LANE TRANSIT DISTRICT

FLEET PROCUREMENT PLAN

PHASE I: SELECTION OF PRIORITY FUELS/TECHNOLOGIES REPORT – TRANSIT FLEET

February 2022

Final

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ACRONYMS AND TERMS

Acronym/Term	Description
BEB	Battery-Electric Bus
BRT	Bus Rapid Transit
CNG	Compressed Natural Gas
dHEB	Diesel-hybrid electric bus
EWEB	Eugene Water & Electric Board
FCEB	Fuel Cell Electric Bus
FPP	Fleet Procurement Plan
GHG	Greenhouse Gas
GH2	Gaseous Hydrogen
ICE	Internal Combustion Engine
kW	Kilowatt
kWh	Kilowatt-hour
LH2	Liquid Hydrogen
LTD	Lane Transit District
NFPA	National Fire Protection Association
O&M	Operations and Maintenance
RNG	Renewable Natural Gas
R99	Renewable Diesel
SME	Subject Matter Expert
SMR	Steam Methane Reform
SUB	Springfield Utility Board
ZEV	Zero-Emission Vehicle(s)

EXECUTIVE SUMMARY

The Phase I: Selection of Priority Fuels/Technologies Report – Transit Fleet documents the Fatal Flaws Analysis evaluation conducted to identify and select fuels/technologies that are deemed the most viable for Lane Transit District's (LTD) future transit fleet. The fuels selected in this report will be further evaluated and refined in Phase II, which will include the development of LTD's 15-Year Fleet Procurement Plan.

ES1 BACKGROUND

As the primary public transit provider for Lane County, OR, which serves the Eugene/Springfield metro area, LTD's mission is connecting our community. In all that we do, we are committed to creating a more connected, sustainable, and equitable community. In 2020, LTD adopted the Climate Action Policy Statement and Fleet Procurement Goals, which commits to three general goals: 1) retire and replace 25 of the existing fossil fuel fleet with battery-electric buses (BEBs) by 2023, 2) a 75 percent tailpipe greenhouse gas (GHG) emission reduction from LTD-owned fleet vehicles by 2030 and phasing out fossil fuels by 2035, and 3) a deliberate exploration of emerging technology and fuels.

LTD has already taken the first steps to meeting its Climate Action Policy Statement and Fleet Procurement Goals by placing its first 11 BEBs in service (June 2021). The first 11 BEBs are New Flyer XE40s (with a 388 kilowatt-hour [kWh] capacity) and are charged by one of four 150 kilowatt (kW) ABB chargers. LTD is currently procuring an additional 19 longer-range BEBs – New Flyer XE40s (525 kWh) - that will bring their total BEB fleet to 30 vehicles, surpassing the Board's Climate Action Policy Statement and Fleet Procurement Goals of having procured 25 BEBs by 2023.

Pursuant to these goals, LTD plans to develop a 15-Year Fleet Procurement Plan that will provide the framework and actionable steps that need to be taken to procure and operate LTD's future fleet. The fuel/technologies that are selected will be informed by a two-phase project:

— Phase I: Selection of Priority Fuels/Technologies Report – Transit Fleet (this report)[1]

— Phase II: 15-Year Fleet Procurement Plan

Table ES-1 summarizes the fuels and technologies evaluated in this report.

Table ES-1. Fuels/Technologies Evaluated in Phase I

Fuel Type	Technology/Generation/Vehicle Type	Description
Renewable Diesel (R99)	Internal Combustion Engine (ICE)	Existing LTD fuel/technology. R99 diesel fuel, which is comprised of 99 percent renewable diesel and 1 percent petroleum diesel, is trucked to Eugene and dispensed to LTD's ICE vehicles.
	Diesel Hybrid (dHEB)	Existing LTD fuel/technology. R99 diesel fuel is trucked to Eugene and dispensed to LTD's dHEB fleet. This fuel powers an ICE that generates electricity for a battery, which powers an electric motor.
Renewable Natural Gas (RNG)	Internal Combustion Engine (ICE)	Renewable natural gas, which is produced from the waste of plants and animals powers an ICE. This fuel/technology is gaseous and would require additional infrastructure on LTD's site, including compression and storage equipment.

1 There is also a Selection of Priority Fuels/Technologies Report for LTD's Paratransit Fleet

Fuel Type	Technology/Generation/Vehicle Type	Description
Electricity	Battery-Electric	Electricity is stored in rechargeable battery packs that power an electric motor. This fuel/technology would require additional infrastructure on LTD's site, including charging and electrical equipment.
Gaseous Hydrogen (GH2)	On-Site Generated GH2 via Steam Methane Reformation (SMR)	Gaseous hydrogen (GH2), generated by SMR, is used to power a fuel cell that powers an electric motor. This fuel/technology is gaseous and would require additional infrastructure on LTD's site, including compression and storage equipment.
	On-Site Generated GH2 via Electrolysis	GH2, generated by electrolysis, is used to power a fuel cell that powers an electric motor. This fuel/technology is gaseous and would require additional infrastructure on LTD's site, including compression and storage equipment.
Liquid Hydrogen (LH2)	Locally Generated and Delivered LH2	LH2, generated by a local supplier is delivered by truck to LTD, vaporized, compressed, and stored on LTD's site and used to power a fuel cell that powers an electric motor.
	Nationally Generated and Delivered LH2	LH2, generated by a national supplier is delivered by truck to LTD, vaporized, compressed, and stored on LTD's site and used to power a fuel cell that powers an electric motor.

Source: WSP

ES2 EVALUATION APPROACH

It was determined that evaluation metrics align with LTD's Triple-Bottom-Line Approach to Sustainability to best capture the suitability of each fuel/technology. Three fuel/technology evaluation categories were developed based on this approach: Operational Impact, Social Equity/Environmental Impact, and Lifecycle Costs. The Operational Impact category evaluates metrics that focus on a fuel/technology's operational outcomes. Social Equity/Environmental Impact evaluates metrics that focus on a fuel/technology's impact to social equity and the environment – with a particular focus on LTD's Climate Action Statement and Fleet Procurement Goals. The third and final category, Lifecycle Costs evaluates the economic value and costs associated with adopting the fuel/technology.

Table ES-2 summarizes the fuel/technology evaluation categories and associated quantitative and qualitative metrics used to compare each fuel/technology.

Table ES-2. Fuel/Technology Evaluation Metrics Summary

Evaluation Category	Evaluation Metric
Operational Impact	– Vehicle Range – Physical Space Requirements – Fueling or Charging Time
Social Equity/ Environmental Impact	– Lifecycle GHG Emissions – 75 Percent Reduction in Tailpipe GHG Emissions – Elimination of Fossil Fuel Vehicles by 2035 – Local Air Quality
Lifecycle Costs	– Vehicle Capital Costs – Infrastructure Capital Costs – Annual Fuel or Electricity Costs – Lifecycle Operating and Maintenance Costs – Financial Incentives

Source: WSP

To evaluate each fuel/technology, data for each metric were collected, processed, and weighted based on criteria established with LTD. Each metric value was then assigned a score based on a zero to two scale. A zero (or "low") was assigned if the fuel/technology doesn't meet criteria or was dramatically lower than other scores (ex. if emissions exceed Policy goals), a one (or "medium") was assigned if the fuel/technology moderately meets the criteria, and a two (or "high") was assigned if the fuel/technology meets or exceeds the criteria. Some metrics use LTD's existing conditions as a baseline for comparison, whereas other metrics' scores are relative to the fuels/technologies being analyzed. Each score was rounded to the nearest whole number and presented as a Harvey ball symbol for ease of understanding and analysis. It should be noted that all values were rounded to the nearest whole number.

Table ES-3 presents the screening threshold for each metric.

Table ES-3. Evaluation Methodology

Symbol	Score	Description
●	2 (High)	A high score indicates that the fuel/technology satisfies LTD requirements or has a low potential for negative impacts.
◑	1 (Medium)	A medium score indicates that the fuel/technology moderately meets LTD requirements or has a moderate potential for negative impacts.
○	0 (Low)	A low score indicates that the fuel/technology does not meet LTD requirements or has a high potential for negative impacts.

Source: WSP

For each evaluation category, a fuel/technology's scores for each metric were summed and averaged (and rounded to the nearest whole number) to determine an overall score for that category. It is assumed that if a fuel/technology scores "high" for any category, it may be viable for further study in Phase II.

ES3 FINDINGS

Based on the analyzed Operational Impact metrics, renewable diesel and RNG appear to yield the most Operational Impact benefits. This is primarily due to the relatively high vehicle ranges and short fueling times. All other fuels/technologies had "medium" or "low" scores for Operational Impact.

Based on the analyzed Social Equity/Environmental Impact metrics, RNG, battery-electric, and hydrogen-based fuels/technologies appear to yield the most Social Equity/Environmental Impact benefits. This is primarily due to them exceeding a 75 percent reduction in tailpipe emissions, elimination of fossil fuel vehicles by 2035, and relatively low levels of lifecycle GHG emissions.

Based on the analyzed Lifecycle Costs metrics, RNG and ICEs powered by renewable diesel yield the most Lifecycle Costs benefits. This is primarily due to them having relatively low capital costs for vehicles, infrastructure, fuel, and operating and maintenance costs.

Table ES-4 summarizes the Phase I evaluation category scores for each fuel/technology type.

Table ES-4. Phase I Score Summary

Evaluation Category	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Operational Impact Score	High ●	High ●	High ●	Low ○	Medium ◑	Medium ◑	Medium ◑	Medium ◑
Social Equity/Environmental Impact Score	Medium ◑	Medium ◑	High ●	High ●	High ●	High ●	High ●	High ●
Lifecycle Costs Score	High ●	Medium ◑	High ●	Medium ◑	Medium ◑	Medium ◑	Medium ◑	Medium ◑
Selected to move into Phase II	Yes	No	Yes	Yes	No	No	Yes	Yes

Source: WSP

Based on the analysis, all evaluated fuels/technologies scored "high" on one or more of the evaluation categories. However, there were several fatal flaws identified that eliminate some of these fuels from further consideration in Phase II.

Although LTD currently uses dHEB vehicles powered by renewable diesel, dHEBs are more expensive to procure and have a reduced market availability as compared to ICE counterparts. Since renewable diesel can only be used as a transition fuel since it still consists of 1% fossil fuel and any interruptions in supply would require LTD to revert to fossil diesel - it is recommended that LTD's dHEB fleet be permanently retired and replaced with ICE vehicles (powered by renewable diesel) or ZEBs, depending on procurement goals and timing, which will be further explored in Phase II.

On-site generation of hydrogen whether via SMR or electrolysis is also not considered a viable fuel/technology at this time. LTD's existing lot cannot fit both hydrogen storage and hydrogen production infrastructure without removing bus parking. If the unused land next to the employee parking lot is taken into consideration, then hydrogen generation may be viable. The issue is not the physical footprint of the equipment alone, but the footprint combined with the required setbacks established by the National Fire Protection Agency (NFPA). The production and storage equipment would be subject to strict NFPA setbacks, such as maintaining a 50-foot gap between infrastructure and the property line. The residential housing adjacent to the property may also be a barrier to adoption due to safety or general community concerns. Further detailed analysis and decisions/assumptions would have to be made to commit to this fuel/technology; for this reason, WSP recommends that it not be considered in Phase II.

As previously mentioned, LTD has also procured 30 BEBs. Based on existing conditions, the limited range of this fuel/technology does not appear to be a feasible solution that can meet the demands of the LTD's 60-foot-serving blocks and EmX service; however, the technology is rapidly advancing and there are several strategies that LTD could consider to extend range (including opportunity charging, charge management strategies, service changes, etc.). For this reason, the battery-electric technology will also be considered in Phase II.

Therefore, it is recommended that Phase II considers renewable diesel as a transition fuel for LTD's ICE vehicles and either RNG, battery-electric, or locally- or nationally-delivered LH2 as a long-term solution.

Table ES-5 summarizes each analyzed fuel/technology and the justification for why or why it will not be considered during Phase II.

Table ES-5. Selected Fuels/Technologies Summary

Fuel/Technology	Considered in Phase II?	Justification
Renewable Diesel (R99)/ Internal Combustion Engine (ICE)	Yes	R99 is the existing fuel, scored high for the Operational Impact and Lifecycle Costs score. R99, currently used by LTD, will be considered as the transition fuel to a future fuel/technology. At this time, it does not have long-term applicability because it still contains 1% fossil fuel.
Renewable Diesel (R99)/ Diesel Hybrid (dHEB)	No	While LTD currently operates some dHEBs, it is more financially viable to operate the ICEs with renewable diesel until the new fuel is adopted.
Renewable Natural Gas (RNG)/ Internal Combustion Engine (ICE)	Yes	RNG scored high in all three evaluation categories and will be considered in Phase II.
Electricity/ Battery-Electric	Yes	Battery-electric technology currently cannot support the ranges required by LTD's bus fleet; however, it is recommended that it be further evaluated in Phase II.
On-Site Generated GH2 via Steam Methane Reformation (SMR)	No	SMR on-site would require a significant investment and space at LTD's facility – space that is not currently available. Therefore, it cannot be considered for the 15-year plan.
On-Site Generated GH2 via Electrolysis	No	Electrolysis on-site would require a significant investment and space at LTD's facility – space that is not currently available. Therefore, it cannot be considered for the 15-year plan.
Locally Generated and Delivered LH2	Yes	Locally-supplied hydrogen scored high on the Social Equity/Environmental Impact category. There is a lot of potential promise, as well as significant uncertainty, of this local project that will be further explored in Phase II.
Nationally Generated and Delivered LH2	Yes	Nationally-supplied hydrogen scored high on the Social Equity/Environmental Impact category. There is a lot of potential promise in this fuel/technology that will be further explored in Phase II.

Source: WSP

ES4 NEXT STEPS

In Phase II, further refinements and research will be conducted to ensure that both the transition fuel/technology (renewable diesel) and selected fuel/technology types (RNG, BEB, and delivered LH2) are fully understood. This includes the sourcing and long-term outlooks of the market and greater detail with respect to the facility requirements and how the transition will impact LTD's maintenance and operations. This information will then inform the development of 15-year planning scenarios that present the paths that LTD can take to meeting its goals. Phase II will conclude with an actionable Fleet Procurement Plan that will guide LTD through the next 15 years of its transition.

1 INTRODUCTION

This report (Phase I: Selection of Priority Fuels/Technologies Report – Transit Fleet) documents the Fatal Flaws Analysis evaluation conducted to identify and select fuels/technologies that best meet Lane Transit District's (LTD) transit fleet's service needs and are consistent with LTD's Climate Action Policy Statement and Fleet Procurement Goals, Long-Range Transit Plan, and Sustainability Policy. The fuels/technologies screened, analyzed, and selected in this report will be further evaluated and refined in Phase II, which will be the development of LTD's 15-Year Fleet Procurement Plan.

1.1 STUDY BACKGROUND

In 2020, LTD adopted the Climate Action Policy Statement and Fleet Procurement Goals, which commits to three general goals: 1) retire and replace 25 of the existing fossil fuel fleet with battery-electric buses (BEBs) by 2023, 2) a 75 percent tailpipe greenhouse gas (GHG) emission reduction from LTD's fleet vehicles by 2030 and phasing out fossil fuels vehicles by 2035, and 3) a deliberate exploration of emerging technology and fuels.

Pursuant to these goals, LTD plans to develop a 15-Year Fleet Procurement Plan that will provide the framework and actionable steps that need to be taken to procure and operate LTD's future fleet. The fuel/technology that is selected will be informed by a two-phase project:

— Phase I: Selection of Priority Fuels/Technologies Report – Transit Fleet (this report)[2]

— Phase II: 15-Year Fleet Procurement Plan

The 15-Year Fleet Procurement Plan will support LTD's ongoing commitment to providing high-quality transit service and increasing ridership in the most sustainable manner possible (financially, environmentally, and socially).

1.2 TRANSIT FLEET BACKGROUND

LTD operates fixed-route and bus rapid transit (BRT) service on 31 routes with a 100-bus fleet. The fleet consists of (64) 40-foot buses and (36) 60-foot articulated buses – 22 of which are dedicated for LTD's EmX BRT service. Approximately 30 percent of the fleet have internal combustion engines (ICE) that are powered by diesel, 60 percent are diesel-hybrid electric buses (dHEBs), and approximately 10% are battery-electric.

In September 2020, LTD transitioned from conventional B5 ultra-low sulfur diesel (95 percent fossil diesel/5 percent biodiesel) to R99 renewable diesel (99 percent renewable diesel/1 percent fossil diesel). R99, though more expensive than B5, emits fewer lifecycle GHGs than conventional diesel fuel. Renewable diesel is chemically identical to fossil diesel but is sourced from renewable materials such as plant and animal waste. LTD currently procures its R99 based on monthly bid cycles. Commonly, only a single fuel supplier that can meet this request. The fuel is produced in Asia, shipped to Portland, and trucked to Eugene. New sources of domestically-produced supply are being developed in both California and Oregon among other locations in the US and are expected to enter the market in 2022.

LTD has already taken the first steps to meeting its Climate Action Policy Statement and Fleet Procurement Goals by placing its first 11 BEBs in service (June 2021). The first 11 BEBs are New Flyer XE40s (with a 388 kilowatt-hour [kWh] capacity) and are charged by one of four 150 kilowatt (kW) ABB chargers. LTD is currently procuring an additional 19

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longer-range BEBs – New Flyer XE40s (525 kWh) - that will bring their total BEB fleet to 30 vehicles, surpassing the Board's Climate Action Policy Statement and Fleet Procurement Goals Policy of having procured 25 BEBs by 2023.

1.3 REPORT PURPOSE AND STRUCTURE

The purpose of this report is to identify the most viable fuels/technologies for LTD's transition to a 100 percent fossil fuel-free fleet. The findings of this report – and selected fuels/technologies - will serve as the foundation for further refinements, evaluation, and development of the 15-Year Fleet Procurement Plan in Phase II. The technologies studied here are dynamic and the market conditions and rapidly changing. This report attempts to provide a snapshot of existing conditions with the understanding that LTD will need to update this information periodically as conditions change.

This report is organized into six main sections:

1. **Introduction** – Overview of the Study Background and LTD's fleet.
2. **Evaluation Approach –** Overview of the fuels/technologies under consideration, evaluation metrics, and evaluation methodology.
3. **Operational Impact –** Compares the metrics of each analyzed fuel/technology with consideration to operational impacts.
4. **Social Equity/Environmental Impact –** Compares the metrics of each analyzed fuel/technology with consideration to social equity and environmental impacts.
5. **Lifecycle Costs –** Compares the metrics of each analyzed fuel/technology with consideration to lifecycle costs.
6. **Findings, Selected Fuels/Technologies, and Next Steps** – Summarizes the evaluations and identifies the fuels/technologies that will be considered and further analyzed in Phase II.

2 EVALUATION APPROACH

The following section provides an overview of the fuel/technology selection process, evaluation criteria, and evaluation methodology.

2.1 FUEL/TECHNOLOGY SELECTION

To meet the Climate Action Policy Statement and Fleet Procurement Goals, LTD identified several fuel/technology types that should be analyzed and considered in their long-term fleet procurement plans. In advance of a detailed fatal flaws analysis, initial screening analyses were conducted to eliminate the fuels/technologies that did not meet the Climate Action Statement and Fleet Procurement Goals Policy. Table 2-1 describes each of these fuels/technologies initially considered for analysis.

Table 2-1. Fuels/Technologies Considered for Evaluation

Fuel Type	Technology/Generation/Vehicle Type	Description
Renewable Diesel (R99)	Internal Combustion Engine (ICE)	Existing LTD fuel/technology. R99 diesel fuel, which is comprised of 99 percent renewable diesel and 1 percent petroleum diesel, is trucked to Eugene and dispensed to LTD's ICE vehicles.
	Diesel Hybrid (dHEB)	Existing LTD fuel/technology. R99 diesel fuel is trucked to Eugene and dispensed to LTD's dHEB fleet. This fuel powers an ICE that generates electricity for a battery, which powers an electric motor.
Renewable Diesel (R50)	Internal Combustion Engine (ICE)	Potential fuel. R50 diesel fuel, which is comprised of 50 percent renewable diesel and 50 percent petroleum diesel, would be trucked to Eugene and dispensed to LTD's ICE vehicles.
	Diesel Hybrid (dHEB)	R50 diesel fuel would be trucked to Eugene and dispensed to LTD's dHEB fleet. This fuel powers an ICE that generates electricity for a battery, which powers an electric motor.
Renewable Natural Gas (RNG)	Internal Combustion Engine (ICE)	Renewable natural gas, which is produced from the waste of plants and animals powers an ICE. This fuel/technology is gaseous and would require additional infrastructure on LTD's site, including compression and storage equipment.
Hydrogen (H2)	Steam Methane Reformation (SMR)	Gaseous hydrogen (GH2), generated by SMR is used to power a fuel cell that powers an electric motor. This fuel/technology is gaseous and would require additional infrastructure on LTD's site, including compression and storage equipment.
	Electrolysis	GH2, generated by electrolysis, is used to power a fuel cell that powers an electric motor. This fuel/technology is gaseous and would require additional infrastructure, including compression and storage equipment.
Electricity	Battery-Electric	Electricity is stored in rechargeable battery packs that power an electric motor. This fuel/technology would require additional infrastructure on LTD's site, including charging and electrical equipment.

Source: WSP, LTD

It should be noted that the repowering of LTD's existing vehicles was eliminated from consideration because the process is expensive, time consuming, and because LTD's fleet is aging, it is more effective to replace these vehicles with purpose-built ZEBs. While not considered here, if LTD continues to use a transition fuel as certain technologies and fuels continue to mature, repowering vehicles could be a strategic choice later within the latter half of the 15-year time horizon of the Climate Action Policy Statement and Fleet Procurement Goals. LTD would need to study that option more in-depth at that time.

2.1.1 INITIAL SCREENING

The fuels/technologies that LTD selected were initially screened to determine if they met two criteria: 1) whether they had a "Proven Record of Performance", which was defined as being currently available on the market and in being used in transit operations, and 2) whether they met the Climate Action Policy Statement and Fleet Procurement Goals' requirements. Based on criterion #2, it was determined that the R50 fuel be eliminated from further evaluation. The remaining fuels/technologies: renewable diesel, RNG, hydrogen, and battery-electric, were all selected for further evaluation. R99, although only 99 percent fossil fuel-free, is currently used to fuel LTD's fleet and will continue to serve as a transition fuel.

2.1.2 ADDITIONAL SCREENING

The consideration of hydrogen fuel and battery-electric requires further refinements and classifications to accurately assess their performance. Gaseous hydrogen (GH2), as noted, can be produced at LTD's facility via SMR or electrolysis. However, it can also be produced offsite by either a local or regional/national supplier and delivered either as GH2 or as a liquid (LH2) and stored at LTD's facility. LH2 can be transported in greater volumes than compressed GH2, thus, reducing the number of trips and costs of transport; therefore, WSP recommends that LTD considers LH2 over GH2 if delivered hydrogen is the preferred fuel/technology. These additional options yield different outcomes and thus were added to the list of fuels/technologies to be evaluated.

For battery-electric, batteries vary in their energy storage capacity (kWh) – which directly impacts metrics such as vehicle and infrastructure costs, and range. Since the technology is still evolving, it is difficult to forecast future performance. For that reason, battery-electric was initially analyzed under three categories: 1) *existing* – which is based on the (11) 40-foot, 388 kWh buses that LTD currently operates, 2) *planned* – which is based on the (19) 40-foot, 525 kWh buses that LTD is currently procuring, and 3) *future* – which is based on the conditions of a full fleet transition of 525 kWh 40-foot and 60-foot buses. It should be noted that although data were collected and analyzed for the existing and planned scenarios, only the future scenario was evaluated and compared to other fuels/technologies since it considers a full fleet of 40- and 60-foot buses. All evaluated fuels/technologies were based on a 70-bus replacement since 30 of LTD's buses will be battery-electric by 2022.

While this analysis sought to only evaluate fuels and technologies that are currently available on the market, an exception was made for locally-delivered LH2. Local utility, Eugene Water & Electric Board (EWEB), is currently exploring the possibility of using electrolysis to generate renewable hydrogen - LTD could be a potential end user of this hydrogen. However, since the viability of this project is still being evaluated, the specific infrastructure, fuel form (GH2 or LH2), and costs are still uncertain. This project is represented in the locally-delivered LH2 scenario, this scenario assumes fuel costs at $5-8/kg amongst other potential benefits; however, these assumptions could be overly optimistic and will have to be further evaluated in Phase II.

Table 2-2 summarizes the fuels/technologies evaluated in Phase I.

Table 2-2. Fuels/Technologies Evaluated in Phase I

Fuel Type	Technology/Generation/Vehicle Type	Description
Renewable Diesel (R99)	Internal Combustion Engine (ICE)	Existing LTD fuel/technology. R99 diesel fuel, which is comprised of 99 percent renewable diesel and 1 percent petroleum diesel, is trucked to Eugene and dispensed to LTD's ICE vehicles.
	Diesel Hybrid (dHEB)	Existing LTD fuel/technology. R99 diesel fuel is trucked to Eugene and dispensed to LTD's dHEB fleet. This fuel powers an ICE that generates electricity for a battery, which powers an electric motor.
Renewable Natural Gas (RNG)	Internal Combustion Engine (ICE)	Renewable natural gas, which is produced from the waste of plants and animals powers an ICE. This fuel/technology is gaseous and would require additional infrastructure on LTD's site, including compression and storage equipment.
Electricity	Battery-Electric	Electricity is stored in rechargeable battery packs that power an electric motor. This fuel/technology would require additional infrastructure on LTD's site, including charging and electrical equipment.
Gaseous Hydrogen (GH2)	On-Site Generated GH2 via Steam Methane Reformation (SMR)	Gaseous hydrogen (GH2), generated by SMR, is used to power a fuel cell that powers an electric motor. This fuel/technology is gaseous and would require additional infrastructure on LTD's site, including compression and storage equipment.
	On-Site Generated GH2 via Electrolysis	GH2, generated by electrolysis, is used to power a fuel cell that powers an electric motor. This fuel/technology is gaseous and would require additional infrastructure on LTD's site, including compression and storage equipment.
Liquid Hydrogen (LH2)	Locally Generated and Delivered LH2	LH2, generated by a local supplier is delivered by truck to LTD, vaporized, compressed and stored on LTD's site and used to power a fuel cell that powers an electric motor.
	Nationally Generated and Delivered LH2	LH2, generated by a national supplier is delivered by truck to LTD, vaporized, compressed and stored on LTD's site and used to power a fuel cell that powers an electric motor.

Source: WSP, LTD

2.2 EVALUATION METRICS

To develop evaluation metrics and an analysis approach that would best suit LTD's goals, two groups of industry experts were established. The first group was comprised of subject matter experts (SMEs) from LTD's staff in transit operations heavy-duty vehicle maintenance, and service planning and delivery. This group was tasked with developing a detailed evaluation matrix that would be used to measure the performance of each fuel/technology type. The second group consisted of external regional stakeholders, including utility service providers, fuel distributors, local jurisdictions, social equity organizations, and other SMEs that would ensure that the technical analysis conducted during Phase I was sound. A comprehensive list of internal and external project stakeholders can be found in Appendix A.

It was determined that evaluation metrics align with LTD's Triple-Bottom-Line Approach to Sustainability to best capture the suitability of each fuel/technology. Three fuel/technology evaluation categories were developed based on this approach: Operational Impact, Social Equity/Environmental Impact, and Lifecycle Costs. The Operational Impact category evaluates metrics that focus on a fuel/technology's operational outcomes. Social Equity/Environmental Impact evaluates metrics that focus on a fuel/technology's impact to social equity and the environment – with a particular focus on LTD's Climate Action Statement and Fleet Procurement Goals. The third and final category, Lifecycle Costs evaluates the economic value and costs associated with adopting the fuel/technology. Table 2-3 summarizes the fuel/technology evaluation category and evaluation metrics used to screen each fuel/technology type.

Table 2-3. Fuel/Technology Evaluation Metrics Summary

Evaluation Category	Evaluation Metric
Operational Impact	– Vehicle Range – Physical Space Requirements – Fueling or Charging Time
Social Equity/ Environmental Impact	– Lifecycle GHG Emissions – 75 Percent Reduction in Tailpipe GHG Emissions – Elimination of Fossil Fuel Vehicles by 2035 – Local Air Quality
Lifecycle Costs	– Vehicle Capital Costs – Infrastructure Capital Costs – Annual Fuel or Electricity Costs – Lifecycle Operating and Maintenance Costs – Financial Incentives

Source: WSP, LTD

Note: Metrics associated with Social Equity/Environmental Impact and Lifecycle Costs categories align with the mission of LTD's Triple-Bottom-Line Approach to Sustainability. The Social Equity/Environmental Impact category aims to evaluate a fuel/technology's ability to ensure that LTD is "Caring for people including the communities in which we operate, our stakeholders, and our employees." and "Using natural resources efficiently and protecting our physical environment." The Lifecycle Costs category aims to evaluate a fuel/technology based on LTD's goal of "Being responsible stewards of financial resources."

The following subsections provide a summary of each fuel/technology evaluation category, including a description of each metric, its data type, classification, and source(s).

2.2.1 OPERATIONAL IMPACT

The Operational Impact category evaluates fuels/technologies based on the potential changes and adaptations that are needed to adopt the fuel/technology. Vehicle range considers the distance that the vehicle can travel on a single fuel or charge event – this informs infrastructure requirements and costs. Physical space requirements account for the spatial requirements at the operating facility for the storage of the vehicles and required infrastructure. Lastly, fueling or charging time analyzes the time it takes for a vehicle to refuel or charge. This also has a direct impact on operations at the facility. Table 2-4 summarizes the Operational Impact metrics considered in the fuel/technology evaluation.

Table 2-4. Operational Impact Metrics Summary

Evaluation Metric	Description	Data Type	Data Classification	Source
Vehicle Range	The range of the fuel/technology type.	Quantitative	Number of miles per fueling/charging event	LTD, New Flyer, BYD, Proterra, Altoona Testing
Physical Space Requirements	The scale of the space required to accommodate new infrastructure at LTD's Glenwood headquarters and bus yard.	Qualitative	Low, Medium, High	LTD, Ballard Power, Linde, Air Liquide, Air Products
Fueling or Charging Time	The time it takes to fully fuel or charge the vehicle.	Quantitative	Time in hours	LTD, AC Transit

Source: WSP, LTD

2.2.2 SOCIAL EQUITY/ENVIRONMENTAL IMPACT

Several metrics aligned with LTD's Social Equity/Environmental Impact goal of "caring for people including the communities in which we operate, our stakeholders, and our employees." and "using natural resources efficiently and protecting our physical environment."

Metrics include Lifecycle GHG emissions and the fuel/technology's ability to meet the Climate Action Policy Statement and Fleet Procurement Goals of achieving a 75 percent reduction in lifecycle GHG emissions and an elimination of fossil fuel vehicles by 2035. The local air quality metric analyzes the negative externalities and impacts to the community that may occur with the adoption of the new fuel/technology. Table 2-5 summarizes the Social Equity/Environmental Impact metrics considered in the fuel/technology evaluation.

Table 2-5. Social Equity/Environmental Impact Metrics Summary

Evaluation Metric	Description	Data Type	Data Classification	Source
Lifecycle GHG Emissions	A measure of GHG emissions.	Quantitative	Gram of CO2e/mile	Oregon Clean Fuels Program (OCFP)
75 Percent Reduction in Tailpipe GHG Emissions	Whether or not the fuel type/technology would reduce at least 75 percent tailpipe emissions when compared to the standard five-year carbon intensity average.	Qualitative	Yes or No	OCFP
Elimination of Fossil Fuel Vehicles by 2035	Whether or not the fuel/technology will result in an elimination of fossil fuel vehicles by 2035	Qualitative	Yes or No	OCFP, LTD
Local Air Quality*	A measure of tailpipe emissions, categorized by six pollutants: CO, Nitrogen Oxides, PM10, PM2.5, VOCs, and Sulfur Oxides	Quantitative	Grams per mile	OCFP, AFLEET Tool

Source: WSP, LTD

Note: *Criteria pollutants vary in their adverse effects and toxicity; therefore, WSP used Caltrans' B/C Sketch Model v7.2 to develop a weighted score to more accurately account for these effects.

2.2.3 LIFECYCLE COSTS

The Lifecycle Costs evaluation category reflects LTD's goal of "being responsible stewards of financial resources." The lifecycle cost factors studied included vehicle capital costs, infrastructure capital costs, annual fuel/electricity costs, lifecycle operating costs, and financial incentives. Table 2-6 summarizes the Lifecycle Costs metrics considered in the fuel/technology evaluation.

Table 2-6. Lifecycle Costs Metrics Summary

Evaluation Metric	Description	Data Type	Data Classification	Source
Vehicle Capital Costs	The purchase price of a vehicle, inclusive of LTD's preferred options, contingency, and service preparation.	Quantitative	Dollar value, per bus	LTD, Statewide Contracts (CA, WA, and VA)
Infrastructure Capital Costs*	The capital costs of infrastructure to support 70 vehicles of the fuel/technology at LTD's Glenwood bus yard.	Quantitative	Dollar value, for 70 buses	LTD, NW Natural, Ballard, Linde, Air Liquide, Air Products, Cherriots, SPUD, EWEB
Annual Fuel or Electricity Costs**	The costs to fuel or charge each vehicle. Adjusted to include Federal and State incentives, such as OCFP and RIN Credits.	Quantitative	Dollar value, per bus	LTD, OCFP, Federal Renewable Fuel Standard Program
Lifecycle Operating and Maintenance Costs	The costs to operate and maintain a vehicle over its 12-year useful life, inclusive of preventative maintenance, retirement, and overhaul costs.	Quantitative	Dollar value, per bus	LTD, King County Metro, AC Transit, NREL
Financial Incentives	The availability of competitive grants and other funding.	Qualitative	Low, Medium, High	FTA, STIF, CMAQ

Source: WSP

Notes: *The infrastructure costs include design, materials, and labor. In most instances, estimates do not include any potential required upgrades to LTD's transformer and electrical switchgear.

**Based on an estimated 40,000 annual miles traveled per bus. Electricity calculations were based on the Springfield Utility Board (SUB) energy prices (between five and six cents/kWh – depending on season). SUB does not utilize time-of-use (TOU) pricing, but the current rate schedule does include demand charges set by the peak amount of electricity delivered to LTD's site each month. All values rounded to the nearest thousandth.

2.3 EVALUATION METHODOLOGY

The weighted average values of each quantitative metric were calculated on the basis of LTD's fleet makeup of 59% 40-foot vehicles, 12% 60-foot vehicles, and 30% EmX vehicles. Individual values for each fleet were multiplied by their percent fleet makeup to get a weighted average across LTD's Fleet.

To evaluate each fuel/technology, data for each metric were collected, processed, and analyzed. Each metric value was then assigned a score based on a zero to two scale. A zero (or "low") was assigned if the fuel/technology doesn't meet criteria or was dramatically lower than other scores (ex. if emissions exceed Policy goals), a one (or "medium") was assigned if the fuel/technology moderately meets the criteria, and a two (or "high") was assigned if the fuel/technology meets or exceeds the criteria. Some metrics use LTD's existing conditions as a baseline for comparison, whereas other metrics' scores are relative to the fuels/technologies being analyzed. Each score was rounded to the nearest whole number and presented as a Harvey ball symbol for ease of understanding and analysis. It should be noted that all values were rounded to the nearest whole number.

In this report, each score is represented by a Harvey ball symbol for ease of understanding and analysis. Table 2-7 presents the screening threshold for each metric.

Table 2-7. Evaluation Methodology

Symbol	Score	Description
●	2 (High)	A high score indicates that the fuel/technology highly supports and satisfies the metric or has a low potential for negative impacts.
◑	1 (Medium)	A medium score indicates that the fuel/technology moderately supports and satisfies the metric or has a moderate potential for negative impacts.
○	0 (Low)	A low score indicates that the fuel/technology does not support or conflicts with the metric or has a high potential for negative impacts.

Source: WSP

For each evaluation category, a fuel/technology's scores for each metric were summed and averaged (and rounded to the nearest whole number) to determine an overall score for that category. It is assumed that if a fuel/technology scores "high" for any category, it may be viable for further study in Phase II.

The following sections summarize the scores for each fuel/technology type by evaluation category and metric.

3 OPERATIONAL IMPACT

The following section summarizes the Operational Impact evaluation and scores for each fuel/technology type.

3.1 VEHICLE RANGE

Vehicle range refers to the maximum distance that can be achieved on a single fill or charge. Fuels/technologies with higher ranges are the most advantageous to LTD. Based on the evaluation, renewable diesel and RNG provide the highest range (300 miles). LH2 and GH2 provide the second highest range (250 miles), and battery-electric provides the lowest range (less than 125 miles). Table 3-1 summarizes the estimated vehicle ranges and associated scores by fuel/technology type.

Table 3-1. Vehicle Range Evaluation (miles per vehicle, per charge event)

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Vehicle Range	300	300	300	120	250	250	250	250
Vehicle Range Score	●	●	●	○	◑	◑	◑	◑

Source: LTD, New Flyer, BYD, Proterra, Altoona Testing

3.2 PHYSICAL SPACE REQUIREMENTS

Physical space requirements refer to the amount of real estate required for the infrastructure that supports the fuel/technology. Fuels/technologies with no or low physical space requirements are the most advantageous to LTD and score the highest. Based on the evaluation, renewable diesel requires no additional physical space since it is currently being used by LTD. Delivered LH2, RNG, and battery-electric serve as the next best alternative (medium), and GH2 produced onsite is the least advantageous (high) due to the need to install both fuel production and dispensing equipment and National Fire Protection Association (NFPA) required setbacks around hydrogen production equipment. Table 3-2 summarizes the physical space requirements and associated scores by fuel/technology type.

Table 3-2. Physical Space Requirements Evaluation

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Physical Space Requirements	None	None	Medium	Medium	High	High	Medium	Medium
Physical Space Requirements Score	●	●	◑	◑	○	○	◑	◑

Source: LTD, Ballard Power, Linde, Air Liquide, Air Products

3.3 FUELING OR CHARGING TIME

Fueling or charging time is the time it takes to replenish an empty tank or battery from empty to full. Fuels/technologies that have shorter fueling or charging times are the most advantageous to LTD. Based on this analysis, RNG and LH2/GH2 require the shortest time to fuel (seven minutes). Renewable diesel provides the second shortest fuel times (15 minutes), and battery-electric takes the longest time to recharge, six hours (varies based on charger, battery state-of-charge, and battery capacity). Table 3-3 summarizes the estimated fuel or charging times and associated scores by fuel/technology type.

Table 3-3. Fueling or Charging Time Evaluation (time, per vehicle)

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Fueling or Charging Time	00:15	00:15	00:07	06:00	00:07	00:07	00:07	00:07
Fueling or Charging Time Score	●	●	●	○	●	●	●	●

Source: LTD, AC Transit

3.4 OPERATIONAL IMPACT SUMMARY

Based on the analyzed Operational Impact metrics, renewable diesel and RNG fuels appear to yield the most operational benefits. This is primarily due to the relatively high vehicle ranges, short fueling times, and a relatively low spatial impact (or none, in the case of renewable diesel). Hydrogen fuels had "medium" scores for Operational Impact and battery-electric scored "low". Table 3-4 summarizes the Operational Impact evaluation metrics and scores.

Table 3-4. Operational Impact Evaluation Summary

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Vehicle Range	300 ●	300 ●	300 ●	120 ○	250 ◑	250 ◑	250 ◑	250 ◑
Physical Space Requirements	None ●	None ●	Medium ◑	Medium ◑	High ○	High ○	Medium ◑	Medium ◑
Fueling or Charging Time	00:15 ●	00:15 ●	00:07 ●	06:00 ○	00:07 ●	00:07 ●	00:07 ●	00:07 ●
Total Operational Impact Score (Avg)	High ●	High ●	High ●	Low ○	Medium ◑	Medium ◑	Medium ◑	Medium ◑

Source: WSP, LTD, Vehicle OEMs, AFLEET, Fuel Providers, Peer Agencies

Note: Total Score is rounded to the nearest whole number.

4 SOCIAL EQUITY/ENVIRONMENTAL IMPACT

The following section summarizes the Social Equity/Environmental Impact evaluations and scores for each fuel/technology type.

4.1 LIFECYCLE GHG EMISSIONS

Lifecycle GHG emissions refers to both the tailpipe and upstream emissions from production and delivery of the fuel/technology (grams). Fuels and technologies with fewer grams of emissions are the most advantageous for LTD. Based on this analysis, battery-electric provides the fewest amount of lifecycle GHG emissions (85 grams/mi). Hydrogen (electrolysis and local delivery) provide the second and third fewest, respectively – followed by renewable diesel for dHEBs and ICEs. LH2 delivered from a fossil-based national source or generated on-site via SMR (GH2) provided the highest relative GHG emissions. Table 4-1 summarizes annual lifecycle GHG emission metrics and associated scores by fuel/technology type.

Table 4-1. Lifecycle GHG Emissions Evaluation (g of CO2e/mil per vehicle)

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Lifecycle GHG Emissions	919	784	1,273	85	2,423	657	657	3,209
Lifecycle GHG Emissions Score	◑	◑	◑	●	○	◑	◑	○

Source: Oregon Clean Fuels Program

4.2 75 PERCENT REDUCTION IN TAILPIPE GHG EMISSIONS

A 75 percent reduction in tailpipe GHG emissions is a goal of the Climate Action Policy Statement and Fleet Procurement Goals. If a fuel/technology achieves this, it is in compliance. A fuel/technology that is in compliance is the most advantageous to LTD. Based on the analysis, all analyzed fuels/technologies meet this requirement – renewable diesel achieves 99 percent, and all other fuels/technologies achieve 100 percent. Table 4-2 summarizes the 75 percent reduction in tailpipe GHG emissions metric and associated scores by fuel/technology type.

Table 4-2. 75 Percent Reduction in Tailpipe GHG Emissions Evaluation

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
75 Percent Reduction in Tailpipe GHG Emissions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
75 Percent Reduction in Tailpipe GHG Emissions Score	●	●	●	●	●	●	●	●

Source: Oregon Clean Fuels Program

4.3 ELIMINATION OF FOSSIL FUEL VEHICLES BY 2035

An elimination of all fossil fuel vehicles by 2035 is a goal of the Climate Action Policy Statement and Fleet Procurement Goals. If a fuel/technology achieves this, it is in compliance. A fuel/technology that is in compliance is the most advantageous to LTD. Renewable diesel is only 99% renewable, therefore, it doesn't meet the requirements. There is a possibility that more renewable diesel in Oregon could be blended with 1% biodiesel (opposed to 1% fossil diesel) to make it a fully renewable product. Based on the analysis, RNG, battery-electric, GH2 on-site (SMR or electrolysis) and LH2 delivered locally meet this requirement. RNG and SMR (via RNG) are considered non-fossil fuels because they are sourced from organic waste. LH2 that is locally-delivered is considered a non-fossil fuel because it would be produced using excess hydroelectricity. With Power Purchasing Agreements (PPAs), it is possible that LTD could source fossil fuel-free electricity. Table 4-3 summarizes the elimination of fossil fuel vehicles by 2035 metric and associated scores by fuel/technology type.

Table 4-3. Elimination of Fossil Fuel Vehicles by 2035 Evaluation

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Elimination of Fossil Fuel Vehicles by 2035	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Elimination of Fossil Fuel Vehicles by 2035 Score	○	○	●	●	●	●	●	●

Source: LTD, Oregon Clean Fuels Program

4.4 LOCAL AIR QUALITY

Local air quality refers to the annual tailpipe emissions of the six common criteria pollutants: carbon monoxide, nitrogen oxides, PM10, PM2.5, volatile organic compounds, and sulfur oxides (grams per mile, per bus). Fuels/technologies with fewer emissions are the most advantageous for LTD and its service area. Based on this analysis, LH2/GH2, and battery-electric yield the least amount of tailpipe emissions (0.11 grams). RNG provide the second least amount of emissions (0.24), and renewable diesel emits the relatively highest volume of emissions (0.54). Table 4-4 summarizes local air quality and associated scores by fuel/technology type.

Table 4-4. Local Air Quality Evaluation (g/mi, per vehicle)

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Local Air Quality	0.54	0.54	0.24	0.11	0.11	0.11	0.11	0.11
Local Air Quality Score	○	○	◑	●	●	●	●	●

Source: AFLEET, Oregon Clean Fuels Program

4.5 SOCIAL EQUITY/ENVIRONMENTAL IMPACT SUMMARY

Based on the analyzed Social Equity/Environmental Impact metrics, RNG and locally-delivered LH2 appear to yield the most Social Equity/Environmental Impact benefits. This is primarily due to them exceeding a 75 percent reduction in tailpipe emissions, 100 percent elimination of fossil fuels, and relatively low levels of lifecycle GHG emissions. Table 4-5 summarizes the Social Equity/Environmental Impact evaluation metrics and scores.

Table 4-5. Social Equity/Environmental Impact Evaluation Summary

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Lifecycle GHG Emissions	919 ◑	784 ◑	1,273 ◑	85 ●	2,423 ○	657 ◑	657 ◑	3,209 ○
75 Percent Reduction in Tailpipe GHG Emissions	Yes ●	Yes ●	Yes ●	Yes ●	Yes ●	Yes ●	Yes ●	Yes ●
Elimination of Fossil Fuel Vehicles by 2035	No ○	No ○	Yes ●	Yes ●	Yes ●	Yes ●	Yes ●	Yes ●
Local Air Quality	0.54 ○	0.54 ○	0.24 ◑	0.11 ●	0.11 ●	0.11 ●	0.11 ●	0.11 ●
Total Social Equity/Environmental Impact Score (Avg.)	Medium ◑	Medium ◑	High ●	High ●	High ●	High ●	High ●	High ●

Source: LTD, Oregon Clean Fuels Program

Note: Total Score is rounded to the nearest whole number.

5 LIFECYCLE COSTS

The following section summarizes the Lifecycle Costs evaluations and scores for each fuel/technology type.

5.1 VEHICLE CAPITAL COSTS

Vehicle capital costs represent the purchase price of a vehicle (inclusive of LTD's preferred options). Fuels/technologies with the cheapest vehicles are the most advantageous to LTD. Based on the evaluation, ICE vehicles powered by renewable diesel or RNG are the cheapest ($645,000 to $851,000). BEBs and LH2/GH2 vehicles are the most expensive – ranging from $1.2 to $1.4 million, respectively. Table 5-1 summarizes the estimated vehicle capital costs and associated scores by fuel/technology type.

Table 5-1. Vehicle Capital Costs Evaluation (per vehicle)

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Vehicle Capital Costs	$645K	$851K	$745K	$1.2M	$1.4M	$1.4M	$1.4M	$1.4M
Vehicle Capital Costs Score	●	●	●	○	○	○	○	○

Source: LTD, Statewide Contracts from CA, WA, VA

5.2 INFRASTRUCTURE CAPITAL COSTS

Infrastructure capital costs are the costs associated with constructing the infrastructure to operate and maintain the fuel/technology. Fuels/technologies with the cheapest infrastructure costs are the most advantageous to LTD. Based on the evaluation, infrastructure to support a renewable diesel fleet is the cheapest ($15,000). Infrastructure to support battery-electric and RNG are the second cheapest – ranging between $58,000 and $61,000, respectively. Hydrogen-supporting infrastructure, on-site in particular, is the most expensive – approximately $500K. Table 5-2 summarizes the estimated infrastructure capital costs and associated scores by fuel/technology type.

Table 5-2. Infrastructure Capital Costs Evaluation (for 70 vehicles)

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Infrastructure Capital Costs	$1.1M	$1.1M	$4.3M	$4.1M	$34.9M	$31.2M	$19.4M	$19.4M
Infrastructure Capital Costs Score	●	●	◑	◑	○	○	○	○

Source: LTD, NW Natural, Ballard, Linde, Air Products, Cherriots, SPUD, EWEB
Note: Infrastructure supporting. LTD's procured 30 BEBs is not included in these costs.

5.3 ANNUAL FUEL OR ELECTRICITY COSTS

Fuel or electricity costs are the costs associated with operating the fuel/technology (annually). It was assumed that all vehicles travel 40,000 miles per year. Fuels/technologies with the cheapest fuel or electricity costs are the most advantageous to LTD. Based on the evaluation, RNG has the cheapest fuel cost ($3,000), followed by battery-electric ($12,000), and renewable diesel for a dHEB or ICE fleet ($20,000 and $23,000, respectively). GH2 generated on site or delivered nationally (LH2) is the most expensive with annual fuel and electricity costs upwards of $81,000. Table 5-4 summarizes the annual fuel or electricity costs and associated scores by fuel/technology type.

Table 5-3. Annual Fuel or Electricity Costs Evaluation (annual per vehicle)

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Annual Fuel or Electricity Costs	$23K	$20K	$3K	$12K	$81K	$81K	$27K	$44K
Annual Fuel or Electricity Costs Score	●	●	●	●	○	○	◑	○

Source: LTD, Oregon Clean Fuels Program, Federal Renewable Standard Program

5.4 LIFECYCLE OPERATING AND MAINTENANCE COSTS

Lifecycle operating and maintenance costs are the costs associated with the operation and maintenance of the fuel/technology over the life of the vehicle. The minimum useful life as defined by FTA is 12 years. Fuels/technologies with the cheapest operating and maintenance costs are the most advantageous to LTD. Based on the evaluation, RNG and renewable diesel (for ICE) are the cheapest for LTD to maintain ($368,000 and $499,000, respectively). Hydrogen fuel is next – between $680,000 and $686,000, and battery-electric is the most expensive to maintain with approximately $926,000 annual maintenance costs. Table 5-4 summarizes the estimated lifecycle operating and maintenance costs and associated scores by fuel/technology type.

Table 5-4. Lifecycle Operating and Maintenance Costs Evaluation (per vehicle, 12-year useful life)

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Lifecycle Operating and Maintenance Costs	$499K	$767K	$368K	$926K	$686K	$686K	$686K	$686K
Lifecycle Operating and Maintenance Costs Score	●	○	●	○	◑	◑	◑	◑

Source: LTD, NREL, King County Metro, AC Transit

5.5 FINANCIAL INCENTIVES

Financial incentives gauge the type of funding and grants available to support the transition to the fuel/technology. Fuels/technologies with a high level of financial incentives are the most advantageous to LTD. Based on the evaluation, all fuels/technologies have a "high" amount of funding available, with the exception of renewable diesel that has a medium amount of funding available. Table 5-5 summarizes the estimated financial incentives and associated scores by fuel/technology type.

Table 5-5. Financial Incentives Evaluation

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Financial Incentives	Medium	Medium	High	High	High	High	High	High
Financial Incentives Score	◑	◑	●	●	●	●	●	●

Source: FTA, STIF, CMAQ

5.6 LIFECYCLE COSTS SUMMARY

Based on the analyzed Lifecycle Costs metrics, RNG and ICEs powered by renewable diesel yield the most Lifecycle Costs benefits. This is primarily due to them having relatively low capital costs for vehicles, infrastructure, fuel, and operating and maintenance costs. Table 5-6 summarizes the Lifecycle Costs evaluation metrics and scores.

Table 5-6. Lifecycle Costs Evaluation Summary

Metric	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Vehicle Capital Costs	$645K ●	$851K ●	$745K ●	$1.2M ○	$1.4M ○	$1.4M ○	$1.4M ○	$1.4M ○
Infrastructure Capital Costs	$1.1M ●	$1.1M ●	$4.3M ◑	$4.1M ◑	$34.9M ○	$31.2M ○	$19.4M ○	$19.4M ○
Annual Fuel or Electricity Costs	$23K ●	$20K ●	$3K ●	$12K ●	$81K ○	$81K ○	$27K ◑	$44K ○
Lifecycle Operating and Maintenance Costs	$499K ●	$767K ○	$368K ●	$926K ○	$686K ◑	$686K ◑	$686K ◑	$686K ◑
Financial Incentives	Medium ◑	Medium ◑	High ●	High ●	High ●	High ●	High ●	High ●
Lifecycle Costs Total Score (Avg.)	High ●	Medium ◑	High ●	Medium ◑	Medium ◑	Medium ◑	Medium ◑	Medium ◑

Source: LTD, Supplier OEMs, Peer Agencies

Note: Total Score is rounded to the nearest whole number.

6 FINDINGS, SELECTED FUELS/TECHNOLOGIES, AND NEXT STEPS

The following section presents the findings of each evaluation category, the fuels/technologies selected based on the analysis, and the next steps to be carried out in Phase II.

6.1 PHASE I FINDINGS

Based on the analyzed Operational Impact metrics, renewable diesel and RNG appear to yield the most Operational Impact benefits. This is primarily due to the relatively high vehicle ranges and short fueling times. All other fuels/technologies had "medium" or "low" scores for Operational Impact.

Based on the analyzed Social Equity/Environmental Impact metrics, RNG, battery-electric, and hydrogen-based fuels/technologies appear to yield the most Social Equity/Environmental Impact benefits. This is primarily due to them exceeding a 75 percent reduction in tailpipe emissions, elimination of fossil fuel vehicles by 2035, and relatively low levels of lifecycle GHG emissions.

Based on the analyzed Lifecycle Costs metrics, RNG and ICEs powered by renewable diesel yield the most Lifecycle Costs benefits. This is primarily due to them having relatively low capital costs for vehicles, infrastructure, fuel, and operating and maintenance costs.

Table 6-1 summarizes the Phase I evaluation category scores for each fuel/technology type.

Table 6-1. Phase I Score Summary

Evaluation Category	Renewable Diesel		RNG	BEB	GH2 Generated On-Site		LH2 Delivered	
	ICE	dHEB			SMR	Electrolysis	Local	National
Operational Impact Score	High ●	High ●	High ●	Low ○	Medium ◑	Medium ◑	Medium ◑	Medium ◑
Social Equity/Environmental Impact Score	Medium ◑	Medium ◑	High ●	High ●	High ●	High ●	High ●	High ●
Lifecycle Costs Score	High ●	Medium ◑	High ●	Medium ◑	Medium ◑	Medium ◑	Medium ◑	Medium ◑
Selected to move into Phase II	Yes	No	Yes	Yes	No	No	Yes	Yes

Source: WSP

Based on the analysis, all evaluated fuels/technologies scored "high" on one or more of the evaluation categories. However, there were several fatal flaws identified that eliminate some of these fuels from further consideration in Phase II.

Although LTD currently uses dHEB vehicles powered by renewable diesel, dHEBs are more expensive to procure and have a reduced market availability as compared to ICE counterparts. Since renewable diesel can only be used as a transition fuel since it still consists of 1% fossil fuel and any interruptions in supply would require LTD to revert to fossil diesel - it is recommended that LTD's dHEB fleet be permanently retired and replaced with ICE vehicles (powered by renewable diesel) or ZEBs, depending on procurement goals and timing, which will be further explored in Phase II.

On-site generation of hydrogen whether via SMR or electrolysis is also not considered a viable fuel/technology at this time. LTD's existing lot cannot fit both hydrogen storage and hydrogen production infrastructure without removing bus parking. If the unused land next to the employee parking lot is taken into consideration, then hydrogen generation may be viable. The issue is not the physical footprint of the equipment alone, but the footprint combined with the required setbacks established by the National Fire Protection Agency (NFPA). The production and storage equipment would be subject to strict NFPA setbacks, such as maintaining a 50-foot gap between infrastructure and the property line. The residential housing adjacent to the property may also be a barrier to adoption due to safety or general community concerns. Further detailed analysis and decisions/assumptions would have to be made to commit to this fuel/technology; for this reason, WSP recommends that it not be considered in Phase II.

As previously mentioned, LTD has also procured 30 BEBs. Based on existing conditions, the limited range of this fuel/technology does not appear to be a feasible solution that can meet the demands of the LTD's 60-foot-serving blocks and EmX service; however, the technology is rapidly advancing and there are several strategies that LTD could consider to extend range (including opportunity charging, charge management strategies, service changes, etc.). For this reason, the battery-electric technology will also be considered in Phase II.

Therefore, it is recommended that Phase II considers renewable diesel as a transition fuel for LTD's ICE vehicles and either RNG, battery-electric, or locally- or nationally-delivered LH2 as a long-term solution.

Table 6-2 summarizes whether the options evaluated herein will be evaluated in Phase II and a brief explanation of why.

Table 6-2. Selected Fuels/Technologies Summary

Fuel/Technology	Considered in Phase II?	Justification
Renewable Diesel (R99)/ Internal Combustion Engine (ICE)	Yes	R99 is the existing fuel, scored high for the Operational Impact and Lifecycle Costs score. R99, currently used by LTD, will be considered as the transition fuel to a future fuel/technology. At this time, it does not have long-term applicability because it still contains 1% fossil fuel.
Renewable Diesel (R99)/ Diesel Hybrid (dHEB)	No	While LTD currently operates some dHEBs, it is more financially viable to operate the ICEs with renewable diesel until the new fuel is adopted.
Renewable Natural Gas (RNG)/ Internal Combustion Engine (ICE)	Yes	RNG scored high in all three evaluation categories and will be considered in Phase II.
Electricity/ Battery-Electric	Yes	Battery-electric technology currently cannot support the ranges required by LTD's bus fleet; however, it is recommended that it be further evaluated in Phase II.
On-Site Generated GH2 via Steam Methane Reformation (SMR)	No	SMR on-site would require a significant investment and space at LTD's facility – space that is not currently available. Therefore, it cannot be considered for the 15-year plan.
On-Site Generated GH2 via Electrolysis	No	Electrolysis on-site would require a significant investment and space at LTD's facility – space that is not currently available. Therefore, it cannot be considered for the 15-year plan.
Locally Generated and Delivered LH2	Yes	Locally-supplied hydrogen scored high on the Social Equity/Environmental Impact category. There is a lot of potential promise, as well as significant uncertainty, of this local project that will be further explored in Phase II.
Nationally Generated and Delivered LH2	Yes	Nationally-supplied hydrogen scored high on the Social Equity/Environmental Impact category. There is a lot of potential promise in this fuel/technology that will be further explored in Phase II.

Source: WSP

6.2 NEXT STEPS

In Phase II, further refinements and research will be conducted to ensure that both the transition fuel/technology (renewable diesel) and selected fuel/technology types (RNG, BEB, and delivered LH2) are fully understood. This includes the sourcing and long-term outlooks of the market and greater detail with respect to the facility requirements and how the transition will impact LTD's maintenance and operations. This information will then inform the development of 15-year planning scenarios that present the paths that LTD can take to meeting its goals. Phase II will conclude with an actionable Fleet Procurement Plan that will guide LTD through the next 15 years of its transition.

Appendix A: List of Stakeholders

Table 1. Internal Stakeholders

Name	Title , Department
Ric Adams	Maintenance Supervisor, Fleet Management Department
Rebecca Bailey	Operations Supervisor, Operations Department
Eric Evers	Maintenance Manager, Fleet Management Department
Kelly Hoell	Sustainability Program Manager, Fleet Management Department
Matt Imlach	Fleet Management Director, Fleet Management Department
Heather Lindsay	Service Planner, Planning and Development Department
Robin Mayall	Director of Information Technology and Strategic Innovation, IT Department
Steve Parrott	ITS Manager, IT Department
Cosette Rees	Director, Accessible and Customer Services Department
Allen Shipp	Journey-Level Mechanic, Fleet Management Department
Nash Siegrist	Bus Operator / Operations Training Assistant Supervisor, Operations Department
Randi Staudinger	Project Manager, Facilities Management Department
David Svendsen	Maintenance Supervisor, Fleet Management Department
Frank Wilson	Public Safety and System Security Manager, Operations Department

Table 2. External Stakeholders

Name	Organization
Joy Alafia	Western Propane Gas Association
Haley Case-Scott	Beyond Toxics/NAACP
Alex Cuyler	Lane County
Christina Grabo	Bluestar Propane
Michael Graham	Columbia Willamette Clean Cities Coalition
Chris Kroeker	NW Natural
Sydney Krueger	Ballard Power
Garrett Kruger	Rousch
Frank Lawson	Eugene Water & Electric Board (EWEB)
Ethan Nelson	City of Eugene
Aimée Okotie-Oyekan	Beyond Toxics/NAACP
Jeff Orlandini	Lane County
Bill Peters	Oregon Clean Fuels Program
Tracy Richardson	Springfield Utility Board
Alex Schay	Northwest Alliance for Clean Transportation
Matt Stouder	Metropolitan Wastewater Management Commission (MWMC)
Mark Van Eeckhout	Metropolitan Wastewater Management Commission (MWMC)
Cory Ann Wind	Oregon Clean Fuels Program
Various Representatives	Carson
	Tyree
	Christensen
	Petroleum Traders
	Wilcox and Flegel
	McCall
	Oregon Petroleum Transport Company

Appendix B: Matrix Data and Outputs

		BUS FLEET - VALUES											
		Baseline				Future							
Weighting Criteria	Recommended Weighting	Diesel ICE R99	Diesel Hybrid R99	Electric - 40' 388 kWh with 150 kW 3:1 depot charge	Electric 40' 528 kWH with 150 kW 3:1 depot charge	RNG - contracted (Wastewater)	RNG - Direct pipeline (Landfill)	BEB - 528 kWh 40' & 620 kWh 60' with 150 kW 2:1 depot charge	Hydrogen - Trucked in via fossil SMR	Hydrogen - On-site SMR with RNG	Hydrogen - On-site with electroysis	Hydrogen - EWEB option, baseline fuel cost ($8/kg)	Hydrogen - EWEB Option, break even fuel cost $5/kg
Capital Cost (Vehicle including options, contingency and service prep)	**7.00%**	**$ 644,882**	**$ 850,839**	**$ 901,967**	**$ 945,891**	**$ 745,388**	**$ 745,388**	**$ 1,186,751**	**$ 1,353,557**	**$ 1,353,557**	**$ 1,353,557**	**$ 1,353,557**	**$ 1,353,557**
Capital Cost (Vehicle) 40' Fleet	*61%*	*$ 534,990*	*$ 696,990*	*$ 901,967*	*$ 945,891*	*$ 589,990*	*$ 589,990*	*$ 945,891*	*$ 1,148,659*	*$ 1,148,659*	*$ 1,148,659*	*$ 1,148,659*	*$ 1,148,659*
Capital Cost (Vehicle) 60' Fleet	*15%*	*$ 769,990*	*$ 1,014,990*	*$ -*	*$ -*	*$ 911,990*	*$ 911,990*	*$ 1,488,668*	*$ 1,598,535*	*$ 1,598,535*	*$ 1,598,535*	*$ 1,598,535*	*$ 1,598,535*
Capital Cost (Vehicle) 60' EMX Fleet	*24%*	*$ 849,990*	*$ 1,144,990*	*$ -*	*$ -*	*$ 1,041,990*	*$ 1,041,990*	*$ 1,618,668*	*$ 1,728,535*	*$ 1,728,535*	*$ 1,728,535*	*$ 1,728,535*	*$ 1,728,535*
Capital Cost Infrastructure (per vehicle rate)	**7%**	**$ 15,000**	**$ 15,000**	**$ 69,173**	**$ 60,992**	**$ 60,571**	**$ 60,571**	**$ 58,315**	**$ 276,571**	**$ 498,240**	**$ 446,415**	**$ 276,571**	**$ 276,571**
Fuel Cost (per 40,000 mi)	**7.00%**	**$ 22,714**	**$ 19,724**	**$ 41,707**	**$ 41,440**	**$ 2,870**	**$ 3,024**	**$ 12,140**	**$ 44,145**	**$ 55,504**	**$ 71,731**	**$ 44,145**	**$ 27,322**
40' Fleet	*59%*	*$ 22,069*	*$ 16,552*	*$ 41,707*	*$ 41,440*	*$ 2,804*	*$ 2,793*	*$ 10,151*	*$ 37,045*	*$ 40,219*	*$ 51,978*	*$ 37,045*	*$ 22,927*
60' Fleet	*12%*	*$ 23,415*	*$ 24,000*	*$ -*	*$ -*	*$ 3,365*	*$ 3,352*	*$ 14,824*	*$ 53,715*	*$ 58,318*	*$ 75,368*	*$ 53,715*	*$ 33,245*
EMX Fleet	*30%*	*$ 23,711*	*$ 24,304*	*$ -*	*$ -*	*$ 2,804*	*$ 3,352*	*$ 15,011*	*$ 54,395*	*$ 84,561*	*$ 109,284*	*$ 54,395*	*$ 33,665*
Operating Cost (Maintenance Cost per 40,000 mi)	**7.00%**	**$ 499,212**	**$ 767,260**	**$ 922,155**	**$ 922,155**	**$ 367,691**	**$ 367,691**	**$ 926,367**	**$ 685,778**	**$ 780,211**	**$ 685,778**	**$ 680,778**	**$ 680,778**
Operating Cost (Maintenance) 40' Fleet	*61%*	*$ 476,783*	*$ 761,354*	*$ 922,155*	*$ 922,155*	*$ 306,341*	*$ 306,341*	*$ 918,206*	*$ 655,443*	*$ 809,518*	*$ 655,443*	*$ 650,443*	*$ 650,443*
Operating Cost (Maintenance) 60' Fleet	*15%*	*$ 534,726*	*$ 776,611*	*$ -*	*$ -*	*$ 464,828*	*$ 464,828*	*$ 939,289*	*$ 733,809*	*$ 733,809*	*$ 733,809*	*$ 728,809*	*$ 728,809*
Operating Cost (Maintenance) EMX Fleet	*24%*	*$ 534,726*	*$ 776,611*	*$ -*	*$ -*	*$ 464,828*	*$ 464,828*	*$ 939,289*	*$ 733,809*	*$ 733,809*	*$ 733,809*	*$ 728,809*	*$ 728,809*
Financial Incentives	**5.00%**	**Medium**	**Medium**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**
75% reduction Tailpipe GHG emissions (Meets LTD Climate Policy)	**7.00%**	**99%**	**99%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Lifecycle GHG emissions (g/yr)	**9.00%**	**922**	**801**	**73**	**73**	**1,713**	**1,392**	**87**	**2,581**	**2,299**	**623**	**528**	**528**
Lifecycle GHG emissions 40' Fleet	*59%*	*896*	*672*	*73*	*73*	*1,582*	*1,285*	*73*	*2,166*	*1,666*	*452*	*443*	*443*
Lifecycle GHG emissions 60' Fleet	*12%*	*951*	*975*	*-*	*-*	*1,899*	*1,542*	*106*	*3,140*	*2,416*	*655*	*643*	*643*
Lifecycle GHG emissions EMX Fleet	*30%*	*963*	*987*	*-*	*-*	*1,899*	*1,542*	*108*	*3,180*	*3,503*	*950*	*651*	*651*
0% Fossil Fuel (Meets LTD Climate Policy)	**7.00%**	**No**	**No**	**No**	**No**	**Yes**	**Yes**	**No**	**No**	**Yes**	**No**	**yes**	**yes**
Local Air Quality (Criteria Air Polutants) (g/VMT)	**7.00%**	**0.54**	**0.54**	**0.11**	**0.11**	**0.24**	**0.24**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**
40' Fleet	*59%*	*0.54*	*0.54*	*0.11*	*0.11*	*0.24*	*0.24*	*0.11*	*0.11*	*0.11*	*0.11*	*0.11*	*0.11*
60' Fleet	*12%*	*0.54*	*0.54*	*-*	*-*	*0.24*	*0.24*	*0.11*	*0.11*	*0.11*	*0.11*	*0.11*	*0.11*
EMX Fleet	*30%*	*0.54*	*0.54*	*-*	*-*	*0.24*	*0.24*	*0.11*	*0.11*	*0.11*	*0.11*	*0.11*	*0.11*
Vehicle Range & Duty Cycle (miles per tank fill/depot charge)	**15.00%**	**300.0**	**300.0**	**103.5**	**210.0**	**300.0**	**300.0**	**122.1**	**250.0**	**250.0**	**250.0**	**250.0**	**250.0**
Vehicle Range & Duty Cycle - 40' fleet	*59%*	*300.0*	*300.0*	*103.5*	*210.0*	*300.0*	*300.0*	*140.0*	*250.0*	*250.0*	*250.0*	*250.0*	*250.0*
Vehicle Range & Duty Cycle - 60' fleet	*12%*	*300.0*	*300.0*	*-*	*-*	*300.0*	*300.0*	*105.0*	*250.0*	*250.0*	*250.0*	*250.0*	*250.0*
Vehicle Range & Duty Cycle - EmX Fleet	*30%*	*300.0*	*300.0*	*-*	*-*	*300.0*	*300.0*	*93.3*	*250.0*	*250.0*	*250.0*	*250.0*	*250.0*
Physical Space Requirements - Qualitative	**7.00%**	*no new space required*	*no new space required*	*6-9 parking spaces lost with installation of charging infrastructure for first 30 electric buses*	*6-9 parking spaces lost with installation of charging infrastructure for first 30 electric buses*	*Space needed for storage & Compression*	*Space needed for storage & Compression*	*Charging equipment requires new parking layout*	*Space required for hydrogen storage & compression equipment and NFPA required setbacks*	*Space required for hydrogen storage, compression, & generation equipment and NFPA required*	*Space required for hydrogen storage, compression, & generation equipment and NFPA required setbacks*	*Space required for hydrogen storage & compression equipment and NFPA required setbacks*	*Space required for hydrogen storage & compression equipment and NFPA required setbacks*
Fueling/Charging Time (hours)	**5.00%**	***0.3***	***0.3***	***3.0***	***5.5***	***0.1***	***0.1***	***6.0***	***0.1***	***0.1***	***0.1***	***0.1***	***0.1***
Disaster Resiliency	**5.00%**	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Long Term Fuel Availability	**5.00%**	Medium	Medium	High	High	Medium	Medium	High	Medium	Medium	High	High	High