Hydrogen-Powered Garbage Trucks for the City of Palo Alto

A FINANCIAL, ENVIRONMENTAL, AND POLICY ANALYSIS

MS&E 108 PROJECT PITCH

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Meet the Team



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M.S. in Sustainability Science



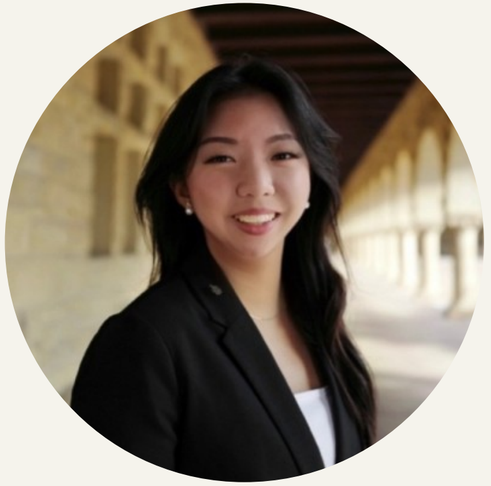
Vel Senthil

B.S. in MS&E



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B.S. in MS&E,
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Introduction

Problem Statement

A lack of **financial strategy** and **environmental analysis** on fleet management in the City of Palo Alto hinders the *investment decision* on hydrogen-powered garbage trucks.

Key Stakeholders



Brad Eggleston (DM)

Director of Public Works, City of Palo Alto



Phil Bobel

Prev. Manager of Public Works, City of Palo Alto



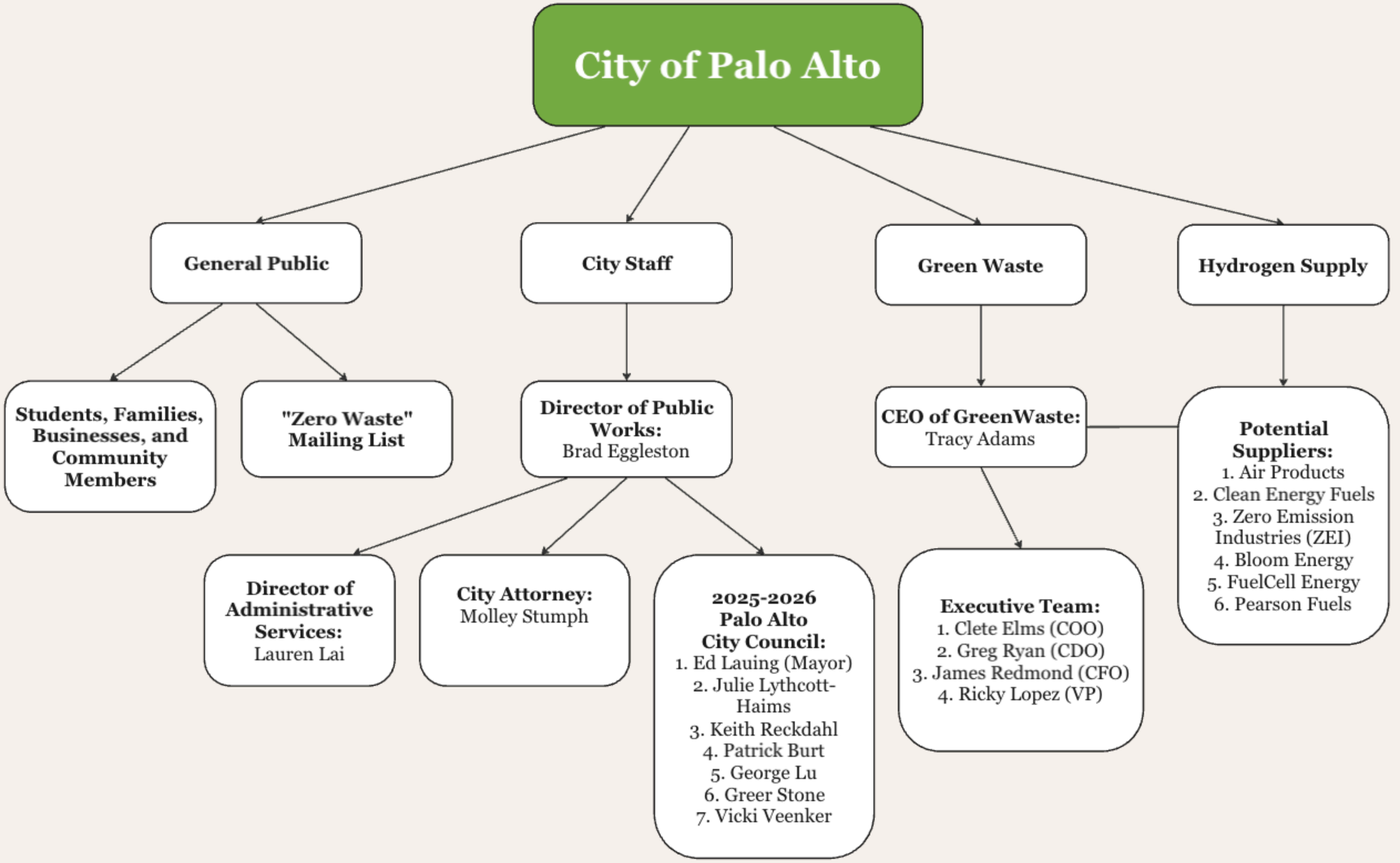
Lauren Lai

Director of Administrative Services, City of Palo Alto



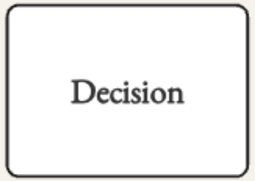
Tracy Adams

Chief Executive Officer of GreenWaste

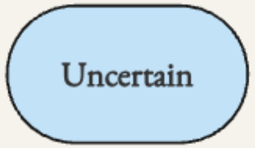

City of Palo Alto
General Public
City Staff
Green Waste
Hydrogen Supply
Students, Families, Businesses, and Community Members
"Zero Waste" Mailing List
Director of Public Works: Brad Eggleston
CEO of GreenWaste: Tracy Adams
Potential Suppliers:
1. Air Products
2. Clean Energy Fuels
3. Zero Emission Industries (ZEI)
4. Bloom Energy
5. FuelCell Energy
6. Pearson Fuels
Director of Administrative Services: Lauren Lai
City Attorney: Molley Stumph
2025-2026 Palo Alto City Council:
1. Ed Lauing (Mayor)
2. Julie Lythcott-Haims
3. Keith Reckdahl
4. Patrick Burt
5. George Lu
6. Greer Stone
7. Vicki Veenker
Executive Team:
1. Clete Elms (COO)
2. Greg Ryan (CDO)
3. James Redmond (CFO)
4. Ricky Lopez (VP)

Methods

A. Decision Quality Framework



A **decision node** represents a distinction to be resolved under the full control of the DM



An **uncertain node** represents a distinction which is not directly controlled by the decision maker



A **deterministic node** represents an uncertain variable that is functionally determined by its parents

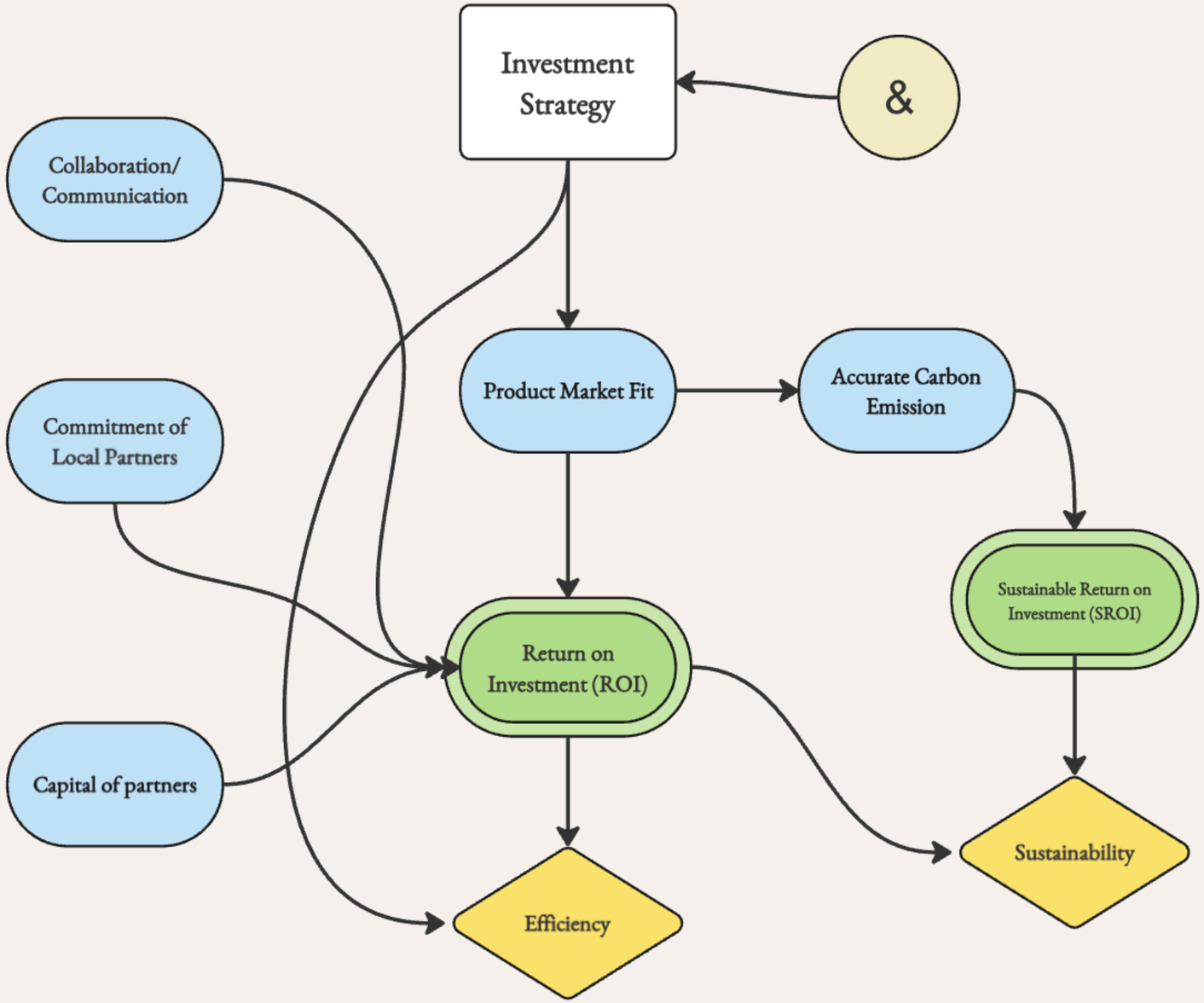


A **value node** represents the uncertain prospect affected by the decision maker's choices



The background state of information

Related Course: MS&E 152



Influence Diagram for Decision Quality

Based on the influence of many nodes, there is high value in **sustainability** given that the DM wants to prioritize SROI.

Related Course: MS&E 152

B. Comparative Cost Framework

Truck Options

- Diesel
- Biodiesel (B100)
- CNG
- RNG
- Electric
- Hydrogen

Capital Costs

Up-front truck purchase and fleet integration

Operational Costs

Recruitment and training, wages and benefits, management, etc.

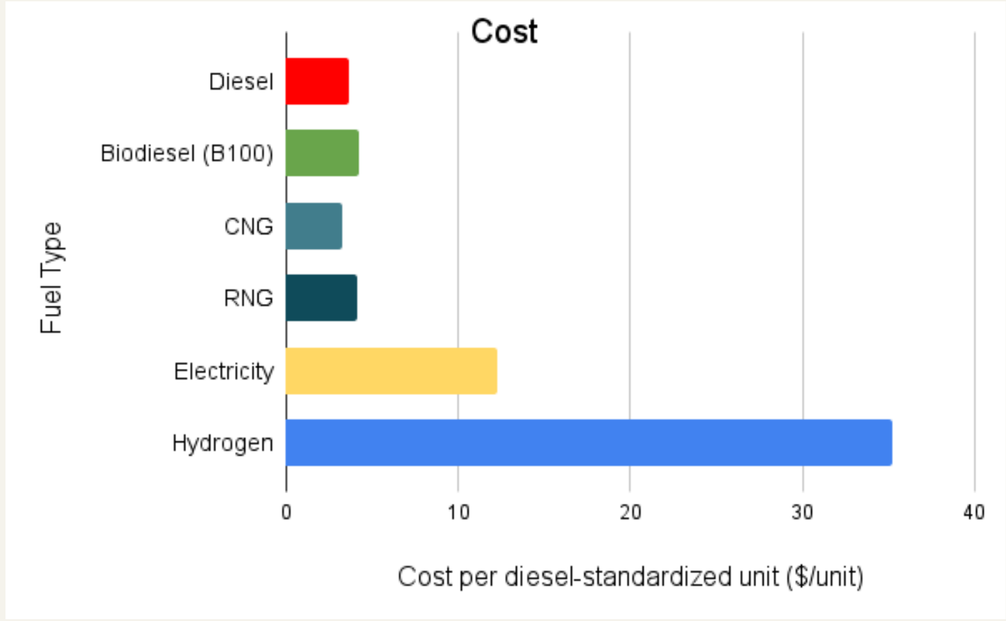
Social Cost of Carbon

Related Course: MS&E 245A

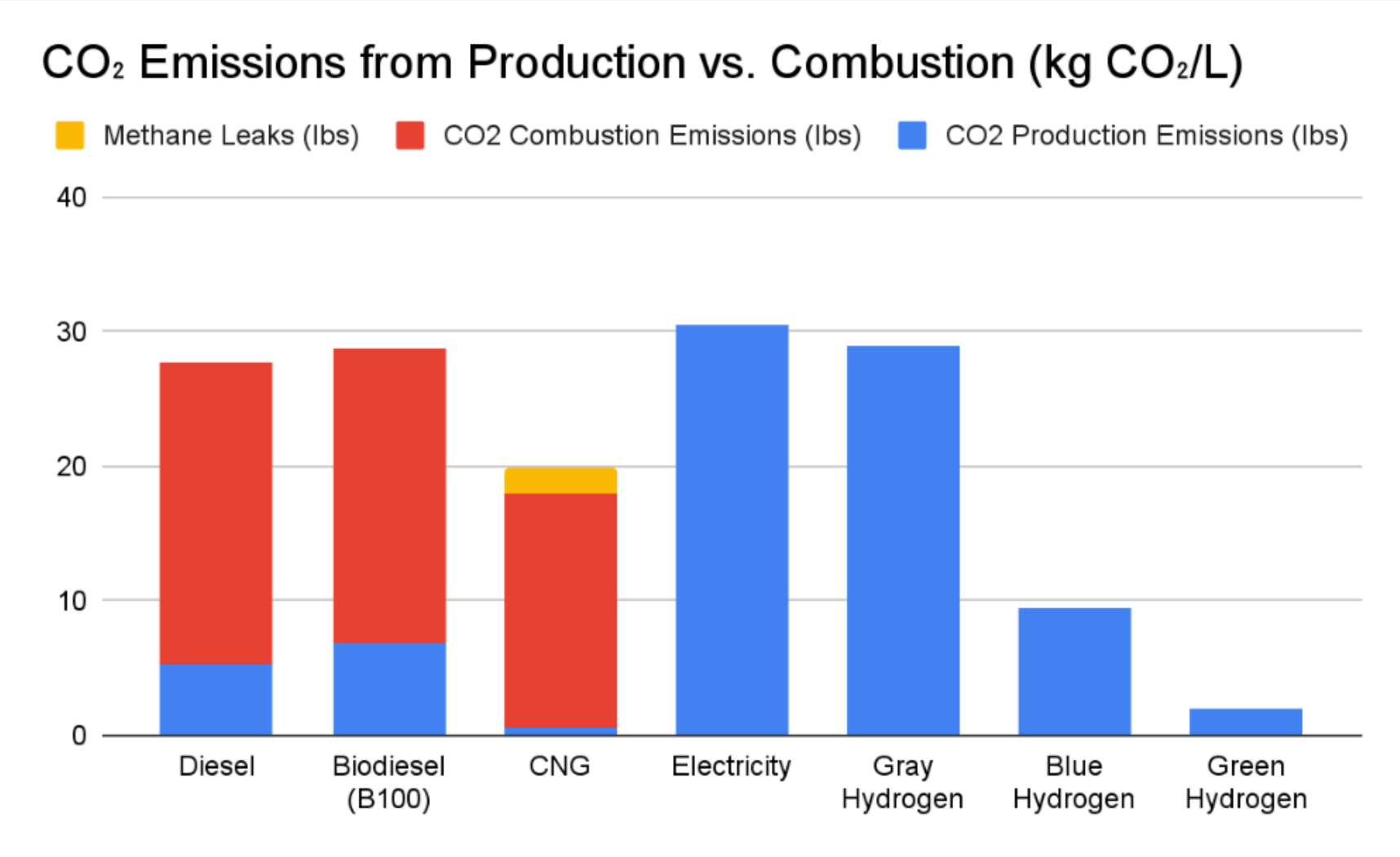
Standardizing Fuel Cost Comparisons

To fairly compare fuel costs, all fuels are converted into Diesel-Equivalent Gallons (DEG).

Fuel Type	Energy Content per Respective Unit	Fuel Sources to Diesel-Equivalent Gallon (DEG)
Diesel	128,488 BTU/gallon	1 gallon
Biodiesel (B100)	119,550 BTU/gallon	1.08 gallons
CNG	114,000 BTU/GGE	1.13 GGE
RNG	114,000 BTU/GGE	1.13 GGE
Electricity	3,414 BTU/kWh	37.64 kWh
Hydrogen	51,532 BTU/lb	2.49 lbs



Fuel Type vs. Production and Combustion CO2 Emissions (kg)



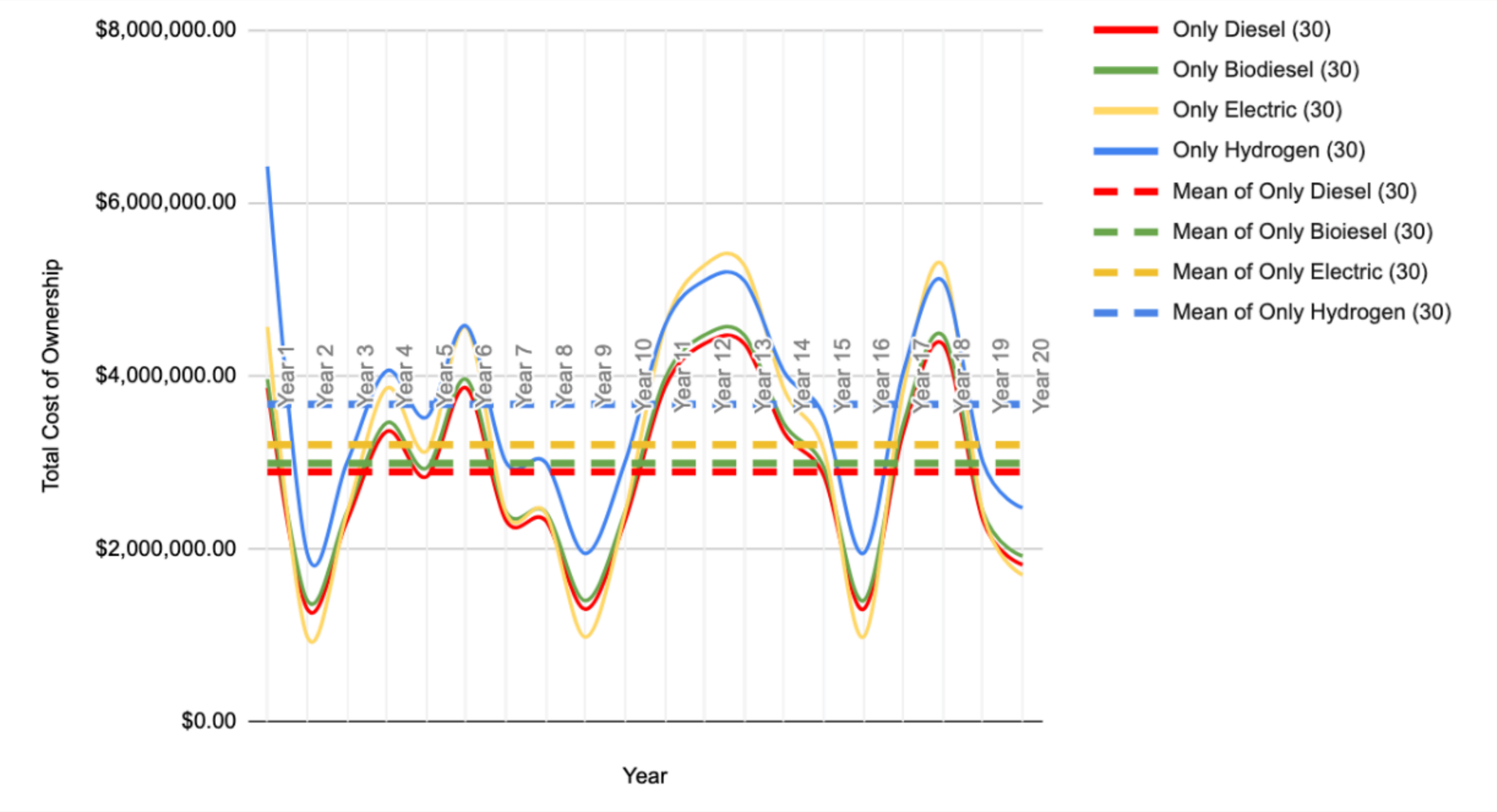
Constants

- **Truck Replacement Cycle –** Each garbage truck is replaced every 7 years
- **Inflation Impact –** Average inflation rate of 2.5% over a 20-year period
- **Labor Costs & Workforce –** Average of 45 workers, each earning $19/hr. 1 truck = 1 worker
- **Hydrogen Supply Chain –** Hydrogen suppliers have an existing partnership with GreenWaste
- **Scenario Initialization –** Each scenario begins with 30 trucks
- **Operational Schedule & Refueling –**
  - Trucks operate one day per week and refuel exclusively at the designated docking station
  - Trucks operate for a full day and complete two routes without requiring refueling
  - No mid-route refueling

Total Cost of Ownership =

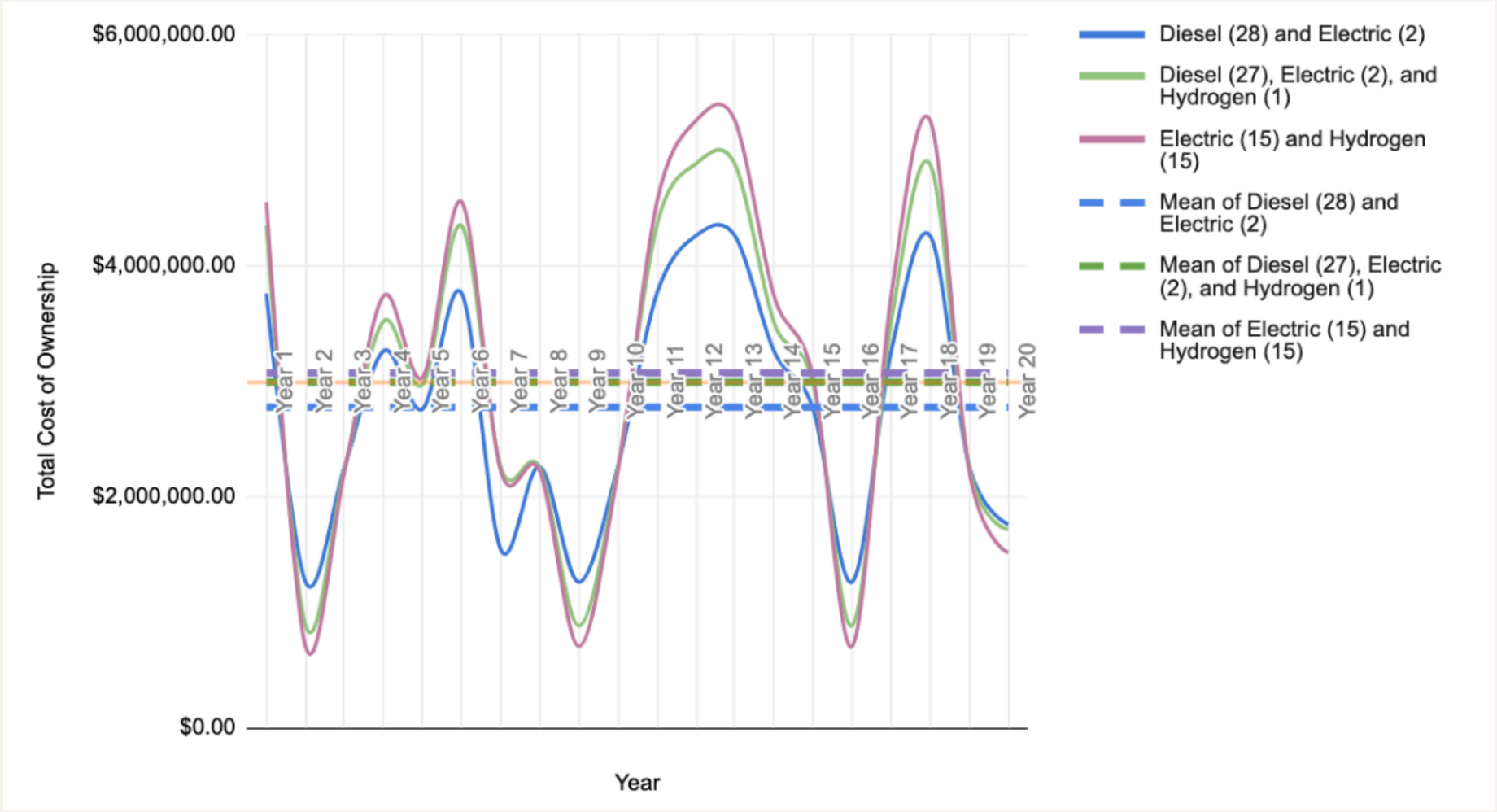
(Inflation corrected truck acquisition cost
* # of trucks being replaced/ year)
+ inflation-adjusted annual cost of charging/refueling)
+ annual labor cost
+ maintenance cost

Cost of Ownership over 20 Years (Uniform)



Related Course: MS&E 125

Cost of Ownership over 20 Years (Combination)



Related Course: MS&E 125

C. Environmental Impact Framework

	Diesel	Hydrogen	Green Hydrogen	Electric
CO2 Emissions for Life Cycle	987 metric tons	~200 metric tons	~50 metric tons	1,262 metric tons
Fuel/Energy Consumption	62 metric tons	~150 metric tons	~40 metric tons	1,020 metric tons
Other Emission Concerns (Manufacturing /Repair)	101 metric tons	~50 metric tons	~10 metric tons	203 metric tons

Figure 6.A: Life Cycle Analysis for Different Fuel Types

Sustainable Return on Investment

A sustainable return on investment model is a framework designed to measure the **environmental value** of a pilot or investment beyond the scope of revenue.

Sustainable Return on Investment

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$$\textbf{Sustainable Return on Investment (SROI)} = \frac{\text{Environmental} + \text{Health Impacts}}{\text{Total Investment}}$$

Calculating SROI for Different Fuel Types

Fuel Type	CO2 Emissions (metric tons per lifecycle)	Health Impacts ($50 dollars per ton)	Total Investment (In Year 3)	S-ROI Calculated
Diesel	987	$49,350	$2,324,436.45	0.0216
Electric	1,262	$63,100	$2,413,395.94	1,262.02
Hydrogen	50	$2,500	$2,996,501.46	0.0008

Normalizing SROI for Different Fuel Types

Fuel Type	CO2 Emissions (metric tons per lifecycle)	Health Impacts ($50 dollars per ton)	Total Investment (In Year 3)	S-ROI Calculated
Diesel	1	2	3	1
Electric	2	1	2	1.5
Hydrogen	3	3	1	6

Related Course: MS&E 165

D. Regulatory and Political Analysis

Federal Policy Shifts

CARB Waiver Withdrawn (Jan 25) – CA unable to enforce federal ACF rules.

Executive Order: “Unleashing American Energy”

- Revoked Biden’s 50% EV sales target.
- Froze $5B in EV charging grants.
- Proposed cutting EV & hydrogen tax credits.

Funding & Legal Uncertainty

- IRA & IIJA clean energy funds paused (incl. $7B hydrogen hubs).
- Courts blocked full cancellation, but delays expected.

Hydrogen Policy: Mixed Signals

- Federal support unclear; 45V tax credit ($3/kg) remains.
- Possible preference for blue hydrogen (natural gas + CCS).

California’s Hydrogen/ZEV Policy

Public Fleet Mandates – Palo Alto must transition to ZEVs.

- 50% new ZEVs now, 100% by 2027.
- No new diesel trucks post-2030.

Major Investments

- $1.4B for ZEV infrastructure (incl. hydrogen stations).
- HVIP: Up to $240K per hydrogen truck.
- LCFS Credits: $3–$6/kg for hydrogen fuel.

Challenges

- HVIP budget cut for 2024-25.
- Large fleets (50+ trucks) no longer eligible for incentives.

Future Scenarios for Hydrogen Fleets

Scenario 1: Worst Case for Hydrogen

🚨 No federal support, hydrogen truck costs rise.

🚨 Palo Alto complies with ZEV mandates but favors battery-electric.

Scenario 2: Status Quo

⚖️ 45V tax credit remains, no new federal grants.

⚖️ CA incentives help hydrogen stay competitive.

⚖️ Regional fueling coordination required.

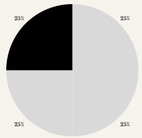
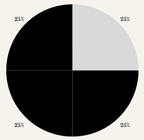
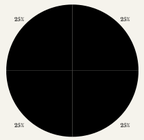
Scenario 3: Best Case for Hydrogen

✅ Federal backs hydrogen expansion.

✅ Lower hydrogen fuel costs, infrastructure funding returns.

✅ Palo Alto can scale hydrogen fleet with strong incentives.

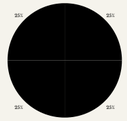
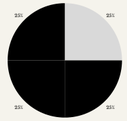
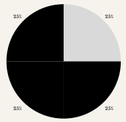
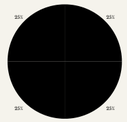
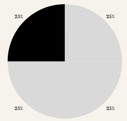
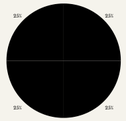
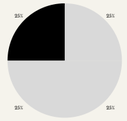
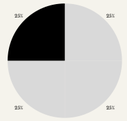
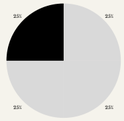
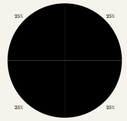
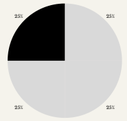
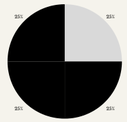
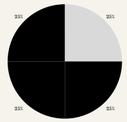
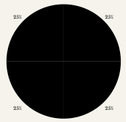
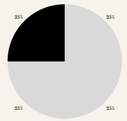
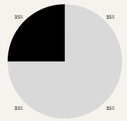
MoSCoW Framework for Prioritizing Investments

Legend	Cost of Ownership	Social Cost of Carbon (SCC)	Regulatory Risk	Reccommendation (MoSCoW)
	Low Cost	Low Cost	Low Risk	Must Invest
	Medium Cost	Medium Cost	Medium Risk	Should Invest
	High Cost	High Cost	High Risk	Could Invest
	Extreme Cost	Extreme Cost	Extreme Risk	Won’t Invest

Related Course: MS&E 165

20-Year Scenario Analysis

↑ higher average => lower investment
↓ lower average => higher investment

Truck Type	Cost of Ownership	Social Cost of Carbon (SCC)	Regulatory Risk	Average	Reccommendation (MoSCoW)
Diesel (30)				0.67	Could Invest
Electric (30)				0.67	Could Invest
Hydrogen (30)				0.5	Should Invest
Diesel (28) and Electric (2)				0.5	Should Invest
Diesel (27), Electric (2), and Hydrogen (1)				0.67	Could Invest
Electric (15) and Hydrogen (15)				0.5	Should Invest

Conclusion & Recommendations

Recap: we've completed the following analysis:

1. Decision Quality Framework
2. Comparative Cost Analysis
3. Environmental Impact Framework
4. Regulatory and Policy Analysis

Recommendation based on our 20-Year Scenario Analysis:

1. Gradually invest in more electric hydrogen trucks
2. Stop the investment of more diesel trucks

Next Steps

So here’s what the City of Palo Alto needs to do:

1. Gather data points from neighboring cities’ pilots
2. Re-factor hydrogen and electric trucks’ replacement rate into a 20-year cost analysis
3. Start sales conversations to get hydrogen and electric truck deals rolling!

Questions?

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City of Palo Alto

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