individual households make decisions on purchasing electric vehicles or upgrading heating systems.

Non-covered entity demand for allowances is modeled with constraints on maximum holdings, a hurdle rate, and sensitivity to price rises. The maximum holdings were calibrated in proportion to the non-covered entity holdings seen in the California – Quebec market. This maximum limit was assumed to be 60 million allowances in 2023 and reduced proportionately with the cap to 2050. In practice, modeled allowance holdings for non-covered entities typically fluctuate at around half of the upper limit. The hurdle rate and demand sensitivity is calibrated based on literature and expert interviews. Sensitivity tests are run on these parameters to show the range of variability in modeled prices caused by this uncertainty, as shown in Section 3.3.2. The impact of these sensitivities suggest that such assumptions have only a small impact on allowance prices.

4.2.2.6 Demand elasticities

Short and long run elasticities of demand are included for each sector to represent how final demand might respond to prices. These demand elasticities quantify the reduction in demand for a product when the price of that product rises. Price rises are calculated from the increase in cost based on the allowance price and the emissions intensity of a particular activity. Short run elasticities are smaller than long run and represent demand reduction in a single year. Long run elasticities represent longer term reductions in output and typically take 2-4 years for demand reductions to be realized. These elasticities

[49] For example in the EU ETS power companies appear to hedge 4 years ahead (ISDA, Role of derivatives in carbon markets, 2012)

were estimated based on academic literature.[50] Long term elasticities were only included for the use of natural gas and other fuels in buildings and transport sectors, where there was limited data for short term elasticities these were set as one third of the long-term elasticity.

[50] Kenneth Gillingham, Identifying the elasticity of driving: Evidence from a gasoline price shock in California, Regional Science and Urban Economics, Volume 47, 2014
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