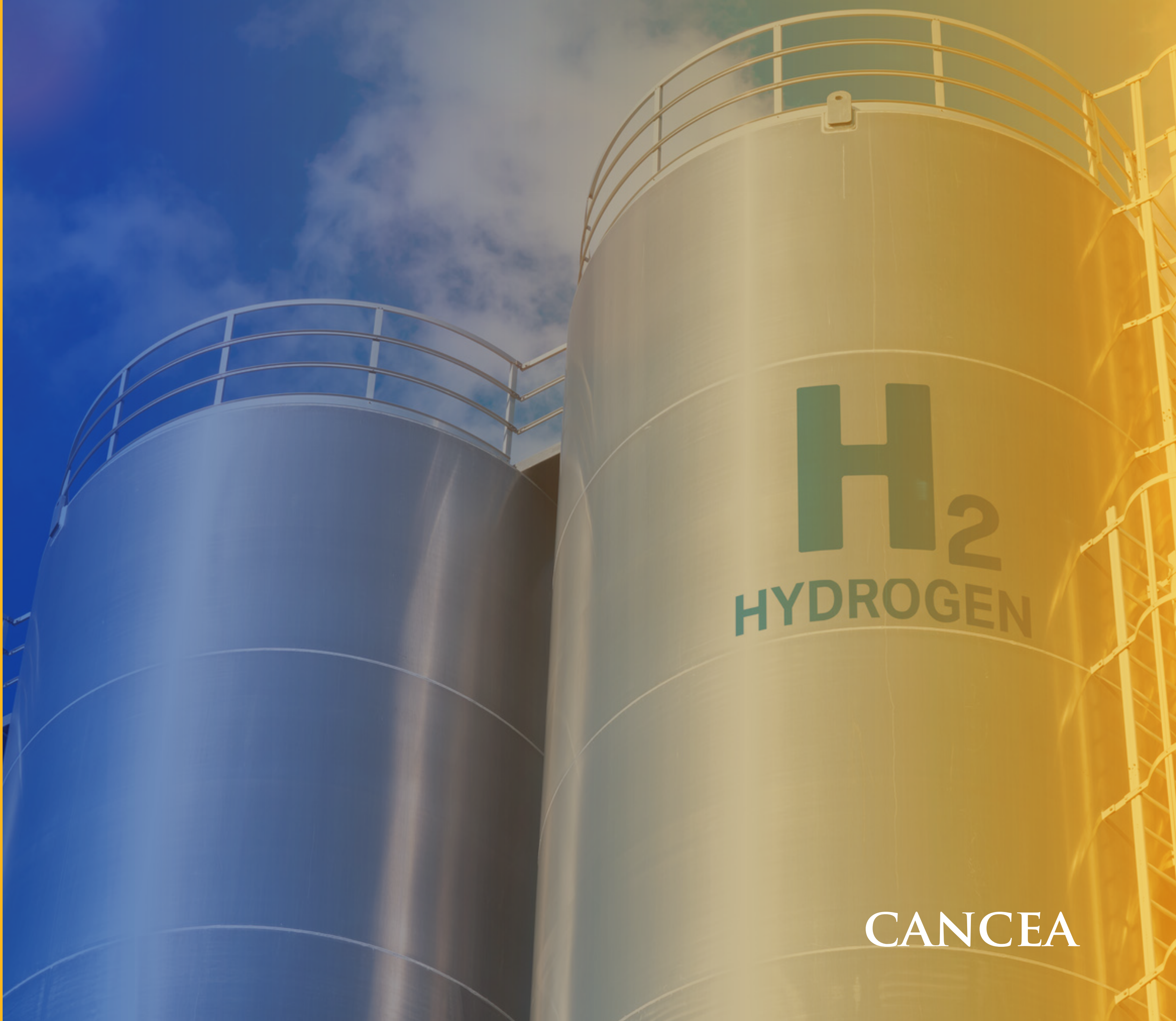
Economic Contribution of CCS and H2 Investments in Ontario 2024-2050

Research Report | October 2023



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Executive Summary

In light of the pressing social and economic issues posed by climate change, researchers, policymakers, and organizations have been focusing attention on developing approaches aimed at meeting emission reduction targets. In particular, the recent report "Pathways to Decarbonization"[1] (Independent Electricity System Operator (IESO), 2022) examined the investments in infrastructure required to decarbonize Ontario's electrical grid by 2050. The report covered a wide range of technologies, such as renewable energy, nuclear power, and hydrogen gas systems.

In addition, the "Pathways to Net Zero Emissions for Ontario"[2] report (Guidehouse, 2023) examined different approaches to achieving a net-zero energy system in Ontario by 2050, including a diversified scenario in which emissions are reduced over time through targeted electrification, paired with leveraging the gas system to deliver low- and zero-carbon fuels such as renewable natural gas and hydrogen, and advancing carbon capture and storage (CCS). This scenario was contrasted with an electrification scenario in which various sectors of the economy—such as building heating, transportation, and low and medium temperature industrial processes—are electrified, while hydrogen is used as a replacement for natural gas in systems that remain on gas, and CCS is adopted in high temperature processes. Overall, the diversified scenario, requiring a total of $681 billion of capital investment by 2050, was found to be the most cost-effective approach. Nonetheless, in both scenarios, H2 and CCS were required, to varying extents, in the industrial and transportation sectors, which underscores the importance of the timely implementation of these technologies. Similarly, the Canadian Energy Regulator's "Canada's Energy Future 2023" notes the importance of CCS and hydrogen in shaping Canada's energy outlook.[3]

This report presents the economic contributions to Ontario between 2024 and 2050 from a subset of the diversified scenario investments, those being in CCS and hydrogen gas systems. These investments, totalling up to $95 billion[4] by 2050, include direct and indirect investments in both infrastructure and operations relating to the production and transmission of hydrogen, carbon capture, transportation, and sequestration technologies, and end-user technologies. These schedules assume that investments will be carried out in a timely manner, preventing the loss of industry in Ontario that could result from the lack of infrastructure and legislation enabling firms to meet their emissions reduction targets. Together, these schedules comprise one of many potential pathways to net zero emissions in Ontario.

In addition, the opportunity costs of delays in the implementation of proposed investments are studied. These costs encompass lost economic gains such as GDP and employment contributions, in addition to potentially putting at risk the achievement of net-zero emissions by 2050. Delays of 3- and 5-year are analyzed.

[1] Pathways to Decarbonization (ieso.ca)

[2] Pathways to Net-Zero Emissions In Ontario | Enbridge Gas

[3] The report examines various net-zero scenarios. It finds that hydrogen will be a key alternative to electricity in heavy freight transportation, aviation, and certain industrial processes, with hydrogen making up 12% of the energy mix by 2050 in their Global Net-zero scenario. Moreover, in their Global Net-zero scenario, they find that by 2050, CCS is expected to capture an amount of emissions equivalent to 9% of Canada's total GHG emissions in 2021.

[4] For a breakdown of total investments and costs from the diversified scenario, see pages 43 and 44 of Guidehouse's "Pathways to Net Zero Emissions for Ontario" report.

Economic Contributions of Investments in CCS and H2 Technologies

$95 billion In investment and operations	Total investment in CCS and H2 amounts up to $95 billion by 2050, as part of a larger $681 billion diversified net-zero investment schedule
$8 billion annual average in GDP **$218 billion** total GDP	Corresponding to more than 1% of Ontario's current annual GDP and a $218 billion total GDP contribution between 2024 and 2050
44,343 annual average of jobs supported **1.2 million** job years total	With an average of nearly $4 billion in annual wage income and a total employment contribution of 1.2 million job-years

Magnitude of Impact: An investment up to $95 billion in low-carbon hydrogen and CCS to facilitate Ontario's transition to a clean energy future is expected to support over $218.8 billion in economic activity and 1.2 million job-years from 2024 to 2050.

Sectoral Contributions: Investing in hydrogen and CCS, particularly in hard-to-abate sectors such as cement, streel, and fertilizer manufacturing, serves as the catalyst for substantial economic expansion, both for the entire Ontario economy and for specific industry sectors. The broader Manufacturing sector stands to gain the highest returns from this initiative due to increased demand for manufactured goods, while the Utilities sector receives the second highest contribution in terms of average annual GDP and labour income, and the Retail Trade sector earns the second highest contribution in terms of average annual jobs created.

Detailed Analysis: The investment in hydrogen and CCS generates a significant economic impact across Ontario, contributing $114.5 billion into direct economic activity, complemented with $69.7 billion in indirect and $34.5 billion in induced economic activities. This underscores the pivotal nature of investments in hydrogen and CCS as a key opportunity for significant economic growth in the province.

The High Opportunity Costs of Delays

The "base case" in our analysis corresponds to investment schedules articulated by the diversified scenario presented in Guidehouse's "Pathways to Net Zero Emissions for Ontario". These schedules cover the 2024-2050 period.

The opportunity costs of delays, relative to the base case, in the implementation of proposed investments are significant to the Ontario economy. Such delays could stem from factors such as legislative impediments, unavailability of funds or constraints in the supply of labour and capital demanded by the proposed schedules. The resulting costs encompass forgone economic benefits in the form of lost GDP and employment contributions. Delays of 3- and 5-year are analyzed.

$53 billion
GDP at risk by 2050
272,510
Job years at risk

A 3-year delay of investments results in a 24% loss in GDP contribution and a 23% loss in job-years contribution by 2050, which amounts to approximately 272,510 job years at risk.

$84 billion
GDP at risk by 2050
435,100
Job years at risk

A 5-year delay of investments results in 38% in total GDP contribution and a 36% loss of total job-years contribution by 2050, which amounts to approximately 435,100 job years at risk.

Immediate Impact: Any delay in implementing the proposed investments will have significant negative economic repercussions. A 3-year postponement is projected to result in a $52.7 billion reduction in total GDP contribution up to 2050, while a 5-year delay could increase this loss to $83.7 billion.

Job Market Implications: Correspondingly, 23% and 36% job-years supported would also be at risk for the 3- and 5-year delays, respectively.

Efficiency Concerns: Beyond the immediate financial ramifications, our findings indicate that investment delays will also compromise the efficiency of investments, yielding diminishing returns over time.

Conclusions

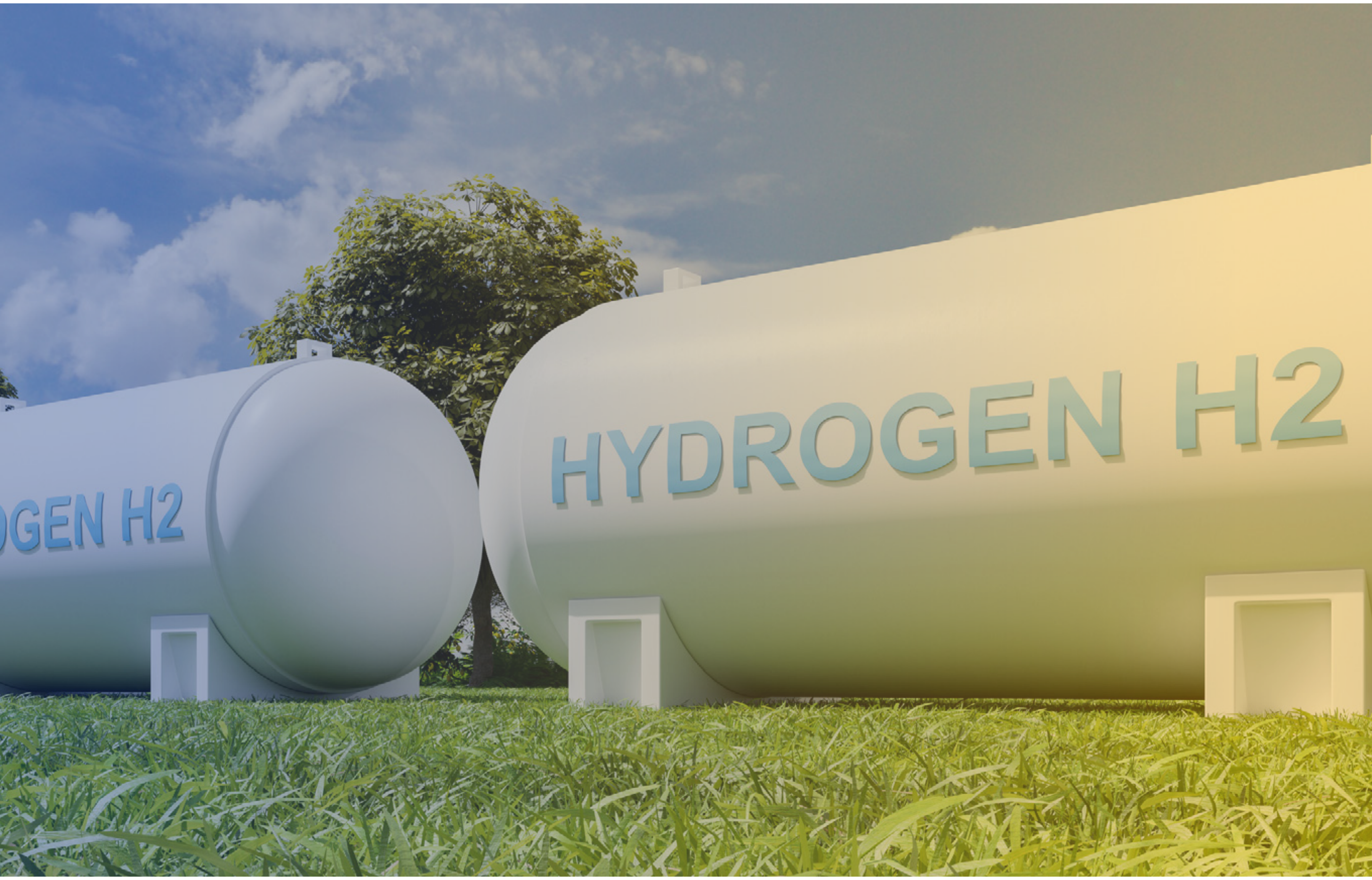
As Ontario faces the formidable challenges posed by climate change, this report has provided a view of the economic advantages and risks associated with delaying significant emissions reduction investments in hydrogen, carbon capture, transportation, and sequestration technologies, and end-user technologies. Within the context of a broader $681 billion diversified net-zero investment pathway, the focus on CCS and hydrogen gas systems entails an up to $95 billion investment plan. This strategic endeavour is projected to result in a staggering $218.8 billion boost to Ontario's economy between 2024 and 2050, fostering an annual average of 44,343 jobs, equivalent to a remarkable 1.2 million job-years of employment opportunities.

The Manufacturing sector stands out as the most significant beneficiary of investments in hydrogen and CCS, capitalizing on increased demands as the economy expands. Meanwhile, the Utilities and Retail Trade sectors also reap notable rewards, significantly contributing to GDP and job creation. The sizeable contributions attributable to the Utilities sector are expected, considering that this sector will play a key role in carrying out the proposed investments.

Our detailed analysis shows a multi-layered economic impact. Direct economic contributions are expected to be around $114.5 billion, with indirect and induced effects contributing an additional $69.7 billion and $34.5 billion, respectively. This analysis reaffirms that the proposed investments are not just impactful in terms of GHG reduction, but also in economic stimulation.

The report also delves into the large opportunity costs associated with any delays in implementing these investments. A 3-year delay could result in a 24% loss in total GDP contributions, amounting to $52.7 billion by 2050, accompanied by a 23% reduction in job-years, risking 272,510 job-years. Extending the delay to 5 years would exacerbate these losses, threatening $83.7 billion in GDP and 435,100 job-years, equivalent to 38% and 36% reductions, respectively. These losses stem primarily from the decreased efficiency of delayed investments, which causes them to yield diminishing returns over time.

Given the data and analysis presented, swift implementation of the proposed approach can generate significant economic benefits for Ontario. Investments in CCS and hydrogen technologies not only contribute to achieving net-zero emissions by 2050 but also yield significant economic benefits to Ontarians. Importantly, implementation delays due to legislative impediments, unavailability of funds or constraints in the supply of required capital and labour inputs can result in significant economic and employment losses. Therefore, timely implementation of emissions reduction investments is imperative for optimizing their resulting economic benefits.



1.0 Introduction

1.1 Background

The escalating importance of climate change within global policy discourse has spurred vast research into various strategies for meeting temperature goals. In the Canadian context, the Canadian Energy Regulator (CER)'s "Canada's Energy Future 2023" report recognizes the need for a diversified approach for achieving full decarbonization of electricity grids (Canada Energy Regulator, 2023). Additionally, the Independent Electricity System Operator (IESO)'s "Pathways to Decarbonization", which examined the investments in infrastructure required to decarbonize Ontario's electrical grid by 2050 (although it covered a less diverse set of investment areas than CER's report[5]), recommended a multi-faceted approach for achieving emission targets that retain natural gas-based electricity generation until viable alternatives are established and scaled. In its report, IESO delineated an approach totalling $375 billion to $425 billion in necessary investments.

A balanced approach to achieving net zero emissions, which supports the introduction of low- or zero-carbon gasses in the power generation system in addition to carbon capture and storage (CCS) technologies across industries, offers a more cost-effective approach to emissions reduction compared to abrupt, short-term decarbonization. It envisions the integration of emergent technologies aimed at mitigating emissions from existing natural gas operations, complemented by advancements in renewable energy, carbon capture, and other sectors. Specifically, innovations in CCS enable the sequestration of carbon dioxide emissions from industrial activities for long-term subterranean storage. CCS is expected to reduce GHG emissions from natural gas, which is important for heavy or "hard-to-abate" industries with few other decarbonization alternatives, and to support the production of low-carbon hydrogen. Furthermore, GHG emissions from current natural gas systems can be curtailed by substituting natural gas with lower-carbon or carbon-neutral gases like renewable natural gas (RNG) and hydrogen.

1.2 Objective

In 2022, Guidehouse prepared a report entitled "Pathways to Net Zero Emissions for Ontario" (Guidehouse, 2023) (the "Pathways" report). The report examined various strategies by which Ontario's energy infrastructure could facilitate the province's transition to net-zero emissions by 2050, and concluded that a diversified scenario, marked by advancements in electrification, the adoption of low-carbon hydrogen in processes currently dependent on natural gas, and CCS, would be the more cost-effective approach. The diversified pathway identified the need for investments nearing $700 billion to achieve net zero in the province, with up to $95 billion devoted to essential investments in electricity, hydrogen, and renewable methane capabilities, as well as storage and infrastructure, all aimed at realizing the net-zero emissions goal by 2050.

[5] IESO's report did not account for investments in carbon capture and storage technologies.

The present report aims to quantify the economic implications of this $95 billion investment strategy from 2024 to 2050. It primarily examines the aggregate and sector-specific impacts of the proposed investment schedules on Ontario's Gross Domestic Product (GDP), average labour income, and employment opportunities. Moreover, it studies the opportunity costs—in the form of forgone economic contributions—that could arise due to potential delays in the implementation of Guidehouse's pathway investments, relative to the timing presented in the Guidehouse report.

For the sake of presenting a more achievable investment timeline across all designated areas, slight modifications were made to the investment schedules originally set forth in Guidehouse's "Pathways" report. For each investment area, this consisted in redistributing portions of total investments, particularly those initially scheduled to occur between 2024 and 2030, across future years. Prior to this adjustment, some of the identified investments – principally, steam methane reforming (SMR) with CCS and end-user industry CCS – were sizeable and potentially unfeasible in the beginning years of the reference period. Nonetheless, total investments to 2050 remained the same for each investment area[6], ensuring that net zero targets will be met.

1.3 Scope of Investments

1.3.1 Descriptions of Systems and Programs

Guidehouse's "Pathways" report outlines specific investment domains connected to Ontario's electricity system, hydrogen gas infrastructure, and end-user technologies, all aimed at achieving net-zero emissions through a diversified strategy. Within this framework, Ontario's electricity system encompasses power generation facilities and the associated capital equipment. The hydrogen gas system refers to the infrastructure designed for hydrogen production, transmission, and storage. Meanwhile, end-user technologies are those that find application across various industrial sectors, as well as in residential settings.

Guidehouse's diversified strategy for reaching net-zero emissions seeks to couple a gradual phase-out of high-emission solutions with parallel investments in the advancement of alternative, cleaner solutions and infrastructures. Hydrogen, touted as a cleaner substitute for natural gas in applications ranging from electricity generation to heating and transportation, is anticipated to play a key role in this regard. Additionally, the expansion and deployment of CCS systems will act as a key mitigating factor for emissions emanating from current high-emission setups such as hard-to-abate industries that include the steel, cement, and refining sectors. Consequently, the investment scenarios delineated in this report allocate substantial resources to both the development of transmission and storage systems for hydrogen and the integration of CCS solutions with existing high-emission technologies and industries. In addition, leveraging the existing gas distribution system to deliver made-in-Ontario renewable gasses, including hydrogen, can prove useful in supporting the clean energy transition in the province.

[6] For each investment category, the adjustment procedure was as follows: of the original 2030 investment value, 25% of it was kept prior to, or in 2030, while the remaining 75% was redistributed over the 2031-2040 period. Then, of the original 2040 investment value, 75% of it was kept prior to, or in, 2040, while the remaining 25% was redistributed over the 2041-2050 period. This resulted in smoother investment schedules.

A comprehensive list of programs included in Guidehouse's report is provided in Table 1 below.

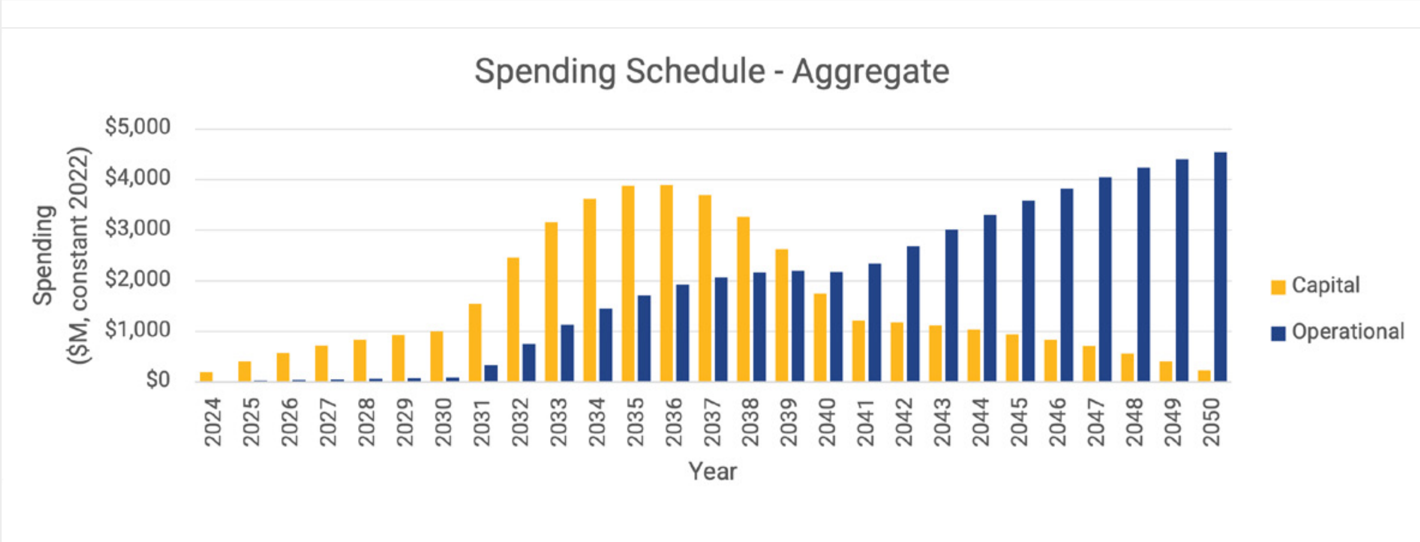
Table 1 **Descriptions of programs**

Program	System	Description
Biomass power plants paired with CCS	Electricity system	Power generation through direct combustion of biomass material, paired with CCS to create negative emissions.
Combined-cycle gas turbine (CCGT) power plants with hydrogen	Electricity system	Power generation through the use of a gas and a steam turbine together, in which hydrogen is used in place of natural gas.
Steam methane re-forming (SMR) paired with CCS	Gas system (H2)	Process in which methane from natural gas is heated, with steam, to produce a mixture of car-bon dioxide and hydrogen (Student Energy, 2023) paired with CCS.
Natural gas paired with CCS	Gas system (natural gas)	Use of natural gas paired with CCS in hard-to-abate industrial processes, such as steel and cement production.
Electrolysis	Gas system (H2)	Process of using electricity to split water into hydrogen and oxygen.
H2 salt cavern stor-age	Gas system (H2)	Hydrogen is purified, compressed, and injected into underground salt caverns.
H2 pipelines – repur-posing (H2 transmis-sion)	Gas system (H2)	Dedicated network of hydrogen pipelines to deliv-er hydrogen. Some natural gas infrastructure will be repurposed to this end.
Indirect end-user equipment	End user (residential buildings)	This includes, for example, hybrid heating sys-tems and gas heat pumps.
Industry CCS	End user (energy-in-tensive industries)	Capture, transportation, and sequestration of carbon dioxide emissions from medium and high temperature industrial processes.

1.3.2 Aggregate Spending

The Guidehouse diversified scenario's schedule for capital investments and operational expenditures across the electricity and gas systems are delineated in Figure 1. Between 2024 and 2050, direct spending on the construction and operation of the diversified scenario's programs is projected to amount up to $95 billion (in constant 2022 dollars). As anticipated, operational expenditures gradually constitute a larger proportion of the total spending, indicative of the completion of essential infrastructure and technology investments in the earlier years. Significantly, from the year 2040 onwards, the majority of the aggregate spending transitions to operational expenditures, while most aggregate spending until the early 2030s stems from capital investments.

Figure 1 **The capital and operational spending of all projects included in the analysis**

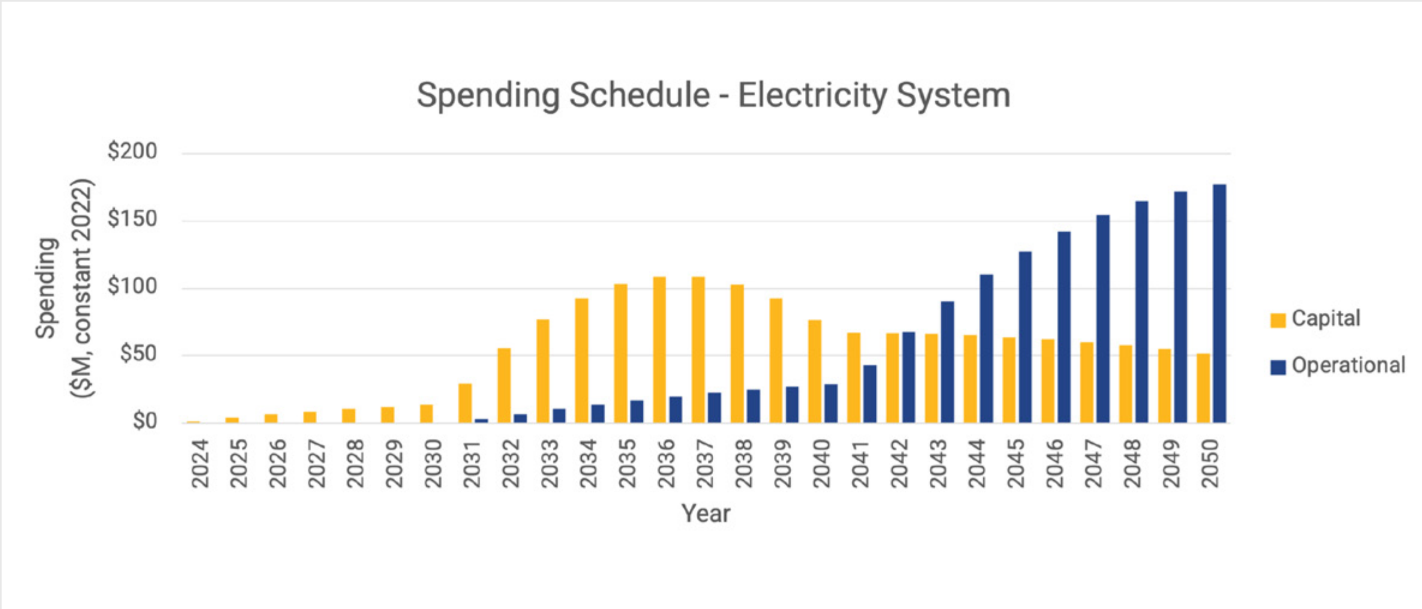


1.3.3 Electricity System Investments

The expenditure schedule for the electricity system is shown in Figure 2. The period from 2024 to 2040 is characterized by elevated levels of capital investments and comparatively lower operational costs. Conversely, from 2041 onwards, the focus shifts to higher operational expenditures and reduced capital investments, which peak in 2036. This implies that the essential infrastructure and technological improvements are expected to be realized by 2040.

Moreover, as detailed in Appendix A, within the electricity system, all capital investments leading up to 2040 are allocated exclusively to CCGT power plants powered by hydrogen. Notably, there are no expenditures directed towards Biomass power plants integrated with CCS until 2040.

Figure 2 **The capital and operational spending of projects within the electricity system**

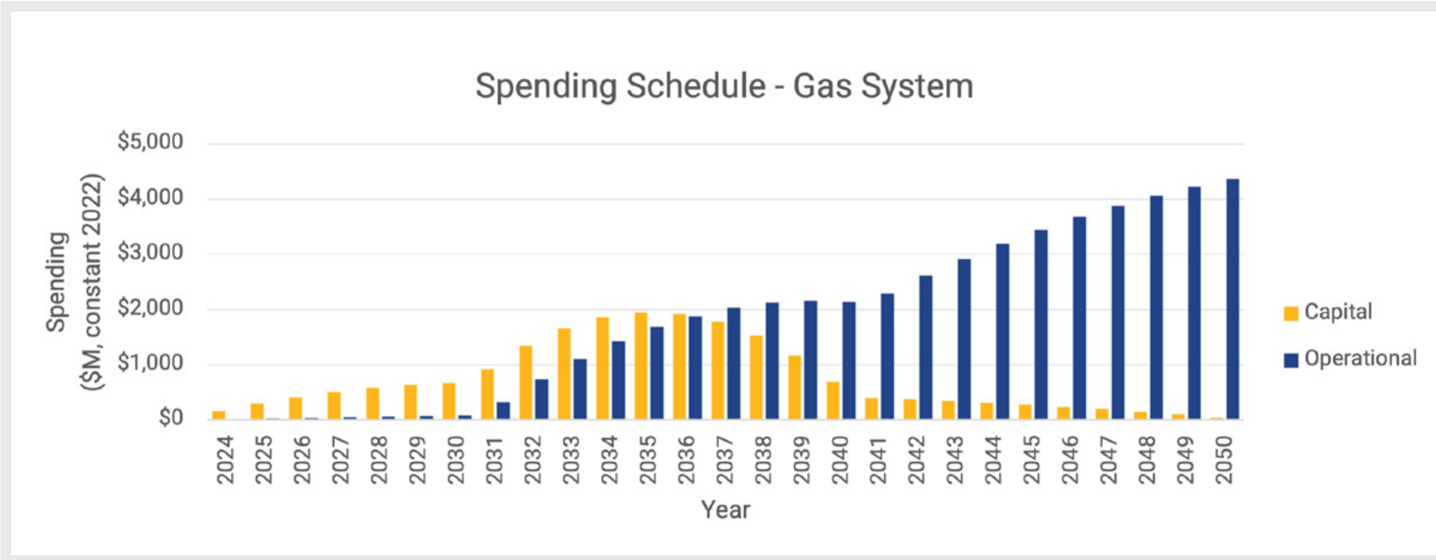


1.3.4 Gas System Investments

For the gas system (including both natural gas and hydrogen infrastructure and operations), the expenditure schedule is outlined in Figure 3. Capital investments demonstrate a consistent decline throughout the reference period, reaching minimal levels by 2041. Conversely, operational expenditures exhibit a continuous upward trend from 2024 to 2050.

As indicated in Appendix A, the gas system sees no capital investments directed towards natural gas power plants for the entire period from 2024 to 2050. Investments in electrolyzers become prominent during the 2030s, peaking in 2036, only to decline in the subsequent decade. This reduction is indicative of the successful completion of necessary technological and infrastructural milestones. Consequently, operational expenses for this program follow an inverse trajectory, owing to the increased maintenance and operational costs associated with the expanded infrastructure. Finally, initial investment in steam methane reforming coupled with CCS is robust but gradually diminishes over time, reaching low levels from 2040 onwards. Operational expenditures for this initiative, in contrast, display an escalating pattern.

Figure 3 **The capital and operational spending of projects within the gas system (both H2 and natural gas)**



In aggregate, capital investments are predominantly concentrated in the gas system. A closer examination of the individual program spending schedules, as laid out in Appendix A, reveals that steam methane reforming combined with CCS is the primary driver of this spending discrepancy between the two systems. In contrast, Biomass power plants integrated with CCS account for the minimal investment throughout the reference period, with zero expenses until 2040.

Notably, the capital investment timeline for electricity systems extends up to 2050, whereas most necessary capital investments for gas systems are anticipated to be fulfilled by 2040. This investment trajectory aligns coherently with the previously discussed goals. Specifically, the operation of a modernized electricity system—fueled by hydrogen-based power generation technologies like CCGT with H2—will necessitate a fully developed infrastructure for hydrogen production and distribution.

1.3.5 End-User Technologies Spending

Next, the investment schedule for indirect end-user technologies is shown in Figure 4. The investment patterns for both technologies exhibit similar trends: an accelerating increase in spending until the mid-2030s, followed by a gradual decrease through the end of the period. Operational expenses for indirect end-user technologies are notably absent, reflecting the program's focus on small-scale residential buildings. Conversely, industry CCS does incur operational costs, albeit at minimal levels throughout the reference period. This suggests that, for industry CCS, most of the costs stem from its development and implementation in industrial processes, while operational costs, incurred after implementation, are relatively low.

In addition, as seen in the program-specific spending schedules presented in Appendix A, the decrease in investment for Industry CCS is met by a concurrent increase in spending for power generation programs paired with CCS, namely biomass combined with CCS, CCGT combined with CCS, and steam methane reforming combined with CCS. This suggests that the evolution of CCS systems is crucial for the achievement of net zero emissions through the proposed approach.

Figure 4 **The capital and operational spending of end-user projects**

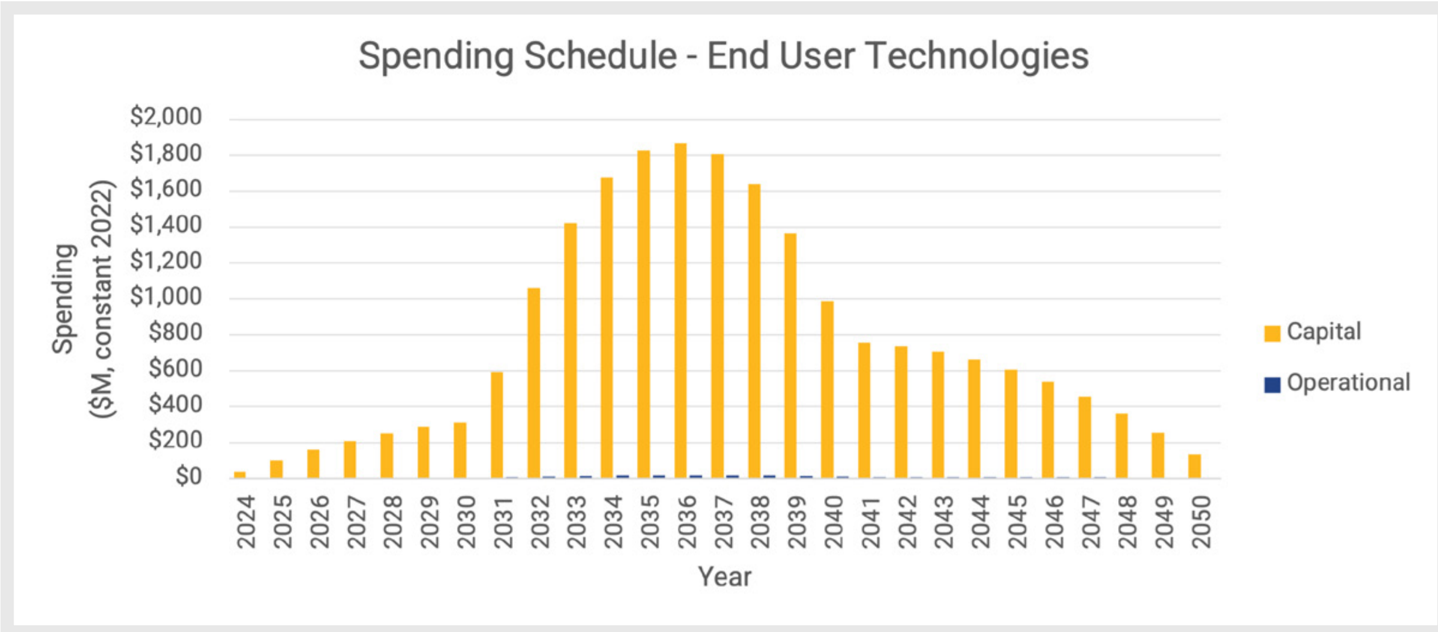


Figure 5 lists total emissions for Ontario's top 20 high-emitting industrial sectors, each identified by their corresponding 6-digit NAICS codes, for 2021. These sectors cumulatively represent more than 90% of the province's total industrial emissions. It's noteworthy that the emission figures for the lower-emitting sectors may not be wholly accurate because these businesses are not obliged to report their emissions if they emit less than 10,000 tonnes of CO2 per year. However, as the high-emitting sectors—which make up the majority of industrial emissions—are required to report, the summarized figures likely offer a reliable snapshot of the province's total industrial emissions.

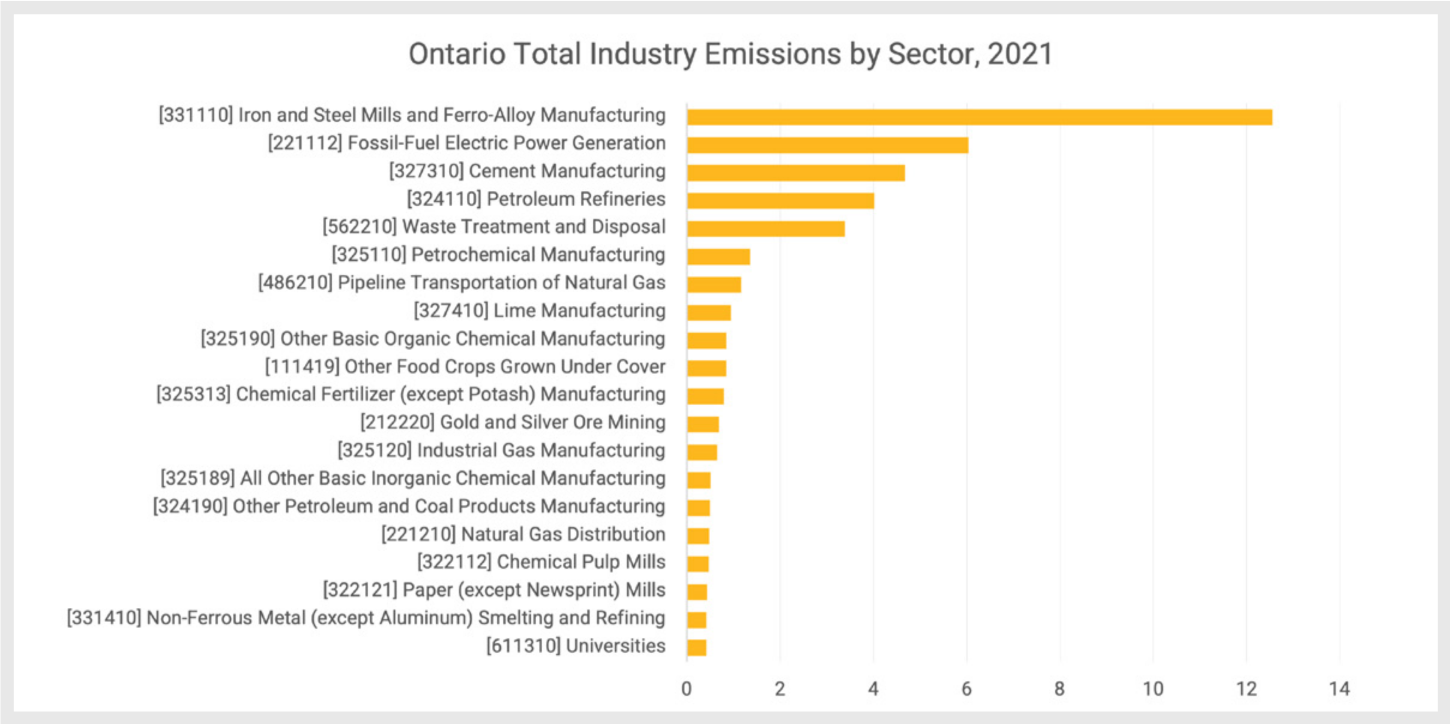
This data underlines the critical role of CCS technologies in achieving net zero emissions via a diversified approach. CCS is the most near-term, cost-effective solution for reducing emissions in high-emitting sectors like iron and steel production, cement manufacturing, and oil refining, as well as in fossil-fuel-based power generation. Therefore, the implementation of CCS systems across both industrial end-users and power generators is well-justified.

Furthermore, the emission data can be used to forecast the costs linked to CCS—covering capture, transportation, and storage of CO2—across industries over the reference timeline[7]. The anticipated average cost for CCS per tonne of CO2 is set at $102[8].

[7] See Navigant's "Gas for Climate" report (2019) (pages 145 and 146) for the methodology adopted in the estimation of CCS costs given industrial emission levels (Navigant, 2019). The same approach was adopted in the estimation of the presented average costs for CCS per tonne of CO2, given appropriately weights given to Canadian industries according to their emissions.

[8] Given that this number was obtained as a weighted average of CCS costs across industries, accounting for industry-level emission levels, it differs slightly from the $95/ tonne presented in Guidehouse's report.

Figure 5 **Ontario total industry emissions by sector, 2021**



Source: Government of Canada, Greenhouse Gas Reporting Program (GHGRP), 2021 (Canada, 2023)

2.0 Scenarios and Approach

2.1 Analysis Scenarios

The baseline scenario analyzes the economic contribution of proposed investment schedules starting in 2024. However, a variety of factors, ranging from political to logistical, can hamper the immediate implementation of proposed programs. Expectedly, the consequent delays result in reduced contributions, due to both the direct lack of investment in infrastructure and the indirect effects throughout the broader economy. To illustrate the foregone economic benefits associated with potential delays, in addition to the baseline scenario this report analyzes two alternative scenarios, in which investments are delayed by 3 and 5 years, respectively.

The resulting forgone benefits are quantified, for instance, in the form of GDP and job-years of work opportunity costs. These numbers represent the forgone economic benefits from impediments that can arise in the implementation of the proposed program.

2.2 Approach

This study utilizes CANCEA's agent-based modelling platform to analyze the economic contributions of the CCS- and H2-related proposed programs. Spending schedules were obtained from the Pathways to Net Zero Emissions study.

CANCEA's agent-based platform is a detailed socioeconomic simulation platform designed to analyze policy and infrastructure scenarios. It performs calculations on the level of individual people, firms, and governments, which are modelled using extensive data inputs. For example, data inputs for individual households include, in addition to demographics, factors such as household structure, labour force participation, and finances. Businesses are modelled using a combination of Statistics Canada data and input/output tables at the local level. Importantly, the platform is geospatial and covers more than 56,000 dissemination areas across Canada.

The economic contribution from the proposed programs arise from the increased economic activity induced by infrastructural and technological investments, and operational expenses. The structure of CANCEA's model allows it to accurately trace out the widespread economic effects of the initiatives, hence producing figures relating to impacts on key economic metrics such as GDP and jobs supported. Specifically, the contributions are identified from following dissemination channels:

Direct effects: these include the economic activity generated by the construction of infrastructure and related maintenance, as well as operating wages.

Indirect effects: these include all economic activity that arises through business-to-business interactions within the supply chain. Indirect effects include input expenditures, as well as the follow-on expenditures that are generated further up and down the supply chain in all sectors of the economy.

Induced effects: these include all economic activity generated through the spending of wages earned by employees working in either the targeted investment areas or related industry sectors. Induced effects also include expenditures on increased capacity or the replacement of depreciating capital stock that result from reinvesting business profits. These purchases or activities can lead to further hiring, resulting in income and tax revenues that reverberate throughout the economy.

As a caveat to the approach adopted in this analysis, it should be noted that constraints on the supply of inputs to the infrastructure projects included, especially of labour inputs, were not implemented. This assumes that the necessary infrastructural and technological advancements will not be hindered by input supply shortages during the reference period.

3.0 Results

3.1 Economic Contribution

3.1.1 Ontario

This section presents our results regarding the economic contribution to Ontario of the diversified pathways' associated programs. Findings on how the $95 billion investment would stimulate Ontario's economy are summarized in Table 2. Between 2024 and 2050, strategic investments in CCS and hydrogen are projected to help Ontario on the path to net zero while driving significant economic growth, contributing over $218.8B in economic activity. This includes $114.5B in direct economic effects, $69.7B in indirect economic effects, and $34.5B in induced economic effects. Notably, the estimated average annual GDP boost of $8.1 billion constitutes roughly 1% of Ontario's yearly GDP. These promising figures underscore the substantial economic benefits to Ontario that can be realized through investments in CCS and hydrogen from 2024 to 2050.

Table 2 **Total economic contribution to Ontario of proposed investments**

Metric	Direct effect	Indirect effect	Induced effect	Total
Total GDP ($M)	$114,571	$69,681	$34,552	$218,804
Average Annual GDP ($M)	$4,243	$2,581	$1,280	$8,104
Average Annual Labour Income ($M)	$1,720	$1,368	$548	$3,636
Job-years supported	393,133	496,688	307,453	1,197,273
Average Annual FTEs	14,560	18,396	11,387	44,343

Figure 6 and Figure 7 further dissect the year-by-year contributions to GDP and job creation, separating the impacts into direct, indirect, and induced effects. Overall, the bulk of contributions is concentrated in the 2040s, with sizeable contributions also present in the 2030s. This trend aligns with the diversified pathway's investment schedules, which identify extensive investments for the associated programs in the 2030s and shift the focus to operational expenses in the 2040s. In essence, the high investment levels in the 2030s serve to lay the groundwork for economic activity in the 2040s through operational activities, such as wages and subsequent consumer spending.

The slight downturn in economic activity around 2040 is expected, since the completion of most capital infrastructure projects by 2040 signifies a drop in GDP contribution generated by the construction of infrastructure (direct effect) as well as input expenditures contemplated by those projects (indirect effect). However, the remaining contributions, which arise from the spending of wages (induced effects), are not significantly affected.

When comparing GDP contributions and job creation, a distinct pattern emerges. In the case of job creation, indirect effects outweigh both direct and induced effects. This suggests that the ripple effects along the supply chain play a more pivotal role in generating employment opportunities than either direct construction activities or the broader economic impact of wage expenditures. On the flip side, direct contributions through infrastructure construction are more influential in boosting GDP over time than the other two categories.

A crucial aspect of this analysis is its resilience to variations in cost factors and capital levels during the project's lifespan. For a side-by-side comparison between the baseline scenario and alternative scenarios featuring differing cost structures, refer to Figure 24 in Appendix A.

Figure 6 **Annual GDP contribution to Ontario from proposed investments, by type of effect**

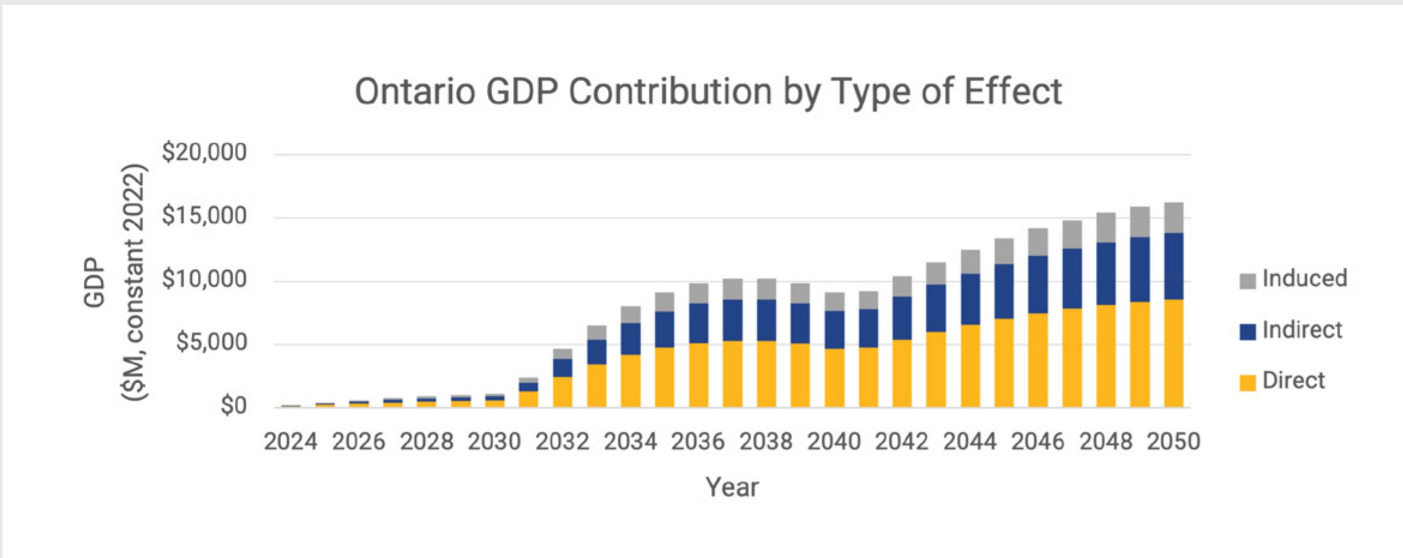
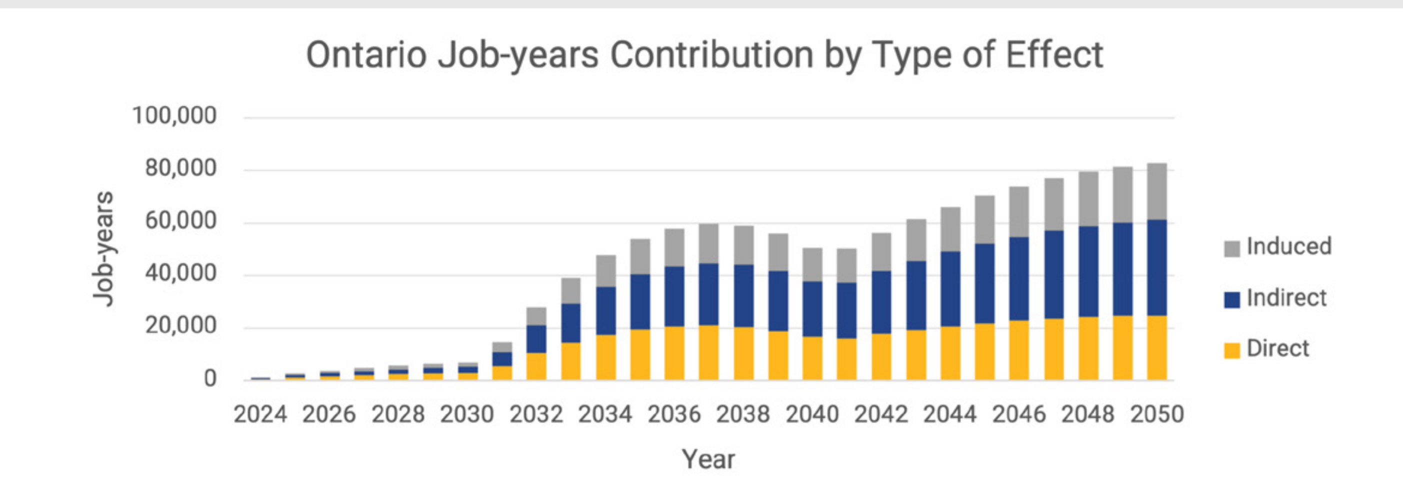


Figure 7 **Annual job-years contribution to Ontario from proposed investments, by type of effect**

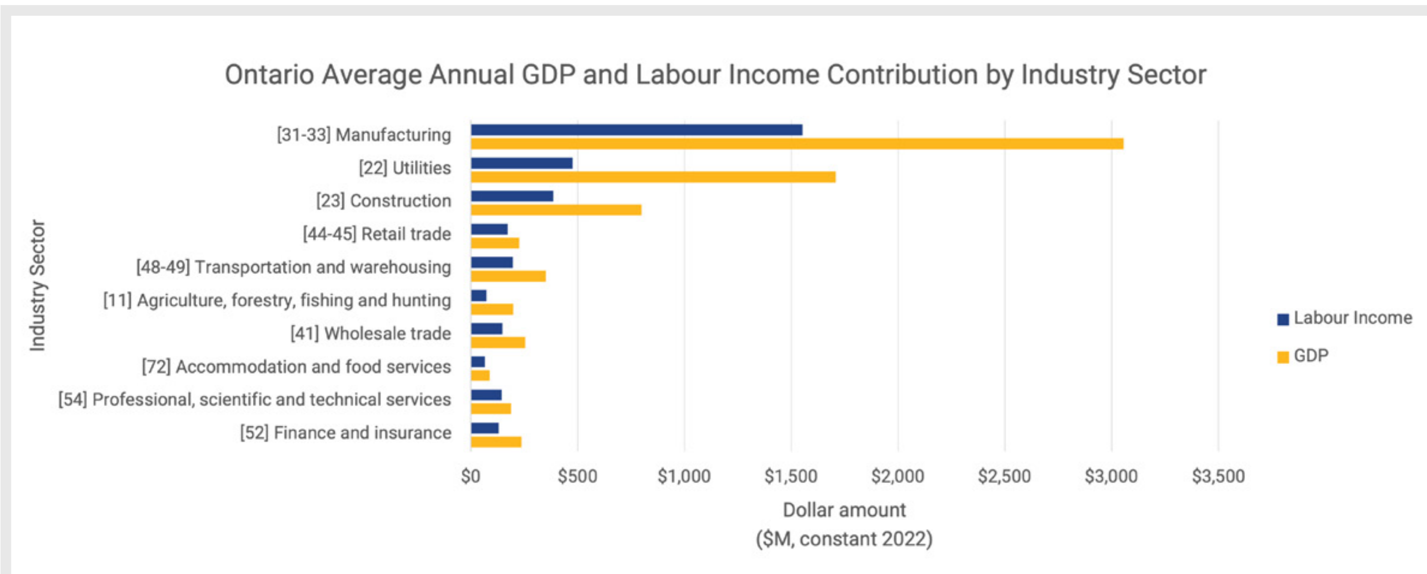


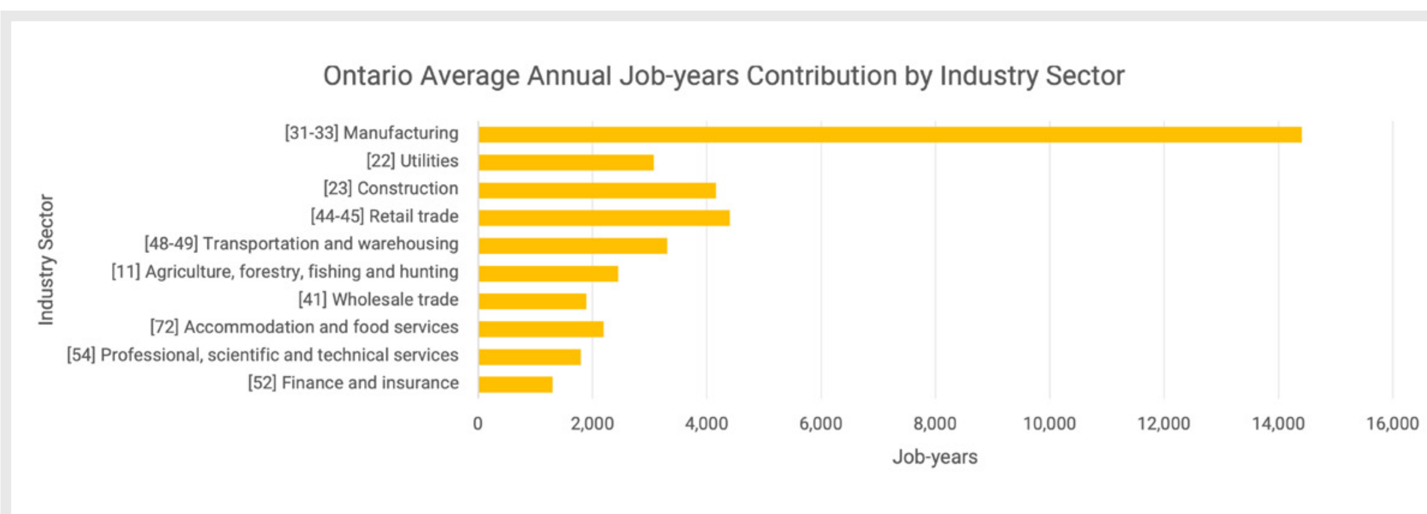
3.1.2 Industry sectors

This section further evaluates the results presented above by examining contributions by industry sector, for the top 10 sector by annual GDP contribution. The average yearly economic contributions by industry, categorized according to the 2-digit NAICS code, are shown in Figure 8 below. The Manufacturing sector emerges as the leading contributor across all key metrics—GDP, employment measured in job-years, and labor income, followed by Utilities for contributions to GDP and labour income, and Retail Trade for job creation in terms of job-years. The Manufacturing sector's dominant role is anticipated, as the broader economic growth spurred by the diversified pathway's investments naturally boosts the demand for manufactured goods, including not only products for the construction and operation of the infrastructure, but also essential items like food and other common consumer goods.

Less intuitively, sectors such as Agriculture and Fishing and Accommodation and Food Services also benefit from the presented investment schedule, albeit to a much smaller extent. This simply corresponds with the ripple effects associated with the resulting economic expansion, which drives economy activity throughout the province.

Figure 8 **Average annual GDP, labour income, and job-years contributions to Ontario from proposed investments, by industry sector**





3.2 Opportunity Costs of Delays

This section explores the repercussions of 3- and 5-year delays in the implementation of the presented investment schedule on the Ontario economy, in comparison with a no-delay baseline scenario. These delay scenarios may stem from legislative obstacles or input supply constraints and consist in the late implementation of proposed investment schedules. The resulting repercussions consist of opportunity costs in the form of forgone economic contributions, in addition to potentially putting at risk the achievement of net-zero emissions by 2050. Table 3 and Table 4 below depict our findings in this regard.

Significantly, both delay situations substantially diminish economic contributions. A 3-year delay in the implementation of the diversified pathways' associated investments shaves off $52.7 billion from the total GDP contributions up to the year 2050. Extending the delay to 5 years exacerbates this loss, with a $83.7 billion decrease in GDP contribution. In percentage terms, these translate to a 24% and 38% shrinkage in total annual GDP contribution for the 3- and 5-year delays, respectively. Job creation also suffers, declining by approximately 23% in a 3-year delay scenario and by 36% when the delay stretches to 5 years.

Table 3 **Total economic contribution to Ontario from proposed Investments, by delay scenario**

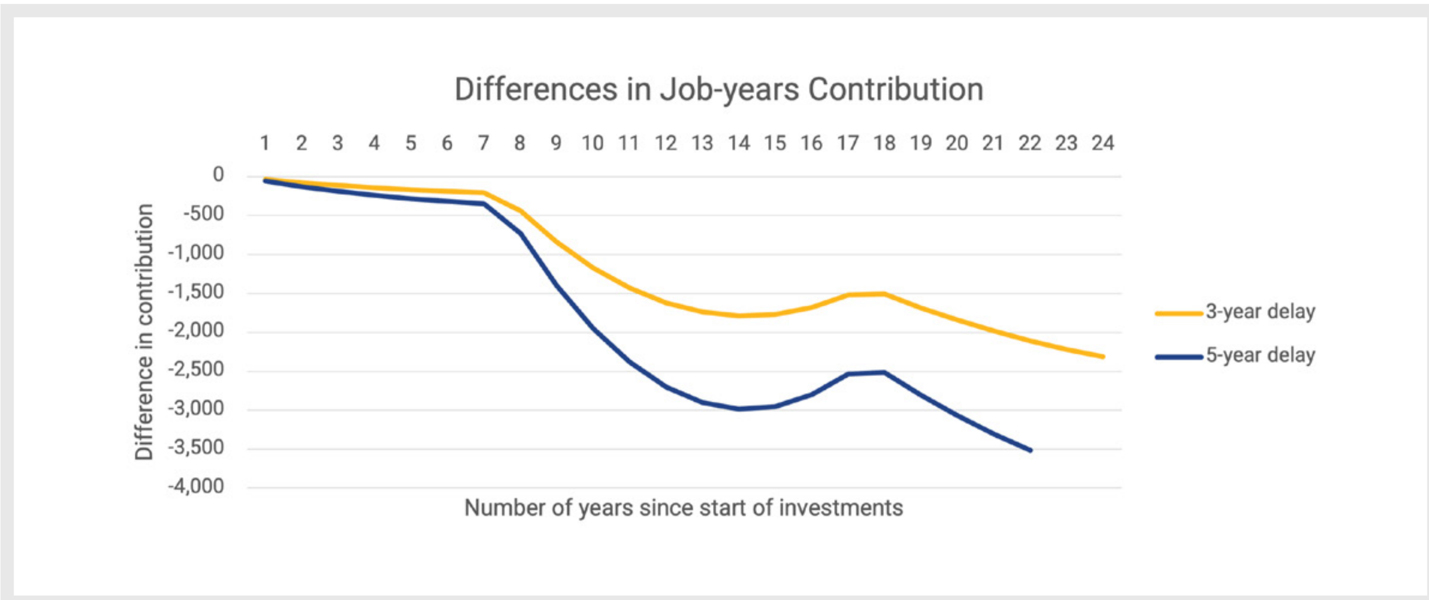
Metric	Base case (no delay)	3-year investment delay	5-year investment delay
Total GDP ($M)	$218,804	$166,088	$135,101
Average Annual GDP ($M)	$8,104	$6,151	$5,004
Average Annual Labour Income ($M)	$3,636	$2,792	$2,291
Job-years supported	1,197,273	924,702	762,221
Average Annual FTEs	44,343	34,248	28,230

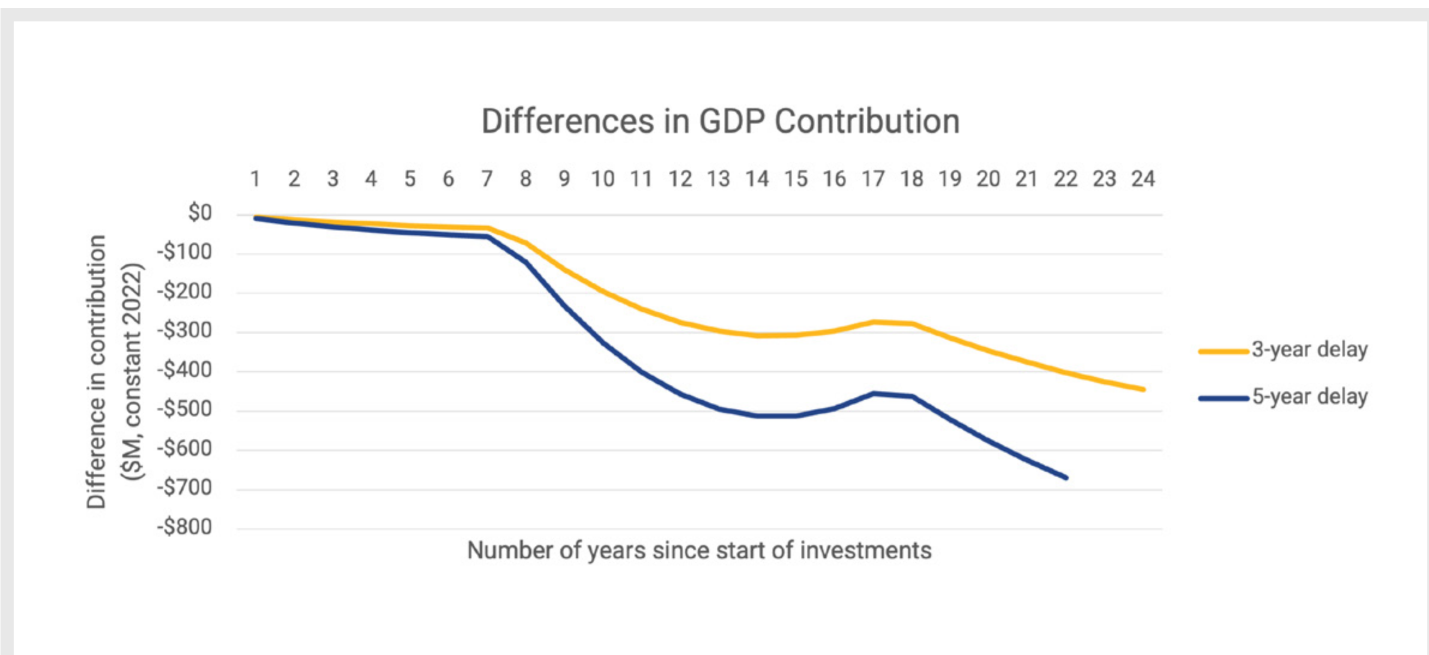
Table 4 **Opportunity costs (forgone economic contributions) of delay scenarios**

Metric	3-year investment delay	5-year investment delay
Total GDP ($M)	-$52,716	-$83,704
Average Annual GDP ($M)	-$1,952	-$3,100
Average Annual Labour Income ($M)	-$845	-$1,345
Job-years supported	-272,571	-435,052
Average Annual FTEs	-10,095	-16,113

Finally, Figure 9 shows the differences in contribution between each of the delay cases and the base case, by the number of years since the start of investments. For clarity, in the charts below, the year labeled "1" signifies 2024 for the baseline, 2027 for the 3-year delay, and 2029 for the 5-year delay. The charts show that with respect to both the GDP and job-years contributions, a larger delay results in larger differences in contribution relative to the baseline scenario for each since the start of investments. This means that delaying investments in CCS and hydrogen not only diminish their overall impact but also erode their efficiency in generating economic benefits, translating into lost opportunities and reduced returns. This loss in efficiency increases with the size of the delay.

Figure 9 **Differences relative to baseline scenario in annual contributions by number of years since start of investments, by scenario**





4.0 Conclusions

This report examined the economic contributions to Ontario from 2024 to 2050 from a subset of investments identified under the diversified approach to net zero emissions in Ontario delineated in Guidehouse's "Pathways to Net Zero Emissions for Ontario" report. These investments focus on CCS and hydrogen gas systems. Totalling up to $95 billion by 2050, they include infrastructure and operations relating to the production and transmission of hydrogen; carbon capture, transportation, and sequestration technologies; and indirect end-user technologies.

Economic Contribution of Investments

Guidehouse's diversified pathway shows that between 2024 and 2050, Ontario's strategic investments of up to $95 billion in CCS and hydrogen would will have a profound impact on the economy. It would support over $218 billion in economic activity, sustain 1.2 million job-years, and boost our annual GDP by $8 billion, create over 44,000 jobs per year, and add $4 billion to Ontario's annual wage income. Hence, Guidehouse's diversified pathway stands to create significant benefits for Ontario's economy.

A wide spectrum of sectors within Ontario are poised to benefit from the contributions of CCS and hydrogen investments to Ontario's GDP, job-years, and labour income. Among these sectors, the Manufacturing sector, which covers hard-to-abate sectors such as steel and cement production and refining, emerges as the principal beneficiary, predominantly due to the increased demand for manufactured goods that would stem from economic expansion. This surge in economic contribution stems from multiple channels, including both direct investments and the multiplier effect generated when individuals reinvest their earnings into the economy.

The Cost of Delay

Timeliness is paramount to the contributions of CCS and hydrogen investments. Delays in the implementation of presented investment schedules have cascading negative effects on investments and contributions to GDP, job-years, and labour income. For instance, a 3-year delay in implementation could result in a significant $52.7 billion reduction in total GDP contribution, equating to a 24% decline compared to a no-delay scenario. Stretching the delay to 5 years would exacerbate the loss to $83.7 billion, amounting to a substantial 38% drop in total GDP contributions. Job-years would also be significantly affected in a similar vein, with a 3-year delay causing a notable 23% reduction, while a 5-year delay could result in a substantial 36% decline. These numbers underscore the need for swift action, including clear policies and regulatory processes, transparent frameworks, and enhanced communication, to prevent delays in CCS and hydrogen investments, with a view to fostering economic growth and creating jobs for Ontarians.

Moreover, the estimated economic contributions associated with delays, while following a similar trajectory to the no-delay scenario, become less efficient in generating economic contributions, magnifying the opportunity costs. This indicates that delays not only defer economic benefits but also compromise the potential of return on investments.

Summary

In summary, the results of our analysis underscore the significance of timely investments in Ontario's electricity and gas systems, hydrogen infrastructure, and carbon capture and storage technologies. These strategic investments would foster substantial economic activity in the decades ahead. Nonetheless, it is imperative to recognize that a large share of these contributions is at risk from possible investment delays. Such delays could not only jeopardize the long-term efficiency and effectiveness of these investments but also impact their capacity to drive economic growth in Ontario.

A. Investments by Technology Type

The charts below depict the spending schedules for each investment area identified in the "Pathways to Net Zero Emissions for Ontario" report (Guidehouse, 2023), over the 2024-2050 period. Spending includes capital investments and operational expenses.

Figure 10 **The capital and operational spending in biomass power plants paired with CCS**

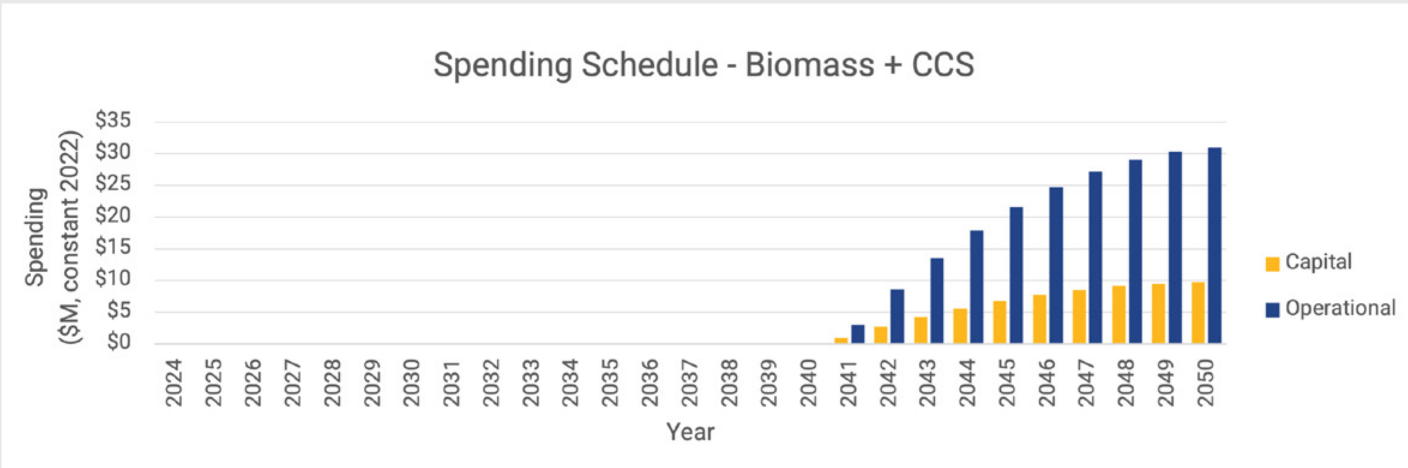


Figure 11 **The capital and operational spending in CCGT power plants with hydrogen**

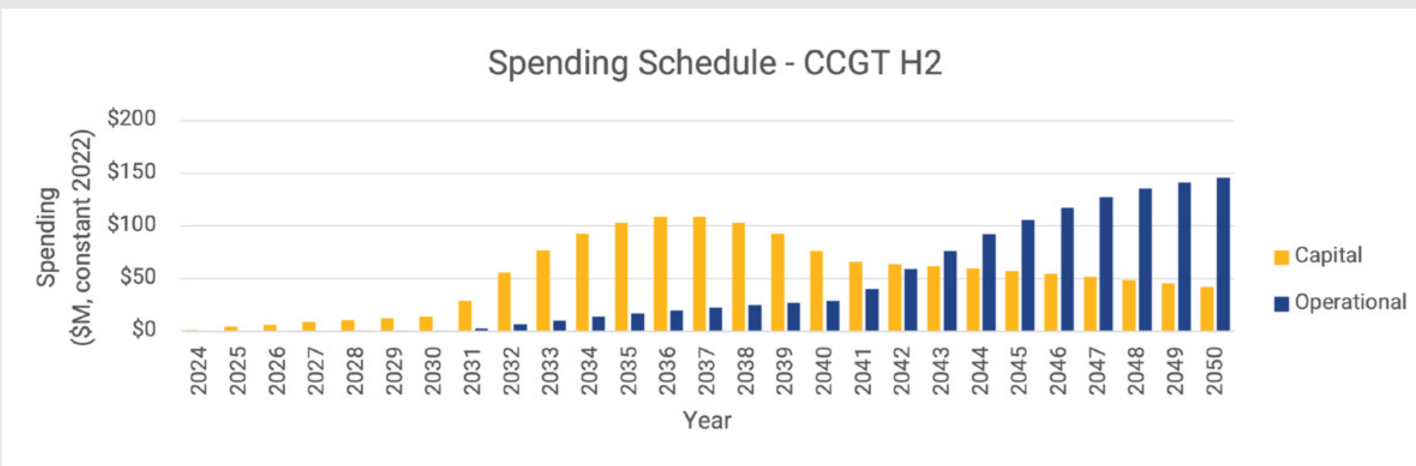


Figure 12 **The capital and operational spending in the use of natural gas in industrial processes paired with CCS**

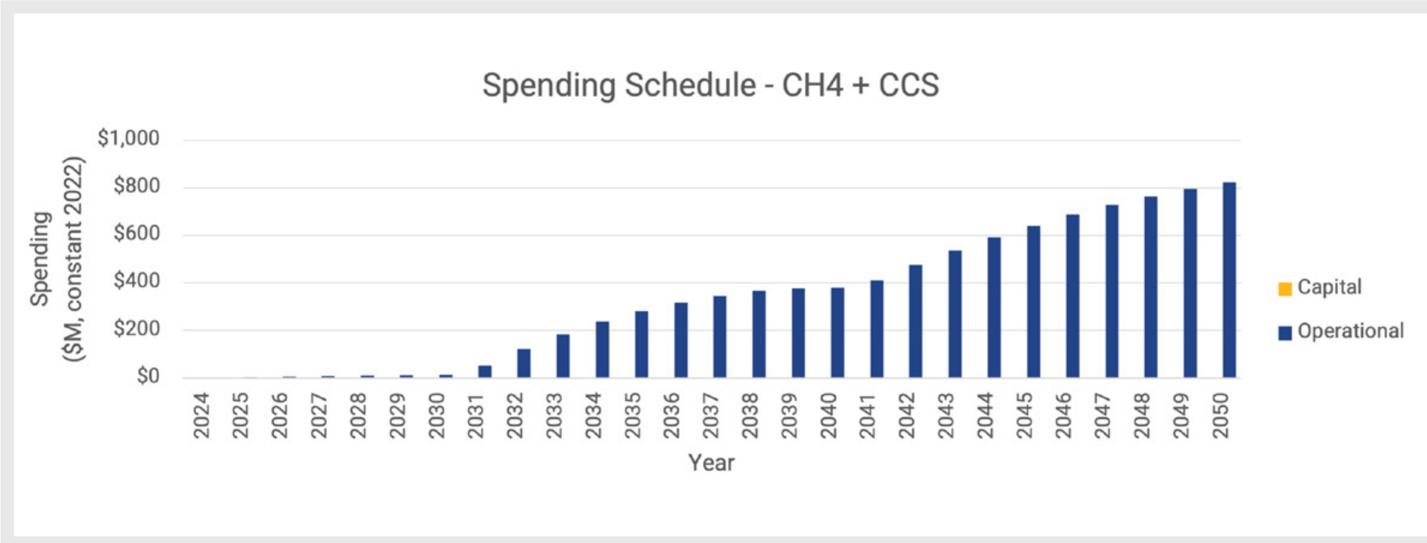


Figure 13 **The capital and operational spending in electrolyzers**

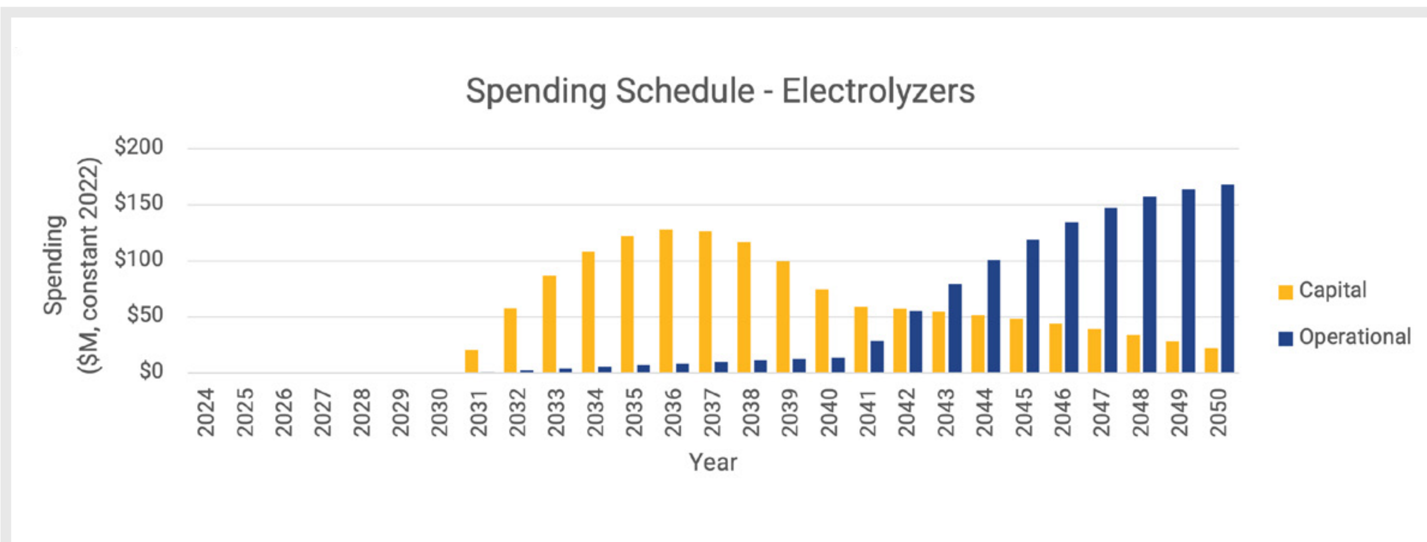


Figure 14 **The capital and operational spending in indirect end-user technologies**

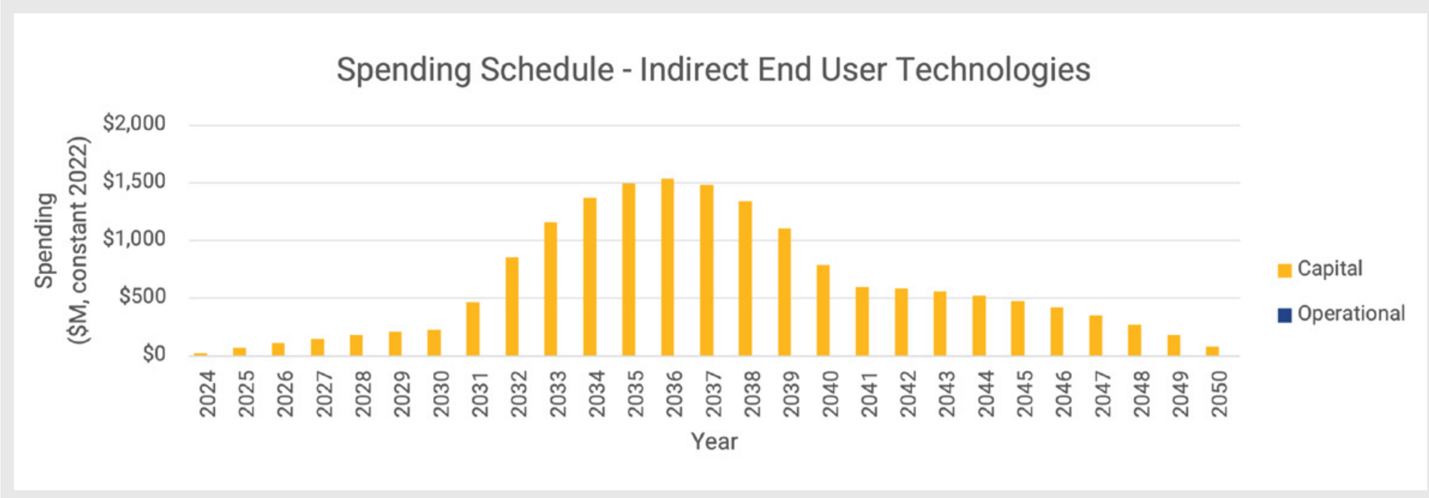


Figure 15 **The capital and operational spending in hydrogen salt cavern storage**

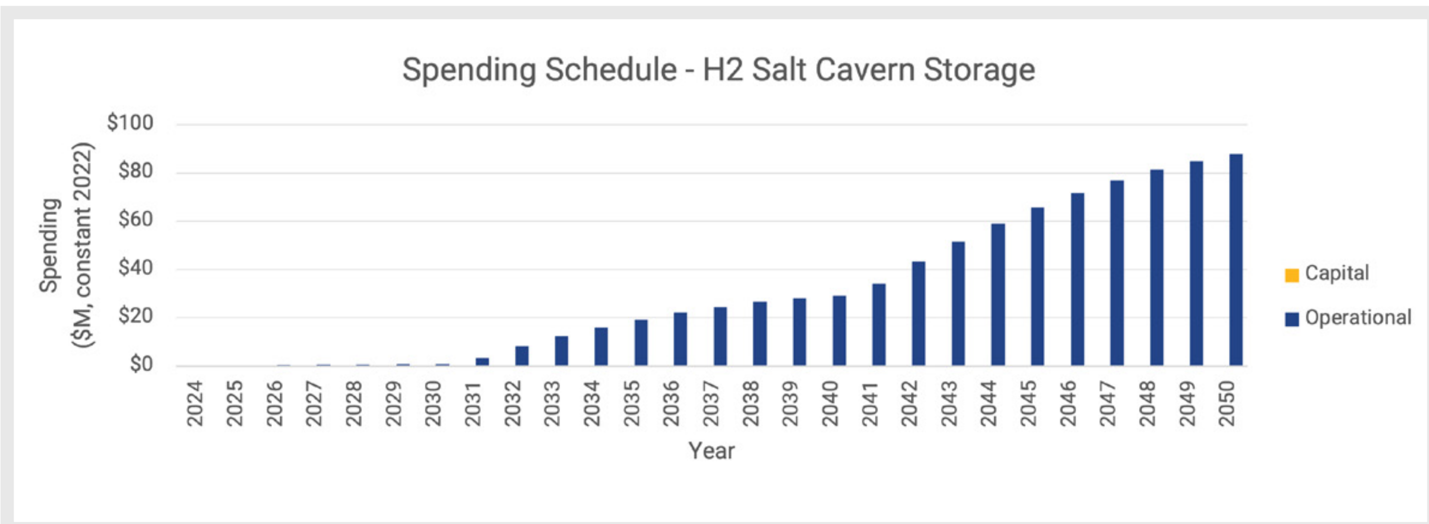


Figure 16 **The capital and operational spending in hydrogen transmission**

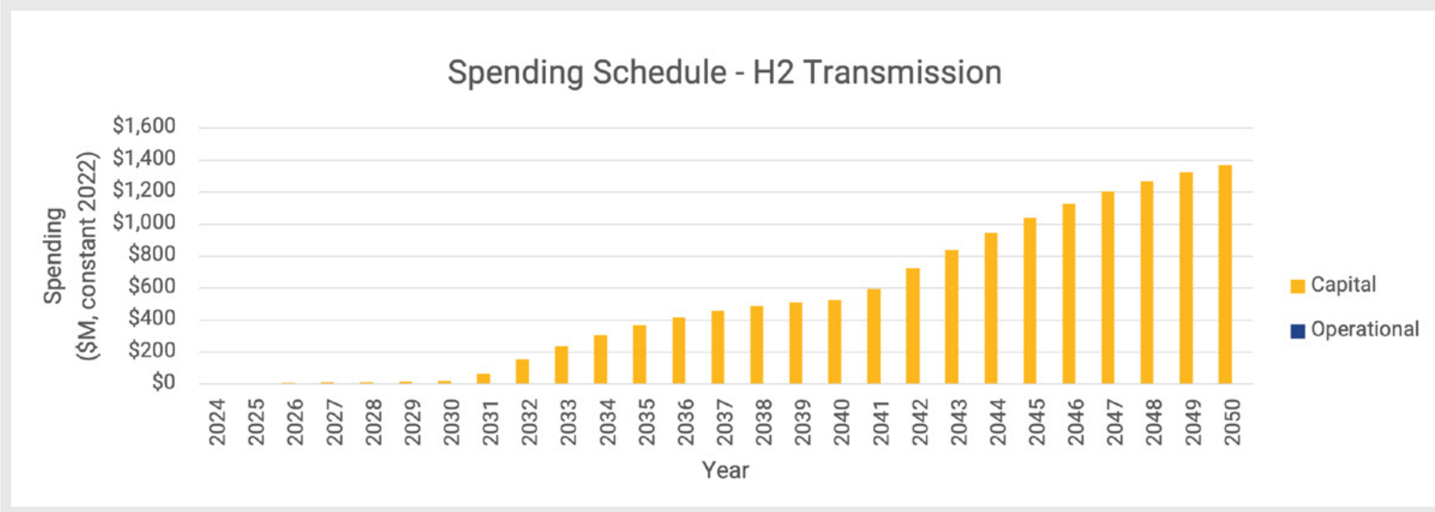


Figure 17 **The capital and operational spending in end-user industry CCS**

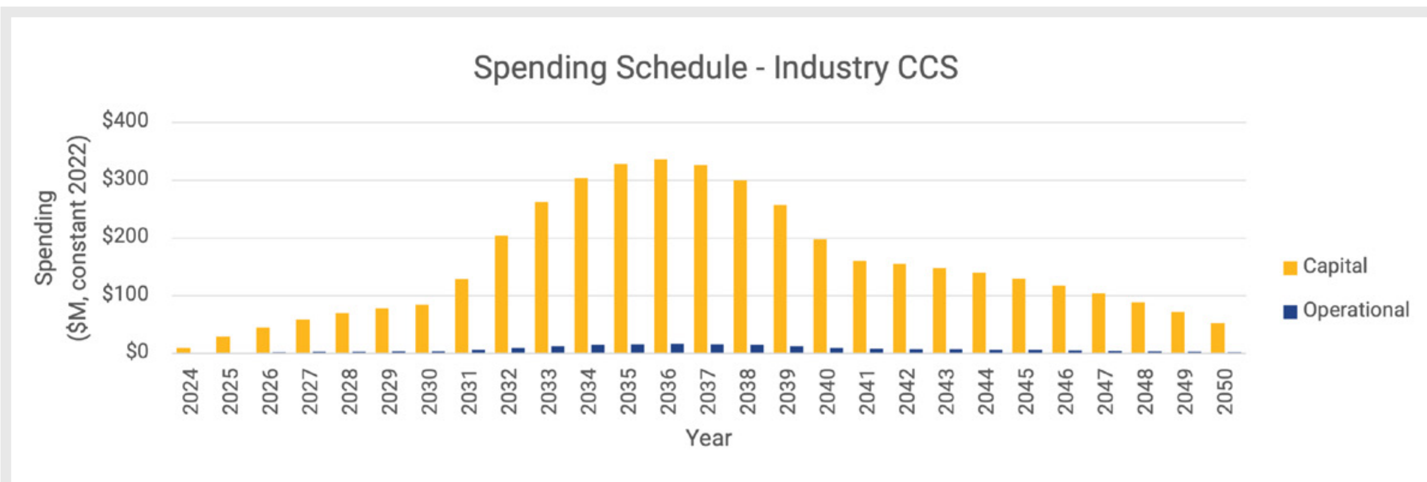


Figure 18 **The capital and operational spending in SMR paired with CCS**

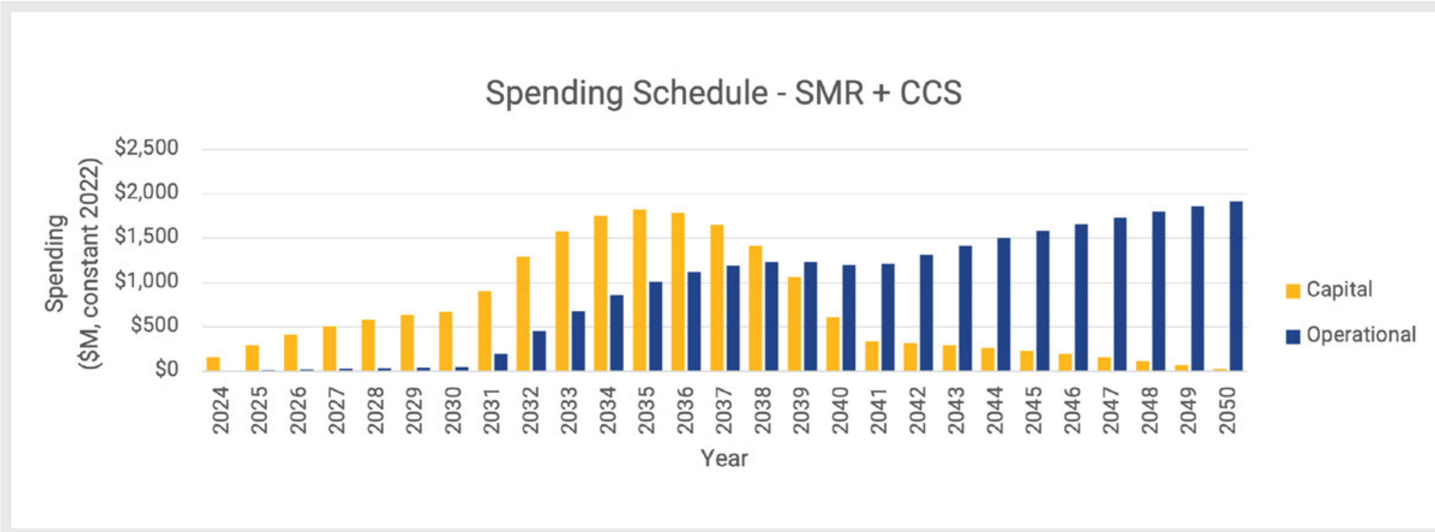
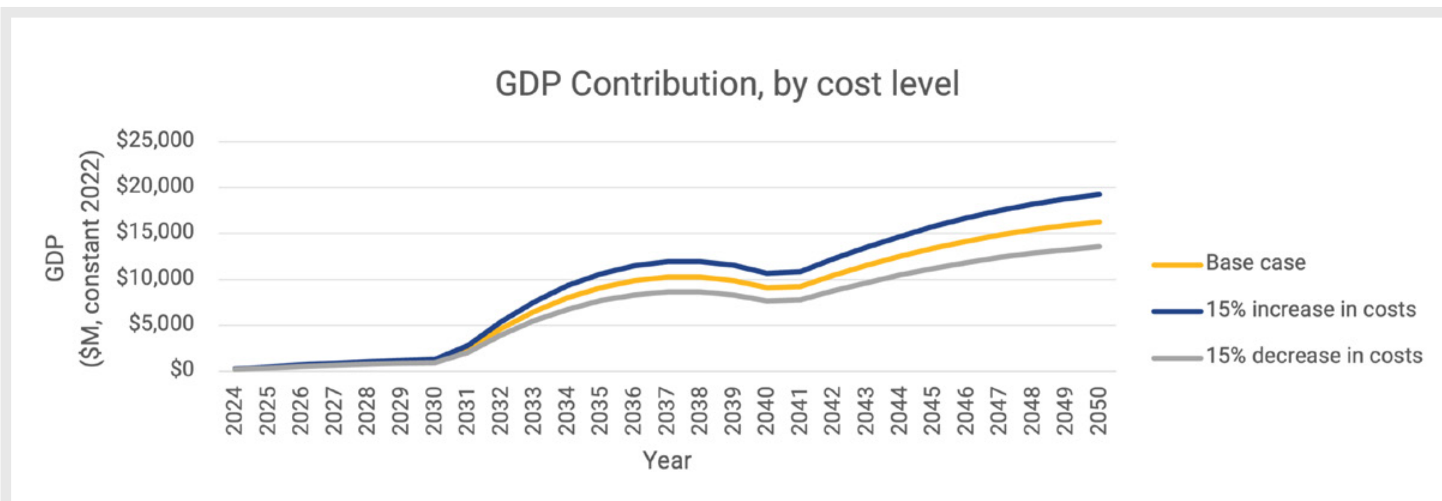
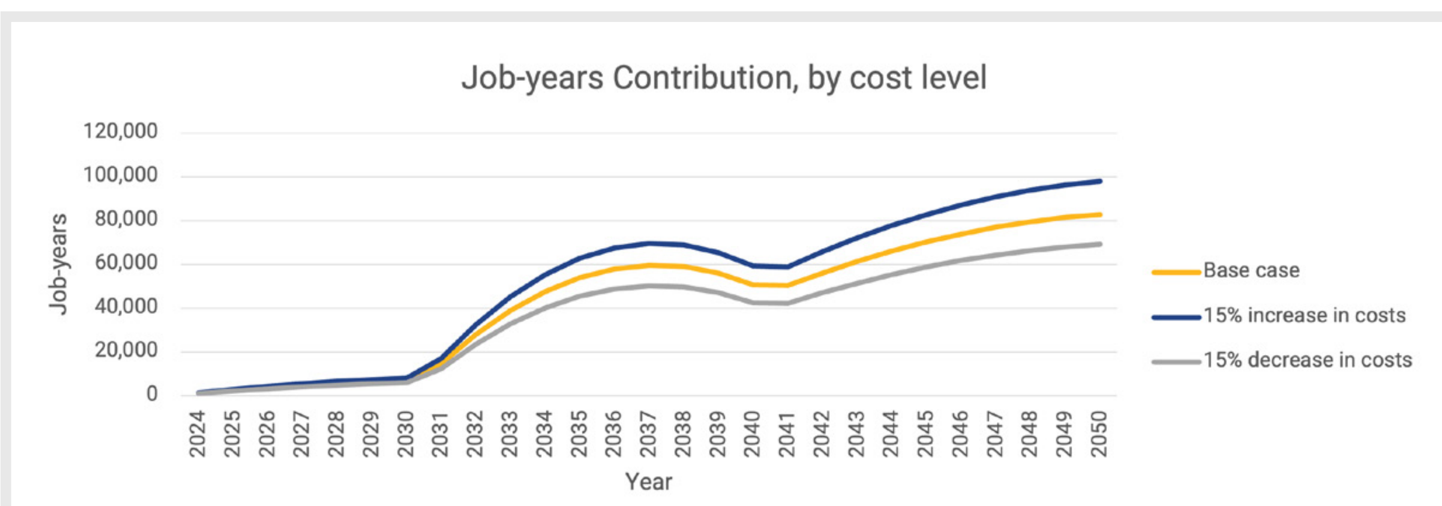


Figure 19 **Total GDP and job-years contributions to Ontario from proposed investments, by cost level**





B. Glossary

CCS – Carbon Capture and Storage

RNG – Renewable Natural Gas

SMR – Steam Methane Reforming

CCGT – Combined-cycle Gas Turbine

H2 – Hydrogen

C. Bibliography

Canada Energy Regulator. (2023). Canada's Eenergy Future 2023. Canada Energy Regulator. Retrieved from https://ppforum.ca/wp-content/uploads/2023/07/Canada%E2%80%99sCleanElectricitySupply-PPF-July2023-EN-1.pdf

Canada, G. o. (2023). Greenhouse Gas Reporting Program (GHGRP) - Facility Greenhouse Gas (GHG) Data. Retrieved from Government of Canada: https://open.canada.ca/data/en/dataset/a8ba14b7-7f23-462a-bdbb-83b0ef629823

Guidehouse. (2023). Pathways to Net Zero Emissions in Ontario. Enbridge Gas Inc. Retrieved from https://www.enbridgegas.com/-/media/Extranet-Pages/Sustainability/Pathways-to-Net-Zero/Enbridge-Ontario-Pathways-Report.ashx?la=en&rev=8fcdf4296a2c4a56af49da58a429f89b&hash=6756E8884422517D2213E700C954B215

Independent Electricity System Operator (IESO). (2022). Pathways to Decarbonization. IESO. Retrieved from https://www.ieso.ca/en/Learn/The-Evolving-Grid/Pathways-to-Decarbonization

Navigant. (2019). Gas for Climate. Navigant. Retrieved from https://gasforclimate2050.eu/wp-content/uploads/2020/03/Navigant-Gas-for-Climate-The-optimal-role-for-gas-in-a-net-zero-emissions-energy-system-March-2019.pdf

Ontario. (2022). Geologic carbon storage. Retrieved from Ontario: https://www.ontario.ca/page/geologic-carbon-storage

Public Policy Forum. (2023). A Blueprint for Growing Canada's Clean Electricity Supply - and Fast. Public Policy Forum.

Student Energy. (2023). Steam Methane Reforming. Retrieved from https://studentenergy.org/production/steam-methane-reforming/