Final Report

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ECONOMIC AND QUALITATIVE IMPACTS OF COSMIC EXPLORER

Prepared for

COSMIC EXPLORER

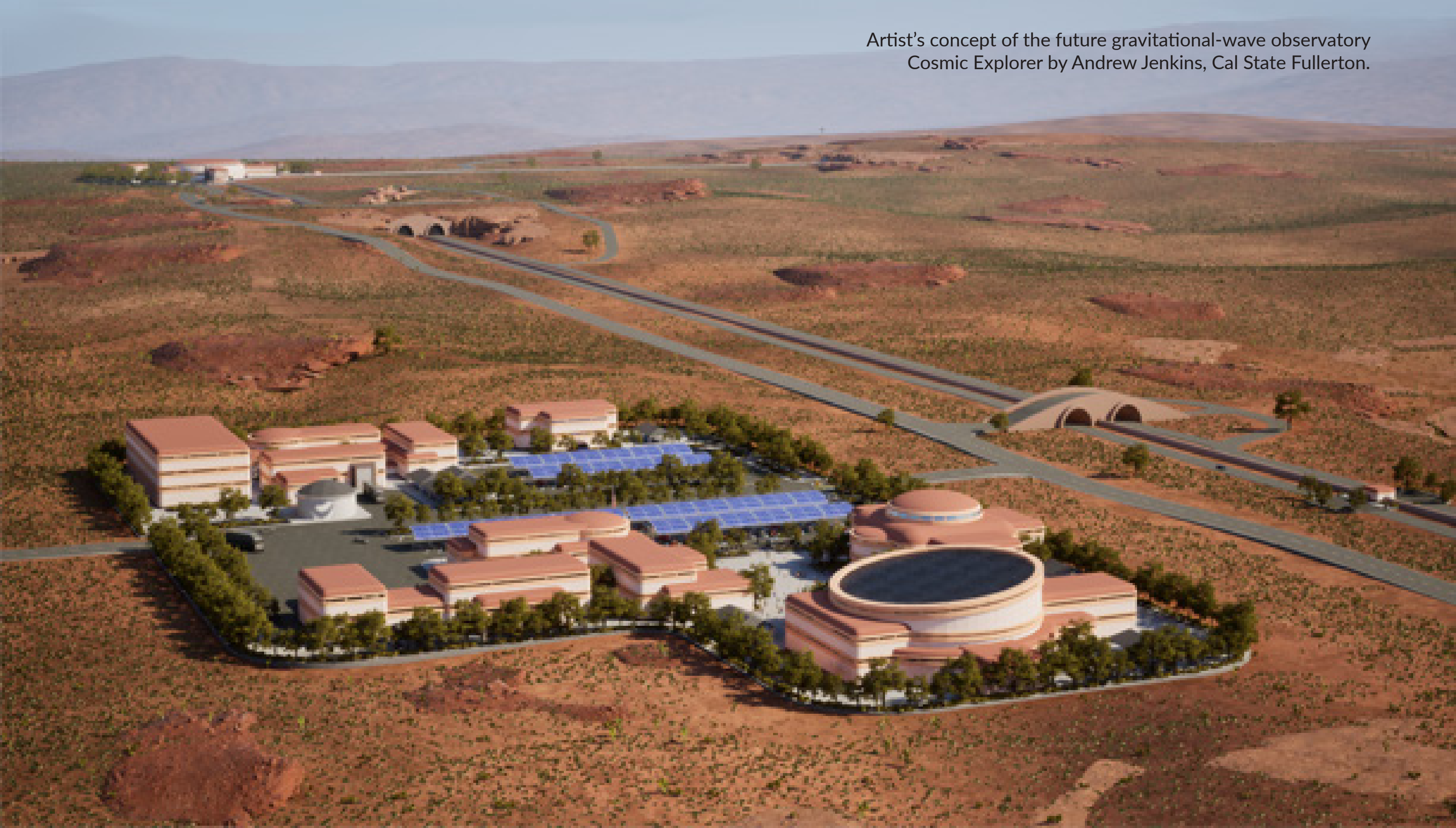
Prepared by

Economic & Planning Systems, Inc.
The Economics of Land Use

ECONOMIC AND QUALITATIVE IMPACTS OF COSMIC EXPLORER

Executive Summary

Cosmic Explorer (CE) is a next-generation gravitational-wave observatory that promises to advance fundamental science and expand the boundaries of human understanding of the universe. Beyond enabling scientific discoveries, the construction and operation of CE is expected to generate mutually positive benefits to the regions and communities where CE's observatories are located. This executive summary provides an overview of CE's projected local economic impacts, from both one-time construction and annual ongoing operations. It also highlights broader qualitative benefits—ranging from anticipated direct community impacts to advances in scientific research and technological innovations.



Artist's concept of the future gravitational-wave observatory Cosmic Explorer by Andrew Jenkins, Cal State Fullerton.

Economic Impacts

One-Time Construction Impacts

$2.0 **Billion (2024$)**
Construction Cost

(For CE's two planned observatories)

$1.2 B ⟶ 40 km Observatory

$800 M ⟶ 20 km Observatory

50% ($1.0 B) spent locally supporting local contractors, labor, and materials suppliers

10,200
Total One-Time Jobs

8,000+ ⟶ Direct Construction Jobs

~2,000 ⟶ Additional Jobs in Local Business

Over 5 years about 2,000 jobs in the local economy spurred by project construction

$1.3 **Billion**
Total Local Economic Output

$1.0 B ⟶ Direct Project Spending

$310 M ⟶ Indirect/Local Ripple Effects

Recurring Operational Impacts

467
Local Jobs Supported Annually

293 ⟶ Direct Project-Related Jobs

174 ⟶ Additional Jobs in Local Economy spurred by Project Operations

$102.6 **Million**
New Annual Local Economic Output

$73.4 M ⟶ Direct Project Output

$29.2 M ⟶ Catalyzed by Project Opertaions Economic Activity

$58.6 Million in annual worker compensation

Workforce Composition

1/3 Administrative Roles
- Local residents managing operations, education, and public engagement

2/3 Technical & Research Roles
- Operators, engineers, PhDs, and scientists advancing gravitational-wave research
- Mix of local, national, and international talent

Qualitative Impacts

Community Impacts

CE will create mutually beneficial relationships with local communities, redefining and demonstrating new community partnership models. CE seeks to create partnerships that empower communities, identify and respond to community priorities, and build a reciprocal relationship that extends through CE's lifetime. This holistic approach offers opportunities to include community voices in the development and operation of the facility in alignment with the goals of the Astro2020 Decadal Survey.

CE community partnerships, as directed by local communities, will support STEM training and education for K-14 teachers and students. STEM education has been at the forefront of community outreach from similar facilities like LIGO. This includes enhancing science literacy and opening young minds to potential careers in a range of STEM industries. Formats for this engagement may include teacher workshops, school visits, and field trips. In addition, facilities at both CE sites will include Scientific Exploration Centers for the public, modeled after LIGO facilities that host about 10,000 visitors annually.

Where appropriate, CE will look to partner with local educational institutions to develop training programs for a range of career types and needed skills for CE operation. CE operational plans anticipate employing half of the facility's staff from the local workforce. Employment opportunities include administrative staff and specialized operators and may require specialized training.

Academic and Scientific Contributions

CE may encourage large investments that will have a transformative impact on the higher education system. Investments from National Science Foundation and private donors can ripple across university departments, having a significant impact on university ecosystems and STEM education more generally.

CE aims to operate using a new collaboration model that increases data accessibility and will accelerate scientific discovery. Realizing CE's full scientific potential will require unprecedented national and international cooperation. Building on existing global partnerships among gravitational-wave observatories, this collaboration will help pioneer innovative approaches to data sharing and collaboration across institutions and borders. These efforts will not only broaden access to scientific knowledge but also strengthen and solidify U.S. leadership in the global scientific community.

CE represents the next frontier of physics and will deepen our fundamental understanding of physics and the history of the universe. CE will likely enable answers and generate further inquiries around the understanding of three broad topics: extreme gravity and fundamental physics, black holes and neutron stars through cosmic time, and the dynamics of dense matter.

Technological Innovations and Downstream Impacts

The development of next-generation gravitational-wave facilities like CE is expected to drive technological innovation and create downstream economic opportunities. Gravitational-wave research has already led to advancements across diverse sectors—including medical technology, defense, and sustainable energy—through the development of novel tools, materials, and procedures. CE's technological upgrades represent a major leap beyond the current generation of observatories, and these innovations are likely to translate into new commercial applications. These advancements could stimulate demand for new midstream suppliers and manufacturing capabilities, creating opportunities for US-based firms to grow and lead in emerging markets. In parallel, CE will help cultivate a highly skilled workforce with expertise applicable across a broad range of industries, enhancing national competitiveness and supporting the growth of new economic sectors.

1. Project Overview

This Chapter provides an overview of the proposed Cosmic Explorer (CE) project, including its purpose, potential locations, and expected investments, and a summary of the approach used to conduct this economic impact analysis. This information provides the foundations for the Economic Impact Analysis in **Chapter 3** and the description of Qualitative Impacts in **Chapter 4**.

Study Purpose

CE is expected to make contributions to scientific knowledge and technology that will have far-reaching impacts on human understanding of the universe. CE will also result in a range of economic benefits to the communities where it is located.

The purpose of this report by Economic & Planning Systems, Inc. (EPS) is to provide estimates of these impacts. This report details the potential local economic impacts – jobs, compensation, economic output – associated with the construction and ongoing operation of the proposed Cosmic Explorer observatories. Additionally, the report describes a number of Cosmic Explorer's other potential qualitative impacts , including benefits to the local communities, scientific discovery and higher education, and technological innovation and industry.

Project Overview

Background

On September 14, 2015, nearly a century after Albert Einstein predicted the existence of gravitational waves and 13 years after the construction of the National Science Foundation (NSF)-funded Laser Interferometer Gravitational-Wave Observatory (LIGO), the first gravitational wave was detected. This discovery marked a watershed moment in astronomy and astrophysics, with LIGO founders Barry Barish, Kip Thorne, and Rainer Weiss winning the 2017 Nobel Prize in Physics.

Gravitational waves are "ripples" in spacetime produced from the most powerful astrophysical events in the universe, such as merging black holes or colliding neutron stars. The first detection by LIGO and the subsequent detection of other gravitational wave events have ushered in a new era of astronomy. Studying gravitational wave events offers a new way to observe the universe by providing insights into cosmic events and phenomena that were previously undetectable, providing insights into understanding physics and the origins of the universe.

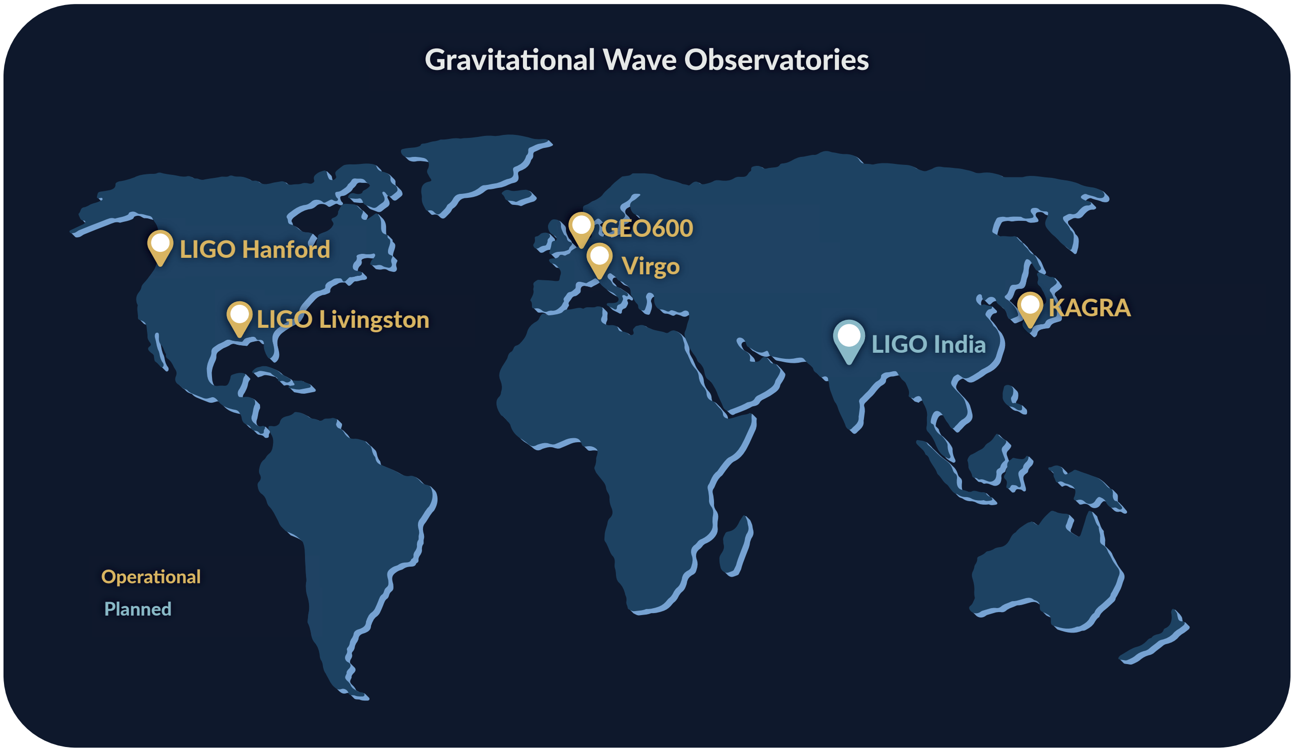
There are four operational gravitational wave observatories worldwide: KAGRA in Japan, Virgo in Italy (a French-Italian consortium), and two facilities in the US. The US observatories are based in Washington State (LIGO Hanford Observatory or LHO) and in Louisiana (LIGO Livingston Observatory or LLO) which began operation in 1999. These LIGO facilities have undergone a series of upgrades, including the installation of new Advanced LIGO detectors completed in 2015, which were three times more sensitive than the initial LIGO's capabilities. There is also a joint US-India detector planned for construction in India (LIGO-India or LIO) that will greatly enhance the world-wide network's ability to extract the best information from gravitational waves.

Planning has already started for the next generation of gravitational wave detectors. The Einstein Telescope is a proposed observatory currently under study that would be based in Europe. The Laser Interferometer Space Antenna (LISA) is a planned space-borne observatory expected in the 2030s. Cosmic Explorer, the focus of this report, is a set of US-based observatories that will significantly scale current detectors, pushing gravitational wave observation to the edge of the known universe.

Kip Thorne on winning the 2017 Nobel Prize in Physics

"The prize rightfully belongs to the hundreds of LIGO scientists and engineers who built and perfected our complex gravitational-wave interferometers, and the hundreds of LIGO and Virgo scientists who found the gravitational-wave signals in LIGO's noisy data and extracted the waves' information," Thorne says. "It is unfortunate that, due to the statutes of the Nobel Foundation, the prize has to go to no more than three people, when our marvelous discovery is the work of more than a thousand."

Source: https://www.ligo.caltech.edu/page/press-release-2017-nobel-prize#cit



Cosmic Explorer Mission and Facilities

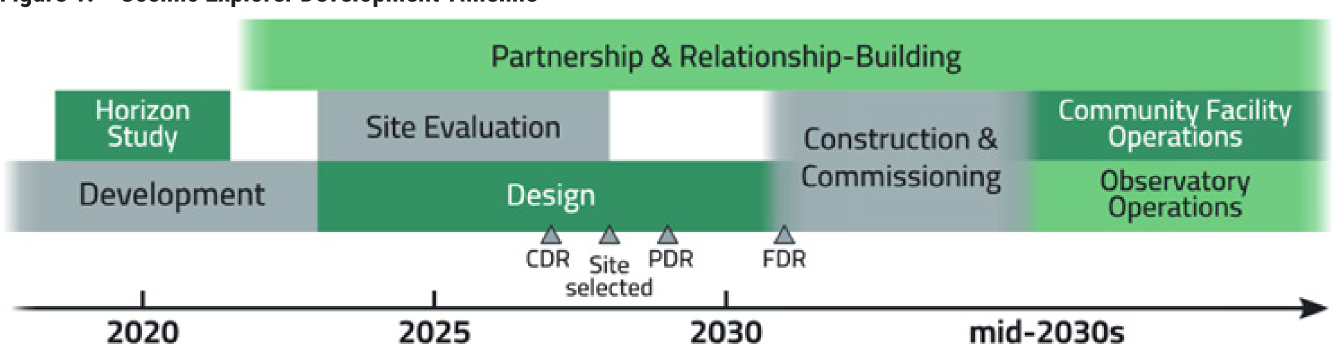
CE is a set of next-generation gravitational wave observatories that will build on the foundations of existing gravitational wave detectors. CE will enable transformative discoveries in physics and astronomy while providing a novel approach to how US science can partner in mutually beneficial relationships with indigenous and other local communities. CE will observe black holes and neutron stars across cosmic time, probe the nature of the most extreme matter in the universe, and explore questions on the nature of gravity and fundamental physics. These scientific achievements will be made possible by CE's scale and innovative technology, which deliver a sensitivity roughly 10 times greater than that of today's observatories.

The design and initial development of Cosmic Explorer are underway, led by a project team of over 50 members (The Cosmic Explorer Project or "CE Project") in collaboration with a consortium of more than 450 experts. The CE Project is currently in the site search and research phase, with the full development timeline outlined below in **Figure 1**. CE is currently funded by the NSF for the initial activities in Conceptual Design phase. Subsequent funding from the NSF would enable detailed design and engineering, and ultimately construction and operation.

The overarching design of CE envisions two planned observatories. Although it is possible that only one will be constructed, depending on ongoing design development and available funding. The two-observatory configuration is designed to maximize scientific output. One observatory would feature two 40 km arms, offering unparalleled broadband sensitivity for detecting gravitational waves. The second observatory, with 20 km arms, would enhance the network's ability to localize sources, detect polarization, and tune sensitivity to specific signals.

Each observatory will house a laser interferometer with two long arms arranged in an L-shaped configuration. A rendering of one possible design of a CE observatory can be seen in **Figure 2**. The 40 km arms and 20 km arms will be constructed on flat, seismically quiet land to ensure optimal performance. The scale of CE's arms far surpasses that of current LIGO facilities, which are 4 kilometers in length. Other planned site facilities include project offices and a science education center at each observatory.

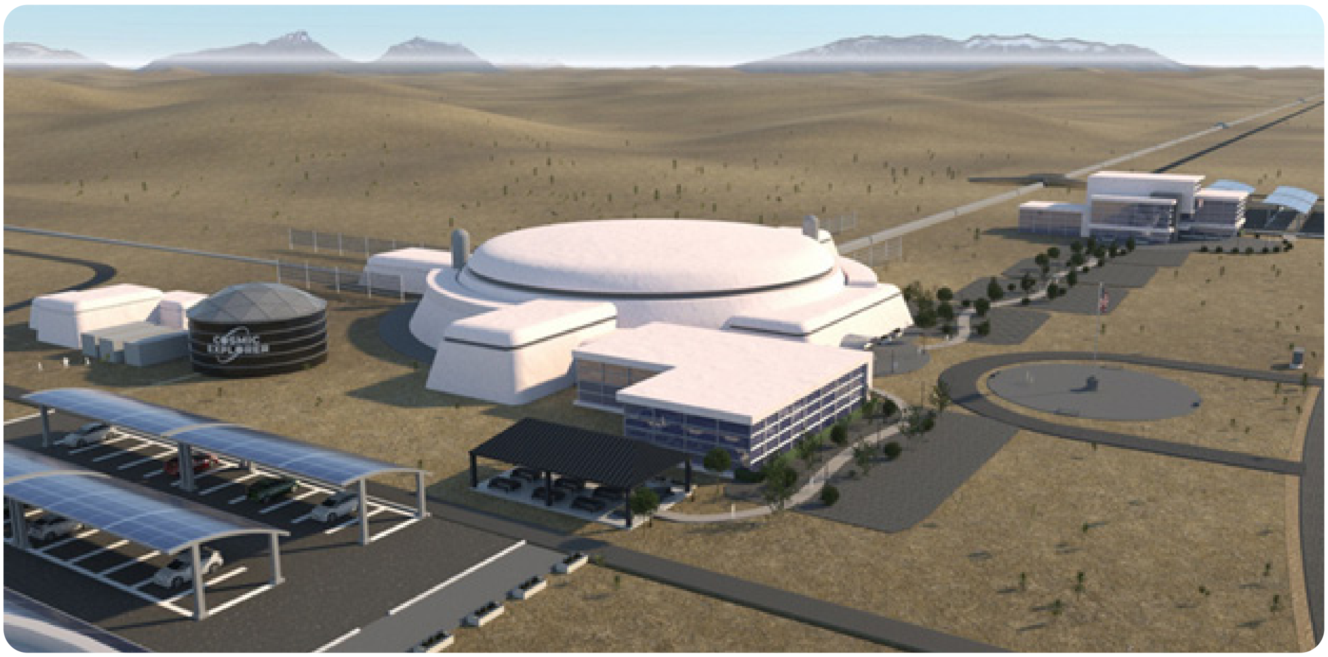
Figure 1. Cosmic Explorer Development Timeline



Source: The Cosmic Explorer Project; Cosmic Explorer

Additionally, each observatory site will be separated by thousands of kilometers, like the LIGO facilities in Washinton and Louisiana that are more than 3,000 kilometers a part. This separation is required to improve the ability to detect and confirm gravitational waves with high precision and confidence. The wide distance between facilities is vital to account for local vibrations and to identify the sky location of sources using the gravitational wave travel time. Gravitational wave observatories, in the US and across the globe, work in conjunction with each other to triangulate the location of gravitational wave events. The greater the distance between observatories, the more accurate its triangulation.

Figure 2. Rendering of Cosmic Explorer Facility

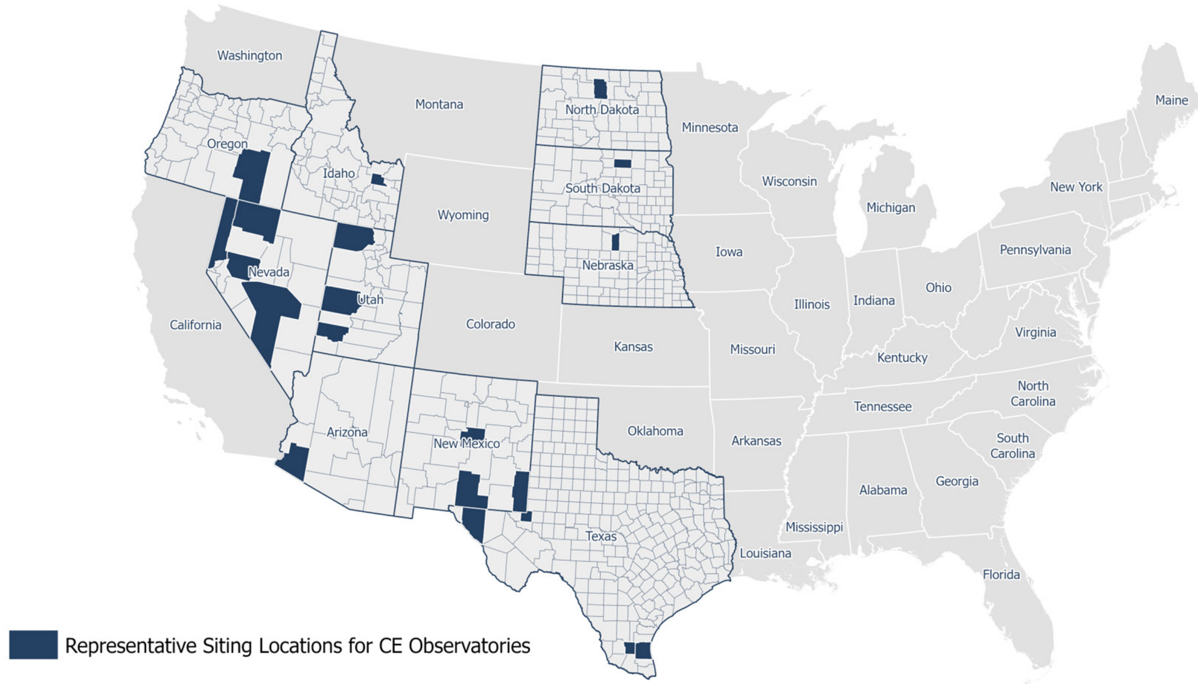


Source: The Cosmic Explorer Project

Potential Locations

The CE Project is currently exploring potential site locations. As stated above, each CE observatory will be thousands of kilometers apart to improve the accuracy of detection. The potential sites vary across the US and correspond to a variety of identified requirements. A representative, but incomplete set of county locations are shown below in **Figure 3**. The ideal site is characterized by quiet ambient environmental conditions, favorable geological terrain and topography, access to strategic infrastructure to support project operations, proximity to a metropolitan area that will facilitate the development and maintenance of a scientific workforce, and strong community relationships between CE and the host communities. As such, identification and evaluation of suitable sites for CE will consider many factors, including the physical criteria and the socio-cultural context of each observatory siting. For more information on these factors, see Criteria for identifying and evaluating locations that could potentially host the Cosmic Explorer observatories.

Figure 3. Representative, Incomplete, Potential Siting Locations for CE Observatories



Source: The Cosmic Explorer Project

Physical criteria include the observatory footprint, environment and geology, environmental limits to sensitivity, surrounding infrastructure, global separation and orientation, land rights and permitting, and cost factors. Each of these categories constitutes a technical and specific requirement for CE operation given the sheer size and extreme sensitivity needed for gravitational wave detection. Additionally, there is a range of socio-cultural factors that the CE Project is integrating into its site evaluation methods. Furthermore, the CE Project aims to create a set of mutually beneficial relationships with the communities that host the CE observatories throughout the lifecycle of CE. This effort will require proactive engagement with communities and a deep understanding of the social, cultural, tribal, and inter-community landscape in which CE observatories will operate.

Given the uncertainty around siting, EPS identified the characteristics of an illustrative county that could serve as an economic "median" of the counties under consideration and the basis for the economic analysis in this report (see **Appendix A**). More detail about the CE site selection process can be found in the found in the report, "Criteria for identifying and evaluating locations that could potentially host the Cosmic Explorer observatories."

Local Community Building

"Cosmic Explorer's approach to location identification and evaluation necessarily includes a thorough study of the historical and social landscape as well as early and consistent relationship building with local and Indigenous communities."

Source:
Daniel, Kathryne J., Joshua R. Smith, Stefan Ballmer, Warren Bristol, Jennifer C. Driggers, Anamaria Effler, Matthew Evans et al. "Criteria for identifying and evaluating locations that could potentially host the Cosmic Explorer observatories." arXiv preprint arXiv:2410.00293

2. Approach and Investment Costs

This Chapter outlines the approach taken to estimate the economic and qualitative impacts as well as the estimated costs of construction and operation of Cosmic Explorer facilities. The approach was developed based on a review of the approaches taken by studies of other large scientific projects, EPS experience, and the unique attributes of Cosmic Explorer. Key project details and the associated cost information that underpins the economic impact analysis are also provided.

Approach

EPS estimates the economic and qualitative impacts of CE using industry-standard modeling systems and a broad body of research on the effects of large facilities.

There is a substantial body of literature in the US and internationally evaluating the local economic impacts of large investments in a broad range of public and private projects. To quantify local economic impacts, these studies typically rely on location-specific input/output (I/O) economic modeling systems that use a data map of existing interconnections between industries to estimate the expected impacts of new projects on the local economy when available. In some cases, these studies pull the equivalent information from other studies of similar facilities in similar locations. The studies also often provide qualitative descriptions of additional project benefits. Much of the literature has focused on major transportation/ public works projects, industrial parks, or other types of large projects that include more common and well-studied project components.

To identify the appropriate approach to assess CE's economic impacts, precedent economic studies/ literature on other gravitational wave facilities were identified. At the time of preparation of this report, there was only one such study available, conducted in 2018, that assessed the economic impacts of the potential Einstein Telescope (ET) in Europe. This report combined multiplier[1] assumptions from other studies of scientific facilities with construction and operational inputs to estimate a general multiplier range for ET's impacts. The study did not provide significant technical detail or distinguish between one-time construction impacts and ongoing operational impacts.

[1] Multipliers are measures of change that describe how a given change in a particular industry generates impacts in the overall economy. Multipliers are a measure of an industry's connection to the wider local economy.

Due to the limited number of studies of gravitational wave facilities, the review of existing studies was expanded to include economic studies of different types of scientific facilities in the U.S. and Europe. **Figure 4** shows nine (9) scientific facilities, including ET, where studies have been conducted to estimate economic impacts and other qualitative benefits. For each of the facilities, the geographic location, area of scientific focus, approach to economic analysis, and qualitative factors considered were noted.

For economic impact analysis, the US studies typically used input-output models, including the Impact Analysis for Planning (IMPLAN) and Regional Input–Output Modeling System (RIMS) models. In general, the level of aggregation in the studies made it hard to discern specific data or conclusions that could underpin the CE analysis. As a result, EPS determined that a combination of project specific information from the CE Project and the use of the IMPLAN modelling software, that provides distinct results for different counties in the US, would be the best approach for this report's local economic impact analysis.[2]

For qualitative benefits, these studies described a broad range of additional benefit types, though the most common themes fell into one of three categories: (1) community benefits; (2) academic and scientific benefits; and (3) technological innovation/ research and development benefits. Building on these themes and the nature and intent of CE, this report divides the potential CE qualitative impacts into the following three categories:

- Community Integration
- Academic and Scientific Contributions
- Technological Innovation and Downstream Impacts

[2] Either IMPLAN or RIMS could have been used. IMPLAN was selected as it provides the detail and flexibility required for this analysis and because EPS has used it for similar analyses on projects throughout the US.

Figure 4. Other Studies on Scientific Institutions

Institution		Einstein Telescope	Sandford Underground Research Facility (SURF)	Lawrence Berkeley National Lab	Fermilab
Scientific Focus		Gravitational Wave Detector	Dark matter and neutrino physics research, biology, geology, and engineering	Discovery science, clean energy, healthy earth and ecological systems, future of science	Science research facility specializing in high-energy particle physics
Study Area		Belgium, Germany, and the Netherlands	Western South Dakota; South Dakota	Bay Area, CA, USA	Chicago, IL; State of Illinois
Economic Analysis	Construction	Provided a combined construction and operations multiplier	Construction and capital equipment to accommodate new experiments	Capital projects, including the development of new facilities and new sophisticated instruments, ranging from 5-10% of total budget. Not differentiated from operational spending.	No construction or capital expense component, but includes discussion on new research initiatives, which includes construction
	Operations		Annual operational spend from salaries, equipment, facility maintenance, office supplies, and utilities. Includes employee count.	Includes both operational and construction spending. Employee figures provided as well.	Annual operations are based on payroll be geography, purchase order spending, technology transfer. Includes employee count.
	Other Factors	Discussion around 4 different scenarios	Considered net fiscal impact and economic impacts of visitor spending	Includes startup ecosystem and special attention to small business procurement	Includes visitor impacts, net fiscal impacts, and spending on small businesses and minority owned businesses
	Methodology	Reviewed spending from major scientific institutions	RIMS II multipliers	IMPLAN multipliers	RIMS II multipliers
Qualitative Analysis Focus		Technological Societal (community, education, workforce, STEM, R&D and entrepreneurship) Scientific Fields Science Community Hub (region developing reputation and visibility)	No qualitative component	Research, Innovation, and Knowledge Transfer Commercialization and Firm Creation Strategic Partnerships and Collaboration Outreach (Local K-12 STEM and Workforce Development and Education)	Education and Outreach Tourism Key Research Initiatives

Figure 4. Other Studies on Scientific Institutions

<table>
<tr><th colspan="2">Institution</th><th>Astronomy in Hawai'i</th><th>Argonne National Laboratory</th><th>The High-Luminosity Large Hadron Collider (HL-LHC)</th><th>Importance of Physics to the Economies of Europe</th><th>Diamond Light Source</th></tr>
<tr><td colspan="2">Scientific Focus</td><td>Overview of Hawaii astronomy sector</td><td>Conducts research in a wide variety of fields: energy, fundamental research in physics, chemistry, and materials science, and others.</td><td>Physics</td><td>Overview of the physics sector's contribution to the European economy.</td><td>Synchrotron light source</td></tr>
<tr><td colspan="2">Study Area</td><td>Counties of Hawaii and state overall</td><td>Chicago, IL; State of Illinois; Midwest Region</td><td>Generalized Impacts</td><td>Europe</td><td>United Kingdom</td></tr>
<tr><td rowspan="4">Economic Analysis</td><td>Construction</td><td>Construction costs not differentiated in analysis</td><td>Construction costs not differentiated in analysis</td><td rowspan="2">Investment and operations costs used estimated net present value (NPV), including social costs and benefits related to the project</td><td rowspan="2">Overall impact of employment, salary, and value added gathered through Eurostat's Structural Business Statistics. Construction and operational impacts are not differentiated.</td><td rowspan="2">Construction and operation costs not differentiated. Rather, a quantitative review of economic impacts looks at the combined costs of construction and operation while also detailing quantitative impacts of scientific, technological, and wider society.</td></tr>
<tr><td>Operations</td><td>Operations include information on salaries, rent on facilities and equipment, capital purchases, information services, maintenance, and construction</td><td>Argonne financial documents, salary & wage data, FTE count, contractor payments, procurements of goods and services, capital improvement and construction projects</td></tr>
<tr><td>Other Factors</td><td>Section for students and visitors</td><td>Section on visitors and estimation of license royalties. Notes on supplier categories including small businesses, woman owned small businesses, veteran owned small businesses, etc.</td><td>Cost-benefit analysis of social benefits including human capital, publications, technological spillovers, cultural benefits, and public good value</td><td>Includes comparisons of physics sector across counties in Europe, between economic sectors, and the survival rate of physics-based companies</td><td>Reviewed overall impact as well as scientific, technological, and societal impacts</td></tr>
<tr><td>Methodology</td><td>2017 Hawai'i Inner-County Input-Output Model</td><td>IMPLAN multipliers, noted similarities to other DOE</td><td>Monte Carlo calculation of NPV of different scenarios</td><td>Eurostat's supply, use and input-output datasets are used to generate indirect and induced impacts</td><td>Evaluation frameworks and metrics used are internally created</td></tr>
<tr><td colspan="2">Qualitative Analysis Focus</td><td>Case Studies of Spillovers:
-Network
-Knowledge
-Education
-Local Businesses
-Research
-Industry Spinoff examples</td><td>Argonne Research and Innovation
Scholarly Impact
Technological Development
Community Outreach</td><td>No qualitative component discussed</td><td>International Trade
Investment
Research and Development</td><td>Science
Technology
Society</td></tr>
</table>

Investment Costs

Planned investments in facility construction and ongoing operations are critical determinants of project economic impact analysis. Because of the uniqueness of CE, EPS worked closely with the CE Project to understand the proposed CE observatories and the expected investments in the development of the facilities and their ongoing operations. Interviews with and input from LIGO facility staff provided important insights into expected facility operations.

This section summarizes the current, planning-level budgets for the construction of and operation of both CE observatories. These initial cost estimates were provided by the CE Project. The cost figures represent the best, currently available cost estimates in 2024 dollars. These costs should not be considered final and will fluctuate based on a variety of factors, including: final design of the observatories, the siting of each observatory, labor availability, material costs, cost inflation, and the availability of funding (e.g., from the NSF or another entity) for construction and annual operations. It is possible that individual observatory costs might be somewhat higher if only one of them is built (due to the loss of some economies of design/ scale), although an accurate assessment of these potential cost changes is not possible at this stage of project study. The economic impact estimates in this report could be updated at a later date to reflect revisions/ updates to the expected project(s) and investments, if appropriate.

Capital/Construction Costs

In 2021, CE Project developed an estimate of observatory construction costs for both the 20 km and 40 km observatories. Construction estimates were divided into three separate categories: civil engineering, vacuum, and detector. Each of these was further disaggregated by construction task and workforce and capital costs. The CE Project also developed estimates of the proportion of the different construction activities that would be expected to be sourced locally (both labor and materials) if sufficient capacity in the locality (county) exists, and those that, due to their specialized nature/ uniqueness of component, would be expected to be sourced outside of the local area (referred to as "national"[3]). Highly specialized segments like the manufacturing of the CE vacuum and detector components were not included as they are sourced from specific suppliers around the globe.

While all this economic activity/ spending will provide economic impacts nationwide, the study's economic impact analysis focuses on the potential local spending to understand the potential for new projects to generate local jobs, income, and economic output.

[3] The term "national" is used to refer to non-local (county) spending/ economic activity. In reality, this includes spending in the large region, but outside of the county, spending elsewhere in the US, as well as potential international spending.

Figure 5 below provides a high-level summary of observatory development costs by observatory and by potential local vs. national spending. The original 2021 estimates were inflated to 2024 dollars. **Figure 36** in **Appendix C** provides more detailed cost information. Key estimates include:

- The total construction cost for both observatories is estimated at about $2.0 billion in 2024 dollar terms, including about $1.2 billion for the 40 km observatory and $800 million for the 20 km observatory.
- About 50 percent of the construction-related expenditures for labor and materials, or $1 billion, could occur in the local jurisdictions, with the other half expected to occur outside of the local area, both nationally and globally.
- Of the potential local spending, about $630 million is associated with the 40 km site (including $530 million for workforce and $100 million for materials/ fixtures).
- Of the potential local spending, about $390 million is associated with the 20 km site (including $330 million for workforce and $60 million for materials/ fixtures).
- The majority of the $1 billion national/ global spending stems from the special components needed for CE during the vacuum and detector phases of construction.

Figure 5. CE Construction Budget (2024 dollars)

Construction Budget	Local	National	Total
40 km Observatory	$629,550,000	$559,250,000	$1,188,790,000
20 km Observatory	$390,190,000	$413,000,000	$803,190,000
Combined Total	**$1,019,740,000**	**$972,250,000**	**$1,991,980,000**

Sources: The Cosmic Explorer Project; Economic & Planning Systems, Inc.

Annual Operating Budget and Staffing

In 2024, CE Project compiled an estimated annual budget and staffing plan for the operation of both the 20 km and 40 km facilities assuming that they are fully staffed on-site (additional costs associated with support from affiliated universities are not included). These estimates were developed by examining the current operations costs and staffing at LIGO facilities and adjusting for the scale and optimal staffing at the two CE observatories. Within the economic operations modeling in this report, the 20 km observatory totals about one-third of operational costs while the 40 km observatory totals two-thirds of allocated costs.

Figure 6 below details the combined budget for the two observatories as well as the operations of just a single observatory. The budget for both the 20 km and 40 km observatory totals $73.3 million with 293 direct staff. Under the conditions of one operating site, the operational budget totals $50.0 million with 200 total staff. The below operations model allows for various data sharing policies and frameworks.

Figure 6. CE Annual Operations Budget (2024 dollars)

Operations Budget for Two Sites [1]	Combined Sites	One Site
Commissioning (of established instrument)	$2,330,000	$1,589,795
Detector Improvements	$6,594,000	$4,499,189
Detector Calibration & Characterization (of established instrument)	$1,635,000	$1,115,586
Outreach Centers/EPO/Community Relations/Communications	$2,373,000	$1,619,135
Directorate	$1,561,000	$1,065,095
Business Office	$1,675,000	$1,142,879
Control & Data Systems	$4,675,000	$3,189,825
Commissioning (for design sensitivity)	$654,000	$446,234
Control-room operation and monitoring	$1,609,000	$1,097,846
Data Archival & Scientific Computing	$4,273,000	$2,915,534
Detector Operations & Maintenance	$2,385,000	$1,627,323
Detector Calibration & Characterization	$2,377,000	$1,621,864
Environment, Health, & Safety	$1,209,000	$824,920
Facilities Operations & Maintenance	$17,590,000	$12,001,931
General Computing/IT	$5,220,000	$3,561,687
LIGO Open Science Center	$1,190,000	$811,956
Management	$2,229,000	$1,520,881
Systems, Optics, & Mechanics O&M	$620,000	$423,036
Travel for LIGO Operations	$216,000	$147,380
Vacuum Operations & Maintenance	$12,898,000	$8,800,506
Grand Total	***$73,313,000***	***$50,022,600***
Compensation [2]	**$51,319,100**	**$35,015,820**
Total Staff [3]	**293**	**200**

[1] There is an assumption that there is some offsite support for the 40 km and 20 km sites not accounted for here. This support could come from a campus, a consortium of universities, or a professional project operator. This mirrors the kind of support that LIGO is provided from various institutions.

[2] Salaries are estimated to account for about 70 percent of the operational budget.

[3] Total operational staff breakdown was provided by the Cosmic Explorer Team.

Sources: The Cosmic Explorer Project; Economic & Planning Systems, Inc.

As shown in **Figure 7**, staffing is expected to be divided approximately equally between administrative staff, specialized operators, engineers/ PhDs, and scientists. Administrative staff, about one-third of the total, will oversee CE's business office, outreach and community relations, management, facility operations and management, and the LIGO Open Science Center. The CE Project expects that the majority of these positions could be sourced locally. The remaining two-thirds of staff will consist of both specialized operators and a range of engineers, PhDs, and scientists conducting gravitational wave research. Depending on local labor availability and training, some of the specialized operators could also be sourced locally, while the CE engineers and scientists conducting research will likely be hired from across the US and internationally.

Figure 7. Local CE Operations Staffing

CE Employment	20 km Observatory	40 km Observatory	Both Sites
Administrative	32	68	100
Specialized Operators	31	66	97
Engineers/PhDs/Scientists	31	66	97
Total Operational Staff	**93**	**200**	**293**

Sources: The Cosmic Explorer Project; EPS

3. Economic Impact Analysis

This chapter describes the local economic impact analysis of CE, including the economic impacts of the construction of the two observatories and their ongoing operations. It provides a model overview, a set of key definitions, a summary of combined results, and more detailed results for a 40 km observatory. It is also complemented by referenced appendices that provide the detailed results for a 20 km observatory as well as additional information on certain cost increases.

At the end of the chapter, there are brief sections on: (1) other economic impacts not captured in this report; and (2) findings of a different set of studies sought to estimate the larger societal impact of science and physics-based industries.

Model Overview

To measure the economic impacts of construction and annual operations for Cosmic Explorer, EPS uses the IMPLAN (software, which is an input/output (I/O) economic modeling system. The model and software draw data from several state and federal sources, including the Bureau of Economic Analysis, Bureau of Labor Statistics (BLS), and the Census Bureau. The results in this report reflect the most current data available from IMPLAN (2022). The IMPLAN model is specifically calibrated to estimate local (county level) economic impacts of different types of projects and investments. It is one of the most commonly used models for evaluating local (county level) economic impacts in the U.S.

The economic impact analysis includes two key components—an economic impact analysis of the construction of Cosmic Explorer and the economic impact analysis of the ongoing operations of Cosmic Explorer. These economic impact analyses are driven by the estimated investments and ongoing employment associated with the two CE observatory sites as described in **Chapter 2**. These estimates of observatory construction costs as well as ongoing operational staff provide the key inputs that, with the use of the IMPLAN model, allow for the quantification of the potential suite of direct economic impact metrics (jobs, compensation, and economic output) as well as the additional "multiplier" effects (indirect and induced effects) on the local economy (definitions provided below).

Appendix A provides some additional contextual notes on the underlying assumptions incorporated into Input-Output (I/O) models and their associated uses and limitations. The following context is especially important for this analysis of Cosmic Explorer:

- **Geographic Uncertainty.** The geographic uncertainty over the location of Cosmic Explorer poses some challenges concerning the specification of the IMPLAN model runs. Where a location is known, IMPLAN provides the specific economic calculator for the county. As described in **Appendix A**, to provide a good approximation of the economic impacts that could be expected from Cosmic Explorer, EPS studied the IMPLAN model and metrics for the broad range of potential counties that have been initially identified by the Cosmic Explorer Project. Based on this review, EPS then identified a county that represented a median perspective on potential economic impacts among the different counties. County-specific estimates could be provided once the likely geographic location(s) of CE becomes clear.
- **Local Capacity.** I/O models assume that local businesses and suppliers have sufficient capacity to respond to changes in demand by increasing their output and hiring additional workers. For some of the potential county locations of the Cosmic Explorer observatory(ies), there may, in reality, be some constraints on the availability of labor and local materials. As a result, the economic estimates provided should be seen as the potential local economic impact. To be fully realized at the local level, close collaboration will likely be required between Cosmic Explorer, the local community, and public officials such as county economic development departments/ agencies.

Definitions

The local economic impact analysis is driven by the estimated one-time construction costs and ongoing expenditures for annual operations for the different observatory sizes described in **Chapter 1**. The initial round of spending for CE construction and operations is referred to as the direct effect. Next the model quantifies the impacts associated with the ripple or multiplier effects that result from Cosmic Explorer's expenditures. The multiplier effects are categorized as indirect or induced effects. Indirect effects represent the positive ripple effects on local suppliers associated with project spending while induced effects represent the positive ripple effects associated with the spending from new household income of the project workforce.

This Report measures and provides economic impacts using the common economic metrics reported by the IMPLAN model, including employment, employee compensation/ income, and economic output, as defined below.

- **Employment** is equivalent to jobs, a headcount that includes part-time and full-time workers.
- **Employee Compensation** represents payments to labor in the form of both income and fringe benefits paid by the employer (e.g., health, retirement).
- **Economic Output** represents a measure of total economic activity/ spending, calculated as production value including intermediate inputs (i.e., the goods and services used in the production of final products). Output includes spending on employee compensation as well as the production value of each intermediate input, such as equipment, supplies, insurance, rents, utilities, communication services, printing, and other goods and services.

Results

This section begins with a summary of the combined economic impact analysis for the 20 km and 40 km observatory scenarios, followed by detailed results for the 40 km observatory. Detailed findings for the 20 km observatory and a more comprehensive overview of the combined sites are provided in **Appendix B**.

The analysis quantifies CE's one-time construction and annual operational local economic impacts. Although the two observatories will be located in different regions of the country—at least 1,000 miles apart—the analysis applies the same median county approach for both sites (see **Appendix A** for details). The economic multipliers used to estimate the impacts of CE's construction and operations are based on a consistent set of economic ratios drawn from a list of 20 preliminary siting locations. These multipliers vary across counties due to differences in industry structure, labor markets, and supply chain interconnections. Using the median county provides a standardized and representative basis for estimating impacts, balancing these variations across candidate locations. This approach offers the most reliable method for modeling economic impacts while site selection is still in progress. Once final locations are identified, more tailored, site-specific analyses can be conducted.

Summary of Results

One-Time Construction Impacts

The combined economic activity from one-time construction at both sites will generate measurable impacts on economic output, employment, and employee compensation. It is estimated that the construction period for both CE observatories will last five years with peak economic activity in years one and two. Direct employment will total over 8,000 job-years with an additional nearly 2,000 job-years associated with indirect and induced impacts, generating a combined total of over 10,000 local job-years. Job-years is a metric that provides an estimate of job-year equivalents, meaning that 10,000 jobs-year could mean 10,000 jobs for one year or 1,000 jobs for 10 years. Given the expectation of a 5-year construction schedule for CE, the estimate represents an average of 2,000 local construction jobs for five years. **Figure 8** below provides a breakdown of all employment types during CE's construction phase.

10,200
Total One-Time Jobs

$1.3 Billion
Total Local Economic Output

Construction on both sites will produce $1 billion in local economic output in the localized economy with an additional $310 million in indirect and induced economic output, altogether stimulating $1.3 billion total local economic output. **Figure 9** details the total economic output during the CE's construction phase.

Figure 8. Total Local Employment Breakdown from Construction

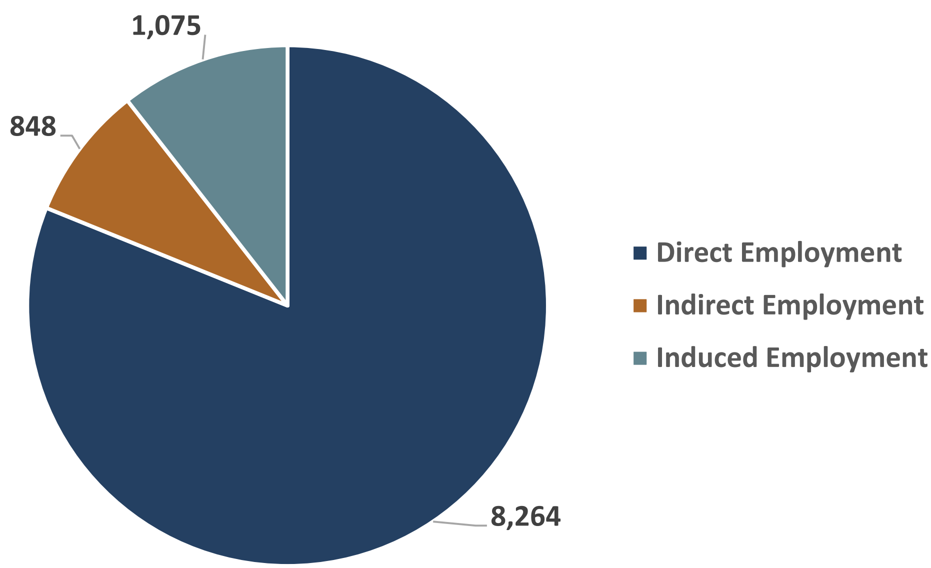
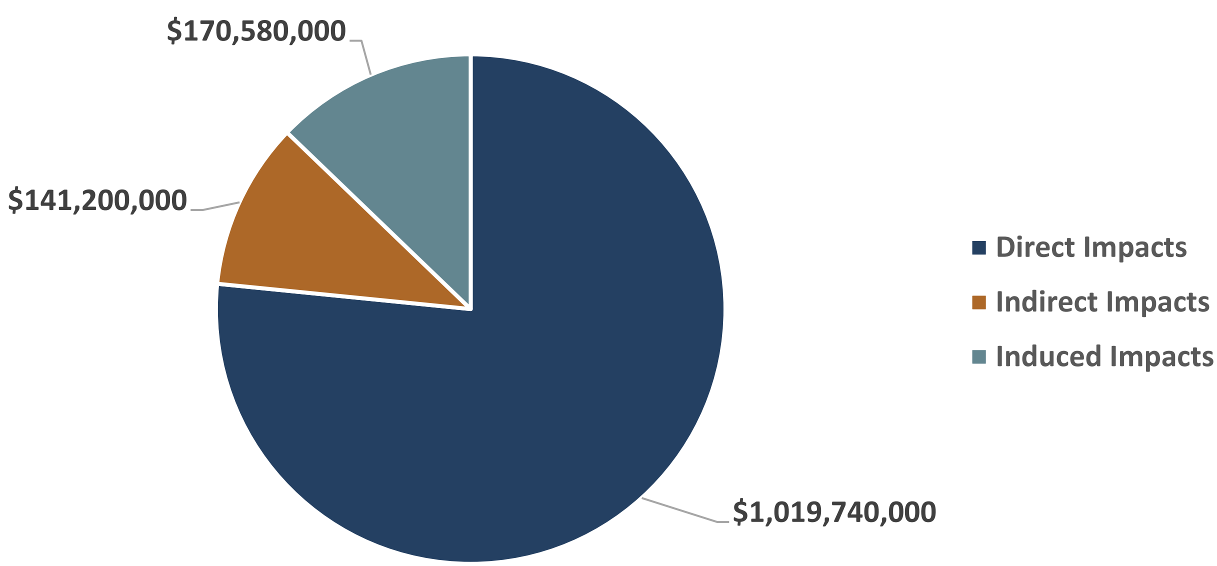


Figure 9. Total Local Economic Output Breakdown from Construction



Operational Impacts

The combined economic activity associated with the ongoing operations of the 20 km and 40 km observatories will lead to 293 direct jobs annually, supporting an additional 174 indirect and induced jobs, for a total annual job generation of 467 total jobs (**Figure 10**). The annual operations of the observatory will generate $73.4 million in direct output and about $29.2 million in indirect and induced economic output to support direct operations, providing $102.6 million in total economic output on an annual basis (**Figure 11**).

467
Local Jobs
Supported Annually

$102.6 Million
New Annual Local
Economic Output

Figure 10. Local Operations Annual Employment Breakdown

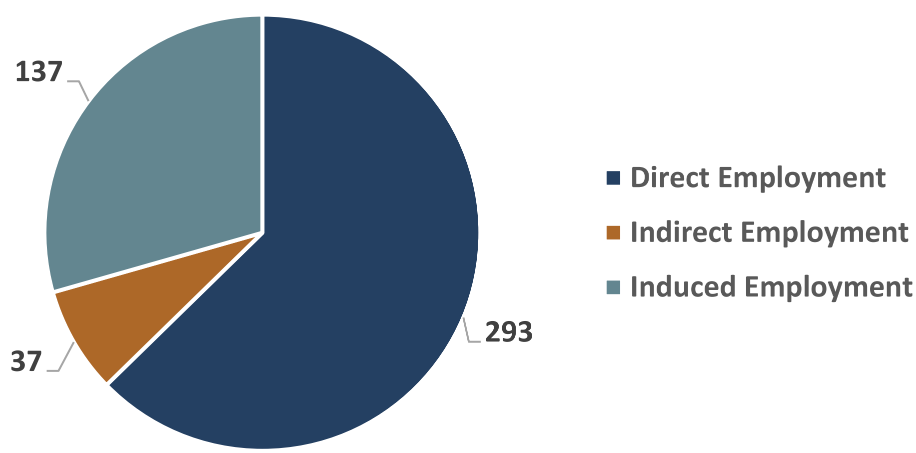
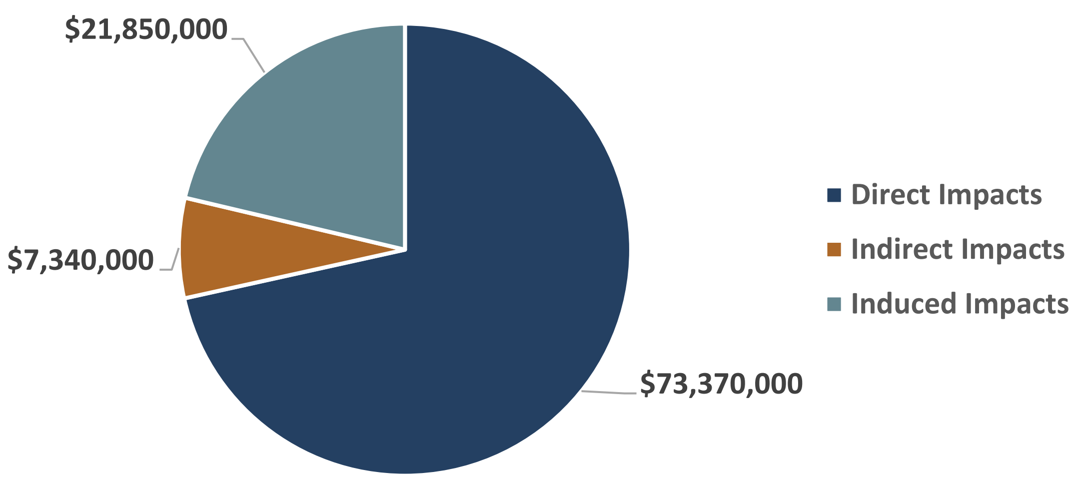


Figure 11. Local Operations Economic Output Breakdown



40 km Site

One-Time Construction Impacts

The 40 km site will produce the largest economic impact of the two sites (about 60 percent of the total for both observatories). **Figure 12** illustrates these impacts on a county basis with total employment expected to generate 6,289 job-years and produce a total output of $822 million of economic activity over the course of construction. Additional details on the range of direct construction occupation positions, the construction timeline, and the industries expected to benefit from the indirect and induced economic activity are provided below.

Figure 12. Local 40 km Site Construction Impact

Type of Impact	Employment[1]	Employee Compensation	Economic Output
Construction Phase			
Direct Impacts	5,102	$218,930,000	$629,550,000
Indirect Impacts	523	$22,490,000	$87,170,000
Induced Impacts	664	$27,180,000	$105,310,000
Total Impacts	**6,289**	**$268,600,000**	**$822,030,000**

[1] Values represent job-years, i.e., the roughly 5,000 annual construction direct jobs could represent about 1,000 jobs over the course of five years or 500 jobs over 10 years.

[2] Employee compensation includes benefits in addition to wages and salaries.

Source: IMPLAN; The Cosmic Explorer Project; Economic & Planning Systems, Inc.

Output: Construction operations are estimated to generate approximately $630 million in direct one-time industry output. This would also result in $87 million in indirect one-time impacts stemming from business-to-business transactions in the county to support direct construction activity. Household spending from direct and indirect employment would also generate $105 million in induced impacts. All combined, the CE 40 km site will generate a total of $822 million in local economic activity for the county.

Employment: The 6,289 total jobs comprises of 5,102 direct jobs, 523 indirect jobs, and 664 induced jobs. Employment includes both full-time and part-time workers. Employment refers to the number of jobs in each year (“job-years”) summed up over the entire estimated period of construction for the Project.

Employee Compensation: The direct construction activity would result in approximately $219 million construction employee compensation, in the form of salary, wages, and benefits. Indirect employee compensation impacts would total approximately $22.5 million and induced employee compensation impacts $27 million for a total annual employee compensation impact of approximately $267 million. The average annual salary per employee totals about $43,000. Compensation would vary by position and industry and will also be affected by the selected site location and the associated labor market opportunities/ constraints.

Occupational Positions: Employment is expected to span across a diverse range of construction occupations. **Figure 13** below provides an outline of estimated direct employment positions with their corresponding average income. These positions and their compensation would be similar for the 20 km site. Annual income per position is expected to range from $28,000 to $100,000 with an average of $43,000. Additionally, there are expected to be more specialized occupations, especially for configuration and installation of the vacuum and detector systems, that will feature a higher proportion of engineers and technical workers.

Construction Timeline and Local Construction Costs: Figure 14 and **Figure 15** below present an overview of the expected direct construction costs and employment over the CE planning and construction period. Costs associated with the conceptual design and final design of CE in 2029 represent an aggregated total that runs from 2023 to 2029. According to CE Project estimates, construction activity will peak during the first two years—projected to be 2030 and 2031—immediately following the planning and design phase. During this peak period, annual construction costs are expected to average approximately $157 million, supporting around 1,300 direct jobs per year. Both construction spending and employment are projected to gradually decline in the following years, with completion anticipated by the fifth year of construction (estimated 2035).

Figure 13. Local 40 km Site Direct Construction Needs and Salary

Broad Aggregation Level Occupation	Employment Totals	Average Income
Carpenters	424	$43,000
Construction Laborers	420	$33,000
First-Line Supervisors of Construction Trades and Extraction Workers	346	$53,000
Construction Managers	288	$77,000
Logisticians and Project Management Specialists	203	$68,000
General and Operations Managers	131	$99,000
Office Clerks, General	90	$28,000
Secretaries and Administrative Assistants	83	$36,000
Civil Engineers	76	$56,000
Cost Estimators	74	$59,000
Laborers and Material Movers	71	$30,000
Automotive Technicians and Repairers	64	$40,000
Construction Equipment Operators	61	$45,000
Bookkeeping, Accounting, and Auditing Clerks	59	$35,000
Cement Masons, Concrete Finishers, and Terrazzo Workers	55	$38,000
Electricians	53	$44,000
Structural Iron and Steel Workers	52	$41,000

Sources: IMPLAN; Economic & Planning Systems, Inc.

Figure 14. 40 km Site Construction Timeline and Costs

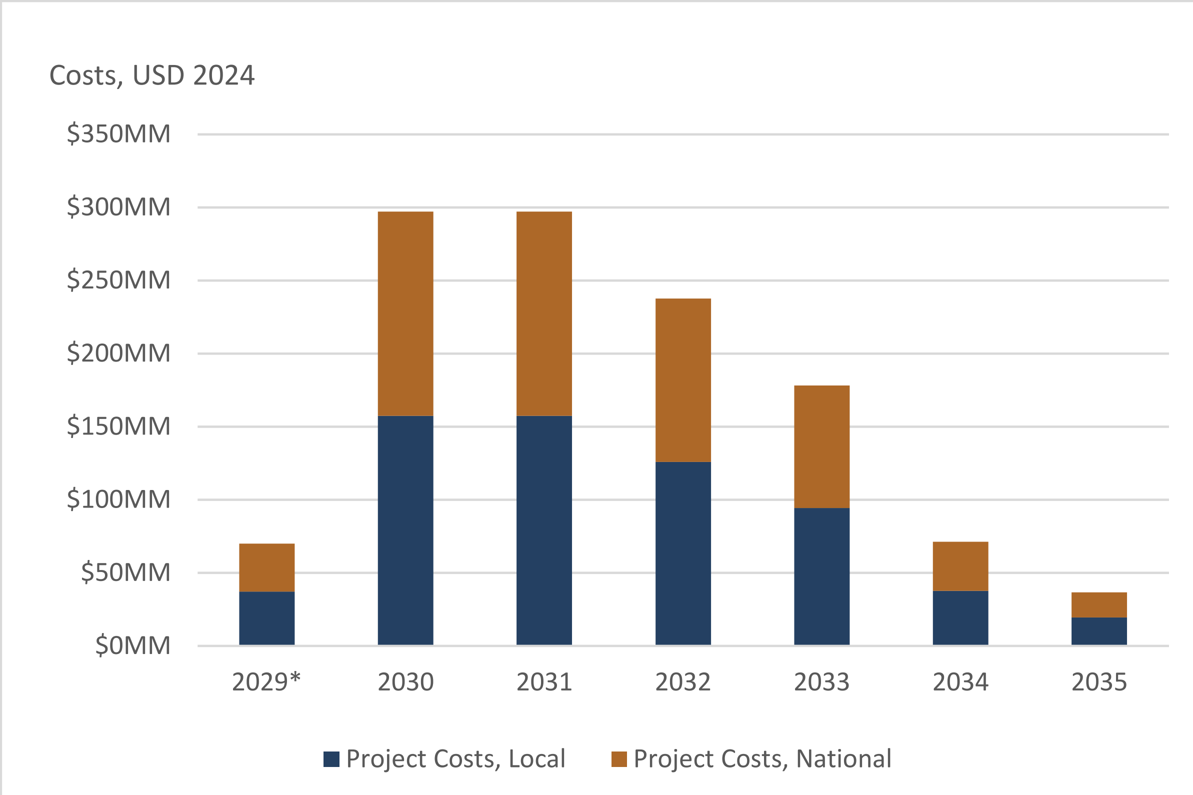
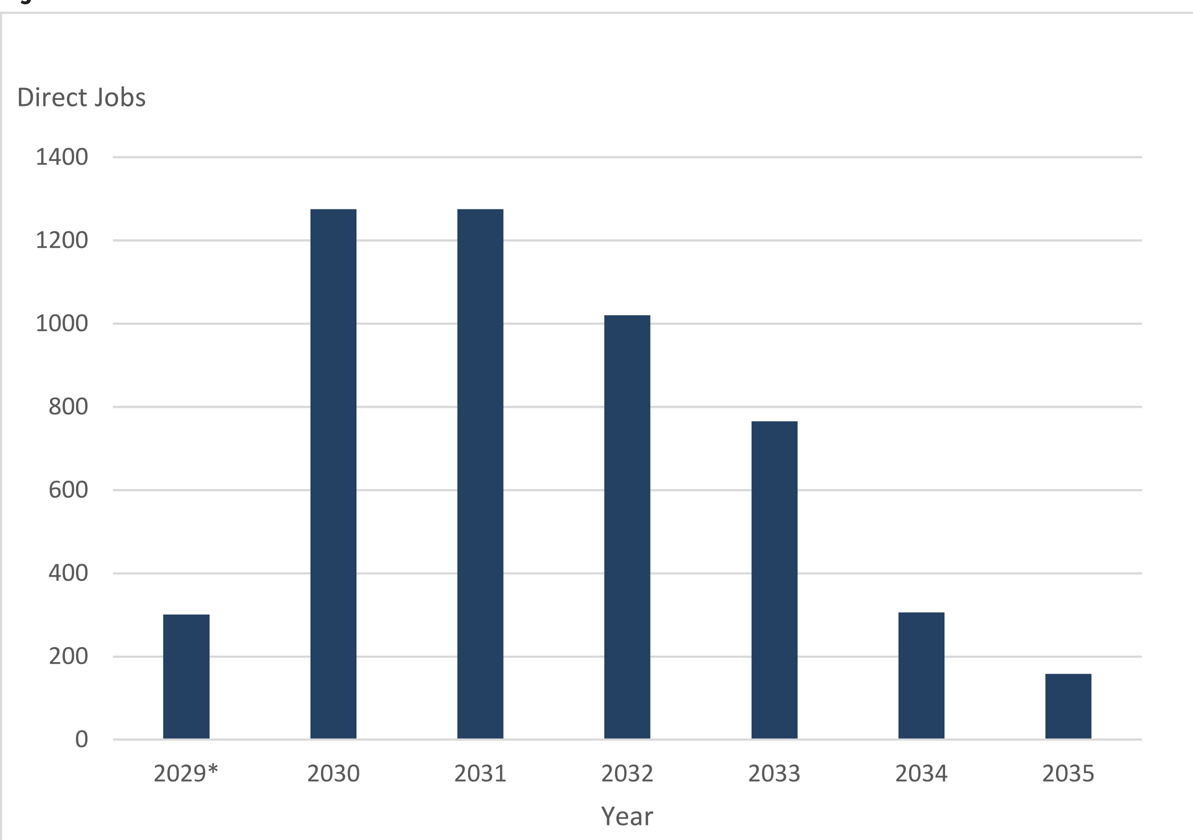


Figure 15. 40 km local Construction Timeline



Indirect and Induced Industries: Figure 16 and **Figure 17** below highlight the largest industry impacts from indirect and induced economic activity. Indirect impacts result from business-to-business spending related to CE's construction and operations—for example, purchases from suppliers. The most affected industries include retail trade, real estate and rental and leasing, and transportation and warehousing, which together account for approximately $50 million, or 57 percent of total indirect output.

Induced impacts stem from household spending by workers whose incomes are supported by the Project. This includes spending on housing, healthcare, and retail goods. The top induced industries—real estate and rental housing, health care and social assistance, and retail trade—total about $66 million, or roughly 62 percent of total induced output.

Some industries, such as real estate and retail trade, appear in both categories but play different roles. Indirect impacts reflect business demand (e.g., leasing commercial space), while induced impacts reflect household consumption (e.g., spending on rent or shopping). Job estimates align with these spending patterns and are derived using industry-specific employment-to-output ratios.

Figure 16. 40 km: Largest Local Impacts for Indirect Industries

NAICS 2-Digit Industry	Indirect Output
Retail Trade	$27,418,360
Real Estate and Rental and Leasing	$15,179,667
Transportation and Warehousing	$7,191,055
Professional, Scientific, and Technical Services	$5,749,658
Wholesale Trade	$5,273,525
Total [1]	**$87,170,000**

[1] The largest indirect industries do not total to the $87 million sum. This number instead reflects the grand total of all indirect industries based on CE Construction.

Sources: IMPLAN; Economic & Planning Systems, Inc.

Figure 17. 40 km: Largest Local Impacts for Induced Industries

NAICS 2-Digit Industry	Indirect Output
Real Estate and Rental and Leasing	$26,170,000
Health Care and Social Assistance	$23,110,000
Retail Trade	$16,520,000
Accommodation and Food Services	$8,110,000
Government Enterprises	$6,830,000
Total [1]	**$105,310,000**

[1] The largest indirect industries do not total to the $105 million sum. This number instead reflects the grand total of all induced industries based on CE Construction.

Sources: IMPLAN; Economic & Planning Systems, Inc.

Annualized Operational Impacts

On an annual basis, operations for the CE 40 km observatory produce 319 total jobs throughout the county and generate a total output of about $70.0 million, as illustrated below in **Figure 18**. These annual ongoing economic impacts capture the direct, indirect, and induced impacts generated by CE. Impacts associated with these economic activities are estimated based on employment estimates. It is important to note the potential deviation in terms of scaling between each observatory site and changes based on siting location.

Figure 18. 40 km Local Annual Operations Impacts

Type of Impact	Employment[1]	Employee Compensation	Economic Output
Operations Phase (Annual)			
Direct Impacts	200	$35,040,000	$50,060,000
Indirect Impacts	25	$1,120,000	$5,010,000
Induced Impacts	94	$3,840,000	$14,910,000
Total Impacts	**319**	**$40,000,000**	**$69,980,000**

[1] Values represent annual jobs, i.e., the 183 direct jobs are over a one-year period.

[2] Employee compensation includes benefits in addition to wages and salaries.

Source: IMPLAN; The Cosmic Explorer Project; Economic & Planning Systems, Inc.

Annual Output: CE operations for the 40 km observatory are estimated to generate $50 million in direct industry output annually. Local spending will result in about $5 million in indirect industry output impacts from business-to-business transactions as result of direct operations. Household spending from direct and indirect employment will generate $15 million in induced impacts. All economic output activity combined totals just under $70 million on an annual basis. Over a 50-year lifecycle of CE operations, output is estimated to generate about $3.5 billion in total economic output in the county in which it operates.

Annual Employment and Occupational Needs: The 200 direct jobs will generate 25 indirect and 94 induced jobs annually for a total employment impact of approximately 319 jobs on an annual basis. The 200 direct jobs from daily CE operations will encompass a variety of employment needs for CE that exist beyond the technical research needs of gravitational wave research.

Employee Compensation: Of the $50 million in direct industry output reported above, approximately $35 million will be received by employees employed in the Project in the form of salary, wages, and benefits. Indirect and induced employee compensation impacts total approximately $5 million for a total annual employee compensation impact of about $40 million. Over a 50-year lifecycle of CE operations, total employee compensation is estimated to generate about $2.0 billion. Average salary including benefits totals $175,000 per direct employment, $45,000 per indirect employment, and $41,000 per induced employment.

Other Economic Impacts

The primary focus of the economic impact analysis in this report is on the positive economic impacts from the proposed construction and ongoing operation of Cosmic Explorer at the local/ county level. This section briefly describes some of the additional economic impacts that are not covered in this study, including some additional, potential positive local impacts, local challenges that new economic investment can generate, and broader and more geographically widespread economic impacts.

Facility Upgrades

Throughout CE's lifetime, CE will likely feature periodic capital upgrades similar to the periodic improvements at LIGO. As an example, Advanced LIGO, the latest improvement to the LIGO observatories, included detector upgrades of value of about $310 million (2024-dollars) in 2010 that enabled the first detection of gravitational waves in 2015. These facility upgrades will bring additional local economic impacts associated with their construction. Due to the uncertainty of the timing and the level of additional costs, these additional investments were not quantified in the prior section.

Community and Scientific Education Centers

Both the CE 20 km and 40 km sites are planned to include an experiential scientific center. The planning for the center will ultimately involve discussions between the CE Project and the local community (discussed further in the Chapter 4) with the exact nature of these centers yet to be determined. When developed, these experiential science centers, similar to existing facilities at LIGO, will attract a broad range and visitors and additional visitor spending and economic activity to the county. These additional, potential local economic impacts have not been quantified in this report.

Managing Economic Development

While the Cosmic Explorer (CE) Project is expected to generate significant positive economic impacts—such as new jobs, increased salaries, and expanded local economic activity—these benefits can, in some cases, be accompanied by unintended negative consequences. Such impacts often arise when there are major constraints on the local supply of labor and housing.

For example, if the available local workforce is limited, CE may compete with other projects for construction labor, driving up wages and potentially making other developments less financially viable during the same period. Similarly, if housing availability is tight, an influx of temporary or permanent workers could place additional pressure on the housing market, leading to rising prices and reduced availability for current residents.

In addition to these economic pressures, large-scale infrastructure projects, especially those requiring temporary workforce accommodation, can pose broader social challenges for nearby communities. The CE Project is committed to working proactively with local governments, public agencies, and community organizations to plan and manage worker housing in a way that promotes safety, supports community well-being, and avoids or mitigates adverse impacts. This includes exploring appropriate housing strategies, adopting strong worker conduct policies, and engaging with stakeholders throughout the planning and construction process. Through early and sustained collaboration, the CE Project aims to maximize local benefits while minimizing unintended harms during both construction and long-term operations.

Broader Impacts

Beyond the local impacts quantified in this study, there is a distinct set of literature that focuses on the broader economic benefits of scientific research, development, and education on economies as a whole. Cosmic Explorer would be a new and important component of this international and multifaceted ecosystem, though it is difficult to disentangle the contributions of individual investments in scientific research from the collective impact of scientific progress and education.

Several of these types of studies have focused on the contributions of physics-based industries to the U.S. and European economies. Some studies have sought to estimate the aggregate multiplier effects when taking account of these larger geographies and the multiple effects of these industries, while others have sought to track the knock-on effects of investments in research and development on economic activity. As an example, a 2018 study by the European Physics Society found that:

- **Physics-based industries account for over 16% of total turnover (economic activity) in Europe.**[4] Physics-based industries were defined as those sectors of the European economy where the use of physics – in terms of technologies and expertise – is critical to their existence. This includes industries where workers with physics training would be employed and where activities rely heavily on physics theories and results to achieve commercial goals.
- **For every job in physics-based industries, an average of 3.34 jobs are supported in the wider economy.** Similar to local economic impact analysis, this estimate of total jobs includes the direct jobs in physics-based industries, indirect jobs associated with the supply chain, and induced effects associated with worker spending. The estimated multiplier effects were 1.54 for indirect jobs and 0.8 for induced jobs. These are substantially higher than those used in the local economic impact analysis as they include a much broader geographic area and more expansive set of industries.

[4] Europe in this instance includes 28 EU countries, Norway, Iceland, and Switzerland.

4. Qualitative Impacts

Overview

Beyond the economic metrics associated directly with facility construction and operation detailed in the previous section, CE promises to create a range of enduring qualitative benefits on local and global levels. The scope and mission of CE suggest a dramatic opportunity to redefine the form of partnerships between scientific facilities and local communities, catalyze funding at US universities, bolster US leadership in physics and science, and incubate nascent and cutting-edge technology and industry. By advancing innovation across a broad range of sectors, CE can contribute to maintaining the US's competitive edge in science-driven industries and reinforce its role as a global leader in technological development.

To understand the potential scope of CE's qualitative benefits, EPS interviewed over 15 CE Project staff, Laser Interferometer Gravitational-Wave Observatory (LIGO) facility staff, and other scientific personnel involved with the development of CE. EPS also considered the observed impacts of LIGO facilities over the past 20+ years. LIGO serves as a critical reference point as it represents the foundation on which CE is being built. This is best understood through LIGO's transformative role in fostering local and regional partnerships, driving scientific discovery, and enabling downstream technological innovation. Although LIGO underpins many of CE's visions and goals, CE hopes to far exceed LIGO's impacts and have a substantive far-reaching positive impact locally, across the US, and throughout the globe. By integrating LIGO's legacy and the current operating model of LIGO with insights from expert interviews, this section outlines CE's anticipated long-ranging impacts as the following:

1. **Community Integration:** impacts from partnerships with local communities where the CE observatories operate.
2. **Academic and Scientific Contributions:** impacts on higher education, international collaboration, and scientific exploration.
3. **Technological Innovations and Downstream Impacts:** the potential innovations that could lead to spin-off technologies and downstream impacts on industry and workforce capabilities.

It is important to note that the qualitative benefits of CE will largely depend on the future formation of partnerships between CE and communities, academic institutions, and the global scientific community. The exact nature of these impacts remains uncertain while potential collaborations are under exploration and the planning of CE is in development.

Community Integration

An essential aim for CE is to cultivate a holistic approach in partnering with the local communities that will host each observatory. The CE Project aims to create mutually beneficial impacts between the science community and local communities through a values-based engagement model. CE seeks to identify and respond to community priorities, and build a reciprocal relationship that extends through CE's lifetime. This holistic approach to building partnerships lets communities drive the potential range of impacts. This contrasts with historical approaches to building community relationships in the astrophysics and astronomy field, which has been characterized by the primacy of scientific pursuits and exclusion of local voices.

The exact nature of these partnerships and proceeding benefits will be dictated by community priorities and as such are currently unknown. However, based on engagement models at LIGO facilities and the ongoing efforts to engage communities during the CE planning process, CE is anticipated to impact local communities at least through local education, inclusive relationship building, and workforce opportunities.

Community Partnership in Practice

"Community partnerships will be part of the location identification and evaluation process and, significantly, not something that begins after a small number of physically promising locations have already been identified. This approach is adopted in order to respectfully work within the socio-cultural context and evolving legal landscape."

Source:
Pathways to Discovery in Astronomy and Astrophysics for the 2020s, Appendix

Local Education

Education is at the forefront of community engagement efforts for the existing LIGO observatories. Interviews with the CE Project indicate that initial feedback from local communities have emphasized that CE's impacts should be focused on aiding and supporting the next generation. Providing education benefits is seen as a likely part of community integration efforts, as CE seeks to build on LIGO's community engagement and education efforts.

The LIGO Hanford Observatory (LHO) and the LIGO Livingston Observatory (LLO) have made partnerships and outreach to local education a key objective. LHO and LLO have focused on K-14 education through science literacy programs, teacher workshops, visits to schools, and hosting field trips at LIGO Scientific Education Centers. Additionally, both these education centers receive about 10,000 students each annually through field trips. Interviews with LIGO staff suggest the range of interactions with teachers and students is critical because it opens young minds to a whole range of careers in STEM industries. CE seeks to build on LIGO's success with the construction and operation of scientific education centers modeled after LIGO, a possible mode of facilitating community integration.

Although outreach, engagement, and partnerships with local communities are just beginning to be explored, local education may be a part of community relationship building. Ultimately, the educational programs that come through CE will be dictated by community priorities and aspirations.

Inclusive Relationship Building

A core pillar of CE's community integration mission is to create and foster positive multi-beneficial impacts with communities by including community voices through all phases of development including site evaluation and the lifecycle of the CE observatories. This follows CE's commitment to the goals and visions outlined in the Astro2020 Decadal Survey, which sets national priorities, shapes funding decisions, and provides strategic guidance for the American astronomy and astrophysics profession for the next decade. By building inclusive relationships, CE represents a departure from typical community interaction and offers an opportunity to serve as a model for future community engagement not only in science but in all fields. These efforts extend to indigenous communities, rural populations, and local populations of color through the site evaluation phase, CE observatory construction, the CE operational lifecycle and beyond.

One focal point currently underway is an attempt to build partnerships with local indigenous communities that inhabit or have ancestral ties with the land where potential CE observatories might operate. As such, the CE Project created an Indigenous and Place-based Partnerships & Responsible Siting (IPP-RS) team whose primary aim is to build, strengthen, and maintain positive and mutually beneficial relationships with indigenous communities. In this partnership, CE plans to "go beyond institutional, local, state, federal and international regulations and protocols, ensuring accountability throughout the lifetime of the observatory."[5] Outreach to indigenous communities to build these relationships will begin in the initial site evaluation phase and will continue through construction, operation, and divestment. These efforts are currently underway by the IPP-RS team.

The efforts toward inclusive relationship building are simultaneously directed toward the local education needs, drawing from the experiences of both the LHO and LLO sites. By the nature of the facilities' locations, students will have access to opportunities and experiences that they likely would not have had otherwise.

Astro2020 Healthy Partnerships with Indigenous Communities

(1) Culturally supported pathways for inclusion in the Profession.

(2) Equitable access to education, current and emerging technologies, and economic benefits of hosting an astronomical facility.

(3) Responsible stewardship in recognition of the use of Indigenous lands by non-Indigenous entities. This last includes partnership with Indigenous communities in order to make reparations and to enter respectful dialogue about the construction of future facilities.

Source:
Astro2020 Decadal Survey, Appendix N

[5] Daniel, Kathryne J., Joshua R. Smith, Stefan Ballmer, Warren Bristol, Jennifer C. Driggers, Anamaria Effler, Matthew Evans et al. "Criteria for identifying and evaluating locations that could potentially host the Cosmic Explorer observatories." arXiv preprint arXiv:2410.00293 (2024).

Workforce Opportunities

CE will bring a range of employment opportunities for the surrounding regions, creating significant temporary and recurring jobs. This includes construction jobs, which are further detailed in the Occupational Positions subsection in the Quantitative Analysis in Chapter 3. Construction of both observatories will generate significant employment, totaling about 10,000 full-time and part-time jobs for both sites combined over the duration of CE construction as seen below in **Figure 19**. These jobs are temporary in nature, lasting the duration of the construction phase for the facilities, which is predicted to last about five years.

CE will also generate recurring annual jobs at both sites. The staff needs at both facilities incorporate a variety of subdisciplines that go beyond the academic and scientific personnel and include administrative staff and specialized operators that help run the engineering aspects of the observatories. The educational needs for these jobs would not necessarily require college degrees but may require specific training. The CE Project suggests that the majority of these roles—constituting more than half of each observatories' staff personnel—could be sourced locally. Assuming the 20 km site will include 93 staff while the 40 km site will include 200 staff, this suggests the potential for 62 and 134 positions to be filled locally at each location, respectively. Where appropriate and pending community needs as directed by community stakeholders, CE will partner with local and regional institutions to develop training programs to support the range of career types and skills needed for daily operations.

Figure 19. Employment Created Through CE Construction

Type of Employment[1]	20 km Site	40 km Site	Combined Sites
Construction			
Direct Employment	3,162	5,102	8,264
Indirect Employment	324	523	848
Induced Employment	411	664	1,075
Total Construction Jobs	**3,898**	**6,289**	**10,187**
Local Operations Staff[2]			
Administraitve	32	68	100
Specialized Staff	31	66	97
Total Operations Jobs	**62**	**134**	**196**

[1] Values represent job-years, i.e., the 10,187 annual construction direct jobs could represent about 2,000 jobs over the course of five years or 1,000 jobs over 10 years.

[2] Local operations staff exludes scientists and engineers that will likely be sourced nationally due to position requirements. Total operational jobs are meant to be illustrative of direct local employment opportunities.

Source: IMPLAN; The Cosmic Explorer Project; Economic & Planning Systems, Inc.

Academic and Scientific Contributions

CE's impact on academic institutions and scientific discovery will occur throughout the observatory's operation. With the research enabled by next generation gravitational wave research, CE will create a range of positive impacts on higher education and the global scientific community. This section seeks to highlight these notable academic and scientific contributions as indicated by expert interviews. More extensive reporting of CE's scientific objectives around gravitational-wave science can be found in the Cosmic Explorer Horizon Study and the NSF Cosmic Explorer White Paper.

As noted previously, the potential contributions from CE remain abstract while CE is in its development phase. The gravitational-wave science enabled by CE and its subsequent downstream contributions are still at least a decade away from 2025. Still, interviewees emphasized how CE could bolster institutions of higher education while supporting a new generation of science, technology, engineering, and mathematics (STEM) workers; produce new collaborative partnerships connecting CE to the rest of the US and world; cement US leadership in gravitational-wave science; and revolutionize human understanding of the universe.

Higher Education and STEM Linkages

One promising offshoot of CE operation and future scientific discovery are the linkages to higher education. CE scientific discovery will catalyze interest in university physics departments and higher education more generally, attract new investment in institutions of higher education, and help develop a robust STEM workforce.

University physics departments that are part of the LIGO Scientific Collaboration receive funding from the NSF and other federal, international, and private sources to conduct groundbreaking research; it is expected the same will be true for the community around CE. Students at these institutions are actively involved in scientific discoveries, receiving a unique opportunity unparalleled at other universities. Additionally, LIGO has generated significant publicity with the first gravitational wave detection in 2015, leading to the 2017 Nobel Prize in Physics. Interviewees from universities across the US and the UK suggest the high-profile nature of CE could further catalyze interest in STEM departments and investment in colleges and universities more broadly on local and national levels. New funding from NSF and other sources could have a transformative impact on university departments, pushing the boundaries of science that could inspire a new generation of students. This would be the case for all universities associated with CE, but particularly for the host universities most directly involved with the operations of the observatory. For example, LLO has served as a draw for Louisiana State University to attract faculty and graduate students, and discoveries at the observatory have been heavily publicized by the university and the State of Louisiana, raising the school's profile significantly.

Knowledge-Sharing and Collaboration

A core principle of gravitational-wave science is that it relies on both national and international cooperation. CE seeks to expand upon an already strong global network by promoting innovative models for data sharing and increasing access to scientific data. Experts believe that new global partnerships will accelerate discovery and reinforce U.S. leadership in the international scientific community.

Currently, LHO and LLO coordinate with other observatories such as Virgo and KAGRA to triangulate the origin of a gravitational wave. Each observatory in turn is supported by a vast international network of scientists and institutions. LHO and LLO efforts are built around the LIGO Scientific Collaboration (LSC), the Virgo interferometer by the Virgo Collaboration, and the KAGRA observatory by the KAGRA Collaboration. Together, these entities comprise the LIGO-Virgo-KAGRA Collaboration (LVK Collaboration).

While the LVK collaboration demonstrates the potential for deep international collaboration, important limitations remain. The detectors are not fully integrated, collaboration tends to occur in short bursts rather than through sustained engagement, and the current operating structure does not consistently support open, widespread data sharing—an essential element of CE's vision for enabling new scientific breakthroughs.

With the advent of CE and the planned Einstein Telescope in Europe, interviewees outlined a vision that includes formalizing relationships among LIGO, Virgo, and KAGRA beyond the existing LVK Collaboration. This emerging partnership is still in its early stages and will require significant commitment from the US physics and astronomy community. The ultimate goal is to make CE data openly and promptly available, along with the tools needed to ensure it can be widely accessed and used. Such a commitment would lay a strong foundation for accelerating scientific discovery and is essential to the long-term success of gravitational-wave science. A partnership of this nature represents the leading edge of international scientific collaboration, signaling a transformative cultural shift in how science and data are shared—one for which no current model yet exists.

The sequential operation of LIGO and CE, supported by NSF funding and embedded in a global partnership, would strengthen US leadership on the world stage and affirm its role as a central hub of gravitational-wave research. This leadership is essential for shaping global scientific priorities, attracting top research talent, and ensuring the U.S. remains at the forefront of transformative discoveries in astrophysics.

New Scientific Discoveries

Many of the most exciting contributions enabled by CE center on discoveries at the leading edge of a rapidly evolving scientific field. These breakthroughs stem from three major improvements CE brings to gravitational-wave astronomy: greater sensitivity, enhanced measurement precision, and access to new observational windows—regions of space and time previously beyond our reach. Together, these advancements will not only help answer fundamental questions about the universe but also generate entirely new scientific inquiries.

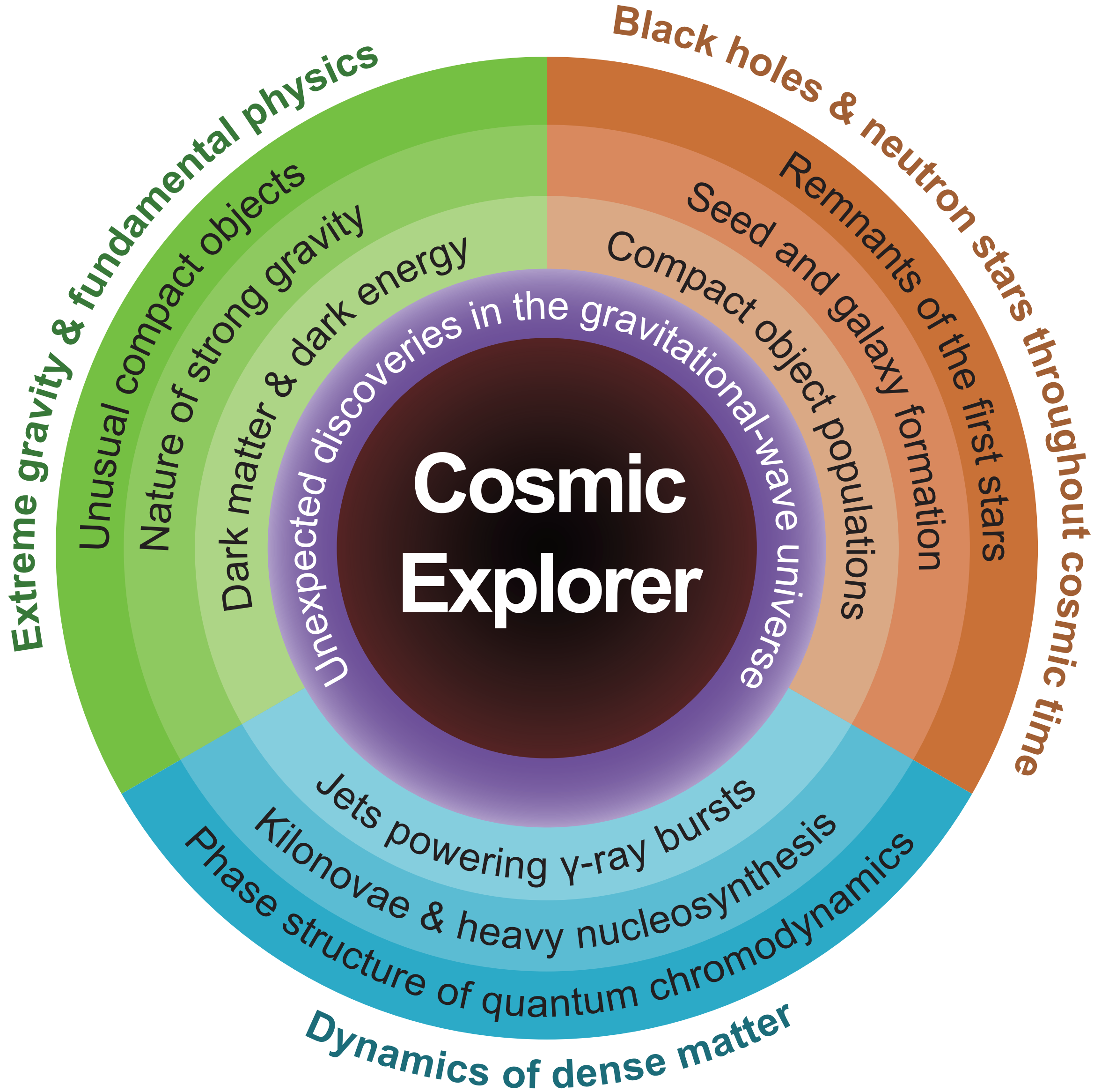
Citing Collaboration and Connectivity

The strength of scientific collaboration may be best measured by publication data. Interviewees suggested that the best representation of such metrics comes from The European Organization for Nuclear Research (CERN). CERN routinely features a co-author list of 5,000-6,000 authors and has produced 690 published articles in 2024. CE seeks to mirror such metrics, and the wider gravitational-wave science community has achieved several milestones. The first detection has been cited over 17,000 times and the most recent article produced by LVK Collaboration has an author list of over 1,700. These represent large milestones. However, it is likely such metrics will increase substantially as the result of CE that will allow more gravitational-wave detections with deeper insights and from a formal partnership currently envisioned by the astrophysics community.

The current generation of LIGO observatories—responsible for detecting the first gravitational-wave event in 2015—marked a significant leap in scientific capability. However, their observational reach is largely limited to the local universe (roughly one thousandth of the universe). According to gravitational-wave researchers, CE represents a dramatic expansion in our ability to observe the cosmos, enabling scientists to probe the farthest reaches of the observable universe. This will allow for the study of black holes and neutron stars from the early universe and may provide critical insights into fundamental mysteries such as the nature of dark matter and dark energy. With such phenomenal reach, there may likely be new surprises and discoveries the scientific community could not have foreseen.

Gravitational-wave events detected by CE—supported by a global network of observatories—will significantly deepen our knowledge across three broad scientific frontiers, illustrated in **Figure 20**: (1) extreme gravity and fundamental physics, (2) black holes and neutron stars through cosmic time, and (3) the dynamics of dense matter. More information on these topics can be found in the Cosmic Explorer Horizon Study and the NSF Cosmic Explorer White Paper.

Figure 20. Central science themes and objectives that will be addressed by Cosmic Explorer



Source: The Cosmic Explorer Project

Technological Innovations and Downstream Impacts

The technological impacts of CE will emerge during its planning phase and continue through its operation. While the full scope of innovations is challenging to predict, experts anticipate that CE will generate technological advancements, driving new scientific discoveries and will lead to new downstream products and services. The technological reach of gravitational wave research already stretches from healthcare to telecommunications, influencing advancements in a wide variety of areas and driving innovation across multiple industries. This section explores some of these impacts by looking deeper at CE specific innovations, commercialization opportunities, manufacturing opportunities, and how CE will develop a pipeline of sophisticated workforce talent. Specific advances related to the operation of CE and its advancements over other gravitational wave detectors are further detailed in **Appendix D**.

Commercialization Opportunities

The commercialization opportunities from CE's technological innovations are promising impact for a range of industries, but the impact remains difficult to predict. Gravitational wave research from the current generation of observatories have produced a number of new technologies, some of which are illustrated below in **Figure 21**. CE will likely build on these and could open up a whole new range of commercialization opportunities. Experts interviewed indicate that precision engineering, software and computing including machine learning, data analysis, vacuum systems, and vibration mitigation are all fields with strong potential for technological spinoffs.

Interviewed experts indicate the fields of precision engineering, software and computing, data analysis, vacuum systems, and vibration mitigation are ripe for technological spinoffs. Notable opportunity areas for commercialization include:

- **Optical Coatings.** These are thin layers of glass or crystal materials applied to specialized mirrors making CE's mirrors exceptionally reflective, enabling optical instruments to detect gravitational waves. Improvements in CE optical coatings help with light absorption—the fraction of light that is absorbed by the mirror and with minimizing mechanical noise associated with the temperature driven vibration of molecules. High-performance coatings have applications in telecommunications (both commercial and military), precision optics, such as advanced telescopes, laser systems, precision time-keeping and navigation, and semiconductor manufacturing.
- **Quantum Sensing.** Quantum sensing is a practical way for researchers to manipulate the rules of quantum mechanics to enhance CE detectors' ability to measure extremely tiny distances. CE would provide incremental improvements on LIGO facilities, but interviewees indicate there is significant potential around further advancements. The innovations in quantum sensing that enable higher precision could be adapted into other uses including quantum computers, navigation, microscopy, and other uses in the precision measurement community.

- **Controls and Instrumentation.** These components are the systems and devices used to monitor, stabilize, and optimize the operation of CE. The sensitivity planned for CE is unprecedented and will minimize noise sources and maintain stability over long observation periods. Further advancements will have impacts on a wide range of applications in quantum computing, electrical engineering, research labs, STEM education and research and development.
- **Seismic Isolation.** Seismic isolation systems are utilized to protect the mirrors and other sensitive equipment of gravitational wave observatories, effectively isolating any noise from residual ground motion. Improvements in seismic isolation systems in CE will enhance low-frequency sensitivity of CE and initially target a moderate improvement over LIGO. The tools behind seismic isolation could impact industries that require extreme precision and stability. Some examples include nanometer-scale semiconductor manufacturing, micromanufacturing, and enhancements to microscopy.
- **Nuclear Simulations.** The data observed and researched through studying neutron star collisions will help scientists more deeply understand nuclear reactions. The biggest opportunity from nuclear simulations stems from the analysis and computer simulations performed by researchers. These tools could be used to improve big data analysis and throughout tech industries.
- **Simulation Systems.** These refer to the codes that model optical systems. These codes are critical for designing and optimizing CE's performance. One example is the FINESSE simulation tool, which is used to model the model the behavior of complex optical interferometers. Such simulation systems are extremely versatile and could advance a number of industries, especially those that rely on precision optical systems.

Manufacturing Opportunities

There may be opportunities for US firms to provide manufacturing support to CE observatories. Currently, gravitational wave observatories are dependent on a limited number of vendors operating primarily in Europe. These suppliers are unique due to the scale and size of equipment required for observatories. This includes equipment used for optics and photonics, mirror coatings, and suspension development among others. The technology and expertise for these technical gravitational wave components exist within the US and US firms could capitalize on the new opportunities associated with Cosmic Explorer in these mid-stream markets. As these CE generated and inspired technologies and applications find a broader use, the opportunities for these firms could multiply.

Workforce Pipeline to Other Sectors

The innovations behind CE and gravitational wave research are supported by a highly educated and capable scientific workforce. While many of these scientists and engineers will remain in the fields of astrophysics and astronomy in pursuit of scientific knowledge and discoveries, many others will take the skills and expertise they develop into other industries with the potential to have transformational impacts on technical industries, finance, national labs, and a variety of other professions.

Figure 21. Gravitational Wave Induced Technologies

Case Studies in Action

- Liquid Instruments' Moku Platform. The firm Liquid Instruments has its roots in control and instrumentation of gravitational wave discovery. Liquid Instruments manufactures the Moku, which combines the functionality of over 10 professional grade instruments (oscilloscope, spectrum analyzer). The Moku platform has applications in electronics, integrated circuits, signal processing, and renewable energy.
- MEMS Gravimeters/Wee-g. These are highly sensitive devices used to measure local variations in gravitational fields. The low-cost portable device has a wide range of practical applications in civil engineering, hydrogeology, energy, geology, infrastructure monitoring, and defense and security. The Wee-g is a direct spinoff from gravitational research suspension modeling at the University of Glasgow's Institute for Gravitational Research (IGR).[6]
- Nanokicking. Nanokicking is a medical technique that applies mechanical vibrations to stimulate cells, particularly stem cells, to enhance bone growth that is currently headed into clinical trials. Nanokicking was borne out of interdisciplinary research between gravitational wave researchers and stem cell engineers from the University of the West of Scotland and the University of Glasgow.[7] [8]
- Optos Eye Scanner. Using data analysis methods employed in gravitational wave research, medical technology company Optos partnered with the University of Glasgow's IGR to improve the quality control and detection of retinal defects. This has allowed companies to provide improved services to a greater number of patients cost effectively. [9]

6 https://www.gla.ac.uk/schools/physics/research/groups/igr/impact/

7 https://www.gla.ac.uk/news/archiveofnews/2013/april/headline_274263_en.html

8 Robertson SN, Campsie P, Childs PG, Madsen F, Donnelly H, Henriquez FL, Mackay WG, Salmerón-Sánchez M, Tsimbouri MP, Williams C, Dalby MJ, Reid S. Control of cell behaviour through nanovibrational stimulation: nanokicking. Philos Trans A Math Phys Eng Sci. 2018 May 28;376(2120):20170290. doi: 10.1098/rsta.2017.0290. PMID: 29661978; PMCID: PMC5915650.

9 https://rse.org.uk/wp-content/uploads/2023/08/20-Science-Scotland.pdf

Appendix A: Input-Output Modelling Context

Notes on Input-Output Modeling

There are several important notes relevant to the interpretation of IMPLAN model estimates derived in this report.

IMPLAN is an industry standard tool that allows for quantifying and analyzing the impacts of specific projects. Its strengths are in its detailed economic insights over a wide variety of specific economic sectors, understanding the linkages between industries, transparency over the tool's calculations and sources of data, and the power metrics produced by the model such as the indirect and induced impacts on output, labor income, and employment. However, there are several important limitations and caveats to note with IMPLAN within this analysis.

First, IMPLAN is a static model, meaning price changes are not built into the model and are not affected by impact runs. The I/O model assumes that consumer preferences, government policy, technology, and prices all remain constant. Therefore, it is better for short- to medium-term forecasts.

Second, the I/O methodology assumes that demand for goods and services by industries or households directly relates to the increase in income and that an increase in demand results in a proportional increase in *local* supply and employment. This assumes fixed linear relationships between input (resource) use and output and between income and consumption. This assumption allows for economic modeling and best estimates of economic impacts, recognizing that, in reality, responses to final demand changes may not occur in direct linear proportions.

Third, I/O models assume that local suppliers have sufficient capacity to respond to changes in final demand by increasing their output and hiring additional workers without shifting any production resources (inputs) from other competing needs. This assumption may not hold in areas with tight labor or capital markets since suppliers may find it difficult to obtain these labor or material inputs or other resources necessary to expand production. Furthermore, it is important to note that I/O modeling does not delineate the origin of labor and whether or not the employees supported by projects would reside within the County or region of interest.

Siting Decisions and Methodology for Localizing Impacts

Current CE plans indicate there will be two observatories, a 20 and a 40 km site. The CE Project is currently exploring up to 20 potential locations across the US for both observatories. It is common to quantify the economic impacts of research institutes by using multipliers associated with a specific geography (i.e. county, multi-county, state). Given the uncertainty of CE sitting, EPS reviewed the multipliers of all 20 potential CE locations to understand the range of impacts associated with different sites across the US. This entailed examining related construction and operational sectors related to CE.

To prevent a misrepresentation from either a lower or higher set of multipliers from the potential CE locations, EPS utilized a specific county from those under consideration that represented the median multiplier between all 20 sites. This median county is chosen to serve as the statistical average represented in this report. Consequently, the 20 km, 40 km, and combined economic impacts of CE could be greater or smaller than the figures shown in this report. EPS believes the numbers represented herein provide an illustrative view of CE construction and operational impacts for any site.

Appendix B: Economic Impact Results of 20 km Observatory and Combined Impacts

20 km Site

One-Time Construction Impacts

Figure 22 illustrates the 20 km site's impact on economic output, employment, and employee compensation. Total employment is expected to generate **3,898 jobs-years** and produce a total output of **$509 million** of economic activity over the course of construction. This analysis further examines the variety of direct construction occupation positions, construction timeline, and likely indirect and induced industries affected by construction.

Figure 22 Local 20 km Site Construction Impacts

Type of Impact	Employment[1]	Employee Compensation[2]	Economic Output
Construction Phase			
Direct Impacts	3,162	$135,690,000	$390,190,000
Indirect Impacts	324	$13,940,000	$54,030,000
Induced Impacts	411	$16,840,000	$65,270,000
Total Impacts	**3,898**	**$166,470,000**	**$509,490,000**

[1] Values represent job-years, i.e., the approximately 3,000 annual construction direct jobs could represent about 1,500 jobs over the course of two years or 1,000 jobs over three years.

[2] Employee compensation includes benefits in addition to wages and salaries.

Source: IMPLAN; The Cosmic Explorer Project; Economic & Planning Systems, Inc.

Output: Construction operations are estimated to generate approximately $390 million in direct one-time industry output. Local spending will result in $54 million in indirect one-time impacts stemming from business-to-business transactions to support direct construction costs. Household spending from direct and indirect employment will generate $65 million in induced impacts. All combined, the CE construction for the 20 km site will generate a total of $509 million in localized economic activity for the county.

Employment: CE employment for construction includes 3,162 direct jobs, 324 indirect jobs, and 411 induced jobs for a total employment impact of 3,898. Employment includes both full-time and part-time workers. Employment refers to the number of jobs in each year summed up over the entire estimated period of construction for the Project.

Employee Compensation: Of the $509 million in direct industry output reported above, approximately $136 million will be received by construction employees in the form of salary, wages, and benefits. Indirect employee compensation impacts total approximately $14 million, induced employee compensation impacts total $17 million, for a total annual employee compensation impact of about $166 million. The average annual salary per employee totals about $43,000. As noted previously, compensation will range based on site location and can be further influenced by local labor market constraints.

Occupational Positions: Employment is expected to span across a diverse range of construction occupations. **Figure 23** below provides an outline of estimated direct employment positions with their corresponding average income. Annual income per position is expected to range from $28,000 to $100,000 with an average of $43,000. Additionally, there are expected to be more specialized occupations, especially for configuration and installation of the vacuum and detector systems that will feature a higher proportion of engineers and technical workers.

Figure 23 Local 20 km Site Direct Construction Needs and Salary

Broad Aggregation Level Occupation	Employment Totals	Average Income
Carpenters	263	$43,000
Construction Laborers	260	$33,000
First-Line Supervisors of Construction Trades and Extraction Worke	214	$53,000
Construction Managers	178	$77,000
Logisticians and Project Management Specialists	126	$68,000
General and Operations Managers	81	$99,000
Office Clerks, General	56	$28,000
Secretaries and Administrative Assistants	51	$36,000
Civil Engineers	47	$56,000
Cost Estimators	46	$59,000
Laborers and Material Movers	44	$30,000
Automotive Technicians and Repairers	40	$40,000
Construction Equipment Operators	38	$45,000
Bookkeeping, Accounting, and Auditing Clerks	37	$35,000
Cement Masons, Concrete Finishers, and Terrazzo Workers	34	$38,000
Electricians	33	$44,000
Structural Iron and Steel Workers	32	$41,000

Sources: IMPLAN; Economic & Planning Systems, Inc.

Construction Timeline and Local Construction Costs: Figure 24 and **Figure 25** below provide an overview of expected direct construction costs and employment over the planning and construction period for the 20 km site. Costs associated with the conceptual design and final design of CE in 2029 represent an aggregated total that runs from 2023 to 2029. Both construction costs and employment will peak in the first two years (estimated to occur in 2030 and 2031) of construction activity that immediately follows the planning and design period. Construction costs will average approximately $98 million per year and about 800 annual direct jobs during the peak period. Constitution and employment will then gradually decrease until completion in year five of construction activity (estimated 2035).

Figure 24 20 km Site Construction Timeline and Costs

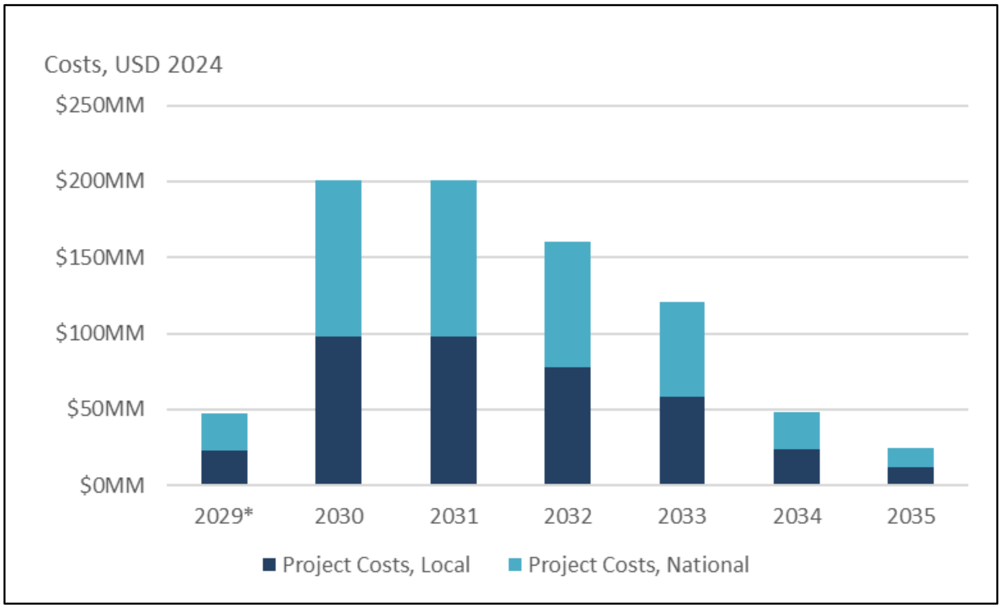
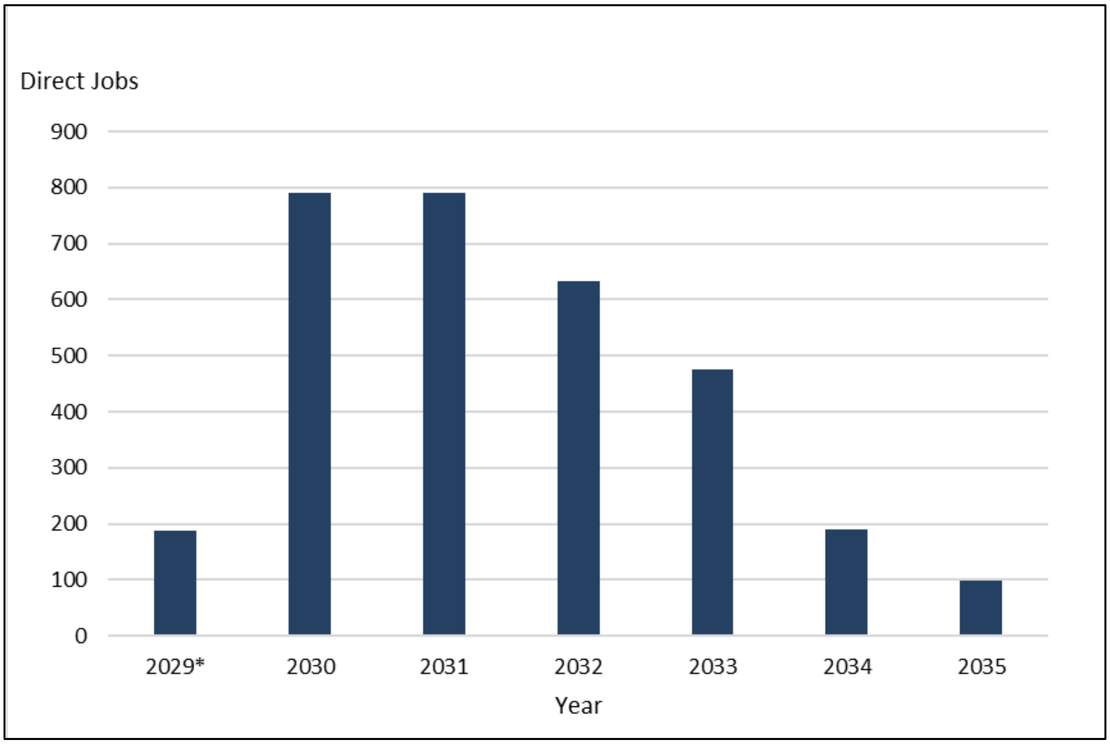


Figure 25   20 km Local Construction Timeline



Indirect and Indued Industries: Figure 26 and **Figure 27** below provide an overview of the largest impacts by indirect and induced industries. The largest indirect industries affected include retail trade, real estate and rental and leasing, and transportation and warehousing, totaling $31 million of indirect output or about 58 percent of total indirect output. The largest impacted induced industries include real estate and rental housing and leasing, health care and social assistance, and retail trade, combining to total $41 million in induced spending from localized household spending. This represents about 63 percent of total induced output.

Figure 26 20 km Largest Local Impacted Indirect Industries

NAICS 2-Digit Industry	Indirect Output
Retail Trade	$16,990,000
Real Estate and Rental and Leasing	$9,410,000
Transportation and Warehousing	$4,460,000
Professional, Scientific, and Technical Services	$3,560,000
Wholesale Trade	$3,270,000
Total [1]	**$54,030,000**

[1] The largest indirect industries do not total to the $54 million sum. This number instead reflects the grand total of all indirect industries based on CE Construction.

Sources: IMPLAN; Economic & Planning Systems, Inc.

Figure 27 20 km Largest Local Impacted Induced Industries

NAICS 2-Digit Industry	Indirect Output
Real Estate and Rental and Leasing	$16,220,000
Health Care and Social Assistance	$14,320,000
Retail Trade	$10,240,000
Accommodation and Food Services	$5,030,000
Government Enterprises	$4,230,000
Total [1]	**$65,270,000**

[1] The largest indirect industries do not total to the $65 million sum. This number instead reflects the grand total of all induced industries based on CE Construction.

Sources: IMPLAN; Economic & Planning Systems, Inc.

Operational Impacts

On an annual basis, operations for the CE 20 km observatory will produce 148 jobs throughout the county and generate an output of about $33 million, as illustrated below in **Figure 28**. These annual ongoing economic impacts capture the direct, indirect, and induced impacts generated by the combination of businesses located as result of CE. This section will detail the annual economic output, employment and occupation needs, and employee compensation. Direct employment is estimated by the CE Project.

Figure 28 20 km Local Annual Operations Impacts

Type of Impact	Employment[1]	Employee Compensation[2]	Economic Output
Operations Phase (Annual)			
Direct Impacts	93	$16,320,000	$23,310,000
Indirect Impacts	12	$520,000	$2,330,000
Induced Impacts	44	$1,790,000	$6,940,000
Total Impacts	**148**	**$18,630,000**	**$32,580,000**

[1] Values represent annual jobs, i.e., the 99 direct jobs are over a one-year period.

[2] Employee compensation includes benefits in addition to wages and salaries.

Source: IMPLAN; The Cosmic Explorer Project; Economic & Planning Systems, Inc.

Annual Output: CE operations are estimated to generate $23 million in direct industry output annually. Local spending will result in about $2 million in indirect industry output impacts from business-to-business transactions as result of direct operations. Household spending from direct and indirect employment will generate about $7 million in induced impacts. All economic output activity combined totals about $33 million on an annual basis. Over a 50-year lifecycle of CE operations, output is estimated to generate about $1.63 billion in total economic output.

Annual Employment and Occupational Needs: The 93 direct jobs will generate 12 indirect and 44 induced jobs annually for a total employment impact of approximately 148 jobs on an annual basis. The 93 direct jobs from daily CE operations will encompass a variety of employment needs for CE that exist beyond the technical research needs of gravitational wave research.

Employee Compensation: Of the $23 million in direct industry output reported above, approximately $16 million will be received by employees employed in the Project in the form of salary, wages, and benefits. Indirect and induced employee compensation impacts total over $2.3 million for a total annual employee compensation impact of about $19 million. Over a 50-year lifecycle of CE operations, total employee compensation is estimated to generate about $932 million. Average salary including benefits totals $175,000 per direct employment, $45,000 per indirect employment, and $41,000 per induced employment.

Combined Site Impacts

Construction Impacts

The combined economic activity generated from the construction of both sites will produce measurable impacts in terms of economic output, employment, and employee compensation. **Figure 29** illustrates these impacts on a county basis with total employment expecting to generate **10,187 total jobs** and produce a total output of **$1.33 billion** in economic activity over the course of construction. This analysis further examines the variety of direct construction occupation positions, construction timeline, and likely indirect and induced industries affected by construction.

Figure 29 Combined Local Sites Construction Impacts

Type of Impact	Employment[1]	Employee Compensation[2]	Economic Output
Construction Phase			
Direct Impacts	8,264	$354,620,000	$1,019,740,000
Indirect Impacts	848	$36,430,000	$141,200,000
Induced Impacts	1,075	$44,020,000	$170,580,000
Total Impacts	**10,187**	**$435,070,000**	**$1,331,520,000**

[1] Values represent job-years, i.e., the approximately 8,000 direct construction jobs could represent about 2,000 jobs over the course of four years or 1,000 jobs over eight years.

[2] Employee compensation includes benefits in addition to wages and salaries.

Source: IMPLAN; The Cosmic Explorer Project; Economic & Planning Systems, Inc.

Output: Construction operations are estimated to generate approximately $1.02 billion in direct one-time industry output. Local spending will result in $141 million in indirect one-time impacts stemming from business-to-business transactions to support direct construction costs. Household spending from direct and indirect employment will generate $171 million in induced impacts. Between both sites and their associated locations, CE construction will produce a grand total of $1.33 billion million in localized economic activity.

Employment: Construction employment includes 8,264 direct jobs, 848 indirect jobs, and 1,075 induced jobs for a total employment impact of 10,187. These figures include both full-time and part-time workers. Employment refers to the number of jobs in each year summed up over the entire estimated period of construction for the Project.

Employee Compensation: Of the $1 billion in direct industry output reported above, approximately $355 million will be received by construction employees in the form of salary, wages, and benefits. Indirect employee compensation impacts total approximately $36 million, induced employee compensation impacts total $44 million, for a total annual employee compensation impact of approximately $435 million. The average annual salary per employee totals about $43,000.

Occupational Positions: Employment is expected to span across a diverse range of construction occupations. **Figure 13** below provides an outline of estimated direct employment positions with their corresponding average income. Annual income per position is expected to range from $28,000 to $100,000 with an average of $43,000. Additionally, there are expected to be more specialized occupations, especially for configuration and installation of the vacuum and detector systems that will feature a higher proportion of engineers and technical workers.

Figure 30 Combined Local Site Direct Construction Needs and Salary

Occupations	Employment Totals	Average Income
Carpenters	687	$43,000
Construction Laborers	680	$33,000
First-Line Supervisors of Construction Trades and Extraction Worke	560	$53,000
Construction Managers	466	$77,000
Logisticians and Project Management Specialists	329	$68,000
General and Operations Managers	212	$99,000
Office Clerks, General	146	$28,000
Secretaries and Administrative Assistants	134	$36,000
Civil Engineers	124	$56,000
Cost Estimators	120	$59,000
Laborers and Material Movers	115	$30,000
Automotive Technicians and Repairers	104	$40,000
Construction Equipment Operators	99	$45,000
Bookkeeping, Accounting, and Auditing Clerks	96	$35,000
Cement Masons, Concrete Finishers, and Terrazzo Workers	89	$38,000
Electricians	85	$44,000
Structural Iron and Steel Workers	84	$41,000

Sources: IMPLAN; Economic & Planning Systems, Inc.

Construction Timeline and Local Construction Costs: Figure 31 and **Figure 32** below provide an overview of expected direct construction costs and employment over the planning and construction period for CE. Costs associated with the conceptual design and final design of CE in 2029 represent an aggregated total that runs from 2023 to 2029. Both construction costs and employment will peak in the first two years (estimated to occur in 2030 and 2031) of construction activity that immediately follow the planning and design period. Construction costs will average approximately $255 million per year and over 2,000 annual direct jobs during the peak period. Constitution and employment will then gradually decrease until completion in year five of construction activity (estimated 2035).

Figure 31 Combined Site Construction Timeline and Costs

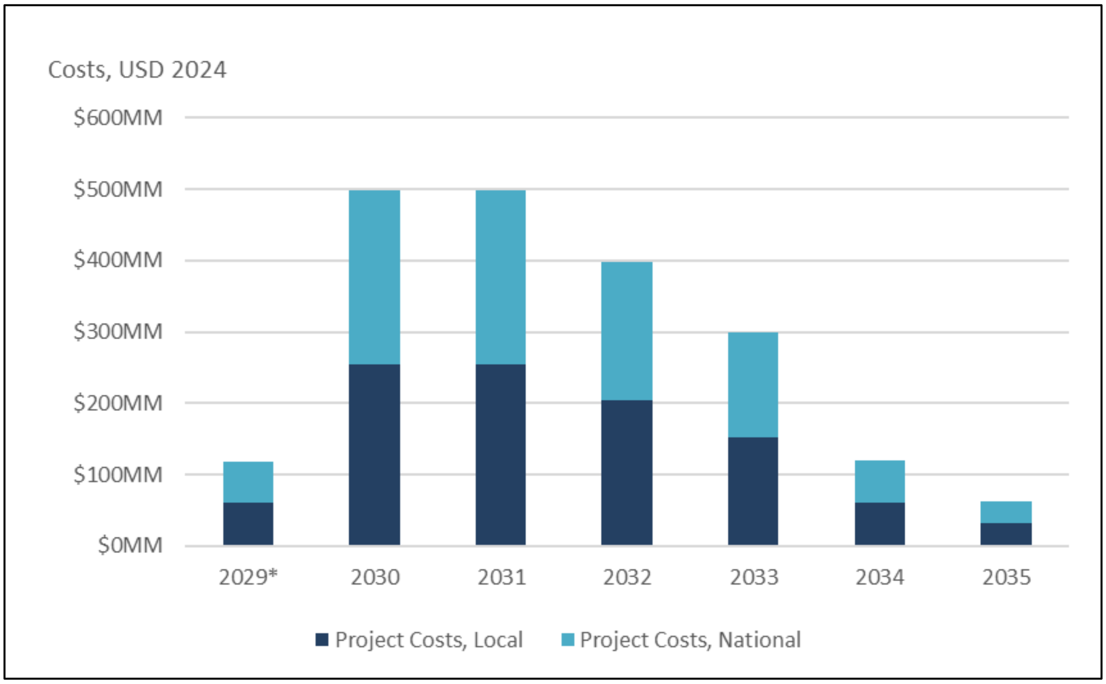
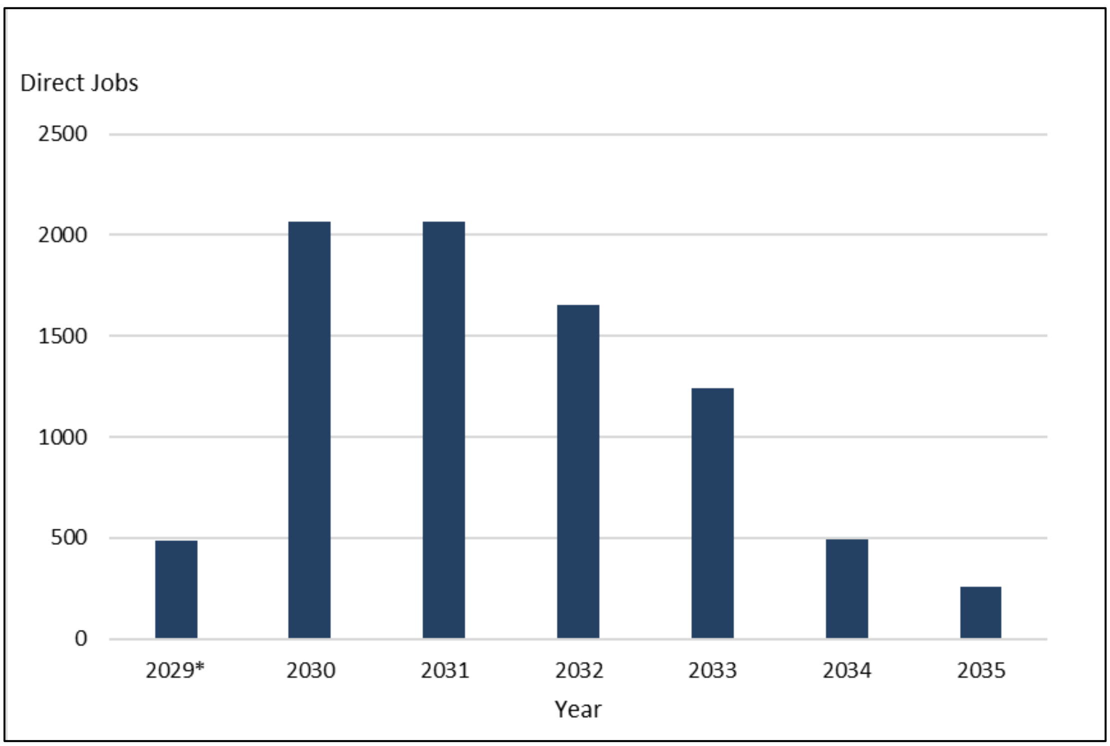


Figure 32 Combined Local Construction Timeline



Indirect and Indued Industries: Figure 33 and **Figure 34** below provide an overview of the largest impacts by indirect and induced industries. The largest indirect industries affected include retail trade, real estate and rental and leasing, and transportation and warehousing, totaling $81 million of indirect output or about 57 percent of total indirect output. The largest impacted induced industries include real estate and rental housing and leasing, health care and social assistance, and retail trade, combining to total $107 million in induced spending from localized household spending. This represents about 62 percent of total induced output.

Figure 33 Combined Largest Local Impacted Indirect Industries

NAICS 2-Digit Industry	Indirect Output
Retail Trade	$44,410,000
Real Estate and Rental and Leasing	$24,590,000
Transportation and Warehousing	$11,650,000
Professional, Scientific, and Technical Services	$9,310,000
Wholesale Trade	$8,540,000
Total [1]	**$141,200,000**

[1] The largest indirect industries do not total to the $141 million sum. This number instead reflects the grand total of all indirect industries based on CE Construction.

Sources: IMPLAN; Economic & Planning Systems, Inc.

Figure 34 Combined Largest Local Impacted Indirect Industries

NAICS 2-Digit Industry	Induced Output
Real Estate and Rental and Leasing	$42,390,000
Health Care and Social Assistance	$37,430,000
Retail Trade	$26,760,000
Accommodation and Food Services	$13,140,000
Government Enterprises	$11,060,000
Total	**$170,570,000**

[1] The largest induced industries do not total to the $171 million sum. This number instead reflects the grand total of all induced industries based on CE Construction.

Sources: IMPLAN; Economic & Planning Systems, Inc.

Operational Impacts

Combining both the 20 and 40 km annual operations will produce **467 total jobs** and generate an output of just about **$103 million**, as illustrated below in **Figure 35**. As in the previous subsections, this subsection will detail economic output, employment, and compensation.

Figure 35 Combined Sites Local Annual Operations Impacts

Type of Impact	Employment[1]	Employee Compensation[2]	Economic Output
Construction Phase			
Direct Impacts	293	$51,360,000	$73,370,000
Indirect Impacts	37	$1,640,000	$7,340,000
Induced Impacts	137	$5,630,000	$21,850,000
Total Impacts	**467**	**$58,630,000**	**$102,560,000**

[1] Values represent job-years, i.e., the approximately 8,000 direct construction jobs could represent about 2,000 jobs over the course of four years or 1,000 jobs over eight years.

[2] Employee compensation includes benefits in addition to wages and salaries.

Source: IMPLAN; The Cosmic Explorer Project; Economic & Planning Systems, Inc.

Annual Output: CE operations are estimated to generate $73 million in direct industry output annually. Local spending will result in about $7 million in indirect industry output impacts from business-to-business transactions as result of direct operations. Household spending from direct and indirect employment will generate about $22 million in induced impacts. All economic output activity combined totals over $103 million on an annual basis. Over a 50-year lifecycle of CE operations, output is estimated to generate about $5.1 billion in total economic output in the county in which it operates.

Annual Employment and Occupational Needs: The 293 direct jobs will generate 37 indirect and 137 induced jobs annually for a total employment impact of approximately 467 jobs on an annual basis. The 293 direct jobs from daily CE operations will encompass a variety of employment needs for CE that exist beyond the technical research needs of gravitational wave research.

Employee Compensation: Of the $73 million in direct industry output reported above, approximately $51 million will be received by employees employed in the Project in the form of salary, wages, and benefits. Indirect and induced employee compensation impacts total approximately $7 million for a total annual employee compensation impact of about $59 million. Over a 50-year lifecycle of CE operations, total employee compensation is estimated to generate about $2.9 billion. Average salary including benefits totals $175,000 per direct employment, $45,000 per indirect employment, and $41,000 per induced employment.

Appendix C: Supporting Figures

Figure 36 Cosmic Explorer Detailed Construction Budget

Construction Budget	Civil Engineering	Vacuum	Detector	Total
40K Observatory				
Local	**$337,950,000**	**$249,370,000**	**$42,230,000**	**$629,550,000**
Workforce	$272,390,000	$215,850,000	$41,830,000	$530,070,000
Capital	$65,560,000	$33,520,000	$400,000	$99,480,000
National	**$125,610,000**	**$228,510,000**	**$205,130,000**	**$559,250,000**
Workforce	$47,860,000	$69,460,000	$105,710,000	$223,030,000
Capital	$77,750,000	$159,050,000	$99,410,000	$336,210,000
Combined	**$463,560,000**	**$477,870,000**	**$247,360,000**	**$1,188,790,000**
Workforce	$320,250,000	$285,310,000	$147,540,000	$753,100,000
Capital	$143,310,000	$192,560,000	$99,810,000	$435,680,000
20K Observatory				
Local	**$208,780,000**	**$139,180,000**	**$42,230,000**	**$390,190,000**
Workforce	$169,340,000	$120,470,000	$41,830,000	$331,640,000
Capital	$39,430,000	$18,710,000	$400,000	$58,540,000
National	**$80,330,000**	**$127,540,000**	**$205,130,000**	**$413,000,000**
Workforce	$37,420,000	$38,770,000	$105,710,000	$181,900,000
Capital	$42,910,000	$88,770,000	$99,410,000	$231,090,000
Combined	**$289,110,000**	**$266,720,000**	**$247,360,000**	**$803,190,000**
Workforce	$206,760,000	$159,240,000	$147,540,000	$513,540,000
Capital	$82,350,000	$107,480,000	$99,810,000	$289,640,000

Sources: The Cosmic Explorer Project; Economic & Planning Systems, Inc.

Appendix D: CE Specific Innovations

The planning, construction, ongoing operation, and potential future upgrades of CE will drive technological advancements that lay the groundwork for new discoveries in both science and industry. CE will incorporate highly technical and sophisticated improvements compared to earlier generations of gravitational wave observatories. During the formal project design phase, CE will develop and optimize key aspects of its infrastructure, including civil engineering, the vacuum system, and detectors.

Civil engineering efforts will focus on vibration-reducing technologies designed to mitigate seismic activity and infrasound. The vacuum system, while building on the foundations of systems used in LIGO and other gravitational wave detectors, aims to deliver improvements. Notably, CE's vacuum tubing will be on a far larger scale: each arm of the observatory will span 20 to 40 km, compared to LIGO's 4 km arms. The most significant technological advancements, however, are expected in CE's detectors. These innovations will be critical for enhancing CE’s sensitivity and precision and may also unlock commercialization opportunities. Some of these technologies of focus, discussed in **Chapter 4**, include large optics, suspensions and seismic isolation lasers and squeezed light, and calibration and computing.

Altogether, improvements in each of these CE components will significantly enhance the observatory’s capabilities, pushing the reach of gravitational wave detection to the edge of the observable universe. Future improvements and iterations for gravitational wave detection will be further built on these already far advancing technological advancements. For more information on CE specific innovations see the “Design Stage R&D for Cosmic Explorer a Review of Critical Technologies.”

ECONOMIC AND QUALITATIVE IMPACT REPORT

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COSMIC EXPLORER

Prepared by

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The Economics of Land Use