Hydrogen Sustainable Infrastructure Guidelines (H_2SIG)

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Prepared by:

Strategic Analysis Inc.

Rev.0

STRATEGIC ANALYSIS INC.

Project Executive Summary

Policy support and national interest in hydrogen (H_2) as a way for reducing greenhouse gas (GHG) emissions has undergone a recent resurgence. If H_2 is successfully deployed at anticipated scales, it will require billions of dollars in infrastructure project investment impacting every community in the United States. Consequently, the sustainability of future H_2 infrastructure projects must be evaluated to measure environmental, economic, and social impacts.

Infrastructure interacts with major global challenges inclusive of climate change, resilience, equity and social justice, environmental protection and biodiversity, public health, and economic recovery. Hydrogen-related projects are not unique in this way and will require equal care in assessing as other infrastructure projects; however, no known sustainability evaluation frameworks have yet been applied specifically to H_2 infrastructure projects. Thus, this effort conducted by Strategic Analysis Inc. (SA) directly addresses the problem of how to apply sustainability assessments to the unique aspects of H_2 infrastructure projects. The effort leverages the Envision® sustainability framework developed by the Institute for Sustainable Infrastructure (ISI) intended for application to a broad range of infrastructure development projects. Used predominantly in North America, Envision is a flexible system of criteria and performance objectives that aids decision makers and project teams identify sustainable approaches during the planning, design, and construction of infrastructure projects that will continue throughout the project's operations, maintenance, and end-of-life phases.

The goal of this work is to provide guidelines for applying sustainable practices to H_2 projects, enable all stakeholders to evaluate sustainability tradeoffs for H_2 projects, and to demonstrate the feasibility and advantages of applying Envision to H_2 projects. These advantages can include lowering risks for hydrogen infrastructure and standardizing and validating the sustainability of H_2 projects.

Through this work the team has developed this H_2 Sustainable Infrastructure Guidelines (H_2SIG) document to assist project developers, investors, and regulators in straightforward application of the Envision® framework to systematically enhance clarity and increase objectivity across hydrogen projects. This H_2SIG report provides a brief introduction to Envision, the types of H_2 projects considered within the H_2SIG, and the 18 H_2-priority Envision sustainability indicators (credits) that are most applicable to H_2 projects. For each credit, the team identified recommended practices, tools and references, examples for addressing credit requirements, and listed related Envision credits. Subject matter experts (SMEs) from 20 different organizations (industry, non-profits, municipalities, emissions regulators, and national labs) were engaged through 7 focus groups to discuss the H_2-prioritized Envision® requirements and elements included in the guidelines. These SMEs also reviewed and provided feedback on the final H_2SIG report.

In addition to the guidelines, the team conducted case studies as a way of demonstrating and informing the guidelines and providing examples and ideas for future projects to use. The case studies were based on publicly available documentation and interviews with respective organizations. Two case studies were conducted, each consisting of several projects of a similar type: 1) a trio of projects covering refueling stations with fuel cell electric bus (FCEB) deployments and 2) two projects covering tri-generation systems producing electricity, hydrogen, and water or heat. Results from these case studies are provided in the Appendix and show great potential for scoring well on the H_2-priority Envision credits.

The following are key takeaways after drafting the H_2SIG and conducting the case studies:

- Envision®, or any other sustainability practice, should be incorporated at the very beginning of project planning to maximize its impact and minimize its cost.
- Collaboration in planning with key community stakeholders not only facilitates community engagement, but also unlocks synergies in broader infrastructure systems.

Based on detailed consideration of the H_2-prioritized credits and evaluation of the case study projects, hydrogen projects can potentially achieve high Envision scores in the following areas:

- Reducing GHG emissions affecting climate change
- Reducing air pollutant emissions affecting the health of communities
- Synergistically handling waste byproducts
- Integrating into existing infrastructure
- Incorporating renewable energy
- Addressing equity and environmental justice

Additionally, hydrogen projects could improve in the following sustainable practices:

- 2-way communication engagement and collaborative planning with stakeholders
- Educational awareness of hydrogen technology
- Tracking and reporting on water use and water quality
- Monetizing and including environmental and social benefits in life-cycle costs

The authors believe that using a sustainability framework can help address some of the barriers that H_2 projects face, such as permitting, high-cost, and public opposition due to fear of H_2 safety or NIMBY-ism. To compete with lower cost, well-known technologies, and create the next generation of resilient infrastructure, H_2 projects should seriously consider implementation of sustainable practices. Such practices are not always easy to apply, particularly if not considered at project conception. However, the DOE-funded H_2-Hubs provide a useful example via their requirement to develop community benefits plans, which showed how requiring elements of sustainability can help shift how the industry thinks about project development. This can include the impacts to society and the environment, potential for interconnected infrastructure to build resiliency and efficiency, and balancing challenging trade-offs to make the best design decisions for both the project and its stakeholders.

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Project Title: Hydrogen Sustainability Assessment Methods for Project Development

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This work requires partnership with sustainability, research, and technical groups to review the hydrogen guidelines provided in this document. SA developed these guidelines in close collaboration and with guidance from the Institute for Sustainable Infrastructure (ISI), specifically Verification Director Kristi Wamstad and Senior Research Associate Judith Rodriguez, who are considered team members on this project. Individuals from the following organizations were instrumental in reviewing and providing feedback on the guidelines. SA appreciates the assistance provided by these organizations:

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California Air Resources Board
South Coast Air Quality Management District
Pacific Gas & Electric
University of Maryland
Sandia National Laboratory
National Renewable Energy Laboratory
Central Contra Costa Sanitary District
Mott MacDonald
OP Cleantech
ThinkWatts Foundation
Sargent & Lundy
Washington Gas
Green Hydrogen Organisation

This work would also not be possible without the expertise and participation from our case study projects on hydrogen fuel cell electric buses with refueling stations and tri-generation hydrogen production systems. Participation from the Southeastern Pennsylvania Transportation Authority, SunLine Transit Agency, FuelCell Energy, and Toyota are very much appreciated.

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This report in no way serves as a substitute for or equivalent to using ISI's Envision Guidance Manual or policies. Those using these resources cannot publicly suggest or infer that a specific level of achievement has been met based on the guidelines alone.

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Table of Abbreviations

ANL	Argonne National Laboratory
ATR	autothermal reforming
CCUS	carbon capture utilization and storage
CR	Climate Resilience Envision Category
DAC	disadvantaged communities
DEIA	diversity, equity, inclusion, and accessibility
DOE	Department of Energy
EERE	DOE Office of Energy Efficiency and Renewable Energy
FCEV	fuel cell electric vehicle
FCEB	fuel cell electric bus
GHS	Green Hydrogen Standard
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
H_2	hydrogen
H_2EDGE	Hydrogen Education for a Decarbonized Global Economy
H_2SIG	Hydrogen Sustainable Infrastructure Guidelines
HFTO	EERE Hydrogen and Fuel Cell Technologies Office
HyCReD	Hydrogen Component Reliability Database
HyRAM	Hydrogen Risk Assessment Models
HySCAN	Hydrogen Safety Codes & Standards Applicability Navigator
ISI	Institute for Sustainable Infrastructure
LCFS	Low Carbon Fuel Standard
LD	Leadership Envision Category
LDV	light-duty vehicle
MCFC	molten carbonate fuel cell
NREL	National Renewable Energy Laboratory
NW	Natural World Envision Category
PEM	proton exchange membrane
QL	Quality of Life Envision Category
R&D	research and development
RA	Resource Allocation Envision Category
SA	Strategic Analysis, Inc.
SOFC	solid oxide fuel cell

Foreword

Sustainability, specifically reducing greenhouse gas emissions to avert the worst effects of climate change, is an animating principle for investing in hydrogen infrastructure. Sustainable development was defined by the 1987 UN World Commission on Environment and Development report as:

"…development that meets the needs of the present without compromising the ability of future generations to meet their own need."

Our current quality of life cannot be bought at the expense of future generations. Thus, sustainability is not only about protecting the environment, but also about preserving the ability of society to sustain itself. Consequently, sustainability must be evaluated considering environment, economic, and social impacts as all three must be simultaneously maintained at high standards.

Community infrastructure development is subject to the resource constraints of multiple departments and agencies, each with different schedules, agendas, mandates, budget cycles, and funding sources. The guidelines provided in this report attempt to facilitate evaluating how well hydrogen infrastructure projects contribute to the efficiency and long-term sustainability of the communities they serve by using the sustainable infrastructure framework evaluation tool, Envision.[1]

Policy support and national interest in hydrogen as a tool for reducing greenhouse gas (GHG) emissions has undergone a recent resurgence. In the U.S. the Bipartisan Infrastructure Law signed in 2021 and the Inflation Reduction Act signed in 2022 allocate significant public resources towards building domestic hydrogen generation, transport, and consumption capacity. Governments in the European Union, Canada, Korea, and Japan have undertaken similar national efforts towards hydrogen. Total global electrolyzer capacity, a key component of renewable hydrogen infrastructure, has grown by ~475% since 2019[2] and annual electrolyzer installations are projected to grow annually by a 10% compound annual growth rate (CAGR) out to 2030. Hydrogen, especially hydrogen produced from renewable energy resources, can be integrated into the economy at multiple levels as articulated in the H_2@Scale program.[3] For example, hydrogen can be used directly as a combustion or electrochemical fuel, as a feedstock for ammonia and other industrial chemicals production, and can function as a long duration energy storage medium, which is needed for variable renewable energy that would otherwise be curtailed.

Significant infrastructure is needed to support widespread hydrogen integration into the economy. In addition to hydrogen production plants, infrastructure to transport, store, and use hydrogen is needed. Such a build out will impact the communities where such projects are built, and in some cases, the

[1] Envision is the lone U.S. sustainability model and is globally recognized and accepted. https://sustainableinfrastructure.org/envision/overview-of-envision/
[2] https://www.iea.org/reports/electrolysers (242 MW total capacity in 2019; 1,398 MW total capacity by year end 2022)
[3] https://www.energy.gov/eere/fuelcells/articles/h2scale-handout

impacts can affect large regions, for example an interstate pipeline. Not only do we need to ask, "are we doing the project right?", but we should also ask "are we doing the right project?"[4]

Due to the nascent nature of H_2 infrastructure, a great deal of education and outreach can improve public opinion of these new technologies. There have been objections from the public and public officials on these H_2 projects due to lack of communication and understanding of the technology.[5] By using a sustainability framework, stakeholders can be part of the decision process and take comfort in the fact that these projects are designed to benefit their community and future generations.

[4] Envision Guidance Manual (Version 3) by the Institute for Sustainable Infrastructure, ISBN 978-1-7322147-0-5, Third Edition, 2018.

[5] https://www.eenews.net/articles/la-legal-showdown-may-preview-national-battle-over-hydrogen/
https://insideclimatenews.org/news/22112023/new-york-clean-hydrogen-indigenous-nation-sees-threat/
https://penncapital-star.com/energy-environment/hydrogen-hubs-face-scrutiny-at-senate-dems-hearing/
https://www.sierraclub.org/press-releases/2023/03/california-ej-and-climate-advocates-urge-greater-transparency-and-community

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1 Overview and Background

The US Department of Energy (DOE) has tasked SA, via an SBIR Phase 1 project, to investigate sustainability frameworks for hydrogen (H_2) infrastructure.[6] While sustainability frameworks exist for construction projects, none are tailored to H_2 infrastructure nor address the unique attributes of H_2. SA's approach is to use the existing sustainability evaluation framework, the Envision Sustainable Infrastructure Framework (Envision) to create a set of guidelines and best practices for assessment of H_2-related infrastructure projects.

Project Goal: Support those interested in conducting sustainability assessment for hydrogen infrastructure projects.

Project Outcomes: A set of formal guidelines and best practices widely accepted and trusted by the multiple stakeholders for evaluating the sustainability of hydrogen infrastructure projects using Envision.

During the project, SA evaluated the compatibility and prioritized Envision credits (i.e., sustainability indicators) for H_2 projects, developed guidelines, and described best practices for their implementation to H_2 infrastructure through the H_2SIG, and demonstrated the application of H_2SIG via Case Studies. Case studies were used to assess the sustainability of a project based on multiple prioritized sustainability criteria. They also provide examples of ways to address sustainability for future projects.

Throughout the process, SA engaged with stakeholders and subject matter experts to ensure the appropriateness and usefulness of the H_2SIG. SA teamed with ISI who provided support to understand the practical application of Envision, suggested credits that could be applicable to H_2 projects, and clarified the importance of sustainable infrastructure through recommended documentation and webinars.

1.1 Team Background

STRATEGIC ANALYSIS

Strategic Analysis, Inc. (SA), the Prime Contractor on the project, is an R&D and science consulting firm providing support to the Federal government and private industry clients. SA has studied a wide variety of H_2 production, H_2 storage, fuel cell (stationary and mobile) and transmission options (pipelines, H_2 truck (gaseous, LH_2) electrical lines), and has extensive experience in modeling tools and life cycle analysis for government and commercial clients.

Institute for Sustainable Infrastructure

The Institute for Sustainable Infrastructure (ISI) is an education and research nonprofit (a 501c3) based in Washington DC. It was established in 2010 by the American Public Works Association (APWA), the American Society of Civil Engineers (ASCE), and the American Council of Engineering Companies (ACEC). ISI advances sustainable infrastructure using the Envision sustainability framework, through education, training and third-party project verification. The

[6] Department of Energy (DOE) Small Business Innovation Research (SBIR) Phase I Award No. DE- SC0023990.

Envision framework was developed in collaboration between ISI and the then Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design.

Envision has been used by over 300 Architectural Engineering and Consulting (AEC) companies, 200+ government organizations, and 85 academic institutions. As of this publication, over 175 projects worldwide have earned an Envision award by demonstrating their sustainable performance by using ISI's third-party verification program.

1.2 Purpose

The purpose of this document is to provide guidelines and support for hydrogen infrastructure projects to incorporate sustainability into the project design process. Envision, described in the next section, is a sustainability framework for infrastructure projects that is used for assessing sustainable approaches and informing decision making toward more restorative practices.

The H_2SIG serves as a bridge to using Envision for hydrogen-related infrastructure projects and includes recommended H_2-related tools and ideas to help address Envision criteria. The H_2SIG presented here is intended to supplement, not replace Envision requirements. Using the H_2SIG does not guarantee any levels of achievement or an award. Regardless of whether a project developer seeks an Envision award, the H_2SIG provides helpful resources and best practices that should be considered for the success of any hydrogen project.

If hydrogen can be successfully deployed at the scale anticipated within the U.S. National Clean Hydrogen Strategy and Roadmap, it will require significant capital for infrastructure project investment and will impact communities across the United States.[7] Sustainability assessments provide a measure of how sustainable and resilient physical infrastructure can be by helping owners, planners, engineers, communities, contractors, and other infrastructure stakeholders to implement more cost-effective, resource-efficient, and adaptable long-term infrastructure investments.

Figure 1 below illustrates one of the key benefits of sustainability assessments: early adoption of sustainability in the planning stage of a project is lower cost and more effective. As the project progresses, the cost of making changes increases and the ability to change decreases. Assessing and implementing sustainability measures early-on in a project design phase can decreases the cost of infrastructure projects. Further, sustainability assessments are used by some authorities to streamline the permitting process, addressing a critical element of soft costs for developers, or are required by statute. See Figure 2. ISI tracks Envision supported

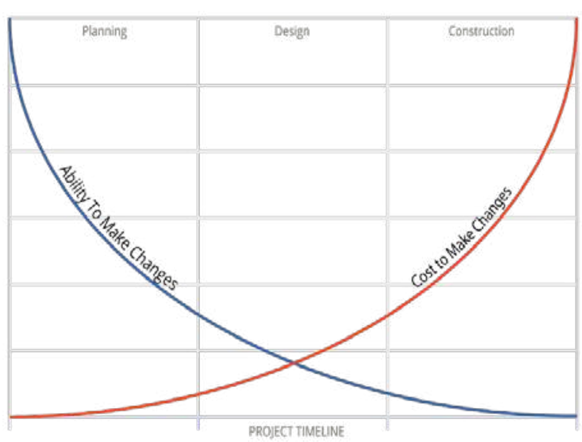


Figure 1. Benefit of Sustainability Assessments[4]

[7] https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf?sfvrsn=c425b44f_5

agencies that are part of the public-sector who use Envision and employ Envision Sustainability Professionals to incorporate sustainability into projects.[8]

California
Proposed legislation in California (SB-44) would streamline judicial review for environmental transit projects that meet sustainability goals.
The California Department of Water Resources Division of Flood Management awards higher state cost-share for applicants who provide evidence that the project would reach a high level of sustainability using a sustainability evaluation framework with higher cost share being awarded for higher levels of achievement.
LA County encourages at least an Envision Silver Award.[9]
Port of Long Beach requires capital projects to complete Envision Pre-assessment Checklist at each design milestone; projects tracking at a Gold level pursue Envision Award.
Florida
Miami-Dade County: Board of County Commissioners adopted a resolution in 2017, amended in 2022, directing the County Mayor to incorporate Envision into the planning, design, construction, and operation of county-funded infrastructure projects.
The City of St. Petersburg has committed to designing all city infrastructure projects to achieve a Gold level of Envision Award.[10]
Missouri
The Envision framework is used by the Kansas City Public Works Department to promote sustainability. Envision will be used internally to evaluate and score projects on their level of sustainability.[11]
New York
NYNJ Port Authority has a minimum of Envision Silver for applicable projects.[12]
Canada
All federally funded infrastructure must conduct a climate change resilience assessment consistent with ISO 31000.
In Metro Vancouver, eligible infrastructure projects will use an integrated design process to pursue a Gold level of Envision Award.[13]

Figure 2: Examples of Authorities requiring or encouraging use of Envision Sustainability Assessments

[8] https://sustainableinfrastructure.org/membership/envision-supported-agencies/
[9] https://pw.lacounty.gov/adm/sustainability/docs/LA%20SIG%20v2.pdf
[10] https://sftool.gov/Content/attachments/Iswg/iswg-tools/Sustainable%20Infrastructure%20and%20the%20Role%20of%20Envision.pdf
[11] https://www.modot.org/sites/default/files/documents/Letter%20of%20Interest%202.1.24.pdf
[12] https://www.panynj.gov/content/dam/port-authority/about/environmental-initiatives-/clean-construction/Sustainable-infrastructure-guidelines.pdf
[13] https://metrovancouver.org/services/air-quality-climate-action/Documents/sustainable-infrastructure-buildings-policy.pdf

By considering and mapping the multiple affected stakeholders, long-term sustainability can be achieved. In summary, expected benefits include:

- Long-term viability through increased resiliency and preparedness.
- Lower costs through management and stakeholder collaboration.
- Reduced negative impacts on the community and the environment.
- Potential to save owners money over time through efficiency improvements and improved project management.
- Enhanced credibility of a third-party rating system.
- Increased transparency via a direct and open examination of the pros and cons of the project and the ways it would impact the community.
- Increased public confidence and involvement in decision making.

1.3 Envision

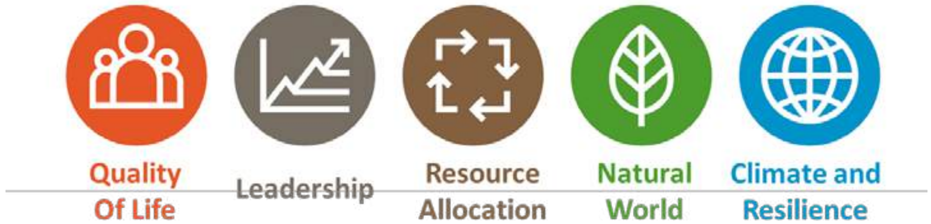
1.3.1 Description of the Envision Sustainability Framework

Envision offers a thorough examination of the sustainability and resiliency of infrastructure projects based on a set of indicators, called "credits". The Envision Award is based on the percentage of points achieved out of all applicable credits. The Envision score represents a project's performance across multiple metrics: quality of life for the host community, engagement and collaboration with all stakeholders, economic prosperity and life-cycle evaluation, resource allocation, interactions with the natural world, effect on climate, and resilience to changing climate. Ideally, an evaluation begins during the planning stage allowing the project team to engage with all relevant stakeholders early in the project and helps to guide early design choices that optimize sustainability across all metrics. [14]

In many ways, Envision can be used as a project development tool that drives better project management and provides practical guidance on how to improve performance. As mentioned above, As mentioned in the previous section, Envision has been adopted by several municipalities, for example the LA County Public Works, the Port of Long Beach, and the Port Authority of New York and New Jersey (PANYNJ), who have incorporated Envision into specific project guidelines. Additionally, implementing practices suggested by Envision can contribute to company Environmental, Social, and Governance (ESG) reporting topic areas such as GHG emissions reductions, improvement to air quality, addressing risk and

[14] https://sustainableinfrastructure.org/touchpoints/

resilience electricity usage, circularity of resources, health and safety, environmental justice, and education and support for communities. There are five categories within Envision:



Each category is further organized into subcategories by subject matter and each subcategory includes three to six credits. In total, there are 64 credits within the Envision framework. Sustainability performance within each credit is measured across a spectrum with points allocated based on the level of achievement met. There are five levels of achievement which may vary depending on the credit:

1. **Improved**: Performance that is above conventional. Slightly exceeds regulatory requirements.
2. **Enhanced**: Sustainable performance that is on the right track. There are indications that superior performance is within reach.
3. **Superior**: Sustainable performance at a very high level.
4. **Conserving**: Performance that has achieved essentially zero negative impact.
5. **Restorative**: Performance that restores natural or social systems. Such performance receives the highest award possible and is celebrated as such.

Figure 3 shows an example credit table with more points allotted to addressing more of the credit requirements.

Improved	Enhanced	Superior	Conserving	Restorative
A	A+B	A+B+C	A+B+C+D	A+B+C+D+E
(5 pts)	(7 pts)	(10 pts)	(15 pts)	(20 pts)
(A) Requirement				
	(B) Requirement			
		(C) Requirement		
			(D) Requirement	
				(E) Requirement

Figure 3. Example credit table showing the incremental nature of the Envision Levels of Achievement

The Envision rating is based on 1000-points system, with each credit contributing to a maximum number of points possible. However, the Envision award is not based on a “perfect score” methodology. Sustainable solutions involve finding the right balance across economic, social, and environmental considerations. Therefore, project teams may decide to invest less in certain strategies to prioritize other opportunities. Or there may be certain topics that are more important to stakeholders or investors. The Envision rating accounts for this variation by using a percentage of points earned across all credits.

In addition, depending on the project, there may be certain credits that do not apply for a project type. For example, night sky light pollution would not be applicable on projects that do not include exterior lighting. There are requirements associated with each credit for determining applicability. [15] For credits deemed "not applicable", the associated points are removed from the denominator of the score.

The Envision Awards range from Verified (20 – 29%), Silver (30 – 39%), Gold (40- 49%), and Platinum (greater than 50%).

The Envision Rating system is summarized in the Envision Guidance Manual, which is publicly available[16] for full transparency and periodically updated by a board of practitioners. For the Envision award, ISI hires employees of independent, third-party verifier companies who are specially trained to review applications. The selection of the verifiers and their company are managed to be entirely anonymous. In this manner, verification assessments are made neutrally, and the same evaluation standards are consistently applied to all projects which gives the public and stakeholders confidence in the evaluation results.

1.3.2 Envision used for Hydrogen Infrastructure Projects

Envision is a holistic sustainability framework meant to apply to all infrastructure projects and thus can encompass H_2 infrastructure projects. However, because of this wide range of project types, the framework is written for maximum inclusivity. Project developers will need to evaluate how Envision relates to unique aspects of hydrogen-related projects, including the applicability of certain credits. The H_2SIG intends to address these issues by:

1. Suggesting prioritized credits that could be addressed by H_2 projects,
2. Providing examples of ways to meet credit requirements,
3. Recommending useful publicly available software tools to determine key metrics relevant to H_2 projects, and
4. Highlighting related credits that could be addressed with the same design features or documentation.

The scope of the H_2SIG provided in this document evaluated 18 Envision credits the authors determined to be a starting point for H_2 projects. However, given the total of 64 credits, it is unlikely points earned for these 18 credits alone would result in an Envision Award. While other credits were not included in

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[15] Projects seeking an Envision Award will have to consider applicability of each credit. Refer to Applicability section of the Envision manual.

[16] The Envision Guidance Manual is free to download from the ISI website under *Resources* after registering.
https://sustainableinfrastructure.org/
https://v4.sustainableinfrastructure.org/register
https://sustainableinfrastructure.org/project-verification/verify-a-project/

this study, it is likely that any project could assess the relevance of additional credits given their unique circumstances.

2 Hydrogen Sustainable Infrastructure Guidelines

2.1 Hydrogen Project Types Considered in H_2SIG

The H_2SIG are tailored for developers and other interested groups who are considering applying and assessing sustainable solutions for their projects. While the H_2SIG may be used to aid in obtaining an Envision award, achieving an award or the highest potential points should not be the sole focus for using these H_2SIG. Identifying and implementing sustainable solutions at any level is a worthwhile endeavor on its own.

Envision is not intended to evaluate interior, conditioned, buildings with the primary purpose of human occupation. Hydrogen projects are typically non-human-habitable infrastructure and will often involve some public funding, particularly in the early stages of deployments.

Based on the authors' evaluation, pursuit of an Envision award is most suitable for larger capital projects, where the benefits of the process may exceed the expense and effort associated with applying for an award and verifying a project. In the representative examples shown below, a small (300kg) onsite hydrogen storage project may be too small to be considered as a stand-alone project while a large multi-ton H_2 storage project with H_2 production and transmission may be considered viable. H_2 infrastructure will often have multiple connected project elements. A list of example project elements by project feature in Figure 4 is not an exhaustive list. Although early phase hydrogen project types were heavily considered for the H_2SIG, all types of infrastructure projects (large and small) could benefit from similar sustainability practices and tools provided in this document.

Project Feature	Example Project Elements
Hydrogen End-Use Applications	End-use applications are a cross-cutting category that often combines elements of production, storage, and transmission • Refueling station for mobility applications • Ammonia production • Direct reduction of iron (steel production) • Combined fuel and energy storage
Hydrogen Production	• Electrolysis / Fuel Cell • By-product hydrogen from chemical plants • Steam methane reforming (SMR) • Autothermal reforming (ATR) • Biomass gasification
Hydrogen Storage	• City gate bulk storage • Trade terminal bulk storage • Sub-surface geologic or engineered storage
Hydrogen Transmission	• Pipelines • Tanker trucks (gaseous and liquid) • Fuel distribution terminals

Figure 4. Table of example H_2 project elements by project feature

2.2 Priority Envision Credits for Hydrogen Infrastructure

Every hydrogen project could likely address many Envision credits. However, there are specific credits that may be more relevant for most hydrogen projects. These high priority credits were identified by considering the following as they relate to hydrogen projects:

- Do H_2 projects already address these credits in some form, and could they possibly score well?
  - For example, all or most H_2 projects address GHG emissions and are designed to be highly energy efficient.
- Could H_2 projects benefit from standardization when measuring the effectiveness and impact of certain design decisions?
  - For example, comparing trade-offs of energy efficiency, cost, emissions, and safety or reversing negative impacts on surrounding communities.
- Do H_2 projects struggle to address these credits, or would they benefit from guidance on best practices?
  - For example, community/stakeholder engagement techniques and integration with existing infrastructure.

Additional information the methodology of selecting H_2-prioritized Envision credits is provided in the Appendix. The list of H_2-prioritized Envision credits are provided below in Figure 5. The guidelines listed in subsequent sections address each of these credits, with the additional credits to be considered in future phases of the project.

Envision Category	Category Credit
Quality of Life	QL 1.2 Enhance Public Safety
	QL 1.4 Minimize Noise and Vibration
	QL 3.1 Advance Equity & Social Justice
Leadership	LD 1.3 Provide for Stakeholder Involvement
	LD 1.4 Pursue Byproduct Synergies
	LD 2.2 Plan for Sustainable Communities
	LD 3.2 Develop Local Skills & Capabilities
	LD 3.3 Conduct a Life-Cycle Economic Evaluation
Resource Allocation	RA 2.1 Reduce Operational Energy Consumption
	RA 2.3 Use Renewable Energy
	RA 3.2 Reduce Operational Water Consumption
Natural World	NW 2.4 Protect Surface and Groundwater Quality
Climate Resilience	CR 1.2 Reduce Greenhouse Gas Emissions
	CR 1.3 Reduce Air Pollutant Emissions
	CR 2.3 Evaluate Risk and Resilience
	CR 2.4 Establish Resilience Goals and Strategies
	CR 2.5 Maximize Resilience
	CR 2.6 Improve Infrastructure Integration

Figure 5. List of H_2-prioritized Envision credits

When reviewing the H_2SIG, it may be helpful to have the Envision Guidance Manual available as a reference. Each credit section below includes a table copied from the respective Envision credit. However, there are more details related to evaluation criteria, documentation guidance, and other requirements within the Envision Guidance Manual for each credit.

For example, the boundary of the project must remain the same throughout all the credits. Also, some credits may require a baseline system for measuring performance improvement. The baseline could vary but must be clearly defined for the relevant credit. The baseline on which to compare must align with one of the following (in order of preference):

1. Existing conditions or the existing system(s) the project will replace.
2. A seriously considered project alternative.
3. Industry “standard practice” or existing codes, standards, or regulatory requirements (e.g., for energy and water; greenhouse gas and air pollution emissions).
4. A project of similar scope and size operating within the same geographical area or within a geographical area with similar operating conditions.

Additionally, projects seeking an Envision award should conduct an initial assessment of all the credits using the Envision V3 Checklist.[17]

2.3 Quality of Life (3 prioritized Credits)

The intent behind many Quality of Life (QL) credits is often relevant to many corporate environmental, social, and corporate governance (ESG) practices. However, ESG practices focus on a company's organizational practices while Envision requirements apply to planning, design, and construction of infrastructure projects. Many QL credits do involve considering local impacts and engagement with affected communities. By engaging host and affected communities during planning stages, hydrogen projects can expect to compare favorably with their alternatives, potentially speeding up permitting processes and gaining stakeholder approval. The following QL credits are related to public health and safety, minimizing noise, and advancing social justice and equity.

2.3.1 QL1.2 Enhance Public Health and Safety

QL1.2 ensures that project teams go beyond standard public health and safety requirements set forth by local laws and regulations while operating their systems. The extent of achievement is primarily measured by how far the health and safety improvements extend beyond the immediate scope of the project boundary. Most hydrogen-based technologies have no inherent advantage in achieving a high score for this credit. However, electrolyzers using renewable electricity and hydrogen fueling stations have a unique opportunity to score high by replacing fossil-based hydrogen production facilities and diesel or gasoline fueling stations, reducing associated air pollutant emissions in the area.[18]

Figure 6 shows the basic requirements needed to meet each level of achievement for QL1.2 along with each level's associated point values. H_2 in general can introduce new safety risks such as leaks leading to explosions and fires. It is important for H_2 projects to not only consider safety within the boundary of the project, but also consider the best safety measures extending to the nearby community. There are many sources of information for hydrogen safety. Hydrogen Safety Codes & Standards Applicability Navigator (HySCAN) provides suggested codes and standards from NFPA2, ANSI, CGA, and ISO based on the types of equipment used onsite.[19] Additionally, the H_2 Tools website has a wealth of best practices in plant design considerations, operating procedures, material compatibility, safety planning, and training.[20]

To achieve an Improved level of achievement, projects must demonstrate they go beyond minimum requirements for public health and safety during operations including OSHA regulations and laws.[21]

[17] The Envision V3 Checklist is free to download from the ISI website under *Resources* after registering.
[18] Air pollutant emissions are also covered in CR 1.3
[19] https://h2tools.org/hyscan/
[20] https://h2tools.org/bestpractices/best-practices-overview
[21] https://www.osha.gov/sites/default/files/publications/osha2254.pdf

If a project can show a net reduction in localized air pollutant emissions and improvement in air quality (for example replacing a diesel refueling station with a hydrogen station to fuel FC vehicles), an Enhanced level of achievement is possible.

Going beyond the project's immediate site location to wider impacts on the community, strategies such as showing the number of bus replacements and the emissions reductions impacting the areas of operation could be relevant for a Superior level of achievement. As highlighted within the Refueling Stations and Fuel Cell Electric Buses Case Study (in Appendix), Sunline Transit showed a weighted emissions reduction from 5 diesel buses to 5 hydrogen fuel cell buses of up to 0.40 tons of criteria air contaminants reduced per year.[22]

Taking this a step further, Sunline also mapped out the disadvantaged communities that would be affected by their routes and dispatched the fuel cell buses to serve those routes. If Sunline could show that the risks and impacts of its project are not disproportionately borne by one community over another, it could qualify for a Conserving level of achievement. And, if the implementation of the project will address a pre-existing negative health and/or safety impact, it could reach the Restorative level of achievement.

Superior, Conserving, and Restorative requirements are good to consider for this credit and may also help projects frame the conversations with host and affected communities regarding public health and safety impacts of the facility (see QL3.1 Advance Equity & Social Justice and LD 1.3 Provide for Stakeholder Involvement). Providing evidence-based data and demonstrating the benefits of hydrogen through reduced air pollutant emissions starts an important conversation.[23] Additional health effects, like heart and lung diseases and mortality rates, should be considered in both QL 1.2 and LD 3.3 Conduct a Life-Cycle Economic Evaluation. And, while more relevant to QL2.3 Improve Access and Wayfinding (which is not discussed in this paper), project teams should be considering public health and safety programs that ensure the local fire department and first responders understand how to handle incidents related to components used in hydrogen infrastructure. This can also overlap with LD 3.2 Develop Local Skills & Capabilities.

For the Conserving level, negative health and safety impacts and/or benefits to the community must be equitably distributed. For hydrogen infrastructure, negative impacts can include NO_x emissions through combustion of H_2 (blending in NG turbines or hydrogen fueled ICE vehicles) and water resources taken from water-strained areas.

An example for achieving the Restorative level could include additional systems that measure air quality and alert the community of unsafe air conditions or installation of sidewalks or crosswalks in heavily vehicle-congested areas.

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[22] CAC for this study included nitrous oxides (NOx), reactive organic gases (ROG), and particulate matter (PM10) https://ww2.arb.ca.gov/sites/default/files/2022-07/SunLine%20AQIP%20Final%20Report%20FINAL_accessible.pdf

[23] The DOE HFTO Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model has helpful sustainability metrics for greenhouse gases (GHGs), criteria air pollutants, energy usage, and water consumption that can be used for providing data during community engagement.

Every hydrogen project requires engagement with the local authorities to obtain permits and project managers often underestimate the challenges and duration for obtaining a permit. While permits generally require a minimum level of safety compliance, Envision requires more than industry standard recommended best management practices. However, considering additional safety measures beyond what may be required by law could facilitate the permitting process. Project developers should consider using the tools described in this section as well as beginning the permitting process well in advance.[24] Consider meeting with the permitting officials in advance to ask questions and fully understand the process. Be prepared by going through the H_2SCAN suggested safety codes and standards. Every location will have a different process and permitting officials may need an education in hydrogen. The US DOE has resources for code officials to become acquainted with hydrogen.[25] The American Institute of Chemical Engineers (AIChE) also has an introduction to hydrogen safety for first responders as well.[26]

Consider becoming a member of the Center for Hydrogen Safety to connect with other developers designing, building, and operating hydrogen infrastructure, gain access to training courses, and access/report to the incident database.

[24] https://h2tools.org/codes-standards/codes-standards-permitting-tools
[25] https://www.hydrogen.energy.gov/program-areas/codes-standards/code_official_training
[26] https://www.aiche.org/ili/academy/courses/ela253/introduction-hydrogen-safety-first-responders

QUALITY OF LIFE: WELLBEING

QL1.2 Enhance Public Health and Safety

20 POINTS	**INTENT** Protect and enhance community health and safety during operation.	**METRIC** Measures taken to increase safety and provide health benefits on the project site, surrounding sites, and the broader community in a just and equitable manner.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A + B	A + B + C	A + B + C + D	A + B + C + D + E	A + B + C + D + E + F
(2) Understanding Impacts	**(7) Prioritizing Risk Reduction**	**(12) Improving Health & Safety**	**(16) Shared Benefits**	**(20) Protecting Communities**

(A) The project meets all health and/or safety regulations and laws for operation.

(B) The project includes health and/or safety improvements beyond minimum requirements established by regulations and laws.

(C) The project improves health and/or safety for its immediate surroundings.

(D) The project demonstrates a net positive impact on health and/or safety for the host or affected communities.

(E) The health and safety benefits and/or negative impacts are equitably distributed within affected communities, and the project team can demonstrate that the project does not disproportionately burden one community over another (i.e., social/environmental justice).

(F) The project provides critical infrastructure services to communities experiencing, or at risk of experiencing, imminent, negative health and/or personal safety impacts

Figure 6. QL1.2 Levels of Achievement

Credits Related to QL1.2:
QL1.1 Improve Community Quality of Life
QL2.2 Encourage Sustainable Transportation
QL2.3 Improve Access and Wayfinding
QL3.1 Advance Equity and Social Justice
NW2.1 Reclaim Brownfields
NW2.3 Reduce Pesticide and Fertilizer Impacts
NW2.4 Protect Surface and Groundwater Quality
CR1.3 Reduce Air Pollutant Emissions
CR2.4 Establish Resilience Goals and Strategies

2.3.2 QL1.4 Minimize Noise & Vibration

Many hydrogen infrastructure projects can attain a high score for credit QL1.4 by virtue of naturally quiet operations of electrochemical devices compared with rotating and combustion machinery. The Envision table in Figure 7 lays out the basic requirements needed to meet each level of achievement for QL1.4 along with their associated point values. Hydrogen projects, especially those that will install electrochemical or similar low-noise components compared with rotating machinery or combustion, may attain high levels of achievement due to the advantages described above. Figure 8 correlates the expected level of achievement for several features of hydrogen infrastructure projects. Achieving any level requires satisfying criteria (A)-(E), which are not necessarily hydrogen-specific but requires a noise assessment and active engagement with the community. When considering strategies to reduce noise and vibration consider first eliminating the source, try to minimize the source or reduce the operation of equipment, and finally if avoidance is not possible attempt to offset or compensate through financial programs to affected groups.

QUALITY OF LIFE: WELLBEING

QL1.4 Minimize Noise and Vibration

12 POINTS	INTENT	METRIC
	Minimize noise and vibrations during operations to maintain and improve community livability.	The extent that operational noise and vibration is assessed and mitigated, and target levels achieved.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A + B	A + B + C	A + B + C + D	A + B + C + D + E	A + B + C + D + E
(1) Noise Assessment	**(3) Target Noise Levels**	**(6) Stakeholder Support**	**(10) No Noise Increase**	**(12) Noise Reductions**
(A) The project team assesses the potential for operational noise impacts on the surrounding community and/or environment. This assessment occurs when applicable vibrations are considered as a potential source of noise and/or disruption. **(B)** Strategies are implemented to mitigate noise and/or vibrations during operations. Noise reduction follows a mitigation hierarchy of avoidance/source elimination, minimization, abatement/receiver reduction, and offsetting/compensation.				
	(C) The project adopts existing, or works with the community to set, target project noise levels for the impacted community			
		(D) The stakeholder engagement process demonstrates community awareness of targets (i.e. criterion C), mitigation strategies (i.e. criterion B), and noise impacts (i.e. criterion A).		
			(E) Noise reduction strategies and controls are sufficient to not increase noise within the surrounding community beyond existing conditions.	**(E)** Noise reduction strategies and controls are sufficient to reduce noise within the surrounding community beyond existing conditions.

Figure 7. QL1.4 Levels of Achievement

Project Feature	Existing Facilities	Expected Level of Achievement	Comments
H_2 Production	Hydrogen produced from SMR using natural gas extraction.	Electrolysis-based systems could achieve Conserving or Restorative if replacing existing infrastructure that has higher noise levels.	Many existing facilities for hydrogen production are based on mechanical compressors and rotating machinery (which are substantial noise sources).
H_2 Storage	Over-road transport (e.g., tube trailers) could be an existing method of bringing hydrogen to the site.	Depending on the H_2 production technology, onsite production could alleviate the noise of additional truck transport. Superior is likely the highest achievement level unless alternative compression (i.e., electrochemical compression) or refrigeration (i.e., absorption refrigeration) systems can be used.	Storage alone is noiseless. But onsite compression and refrigeration found in some storage facilities adds mechanical noise that may impact the host community.
H_2 Transmission	Other pipeline transmission (e.g., fossil gas, oil, etc.)	Superior is likely the highest achievement level for H_2 pipeline unless alternative boost compression noise can be reduced.	The primary sources of noise are from boost compressors along the pipeline.
H_2 End-Use Applications	Internal combustion engine vehicles.	Conserving or Restorative achievement may be possible with H_2 fuel cell vehicles. May depend on the vehicle type and speed. Above 18mph, there may be very little difference for LDVs. [27, 28]	H_2 refueling stations likely have mechanical compressors and noise level should be added to noise of EVs and compared with ICE vehicles.

Figure 8. Expected levels of achievement for QL1.4 for example project elements.

For end-use applications, conserving or restorative is possible with hydrogen fuel cell vehicles. However, a study in 2023 by Peutz Consult GmbH in Germany showed the reduction in noise achievable between a diesel and electric truck depending on the speed of the truck. Figure 9 show the difference being between 4 and 14 dB(A).

For hydrogen production facilities, noise assessments and noise reduction studies can be conducted on equipment and locations around the plant to determine solutions to effectively reduce the noise of the plant. The results of these studies can be used to determine which noise mitigation strategy is best suited for each piece of equipment and plant location. Some examples of typical mitigation strategies include isolators, vibration dampers, acoustic blankets, sound curtains, and sound enclosures.[29,30]

[27] https://www.toi.no/getfile.php/1340825-1434373783/mmarkiv/Forside%202015/compett-foredrag/Lykke%20-Silent%20Urban%20Driving.pdf

[28] https://www.man.eu/corporate/en/experience/quieter-than-youve-ever-heard-before-126656.html#:~:text=The%20e%2DTruck%20is%20around%20half%20as%20loud%20as%20a%20diesel%20truck&text=We%20must%20also%20take%20into,literature%20basis%20to%2011%20dB.

[29] https://www.softdb.com/soundproofing/industrial-noise/

[30] https://www.enoisecontrol.com/testing-facility-sound-levels-noisy-plant/

	NEW MAN ETRUCK	MAN TGX 18.510	DIFFERENCE
Backwards (with/without warning tone)	47,8/45,7 dB(A)	60,9/60,1 dB(A)	**-13,1/14,4 dB(A)**
Accelerated pass-by	50,4 dB(A)	62,4 dB(A)	**-12 dB(A)**
Steady speed 20 km/h	48,9 dB(A)	54,7 dB(A)	**-5,8 dB(A)**
Steady speed 30 km/h	52 dB(A)	56 dB(A)	**-4 dB(A)**

Figure 9. Table of noise comparison between a diesel and electric truck[28]

Credits Related to Q1.4:
LD1.3 Provide for Stakeholder Involvement
RA1.5 Balance Earthwork On Site
NW3.1 Enhance Functional Habitats

2.3.3 QL3.1 Advance Equity and Social Justice

QL3.1 is designed to ensure that issues related to equity and social justice are properly considered in the project development and decision-making processes. This is primarily measured by the degree to which these issues are considered during stakeholder engagement and the commitments the project team makes to address the concerns raised during the engagement process. This credit and how it can be addressed relies on historic context of equity and social justice within the affected community and present-day impacts and needs.

Project designs should consider nearby community injustices (historic and current) and map impacts to communities that could be affected by the project. Tools for mapping communities and regions facing environmental injustices include EJ Screen, the Climate and Economic Justice Screening Tool, and CalEnviroScreen for California.[31,32, 33]

More and more companies are providing training on diversity, equity, inclusion, and belonging (DEIB) and environmental and social justice (ESJ). It is recommended that project developers work to incorporate these aspects into project designs and the development process.

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31 https://ejscreen.epa.gov/mapper/
32 https://screeningtool.geoplatform.gov/en/#3/33.47/-97.5
33 https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40

An example for achieving Restorative could include heavy-goods transit corridors through historically disadvantaged communities that switch from high $PM_{2.5}$ emission vehicles to low or zero emission vehicles if additional steps are taken to properly engage and empower the community to participate in the project development process. This credit is very closely tied with LD 1.3 and the reader should reference the steps for community engagement in that credit section.

Additionally, many projects funded in the United States using Federal funds starting in 2021 include plans for addressing social justice. Justice40 is a Federal Government goal that 40% of all benefits of clean energy flow to disadvantaged communities that are overburdened by pollution.[34] The Office of Energy Justice and Equity within the US DOE identified eight policy priorities to guide DOE's implementation of Justice40.[35] Although these were identified for the US DOE, there are useful elements that can and should be transferred to all H_2 infrastructure projects regardless of funding source.

1. Decrease energy burden in disadvantaged communities (DACs).
2. Decrease environmental exposure and burdens for DACs
3. Increase parity in clean energy technology (e.g., solar, storage) access and adoption in DACs.
4. Increase access to low-cost capital in DACs.
5. Increase clean energy enterprise creation and contracting (Minority Business Enterprise/ Disadvantaged Business Enterprise (MBE/DBE)) in DACs.
6. Increase clean energy jobs, job pipeline, and job training for individuals from DACs.
7. Increase energy resiliency in DACs.
8. Increase energy democracy in DACs.

The DOE-funded H_2-Hubs are all required to produce Community Benefit Plans (CBPs). See the next section (LD1.3) for mor information. The Envision table below in Figure 10 lays out the basic requirements needed to meet each level of achievement for QL3.1 along with each level's associated point values.

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[34] These benefits could include climate change, clean energy and energy efficiency, clean transit, affordable and sustainable housing, training and workforce development, remediation and reduction of legacy pollution, and the development of critical clean water and wastewater infrastructure.
https://www.whitehouse.gov/environmentaljustice/justice40/
Justice40 Initiative | Department of Energy

[35] For more information on the US DOE activities and resources for Clean Hydrogen and Environmental Justice: https://www.energy.gov/eere/fuelcells/clean-hydrogen-and-environmental-justice?utm_medium=email&utm_source=govdelivery

QUALITY OF LIFE: COMMUNITY

QL3.1 Advance Equity and Social Justice

18 POINTS

INTENT
Ensure that equity and social justice are fundamental considerations within project processes and decision making.

METRIC
Degree to which equity and social justice are included in stakeholder engagement, project team commitments, and decision making.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A + B + C	A + B + C + D	A + B + C + D + E	A + B + C + D + E + F	A + B + C + D + E + F + G
(3) Understanding Equity	**(6) Mitigation**	**(10) Empowerment**	**(14) Equitable Access to Benefits**	**(18) Equitable Futures**

(A) Stakeholder engagement is conducted early and informed by the historic context of equity, social justice, and environmental justice. When projects impact, or potentially impact, indigenous communities, specific attention is given to developing a relationship of respect and mutual understanding that supports the autonomy, authority, and rights of these communities.

(B) The project team assesses the social impacts the project will have on the host and affected communities. This includes mapping impacts and benefits across local communities.

(C) Key members of the project team make institutional commitments to equity and social justice, including non-discrimination; diversity and inclusion; and pay equity.

Large-scale projects make targeted and project-specific commitments.

(D) Based on the assessment of social impacts, the project addresses or mitigates social impacts. Mitigation strategies are informed by stakeholder consultation and participation.

(E) The social, economic, and environmental benefits and impacts of the project are shown to not disproportionately favor or disfavor any community.

(F) The project empowers communities to engage in the development process. Qualified professionals identify unconscious biases and barriers to inclusion. Programs target higher rates of engagement, and include transparent grievance mechanisms to facilitate resolutions.

(G) The project positively addresses or corrects an existing or historic injustice or imbalance.

Figure 10. QL3.1 Levels of Achievement

Credits Related to QL3.1:
QL1.2 Enhance Public Health and Safety
QL2.1 Improve Community Mobility and Access
QL2.2 Encourage Sustainable Transportation
QL3.2 Preserve Historic and Cultural Resources
LD1.3 Provide for Stakeholder Involvement
LD2.2 Plan for Sustainable Communities
LD3.1 Stimulate Economic Prosperity and Development
LD3.2 Develop Local Skills and Capabilities

2.4 Leadership (5 prioritized Credits)

Leadership credits explore the development of projects with early communication and collaboration while understanding the long-term holistic view of projects and their lifecycle. The five credits within this category touch on stakeholder involvement, byproduct synergies, plans for sustainable communities, development of local skills & capabilities, and life-cycle economic evaluations.

2.4.1 LD1.3 Provide for Stakeholder Involvement

The goal of LD1.3 is to make stakeholder engagement and involvement a key aspect of the project design process from the very outset of the project. Rather than just educating potentially impacted groups, the expectation is that active communication is established, and opportunities are provided to potential stakeholders to share in the decision-making process of the project. Figure 11 provides a summary of the requirements to meet each level of achievement for LD1.3 along with each level's associated point values.

LEADERSHIP: COLLABORATION

LD1.3 Provide for Stakeholder Involvement

18

POINTS

INTENT

Early and sustained stakeholder engagement and involvement in project decision making.

METRIC

Establishment of sound and meaningful programs for stakeholder identification, early and sustained engagement, and involvement in project decision making.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A + B	A + B + C	A + B + C + D	A + B + C + D + E	A + B + C + D + E + F
(3) Active Engagement	**(6) Direct Engagement**	**(9) Community Involvement**	**(14) Community Satisfaction**	**(18) Stakeholder Partnerships**

(A) Primary and secondary stakeholders are identified through a stakeholder mapping process. Stakeholder concerns and specific objectives for stakeholder engagement are defined.

(B) A proactive stakeholder engagement process is established with clear objectives. This occurs at the earliest stages of planning and is sustained through project construction. Engagement moves beyond education into active dialogue. Stakeholder views are monitored, and a two-way line of communication is established to reply to inquiries. Sufficient opportunities are provided for stakeholders to be involved in decision making. The participation process is transparent with opportunities to provide meaningful input.

(C) A lead person from the project team, in addition to any public involvement lead or manager, works with stakeholder groups to understand communication needs and the desire for and scope of involvement.

(D) There are specific cases in which public input influenced or validated project outcomes. Potentially conflicting stakeholder views were evaluated and addressed equitably during decision making.

(E) Feedback is sought from stakeholders as to their satisfaction with the engagement process, and the resulting decisions were made based on their input.

(F) One or more stakeholders, having mutual interests or interdependencies, are identified and engaged as partners.

Figure 11. Levels of Achievement for LD1.3

If only including project and business stakeholders, the Enhanced level may be achieved but all stakeholders still need to be identified with engagement plans. It is strongly recommended for projects to involve community in the very early stages of the design phase. The timeline of engagement can vary by project, but starting the engagement process in the pre-design or feasibility stage is recommended. As revealed in conversations with experts in hydrogen project development, interacting with the community must be done to ensure a successful project and reduce risks of failed projects. Many developers underestimate the pushback from the community, particularly from the source of the hydrogen. Depending on the community, it may be difficult to obtain participation due to busy schedules and interest. It is good to highlight the many benefits of hydrogen, any potential negative impacts and the mitigation techniques that could be employed, and the impacts to health or effects of climate change if continuing business as usual. Community members appreciate transparency in the engagement process, and this increases trust. Every large infrastructure project will have drawbacks, even if it can be shown to be predominately positive, and it is important to be transparent about how these drawbacks are being handled.

Some hydrogen projects may have some opposition from the community, key stakeholders, or environmental justice groups. A few key areas of opposition that should be noted are included in the Figure 12 below. A list of additional areas of concern for hydrogen projects are described on the Clean Energy Group website.[36] These are only a few examples of the issues that may be raised and should be seriously considered in the project design. The project developers should prioritize the local community and stakeholder group issues as much as possible which can avoid opposition and delays in project implementation.

[36] https://www.cleanegroup.org/initiatives/hydrogen/areas-of-concern/

Technology	Opposition
NG derived hydrogen with Carbon Capture (CC)	CC is considered expensive and there may be a fear that the community will be paying for this additional expense. Use of NG in some cities has caused a decline in local jobs and population.[37] CO_2 pipelines are also considered uneconomical. CO_2 leaks could prevent emergency response vehicles from running. Concern regarding Class VI wells for geologic sequestration of CO_2 in protection of Underground Sources of Drinking Water[38] The public may have an unsupported fear of CO_2 and the dangers of a leak.
NG blending with hydrogen in NG turbines to generate electricity	NO_x emissions can be higher with addition of H_2 (as it burns hotter) and current equipment to monitor NO_x emissions may not be suitable for higher H_2 blend percentages. Blending can reduce emissions, but not 1:1 with percentage of H_2 blend.
Blending hydrogen in NG pipeline	Blending H_2 to more than 5% by volume in existing NG pipelines can raise the chance of leaks.[39] There are also concerns of the cost for upgrades to existing NG pipelines and if ratepayers would experience those costs from utility companies. The public may have unsupported fears of NG/H_2 blends and the enhanced dangers of a leak.
Hydrogen derived from electrolysis	Water usage and limiting resource to community. H_2 is not a good enough use of renewable electricity due to lower efficiency, and any use of renewables to produce H_2 divert from direct electrification, ultimately slowing down efforts to address GHG and pollutant reduction.
Fuel Cell Trucks	Communities uninterested in trucks being converted to zero emission vehicles (ZEVs). The truck traffic also poses a concern that communities have had to bear for decades.
All projects	The absence of engagement with the community or stakeholders can foster mistrust and give rise to unfounded rumors, creating an impression that the project is concealing something. H_2 is an indirect greenhouse gas.[40]

Figure 12. Table of hydrogen project opposition by technology

[37] https://ohiorivervalleyinstitute.org/wp-content/uploads/2022/12/A-Clean-Energy-Pathway-for-Southwestern-Pennsylvania.pdf

[38] Specific environmental justice guidance for underground injection control (UIC) Class VI Permitting and Primacy can be found here: https://www.epa.gov/system/files/documents/2023-08/Memo%20and%20EJ%20Guidance%20for%20UIC%20Class%20VI_August%202023.pdf

[39] Hydrogen Blending Impacts Study conducted by the University of California Riverside funded by the California Public Utilities Commission. There are multiple leakage rates studied based on the material of the pipe, the pressure of the blended gas, and content of H_2: https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M493/K760/493760600.PDF

[40] H_2 is an indirect greenhouse gas and the impact to global warming depends on the amount of hydrogen leaking to the atmosphere: https://repository.library.noaa.gov/pdfjs/web/viewer.html?file=https://repository.library.noaa.gov/view/noaa/54564/noaa_54564_DS1.pdf
https://acp.copernicus.org/articles/24/4217/2024/

The following list of activities for community engagement should be considered during planning for stakeholder engagement.[41] While these activities apply to all community engagement, they are cited here with a special reference to lessons learned on prior H_2 projects. Make sure to track activities through written documentation (meeting notes, feedback forums, etc.).

1. Stakeholder Mapping:
    - Identify key stakeholders in the local community, including residents, local businesses, schools, and community organizations.
2. Engage with community leaders, neighborhood associations, and environmental justice groups.
3. Education and Awareness:
    - Conduct informational sessions and workshops to educate residents about hydrogen production/use, its benefits, and safety measures.
    - Use accessible language and visuals to explain the process and address any misconceptions.
4. Community Meetings:
    - Organize town hall meetings or community forums to discuss the project.
    - Provide as much information as possible about the project, preferably with ample time for the community to review development plans prior to the meeting.
    - Plan for interactions being accessible to most, if not all community members. Arrange meeting times around the community's schedule (i.e., after working hours). If in person, plan for a location easily accessible by public transportation.
    - Provide opportunities for residents to ask questions, express concerns, and share their perspectives.
    - Be prepared and plan to set a schedule for responses to questions and feedback.
5. Collaboration with Local Institutions:
    - Partner with schools and colleges to integrate hydrogen education into their curriculum.
    - Involve students in awareness campaigns and projects related to clean energy.
6. Environmental Justice Considerations:
    - Acknowledge any historical environmental injustices in the area.
    - Ensure that the project benefits the community and does not disproportionately impact vulnerable populations.
    - Consider the US DOE's Justice40 requirements which aim to direct 40% of federal investments to disadvantaged communities.
7. Health and Safety Information:
    - Address safety concerns related to hydrogen production, storage, transmission, and usage.
    - Provide clear information on emergency protocols and risk mitigation.
8. Job Opportunities and Training:
    - Highlight job creation opportunities related to the facility.
    - Offer training programs for local residents to participate in the project workforce.
9. Cultural Sensitivity:
    - Respect the cultural diversity of the local neighborhood.
    - Incorporate community traditions and values into outreach efforts.

[41] This list of activities was inspired by several references: Rocky Mountain Institute, Clean Energy Group, The Green Hydrogen Coalition, and The California Hydrogen Market Development Strategy from the California Governor's Office of Business and Economic Development. The list was then updated after review by professionals with experience in community engagement for infrastructure projects. https://rmi.org/delivering-equitable-and-meaningful-community-benefits-via-clean-hydrogen-hubs/

- Set clear goals for diversity, equity, inclusion, and accessibility (DEIA) within your outreach efforts.

10. Media and Communication:
    - Use local media channels (TV, radio, newspapers) to share updates and project milestones.
    - Create a project website or social media profiles to disseminate information.
11. Feedback Mechanism:
    - Establish a feedback loop to continuously engage with the community.
    - Address concerns promptly and transparently.

Tamarack Institute's Index of Community Engagement Techniques document is an additional resource for tracking community engagement (not specific to H_2 infrastructure) with details and additional guidance on some of the activities listed above.[42]

Creating a community benefits plan (CBP) can help frame conversations with the community as well. The ARCHES H_2 Hub published their CBP that highlights health cost savings, reduction in emissions, new jobs, inclusion of tribal and environmental groups on the board, independent benefits monitoring team with accountability and enforcement mechanisms, among others.[43, 44] The US DOE also conducted forums on community benefits from hydrogen and posted guidance and educational resource material to introduce hydrogen-based supply chains and on designing a CPB through workshops.[45]

To reach the Restorative level, project teams must engage one or more stakeholders as partners with mutual interests or interdependencies. The Clean Energy State Alliance has some recommended strategies for partnering with community representatives.[46]

Credits Related to LD1.3:
QL1.1 Improve Community Quality of Life
QL1.4 Minimize Noise and Vibration
QL2.1 Improve Community Mobility and Access
QL3.1 Advance Equity and Social Justice
QL3.2 Preserve Historic and Cultural Resources
QL3.3 Enhance Views and Local Character
QL3.4 Enhance Public Space and Amenities
LD2.4 Plan for End-of-Life

2.4.2 LD1.4 Pursue Byproduct Synergies

LD1.4 aims to reduce wastes from the proposed project and other nearby infrastructure by implementing alternative use cases for available waste streams. These wastes can include but are not limited to materials/chemicals, energy and heat, emissions, and wastewater. External waste can either be incorporated into the proposed project, or byproducts from the process can be utilized in external

[42] https://cdn2.hubspot.net/hubfs/316071/Resources/Tools/Index%20of%20Engagement%20Techniques.pdf
[43] https://archesh2.org/wp-content/uploads/2023/11/ARCHES_CB_PROPOSAL_for-release.pdf
[44] https://www.energy.gov/infrastructure/about-community-benefits-plans
[45] https://www.energy.gov/justice/harnessing-hydrogen-and-community-benefits-public-forums
[46] https://www.cesa.org/resource-library/resource/community-engagement-models-energy-trust-oregon/

processes. It should be noted that traditional chemical process efficiency improvements such as reactor recycle streams and recuperative heat recovery do not fall within the scope of this credit. Additionally, these waste streams cannot be sold or purchased for profit. Figure 13 provides basic requirements needed to meet each level of achievement for LD1.4 along with each level's associated point values.

LEADERSHIP: COLLABORATION

LD1.4 Pursue Byproduct Synergies

18

POINTS

INTENT

Critically reconsider whether traditional waste streams can be beneficially reused.

METRIC

The extent to which the project team works with external groups to find beneficial use of waste, excess resources, or capacity.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A + B	A + B + C	A + B + D	A + B + D	A + B + E
(3) Initial Investigation	**(6) Synergy Pursued**	**(12) Short-Term Byproduct Reuse**	**(14) Long-Term Byproduct Reuse**	**(18) Circular Economy**
(A) The project team conducts an assessment of the availability and viability of excess resources (i.e., waste) or capacity, including but not limited to waste materials, heating or cooling, financial capacity, land area/space, or management/personnel capacity. **(B)** Candidates for byproduct synergies or reuse are identified. This can include finding a beneficial reuse for the project's waste or excess resources, or the project's beneficial reuse of external waste or excess resources. Project teams should also consider ecosystem services where project waste or excess resources can support natural systems, or where natural systems can process and remove project waste.				
	(C) The project team demonstrates an active attempt to incorporate at least one byproduct synergy or reuse into the project.	**(D)** The project successfully includes a byproduct synergy or reuse. Execution is a short-term or one-time byproduct synergy/reuse (e.g., during construction).	**(D)** The project successfully includes a byproduct synergy or reuse. Execution is a long-term regularly recurring byproduct synergy/reuse throughout project operations.	**(E)** The project is fully engaged in a "circular economy" system whereby the majority of its operational waste is beneficially reused OR the majority of its operational resources are sourced from external waste streams.

Figure 13. Levels of Achievement for LD1.4.

As with any chemical process, hydrogen production technologies offer an abundance of opportunities to both incorporate external byproducts from other chemical processes and find meaningful uses for their process byproducts. Figure 14 provides a non-exhaustive list of potential usable external process wastes that can be fed into the hydrogen production system and internal process byproducts out of the process broken down by typical hydrogen production technologies. Figure 19 also lists saleable vs unused byproducts from similar processes.

This credit aligns well with CR 2.6 to encourage integration with larger connected infrastructure systems. A noted issue facing hydrogen project developers is understanding the ability for hydrogen to be integrated into many infrastructure systems.

Hydrogen Production Technology	Usable External Waste as Feedstock into Process	Usable Byproduct Out of Process
Low Temperature Electrolysis	Curtailed Electricity	Oxygen Heat from cooling electrolyzer stacks
High Temperature Electrolysis	Curtailed Electricity Process Waste Heat (e.g., nuclear power plant)	Oxygen
Steam Methane Reforming	Biogas (from landfills or water treatment facilities)	Carbon Dioxide Waste Heat
Coal Gasification	N/A	Carbon Dioxide
Biomass Gasification	Food Wastes Wood Wastes Municipal Solid Waste	Carbon Dioxide Aromatic Byproducts (e.g., Benzene and Toluene) Tar
Autothermal Reforming	Biogas (from landfills or water treatment facilities) Oxygen	Carbon Dioxide

Figure 14. Hydrogen Production Byproduct Synergies

The Tri-generation Plant in the Port of Long Beach is a good example project for applying to LD 1.4.[47] The Tri-Generation Systems for Hydrogen Production Case Study (in Appendix) reviews all H_2-priority Envision credits for this project. Biogas containing methane is fed to the system, heated up and humidified before internal reforming inside a molten carbonate fuel cell. The fuel cell generates power while producing hydrogen (separated from the fuel cell exhaust). Water is also a product out of the system and can be recycled in the system to humidify the methane.

Main products:

- Electricity – sent to the electric grid or used onsite.
- Hydrogen – sent to a hydrogen refueling station to power zero-emission vehicles.

Feedstock into plant from external source:

- Methane contained in renewable biogas derived from organic waste (i.e., landfill waste, wastewater treatment waste, or animal waste).

Use of byproduct outside of plant:

- Water from the fuel cell exhaust is used to wash cars.

Reuse of byproduct within plant

- *Does not count toward LD 1.4, see RA 2.1 Reduce Operational Energy Consumption*
- Water from the fuel cell exhaust saturates the methane.
- Heat from high-temperature fuel cell exhaust pre-heats the saturated methane.

[47] https://www.fuelcellenergy.com/port-of-long-beach

Waste from the system that is not reused onsite or used external to the plant is CO_2 and NO_x emissions. This project would achieve the Restorative level for this credit because it includes a long-term byproduct synergy (biogas from organic waste) that makes up almost all of the resources coming into the plant.

See example Case Study on Tri-generation systems for additional assessment of Envision credits.

Tools and Resources for collaboration:

- US Hydrogen Hubs are a productive way to connect with currently funded projects with large scale H_2 production facilities. Consider reaching out to a nearby hub for collaboration and opportunities for connected infrastructure: https://www.energy.gov/oced/regional-clean-hydrogen-hubs-selections-award-negotiations
- H_2 Matchmaker was a tool originally designed to connect organizations interested to team on H_2Hub projects: https://www.energy.gov/eere/fuelcells/h2-matchmaker
- Hydrogen @ EPRI also provides tools for collaboration within the H_2-Hubs, the Hydrogen Education for a Decarbonized Global Economy (H2EDGE) initiative in building a framework for hydrogen workforce education, and Hydrogen Testing and Demonstrations.[48]

Credits Related to LD 1.4:
LD1.2 Foster Collaboration and Teamwork
LD2.4 Plan for End-of-Life
RA1.2 Use Recycled Materials
RA1.5 Balance Earthwork On Site
RA3.1 Preserve Water Resources
NW2.1 Reclaim Brownfields
CR2.6 Improve Infrastructure Integration

2.4.3 LD 2.2 Plan for Sustainable Communities

LD2.2 strives to put sustainability at the forefront of the project selection and identification process. The needs of the greater community and how the project can fit within a larger sustainable development plan should be the primary drivers for project selection and identification. This is best illustrated by the tradeoffs between water utilization and emission levels of various hydrogen production technologies. For example, in regions where water may be scarce, technologies such as Steam Methane Reforming (SMR), Autothermal Reforming (ATR) with carbon capture and sequestration (CCS), or tri-generation may be preferred due to lower water utilization relative to more water-intense technologies. Other communities may be struggling with higher levels of air pollution and related health issues, in this case, some form of electrolysis using renewable energy may be favorable. In other cases, when communities may be afflicted by both concerns, a “no-build” option should also be considered in the process as being the most sustainable solution Figure 15 provides a more detailed summary of each level of achievement’s requirements for LD2.2 along with each level’s associated point values.

To meet the Superior level, projects must go beyond the physical boundary of the project to identify impacts to external systems. Conserving and Restorative levels will require collaboration with the

[48] https://hydrogen.epri.com/en/

community to understand their sustainability goals and specific conditions that are currently unsustainable. Like other Leadership Planning credits, design of the infrastructure and associated programs should not be done in isolation. Some common and somewhat obvious sustainability goals are zero waste, zero emissions or carbon neutrality, water conservation, and health and wellbeing of citizens (good jobs, affordable housing, and access to transportation). The more a project can contribute positively to a community, the likelier the community will accept and could be an advocate for the project. Contributions could take the form of both physical structures (community centers, parks, etc.) and programs. For example, the San Diego Airport used incentive-based programs to encourage green taxis to the airport. These incentives included vehicle rebates, reduced taxi permit fees, and maintenance packages. Incentive-based programs could be in coordination with the city to address a specific sustainability goal. Also consider climate adaptation and community resilience plans that could provide ideas of community goals.

LEADERSHIP: PLANNING

LD2.2 Plan for Sustainable Communities

16

POINTS

INTENT

Incorporate sustainability principles into project selection/identification in order to develop the most sustainable project for the community.

METRIC

The degree to which project selection/identification includes sustainability performance assessments and is part of a larger sustainable development plan.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A	A + B	A + B + C	A + B + C + D	A + B + C + D + E
(4) Sustainability Indicators	**(6) Alternative Analysis**	**(9) Sustainability Assessment**	**(12) Sustainable Planning**	**(16) More Sustainable Communities**

(A) Sustainability indicators or outcomes are considered in project selection/identification and planning.

(B) Sustainable performance is included in alternative analyses during project identification. Alternatives include the sustainability of a "no-build" option.

(C) During project identification, the project's potential impact to broader external systems is assessed, such as growth patterns, congestion, energy and water demand/production, and how these impact the overall long-term sustainability of the community or region.

(D) The project is part of a comprehensive sustainable development plan at the level of the infrastructure system, municipality/community, or region. The project demonstrates a direct connection and contribution to achieving specific sustainable development goals identified in the plan.

(E) The project addresses an inherently unsustainable condition within the community.

Figure 15. Levels of Achievement for LD2.2

Credits Related to LD2.2:
QL1.1 Improve Community Quality of Life
QL2.1 Improve Community Mobility and Access
LD1.2 Foster Collaboration and Teamwork
LD3.1 Stimulate Economic Prosperity and Development
RA3.1 Preserve Water Resources
NW1.1 Preserve Sites of High Ecological Value
NW1.3 Preserve Prime Farmland
NW2.1 Reclaim Brownfields

2.4.4 LD 3.2 Develop Local Skills & Capabilities

LD3.2 is designed to enhance the economic prosperity of communities in proximity to new infrastructure projects by providing them the opportunity to grow and improve their skills and knowledge base. This includes identifying current shortcomings in the current capabilities of the local workforce and tailoring training programs to address these limitations. Higher levels of achievement are awarded when these programs are designed to be longstanding and target groups that are economically disadvantaged in the local community. Projects should consider targeting groups whose jobs may be lost because of a transition to a lower-carbon economy, such as fossil fuel-related jobs. Hydrogen projects are particularly well-suited to address this credit as they often involve specialized equipment and processes that will require local upskilling to properly construct and operate. Additionally, hydrogen safety is a key requirement for all projects. Figure 16 provides each level of achievement's requirements along with each level's associated point values for LD 3.2.

To address the Conserving level, considering education programs beyond initial project delivery is required. Community education on hydrogen in general is important and vital for future adoption of hydrogen infrastructure. Encourage the community to learn about the safety, uses, and benefits of using hydrogen. Including a space, on the project campus or nearby, for interactive learning can show the community how the system works and inspire the next generation of hydrogen workforce.

Developing training programs that target economically depressed, underemployed, or disadvantaged communities can address the Restorative level of achievement. This part of the credit overlaps well with the Restorative level of QL 3.1. Revitalizing a disadvantaged community through training and skills can help address historic or current imbalances.

As mentioned in previous credits, there are a few resources on workforce development for H2 projects including H_2EDGE and H_2-DEIA.[49] In 2023, the Hydrogen and Fuel Cells in the Economy (IPHE) and the Hydrogen Council partnered to launch the H_2-DEIA with initiatives to assess the evolving H_2 workforce needs and equip the future hydrogen workforce with the necessary skills to build the hydrogen and fuel cell economy while advancing diversity, equity, inclusion, and accessibility. [50] Tracking both H_2EDGE and H2-DEIA can be a helpful in building the new H_2 workforce.

[49] https://hydrogen.epri.com/en/h2edge.html
[50] https://h2-deia.org/

LEADERSHIP: ECONOMY

LD3.2 Develop Local Skills and Capabilities

16 POINTS

INTENT
Expand the knowledge, skills, and capacity of the community workforce to improve their ability to grow and develop.

METRIC
The inclusion of current and future training programs, informed by skill or capability gaps, and targeted to economically depressed or underemployed communities.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A	A + B	A + B	A + B + C	A + B + C + D
(2) Gaining Skills	**(4) Growing Capacity**	**(8) Building Communities**	**(12) Long-Term Opportunities**	**(16) Community Revitalization**
(A) The project includes training programs for local skill development. This may include designers, contractors, subcontractors, or operators.				
	(B) Beyond general skill development, the project team identifies specific skill or capability gaps in the local workforce. Training programs target these gaps to improve local capacity. Skills are transferable beyond the end of the project.	**(B)** The project team works with, or is informed by, community and local/state workforce development agencies to assess local employment and educational needs. Training programs target these gaps to improve local capacity. Skills are transferable beyond the end of the project. Skills developed are likely to provide the local workforce, agencies, and/or companies with a competitive advantage in the future.		
			(C) Education, skill development programs and/or opportunities will continue after project delivery. This may include community education and awareness training. Programs may be at the organizational level but must be relevant to the project.	
				(D) Training and skill development programs specifically target economically depressed, underemployed, or disadvantaged communities.

Figure 16. Levels of Achievement for LD3.2

Credits Related to LD3.2:
QL1.3 Improve Construction Safety
QL3.1 Advance Equity and Social Justice
LD2.3 Plan for Long-Term Monitoring and Maintenance
LD3.1 Stimulate Economic Prosperity and Development

2.4.5 LD 3.3 Conduct a Life-Cycle Economic Evaluation

LD3.3 intends to elucidate the economic impacts and benefits of the project by conducting a Life-Cycle Cost Analysis (LCCA)**.** The LCCA for this credit not only takes into account the monetary costs of a project, but also includes social and environmental costs. Social cost examples could be the EPA's Social Cost of Greenhouse Gases or the Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE) that is an open-source computer program that calculates the economic value of air pollution-related deaths and illnesses.[51, 52] Other considerations for the cost of air pollution could include healthcare costs, lost productivity, and environmental damages. The LCCA is also used to assess alternative project designs and options to inform the overall project decision making process. Figure 17 summarizes each level of achievement's requirements along with each level's associated point values.

LEADERSHIP: ECONOMY

LD3.3 Conduct a Life-Cycle Economic Evaluation

14 POINTS

INTENT
Utilize economic analyses to identify the full economic implications and the broader social and environmental benefits of the project.

METRIC
The comprehensiveness of the economic analyses used to determine the net impacts of the project, and their use in assessing alternatives to inform decision making.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A	A + B	A + B + C	A + C + D	A + C + D + E
(5) Life-Cycle Cost Analysis	**(7) Life-Cycle Cost Alternatives Analysis**	**(10) Benefit Mapping**	**(12) Sustainability Cost Benefit Analysis**	**(14) Sustainability CBA Alternatives Analysis**
(A) A life-cycle cost analysis (LCCA) is conducted on the whole project to identify the total economic impacts of the project and provide additional insight into decision making.				
	(B) LCCA is used to compare and assess alternatives for at least one major design component.			
		(C) The project team maps the social, environmental, and financial costs and benefits of the project. Costs and benefits must be quantified but not necessarily monetized.		
			(D) The LCCA in criterion A is expanded into a comprehensive sustainability cost benefit analysis based on monetizing the social, environmental, and financial costs and benefits identified in criterion C.	
				(E) The sustainability cost benefit analysis is used to compare and assess alternatives for at least one major design component. The selected alternative produces a net positive present value including social and environmental benefits.

Figure 17. Levels of Achievement for LD3.3

[51] https://www.epa.gov/system/files/documents/2023-12/epa_scghg_2023_report_final.pdf
[52] Environmental Benefits Mapping and Analysis Program - Community Edition (BenMAP-CE) | US EPA

Resources:

Economic Tools

- Levelized Cost of Hydrogen (LCOH) Tool: H2A https://www.nrel.gov/hydrogen/h2a-production-models.html

Mapping Tools:

- ENPLAN
- EJ Screen
- Climate and Economic Justice Screening Tool: https://screeningtool.geoplatform.gov/en/
- InMap maps human health impacts caused by air pollutant emissions and shows how those impacts are distributed among different groups of people: https://inmap.run/

Calculating Impacts and Sustainability Benefits

- Complementary Solutions for Holistic Impact Valuation: Return on Sustainable Investment (ROSI™) and Impact-Weighted Accounting (IWA): https://www.stern.nyu.edu/sites/default/files/assets/documents/ROSI%20IWA%20Publication.pdf
- California Healthy Mobility Options Tool: https://skylab.cdph.ca.gov/HealthyMobilityOptionTool-ITHIM/
- NIST Community Resilience Economic Decision Guide and Online Tool: https://www.nist.gov/community-resilience/edge-and-economic-decision-guide
- A return-on-investment metric for incorporating sustainability in process integration and improvement projects: https://www.nist.gov/community-resilience/edge-and-economic-decision-guide
- New Hampshire Health Care Cost: https://nhhealthcost.nh.gov/costs/select

Related Credits:

QL1.1 Improve Community Quality of Life
LD2.3 Plan for Long-Term Monitoring and Maintenance
LD2.4 Plan for End-of-Life
LD3.1 Stimulate Economic Prosperity and Development
CR2.2 Assess Climate Change Vulnerability
CR2.3 Evaluate Risk and Resilience
CR2.4 Establish Resilience Goals and Strategies

2.5 Resource Allocation (3 prioritized Credits)

Resource Allocation credits consider the quantity, source, and characteristics of resources needed to keep infrastructure operational. The three credits covered in this section cover operational energy consumptions, use of renewable energy, and operational water consumption.

2.5.1 RA2.1 Reduce Operational Energy Consumption

RA2.1 seeks to award projects that reduce their operational energy relative to a baseline system energy consumption estimate. As with any chemical process, hydrogen production facilities have many strategies that can be implemented to reduce energy consumption and the overall efficiency of the process. Figure 18 summarizes the percent reduction of energy consumption necessary to obtain each level of achievement and the associated point values. The percentage reduction must be from a baseline system design that should include existing conditions, a seriously considered alternative, standard practice, or a comparable existing project/facility. Fuels used for vehicle usage can also be included in the estimate. In some cases, energy consumption can vary and thus a range in energy data can be used.

RESOURCE ALLOCATION: ENERGY

RA2.1 Reduce Operational Energy Consumption

26 POINTS	INTENT	METRIC
	Conserve energy by reducing overall operational energy consumption throughout the project life.	Percentage of operational energy reductions achieved.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A + B	A + B	A + B	A + B	Not Available
(6) 10% Energy Reduction	**(12) 30% Energy Reduction**	**(18) 50% Energy Reduction**	**(26) 70% Energy Reduction**	
(A) The project team determines the estimated annual energy consumption of the project. If annual energy consumption varies, the project team submits the range of estimated performance over the project life.				
(B) Operational energy is reduced at least 10%.	**(B)** Operational energy is reduced at least 30%.	**(B)** Operational energy is reduced at least 50%.	**(B)** Operational energy is reduced at least 70%.	

Figure 18. Levels of Achievement for RA2.1

Figure 19 shows a table of hydrogen production pathways, the key end use of hydrogen, feedstock or input sources, waste/byproducts, and common internal energy use (chemical or thermal byproducts). Most systems use some form of internal heat recuperation or recycling of steam/water. To achieve greater reduction in energy consumption, an energy generation or converting system must consider alternative pathways that reduce feedstock energy used, and/or greater internal re-use of byproducts. Better integration is the most valuable way to capture increased efficiency. For energy distribution systems, projects should consider designs that reduce energy losses for high efficiency in energy delivery.

Systems trying to capture CO_2 will likely add more energy use to the project, representing a trade-off with reducing CO_2 emissions.

Production Pathway	Key End-Use for Hydrogen	Feedstock or Input from External Source	Waste or Byproduct Used Internally	Waste or Byproduct Likely Saleable* / Likely Unused✡
Low-Temp Electrolysis	FC Vehicle Mobility NH_3 Long-Term Energy Storage	H_2O Curtailed Electricity Alkaline Salts	Heating and Cooling	**O_2✡** **Low-Grade Heat✡** **Low-Quality or High-Mineral Water✡**
High-Temp Electrolysis	Cooling at Nuclear Reactor FC Vehicle Mobility	Steam/H_2O Electricity	Heating and Cooling	**O_2✡** **High-Grade Heat***
Steam Methane Reforming (SMR)	FC Vehicle Mobility NH_3 Long-Term Energy Storage	Steam/H_2O CH_4	Heat Steam/H_2O H_2	**CO_2*** **High-Grade Heat***
Coal Gasification	Synfuels NH_3 Fertilizer	Coal H_2O Air/O_2	Steam/H_2O	Syngas: **CO✡, CO_2*, CH_4*, H_2O***
Biomass Gasification	Gas Turbine for Electricity FC Vehicle Mobility	Biomass Air Steam/H_2O Heat	Heat Tar	**(N_2S, NH_3, HCL, Tar, Benzene, Toluene, Ethylbenzene, and Xylene (BTEX)) ✡** **CO✡** **CO_2***
Autothermal Reforming (ATR)	Synfuels NH_3 Fertilizer	CH_4 H_2 Steam/H_2O Air	Heat	Syngas: **CO✡, CO_2*, CH_4*, H_2O***

Figure 19. Table of feedstock, waste, byproducts, and common internal use of byproducts for different hydrogen production pathways

Related Credits:

QL1.5 Minimize Light Pollution
QL2.2 Encourage Sustainable Transportation
LD2.1 Establish a Sustainability Management Plan
RA2.4 Commission and Monitor Energy Systems
CR1.2 Reduce Greenhouse Gas Emissions
CR1.3 Reduce Air Pollutant Emissions

2.5.2 RA2.3 Use Renewable Energy

RA2.3 grants points to projects that source their energy from renewable sources considering the total energy consumption over the life of the facility. This includes both renewable electrical and fuel-based energy sources. The types of renewable energy specified for this credit include:

- solar energy (thermal heating, both active and passive, and photovoltaic)
- wind (electricity generation)
- water (hydro or tidal for electricity generation)
- biomass (electricity generation or as fuels)
- geothermal (electricity generation or heating and cooling)
- hydrogen/fuel cells (used as a fuel)
- renewable transportation fuel or electric vehicle use

All hydrogen production technologies can take advantage of the points awarded in this credit; however, it is recommended that projects consider H_2 produced from renewable energy sources to limit greenhouse gases. "Green" H_2 can be described in different ways, but one should consider the International Renewable Energy Agency (IRENA) and Green Hydrogen Standard's definitions of green H_2.[53,54]

- IRENA's Definition: hydrogen produced from renewable energy or water electrolysis powered by renewable electricity generation.
- The Green Hydrogen Standard defines green hydrogen as hydrogen produced from processes emitting <=1 kg CO_2e per kg H_2 taken as an average over a 12-month period (based on the electrolysis production pathway defined by the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) in their working paper).[55]

In sourcing H_2 for use in a refueling station, for example, this credit is good to pair with RA 1.1 Support Sustainable Procurement Practices where preference should be given to suppliers that account for the environmental, economic, and social impacts of their products and have active programs in place for performance improvement.

H_2 production facilities can source their electrical demand from co-located renewable sources such as wind or solar or use renewable energy credits (RECs). Make sure to refer to the Envision manual on RECs or purchase agreements as there are stipulations on location and time of use over the life of the facility. For example, for purchased renewable energy from the grid, the renewable energy sources must be in the same grid as the project. It is recommended that projects try to avoid RECs due to limited ability to verify credit emission claims and possibly distant location generation.

[53] IRENA's definition taken from: Green hydrogen: A guide to policy making (irena.org)
[54] The GH2 Green Hydrogen Standard | Green Hydrogen Organisation
[55] Working Paper Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen: H2PATF Methodology for GHG Quantification in H2 Production_A4FINAL (iphe.net)

SMR or other NG-derived hydrogen processes could source methane from biogas products out of landfills or wastewater treatment facilities. Biomass gasification facilities inherently use renewable biomass as their primary chemical feedstock. Use of biogas from dairy/beef farms should be limited to waste streams and not product streams. The price of a biogas waste stream should only include the cost of processing and delivery of the biogas and should exclude profit to the biogas supplier. If profit is included in the price of biogas, it becomes a product stream. Reductions in the demand for dairy/beef would be more effective at reducing produced GHGs and using biogas as a profitable product stream prevents reductions in the demand for dairy/beef.

Figure 20 provides the requisite percentage of renewable energy usage and associated point values for each level of achievement.

RESOURCE ALLOCATION: ENERGY

RA2.3 Use Renewable Energy

24 POINTS	INTENT	METRIC
	Meet operational energy needs through renewable energy sources.	Extent to which renewable energy sources are incorporated.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A	A	A	A	A
(5) At Least 5%	(10) At Least 15%	(15) At Least 30%	(20) At Least 50%	(24) Net Positive
(A) The project meets: 5% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 15% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 30% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project meets: 50% of energy needs (electricity and fuel) from renewable sources.	**(A)** The project generates a net positive amount of renewable energy.

Figure 20. Levels of Achievement for RA2.3

Projects looking to achieve a Restorative level requires a net positive amount of renewable energy which may be possible for example generating more solar energy than is used onsite and feeding it to the grid or nearby external facilities. Projects cannot claim credit on net positive amounts of renewables that are not used. For example, curtailed electricity not fed to the grid or used elsewhere cannot satisfy net positive renewable energy production.

Related Credits:

CR1.2 Reduce Greenhouse Gas Emissions
CR1.3 Reduce Air Pollutant Emissions

2.5.3 RA3.2 Reduce Operational Water Consumption

Similar to RA2.1, RA3.2 seeks to award projects that reduce their reliance on potable water during operation. This encourages the use of more sustainable alternative water sources such as greywater, recycled water, or stormwater. Many hydrogen projects already utilize these types of water sources into their feedstock in the pursuit of tax credits where water is a scarce resource. The water reduction requirements and points awarded for each level of achievement are summarized in Figure 21 below.

RESOURCE ALLOCATION: WATER

RA3.2 Reduce Operational Water Consumption

22

POINTS

INTENT

Reduce overall water consumption while encouraging the use of greywater, recycled water, and stormwater to meet water needs.

METRIC

Percentage reduction in potable water use and overall water use.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A + B	A + B + C	A + B + C	A + B + C	A + B + C + D
(4) At Least 25% Reduction	**(9) At Least 50% Reduction**	**(13) At Least 75% Reduction**	**(17) 95% Reduction**	**(22) Water Purification**
(A) The project team conducts planning or design reviews to identify potable water reduction strategies during operation of the project. The team has considered using alternatives such as nonpotable water, reused water, recycled water, and stormwater.				
(B) The project reduces potable water use by at least 25%.	**(B)** The project reduces potable water use by at least 50%.	**(B)** The project reduces potable water use by at least 75%.	**(B)** The project reduces potable water use at least 95%.	**(B)** The project reduces potable water use by 100%.
	(C) Overall water use (potable and nonpotable) is reduced by at least 20%.	**(C)** Overall water use (potable and nonpotable) is reduced by at least 30%.	**(C)** Overall water use (potable and nonpotable) is reduced by at least 40%.	**(C)** Overall water use (potable and nonpotable) is reduced by at least 50%.
				(D) The project not only reduces potable water consumption to zero, but also provides water that can be used by the community.

Figure 21. Levels of Achievement for RA3.2

If the type of hydrogen production process is not finalized, trade-offs with water consumption can be incorporated into the decision process along with energy use, cost, emissions, and community acceptance.[56] A list of typical water usage ranges by hydrogen production generation type are provided in Figure 22. It should be noted that the water usage listed is for the hydrogen production process (excluding upstream feedstock or electricity generation water consumption). The listed values include water consumption from water treatment processes (if needed) that contributes roughly half the water consumption but may be recycled back to municipal treatment plants, H_2 production processes, and

[56] Tradeoffs in life cycle water use and greenhouse gas emissions of hydrogen production pathways - ScienceDirect

cooling process (low end of electrolysis ranges excludes water consumption from cooling as air cooling is an option to reduce onsite water consumption).

When considering water electrolysis, there can be a significant difference in water consumption depending on the electricity generation process. Using solar or wind renewable processes can have significantly less water usage compared to grid electricity.[57] If considering CCUS on SMR or other CO_2 producing pathway, adding CCUS could increase the water usage by about 2 kgH_2O/kgH_2. Depending on the type of feedstock, for example biomass, there can be significant water usage to grow biomass.[58, 59] Developers can also use the AWARE-US model (listed below) to determine water stressed areas and locations to avoid when considering high water consuming technologies.

	Water Usage (kg H_20/kg H_2)
Low Temp Electrolysis	26-30[60]
High Temp Electrolysis	26-30[60]
Steam Methane Reforming (SMR)	12-22[60]
Coal Gasification	29[60]
Biomass Gasification	16[60]
Autothermal Reforming (ATR)	7[61]

Figure 22. Typical range in water usage during hydrogen production by technology pathway

To reach Restorative level, projects must produce excess water and provide it to the community. In the example Tri-Generation project that produces excess water, whether the restorative level can be reached may depend on the boundary defined by the project and how the produced water is used. If the Tri-Gen system does not include car washing stations and excess water is provided to the community, the project could achieve Restorative level. The project could alternatively claim this credit as not applicable as it does not require water consumption.

Related Credits:

RA3.1 Preserve Water Resources
CR1.2 Reduce Greenhouse Gas Emissions

Tools/Resources:

- Available Water Remaining for the United States (AWARE-US) model developed by ANL provides monthly water-stress impact to various cities in the US: https://greet.anl.gov/aware

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[57] https://www.energy.gov/sites/default/files/2023-11/1-05-water-consumption-elgowainy.pdf
[58] Life cycle water footprint assessment of syngas production from biomass chemical looping gasification - ScienceDirect
[59] Life cycle water footprint comparison of biomass-to-hydrogen and coal-to-hydrogen processes - ScienceDirect
[60] Development of a Life Cycle Inventory of Water Consumption Associated with the Production of Transportation Fuels (Technical Report) | OSTI.GOV
[61] Water-for-the-Hydrogen-Economy_WaterSMART-Whitepaper_November-2020.pdf (watersmartsolutions.ca)

- Analysis of Water Consumption and Regional Water Stress Associated with Clean Hydrogen Production: https://www.energy.gov/sites/default/files/2023-11/1-05-water-consumption-elgowainy.pdf
- Lifecycle analysis of water consumption for hydrogen production conducted by ANL: Life-Cycle Analysis of Water Consumption for Hydrogen Production (energy.gov)
- Alliance for Water Efficiency has state scorecards (2022) and water saving tips for commercial, industrial, and institutional.

2.6 Natural World (1 prioritized Credits)

Natural World credits consider the impacts on the natural systems and ecosystems where infrastructure projects are located. The single Natural World credit in this section seeks to protect surface and groundwater quality.

2.6.1 NW2.4 Protect Surface and Groundwater Quality

NW2.4 ensures that the project is designed to prevent further contamination of surface and groundwater during the construction and operation of the project. Systems should be put in place to continually monitor conditions throughout the lifetime of the project. Hydrogen production projects are suited to address this credit (as well as RA3.1 Preserve Water Resources) given their typical heavy dependence on water as a feedstock of the process. Many of the requirements for NW2.4 may already be considered through the design of typical hydrogen facilities.

Figure 23 gives the requirements needed to meet each level of achievement for NW2.4 along with each level's associated point values. In addressing this credit, the project should do its best to avoid contamination of surface or groundwater (including temperature changes and salinity). To reach the Superior level, surface or groundwater quality must be monitored with water quality data provided to the public. The Conserving level demonstrates actions to eliminate possible sources of pollution or hazardous materials. Restorative levels push to improve surface or groundwater beyond existing conditions. For example, extra water could be purified sufficiently to be released to nearby surface or ground water sites.

NATURAL WORLD: CONSERVATION

NW2.4 Protect Surface and Groundwater Quality

20 POINTS	Preserve water resources by preventing pollutants from contaminating surface water and groundwater and monitoring impacts during construction and operations.	**METRIC** Designs, plans, and programs instituted to prevent and monitor surface water and groundwater contamination during construction and operations.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A + B	A + B + C	A + B + C + D	A + B + C + D + E	A + B + C + D + E + F
(2) New Pathway Avoidance	**(5) Community Support**	**(9) Risk Reduction**	**(14) Public Reporting**	**(20) Quality Improvement**

(A) The project team determines potential impacts to surface water or groundwater quality, including temperature, during construction and operations.

(B) The project includes spill and leak diversion systems, spill prevention plans, and cleanup. The project does not create new direct pathways for surface water and/or groundwater contamination such as:

- Direct runoff into karst terrain;
- Untreated industrial or chemical discharge to unlined industrial ponds or lakes;
- Reinjection water wells unless water is treated to secondary levels, or local regulations, whichever is more stringent; or
- Chemical, byproduct, or fracking water, injection.

(C) Based on the types of impacts identified in criterion A, the project reduces the risk of quality degradation to surface water and/or groundwater. This should include water temperature.

(D) Adequate measures enable responsive surface water and/or groundwater quality monitoring and reporting mechanisms to provide the public with water quality data.

(E) The project has actively eliminated at least one source of hazardous and/or potentially polluting substances, or replaced them with nonhazardous or nonpolluting substances or materials.

(F) The project improves surface water and/or groundwater quality beyond existing conditions.

Figure 23. Levels of Achievement for NW2.4

Electrolysis processes have an obligation to maintain groundwater conditions given the high-use and handling of water. Figure 24 is an example water purification system that could include carbon filtration, reverse osmosis, and deionization upstream of the electrolyzer. The effluent streams off the water purification system would likely need to be processed depending on the concentration of the dissolved solids. The effluent water stream should not be released into the environment without being tested.[62] It should be noted that water circulated within the electrolyzer is not likely suitable for direct release into the environment either. High temperature solid oxide electrolysis systems may want to include a holding tank of effluent water to equilibrate with the environment before disposal.[63] Recycled water

[62] For example, this Darden Clean Energy Project in California is using electrolysis to generate hydrogen. The project defaulted to zero-liquid discharge/disposal of effluent that had brine with a high concentration of dissolved solids. https://efiling.energy.ca.gov/GetDocument.aspx?tn=253570&DocumentContentId=88793

[63] Holding tanks for the high-temp effluent water could be used until water reaches lower temperatures.

within the electrolyzer system must go through additional filtration due to the contaminants that can come out of the electrolyzer stack like PFAS.[64]

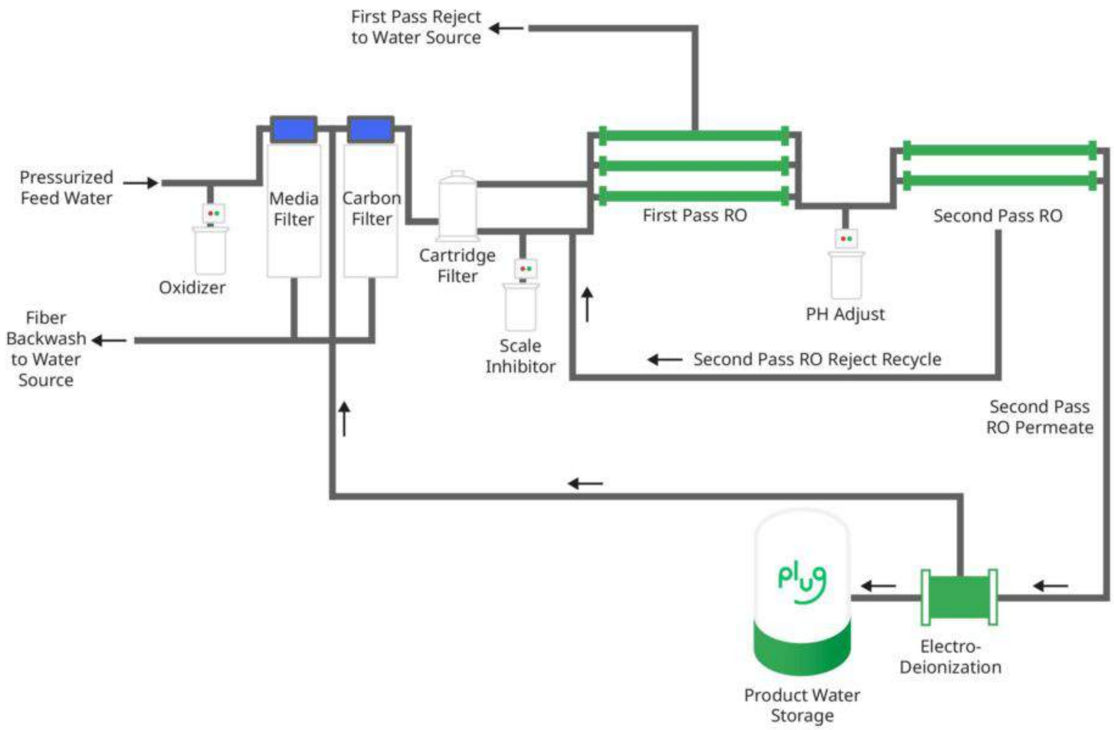

Figure 24. Electrolyzer water purification system[65]

Contamination of wells from geological sequestration of CO_2 should also be considered for projects planning to capture CO_2. Permitting processes are in place to prevent drinking water contamination, however, alternative disposal of CO_2 is recommended if a project seeks to eliminate water contamination sources.[66]

Related Credits:

QL1.2 Enhance Public Health and Safety
RA1.5 Balance Earthwork On Site
RA3.1 Preserve Water Resources
NW1.1 Preserve Sites of High Ecological Value
NW2.1 Reclaim Brownfields
NW2.3 Reduce Pesticide and Fertilizer Impacts
NW3.2 Enhance Wetland and Surface Water Functions

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[64] Keeping the water ultrapure inside electrolyzers: challenges and solutions (hydrogentechworld.com)
[65] Electrolyzers and Water: Saving Water, Powering the World with Green Hydrogen - Plug Power
[66] EPA's Underground Injection Control Guidance for Class VI - Wells used for Geologic Sequestration of Carbon Dioxide: https://www.epa.gov/uic/class-vi-wells-used-geologic-sequestration-carbon-dioxide

2.7 Climate Resilience (6 prioritized Credits)

The Climate Resilience credits cover both minimization of emissions that may contribute to climate change and evaluating risks in the short- and long-term that can affect infrastructure resiliency. The six credits described in this section touch on reductions in GHG and air pollutant emissions, risk assessment, established goals and strategies to address identified risks, maximizing resilience through implementation of the goals and strategies, and improving infrastructure integration for project efficiency and resiliency.

2.7.1 CR1.2 Reduce Greenhouse Gas Emissions

CR1.2 requires a percentage reduction of GHG emissions over the operational lifetime of the project relative to an established baseline with calculations done in units of CO_2eq. Electrolysis, SMR with CCS, and biomass gasification production facilities can possibly score well for this credit, especially if they are replacing an already existing gray hydrogen production facility (fossil fuel derived hydrogen without carbon capture). In terms of transportation technologies, fuel cell vehicle projects and hydrogen fueling stations also offer opportunities to offset GHG emissions from existing transportation infrastructure. However, to track the exact emissions reductions, the project owner would have to know the number of vehicles being replaced. For example, transit bus fleets or trucking fleets that have the number of vehicle replacements documented. Figure 25 summarizes the necessary GHG percentage reduction for each level of achievement and the associated point values.

CLIMATE AND RESILIENCE: EMISSIONS

CR1.2 Reduce Greenhouse Gas Emissions

26 POINTS	INTENT	METRIC
	Reduce greenhouse gas emissions during the operation of the project, reducing project contribution to climate change.	Percentage of reduction in operational greenhouse gas emissions.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A + B	A + B	A + B	A + B	A + B
(8) At Least 10% Reduction	(13) At Least 25% Reduction	(18) At least 50% Reduction	(22) 100% Reduction	(26) Carbon Negative
(A) The project team demonstrates at least a 10% reduction in total CO_2e over the operational life of the project compared to the baseline. Calculations should be in tons CO_2e.	**(A)** The project team demonstrates at least a 25% reduction in total CO_2e over the operational life of the project compared to the baseline. Calculations should be in tons CO_2e.	**(A)** The project team demonstrates at least a 50% reduction in total CO_2e over the operational life of the project compared to the baseline. Calculations should be in tons CO_2e.	**(A)** The project team demonstrates a 100% reduction in total CO_2e over the operational life of the project compared to the baseline. Calculations should be in tons CO_2e.	**(A)** The completed project is carbon negative (i.e., sequesters/removes more CO_2e than it produces over the operational life).
(B) The project team maps and calculates the total annual greenhouse gas emissions of the final project design for reporting purposes. This includes direct and indirect greenhouse gas emissions and sequestration associated with project operations. Calculations must be in CO_2e.				

Figure 25. Levels of Achievement for CR1.2

The baseline system on which to compare must be one of the following (in order of preference):

1. Existing conditions or the existing system(s) the project will replace.
2. A seriously considered project alternative.
3. Industry "standard practice" or existing codes, standards, or regulatory requirements (e.g., for energy and water; greenhouse gas and air pollution emissions).
4. A project of similar scope and size operating within the same geographical area or within a geographical area with similar operating conditions.

Figure 26 provides possible baseline project considerations for different hydrogen projects. Baseline systems can be defined differently for different credits. However, the boundary of the project must be consistently applied to all credits. In 2021, the IEA reported on the emissions intensity of different hydrogen production routes, compared in Figure 27.

Hydrogen Project	Baseline Example
Electrolysis using renewable electricity	Electrolysis using local grid average electricity
Hydrogen refueling station	Electric charging station Gasoline refueling station Diesel refueling station
Hydrogen pipeline	NG Pipeline

Figure 26. Example baseline projects for comparison

	Greenhouse Emissions (kg CO2e/kg H2) with/out CCUS	Greenhouse Emissions (kg CO2e/kg H2) with CCUS
Low Temp Electrolysis[67]	0 (Renewable); 17-50 (NPCC grid - HICC grid [a])[67]	N/A
High Temp Electrolysis[67]	0.1[67]	N/A
Steam Methane Reforming (SMR) with LFG[68]	0.4	N/A
Steam Methane Reforming (SMR)[69]	12	2.5
Coal Gasification[69]	22.7	1.70-3.10
Biomass Gasification[69]	3.6	-17.6
Autothermal Reforming (ATR) [69]	10.5	3

[a] NPCC denotes the Northeast Power Coordinating Council and HICC denotes the Hawaiian Island Coordinating Community

Figure 27. Emissions during hydrogen production for different pathways

[67] 45VH2-GREET, December 2023, https://www.energy.gov/sites/default/files/2024-01/45vh2-greet-2023.zip
[68] https://publications.anl.gov/anlpubs/2022/10/179090.pdf
[69] IEA, Comparison of the emissions intensity of different hydrogen production routes, 2021, IEA, Paris https://www.iea.org/data-and-statistics/charts/comparison-of-the-emissions-intensity-of-different-hydrogen-production-routes-2021, IEA. License: CC BY 4.0

Green ammonia production, ammonia derived from green hydrogen, should consider the emissions sources referenced in the Green Hydrogen Standard (GHS).[70] Emissions related to electricity consumptions could be attributed to all steps in the ammonia production process. Additional fugitive emissions should also be taken into consideration.

For CO_2 producing projects, consideration of active carbon capture is encouraged over purchasing of carbon off-sets. Low Carbon Fuel Standard (LCFS) verification protocols for carbon capture should be considered.[71]

The draft 45V tax credit will require a qualified third-party emissions verifier either from the American National Standards Institute National Accreditation Board or from the California Air Resources Board's LCFS Program. Consider the ISO 14064 and 14065 standards for monitoring, reporting, verification, and validation of GHG emissions. There are firms that specialize in emissions monitoring and test methods including SWRI and RTI International. ISO 14001 standard on environmental management systems (EMS) provides a framework to design and implement an EMS, and continually improve environmental performance. The framework includes monitoring environmental performance and involving stakeholders in environmental commitments.

To reach Restorative, projects need to show removing emissions from the atmosphere. One example is to plant trees or other vegetation. iTree provides a calculator to determine the long-term benefits of tree planting including reduction in carbon dioxide, air pollution, and stormwater impacts, as well as energy savings, and canopy cover.[72]Projects should consider planting trees onsite or within the vicinity of the plant, not at a distant location. This recommendation is not to try to offset a large amount of carbon emissions through planting trees, but more to use tree planting as a way of reaching carbon negative for a plant already reaching near carbon neutral.

Tools/Resources:

- The R&D GREET Model supplies upstream greenhouse gas emissions for quantity of feedstock - developed by ANL: https://www.energy.gov/eere/greet
- Hydrogen Delivered Life Cycle Analysis Tool (H2DLAT) from the Clean Air Task Force: https://www.catf.us/hydrogen-lifecycle-analysis-tool/
- LCA toolkit by the Open Hydrogen Initiative (OHI): https://www.gti.energy/ohi/lca-toolkit/

Related Credits:

QL2.2 Encourage Sustainable Transportation
LD2.1 Establish a Sustainability Management Plan
CR1.1 Reduce Net Embodied Carbon
RA1.5 Balance Earthwork on Site
RA3.2 Reduce Operational Water Consumption
RA3.3 Reduce Construction Water Consumption

[70] https://www.greenhydrogenstandard.org/
[71] https://ww2.arb.ca.gov/lcfs-verification
[72] https://planting.itreetools.org/

2.7.2 CR1.3 Reduce Air Pollutant Emissions

Whereas CR1.2 addresses greenhouse gases which absorb and trap heat in the atmosphere, CR1.3 focuses on air pollutants that have a direct detrimental effect on humans and other living organisms. Tools provided for CR1.2 can also be used for evaluating air pollutant emissions. At the lowest level of achievement, project teams can implement strategies to reduce air pollutants during operations. An Enhanced level of achievement involves demonstrating the use of best available controls systems and monitoring. At Superior or higher, CR1.3 requires the reduction of air pollutants relative to a baseline. Criteria air pollutants include dust ($PM_{2.5}$ and PM_{10}), ozone, SO_x, NO_x, lead, and VOCs. Hydrogen production and transportation technologies are well suited to address this credit for the same reasons described in credit CR1.2. Figure 28 summarizes the necessary air pollutant control strategies for each level of achievement and the associated point values.

Consider the Refueling Stations for Fuel Cell Electric Buses Case Study project that quantified this value for diesel transit bus replacements by H_2 fuel cell buses.

CLIMATE AND RESILIENCE: EMISSIONS

CR1.3 Reduce Air Pollutant Emissions

18 POINTS

INTENT
Reduce emissions of air pollutants: particulate matter (including dust), ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, lead, and volatile organic compounds.

METRIC
Reduction of air pollutants compared to baseline.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A + B	A + B + C	A + B + C + D	A + B + C + D	A + B + C + D + E
(2) Exceeding Requirements	**(4) Ongoing Monitoring**	**(9) VOC Minimization**	**(14) Air Pollutant Elimination**	**(18) Air Quality Improvement**
(A) The project meets all applicable air quality standards and regulations for air pollutants.				
(B) The project implements strategies to reduce air pollutant emissions during operations.	**(B)** The project reduces emissions through the use of best available control systems or best management practices.	**(B)** Air pollution controls are within the 95th percentile, or represent the lowest levels possible compared to projects of similar type.	**(B)** The project eliminates air pollutant sources in the design, chooses a non-polluting alternative, or achieves at least a 98% net reduction in air pollution emissions compared to the baseline.	
	(C) Systems are in place for the ongoing monitoring of any direct sources of air pollution. Processes are in place to identify and address changes in emissions in order to maintain performance targets.			
		(D) The project team assesses whether volatile organic compounds harmful to human health are material to the project and, if so, implement strategies to reduce their use during construction and/or within occupied spaces of the completed project.		
				(E) The project includes the direct removal of previously existing air pollutant sources, or captures and safely stores/disposes of air pollutants for a net positive impact.

Figure 28. Levels of Achievement for CR1.3

Related Credits:

QL1.2 Enhance Public Health and Safety
QL2.2 Encourage Sustainable Transportation
LD2.1 Establish a Sustainability Management Plan
RA2.1 Reduce Operational Energy Consumption
RA2.3 Use Renewable Energy

2.7.3 Risk Assessment, Strategies, and Implementation

The following three sub-sections CR2.3 Evaluate Risk and Resilience, CR2.4 Establish Resilience Goals and Strategies, and CR2.5 Maximize Resilience should be considered together as a 3-step process of (1) identifying and prioritizing the risks, hazards, vulnerabilities, and impacts to the project, (2) developing strategies to address the risks, hazards, and vulnerabilities identified in (1), and (3) implementation of the strategies determined in (2) into the design of the system. CR2.2 Assess Climate Change Vulnerability is not a prioritized credit within the H_2SIG; however, projects are encouraged to also consider this credit in addition to the three credits mentioned in this section. Assessing the risks of a hydrogen project is particularly important to alleviate safety concerns given newer types of production technologies/equipment and the new uses of hydrogen. These assessments are already conducted for projects but using the Envision-guided requirements can help structure the assessment process to full implementation with outsider's opinions and perspectives. Incorporating monitoring systems and developing consistent reporting practices will not only contribute to the safety of any hydrogen system, but it can also contribute to the safety of all future hydrogen systems. Large scale deployment of hydrogen infrastructure is still at an early stage and sharing of failures and maintenance data can collectively help the industry move forward with safer facilities, less accidents, lower fatalities, and prevent the high cost of unwanted incidents.

2.7.3.1 CR2.3 Evaluate Risk and Resilience

CR2.3 outlines the requirements for conducting an all-inclusive risk and resiliency evaluation for the project. The level of achievement is determined by the scope of this evaluation and where the boundary is drawn for the risk assessment. For Improved, only the project site is considered, whereas Enhanced requires interdependencies of the infrastructure system and networks. Superior/Conserving is inclusive of the above and the broader community. Figure 29 summarizes the necessary contents of this evaluation as well as the necessary scope of the evaluation to attain different levels of achievement.

Risk evaluation step details are outlined in the Envision Guidance Manual and include (1) Draw the Boundary, (2) Understand the Asset, (3) Identify Threats/Hazards, (4) Identify Vulnerabilities, and (5) Evaluate Risk.

Projects could consider participating in the Hydrogen Component Reliability Database (HyCReD) effort led by NREL (described in more detail in credit section CR2.5) to address steps 4 (Identify Vulnerabilities) and 5 (Evaluate Risk). Participating in safety/reliability data collection efforts can help address these two steps and give operators access to valuable information.

Hydrogen risk and resilience analysis methods have been developed by several groups and there are instructive resources for conducting a quantitative risk assessment (QRA).

- **Sandia National Laboratory's Hydrogen Safety Codes and Standards website**: https://energy.sandia.gov/programs/sustainable-transportation/hydrogen/hydrogen-safety-codes-and-standards/
- **Hydrogen Plus Other Alternative Fuels Risk Assessment Models (HyRAM+)**: HyRAM+ is a toolkit that facilitates risk assessments using publicly available data and models to estimate the probabilities of equipment failures for different hydrogen-related components and probabilistic models for the effect of heat flux and overpressure on people. This tool extends to other alternative fuels such as methane and propane to allow comparison between counterpart components and equipment: https://energy.sandia.gov/programs/sustainable-transportation/hydrogen/hydrogen-safety-codes-and-standards/hyram/
- **Hydrogen Economy (Second Edition, 2023): Supply Chain, Life Cycle Analysis and Energy Transition for Sustainability, Chapter 15: Hydrogen safety, risk, and reliability analysis**: This book chapter provides the properties and hazards of hydrogen (release, ignition, and fires and explosions, challenges of hydrogen system QRAs, summary of models used in HyRAM, risk metrics, release frequencies and scenarios, and harm models from thermal exposures and overpressure events. https://www.sciencedirect.com/science/article/abs/pii/B9780323995146000121?via%3Dihub
- **Bayotech Risk and Modeling Support White Paper**: Provides an example of risk assessment modeling identifying scenarios with consequence modeling for an SMR system at the Port of Stockton https://www.osti.gov/biblio/1832974

Primary hazards of hydrogen use are its release and subsequent ignition. A hydrogen molecule is very small and can leak through cracks that methane cannot. Hydrogen is easily ignitable, the flames are nearly invisible in daylight, and hydrogen flames can burn hotter than methane flames. The main hazards related to hydrogen release are exposure to thermal radiation from jet fires and exposure to overpressures from explosions. Asphyxiation and projectile damage (from high pressure hydrogen escapes from a ruptured containment vessel) are also considered potential hazards.

In addition to health and safety risks of hydrogen, the project should consider the credit CR2.2 Assess Climate Change Vulnerability that could feed into this CR2.3 credit. For example, rising sea levels, wider temperature swings, droughts, flooding, or larger and more frequent storms.[73]Additionally, weather-related natural disasters, availability of food and water, or widespread economic recession are risks worth considering in this credit. It is also worth considering that H_2 is an indirect GHG and the need to monitor/mitigate H_2 leaks may be critical to prevent extending the life of methane in the atmosphere, which is a very potent GHG.

[73] NOAA Office for Costal Management Digital Coast offers a tool for coastal flood exposure. https://coast.noaa.gov/digitalcoast/tools/flood-exposure.html

CLIMATE AND RESILIENCE: RESILIENCE

CR2.3 Evaluate Risk and Resilience

26 POINTS	INTENT	METRIC
	Conduct a comprehensive, multihazard risk and resilience evaluation.	Scope and comprehensiveness of the multihazard risk and resilience evaluation.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A + B + C + D + E	A + B + C + D + E	A + B + C + D + E	A + B + C + D + E + F	NOT AVAILABLE
(11) Project Evaluation	**(18) System Evaluation**	**(24) Community Evaluation**	**(26) Integrated and Inclusive Approach**	
(A) The project team draws the assessment boundary for subsequent criteria (B, C, D, and E) around the project and its site.	**(A)** The project team draws the assessment boundary for subsequent criteria (B, C, D, and E) around the interdependencies of the project and its associated/connected infrastructure system/network.	**(A)** The project team draws the assessment boundary for subsequent criteria (B, C, D, and E) around the interdependencies of the project, its associated/connected infrastructure system/network, and the broader community.		
(B) Understand the Asset: The project team identifies the objectives and performance goals of the project and related systems. It also identifies the critical assets, systems, and networks that are essential to meeting objectives and performance goals. This should include the associated dependencies and interdependencies within the system. **(C)** Identify Threats/Hazards: The project team identifies threats/hazards (natural hazards and human-induced threats). Project teams may reference existing studies or assessments if relevant to the project and its context. Threats should include both acute shocks and chronic stressors. **(D)** Identify Vulnerability: The project team identifies the vulnerabilities of the critical functions and dependencies of the infrastructure asset and its primary components identified in criterion B to the threats/hazards identified in criterion C. **(E)** Evaluate Risk: The project team evaluates the project risk by determining the likelihood/probability of a threat/hazard occurring and the associated consequences/impacts. Consequences and impacts should be classified as social, environmental, and/or economic/financial.				
			(F) The project team conducts the risk evaluation with the owner and a diverse and integrated team of key stakeholders.	

Figure 29. Levels of Achievement for CR2.3

Related Credits:

LD2.2 Plan for Sustainable Communities
LD3.3 Conduct a Life-Cycle Economic Evaluation
CR2.2 Assess Climate Change Vulnerability
CR2.4 Establish Resilience Goals and Strategies
CR2.5 Maximize Resilience

2.7.3.2 CR2.4 Establish Resilience Goals and Strategies

This credit aims to set resilience goals based on the key assets and process risks established in credit CR2.3. In addition to setting project goals, risk mitigation strategies also need to be developed. The level of achievement for this credit is primarily based on receiving input from key stakeholders and the broader community impacted by the project. Figure 30 summarizes these considerations for each level of achievement and the associated point values.

In taking a comprehensive approach to implementing resilience strategies, a QRA model using HyRAM can quantify scenarios and characterize the harm on people and surrounding equipment. From this, one can make design decisions to eliminate or reduce the impact of identified safety risks.

The Conserving level of achievement requires project resilience goals to align with the broader community or region's resilience goals and plans or develop goals that could aid the community in developing broader community goals. This could take on many forms. One example is earthquake preparedness and emergency response in the City of San Francisco. In San Francisco's resilience plan, one of the strategies for the goal "Prepare Today for San Francisco's Recovery" is to increase training for neighborhood emergency response teams.[74] In considering explosions or disasters either caused by earthquakes or facility-related incidents, emergency response plans should be in place both for the facility and for surrounding communities. An education program could be developed for nearby residents to be prepared in different emergencies. Other examples more specific to hydrogen could be on initiatives to promote community health through preparing for climate change or access to backup power or water in disaster events.

[74] https://sfgov.org/ccsfgsa/sites/default/files/ORR/documents/Resilient%20San%20Francisco_0.pdf

CLIMATE AND RESILIENCE: RESILIENCE

CR2.4 Establish Resilience Goals and Strategies

20 POINTS	INTENT	METRIC
20 POINTS	To support increased project and community resilience through the establishment of clear objectives and goals.	The degree to which resilience goals expand from initial commitments to quantifiable project objectives, long-term operating plans, and community-wide development plans.

LEVELS OF ACHIEVEMENT

<table>
<tr><th>IMPROVED</th><th>ENHANCED</th><th>SUPERIOR</th><th>CONSERVING</th><th>RESTORATIVE</th></tr>
<tr><td>Not Available</td><td>A + B</td><td>A + B + C</td><td>A + B + C + D</td><td>Not Available</td></tr>
<tr><td></td><td>(8) Strategy Development</td><td>(14) Stakeholder Input</td><td>(20) Shared Community Goals</td><td></td></tr>
<tr><td></td><td colspan="3">(A) The project team determines the performance goals of the project and the owner's acceptable level of risk.
(B) The project team uses the results of a risk evaluation (e.g., CR2.3) to develop risk management strategies that meet project performance goals and budget, and increase project resilience. The project team prioritizes strategies that result in the greatest reduction of risk within project cost constraints.</td><td></td></tr>
<tr><td></td><td></td><td colspan="2">(C) The project team engages the owner and key stakeholders in developing or reviewing resilience goals and strategies.</td><td></td></tr>
<tr><td></td><td></td><td></td><td>(D) The project team aligns project resilience goals with broader community- or region-wide resilience goals and plans.
OR
If community resilience goals are lacking, the project team publicly shares its resilience goals in support of developing broader community goals.</td><td></td></tr>
</table>

Figure 30. Levels of Achievement for CR2.4

Related Credits:

QL1.2 Enhance Public Health and Safety
LD1.1 Provide Effective Leadership Commitment
LD2.2 Plan for Sustainable Communities
LD3.3 Conduct a Life-Cycle Economic Evaluation
CR2.2 Assess Climate Change Vulnerability
CR2.3 Evaluate Risk and Resilience
CR2.5 Maximize Resilience

2.7.3.3 CR2.5 Maximize Resilience

This credit aims to implement the goals and strategies of credit CR2.4 during the project development phase. Furthermore, these strategies should be periodically revisited during project development to determine their effectiveness and make any necessary changes. Once the project is in service, additional strategies should be developed for the actual operation and maintenance of the project. Figure 31 gives a simplified overview of the basic requirements needed to meet each level of achievement for CR2.5 along with each level's associated point values.

To achieve a Superior level of achievement, projects are required to incorporate resilience strategies into operations and maintenance of the project. Systems should be in place to continually improve the resilience capabilities of the facility. As mentioned previously, designing a system with sufficient monitoring devices in place with clear and thoughtful reporting practices can help prevent future incidents. Project developers should consider regular reporting to the Hydrogen Component Reliability Database (HyCReD).[75],[76][77] HyCReD is built on mostly data for hydrogen refueling station components, however, there are plans to expand the database to include data from electrolyzer and other hydrogen production facilities. With sufficient data, HyCReD could be used to generate QRA, maintenance plans, and help direct efforts in safety codes and standards for hydrogen-related equipment. Projects planning to report data for HyCReD should also consider the Conserving level for CR 2.6 to show that the project integrates data or monitoring systems with reporting to learn and improve system performance over time (see next section).

The Conserving level of achievement requires measurement or quantification of benefits of resilience. This may be an important exercise if trying to prioritize different strategies/solutions for minimizing the impacts of risks. One example could be monetizing avoided damages or losses based on possible impacts of risks.

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[75] This reference outlines the types of data fields required for reporting data and use in HyCReD. *Design and requirements of a hydrogen component reliability database (HyCReD)* https://www.sciencedirect.com/science/article/abs/pii/S0360319923036236

[76] Virtual Seminar: Increasing Reliability and Safety of Hydrogen Component Reliability Data Collection, March 2024. https://www.youtube.com/watch?v=jA2fh4kcGbE

[77] International Journal of Hydrogen Energy article on HyCReD. https://www.sciencedirect.com/science/article/abs/pii/S0360319923036236

CLIMATE AND RESILIENCE: RESILIENCE

CR2.5 Maximize Resilience

26 POINTS

INTENT
Increase resilience, life-cycle system performance, and the ability to withstand hazards by maximizing durability.

METRIC
The degree to which the project incorporates elements that increase durability, the ability to withstand hazards, and extend useful life.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A + B	A + B + C	A + B + C + D	A + B + C + D + E	Not Available
(11) Improved Resilience Performance	**(15) Thorough Implementation**	**(20) Ongoing Resilience Monitoring**	**(26) Quantifying Improvement**	
(A) The project team develops resilience goals and strategies (e.g., CR2.4) based on a detailed risk evaluation of the project (e.g., CR2.3). **(B)** The project team takes a comprehensive approach to implementing resilience strategies.				
	(C) The project team periodically monitors the implementation of resilience strategies and revisits their effectiveness in addressing project risk throughout project development.			
		(D) Resilience strategies are incorporated into the operations and maintenance of the project. Organization(s) responsible for the ongoing operation of the project have systems in place to maintain, grow, learn, and continually improve resilience capabilities (i.e., "plan, do, check, act").		
			(E) The project team establishes methods for measuring/quantifying the benefits of resilience strategies implemented (e.g., monetary savings from avoided damage or service loss, accelerated recovery time).	

Figure 31. Levels of Achievement for CR2.5

Related Credits:

LD2.3 Plan for Long-Term Monitoring and Maintenance
LD2.1 Establish a Sustainability Management Plan
LD3.1 Stimulate Economic Prosperity and Development
LD1.4 Pursue Byproduct Synergies
QL1.1 Improve Community Quality of Life
QL1.2 Enhance Public Health and Safety
CR2.2 Assess Climate Change Vulnerability
CR2.3 Evaluate Risk and Resilience
CR2.4 Establish Resilience Goals and Strategies

2.7.4 CR2.6 Improve Infrastructure Integration

This credit considers integration at various levels and layers related to the project. A key focus of the integration is the reduction of risk and improvement of resilience against systemic or cascading failures in the project and greater system. This is often improved through increased system efficiency or diversity. Infrastructure systems may include networks of water treatment, connected fueling depots for transit systems, and waste management systems. Figure 32 gives a simplified overview of the basic requirements needed to meet each level of achievement for CR2.6 along with each level of achievement's associated point values.

CLIMATE AND RESILIENCE: RESILIENCE

CR2.6 Improve Infrastructure Integration

18 POINTS

INTENT
Enhance the operational relationships and strengthen the functional integration of the project into connected, efficient, and diverse infrastructure systems.

METRIC
The degree to which the project is integrated into other connected systems, where beneficial and appropriate, in order to increase resilience and systems performance.

LEVELS OF ACHIEVEMENT

IMPROVED	ENHANCED	SUPERIOR	CONSERVING	RESTORATIVE
A	A + B	A + B + C	A + B + C + D	A + B + C + D + E
(2) Internal Integration	(5) Risk Reduction	(9) Systems Integration	(13) Community/ Network Integration	(18) Information Integration

(A) The project increases internal systems integration in order to achieve efficiency or system diversity.

(B) Integration strategies increase resilience and reduce the risk of systemic or cascading failures.

(C) The project leverages its relationship within a larger infrastructure system in order to achieve efficiency or system diversity.

(D) The project integrates networks of infrastructure systems (e.g., water and transportation) in order to achieve efficiency or system diversity. In certain cases, projects may substitute the community integration of non-physical social or economic systems.

(E) The project integrates data or monitoring systems with reporting or preparedness systems in order to learn and improve performance over time.

Figure 32. Levels of Achievement for CR2.6

The [Delta ACES](https://aces-delta.com) project is a good example that could touch on each of the requirements for this credit.[78] The diagram in Figure 32 shows the project layout for achieving long-term energy storage via hydrogen in 2025 and out to 2045.

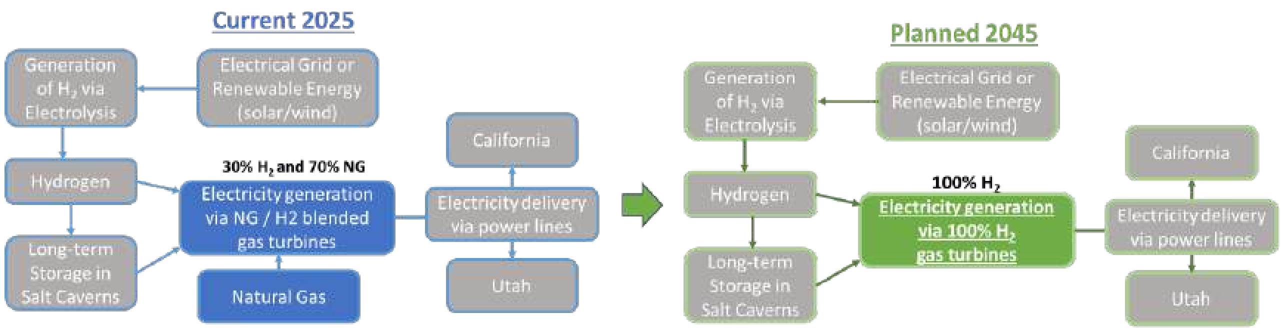

Figure 33. Current and planned future Delta ACES project diagrams

- **Improved:** The system couples energy storage and power production with back up or redundant hydrogen storage and gas turbines. It also utilizes a blend of natural gas and hydrogen in gas turbines.
- **Enhanced:** The project utilizes load balancing of the electrical grid and curtailing renewables as well as back up compressor and storage systems to increase resiliency.
- **Superior:** The system improves utilization/reduces waste from nearby renewable power generation, eliminates the dependence on coal power plants, reduces the dependence of traditional (NG fired) power plants, enables long-term energy storage to provide power to multiple states (California and Utah) during peak season electrical usage that would prevent planned outages, and potentially reduces transportation/delivery requirements for electricity.
- **Conserving:** Although not currently included in the Delta Aces project, one could show an integration with the transportation sector if supplying H_2 fuel for fuel cell trucks or buses. The project would have to demonstrate that the integration with transportation improved efficiency or diversity for existing systems.
- **Restorative:** System controls data and hydrogen production rates are monitored as well as collection of electrical demand over time to determine optimal balance between storing and producing power.

Similarly, to credit LD1.4 Pursue Byproduct Synergies, this project shows collaborative leadership between the renewable energy sector, traditional gas turbine power producer, energy storage, and industrial hydrogen sector. Although these multi-collaborator projects can be challenging, they are needed to generate unique solutions to challenging problems like long-term storage of renewables.

[78] https://aces-delta.com/wp-content/uploads/2022/03/Mitsubishi-Power-White-Paper-Why-the-Western-U.S.-Needs-Energy-Storage.pdf

Examples of Systems Integration or Community Network Integration for H_2 Infrastructure Projects

- H_2 hubs – larger integrated system / hydrogen network
- Water treatment networks
- Connected refueling depots for transit systems
- Waste management systems
- Electric Power Grid
- Low Carbon Fuel Standard (LCFS) (program integration)
- Dedicated H_2 Pipelines – enables scale (Angeles Link– Green H_2 pipeline from central to southern California)
- Co-located with renewable power generation
- Tri-generation systems (H_2, power, water or heat)
- Blending H_2 into NG
- Integrated monitoring, reporting, and sharing of H_2 production between different hydrogen production plants to guarantee H_2 fuel for customers

Integration of hydrogen production with water treatment facilities have been demonstrated, for example a tri-generation system at the Orange County Sanitation District.[79] Many water treatment facilities are centralized plants, however de-centralization, although more expensive, is becoming more popular due to the availability of recycled water that would otherwise be restricted during droughts. De-centralization also reduces the demand on centralized water infrastructure. Permitting, water auditing, and regulatory permits are different in each location and connecting with the local treatment facility on regulation as well as pathways of integration are necessary. Nutrient removal process is also gaining more interest in water treatment although it is an energy-intense process that may benefit from H_2 integration (no known demonstration yet). Each nutrient removal process is often different depending on the equipment and system design.

As mentioned in the previous section, projects planning to report data to HyCReD could address the CR2.6 Restorative level of achievement requirement of integrating data or monitoring systems with reporting to learn and improve performance over time. This credit applies to the specific system applying for award, but projects could also consider applying for CR0.0 Innovate or Exceed Credit Requirements if supplying data to HyCReD. This reporting goes beyond the system or larger infrastructure system in that reporting data to HyCReD will ultimately be used to inform risk assessments and US codes and standards, impacting all future hydrogen projects in the US and making the industry more resilient.

Related Credits:

QL 2.2: Encourage Sustainable Transportation
LD2.2: Plan for Sustainable Communities
NW1.4 Preserve Undeveloped Land
LD1.4 Pursue Byproduct Synergies

[79] https://www.osti.gov/servlets/purl/1053779

3 Appendix: Case Studies

The following case studies were used to assess the sustainability of a project based on hydrogen-prioritized sustainability focus areas (credits) within the Envision® sustainable infrastructure framework. The reader is advised to review the Hydrogen Sustainable Infrastructure Guidelines (H_2SIG) that introduces the Envision® framework and provides guidelines for applying hydrogen-prioritized credits to hydrogen infrastructure projects. These case studies walk through each of the hydrogen-prioritized credits and provide examples of ways to address sustainability for real world applications.

3.1 Refueling Stations for Fuel Cell Electric Buses

Projects Included in the Case Study:

Southeastern Pennsylvania Transportation Authority (SEPTA) Zero Emission Bus Fleet Replacement
Greater Philadelphia Area
Battery Electric and Fuel Cell Electric Bus – Fleet Replacement

SunLine Fuel Cell Buses & Hydrogen Onsite Generation Refueling Station
Riverside County, California
Fuel Cell Electric Bus Fleet and Hydrogen Fueling Station

Island Transit Zero Emission Fleet Transition
Whidbey and Camano Islands, Washington State
Battery Electric and Fuel Cell Electric Bus – Fleet Replacement

3.1.1 Case Study Summary: Refueling Stations for Fuel Cell Electric Buses

The aim of this case study is to determine how well replacing a diesel or natural gas bus fleet with fuel cell electric buses (FCEBs) and hydrogen refueling infrastructure to support the FCEBs will score on a prioritized list of Envision® credits. This case study is a composite investigation of three different FCEB fleet replacement projects across the US: Southeastern Pennsylvania Transit Authority (SEPTA), SunLine Transit, and Island Transit. Select aspects of each project are highlighted for certain Envision® credits to show the highest potential for these types of projects. Documentation for each project was used to assess sustainability requirements and, in some cases, follow-up conversations with the developers helped to refine the assessments. The authors were able to speak to both SEPTA and Sunline Transit to ask questions about their projects and future activities. SEPTA's documentation provided a high level of detail to address certain credits and was therefore used for many of the credits assessments. If a project is not mentioned in a credit, it could mean that it was addressed similarly to projects already mentioned, there was no available documentation and the project contacts were unable to provide information, or the project may not have addressed the credit. Where all projects fell short of the highest level of achievement, recommendations are provided for project developers to consider in the future.

It should be noted that the timing of these projects is different. SEPTA and Island Transit are in the planning stages while the SunLine Transit project has been built and is in operation. Using Envision® and planning for sustainability for any project should be conducted as early in the project planning phase as possible as this provides the lowest cost opportunity for optimization.

The SunLine Transit project documentation included numerous lessons learned and recommendations for issues that may have been resolved if using the Envision® framework. Although there has been no pledge from these project developers to use Envision® in the future, the authors of this report hope the recommendations provided here and the H_2SIG will be useful and encourage sustainable practices in future hydrogen infrastructure projects.

The SEPTA project plans to replace the entire 1,400 bus fleet in the greater Philadelphia area with a combination of battery electric buses (BEBs) and FCEBs. This project is currently in the developmental stages with SEPTA conducting feasibility studies, economic and environmental projections, and conducting pilot bus programs. SEPTA plans to begin its fleet replacement in 2026 and conclude replacements in 2040. The project is currently projected to cost $2-$2.4B in facility upgrades, chargers, vehicle purchases, and includes cost offsets from the Federal Transit Administration (FTA) subsidies. SEPTA is evaluating several design pathways and fleet compositions, but for the purposes of this study, SEPTA's proposed fleet replacement ratio of 4 FCEB to each BEB (4:1 FCEB to BEB fleet) will be used for all relevant credit calculations and to determine the potential level of achievement for each Envision® credit.

Between 2017 and 2020, SunLine Transit added 5 FCEBs to its existing 17 FCEB fleet in addition to upgrading their existing hydrogen refueling station to incorporate an on-site proton exchange membrane (PEM) electrolyzer hydrogen production plant, increasing station production by 900kg H_2/day. The project was funded by the California Air Resources Board (almost $13M) with matching by SunLine (~$6M) for a total of almost $19M. The focus of this project was to reduce emissions while considering other impacts to the community. These impacts are captured in the case study assessment through higher levels of achievement in Quality of Life and Climate and Resilience emissions reductions.

The Island Transit fleet replacement project plans to swap its current fleet of 19 diesel transit buses and 13 diesel cutaways with a mix of FCEBs and BEBs. The agency also plans to replace its 114 sedans, vans, and cutaways used for paratransit and ridesharing with BEBs; however, these additional replacements fall outside of the scope of this case study. Island transit conducted a technology assessment and determined the best course of action would be to replace its buses on Whidbey Island entirely with FCEBs. This will require the construction and installation of a hydrogen storage tank, refueling equipment, and safety and facility upgrades (Hatch, 2023). Out of the three projects assessed, Island Transit provided insights into evaluating potential project risks and bolstering resiliency of its fleet replacement.

Overall, these projects have the potential to score particularly well in the categories of Quality of Life, Leadership, and Resource Allocation. This stems from the reduced level of tailpipe emissions of the FCEBs and BEBs relative to traditional diesel-powered buses. These reduced emissions improve the quality of life of the surrounding communities by providing health benefits. The projects are also well designed in terms alignment with community sustainability goals and implementing workforce development for the neighborhoods they impact. This demonstrates that the projects are committed to taking an active role in instituting a sustainable future for the populations they impact. Lastly, their choice of bus technology is significantly more efficient and cleaner than standard diesel buses. This demonstrates a dedication to preserving the valuable resources the surrounding communities need to sustain their quality of life and promote a healthier environment.

3.1.2 Project Introduction, Definition, and Background

3.1.2.1 SEPTA

SEPTA is currently proposing to replace its entire fleet of 1,400 diesel-powered hybrid electric buses with a combination of BEBs and FCEBs. The proposed fleet replacement came as a response to Pennsylvania Governor Wolf's 2019 executive order setting net GHG emissions reductions across the state from 2005 levels by 26% in 2025 and 80% by 2050. Additionally, the fleet replacement aligns with the City of Philadelphia's 2021 Transit Plan: A Vision for 2045. The fleet of buses currently spans 9 districts and provides transportation to the greater Philadelphia area. The 15-year replacement project is set to begin in 2026 and conclude in 2040.

In addition to bus replacements, SEPTA is also developing plans to modify its existing bus facilities and infrastructure. These modifications will be necessary to support the required electrical and hydrogen infrastructure needed to electrify and fuel its new zero-emission buses. SEPTA is working with PECO, the local electrical utility supplier, to improve electrical infrastructure in the area to better support charging at its depots and potential intermediate charging stations. SEPTA has conducted some analysis to determine which of its depots have the space available to implement hydrogen fueling infrastructure. SEPTA aims to use green hydrogen as its fuel whenever possible and has identified several potential suppliers. They plan to test and pilot 10 FCEB in their Midvale district starting in the summer of 2024.

SEPTA believes this fleet replacement will have a net-positive benefit to the surrounding community and predicts the fleet replacement could reduce GHG and air pollutant emissions by up to 95% in some scenarios. SEPTA plans to target its fleet replacement in minority and economically-disadvantaged communities first as they often disproportionately experience health problems related to air pollution.

SEPTA Project Design and Scope (SEPTA, 2022)

- ***Description:*** This project is designed to replace the current 1,400 existing, diesel-powered hybrid electric bus fleet with a combination of battery and fuel cell electric buses. Modifications, expansions, and additions to fueling depots will be made as needed to accommodate this transition of the transportation infrastructure.
- ***Boundary and Location:*** SEPTA provides bus and transportation services to Philadelphia, Bucks, Chester, Delaware, and Montgomery counties in Pennsylvania. Modifications will be needed at all 9 of SEPTA's bus depots.

- ***Project Size:*** SEPTA's proposed project (used in this assessment) will be a 4:1 split of FCEB to BEB to replace its existing fleet of 1,400 buses plus 5 new buses. They predict this will cost somewhere between $2 and $2.4B in facility upgrades, chargers, and vehicle purchases, including cost offsets from FTA subsidies.
- ***Processes:*** SEPTA will not produce hydrogen on-site due to space limitations in the areas it services. Instead, they plan to truck in liquified hydrogen that will be stored in large outdoor storage tanks. This hydrogen will then be vaporized and dispensed to the buses via multiple refueling stations each equipped with multiple refueling dispensers.
- ***Feedstock Source:*** SEPTA has identified 10 potential hydrogen suppliers that are within 2,000 miles of their region of operation. Two of these suppliers would be able to meet SEPTAs' projected hydrogen demands with entirely green hydrogen. A liquid hydrogen (LH_2) pump and vaporizer would be used to convert the LH_2 to gaseous form before being dispensed to the FCEBs on site.
- ***Product Destination:*** The hydrogen will be trucked in and stored in liquid form at a central storage facility. The hydrogen will then be vaporized to be dispensed into their new FCEB fleet. Buses service five counties in Pennsylvania.
- ***Project Stage:*** This project is currently in the design phase with fleet replacements expected to begin in 2026.
- ***Unknowns and Uncertainties:*** Uncertain if the space requirements for hydrogen storage and dispensing equipment will be feasible at many of the existing bus depots. Uncertain where the hydrogen will be sourced from and if a dedicated production facility will be pursued. Uncertain if a new garage/depot will need to be constructed to accommodate more equipment and buses.

SEPTA Sustainability Management and Collaboration

- ***Sustainability Management* Plan**: SEPTA's most recent sustainability management plan is titled *SEP-TAINABLE 2020* and is a 5-year plan that was released in 2017. This plan extends to multiple forms of public transit including bus, subway, rail, and trolley. (SEPTA, 2017) SEPTA held multiple town halls to gather community and stakeholder input while creating this management plan. (SEPTA, 2016) SEPTA added to this plan with the 2024 Sustainability Playbook (Sustainability Playbook, 2024).
- **Sustainability Consultant:** None identified.

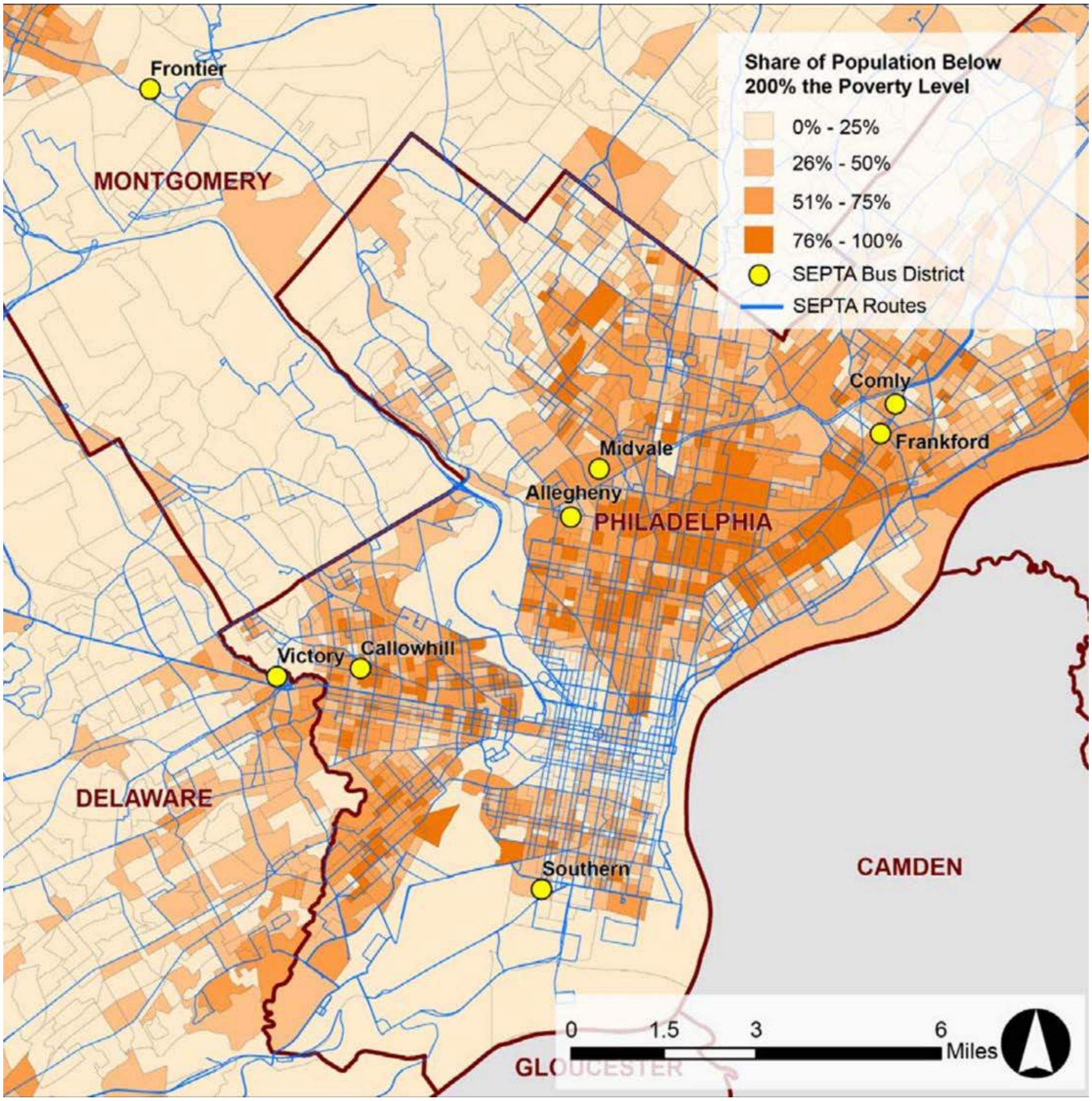

Figure 34. SEPTA Transit Network Map showing the share of population below 200% of the federal poverty level (SEPTA, 2022)

3.1.2.2 SunLine Transit Project

The SunLine Transit project covers many aspects of the H_2-prioritized Envision credits with hydrogen production on-site to refuel their FCEB fleet. The use of FCEBs has many health benefits to the community, but generation of H_2 on-site can create securities and resiliency (at least initially) to maintain bus operations. SunLine uses both PEM electrolysis and steam methane reforming (SMR) to generate hydrogen and has the further option of trucking in H_2 to ensure there is a constant supply of fuel for the FCEBs. In addition to using renewable natural gas for CNG buses, the project also installed solar panels for partial electricity supply to the PEM electrolyzers.

Although the report from which this case study was conducted is several years old, the authors engaged SunLine in several discussions to understand how the system has changed since the report was written. Generating hydrogen on-site is beneficial for resiliency, however, smaller generation systems often present significant cost and management challenges. SunLine expressed a desire to move away from on-site hydrogen production and instead use liquid hydrogen storage tanks to achieve H_2 fuel resiliency. This would require trucking-in hydrogen with diesel trucks in the near term, hopefully transitioning to fuel cell trucks in the future.

SunLine considers FCEBs to be an important technology for decarbonization and continues to work on improving their systems while trying to keep sustainability in mind.

SunLine Transit Project Design and Scope (SunLine Transit Agency)

- ***Description:*** This project included deployment of 5 new 40-ft FCEBs for daily service in the Coachella Valley and included an addition of a PEM electrolyzer system to produce hydrogen as upgrade to their existing hydrogen refueling station (adding to an SMR system running on renewable natural gas). The PEM electrolyzer produced 900kg/day with supporting compression and storage equipment and two 350-bar fueling dispensers.
- ***Boundary and Location:*** Refueling station at SunLine's Thousand Palms facility in California. FCEBs were dispatched in Riverside County to serve disadvantaged communities in Coachella, Indio, and Mecca.
- ***Project Size:*** Total project cost was $18.8M to deploy 5 FCEBs and build a PEM electrolyzer system to generate 900kg H_2/day with refueling station.
- ***Processes:*** H_2 production via SMR and water electrolysis using renewable energy and purchasing renewable energy credits. H_2 stored on-site for 350-bar fueling stations. FCEBs refuel at these stations and provide transport services within Riverside County.
- ***Feedstock Source:*** Water is sourced from the Coachella Valley Water District (CVWD). Renewable natural gas sourced from swine or dairy waste.
- ***Product Destination:*** H_2 is produced as a fuel to be used in the FCEBs. RNG is used as fuel for compressed natural gas buses and a small SMR unit to produce hydrogen for FCEBs. Buses service the Coachella Valley in Riverside County, California.
- ***Project Stage:*** In operation.
- ***Unknowns and Uncertainties:*** After being in service for 4 years, there is interest to move to a liquid (rather than gaseous) H_2 storage system. The electrolyzer system provider has moved away from smaller electrolyzer installations as there have been many operational challenges in the last few years.

SunLine Transit Sustainability Management and Collaboration

- ***Sustainability Management* Plan**: A sustainability management plan is not in place; however, SunLine incorporates many sustainability practices within their project development as well as their operations.
- **Sustainability Consultant:** None identified.

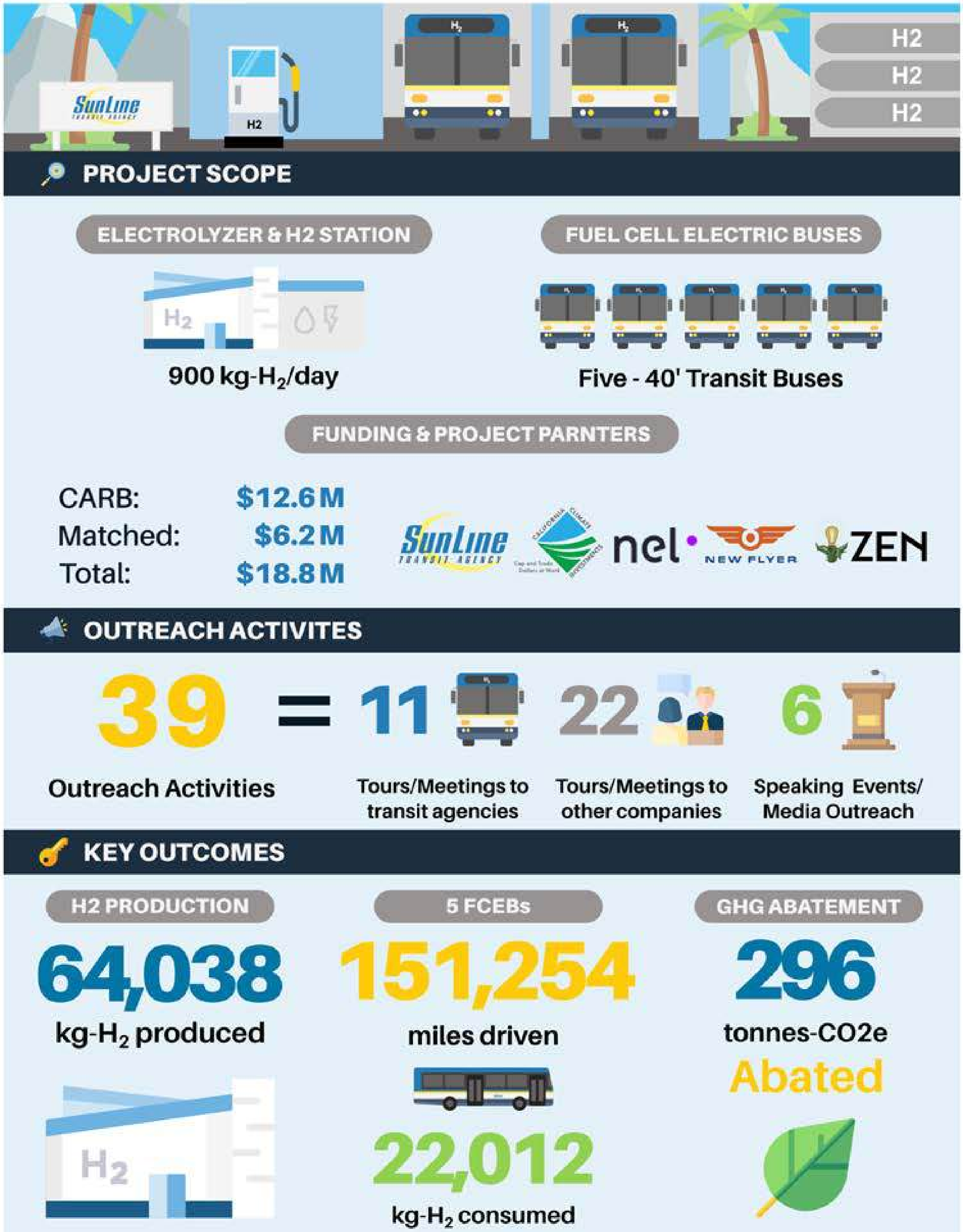

Figure 35. Graphic of SunLine Transit Agency's Fuel Cell Buses & Hydrogen Onsite Regeneration Fueling Station Pilot Commercial Deployment project (SunLine Transit Agency)

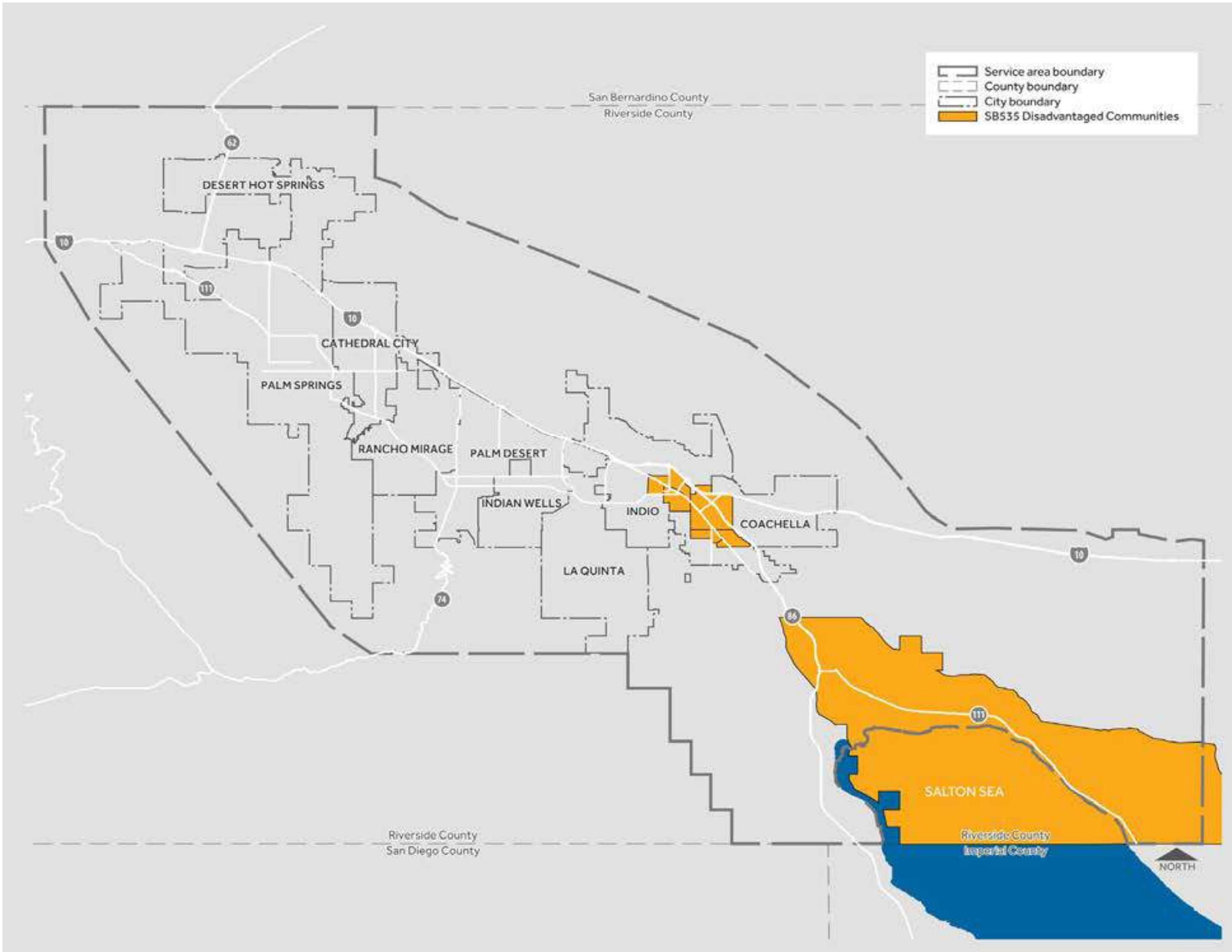

Figure 36. Map of Sunlit Transit Agency's service territory and locations of disadvantaged communities (SunLine Transit Agency)

3.1.2.3 Island Transit Project

Island Transit's fleet replacement is smaller fleet replacement project compared to SEPTA, but it will provide the same environmental and health benefits to its surrounding community. This proposed fleet replacement came as a commitment of Island Transit to the Federal Transit Administration's (FTA) "Sustainable Transit for a Healthy Planet Challenge." Island Transit excelled in evaluating project risks and creating effective resiliency strategies relative to the other fleet replacements investigated in this case study. Though Island Transit addressed and could likely score well for many of the prioritized Envision® credits analyzed in this report, the other project documentation provided a higher level of detail to inform the combined results of this case study and therefore Island Transit may not be mentioned in some of the credits. Although they address the credits very similarly to the other projects, their risk analysis and resiliency framework are the primary highlights for this case study.

Island Transit Project Design and Scope

- ***Description:*** This project is designed to replace the current 19 bus and 13 cutaways diesel fleet with a combination of battery and fuel cell electric buses. Modifications, expansions, and additions to fueling depots will be made as needed to accommodate this transition of the transportation infrastructure.
- ***Boundary and Location:*** Island Transit provides public transportation services to Whidbey and Camano Islands in Washington state.
- ***Project Size:*** This fleet replacement is currently estimated to cost around $6M in vehicle and infrastructure capital expenditures.
- ***Processes:*** Outline the processes involved in the project.
- ***Feedstock Source:*** Current plans will source the hydrogen from a nearby hydrogen producer. An electrolysis facility at East Wenatchee has been identified as a potential candidate.
- ***Product Destination:*** The buses on Whidbey Island currently service 11 different routes across the island.
- ***Project Stage:*** This project is currently in the construction stage and started in 2023. The entire fleet replacement is planned to conclude by 2035.
- ***Unknowns and Uncertainties:*** Island Transit has identified technological robustness, battery performance, supply availability, lack of industry standards, and fire and explosion risks at its main list of unknowns and uncertainties.

Island Transit Sustainability Management and Collaboration

- ***Sustainability Management* Plan**: A sustainability management plan is not in place; however, this fleet transition is part of the Federal Transit Administration's "Sustainable Transit for a Healthy Planet Challenge."
- **Sustainability Consultant:** None identified.

3.1.3 Sustainability Category Assessment

3.1.3.1 Highlights for Quality of Life

Quality of Life

Community Engagement: Extent of community involvement and feedback during the project's design phase. Each project engaged with the community in varying amounts. SunLine conducts outreach in several forms with multiple pathways to provide feedback to SunLine's plans and operations.

Community Impact Assessment: Decreased GHG and air pollutant emissions. Reduced noise levels from the buses. Better economic opportunity in terms of more specialized training.

Addressing equity and social justice: Reduction of noise and emissions in traditionally disadvantaged communities. Fleet changes will be prioritized to happen first in these communities.

Hydrogen Safety and Emergency Response: Hydrogen environmental and fire monitoring. Modification to existing depots for fire safety measures. Overall community and emergency response was not addressed within documentation reviewed.

3.1.3.1.1 QL1.2 Enhance Public Safety

All transit agencies recognize the inherent safety risks that hydrogen storage and fueling stations can pose on its depots and their immediate surroundings. All transit agencies plan to adhere to all safety regulations put into place by the National Fire Protection Agency (NFPA) regarding hydrogen storage, fueling, and bus maintenance. This includes installation of fire walls, flame detection systems, hydrogen gas detection systems, fire suppression systems, and more. SunLine transit also moves beyond what is minimally required by adding electronic equipment on nozzles and additional monitoring systems to prevent leaks or failures throughout the refueling stations and buses. Mechanics continually check equipment and establish new protocols to make these systems safer. These safety systems also extend beyond the boundary of the refueling station and into the community where these buses operate by installing leak detection on buses and bus stops for example.

Asthma, cardiovascular diseases, and other public health issues that arise from air pollution are health risks that can be addressed by these projects. By transitioning to zero-emission buses (ZEBs), SEPTA predicts reducing criterion pollutants (91-95% less NOx and 58-86% less PM2.5) compared to current baseline levels. SunLine calculated the weighted emissions reduction (WER) for NOx, reactive organic gases (ROG), and particulate matter (PM10).

It should be noted that a project can define the boundary to include or exclude the bus fleet. Excluding the bus fleet will reduce the scope of the project. However, if buses are excluded from the boundary of the project, only an Enhanced level of Envison scoring can be achieved. With the bus fleet included in the boundary, the bus routes extending outside of the refueling infrastructure would address the Superior level requirement of demonstrating a net positive impact on health for the host community.

The Conserving level could be reached if the project can show that one community is not disproportionately burdened over another.

Health issues caused by these emissions often disproportionately affect the low-income and minority communities and several of these transit agencies focused operations of ZEBs in disadvantaged communities. SEPTA conducted a Sustainability and Equity analysis to determine where these communities are located. SunLine mapped out several cities and areas where they operate that would benefit the most from ZEBs. Taking another step, transit agencies would need to provide evidence of the prevalence of asthma and cardiovascular diseases in these disadvantaged communities. The EPA’s Environmental Justice Screening and Mapping Tool (EJScreen) could be one source for this data. Additionally, these projects would need to prove that transportation emissions were a contributing factor to these health and safety concerns. Figure *37*, Figure 38, and Figure 39 show maps of traffic proximity, high ozone levels, and asthma within SunLine’s operating area. The city of Indio seems to be the most impacted by traffic, ozone, and asthma, and has disadvantaged communities of whom SunLine plans to service with FCEBs to improve air quality. If these requirements are met, a project could obtain a Restorative level of achievement for this credit and add 20 total points towards their total Envision score.

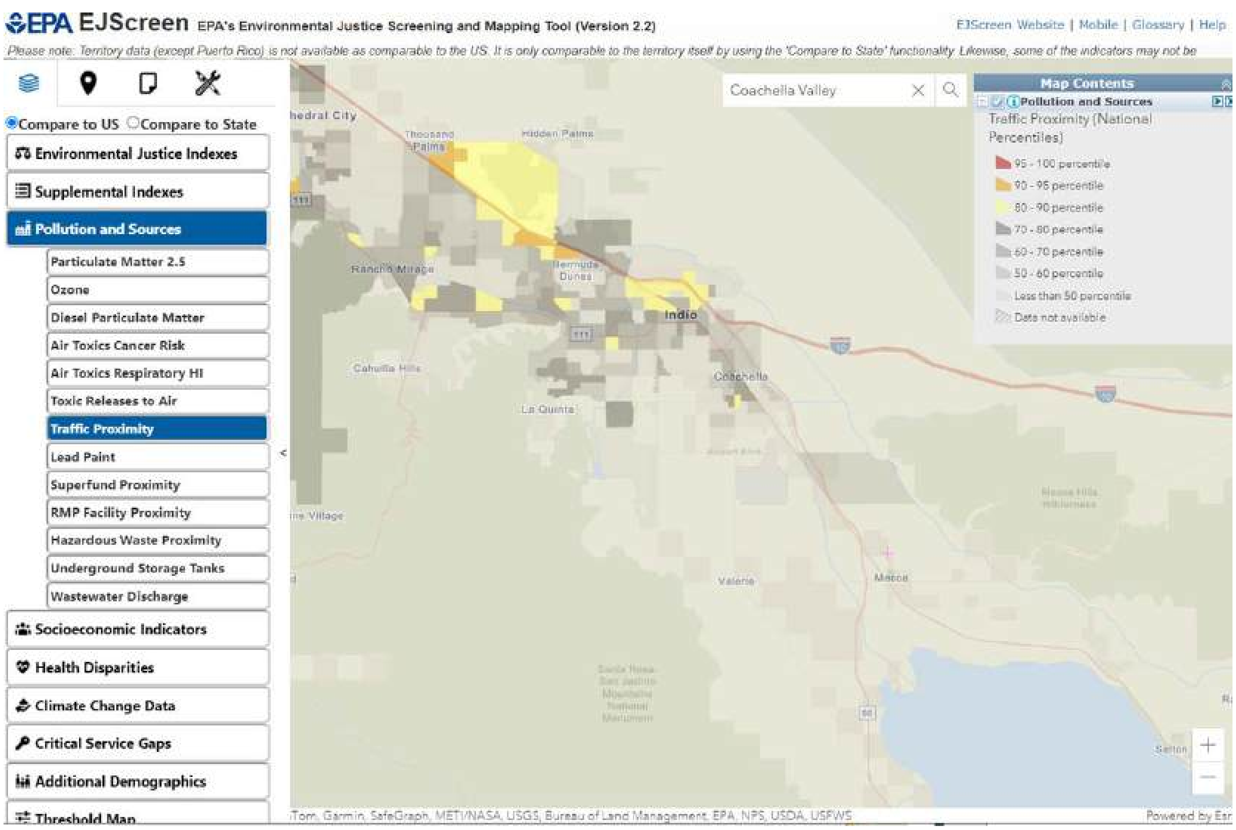

Figure 37. EJ Screen of Coachella Valley mapping Traffic Proximity

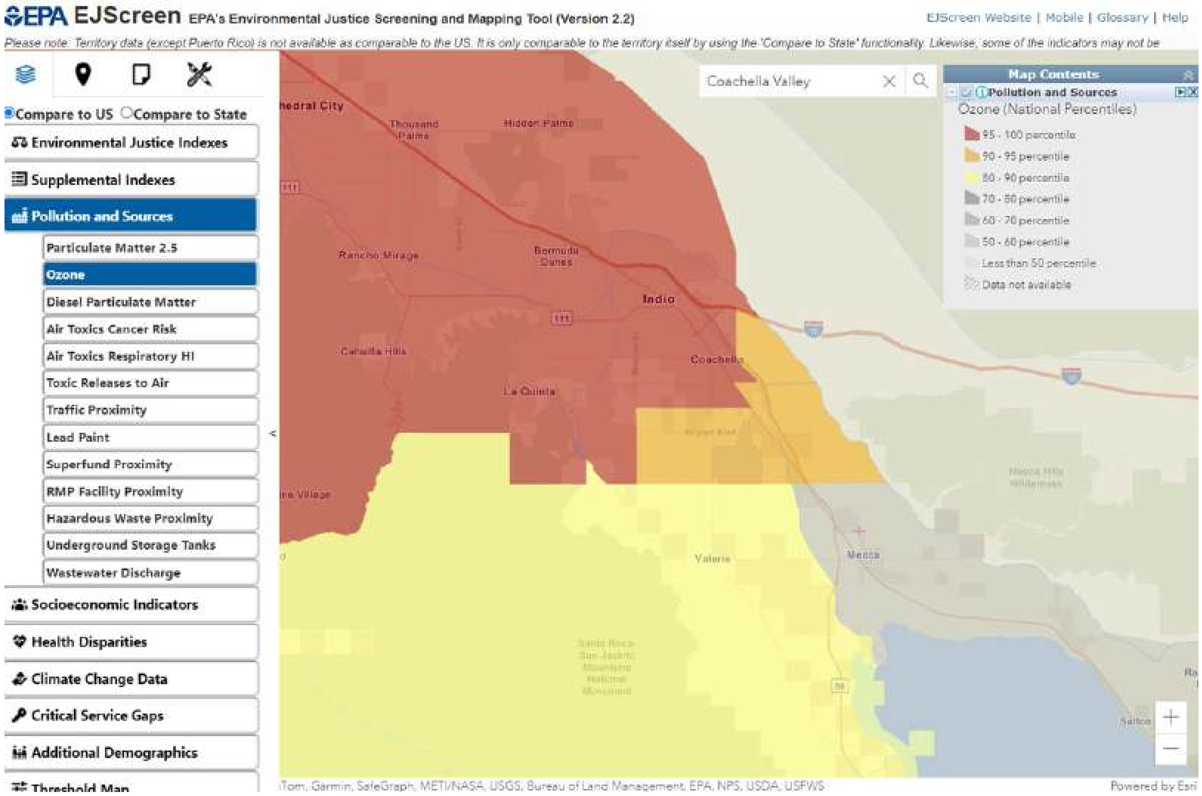

Figure 38. EJ Screen of Coachella Valley mapping Ozone

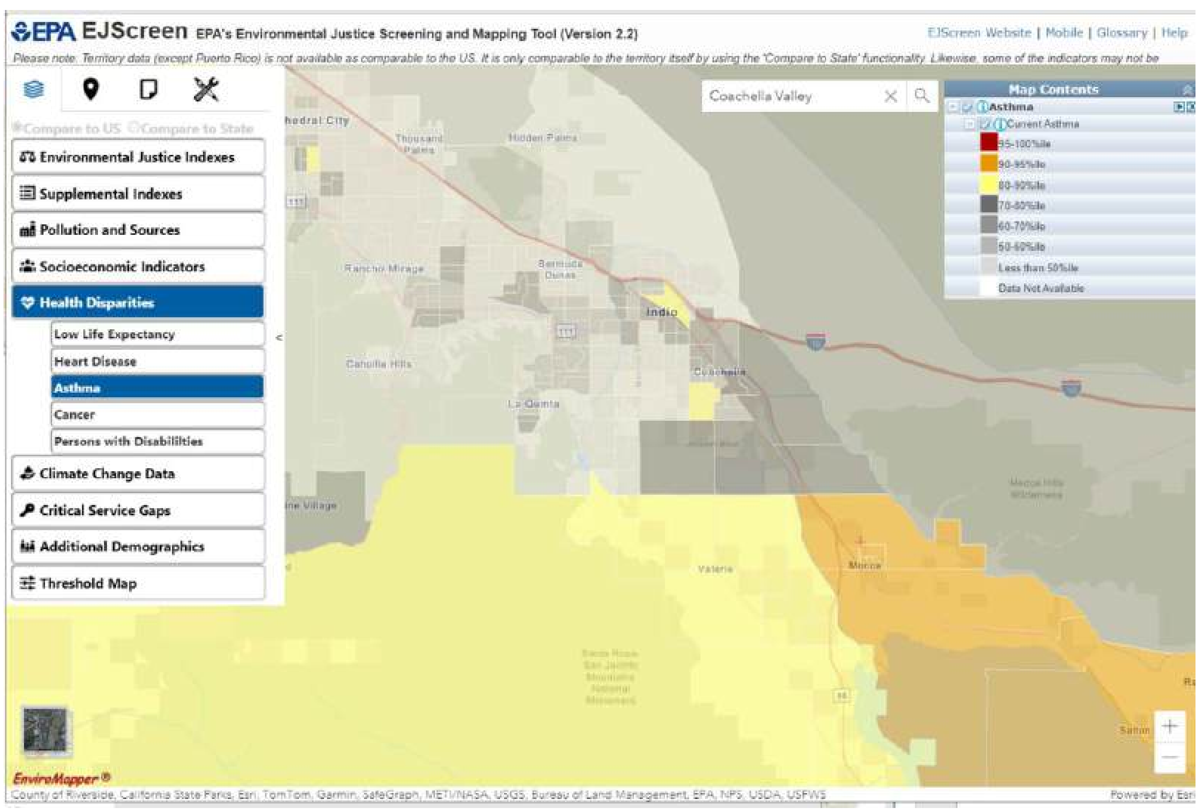

Figure 39. EJ Screen of Coachella Valley mapping Asthma

3.1.3.1.2 QL1.4 Minimize Noise and Vibration

Transit agencies identify reduction in noise as one of the benefits of fleet transitions to ZEBs. As an inherent benefit of their technology, BEB and FCEB are quieter than compressed natural gas (CNG) and significantly quieter than diesel-powered hybrid electric bus fleets and would reduce noise levels relative to existing conditions.

SunLine Transit has commented that liquid H_2 storage can be quieter than compressed gas storage systems. Due to the harsh environment of the site location (high temperatures, flash floods, and windstorms), their electrolyzers are located inside a building. This also helps reduce the noise of pumps and compressors. NG refueling creates more noise than a diesel or liquid H_2 refueling pump, however, trucked-in fuel by diesel trucks would cause more noise and contribute criterion pollutants within the facility and neighborhood. Producing hydrogen on-site can be quieter than trucking in fuel unless the trucks are BEBs or FCEBs. SunLine's refueling stations are near industrial areas that produce significantly more noise than their facility. Noise reduction in service areas is certainly a highlighted benefit to the community.

Transit agencies would need to demonstrate that target noise levels were set and that the broader community and stakeholders were involved in developing these targets. In this instance, the case study projects can expect to reach a level of achievement of Restorative for this credit and receive 12 points towards their total Envision score.

3.1.3.1.3 QL3.1 Advance Equity and Social Justice

The above section on credit QL1.2 outlines that transit agencies are heavily considering equity and social justice in planning and implementation of their fleet change. SEPTA conducted a sustainability and equity analysis to map the impacts and benefits of the communities they serve. However, an important component of this credit requires stakeholder involvement and community engagement in the overall development process of the project. Though SEPTA solicited the input from the broader community in developing its overall sustainability goals (SEPTA, 2016), it is unclear from the Zero-Emission Bus Playbook whether representatives from these disproportionately affected communities have been involved in the project development process. Similarly, SunLine Transit tries to educate the community and has multiple communication pathways for stakeholders to provide feedback. One potential route of engagement could be to collaborate with officials in the disadvantaged communities to determine best practices to alleviate identified impacts to stakeholders. This could be meeting with local health agencies on best practices for mitigating asthma and other health impacts caused by transportation emissions or meeting with rider groups on capping ride fare pricing.

As stated in QL 1.2, benefits and impactors of the project should not disproportionately favor or disfavor any community. Showing that ZEBs being deployed to all service areas would address the benefit of reduced pollutant emissions but the project should also consider whether this would add a significant cost increase to the riders.

If these projects were to address the community's concerns of the project or implement community involvement into the development process, SA believes they could expect to obtain a level of achievement of Conserving or Restorative for this credit and receive 14-18 points towards their total Envision score.

3.1.3.2 *Highlights for Leadership*

Leadership

Life-Cycle Cost Analysis: Most projects perform a life-cycle cost analysis that investigates the capital investment required as well as operational costs. Other environmental and social benefits are often identified, but they are often not monetized and incorporated into the life-cycle cost analysis.

Workforce Education: Transit agencies will have to overhaul its workforce training programs to specifically target mechanics specialized in BEBs and FCEBs. They may also develop apprenticeship programs.

Plan for Sustainable Communities: Many regions are using sustainability to guide development and resiliency plans. Transit agencies are aligning with those plans to better serve the communities in which they operate.

3.1.3.2.1 LD1.3 Provide for Stakeholder Involvement

In reviewing these case study projects, none of the documents specifically address or highlight any community involvement or stakeholder engagement they have conducted other than a broadcasting of information about the project. There are examples of SEPTA engaging the broader community while developing its sustainability management plan (SEPTA, 2016). However, this seems to be a one-off occurrence as opposed to a consistent dialogue between SEPTA, relevant stakeholders, and the broader community. For this credit, transit agencies would have to engage stakeholders and identify their relevant concerns to formulate a structured platform to actively involve them in the decision-making process. Projects would then need to allow stakeholder input to actively influence the outcomes of the project design while also soliciting feedback on how they can improve their overall stakeholder engagement process. If projects were to implement these stakeholder engagement strategies, they could reach a level of achievement of Conserving and add 14 points to their total score. To reach Restorative, the project would have to identify stakeholders to engage as partners on the project.

3.1.3.2.2 LD1.4 Pursue Byproduct Synergies

SEPTA has not detailed any plans to incorporate external waste streams or to find meaningful uses of their wastes during construction or operation of this project. SunLine Transit uses renewable natural gas (derived from waste streams of swine or dairy feed lots) for both their CNG buses and in a small on-site SMR unit to produce hydrogen. Similarl to SEPTA, SunLine has not determined any meaningful use of waste. However, the projects could find a potential reuse for their current fleet of diesel or CNG buses. This could be accomplished through reusing them in another transport application (secondary life) with less stringent operation. If these older buses were repurposed at an external facility instead of going to a landfill, these projects could potentially reach a level of achievement of Enhanced or Superior and score 6-12 points towards their overall Envision score. SunLine's use of renewable natural gas for fuel for CNG and used in SMR to make hydrogen for FCEBs is a long-term by-product reuse that could achieve a Conserving level adding 14 points to the score.

In general, construction waste could also be a byproduct used at an external facility, although many of these refueling station retrofit projects do not have significant construction waste. This credit also includes excess resources such as land, financial resources, and personnel. If these internal resources can be reused external to the project, it could be considered a “reuse” case in the credit.

3.1.3.2.3 LD2.2 Plan for Sustainable Communities

Transit agencies have identified multiple sustainability outcomes they wish to address with their bus fleet transition including lower GHG emissions, lower air pollution emissions, and improving infrastructure services for disadvantaged communities.

SEPTA’s playbook walks through potential projects scenarios which include a no-build option, an entirely new BEB fleet, and a hybrid BEB and FCEB fleet. The latter two are sustainable modifications to their fleet that they plan to pursue. SEPTA has identified how their transportation services impact the broader community and developed sustainability goals that account for how the community’s needs will change in the future (SEPTA, 2017). Their proposed bus fleet transition is an essential component to upholding the goals set within this broader sustainability management plan. In fact, the City of Philadelphia’s 2021 Transit Plan: A Vision for 2045 specifically states, “The City recommends that SEPTA electrify its bus fleet, primarily through the adoption of battery-electric buses (BEBs)” (City of Philadelphia, 2021). Their transition to BEBs and FCEBs will lower GHG emissions and air pollution, actively addressing an inherently unsustainable consequence of using diesel-powered buses in their current fleet.

In addition to addressing GHG emissions, lower air pollution, and improving services for disadvantaged communities, SunLine Transit also considered growth patterns, road congestion, and the source of their power and water supplies. They are committed to clean transportation within all the cities they operate. They interact with the Palm Springs Green Sustainability Commission and discuss issues relating to energy and natural resources conservation, educational programs and natural resource issues including water conservation, air pollution, waste management and recycling.

If transit agencies can show their project has direct alignment with the region’s sustainability goals and addresses an inherently unsustainable condition within the community, a score of Restorative with 16 points could be achieved for this credit.

3.1.3.2.4 LD3.2 Develop Local Skills and Capabilities

Transit agencies recognize that the technologies used in BEBs and FCEBs will require their mechanics to develop new skills from the ones used to maintain and repair their current diesel fleet or CNG fleet. They plan to overhaul current mechanic training programs to tailor their skillset to meet this transition. SEPTA is also making plans to put an apprenticeship program in place for BEB and FCEB mechanics. These new training and apprenticeship programs will continue throughout the lifetime of the project. SunLine Transit is also working with the California Transit Training Consortium to build up training programs for zero emissions vehicles. These skills will likely be transferable beyond the specific projects as the BEB and FCEB markets are poised to continue growing in the coming years. Many skills required to build and operate compressed gas refueling stations apply to both hydrogen and CNG stations such as compressors and dispensers with similar designs. SunLine's electrolyzer is operated by the electrolyzer company, but SunLine also trains an operator to work with them. SunLine operates in several disadvantaged communities and targets training in those communities where there are a large number of mechanics. Island Transit listed workforce skill gaps and training needed by each workforce group for hydrogen fuel cell systems. They also consider partnering with a university or school to help develop curriculum applicable to hydrogen fuel cell technology.

It is not clear if skill gaps, and their proposed training programs, will be informed by local or state workforce development agencies. If the transit agencies allow these workforce development agencies to aid in the development of their training programs, they can expect to reach a level of achievement of Conserving for this credit and receive 12 points towards their overall Envision score. Additionally, if they were to target their training programs to economically disadvantage groups, they could reach a level of Restorative and add an additional 4 points towards their score.

3.1.3.2.5 LD3.3 Conduct a Life-Cycle Economic Evaluation

All project conducted a life-cycle economic evaluation. SEPTA performed an economic evaluation for four major design decisions they evaluated during the project design process. These evaluations looked at capital costs such as vehicle purchases, facility upgrades, and new equipment as well as operating costs such as fuel and maintenance upon completion of the fleet transition. A diagram summarizing an economic evaluation for SEPTA's Southern Division is provided below in Figure 40. SEPTA also quantified social and environmental benefits in the form of aiding disadvantaged communities, reducing emissions, and potentially utilizing more renewable energy. SunLine conducted life-cycle economic evaluation for the buses and refueling stations. The electrolyzer economic evaluation is conducted by the electrolyzer operator to determine whether SunLine keeps the electrolyzer system. SunLine focused on GHG and air pollutant emissions reductions and showed the GHG and CAC cost effectiveness of diesel or CNG buses with FCEBs over a 2- and 10-year timeline in $/ton-GHG or $/ton-CAC. This does not exactly monetize the impacts/benefits of reduced emissions; however, it allows SunLine to compare the effectiveness of the investment of different technologies.

The current state of their life-cycle economic evaluations would earn these transit agencies a level of achievement of Superior, giving them 10 points towards their total Envision score. To enhance their score, they would have to quantify other benefits or impacts their fleet change would bring to the environment and surrounding community. To further improve their score, they would have to monetize these other costs and benefits they have identified for each of the design options and chose a design that provides a net positive present value when including these additional social and environmental concerns. This would bring a transit agency's level of achievement up to Restorative.

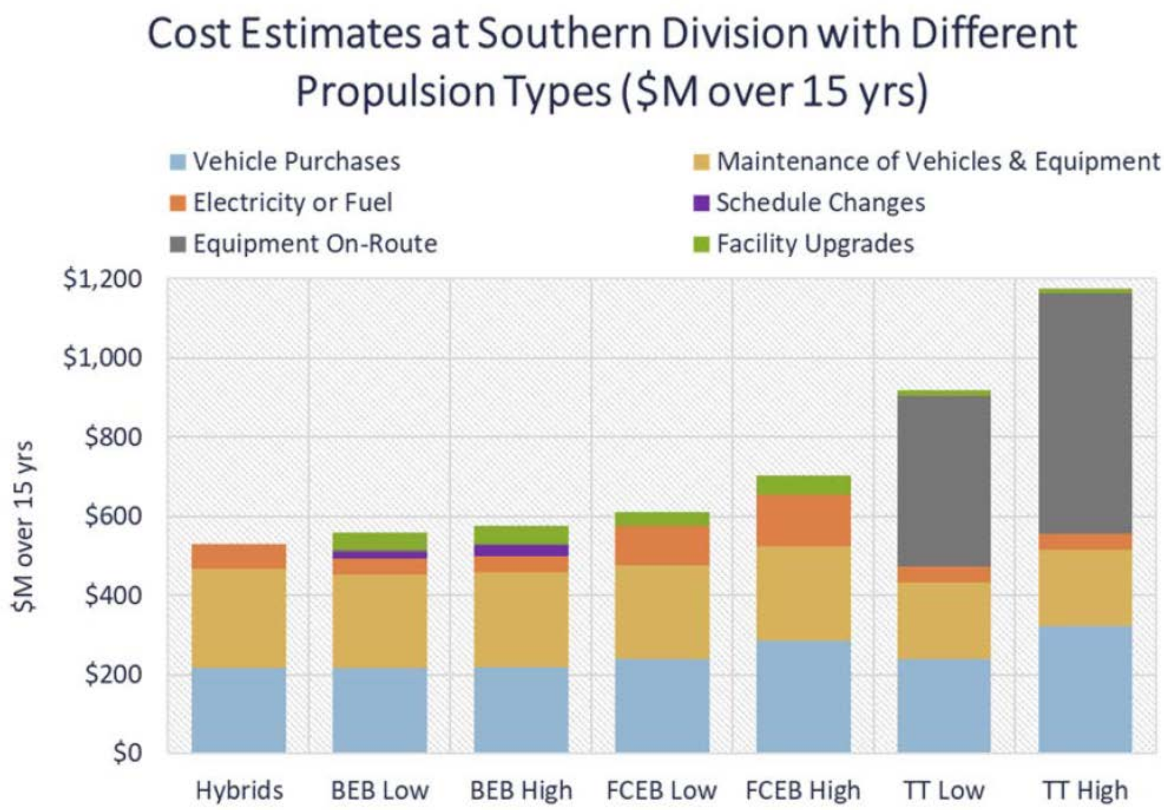

Figure 40. Example Summary of a Life Cycle Economic Evaluation for SEPTA's Southern Division where TT stands for Trackless Trolley (SEPTA, 2022)

3.1.3.3 Highlights for Resource Allocation

Resource Allocation

Renewable Energy Integration: SEPTA will be using renewable energy in the form of hydrogen fuel for its FCEB fleet.

Resource Recovery & Utilization: SEPTA currently has not provided any examples of how excess resources and wastes will be utilized elsewhere.

Water Consumption Assessment: Water consumption and its effects on local water systems and watersheds not addressed in the current documentation.

3.1.3.3.1 RA2.1 Reduce Operational Energy Consumption

SEPTA does not explicitly estimate how much yearly energy they consume with their current diesel-powered hybrid electric bus fleet nor do they provide any predictions on how much a 4:1 FCEB to BEB fleet would consume. However, SEPTA provides enough parameters to estimate the yearly energy consumption for both cases. SEPTA claims that their diesel-powered hybrid electric bus fleet has an average fuel efficiency of 3.67 mi/gal$_{diesel}$ while an FCEB averages 7.17 mi/kgH_2. The BEB are assumed to have an average energy consumption rate of 4.15 kWh/mile throughout their lifetime. SEPTA also estimates that their average bus travels 32,000 mi/year. SEPTA predicts that they will require around 5 additional buses to operate under a mixed FCEB and BEB fleet. With these parameters the yearly energy consumption for both scenarios can be estimated with the diesel-powered hybrid electric bus fleet taken as the base case. The results of these estimates are summarized below in Table 1**.**

Based on these estimates, SEPTA can potentially expect to reduce operational energy consumption from 1,767 TJ/Year to 737 TJ/Year, a 66% reduction. A Similar calculation was conducted for SunLine and if there is a 1:1 replacement of CNG buses with FCEBs, SunLine would expect to reduce energy usage by 55%. This accounts for only the fuel usage and not the operation of the refueling station or hydrogen production from PEM electrolyzer. SunLine would have to compare the hydrogen production unit with the previously installed SMR system, or an alternative electrolysis technology considered (alkaline or solid oxide electrolysis). The energy for compression of NG or H_2 can be similar with CNG at 200-bar and H_2 at 350-bar, but higher pressures would require additional electrical loads. Liquid H_2 pumps would require less electrical loads than compressed H_2 during operation. A full evaluation would have to be conducted to determine the total energy reduction for the system.

Transit agencies could likely reach a level of achievement of Superior for this credit and receive 18 points towards their total Envision score. It should be noted that these fuel usage calculations do not account for differences in fueling mechanisms and their potential energy consumption as well as other energy consumption from hydrogen liquefaction, losses during charging, various auxiliary equipment, etc. Given these considerations, it is possible that reduction in energy consumption could be less than 50%, knocking their level of achievement down to Enhanced.

Table 1. Estimate of Yearly Energy Consumption for SEPTA Fleet Replacement Scenarios

Parameter	Units	Diesel	FCEB	BEB
Average Fuel Efficiency	Various	1.14[a] Miles/kg$_{diesel}$	7.17 Miles/kg$_{H2}$	4.15 kWh/Mile
Average Distance Traveled per Bus	mile/bus/year	32,000	32,000	32,000
Number of Buses	Bus	1,400	1,124	281
Fuel Energy Density	MJ/kg	45	120	N/A
Yearly Energy Consumption	TJ/Year	1,767	602	134

[a] Value determined assuming the density of diesel is 850 kg/m^3

3.1.3.3.2 RA2.3 Use Renewable Energy

Several projects incorporate renewable energy into the project design. SEPTA's proposed fleet replacement will rely heavily on renewable energy sources to meet their consumers' transportation needs. Under the guidelines of this credit, both BEBs and FCEBs would qualify as uses of renewable energy. SEPTA does not provide documentation on the amount of energy their fueling depot facilities use per year; however, this value can be estimated for heating, cooling, lights, auxiliary fueling equipment, etc. but excluding vehicle fuel-related consumption. Based on data from the Energy Information Agency (EIA), a commercial space dedicated to vehicle storage or maintenance consumes energy at a yearly rate[80] of 7.2 kWh/sq. ft. (Commercial Building Energy Consumption Survey, 2016) SEPTA's depots currently have a total floor space of 1.36 million sq. ft which translates to a yearly depot energy consumption of 1.4 million kWh/year or 35.4 TJ/year. Based on the estimates provided in Table 1, SEPTA can expect to have a total yearly energy consumption of 772 TJ/year with 95% of that coming from their proposed FCEB and BEB fleet.

SunLine produces H_2 on-site with the PEM electrolyzer system fed by both solar (covering 869 MWh of BOP energy consumption) and grid electricity (covering 4,982 MWh/year of electrolyzer energy consumption). The grid electricity is offset from purchased renewable energy credits (covering 2,203 MWh/year of energy). Assuming only the FCEBs as part of the updates within the project, they are considered renewable energy (consuming 2,126 MWh/year of energy). This equates to 6.6 TJ/year of renewable energy out of 7.9 TJ/year total energy consumption, covering roughly 83% of total energy consumption. A more detailed analysis would be needed to include refueling station operational energy consumption.

Given these estimates, transit agencies can expect to reach a level of achievement of Conserving for this credit and receive 20 points towards their total Envision score. As in previous credits, the buses can only count toward renewable energy consumption if they are included within the boundary of the project. If H_2 is produced on-site, use of renewable electricity, renewable energy credits, or biogas to produce the H_2 could count toward the use of renewables. The H_2 fuel generated cannot be double counted as fuel used within FCEBs. If H_2 is delivered to the refueling station, it can be considered a renewable energy source regardless of how the H_2 was generated, although it is recommended that low-carbon Hydrogen be sourced.

3.1.3.3.3 RA3.2 Reduce Operational Water Consumption

Operational water consumption was not addressed in the transit agencies' fleet transition plans/projects documentation. Neither diesel-powered hybrid electric buses nor ZEBs require water to operate. There will likely be no reduction in operational water consumption if only trucking-in hydrogen and not producing H_2 on-site. Although little was mentioned on water consumption within SunLine's document, they required 14.32L of water consumption per kg of H_2 generated. The electrolyzer would be the only source of water consumption and would have to be compared to the previously used SMR system that may have used less water. Not enough information was provided in documentation to address this credit; however, H_2 production projects should consider using greywater, recycled water, or stormwater to meet water needs. Electrolyzers in general need higher purity water and include filtration systems. Modifying these filtration systems to use non-potable water should be considered and discussed with electrolyzer equipment providers.

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[80] This is an admittedly crude approximate as building energy consumption can vary considerably by geographic location.

3.1.3.4 Highlights for Natural World

Natural World

Location Appeal: The locations of these projects are or will be built on existing facilities. Although not a prioritized credit, NW 1.4 Preserve Undeveloped Land would capture this reuse of facilities.

Land Use History: Transit agencies will be reusing previous depots and land already dedicated to its current bus fleets. They may need to make some additions or expand the current depots and construct another. In this instance they would be replacing urban landscape with a new industrial facility.

Environmental Assessments: No environmental assessment mentioned in the documentation

3.1.3.4.1 NW.2.4 Protect Surface and Groundwater Quality

Reviewed documentation excludes any plan to address surface and groundwater quality concerns during construction and maintenance of their modified bus depots. During design and construction, transit agencies should consider any pathways that could potentially impact groundwater quality to devise solutions to actively avoid contamination and monitor groundwater conditions in real time. An example pathway could be oil from bus maintenance operations. If transit agencies can assess potential pathways and prevent the creation of any new direct contamination pathways, they can expect to achieve an Enhanced level and receive 5 points towards their score.

3.1.3.5 Highlights for Climate and Resilience

Climate and Resilience

Climate Change Vulnerability: Project-specific locations are impacted differently. SunLine already sees temperature highs of 120°C and occasional flooding. Storms will likely increase in severity in coming years. Similarly in Pennsylvania, according to the Commonwealth of Pennsylvania, the state will be faced with worsened air quality, increased damage from flooding, agricultural losses, and expansion of vector-borne diseases like Lyme Disease. (Protection, 2021)

Risk Assessment: Risk assessments are performed for every project; however, the extent of assessment boundary could expand beyond project borders.

Greenhouse Gas Emissions: Given the investment for ZEBs is to reduce GHG emissions, all transit agencies estimate a reduction of ~50-95% from current levels depending on operation and ZEB technology mix.

Infrastructure Integration: Infrastructure integration was not always mentioned within documentation. ZEBs do consider expansion of service areas to connected transportation (airports and train stations). Additionally, SunLine considers plans to provide public refueling for light-duty vehicles and heavy-duty Class 8 trucks, offering 350- and 700-bar refueling options.

3.1.3.5.1 CR1.2 Reduce Greenhouse Gas Emissions

Every transit agency considering fleet transitions to ZEBs are estimating GHG emissions. SEPTA estimates that if they transition to an entirely FCEB fleet, their total operational GHG emissions reduce by 53-91%, depending on if they source gray or green hydrogen to fuel their buses. Similarly, SunLine estimated 57-80% depending on operational uptime. Island Transit estimated 67-97% emissions reduction depending on whether grey or green hydrogen is used. In all case, this would lead to a level of achievement of Superior for this credit and award them 18 points towards their total Envision score. To reach Conserving, fleets should consider using H_2 from renewable sources and can plant trees to move beyond 100% reduction achieving carbon negative.

3.1.3.5.2 CR1.3 Reduce Air Pollutant Emissions

Similar to CR 1.2, reducing air pollutant emissions is certainly addressed by all transit agencies transitioning to ZEBs. SEPTA estimates that if they transition to a 4:1 FCEB to BEB fleet, they will reduce NOx emissions by 91-95% and $PM_{2.5}$ emissions by 58-86%. Though not directly stated in the documentation, transit agencies acknowledged that the health and safety of riders and operators is very important and regular emission testing is part of their standard fleet operation. The projects assessed for this case study would score at a level of Enhanced for this credit and get 4 points. Although fuel cell systems within FCEBs would not emit VOCs, an analysis would have to be conducted on the full system to ensure no VOCs would be produced as a result of these projects. These VOC emission levels would have to be compared to a similar hydrogen project and the project would need to implement strategies to reduce their use. If projects could implement a full transition to FCEB using renewable-derived hydrogen, emissions could be eliminated from the system and projects could reach a Restorative level of achievement.

3.1.3.5.3 CR2.3 Evaluate Risk and Resilience

Island Transit conducted an analysis to determine the primary areas of risk and uncertainty within the project. This analysis determined that technological robustness, battery performance, reliance on wayside fueling infrastructure, and fire and explosion hazards were the primary risks within the project scope. They also analyzed other risks of associated infrastructure and supply systems and determined that vehicle and fuel supply availability and lack of industry standards were other potential threats to the project's success. Additional risks that may have been considered are natural hazards like damage due to weather. The analysis also describes the impacts these risks can have on the potential function and success of the project. The analysis qualitatively describes the probabilities of each of these different risks, but having probabilistic values would bolster their application for this credit as well as classifying consequences or impacts as social, environmental, or economic. If stronger probability measures can be provided, Island Transit could expect to reach a level of achievement of Enhanced for this credit and receive 18 points towards their Envision score. This project could reach a level of conserving if they expanded their risk analysis to include the connected infrastructure system and the broader community and provided evidence of stakeholder involvement in the evaluation process.

3.1.3.5.4 CR2.4 Establish Resilience Goals and Strategies

Based on the risk analysis mentioned above, Island transit has determined a variety of risk reduction plans and strategies to improve the overall resilience of the project. One strategy is to have the bus vendors keep a technician nearby that can aid in troubleshooting when issues with the bus technology and propulsion system arise. A second strategy is the adoption of a "back-up" fleet either by reaching an agreement with another nearby transit system to supply buses in emergencies or by having a few diesel buses in backup storage. A third strategy is to include contingency or backup fueling and charging solutions in the case of depot shutdown. This set of resiliency goals and strategies would likely give Island Transit a level of achievement of Enhanced and add 8 points to their total Envision score. To reach the level of Conserving, the bus agency would need to involve stakeholders in further developing their strategies and share their plan of action with the community.

3.1.3.5.5 CR2.5 Maximize Resilience

Based on the above two credits, Island Transit has conducted a risk analysis for their fleet transition and developed a set of resiliency strategies to enhance project robustness. If the project team can document that these plans were implemented into the actual project design, the team can reach a level of achievement of Improved for this credit, earning them 11 points. To improve the score, a transit agency would need to develop plans to continually monitor their strategies during project operation and make improvements when deemed necessary. Additionally, transit agencies should determine a way to quantify the benefits as monetary savings to the project by implementing these strategies. For example, if one of the strategies is to purchase back-up buses for emergencies, a cost analysis could determine the monetary spending for extra buses and compare that to loss of service and future impact to rider trust. If a transit agency can do this for all strategies, it could obtain a level of Conserving for this credit and add an additional 15 points towards their total score.

3.1.3.5.6 CR2.6 Improve Infrastructure Integration

Minor levels of integration were mentioned within documentation. Internal integration is achieved through diversified bus technologies (CNG, BEB, or FCEB). Connected transit agencies sharing buses for emergency situations helps to reduce the risk of loss-of-service. Transit agencies have the potential to easily implement design changes to make systems more integrated within larger infrastructure systems and have mentioned future plans that would achieve this. One idea is connection to H_2 Hubs where hydrogen can be produced by multiple suppliers to guarantee delivery of hydrogen. Another idea is to extend the range of the bus fleet to include new routes to other forms of transportation infrastructure such as new routes to local train stations or the airport. If these ideas were implemented, transit agencies could achieve a Superior level and receive 9 points. To reach a Conserving level, the integrated network would expand beyond transportation. For hydrogen production on-site using electrolysis, integration with power service providers or water treatment facilities could be a way of expanding integration. System integration goes beyond physical connections and could be in the form of benefits programs or system arrangements. This element is quite unique to each location and may be limited by availability or participation by other networks. To achieve a Restorative level, projects must incorporate monitoring and reporting for the integrated systems and networks to maintain efficiency and resiliency. Monitoring refueling stations and reporting failures to HyCreD could lead to improved codes and standards and risk assessments in future refueling station projects.

3.1.4 Conclusions and Recommendations: Refueling Stations for Fuel Cell Electric Buses

The bus fleet replacement projects assessed in this case study would potentially score quite well for the H_2-prioritized credits within the Envision framework. The fleet transitions are currently predicted to score somewhere between 168-236 points of the possible 358 from the H_2-prioritized list of credits. A summary of the prioritized credits, the range of level of achievement from the case study documentation, and recommendations for achieving a higher score are summarized in Table 2 below.

Table 2. Matrix of Envision Level of Achievement for the FCEB Refueling Station

Level of Achievement								
Credit	**None**	**Improved**	**Enhanced**	**Superior**	**Conserving**	**Restorative**	**Score Range**	**Recommendations for Achieving a High Score**
QL1.2				X		X	12 - 20	Document and prove that public transportation emissions are a direct threat to public health and safety to demonstrate community benefits from reduced emissions.
QL1.4		X				X	1-12	Develop target noise levels with broader community and stakeholders and demonstrate those target noise levels were met.
QL3.1			X			X	6 - 18	Collaborate with representatives in disadvantaged communities to determine best practice for mitigating impacts from the project.
LD1.3		X				X	3 - 14	Stakeholder mapping and develop stakeholder engagement process.
LD1.4				X	X		12 - 14	Find meaningful reuse for buses and/or components from the previous fleet.
LD2.2					X	X	12 - 16	Demonstrate contribution to regional sustainable development goals and address an inherently unsustainable condition in the community.
LD3.2					X	X	12 - 16	Improve current programs by working with local workforce development agencies and targeting disadvantaged groups.
LD3.3				X			10	Extend economic evaluation to quantify and monetize external benefits of the project.
RA2.1			X	X			12 - 18	Ensure energy efficiency in operation of hydrogen production, liquefaction system, and auxiliary hydrogen fueling equipment.
RA2.3					X		20	Generate more renewable energy than operationally required.

	Level of Achievement							
Credit	None	Improved	Enhanced	Superior	Conserving	Restorative	Score Range	Recommendations for Achieving a High Score
RA3.2	X						0	Consider using greywater, recycled water, or stormwater instead of potable water.
NW2.4	X		X				0 - 5	Determine leak pathways, avoid groundwater contamination pathways, and install active monitoring
CR1.2				X			18	Incorporate additional activities to reduce emissions such as planting trees.
CR1.3			X	X			4-9	Assess VOC emissions and consider transitioning all buses to FCEB using renewable-derived hydrogen.
CR2.3			X				18	Extend risk analysis to include connected infrastructure systems and the community.
CR2.4			X				8	Involve stakeholders in risk management strategy development and share findings with broader community.
CR2.5		X					11	Regularly monitor and improve resiliency strategies and quantify benefits of the strategies
CR2.6				X			9	Expand integration to other networks (i.e., water reclamation or power service providers) and incorporate monitoring and reporting.
Total							168 - 236	N/A

The maximum score of all the projects for each category was taken as a percentage of the total points possible for that category, graphed in Figure 41 below. Keep in mind that these assessments were conducted for projects that had finalized plans and were not considering addressing Envision credits specifically. The dark blue Case Studies - Max line is the summation of the max points for the credits in that category, listed in Table 2. The light blue Case Studies - Min dashed line is the summation of the minimum points for the credits in that category. The potential line (orange) is a general FCEB and refueling station project potential score or likely score if projects were to implement all recommendations. To meet 100% of the category points, the projects would have to obtain the highest level of achievement possible (and would appear as a line along the outer edge of the spider chart). This scoring does not represent a full Envision score as these results consider only the H_2-prioritized credits. A complete Envision score would include the remaining 46 credits (not evaluated in this study).

Quality of Life H_2-prioritized credits are easily addressed for this type of project as all projects scored high on these credits without trying to incorporate Envision. Transit agencies can have a significant impact on community health, safety, and social justice. These types of projects are able to address these concerns that are similar in many communities.

Leadership credits may require more planning to implement and achieve a higher score, although the authors believe these projects could potentially score well in this category. Projects already engage with stakeholders, align with local sustainability goals, address gaps in local skills and educational needs for development and operation, and conduct life-cycle-cost analyses. There are a few extra steps within each credit that could help improve scoring.

Resource Allocation credits, in some cases, required more detailed information to assess that was not always available in reports and thus the authors attempted to estimate simplified values for these credits. The authors anticipate that the scores of these credits could increase with more sufficient information and if systems were designed to be more efficient with sustainable resources.

RA 3.2 and NW 2.4 focus on water consumption and protecting water quality, respectively. Refueling stations without hydrogen production may not have a significant use of water and do not document water usage or water quality within the reviewed reports. For these credits, the authors assumed zero points, but each project may be able to address these credits in some form. Projects should also consider non-applicability if there is no water usage or water contamination within the project. The reason for **Natural World** having a 0% score is because there is only the one credit in that category and protecting surface or groundwater quality was not mentioned in the reports for these case studies.

The greatest opportunity of improvement for transit agencies implementing fleet transitions to FCEBs lies in the **Climate and Resilience** category. As mentioned in the Table 2, expanding risk assessments beyond the project, having external reviewers of the strategies to reduce risk, and including regular monitoring and quantifying benefits of the strategies could help improve scores from 50 to 100%.

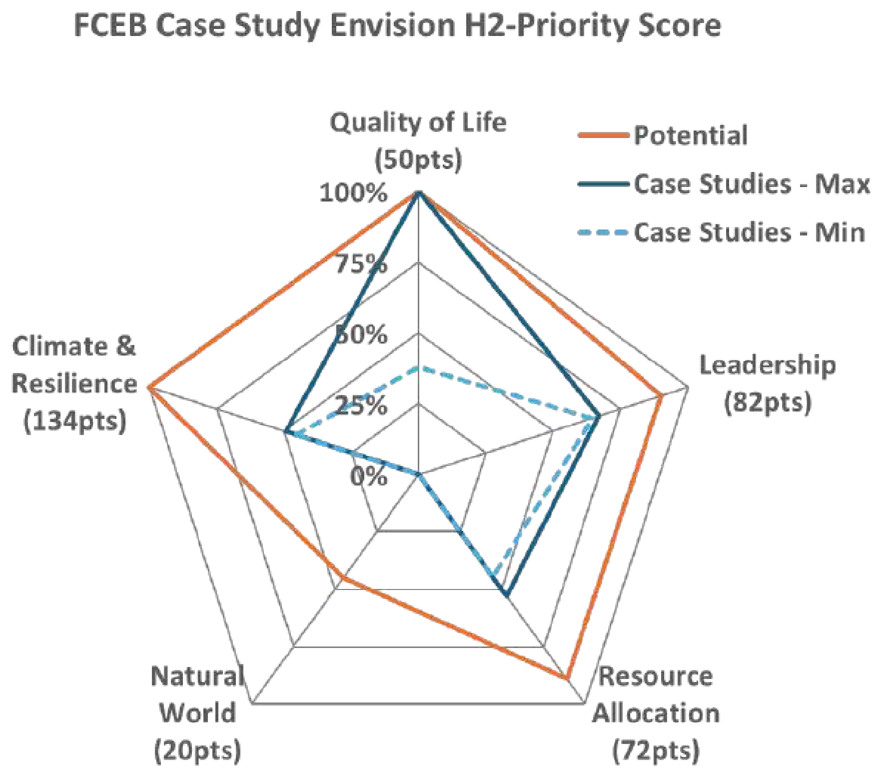

Figure 41. Spider chart of Envision H_2-priority credit scoring for FCEBs

3.1.5 References: Refueling Stations for Fuel Cell Electric Buses

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3.2 Tri-Generation Systems for Hydrogen Production

Projects Included in Case Study:

Port of Long Beach Tri-Generation Plant
Long Beach, California
Hydrogen Tri-Generation Facility

Orange County Sanitation District Tri-Generation Plant
Fountain Valley, California
Hydrogen Tri-Generation Facility

3.2.1 Case Study Summary: Tri-Generation Systems

The aim of this case study is to determine how well a hydrogen tri-generation system would score on a prioritized list of Envision® credits. This case study is a composite investigation of the recently completed tri-generation system at the Port of Long Beach in California and a long-standing tri-generation system installed at a wastewater treatment facility operated by Orange County Sanitation District (OCSD). The Port of Long Beach tri-generation system was commissioned by Toyota to provide hydrogen, power, and water to the Toyota Logistics Services' vehicle processing and distribution center at the port. The Orange County tri-generation facility was a project headed by Air Products to determine the feasibility of co-producing hydrogen, electricity, and heat.

Both tri-generation systems rely on FuelCell Energy's molten carbonate fuel cell technology (MCFC) to generate their respective three product streams. The Port of Long Beach system utilizes biogas to generate 2.35 MW of electrical power, 1,270kg H_2/day, and 5,300 liters of water per day. The biogas is generated via an anaerobic digestor that will use waste streams as its input. The electrical power is used for Toyota's local operations at the port and any excess is sold to Southern California Edison. The hydrogen is used to fuel Toyota's imported light-duty fuel cell electric vehicles (FCEV) as well as fuel cell drayage trucks used at the port. The water is used for Toyota's vehicle washing and maintenance operations at the port. Construction of this project recently concluded, and the system came online in late 2023.

The Orange County tri-generation system also used biogas as a feedstock that was generated via an anaerobic digester that processed waste from one of OCSD's wastewater treatment facilities. This tri-generation system was designed to generate 250kW of electrical power, 100kg H_2/day, and low-grade waste heat. The generated electricity was exported to the local grid while the hydrogen was utilized in a hydrogen refueling station that was also installed at the OCSD facility as part of this project. The heat generate by the tri-gen system was used within the anaerobic digester. This demonstration project began its initial designs in 2001 with the plant officially opening in the latter half of 2011 and ceased operations in 2014.

Overall, these types of projects have the potential to score particularly well in the categories of Resource Allocation and Climate & Resilience. This stems from their utilization of renewable feedstocks to fuel their hydrogen production processes leading to lower greenhouse gas (GHG) emissions relative to traditional hydrogen production pathways such as steam methane reforming (SMR). Additionally, the MCFC technology does not require water for its production process, conserving this valuable resource for more critical uses in the surrounding community. The simultaneous production of valuable product streams lends these projects to easily integrate with other infrastructure systems. This enhances the overall robustness and performance of outside infrastructure systems in the communities these projects operate. The main area for improvement in these projects is related to Quality of Life credits. Focusing more on enhancing public safety, promoting social equity, and engaging directly with stakeholders would significantly help mitigate the project impacts on surrounding communities. Additionally, providing citable evidence and documentation of actions taken to address these impacts would be beneficial for potential project reviewers.

3.2.2 Project Introduction, Definition, and Background

3.2.2.1 Port of Long Beach Tri-Generation System

The Port of Long Beach Tri-Generation system utilizes FuelCell Energy's MCFC technology to produce three distinct product streams. This system uses biogas to generate 2.35 MW of electrical power, 1,270 kg of hydrogen per day, and 5,300 liters of water per day. The biogas is produced by an anaerobic digester processed waste stream. The electrical power supports Toyota's local operations at the port, with any surplus sold to Southern California Edison, a local utility company. The hydrogen fuels Toyota's imported light-duty fuel cell electric vehicles (FCEVs) and fuel cell drayage trucks at the port. The water is used for Toyota's vehicle washing and maintenance operations at the port. Toyota developed this project as part of their goal to reduce overall carbon dioxide emissions and the burden on other natural resources due to their operations.

Port of Long Beach Tri-Gen System Project Design and Scope

- ***Description:*** The Port of Long Beach Tri-Generation facility was commissioned by Toyota to meet fueling demands for imported FCEV and operational electricity demands.
- ***Boundary and Location:*** The tri-generation facility and fueling operations are all localized to a small portion of the Port of Long Beach. The port is located along the southern coast of Los Angeles.
- ***Project Size:*** The electrical output of the tri-generation system is 2.35MW and produces 1,270kg H_2/day and 5,300 liters of water per day.
- ***Processes:*** This process relies on a MCFC technology to produce electricity, hydrogen, and water from a biogas feedstock. The hydrogen must also be purified through standard means to meet FCEV fuel purity requirements.

- ***Feedstock Source:*** Indirect renewable biogas is the primary feedstock for this process. Food and organic waste are processed in an anaerobic digestor, cleaned up to be pipeline-grade natural gas (NG) and injected into the NG pipeline. NG is fed directly to the tri-gen system. The tri-gen system only uses the same amount of NG that the biogas provider injects into the pipeline.
- ***Product Destination:*** The product hydrogen is used to fuel Toyota's Mirai FCEVs received into the port before being sent to dealerships. The hydrogen will also be used in a refueling station to support Toyota Logistics Services (TLS) and heavy-duty drayage truck operations. The electricity is used for Toyota's local operations at the port (including charging battery electric vehicles (BEVs)) and any excess is sold to Southern California Edison under the California Bioenergy Market Adjustment Tariff (BioMAT) program. Generated water is used by the TLS to wash vehicles delivered to the port before delivering to customers.
- ***Project Stage:*** This project began operation in late 2023.
- ***Unknowns and Uncertainties:*** Economic evaluations and risk assessments are not provided or available in the project documentation.

Port of Long Beach Tri-Gen System Sustainability Management and Collaboration

- ***Sustainability Management* Plan**: The Toyota Environmental Challenge 2050 is a global commitment by Toyota that was used to inspire a lot of the design of the Tri-gen system. This Environmental Challenge has goals of zero carbon operations and lifecycle of products, water optimization and minimization, circular economy, and biodiversity. These goals also aligned with the City of Long Beach 2022 Climate Action Plan. The City of Long Beach identified building and energy, air quality, drought, extreme heat, rising sea levels and flooding, transportation, and waste as the primary stressors it would like to tackle through infrastructure improvements and additions.
- **Sustainability Consultant:** No documentation was found for a sustainability consultant used during the planning and implementation of this project.

Figure 42. Tri-Generation Facility at the Port of Long Beach (Toyota Motor North America, 2024)

3.2.2.2 OCSD Tri-Generation System

The OCSD tri-generation system demonstration project was headed by Air Products to determine the viability of a system that could co-produce hydrogen with electricity. Waste heat is also cited as a viable co-product and is used for heating in the anaerobic digester process. Initial project plans proposed using natural gas as the feedstock to produce 250kW of power and 100kg a day of hydrogen. Fuel cell technologies such as polymer electrolyte membrane (PEM), solid oxide (SOFC), and MCFC were investigated as viable options. Later during project development, the DOE requested that the feedstock be changed to a renewable source. The MCFC technology was chosen due to its proven success with renewable feedstocks and the unavailability of SOFC systems with the necessary power output at the time of the project. Air Products partnered with FuelCell Energy to develop the system and integrate it with an anaerobic digester processing wastes from one of the wastewater treatment facilities operated by OCSD. The system came online in late 2011 with excess generated power supplied to the local grid and the hydrogen compressed to be used in a hydrogen refueling station that was also constructed at the OCSD facility as part of this project. As this project was for research and demonstration purposes, documentation included a lifecycle economic evaluation that contributed to the content of this case study.

Orange County Sanitation District Tri-Gen System Project Design and Scope

- ***Description:*** The Orange County Sanitation District Tri-Generation facility was designed by Air Products as part of feasibility study requested by the DOE. The tri-generation facility and hydrogen refueling operations were all localized to a wastewater treatment facility operated by the OCSD.
- ***Boundary and Location:*** The tri-generation facility and fueling operations were all localized to a small portion of the OCSD wastewater facility. The wastewater treatment facility is in Fountain Valley, California.
- ***Project Size:*** The electrical output of the Tri-Generation system was 250kW and produced 100 kgH_2/day. Waste heat was also a viable product stream that was used within the anaerobic digester.
- ***Processes:*** This process relied on a MCFC technology to produce electrical power, hydrogen, and water from a biogas feedstock. The hydrogen was also purified through standard means (Pressure Swing Adsorption) to meet FCEV fuel purity requirements.
- ***Feedstock Source:*** Renewable biogas is the primary feedstock for this process. This biogas comes from an on-site anaerobic digestor that processes waste streams from the OCSD wastewater treatment facility.
- ***Product Destination:*** The product hydrogen was used in a hydrogen refueling station that was also constructed at the site. Any excess electricity that was generated and not used to operate the system was sold to the local grid.
- ***Project Stage:*** This project began operation in late 2011 and ceased operation in 2014.
- ***Unknowns and Uncertainties:*** Detailed risk assessments are not provided or available in the project documentation.

Orange County Sanitation District Tri-Gen System Sustainability Management and Collaboration

- ***Sustainability Management* Plan**: No documentation of a sustainability-focused management plan for the city of Fountain Valley could be found. However, the city did adopt a 2045 General Plan in 2023 that addresses some aspects of sustainability.
- **Sustainability Consultant:** No documentation was found for a sustainability consultant used during the planning and implementation of this project.

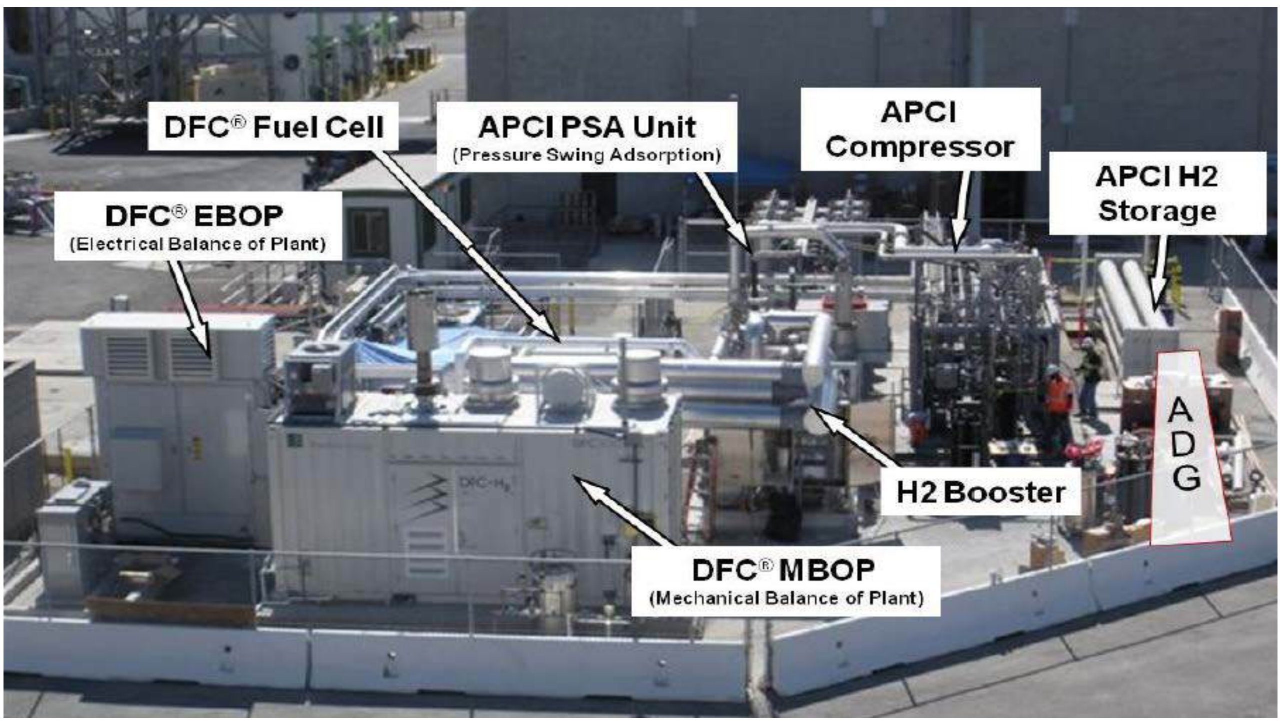

Figure 43. Tri-Generation Facility at Orange County Sanitation District (Heydorn, 2012)

3.2.3 Sustainability Category Assessment

3.2.3.1 Highlights for Quality of Life

Quality of Life

Community Engagement: Not addressed in the available documentation.

Community Impact Assessment: There are few community benefits to this project. It enhances the access to FCEV that are fueled via renewable means. It reduces GHG emissions by using renewably sourced biogas as the primary feedstock in the hydrogen production process. It offsets water use in an already drought-prone community/region. It may provide a renewable form of electric energy to the broader community when there is an excess generated relative to the operational electricity demand.

Addressing Equity and Social Justice: Not addressed in the available documentation.

Hydrogen Safety and Emergency Response: Not addressed in the available documentation.

3.2.3.1.1 QL1.2 Enhance Public Health and Safety

Although public health and safety were not addressed in the documentation for these projects, all safety codes and standards required were implemented for the project. There are also air quality benefits that could address high rates of diesel particulate matter at and near the port, as seen in Figure 44. If the project teams were able to provide documentation of any health and safety improvements beyond legally required regulations and permits, they could reach a level of achievement of Improved for this credit and receive 2 points. Given the diesel particulate matter levels around the port and surrounding communities, EPA's Environmental Justice Screening and Mapping Tool (EJScreen) also showed higher levels of heart disease around the TLS operations (white circle in Figure 45). The Port of Long Beach tri-gen plant projects could possibly enhance the health and safety of the surrounding community through reductions in emissions. Toyota teams with PACCAR to deploy heavy-duty fuel cell trucks that would refuel with H_2 produced by the tri-gen facility. The trucks and their routes would have to be part of the project boundary and show that the diesel trucks displaced by the zero emission fuel cell trucks is a positive health impact in the nearby community. If this can be shown, projects could reach a Restorative level of achievement. If trucks are excluded from the project boundary, it may be worth comparing to preexisting sources of H_2 for the fueling station and whether this H_2 was trucked in with diesel trucks.

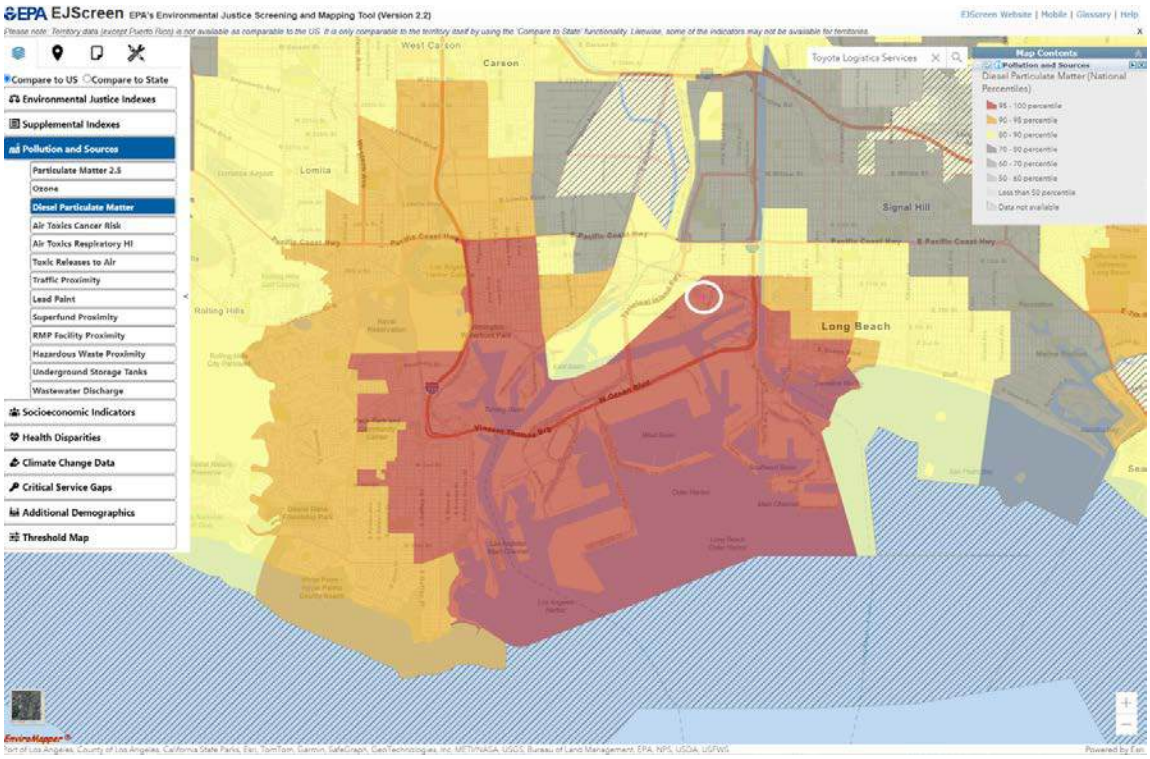

Figure 44. EJ Screen of Port of Long Beach mapping Diesel Particulate Matter

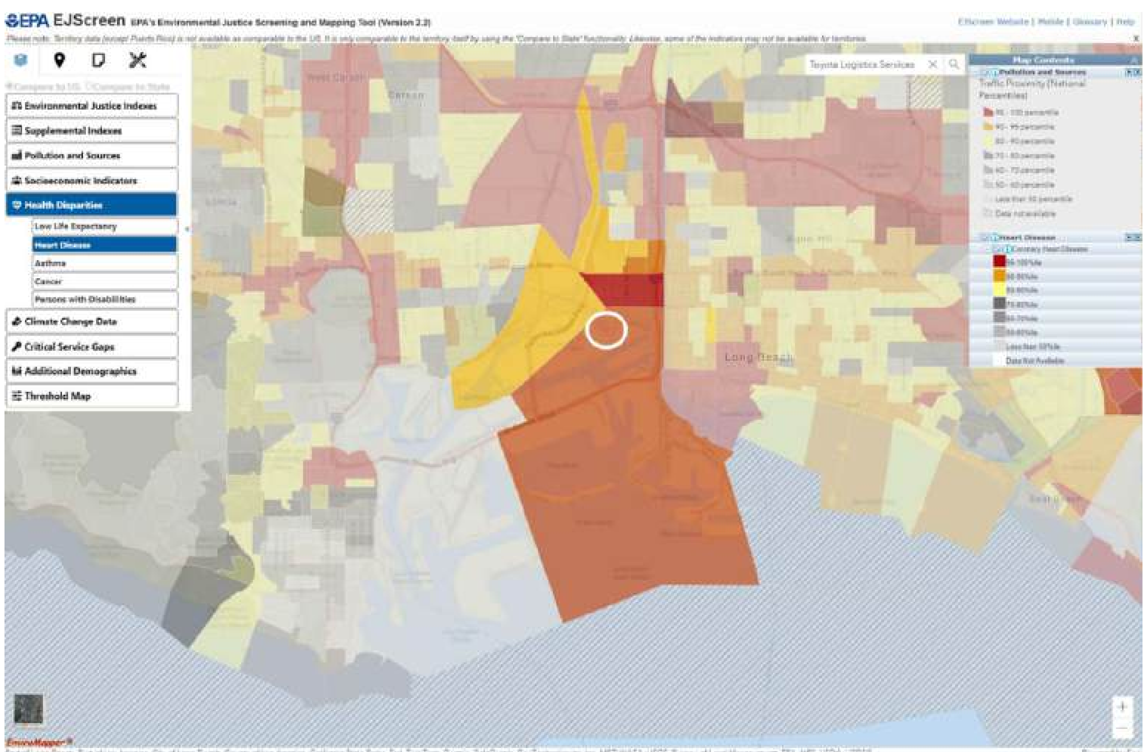

Figure 45. EJ Screen of Port of Long Beach mapping Heart Disease prevalence among adults aged 18 years or older

3.2.3.1.2 QL1.4 Minimize Noise and Vibration

Although noise and vibration levels and mitigation strategies were not addressed in the documentation for these projects, they can potentially score up to a level of Superior for this credit. Similar to the FCEB case study, noise of the fuel cell trucks through the neighborhood can have an impact on noise and vibration levels if trucks are included in the boundary of the project. Even if fuel cell trucks are outside the project boundary, a noise assessment would have to be made for the tri-gen system and the refueling station if inside the project boundary. Fuel cell operation is generally quiet, however the balance of plant components (fans, pumps, compressors, etc.) can contribute to noise during operation. Criteria to meet the Superior level would include a noise assessment that determined potential operational noise impacts with implementation of mitigating strategies during project design. If this noise assessment involved key stakeholders such as the Port of Long Beach or the City of Fountain Valley and the surrounding communities to set target project noise levels, then the project teams would be able to claim a Superior level and up to 6 points for this credit.

3.2.3.1.3 QL3.1 Advance Equity and Social Justice

Social equity and justice are not addressed in any of the documentation for these projects. There was some level of engagement with stakeholder groups working on EJ activities where the project was presented to show best practices to reduce diesel emissions in the area. The project teams have the potential to score up to a level of Restorative for this credit if certain criteria are met and documented. To accomplish this, the project teams would need to engage relevant stakeholders to learn about the historic equity and social justice issues impacting the affected communities. This would involve a mapping process of the projects benefits and impacts to the communities and adjustments to the projects implementation to address these impacts and equitably distribute them to all members of the affected communities. Additionally, project teams must establish a transparent system for addressing community grievances related to the project, ensuring that concerns are resolved effectively.

Using the EJScreen, SA was able to identify Particulate Matter ($PM_{2.5}$) and proximity to Toxic Releases to Air as the primary threats to the communities where these projects are located. These projects are well-positioned to address these concerns due to the nature of their technology. As will be discussed in detail later, MCFCs produce hydrogen at a lower rate of particulate emissions compared to SMR and can utilize GHGs like methane that would otherwise be vented to the atmosphere. If the project teams can demonstrate active stakeholder engagement and response to community grievances, they should be able to address every aspect of this credit and achieve a Restorative level.

3.2.3.2 Highlights for Leadership

Leadership
Life Cycle Cost Analysis: Life cycle cost analysis was conducted for the OCSD project, although evaluation of social and environmental impacts or benefits were not included.
Workforce Education: Sub-contracted apprentices of skilled laborers were educated on the job during the installation and commissioning process.

Plan for Sustainable Communities: The Long Beach tri-generation plant was in response to Toyota's Environmental Challenge 2050 goals that aligned with the City of Long Beach 2022 Climate Action Plan.

3.2.3.2.1 LD1.3 Provide for Stakeholder Involvement

Stakeholder involvement was not addressed in any of the available documentation related to these projects. SA believes these projects have the potential to reach a Restorative level of achievement for this credit and add 14 points towards this score. To accomplish this, the project teams would need to actively map relevant stakeholders and develop an active stakeholder engagement process that involves the stakeholders in the decision-making process. This process would have to include public input influencing or validating project outcomes that would be constantly monitored and updated through an active stakeholder feedback process. One way a project could have done this would have been to engage the Juan Rodriguez Cabrillo High School and the surrounding community of that high school directly affected by toxic air from the port. Parents of students attending the high school or faculty members would have a mutual interest in reducing emissions in the neighborhood and could be identified and engaged as partners.

3.2.3.2.2 LD1.4 Pursue Byproduct Synergies

These projects have stated that they will be sourcing all their chemical feedstock from biogas (Toyota Motor North America, 2024). Biogas is typically produced via anaerobic digestion of waste streams such as food waste, municipal solid waste, or animal wastes. If these projects can document the source of its biogas and show that this biogas is not purchased for a profit, they can expect to obtain a level of achievement of Restorative and receive 18 points toward their total Envision® score. The tri-gen systems would be sourcing all or a majority of their operational resources from an external waste stream.

Water produced within the tri-gen system process can be considered a byproduct waste stream if the vehicle washing station is considered outside the project boundary. This could be considered and counted toward the credit score if the feedstock was not a waste stream.

3.2.3.2.3 LD2.2 Plan for Sustainable Communities

The Port of Long Beach tri-generation system aims to provide sustainable hydrogen, electrical power, and water by using biogas as a chemical feedstock. The project team had considered three design options which included a no-build, using natural gas as the feedstock, and the current design that utilizes biogas. The project team recognized that energy demand and drought conditions as some major sustainability threats to the surrounding community. This project aims to mitigate those concerns by being at the minimal self-sufficient by providing its own energy and water with the potential to furnish any excess of these resources to the community. The goals of Toyota's Environmental Challenge 2050 include zero carbon operations and lifecycle products, water optimization and minimization, circular economy, and biodiversity. These goals fed into the development of the tri-generation system project at the Port of Long Beach. These goals also aligned with the City of Long Beach's 2022 Climate Action Plan that recognized drought and the need for a greater number of renewable energy sources as some of its primary sustainability concerns. The City of Long Beach hopes to mitigate these concerns by enhancing water conservation programs, expanding usage of recycled or wastewater sources, and developing more renewable energy sources (City of Long Beach, 2022). The tri-generation system aligns with the sustainability goals of the broader community. In addition to addressing unsustainable water availability, the project addresses unsustainable fuels (fossil fuels) by production of hydrogen to fuel light, medium, and heavy-duty vehicles. Based on these considerations, the project team can expect to reach a level of achievement of Restorative for this credit and obtain 16 points towards their score.

3.2.3.2.4 LD3.2 Develop Local Skills and Capabilities

Skill development and training programs were not outlined in any of the available documentation for these projects. However, based on additional insights provided by FuelCell Energy, local training and apprenticeship programs were included as part of the system installation and commissioning process. Based on this, the project could expect to reach a level of achievement of Improved for this credit and receive 2 points towards their Envision score. SA believes the projects have the potential to improve to a level of Restorative for this credit and add 16 total points to their score. The project teams would have to work with some form of workforce development agency to identify skill gaps in the local labor force and implement training programs to target these deficiencies. The programs would also have to continue once the projects have become operational. Community awareness and training could be implemented through the local Juan Rodriguez Cabrillo High School, educating both high school students, families, and faculty about hydrogen and zero emission trucks delivering goods from the port. The high school and surrounding communities are considered economically depressed (within the 80-90th percentile of low-income homes according to EJ Screen).

3.2.3.2.5 LD3.3 Conduct a Life-Cycle Economic Evaluation

The OCSD tri-generation project conducted a preliminary life cycle economic evaluation during the early stages of the project to define and guide certain design aspects. The assumptions that went into this economic evaluation are summarized below in Table 3. Using these assumptions, along with equipment, fabrication, and installation quotes, the project team was able to estimate the sale price of hydrogen for the system at varying feedstock costs to achieve a rate of return of 10% for the project. These results are summarized below in Figure 46.

Table 3. Economic Assumptions for the Preliminary LCE of the OCSD Tri-Generation System

Economic Parameter	UOM	Value
Project Life	Years	15
Depreciation	Years	15
Inflation	%	1.9
Tax Depreciation	-	5-Year MACRS
DCF Returns	%	10
Overheads	%	20
Taxes	%	37.8
Maintenance	-	Bottom-up Estimation

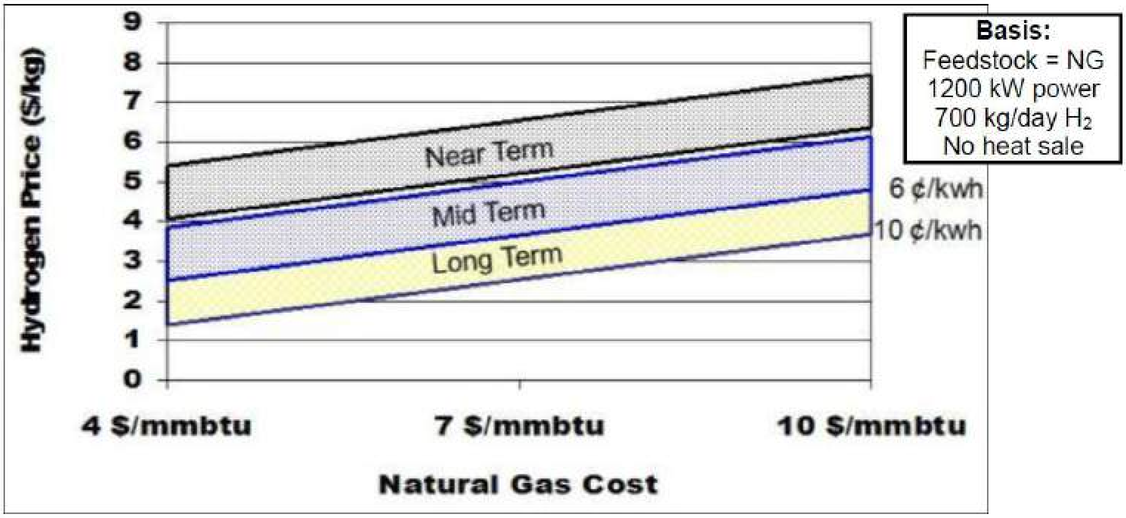

Figure 46. Preliminary System Cost of Hydrogen Estimates as of Function of Feedstock Cost

At this level of analysis, the project team could expect to reach a level of achievement of Improved if they can provide a few additional details on the actual total capital expenditure and expected operating expenses of the total project. Additionally, they should include expected costs for the hydrogen refueling station (if included in the project boundary) that is installed at the site to give a more comprehensive analysis of the project economics involved. The project also considered and ultimately decided to move forward with using biogas as the process feed stock as opposed to natural gas. This design choice adds capital equipment and operational expenses, but it also provides benefits to the environment and community by reducing GHG and other air pollutant emissions. The project team could extend the current analysis to investigate these added costs and monetize the environmental and community benefits of their renewable feedstock choice. If the project based the decision on the most economic pathway of using renewable biogas versus natural gas from the pipeline (including environmental and community benefits as a monetary cost), they could improve their level of achievement to Restorative and receive 14 points towards their Envision® score as opposed to 5 points.

3.2.3.3 Highlights for Resource Allocation

Resource Allocation

Renewable Energy Integration: Biogas is used as the primary feedstock and all energy used in the project will be renewably sourced.

Resource Recovery & Utilization: Food, organic, and municipal wastes will be utilized to generate the biogas as opposed to be directly disposed of. Byproduct water will be used internally to offset water demands for vehicle washing operations. Excess renewable electricity generated by the facility will be sold to the grid to be used elsewhere in the community.

Water Consumption Assessment: Water is not consumed during this project, rather it is produced. The water will act as a replacement for already existing vehicle washing operations performed by Toyota at the port.

3.2.3.3.1 RA2.1 Reduce Operational Energy Consumption

The Envision® guidelines state that energy conversion efficiencies should be used to determine the overall reduction in operational energy consumption for power generation systems. The energy conversion efficiency of a representative SMR plant will be used as the baseline for this credit given this would be the mostly likely alternative technology to produce the required hydrogen. The operational energy consumption and efficiency for this system is not directly stated in the documentation. However, the overall process efficiency can be roughly approximated by performing an energy balance on the input and output streams shown in Figure 47. The inlet streams of the process are ambient air and natural gas or renewable biogas. The air is heated up before entering the air electrode of the MCFC. The fuel is heated up by the air electrode exhaust and humidified by water from the exhaust of the fuel electrode. The heated and humidified fuel enters the reforming and fuel electrode of the MCFC to generate power. In addition, water and H_2 are captured off the exhaust of the reforming and fuel electrode of the MCFC. The hydrogen is separated from the other gases before being transferred to the refueling station.

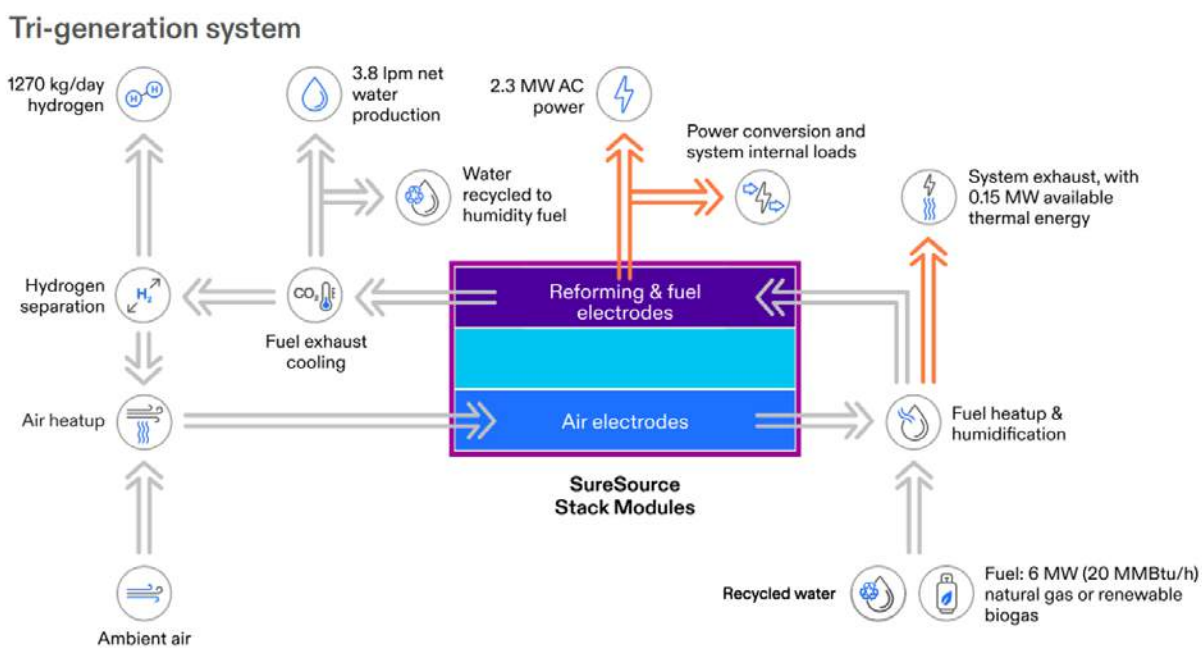

Figure 47. Block Flow Diagram of the Port of Long Beach's Proposed Tri-Generation System (Leo)

The output conditions of the water stream are not provided in the documentation. For this approximation, we assume the energy content of the water stream is that of saturated liquid at atmospheric conditions. The estimated energy content of each of the inlet and outlet streams is summarized below in Table 4. The estimated overall process efficiency is 70% with roughly 38% of the energy converted to electrical power (based on FuelCell Energy's 3000 Carbonate Fuel Cell Power Plant having a similar power rating (FuelCell Energy, 2024)), 29% of the energy converted to H_2, 2.5% converted to heat, and <0.5% converted to water. This estimate aligns with other overall system efficiencies reported in the literature for similar tri-generation systems based on FuelCell Energy's MCFC technology (Spencer, et al., 2013). Likely around 20% of the losses come from parasitic energy loads within the system with the remaining 10% coming from thermal and other miscellaneous losses (Spencer, et al., 2013). The average efficiency of an SMR process ranges from 65-75% (New York State Energy Research and Development Authority). In either case, the process does not improve on the overall efficiency compared to the baseline SMR process, therefore this project would not obtain any level of achievement for this credit. Although FuelCell Energy made minor modifications to improve the tri-gen operability, there is not enough information on the extent of improved efficiency.

Table 4. Process Stream Energy Content of the Proposed Tri-Gen System in Figure 47

Stream	UOM	Value
Input Natural Gas	MW	6.00
System Exhaust	MW	0.15
Power Generation	MW	2.30
Outlet Water	MW	0.03
Outlet Hydrogen	MW	1.76
Overall Efficiency	%	70.7%

3.2.3.3.2 RA2.3 Use Renewable Energy

The tri-generation systems are designed such that all energy demand and parasitic losses of the processing equipment are met by the power and heat generated by the MCFC. Since the projects decided to move forward with sourcing all their methane from renewable biogas, then 100% of the projects' energy demand would be met by renewable sources. Additionally, the excess generation of electricity from the MCFC is fed to the grid. The projects reach a level of achievement of Restorative for this credit and receive 24 points towards their total Envision® score.

3.2.3.3.3 RA3.2 Reduce Operational Water Consumption

For the Port of Long Beach tri-generation plant, the applicability of this credit will depend on how the project team decides to define the project boundary. If the car washing station is not included, then this credit would not be applicable as water would not be consumed in any form during the operation of the system. If the washing station were included, then this credit would apply. Based on this same logic, this credit would not be applicable for the OCSD tri-generation system.

The water generated by the MCFC technology could be able to offset all the potable water demand of the car washing facility. The project team would need to demonstrate that their car washing operations consumes water at a rate that is at least 40% less than a same size baseline SMR hydrogen production facility. In doing so, they can expect to reach at least a level of achievement of Conserving for this project and receive 17 points. To reach Restorative, Toyota would need to reduce its utilization of the generated water for vehicle washing and instead provide some of this excess water for use by the broader community. In this case, the project would be able to add 22 points to its total Envision® score.

3.2.3.4 Highlights for Natural World

Natural World

Location Appeal: This project will be placed directly on the port. This reduces transportation costs and associated emissions required to transport the hydrogen to the port for fueling operations. Furthermore, it will not require the development and destruction of any existing natural habitat as this land has already been developed.

Land Use History: The land was already being used by the port for shipping and cargo handling.

Environmental Assessments: Not addressed in the available documentation.

3.2.3.4.1 NW.2.4 Protect Surface and Groundwater Quality

The tri-generation systems currently have no documentation of how they plan to address surface and groundwater quality concerns during construction and operation. However, a ground water assessment was conducted by Toyota. The project owners may have considered potential leak pathways of plant effluent in water and their potential impact on groundwater quality. If the teams did this and prevented the creation of any new direct contamination pathways, they can expect to boost their level of achievement from Improved to Enhanced and receive 5 points towards their score. Further, if the projects devised solutions to actively avoid contamination and monitor groundwater conditions in real time, they could reach Superior level of achievement. If the car washing facility is included in the project boundary of the Port of Long Beach tri-generation system, they would need to ensure the runoff from this operation is properly drained to the sewer system. Using nonpolluting soaps or cleaning solutions should be considered to prevent groundwater contamination from washing station runoff not going into the sewer. This would address the credit at the level of Conserving.

3.2.3.5 Highlights for Climate and Resilience

Climate and Resilience

Climate Change Vulnerability: The project documentation does not outline many climate change vulnerabilities of the project, but they do note that the project is sited in a region prone to droughts. Another concern outlined by the City of Long Beach in their climate action plan that is pertinent to this project is concerns of rising sea levels.

Risk Assessment: Not addressed in the available documentation.

Greenhouse Gas Emissions: Exact GHG emissions for the project are not presented. The documentation does state that the reduction of GHG emissions can be nearly 100% and potentially carbon negative if waste heat from the fuel cell is used to offset NG burner fuel used in the digester heater.

Infrastructure Integration: Integration with the greater electricity grid by supplying renewable electricity. Enhancement of FCEV fueling capabilities and a reduction of hydrogen fueling transportation traffic to the port.

3.2.3.5.1 CR1.2 Reduce Greenhouse Gas Emissions

For this credit, it is assumed that the baseline is hydrogen generated via SMR as there was no existing hydrogen production infrastructure at the site prior to project development. Since biogas is the only chemical feedstock, the Port of Long Beach tri-generation system is not adding any additional GHG emissions to the atmosphere. Furthermore, the project team claimed the system would be carbon negative if waste heat from the process were to be integrated into the anaerobic digestor's heater in place of a NG burner. At minimum, the project would reach a level of achievement of Conserving while the best-case scenario would be Restorative. However more detailed accounting of the actual GHG emissions for the finished project would be needed to give a definitive score for this credit. If the project achieved the GHG emission reductions they claimed were possible, they could expect to receive between 22-26 points towards their total Envision® score.

3.2.3.5.2 CR1.3 Reduce Air Pollutant Emissions

Similarly for this credit, it is assumed that the baseline is hydrogen generated via SMR as there was no existing hydrogen production infrastructure at the site prior to project development. Exact air pollutant emissions are not provided, but a rough estimate can be calculated from available data given for FuelCell Energy's 3000 Carbonate Fuel Cell Power Plant and assuming a plant power output of 2.3MW (FuelCell Energy, 2024). Values for air pollutant intensity of a representative SMR process were taken from an Argonne National Lab report on updates to the GREET model for hydrogen (Sun & Elgowany, 2019). The estimated air pollutant intensities for both systems are summarized below in Table 5 . The Tri-Gen system achieves roughly a 75% reduction of emissions for all the major air pollutant categories. If proper control and monitoring systems are in place this project would likely achieve Enhanced for this credit and receive 4 points towards their total Envision® score. If the project team assessed whether volatile organic compounds (VOCs) were material to the project and implemented strategies to reduce their use, they could increase their score to Superior.

Table 5. Summary of Air Pollutant Intensities for SMR and Tri-Gen Systems

Air Pollutant	SMR (g/kgH_2)	Tri-Gen (g/kgH_2)	Percent Reduction (%)
NO_x	0.65	0.20	69.8%
SO_x	0.0061	0.002	64.6%
PM_{10}	0.20	0.00039	99.8%

3.2.3.5.3 CR2.3 Evaluate Risk and Resilience

Although risk assessments were not included in reviewed documentation, under the California Environmental Quality Act (CEQA) a risk assessment is required for infrastructure projects. Toyota led the CEQA assessment while FuelCell Energy assessed risks for the design, implementation, integration, and operation processes. The projects could reach a level of achievement of Enhanced with the available information provided. Projects could have expanded risk assessments to the broader community to obtain a Conserving level for this credit and potentially receive 26 points towards their score. To accomplish this, the teams would need to conduct a comprehensive risk analysis that involves key stakeholders. This analysis would need to identify the objectives of the project and the key assets and systems necessary to meet these objectives. Threats and hazards and potential functional vulnerabilities of the key assets due to these threats and hazards must also be identified. The probability of these threats and potential consequences should also be determined and categorized. Finally, this analysis would need to extend to connected infrastructure systems and the broader impacted communities.

3.2.3.5.4 CR2.4 Establish Resilience Goals and Strategies

The project team established resilience goals and strategies based on their risk assessment. For example, FuelCell Energy devised strategies to address safety and security risks to the construction and operation of the project. The project would reach an Enhanced level of achievement and receive 8 points. The tri-generation systems could reach a Conserving level of achievement for this credit and potentially receive 20 points towards their score. To do this, they would need to engage key stakeholders to review the devised strategies, and the resilience goals and strategies would need to align with the Long Beach community resilience goals. Given the location of the Long Beach Tri-generation plant, sea level rise is a concern for both the City of Long Beach and the Port of Long Beach. A 6ft sea level rise shows the potential for the facility (red circle in Figure 48) to be surrounded by water. Strategies to address such a climate risk could be addressed within this credit and could align with strategies proposed by the City of Long Beach or the Port of Long Beach.

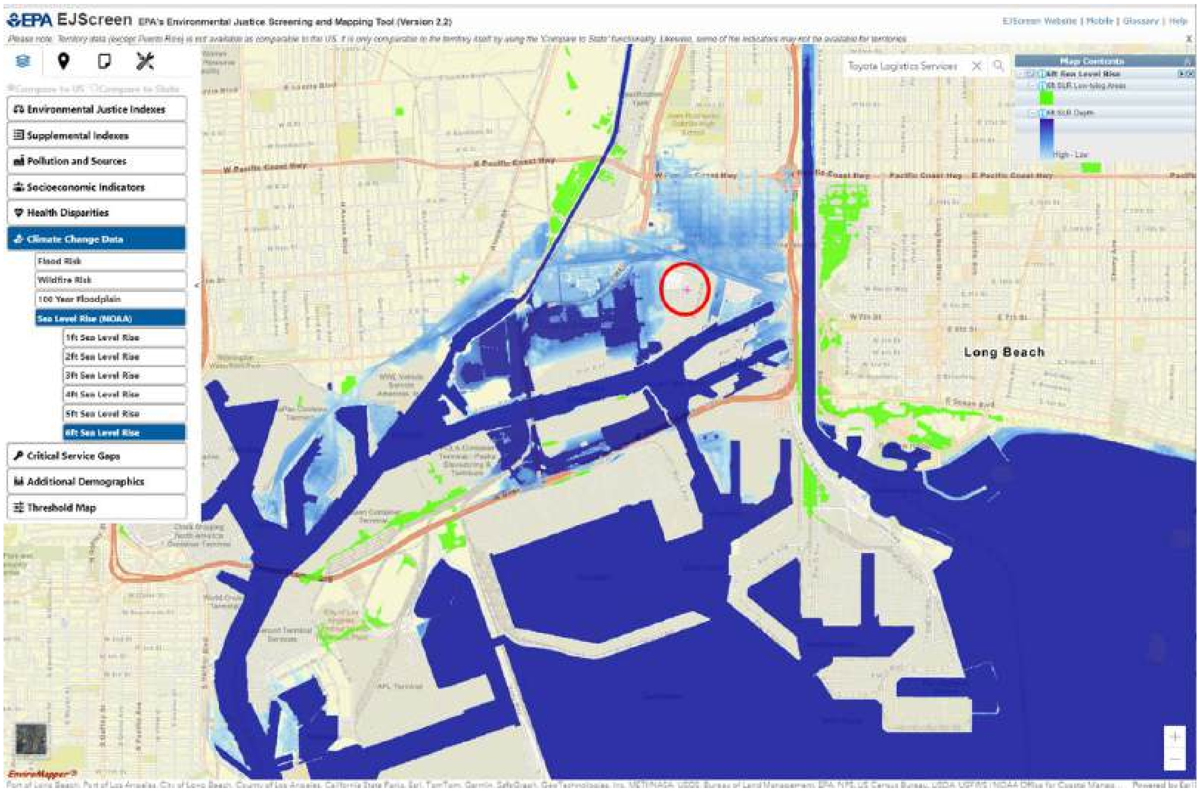

Figure 48. EJ Screen of Port of Long Beach mapping Climate Change Data for 6ft Sea Level Rise

3.2.3.5.5 CR2.5 Maximize Resilience

Resiliency strategies were implemented in the Port of Long Beach tri-generation project including resiliency for the site electrical grid design. The tri-gen system was configured to supply the TLS facility with the power required by the facility, but the excess power generated would be delivered to the Southern California Edison (SCE) utility grid as a renewable power. In the event of an SCE outage, the Tri-gen system is configured to continue delivering power through the common switchgear which connects the Tri-gen and TLS facility to run TLS operations. Additionally, the program management office continually plans, monitors, and mitigates risk to minimize impacts on performance, schedule, and budgets. The Long Beach Tri-gen project could reach a level of achievement of Superior for this credit and potentially receive 20 points towards their score. To reach a Conserving level, the teams would need to quantify the benefits gained from implementing these strategies (i.e., monetary savings from avoided damage or service loss).

3.2.3.5.6 CR2.6 Improve Infrastructure Integration

Given the tri-generation systems produce three valuable product streams, they are well suited to integrate into larger infrastructure systems. The systems are already designed to optimize internal integration by operating all process equipment with internally generated power and utilizing product water for other internal operations. The project teams state that there is the opportunity to utilize excess power by the tri-gen system within the electrical grid of the broader community. Additionally, the reduced dependence on external water sources will add resiliency to the broader water system in instances of draught or other strained conditions. Given these attributes and as long as ongoing system monitoring is put into place to improve performance over time, the projects can expect to reach a level of Restorative for this project and add 18 points to its total Envision score.

3.2.4 Conclusions and Recommendations: Tri-generation Systems

The tri-generation system projects assessed in this case study could potentially score quite well under the Envision framework for the H_2-prioritized credits. The tri-generation systems are currently predicted to score somewhere between 174-191 points of the possible 336 from the H_2-prioritized list of Envision credits (minus 22 points from the RA 3.2 being not applicable). A summary of all the prioritized credits, the range of level of achievement, and predicted score range are summarized in Table 6 below.

Table 6. Matrix of Envision® Level of Achievement for the Tri-Generation System Projects

Level of Achievement									
Credit	N/A	None	Improved	Enhanced	Superior	Conserving	Restorativ	Score Range	Recommendations for Increasing Score
QL1.2			X					2	Document improvements to health and safety beyond the legally required minimum and include fuel cell trucks within project boundary.
QL1.4		X						0	Conduct noise assessment and work with stakeholders to reach set noise targets.
QL3.1		X	X					0 - 3	Map impacts and benefits to local community, identify current or historic social or environmental injustice, engage with stakeholders to be part of the development process.
LD1.3		X						0	Stakeholder mapping, develop stakeholder engagement process, and engage stakeholder as partner.
LD1.4							X	18	N/A
LD2.2							X	16	N/A
LD3.2			X					2	Develop training programs guided by local workforce development agencies, educate community and target disadvantaged neighborhoods.
LD3.3			X					5	Extend economic evaluation to include design alternatives with external benefits monetized
RA2.1		X						0	The baseline would be a seriously considered alternative process that was less efficient.
RA2.3							X	24	N/A

Credit	Level of Achievement							Score Range	Recommendations for Increasing Score
	N/A	None	Improved	Enhanced	Superior	Conserving	Restorativ		
RA3.2	X					X	X	17 - 22	Reduce utilization of generated water for vehicle washing (if including vehicle washing stations in project boundary).
NW2.4		X	X					0 - 5	Determine leak pathways, avoid groundwater contamination pathways, include active monitoring, and remove potentially polluting substances.
CR1.2						X	X	22 - 26	Recycle waste heat to anaerobic digestor.
CR1.3				X				4	Implement proper air pollutant control and monitoring systems and assess the production of and reduce the use of VOCs.
CR2.3				X				18	Conduct comprehensive risk analysis to determine risk probabilities for the system, connected infrastructure systems, and the community
CR2.4				X				8	Develop risk management strategies based on a risk analysis that is informed by stakeholders and aligns with community goals. Consider sea level rise as a common concern with Port of Long Beach.
CR2.5					X			20	Quantify the benefits of resilience strategies implemented.
CR2.6							X	18	Ensure monitoring and reporting systems are in place to improve performance over time.
Total								174-191	N/A

The maximum score of the two projects for each category was taken as a percentage of the total points possible for that category, graphed in Figure 49 below. Keep in mind that these assessments were conducted for projects that had finalized plans and were not considering addressing Envision credits specifically. The dark blue Case Studies - Max line is the summation of the max points for the credits in that category (excluding RA 3.2, 22 points). The light blue Case Studies – Min dashed line is the summation of the minimum points for the credits in that category. The orange Potential line is a general tri-generation project potential score or likely score if projects were to implement all recommendations. To meet 100% of the category points, the projects would have to obtain the highest level of achievement possible for each credit (would be a line along the outer edge of the spider chart). This scoring does not represent a full Envision score as these results consider only the H_2-prioritized credits. A complete Envision score would include the remaining 46 credits (not evaluated in this study).

The tri-generation systems' greatest opportunity of improvement lies in the Quality of Life, Leadership, and Natural World categories. The **Quality of Life** credits have the potential for high scores given the benefits of reduced air emissions by the plant and zero-emission fuel source for fuel cell vehicles. The projects may not have required community engagement to move forward with the project (located on existing Toyota property and somewhat removed from nearby community housing) and thus may not have focused on this area of sustainability compared to FCEB fleet replacement community engagement activities. The **Leadership** credits primarily pertain to improving overall stakeholder involvement and establishing local upskilling programs. Both actions are well within the realm of capability for these projects and would likely lead to greater project performance and operation in the long run. Connecting with local schools to develop educational programs about reducing emissions is recommended. The **Resource Allocation** credits are somewhat limited by the operational efficiency of the tri-gen system in comparison to suggested baseline SMR systems. The **Natural World** credit was addressed to some extent; however, more information is needed to make a full assessment. The low potential for this score is because there is only one H2-prioritized credit in this category. The **Climate and Resilience** credits on reducing risks and improving resiliency were addressed in relation to the project, however the scope of the risk assessments could have moved beyond the integrated network on the project to the broader community with strategies aligning with the City of Long Beach or the Port of Long Beach (i.e., rising sea levels).

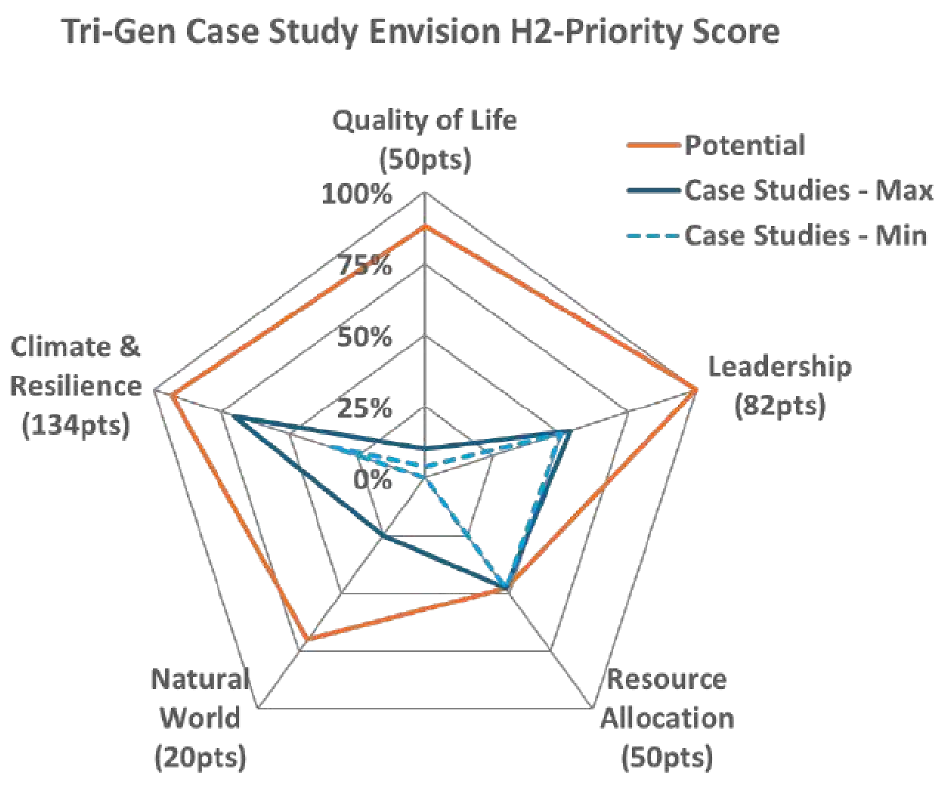

Figure 49. Spider chart of Envision H2-priority credit scoring for Tri-generation systems

3.2.5 References: Tri-generation System

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4 Appendix: Envision's Overlap with Green Hydrogen Standard

The Green Hydrogen Organisation (GH2) developed the Green Hydrogen Standard (GHS) in 2021 in efforts to bring not only reduction in greenhouse gas emissions but sustainability practices, establish standards, and provide accreditation to hydrogen infrastructure projects around the world. Overlap between the GHS and Envision credits is provided in Figure 50 and Figure 51. Bold text in the right column indicates H_2-prioritized credits with guidelines included in this document. Text in the right column with an asterisk (*) indicates secondary Envision credits that can be applied to hydrogen projects but do not currently have guidelines included in this document. There are some credits that were not flagged specifically for H_2 projects, but maybe addressed in similar ways to non-H_2 projects.

Green Hydrogen Standard Requirement	Envision Credit Overlaps
1. Project overview and outlook - Requires publicly documented information about the project	**QL1.1 Improve Community Quality of Life**[81] **QL3.1 Advance Equity and Social Justice** LD1.1 Provide Effective Leadership and Commitment* **LD1.3 Provide for Stakeholder Involvement** **LD2.2 Plan for Sustainable Communities**
2. Stakeholder engagement and government approval -Requires that the project operator publishes a publicly accessible summary of the government licenses and approvals	**QL1.2 Enhance Public Health & Safety** **LD1.3 Provide for Stakeholder Involvement** LD3.1 Stimulate Economic Prosperity & Development*
3. Project location and design - Requires a publicly accessible evaluation of the project location and design	**LD2.2 Plan for Sustainable Communities** CR2.1 Avoid Unsuitable Development* CR2.2 Assess Climate Change Vulnerability* **CR2.6 Improve Infrastructure Integration**
4. Social impact **4A: Affected communities and livelihoods** -Required to assess the project impact on communities -Required to identify public health concerns through experts and actively monitor. -Required to identify and mitigate human rights impacts. -Required to assess impact and contribution to UN's sustainability development goals. **4B: Resettlement** -Required to avoid resettlement; if unavoidable fair compensation and improved living conditions must be given. **4C: Indigenous Peoples** -Requires consultation of indigenous peoples and minimization of negative impacts on them. **4D: Labor and working conditions** **4E: Modern slavery, child and forced labor**	ISI's Minimum Program Requirements – ESG Safeguards **QL 1.4**-1.6*, 2.3*, **3.1**-3.3 – Impact to surrounding community **QL3.1 Advance Equity and Social Justice** **LD1.3 Provide for Stakeholder Involvement** **LD1.4 Pursue Byproduct Synergies** RA1.1 Support Sustainable Procurement Practices LD3.1 Stimulate Economic Prosperity & Development* **LD3.3 Conduct a Life-Cycle Economic Evaluation** **CR1.2 Reduce Greenhouse Gas Emissions** **CR1.3 Reduce Air Pollutant Emissions** QL1.3 Improve Construction Safety **LD3.2 Develop Local Skills & Capabilities**

Figure 50. Overlap of GHS and Envision credits (1)

The reader should note that the GHS focuses on global adoption while Envision does not cover many human rights-specific topics. Many of these are covered by US laws and regulations (i.e., OSHA, rights to form/join unions) and human health for operators inside facilities maybe better covered by LEED certifications on Indoor Environmental Quality. Additionally, some requirements for GHS are qualitative

[81] Bold text in the right column indicates H_2-prioritized credits within H_2SIG. Text in the right column with an asterisk (*) indicates secondary Envision credits that can be applied to hydrogen projects but do not currently included in the H_2SIG.

without distinction in how well a project can address the requirement whereas Envision has levels of achievement, a form of measuring the impact of implementing a requirement.

Green Hydrogen Standard Requirement	Envision Credit Overlap
5. Environmental impact **5A: Renewable energy sources** -Requires the project operator to demonstrate that hydrogen is produced through the electrolysis of water with 100% or near 100% renewable energy. Renewable energy sources: hydropower, wind, solar (solar thermal and solar photovoltaic), geothermal energy, tide, wave and other ocean energy sources **5B: Water use and quality** -Requires a publicly accessible evaluation of the project's utilization of water and the project's approach to wastewater treatment and water pollution **5C: Waste, Noise and Air Quality** -Requires that waste, noise and air quality issues relevant to project implementation and operation have been identified through an assessment process **5D: Biodiversity** -Requires that biodiversity issues relevant to project implementation and operation have been identified through an assessment process **5E: Climate change impact and mitigation** -Requires that projects operate at <=1 kg CO2e per kg H_2 taken as an average over a 12-month period (additional requirements and discussion provided below this figure)	**RA2.3 Use Renewable Energy** RA3.1 Preserve Water Resources* **RA3.2 Reduce Operational Water Consumption** RA3.3 Reduce Construction Water Consumption RA3.4 Monitor Water Systems* **QL1.4 Minimize Noise & Vibration** RA1.2 Use Recycled Materials RA1.3 Reduce Operational Waste* RA1.4 Reduce Construction Waste CR1.1 Reduce Net Embodied Carbon* **CR1.2 Reduce Greenhouse Gas Emissions** **CR1.3 Reduce Air Pollutant Emissions** NW1.1 Preserve Sites of High Ecological Value Ecology: NW3.1-3.5
6. Health and Safety -Expects project operators to have undertaken an assessment of human resource and labor management requirements for the project, including project occupational health and safety (OH&S) issues, risks, and management measures	QL1.3 Improve Construction Safety **LD3.2 Develop Local Skills & Capabilities**
7. Governance, transparency and accountability -Requires project operator addresses transparency, integrity and accountability	Use of ISI's Envision Verification Program LD1.1 Provide Effective Leadership & Commitment Using Envision can "calibrate internal accountability" and "demonstrate good governance to voters, taxpayers, or ratepayers"

Figure 51. Overlap of GHS and Envision credits (2)

The requirement for 5E, from the Figure above, to operate at <=1kgCO_2e per kg H_2 references the methodology for emissions measurement from the International Partnership for Hydrogen and Fuel

Cells in the Economy (IPHE)[82] It should be noted that there are also protocols for green ammonia production within the GHS.

5E also "expects (soon to be required) project operators to calculate and report on the indirect GHG emissions associated with H_2 production processes (e.g., relating to water use and waste disposal), and the emissions associated with the storage, conversion and delivery of H_2 and its derivatives. The energy consumption associated with (re)conversion and the emissions linked to transport are an important consideration." This emissions standard can be more stringent than Envision credit CR 1.2 Reduce Greenhouse Gas Emissions because project boundaries may not take into account emissions upstream of the project or downstream like delivery or derivatives of H_2 like synfuels. This type of requirement has been put forth in Europe and can be challenging for projects to report on, particularly if it requires monitoring of upstream/downstream processes that are not always within the owner/operator's control.

5E "Encourages project operators to calculate and report on the embodied emissions associated with green hydrogen production, including embodied emissions associated with: (i) purchased energy (grid) and energy produced on site (off grid); (ii) construction of H_2 production facilities, and (iii) construction of storage, conversion and delivery infrastructure. GH2 will collaborate with partner organizations to develop and apply methods consistently to all energy providers." This part of 5E overlaps well with CR 1.1 Reduce Net Embodied Carbon. Although CR 1.1 is not a priority credit included in the H_2SIG, it is considered a secondary credit that relates to H_2 projects. Addressing the GHS list of embodied emissions is also a good start to addressing CR 1.1.

In summary, the GHS is specifically focused on hydrogen infrastructure whereas Envision is broader to encompass all types of infrastructure projects. There is, however, a significant amount of overlap between the GHS requirements and Envision credits requirements as both relate to the evaluating the sustainability of projects. A project would benefit from using both GHS and Envision, using Envision's guidance to best document requirements for GHS.

[82] IPHE (2021) Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen https://www.iphe.net/iphe-working-paper-methodology-doc-oct-2021

5 Appendix: Supporting Project Documentation

5.1 Project Tasks and Activities

A list of the project tasks, subtasks and activities are provided in the table below.

Task 1: Review of Envision® Sustainability Framework
1.1: Envision® Sustainability Professional (ENV SP) Training Course
1.2: Review of verification process through similar (i.e., natural gas / energy infrastructure project) example projects
ISI Task: Provide Envision®-awarded project statistics (i.e., categorized projects by type or industry, highest number of awards by Envision® category).
1.3: Review of example projects and best practices
ISI Task: Introduction to and facilitate conversations with third-party contractors (Envision® Sustainable Professionals) who assist on Envision® projects. Provide a list of suggested webinar recordings/courses that review best practices and lessons learned.
1.4: Review of Green Hydrogen Standard and compare to Envision
Task 2: Generate H2 Guidelines for Envision®
2.1: Categorize and prioritize existing Envision® Credits
2.2: Interpretation of sustainability indicator credits and criteria specifically for H2 projects
ISI Task: Assist in generating and reviewing prioritized list of Envision® credits that might apply specifically to H2 projects
2.3: Determine specific tools or models to be used for evaluation of quantitative metrics
2.4: Draft H2 guidelines document
2.5: ISI/DOE Review of H2 guidelines document
ISI Task (Milestone 1): Review H2 guidelines document
ISI Milestone 1: Interim review of H2 guidelines document
Deliverable: Interim DOE Review of H2 guidelines document
Task 3: Community and Stakeholder Engagement & Review
3.1: Generate list of reviewers
ISI Task: Assist SA in generating a list of reviewers who are familiar with Envision® and can provide feedback on SA's guidelines and recommendations for H2 projects using Envision®.
Deliverable 1: Draft List of Reviewers
Deliverable 2: Final List of Reviewers
3.2: Outreach and discussions with reviewers
ISI Task: Assist SA in setting up and implementing an Envision® orientation for reviewers that are unfamiliar with Envision®.
3.3: Update H2 guidelines document based on reviewer feedback
Task 4: Case Studies
4.1: Scope case study projects
Deliverable 3: Preliminary List of Case Studies
Deliverable 4: Final List of Case Studies
4.2: Case study evaluation of prioritized H2- specific framework metrics (Assess 3)
ISI Task: Assist SA in going through the Envision® Checklist for each Case Study to identify requirements to meet the highest level of achievement.
4.3: Update sustainability framework based on findings from Case Studies
4.4: Optional - Conduct additional case study evaluations and update H2 guidelines document
Task 5: Reporting
5.1: Draft Final Report - Same as H2 Guidelines document
ISI Task: Assist in reviewing the draft report to ensure the report captures all relevant work and includes a complete evaluation of Envision® for H2 infrastructure projects.
Deliverable 5: Draft Final Report and H2 Guidelines Document
5.2: External Review of Draft Report and H2 Guidelines Document
5.3: DOE Review of Draft Report and H2 Guidelines Document
5.4: Final Report
ISI Task: Assist in reviewing the final report.
ISI Milestone 2: Review of Final Report
Deliverable 6: Final Report (H2 Guidelines Document)

5.2 Methodology

In the first stage of this project, the SA team focused on understanding Envision® and becoming familiar with the 64 credits within five different sustainability categories. The ISI team provided valuable assistance in understanding the need and reasons for certain requirements with the credits. ISI provided some background on the verification process for Envision® certification, documentation on ways Envision®-certified projects addressed certain credits, statistical information about Envision®-awarded projects, and introduced the SA team to several individuals on the Envision Review Board to be reviewers. After two members of the SA team completed the Envision Sustainable Professional (ENVSP) training program, the team decided to narrow the focus specifically for hydrogen infrastructure projects and down-select a prioritized list of hydrogen-focused credits. A matrix with Envision® credits and types of hydrogen infrastructure projects was generated to track priority credits that could satisfy the following factors:

- If hydrogen projects already address these credits in some form and could possibly score well. For example, all or most hydrogen projects address GHG emissions and design for energy efficiency.
- If hydrogen projects could benefit from standardization when measuring the effectiveness and impact of certain design decisions. For example, comparing trade-offs of energy efficiency, cost, emissions, and safety or heal impacts of surrounding communities.
- If hydrogen projects struggle to address these credits and would benefit from additional guidance on best practices. For example, community engagement and interactions with existing infrastructure.

This matrix shown in Figure 52 is an evaluation of both priority credits for hydrogen infrastructure and the types of hydrogen projects that could address certain credits. Higher priority credits are highlighted in dark green with lower but still relevant credits in light green. Similarly, higher priority H_2 project types are highlighted in green while lower but still relevant hydrogen project types are highlighted in light green. Yellow indicates that a credit could apply to any project and may not specifically relate just to hydrogen projects. White indicates a credit that does not apply to a certain hydrogen project type.

A point summation approach is used to identify which project types and credits are of highest applicability. When summing up the number of hydrogen project types that can address an Envision® credit, the highest values in the far-right column become the priority credits. In summing up the number of credits a project type could address, the highest values in the lowest bottom row indicated the projects possibly best suited for case studies. Additional credits were identified as priority credits based on ISI's feedback and feedback from initial discussions with reviewers. These 18 priority credits became the focus of the Phase 1 effort and became the basis of the Phase 1 hydrogen guidelines developed from this project. A list of the priority credits is provided in Figure 53.

		Project Type Category	Feedstock											H2 Production						Storage							Trans.				End-Use						Capacity			Location				
		Project Type Sub-Category	Renewable Electricity						Other					Electrolysis			Other			H2						Other	Pipeline		Other											Rural		Urban		
		Green - Potential to get high score (conserving/restorative) Yellow - Could apply to most projects White - Not Applicable	Solar PV	Offshore Wind	Onshore Wind	Hydropower	Geothermal	Tidal/Ocean Energy	Methane	Water	Biogass	Biomass	Nuclear Plower	PEM	Alkaline	SOEC	NG w/CCUS	Pyrolysis	Photoelectrochemical	Gaseous H_2 Tanks	Cryo-Compressed H_2 Tanks	Mechanical Compression	EHC (electrochem. H2 Compression)	Liquid Hydrogen	Geological Storage/Salt Cavern	Ammonia	H2 Pipeline	H2 Blending in NG Pipeline	Tube Trailers	Electrical Power Lines	Mobility - Refueling Station	Electrical Power	Long- Term Energy Storage	Ammonia	Iron & Steel	Synthetic Fuel	0-500MW	50MW-1GW	>1GW	No Grid Access	Environmentally Protected	Major Metropolis	Sub-Urban	
Category	Sub-Categor	Credits																																										
Quality of Life	Wellbeing	QL1.1 Improve Community Quality of Life																																										0
		QL1.2 Enhance Public Health & Safety												1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1			1		26
		QL1.3 Improve Construction Safety																																										0
		QL1.4 Minimize Noise & Vibration	1											1	1	1							1		1		1	1			1													9
		QL1.5 Minimize Light Pollution																																						1	1			2
		QL1.6 Minimize Construction Impacts																																										0
	Mobility	QL2.1 Improve Community Mobility Access																													1													1
		QL2.2 Encourage Sustainable Transportation																													1													1
		QL2.3 Improve Access & Wayfinding																													1													1
	Community	QL3.1 Advance Equity & Social Justice	1											1	1	1															1	1												6
		QL3.2 Preserve Historic & Cultural Resources																																										0
		QL3.3 Enhance Views & Local Character																																										0
		QL3.4 Enhance Public Space & Amenities																																										0
Leadership	Collaboration	LD1.1 Provide Effective Leadership & Commitment																																										0
		LD1.2 Foster Collaboration & Teamwork																													1													1
		LD1.3 Provide for Stakeholder Involvement	1	1	1	0.5		0.5						1	1	1	1	1	1								1	1	1	1	1						1	1	1			1		19
		LD1.4 Pursue Byproduct Synergies							1	1	1	1	1	1	1	1		1																										9
	Planning	LD2.1 Establish a Sustainability Management Plan																																										0
		LD2.2 Plan for Sustainable Communities	1	1	1	1	1	1						1	1	1	1	1	1						1		1				1	1												16
		LD2.3 Plan for Long-Term Monitoring & Maintenance																																										0
		LD2.4 Plan for End-of-Life												1	1	1																												3
	Economy	LD3.1 Stimulate Economic Prosperity & Development												1	1	1															1													4
		LD3.2 Develop Local Skills & Capabilities	1	1	1	1	1	1						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1								28
		LD3.3 Conduct a Life-Cycle Economic Evaluation	1	1	1	1	1	1		1				1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1		1	1	1	1	1	1								30
Resource Allocation	Materials	RA1.1 Support Sustainable Procurement Practices																																										0
		RA1.2 Use Recycled Materials																																										0
		RA1.3 Reduce Operational Waste								1				1	1	1	1														1													6
		RA1.4 Reduce Construction Waste																																										0
		RA1.5 Balance Earthwork On Site																																										0
	Energy	RA2.1 Reduce Operational Energy Consumption							1	1	1	1		1	1	1	1	1				1	1								1													12
		RA2.2 Reduce Construction Energy Consumption																													1													1
		RA2.3 Use Renewable Energy	1	1	1	1	1	1																							1													7
		RA2.4 Commission & Monitor Energy Systems												1	1	1	1															1												5
	Water	RA3.1 Preserve Water Resources												1	1	1	1																											4
		RA3.2 Reduce Operational Water Consumption								1				1	1	1	1														1													6
		RA3.3 Reduce Construction Water Consumption																																										0
		RA3.4 Monitor Water Systems								1				1	1	1																												4
Natural World	Siting	NW1.1 Preserve Sites of High Ecological Value																																										0
		NW1.2 Provide Wetland & Surface Water Buffers																																										0
		NW1.3 Preserve Prime Farmland																																										0
		NW1.4 Preserve Undeveloped Land																																										0
	Conservation	NW2.1 Reclaim Brownfields																																										0
		NW2.2 Manage Stormwater								1				1	1	1																												4
		NW2.3 Reduce Pesticide & Fertilizer Impacts																																										0
		NW2.4 Protect Surface & Groundwater Quality	1	1	1	1	1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1					1			28
	Ecology	NW3.1 Enhance Functional Habitats																																										0
		NW3.2 Enhance Wetland & Surface Water Functions																																										0
		NW3.3 Maintain Floodplain Functions																																										0
		NW3.4 Control Invasive Species																																										0
		NW3.5 Protect Soil Health																																										0
Climate and Resilience	Emissions	CR1.1 Reduce Net Embodied Carbon												1	1	1	1			1	1	1		1	1		1	1	1		1													7
		CR1.2 Reduce Greenhouse Gas Emissions	1	1	1	1	1	1		1	1	1	1	1	1	1	1			1	1	1		1	1		1	1	1		1	1												22
		CR1.3 Reduce Air Pollutant Emissions	1	1	1	1	1	1		1	1	1	1	1	1	1	1			1	1	1		1	1		1	1	1		1	1												23
	Resilience	CR2.1 Avoid Unsuitable Development	1	1	1	1	1	1		1	1	1		1	1	1	1			1	1	1		1	1		1	1			1	1	1	1	1									25
		CR2.2 Assess Climate Change Vulnerability	1	1	1	1	1	1		1	1	1		1	1	1	1			1	1	1		1	1		1	1	1		1	1	1	1	1									26
		CR2.3 Evaluate Risk and Resilience	1	1	1	1	1	1		1	1	1		1	1	1	1			1	1	1		1	1		1	1	1		1	1	1	1	1									26
		CR2.4 Establish Resilience Goals and Strategies	1	1	1	1	1	1		1	1	1		1	1	1	1			1	1	1		1	1		1	1	1		1	1	1	1	1									26
		CR2.5 Maximize Resilience	1	1	1	1	1	1		1	1	1		1	1	1	1			1	1	1		1	1		1	1	1		1	1	1	1	1									26
		CR2.6 Improve Infrastructure Integration	1	1	1	1	1	1														1					1	1			1	1												11
			16	14	14	14	13	13	2	14	9	9	2	26	26	26	19	8	6	12	12	14	6	12	13	4	15	15	11	2	27	15	9	9	9	4	2	2	2	1	2	2	0	

Figure 52. Matrix of Envision® credits and hydrogen project types

Based on the matrix, the best types of case studies may include hydrogen projects with renewable energy, electrolysis projects, natural gas with carbon capture usage and storage (CCSU), and mobility for end-use of hydrogen. The guidelines, however, attempt to address a broader variety of hydrogen project type categories. To determine the types of hydrogen projects to focus on for the guidelines, the team also considered high-impact end-uses listed in the DOE Hydrogen Roadmap (industrial processes, heavy-duty transport, high-temperature heat as a gas replacement), and long duration energy storage as a gas replacement). Other considerations were taken for the number of demonstrations for a certain hydrogen project end-use (IEA project database listed the most projects in mobility, electrical power, and ammonia) with graph shown in Figure 54, the cost of hydrogen and the end-use willingness to pay for it shown in Figure 55, and the timeline of the technology.

QL 1.2 Enhance Public Safety
QL 1.4 Minimize Noise and Vibration
QL 3.1 Advance Equity & Social Justice
LD 1.3 Provide for Stakeholder Involvement
LD 1.4 Pursue Byproduct Synergies
LD 2.2 Plan for Sustainable Communities
LD 3.2 Develop Local Skills & Capabilities
LD 3.3 Conduct a Life-Cycle Economic Evaluation
RA 2.1 Reduce Operational Energy Consumption
RA 2.3 Use Renewable Energy
RA 3.2 Reduce Operational Water Consumption
NW 2.4 Protect Surface and Groundwater Quality
CR 1.2 Reduce Greenhouse Gas Emissions
CR 1.3 Reduce Air Pollutant Emissions
CR 2.3 Evaluate Risk and Resilience
CR 2.4 Establish Resilience Goals and Strategies
CR 2.5 Maximize Resilience
CR 2.6 Improve Infrastructure Integration

Figure 53. List of H2-prioritized Envision credits

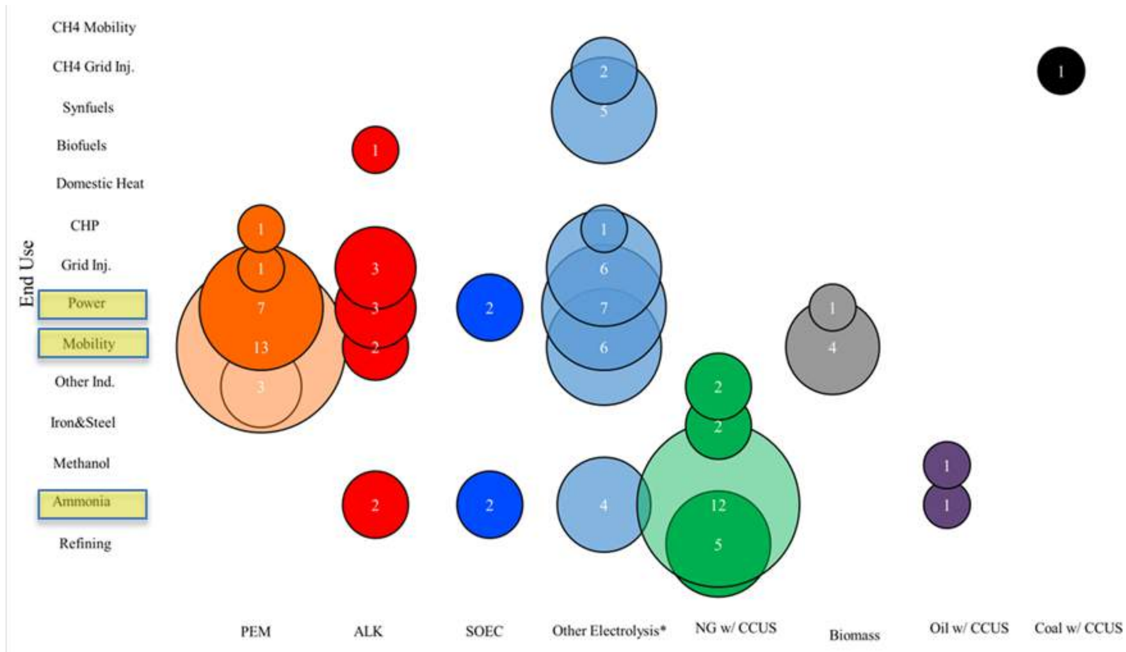

Figure 54. Graph of US hydrogen projects by end-use and hydrogen production technology type[83]

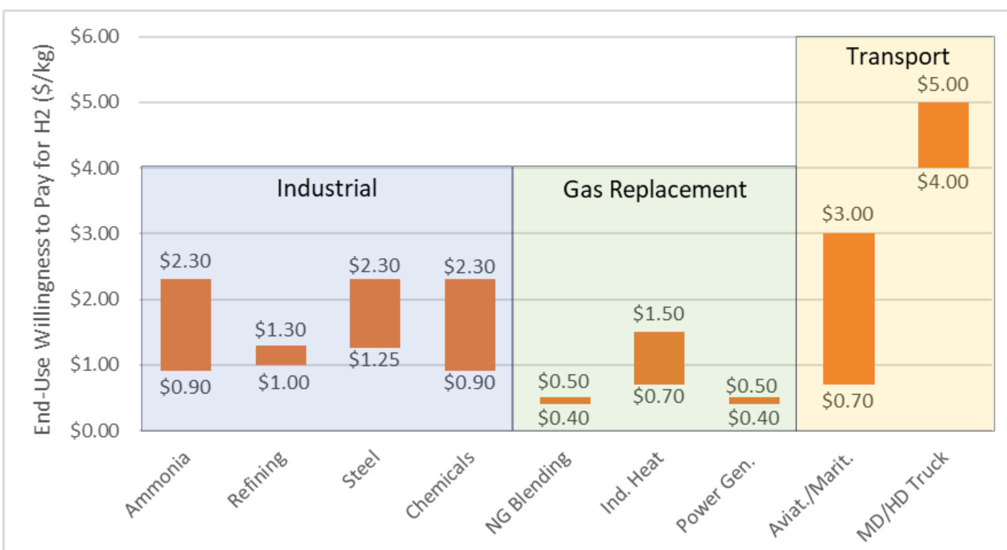

Figure 55. Willingness to pay for hydrogen for each end-use application[84]

[83] IEA Hydrogen Project Database (2021): https://www.iea.org/reports/hydrogen-projects-database . *Other electrolysis describes projects that had not yet determined the electrolysis technology type.

[84] Figure generated from data provided in Miller, E., "From Hydrogen Shot to Hydrogen Hubs", presented at the 2023 DOE Hydrogen Program Annual Merit Review and PEER Evaluation Meeting, June 5, 2023, Arlington, VA.

5.3 Changes in Project Approach

There were no significant changes to the approach of this project. Minor change in approach for case studies switched from demonstrated or operational projects to broader project types (i.e., H2 storage and refueling stations for transit bus fleets) based on public documentation. There were delays in getting a project developer to participate in this study and the team agreed it would be better to conduct case studies on a certain type of hydrogen project with public documentation where example ideas could be shared to address Envision requirements.