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Alternative Fuel Adoption Behavior of Heavy-duty Vehicle Fleets

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Alternative Fuel Adoption Behavior of Heavy-duty Vehicle Fleets

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Civil and Environmental Engineering

by

Youngeun Bae

Dissertation Committee:
Professor Stephen G. Ritchie, Chair
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2021

DEDICATION

To my families

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ACKNOWLEDGEMENTS

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Daum Communications (merged with Kakao Corp. in 2014) 2011 - 2013
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Mitra, Suman K., **Bae, Youngeun**, and Ritchie, Stephen G. "Use of Ridesharing Services among Older Adults in the United States." *Transportation Research Record* 2673.3 (2019): 700-710. https://doi.org/10.1177/0361198119835511

Kim, Jung Ok, Kim, Ji Young, **Bae, Young Eun**, and Yu, Ki Yun. "An Efficient Update for Attribute Data of the Digital Map Using Building Registers: Focused on Building Numbers of the New Address." *Korean Society of Surveying Geodesy Photogrammetry and Cartography* 26.3 (2008): 275-84. Print.

Presentations

Bae, Youngeun, Rindt, Craig R., Mitra, Suman K., and Ritchie, Stephen G. "Perspectives on Viable Alternative Fuels for Heavy-duty Vehicles in 2030s: Qualitative Interviews with California Fleet Operators." *The 100th Annual Meeting of the Transportation Research Board*, Online conference, Jan 2021. Poster presentation.

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Bae, Youngeun, Mitra, Suman K., Rindt, Craig R., and Ritchie, Stephen G. "Factors Influencing Alternative Fuel Adoption Decisions in Heavy-duty Vehicle Fleets in California." *Irvine Symposium on Emerging Research in Transportation 2020: Innovative Proposals of Young Minds*. UCI Student Center, Irvine CA. Jan 2020. Conference and poster presentations.

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Bae, Youngeun, Mitra, Suman K., Rindt, Craig R., and Ritchie, Stephen G. "In-depth Interviews with Heavy-duty Vehicle Fleet Operators: Building a Theory of Alternative Fuel Adoption Behavior in California." *Emerging Scholars Transportation Research Symposium*. Doheny Memorial Library, USC, Los Angeles CA. Mar 2019. Conference presentation.

Bae, Youngeun, Mitra, Suman K., Rindt, Craig R., and Ritchie, Stephen G. "Building a Theory of Alternative Fuel Adoption Behaviors of Heavy-duty Vehicle Fleets in California." *2019 California Transportation Planning Conference*. Westin San Diego, San Diego, CA. Feb 2019. Poster presentation.

Bae, Youngeun, Mitra, Suman K., Rindt, Craig R., and Ritchie, Stephen G. "Alternative Fuel Adoption Behavior of Heavy-duty Vehicle Fleets in California: An Initial Theoretical Framework." *Irvine Symposium on Emerging Research in Transportation 2019: Innovative Proposals of Young Minds*. The Beckman Center, Irvine CA. Jan 2019. Conference presentation.

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Kim, Jung Ok, Kim, Ji Young, **Bae, Young Eun**, and Yu, Ki Yun. "Analysis on the Application Possibility of Building Registers for Update of Digital Map." *KOREA Spatial Information Society 2008 Spring Conference,* Seoul, South Korea, June 2008. Seoul: Korean Society for Geospatial Information System, 2008. 173-179. Print.

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ABSTRACT OF THE DISSERTATION

Alternative Fuel Adoption Behavior of Heavy-duty Vehicle Fleets

by

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Doctor of Philosophy in Civil and Environmental Engineering

University of California, Irvine, 2021

Professor Stephen G. Ritchie, Chair

Alternative fuel adoption by heavy-duty vehicle (HDV) fleets can bring substantial benefits to both current local communities and future generations by reducing air pollutants and greenhouse gas emissions. However, the penetration rate of alternative fuel vehicles (AFVs) is still very low in the HDV sector. Revealing HDV fleet operator perspectives towards alternative fuels can serve as the basis for developing effective policies for accelerating the diffusion of these technologies. This dissertation aims to fill a key knowledge gap, where such fleet operator perspectives have rarely been addressed, by exploring alternative fuel adoption behavior of HDV fleets.

An initial theoretical framework was first developed based upon existing theories and literature to conceptually understand AFV fleet adoption behavior in organizations. This initial framework consists of a five-stage adoption process as well as two levels of sub-

frameworks: at the decision-making unit level and the individual (e.g., vehicle drivers) acceptance level.

Next, it was attempted to empirically improve the initial framework by investigating 20 organizations operating HDVs in the State of California via in-depth qualitative interviews and project reports. A total of 29 adoption and 42 non-adoption cases was probed across various alternative fuel technologies, including natural gas, propane, electricity, hydrogen, biodiesel, and renewable diesel options. The qualitative data was analyzed using content and thematic analyses, by which numerous themes and hypotheses were developed to build a theory explaining heavy-duty AFV fleet adoption behavior.

Based on these qualitative inferences, a conceptual modelling framework was proposed for estimating demand for heavy-duty AFVs under different policy and technology advancement scenarios. An overall structure along with specific modules and components for this framework are presented. As an ongoing work, a stated preference choice experiment was designed to quantitatively operationalize one of the modules, to estimate AFV choice probabilities. The feasibility of this modelling approach is proposed to be examined in a case study interviewing California drayage fleet operators.

Finally, the research findings contribute theoretically and empirically to a better understanding of the demand-side aspects of AFV adoption by HDV fleet operators, particularly in California and in the other US states that follow California's environmental policies.

CHAPTER 1: Introduction

The transportation sector is the largest source of anthropogenic Greenhouse Gas (GHG) emissions in the U.S., with a share of 29% of the U.S. GHG inventory (U.S. EPA, 2019). On-road medium and heavy-duty vehicles (referred as "HDVs" in this dissertation)[1] account for approximately 24% of GHG emissions in the U.S. transportation sector (U.S. EPA, 2019). In addition to the global impacts of GHG emissions, the criteria air pollutants (e.g., nitrogen oxides (NOx), particulate matter (PM), and carbon monoxide (CO)) emitted from diesel HDVs have deleterious effects on the health of local residents (Brugge et al., 2007). At the same time, the freight transportation system, in which HDVs are one of the main components, comprises approximately 9 percent of the nation's gross domestic product (U.S. DOT, 2017) and is responsible for one-third of California economy and jobs (State of California, 2015a). Therefore, it is imperative to execute mitigation strategies for reducing HDV-generated emissions that do not constrain economic growth.

Since approximately 90% of HDVs are used as fleet vehicles (U.S. Census Bureau, 2004)[2], encouraging HDV fleet operators[3] to adopt alternative fuel vehicles (AFVs) running on cleaner fuels than traditional petroleum fuels can be one of the promising solutions to reduce GHG emissions and smog-forming emissions (U.S. DOE, 2013). However, the penetration rate of alternative fuels is very low in the HDV sector. For example, as of

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[1] Medium and heavy-duty vehicles are defined by their gross vehicle weight rating (GVWR), though it varies by agency, with the US Federal Highway Administration (FWHA) definition being vehicles over 10,000 lbs, while U.S. Environmental Protection Agency (EPA) sets the lower limit at 8,500 lbs.

[2] A fleet of vehicles is defined as a group of one or more vehicles belonging to an organization for a business purpose rather than personal transportation use.

[3] A fleet operator means a person who owns and/or manages a fleet of vehicles and is solely or collaboratively involved in the process of fleet purchase decisions for that organization.

December 2018, 95.5% of registered HDVs were powered by diesel or gasoline with only the remaining 4.5% of the vehicles running on alternative fuels in the California HDV sector (California Department of Motor Vehicles, 2018). In order to accelerate the diffusion of AFVs throughout the entire heavy-duty sector, it is critical to understand not only supply-side efforts, but also demand-side characteristics such as HDV fleet operator perceptions, attitudes, and behavior toward alternative fuels. Such improved understanding can help develop more effective demand-side policy and technological strategies. However, there is scant research focusing on heavy-duty AFV adoption behavior, especially from a fleet purchase decision maker's point of view (Bae et al., 2019).

This research aims to fill a key knowledge gap in AFV adoption research by investigating HDV fleet operator perspectives and behavior toward alternative fuels. The specific goal of this research is twofold. First, it attempts to build a theory regarding heavy-duty AFV adoption behavior from HDV fleet operator point of view. Second, it develops a conceptual modelling framework that could be used in future research to analyze the demand for heavy-duty AFVs under different policy and technology advancement scenarios. To these ends, a two-phase research approach has been planned as a mixed method approach: a qualitative research phase followed by a quantitative research phase.

For the first objective, a qualitative research approach was first employed as an inductive strategy for generating a theory informed by data (Bryman, 2012). For this qualitative phase, the State of California was selected as a case study given that there are more than 3,500 fleets (about 2% of the total) that have adopted alternative fuels, which can provide a greater opportunity to comprehensively investigate heavy-duty AFV adoption behavior. Accordingly, 20 organizations in California were investigated via in-depth qualitative interviews and project reports. A total of 29 adoption and 42 non-adoption cases were probed across various alternative fuel technologies, including natural gas, propane, electricity, hydrogen, biodiesel, and renewable diesel options. The qualitative data was analyzed using content and thematic analyses, by which numerous themes and hypotheses emerged to build a theory explaining alternative fuel adoption behavior in HDV fleets. As subsequent tasks, quantitative survey items were designed in an effort to validate the qualitative inferences based on a large representative sample, and thus obtain more generalized findings. The survey data collection and analyses are deferred to future work.

For the second objective, a conceptual modelling framework was first developed based upon the qualitative inferences to serve as the theoretical basis for demand analysis for heavy-duty AFVs. The overall structure along with its integrated modules are presented in this dissertation. As an ongoing work, a stated preference choice experiment was designed to quantitatively operationalize one of the modules, which will estimate AFV choice probabilities under diverse scenarios that would be affected by various policy and technology developments. The feasibility of this modelling approach is proposed to be examined in a case study interviewing California drayage fleet operators.

This dissertation is arranged as follows:

Chapter 2 provides first an overview of various alternative fuel technologies for HDVs. Then, this chapter reviews the literature that addresses alternative fuel adoption in organizations. Comparisons of the reviewed studies, methodologies employed for those studies, and existing theoretical frameworks are summarized. The last part of this chapter addresses the insights obtained from this comprehensive review and explains the knowledge gap in the literature.

Chapter 3 proposes an initial theoretical framework to explain AFV fleet adoption behavior in organizations. This chapter first provides a summary of existing theories and frameworks centering on an organization's innovation adoption behavior. After examining and re-designing such existing frameworks and by synthesizing the findings from the literature review, an initial theoretical framework is formulated, which serves as theoretical background for the qualitative research phase. The proposed initial framework consists of a five-stage adoption process and two levels of sub-frameworks, at both the decision-making unit level and the individual (e.g., vehicle drivers and fleet managers) acceptance level. This initial framework can help organize concepts and explain phenomena that would exist in such fleet behavior.

Chapter 4 presents the methodologies and results of the qualitative research phase that aimed to build a theory of heavy-duty AFV adoption behavior. With the California case study, a broader range of topics related to alternative fuel adoption behavior are addressed, including decision-making processes, factors affecting adoption and non-adoption decisions, vehicle driver acceptance of AFV within an organization, satisfaction on vehicles and refueling facilities, repurchase plans and recommendation experiences to other fleets, opinions on financial incentives, and perspectives on variable alternative fuel options in 2030s. The research findings have many implications for heavy-duty AFV technology improvements and policy suggestions, as well as offering an improved understanding of heavy-duty AFV adoption behavior in organizations.

Chapter 5 propose a conceptual modelling framework for demand analysis of heavy-duty AFVs, which was formulated based upon the extensive findings from the qualitative research phase. After summarizing the qualitative inferences that were used for this modelling, the overall structure consisting of a set of modules is presented. Descriptions of specific components in each module are also elaborated. Lastly, advantages and limitations of this modelling are discussed.

Chapter 6 concludes with a summary of this dissertation research and its main contributions. Ongoing and future work are also addressed, including 1) a quantitative survey of a large representative sample to obtain generalized findings regarding heavy-duty AFV adoption behavior, 2) analyzing AFV choice probabilities under various policy and technology scenarios based on a stated preference choice experiment with a case study of drayage fleets in California, and 3) quantitative demand modelling for heavy-duty AFVs using agent-based modelling and system dynamics model.

CHAPTER 2: Comprehensive Literature Review

According to Rogers' theory of *Diffusion of Innovations* (DOI), an *innovation* is defined as "an idea, practice, or object that is perceived as new by an individual or another unit of adoption" (Rogers, 1983b, p.11). Alternative fuels can be regarded as an innovation in that they can be perceived as new by fleet operators in the circumstances where conventional diesel adoption dominates.

This chapter provides first the current state of alternative fuel technologies for HDVs. Then, this chapter reviews the literature that addressed alternative fuel adoption in organizations, which begins with brief explanations of literature collection strategies and comparison of the reviewed articles. There are several dozen studies on alternative fuel adoption in organizations that operate light-duty vehicle (LDV) fleet, and several such studies focusing on HDV fleets. Meanwhile, existing theories and frameworks (Frambach and Schillewaert, 2002; Rogers, 1983b, 1983a; Tornatzky and Fleischer, 1990) explain organizational behavior of adopting an innovation. Accordingly, such existing frameworks as well as methodologies employed for the previous studies are summarized in a subsequent subchapter. The last part of this chapter addresses the insights obtained from this comprehensive review and explains the knowledge gap in the literature.

2.1. Alternative Fuel Technologies for Heavy-duty Vehicles

Various alternative fuel technologies are available from around 50 different HDV manufacturers across diverse fleet vocations in the U.S., including biodiesel, electricity, ethanol, hydrogen, natural gas, and propane (U.S. DOE, 2021a)[4].

As of March 2021, the most mature alternative fuel technology for HDV applications is compressed natural gas (CNG). CNG is used in many fleet applications including transit, school, and shuttle buses, tractor trucks, refuse trucks, and street sweepers, with around 100 vehicle models available from about 31 manufacturers (U.S. DOE, 2021a). Some of those CNG vehicle manufacturers offer liquefied natural gas (LNG) or propane (a.k.a., liquid petroleum gas (LPG)) options as well. There are over 30 vehicle models available from about 10 manufacturers for each of LNG and propane options (U.S. DOE, 2021a).

Moreover, zero-emission HDV technologies, particularly electric vehicles, have rapidly been advancing in recent years. Around 25 manufacturers provide approximately 100 vehicle models running on electricity across various HDV fleet vocations including transit, school and shuttle buses, tractor trucks, sweepers and refuse trucks (U.S. DOE, 2021a). Hydrogen HDVs have seen slower development, with only a handful of manufacturers who collectively offer fewer than 10 vehicle models for shuttle and transit buses, step van, and tractor trucks (U.S. DOE, 2021a).

[4] See Table A.1 in Appendix A for heavy-duty AFV models and manufacturers available in the U.S.

There is also another group of alternative fuels that involve blending of petroleum diesel or gasoline, such as biodiesel (or B20), and ethanol (or E85)[5]. Some HDV manufacturers provide vehicle models that can be operated using E85 (U.S. DOE, 2021a). In addition, several emerging alternative fuels are available in the U.S., including renewable diesel (U.S. DOE, n.d.). Most of the diesel HDVs that are not technically AFVs are capable of running on biodiesel or renewable diesel (U.S. DOE, 2017, n.d.).

2.2. Data Collection Strategies

Until now, the literature is limited in size and understanding of AFV adoption behavior in the HDV sector. The literature is more robust with findings about alternative fuel adoption in households (e.g., Rezvani et al., 2015; Turcksin et al., 2013), but these findings cannot be directly transferred to HDV fleets (Bae et al., 2019). The business-to-consumer features of household passenger car adoption vs. the business-to-business (B2B) characteristics of fleet vehicle adoption present a major structural distinction that likely restricts the interchangeability of findings from those two sectors (Seitz et al., 2015)[6].

Due to the scarce literature on heavy-duty AFV adoption, the scope of this review was expanded so as to include LDV fleets as well. The emphasis is on studies dealing with the factors that were found to influence AFV fleet adoption behavior in organizations, from

[5] B20 is a blend of biodiesel and petroleum diesel with 6% to 20% biodiesel. E85 is a blend of ethanol and gasoline that contains no more than 85% ethanol.

[6] Compared to household adoption, numerous inherent decision criteria have been found that only apply to AFV fleet adoption behavior in organizations (Bae et al., 2019). Some examples of factors that affect preference toward AFV fleet adoption include whether an organization uses a total cost of ownership approach (e.g., Boutueil, 2016), whether their vehicles are operated on fixed routes (e.g., Sierzchula, 2014), whether the organization seeks first mover advantage (e.g., Altenburg et al., 2017; Sierzchula, 2014), and/or whether they practice corporate social responsibility (e.g., Bennett, 2015; Seitz et al., 2015).

a point of view from fleet operators, vehicle drivers, or any other members who were involved in the adoption process in organizations. To create a more comprehensive and up-to-date overview, peer-reviewed journal papers published during the last two decades along with conference papers or proceedings published within the last five years were reviewed.

Through major academic search engines and databases, including TRID (Transportation Research International Documentation), Transportation Libraries Catalog, Google Scholar, SCOPUS, ScienceDirect, and JSTOR, a keywords search was conducted with words and phrases such as “alternative fuel vehicle*” combined with “fleet”, “organization*” or “commercial” in further combinations with “adoption”, “purchase”, “demand”, “willingness to pay”, “acceptance”, “interview” or “survey”. Backward and forward snowballing techniques were used as well. The review was restricted to studies published in English. The initial list of retrieved sources was refined by omitting irrelevant studies such as the ones dealing with household AFV adoption or others based on an aggregate modelling approach (e.g., (Askin et al., 2015)) which is inherently based on a number of assumptions to simulate a scenario-based future market fraction of AFVs and the objective of which is far from capturing fleet operators’ genuine perspectives. Finally, 34 articles, which used a disaggregated sample of fleet purchase decision makers or fleet drivers, were included in this review. Table 2-1 presents the meta information of the identified 34 articles with the categories such as scope, methodology used, study location, and the number of study participants.

Table 2-1. Meta-information of Reviewed Studies

No.	Author(s), Year	Type	Fuel Type[(1)]	Vehicle Class (Vehicle Type)	Methodology	Statistical Model[(2)]	Location	Number of Respondents
1	(Anderhofstadt and Spinler, 2019)	PRJ[(4)]	ELEC, HD, CNG, LNG	HDV (trucks)	Interview (Delphi)	.	Germany	23
2	(Blynn and Attanucci, 2019)	PRJ	ELEC	HDV (buses)	Interview & Quantitative analysis (mixed method)	.	USA (California, Kentucky, and Massachusetts)	12
3	(Skippon and Chappell, 2019)	PRJ	ELEC	LDV (cars and vans)	Interview	.	UK	4
4	(Zhang et al., 2019)	PRJ	ELEC/AF	L-M-HDVs (trucks)	Survey	CV / logistic regression	China	288
5	(Mohamed et al., 2018)	PRJ	ELEC	HDV (transit)	Interview	.	Canada	11
6	(Globisch et al., 2018a)	PRJ	ELEC	LDV (passenger cars)	Survey	CV / structural equation model	Germany	575 (drivers) [(3)]
7	(Morganti and Browne, 2018)	PRJ	ELEC	LDV (light commercial vehicles ≤ 7000 lbs)	Interview	.	France, UK	23
8	(Morrison et al., 2018)	Conf	BD, CNG, RNG, LNG, LPG, HD, ELEC	L-HDVs (shuttles; emergency response and security vehicles; facilities and maintenance vehicles)	Online survey / Interview	.	USA	33 for survey / 16 for interview
9	(Pfoser et al., 2018)	PRJ	LNG	HDV (heavy-duty and long distance transport)	Online Survey	CV / structural equation model	European Rhine-Main-Danube axis areas	157

No.	Author(s), Year	Type	Fuel Type[1]	Vehicle Class (Vehicle Type)	Methodology	Statistical Model[2]	Location	Number of Respondents
10	(Altenburg et al., 2017)	Conf	ELEC	L-HDV (van or freight trucks)	Interview		The Netherlands	14
11	(Globisch et al., 2018b)	PRJ	ELEC	LDV	Online survey	CV / ordinary least square	Germany	229
12	(Saukkonen et al., 2017)	PRJ	NG, BG	L-HDVs (taxi, delivery, waste management, etc.)	Interview	.	Finland	7
13	(Boutueil, 2016)	PRJ	ELEC	LDV	Interview	.	Paris, France	44
14	(Kaplan et al., 2016)	PRJ	ELEC	L-HDV (commercial vehicles)	Online survey	CV/ structural equation model	Austria, Denmark, and Germany	1,443
15	(Klauenberg et al., 2016)	PRJ	ELEC	LDV	Online Survey	.	Austria and Germany	752
16	(Quak et al., 2016)	PRJ	ELEC	Not found (freight vehicles for daily city logistics)	Reviews of projects and demonstrations	.	Europe	n/a
17	(Wikström et al., 2016)	PRJ	ELEC	LDV (passenger cars and vans)	Focus group	.	Sweden	40
18	(Bennett, 2015)	PRJ	ELEC	LDV	Online survey	CV / partial least squares	UK	364
19	(Seitz et al., 2015)	PRJ	AF	HDV (≥12,000 lbs)	Interview / Online survey	CV / multiple linear regression	Germany	177
20	(Wikström et al., 2015)	PRJ	ELEC	LDV (transport and passenger vehicles)	Survey / Focus Group /	.	Sweden	550 (drivers)

No.	Author(s), Year	Type	Fuel Type(1)	Vehicle Class (Vehicle Type)	Methodology	Statistical Model(2)	Location	Number of Respondents
					Interview / Logbooks			
21	(Kirk et al., 2014)	PRJ	CNG	LDV (vans)	Interview / Focus group	.	UK	15
22	(Koetse and Hoen, 2014)	PRJ	ELEC, HD, E85	LDV	Online Survey	CM /multinomial logit model	The Netherlands	940 (drivers)
23	(Nesbitt and Davies, 2014)	Conf	ELEC	LDV (pickup trucks)	Interview / Online survey	.	California, USA	53 (drivers)
24	(Rolim et al., 2014)	Conf	ELEC	LDV	Interview	.	Portugal	25 (drivers)
25	(Sierzchula, 2014)	PRJ	ELEC	LDV	Interview	.	USA and the Netherlands	11
26	(Wikström et al., 2014)	PRJ	ELEC	LDV	Online Survey / Interview / Logbooks	.	Sweden	42 / 57 / 44 / 30 (5) (drivers)
27	(van Rijnsoever et al., 2013)	PRJ	ELEC, BG, HD	Not found (local government fleets)	Expert Interview / Online survey	CM /ordinal logit model	The Netherlands	50
28	(Walter et al., 2012)	PRJ	HD, CNG/BG	HDV (sweepers)	Expert Interview / Online survey	CM/hierarchical Bayesian analysis	Germany and Switzerland	274
29	(Johns et al., 2009)	PRJ	bi-fuel E85, bi-fuel CNG, bi-fuel LPG	Not found (local government fleets)	Mail Survey	CV /censored normal regression	Illinois, USA	41 (drivers)
30	(Rahm and Coggburn, 2007)	PRJ	BD, E85, ELEC, LPG, CNG, LNG, MTH, HD	L-HDV	Online Survey	.	USA	30

No.	Author(s), Year	Type	Fuel Type[1]	Vehicle Class (Vehicle Type)	Methodology	Statistical Model[2]	Location	Number of Respondents
31	(Loo et al., 2006)	PRJ	LPG	LDV (public light buses)	Survey	CM /multinomial logit model	Hong Kong	483
32	(Nesbitt and Sperling, 2001)	PRJ	AF	LDV	Focus group / Interview / Mail survey	.	California, USA	59 / 39 / 2131[6]
33	(Nesbitt and Sperling, 1998)	PRJ	AF	LDV	Focus group / Interview / Mail survey	.	California, USA	59 / 39 / 2131[6]
34	(Golob et al., 1997)	PRJ	ELEC, CNG, MTH	LDV and medium duty trucks (≤14,000 lbs)	Mail Survey	CM /multinomial conditional logit model	California, USA	2,023

[Note] (1) AF: alternative fuels in general, BD: biodiesel, BG: biogas, CNG: compressed natural gas, ELEC: electricity, E85: flex fuel, HD: hydrogen, LNG: liquefied natural gas, LPG: liquid petroleum gas, MTH: methanol, NG: natural gas. (2) CM: choice modelling method, CV: contingent valuation method. (3) Respondents consist of (or include) fleet vehicle drivers. Otherwise unmentioned, study participants include fleet managers, organization representatives, or other members involved in their fleet purchase decision making. (4) Conference papers or proceedings. Otherwise unmentioned, articles are peer-reviewed journal papers. (5) 42, 57, and 44 for the 1st, 2nd, and 3rd surveys, respectively; 30 for interviews. (6) 59 for focus groups; 39 for one-on-one interviews; 2131 for surveys.

2.3. Comparisons of Reviewed Studies

A summary of the comparisons of the reviewed articles is provided in Table 2-2, in terms of their publication years, scopes, main methodologies, study participants, and study locations. The literature on organizational adoptions of AFV fleet vehicles was very limited especially before 2010. Since the early 2010s, those studies have increased in number: 28 articles (82% of the reviewed studies) were published after 2010. The majority of these studies (68%) focus on electric vehicles (EVs), followed by natural gas or biogas vehicles (21%). Other fuels, such as liquid petroleum gas, methanol, or flex-fuel had gained attention particularly before 2010. In accordance with recent technological advancements, three studies (Anderhofstadt and Spinler, 2019; van Rijnsoever et al., 2013; Walter et al., 2012), which dealt with hydrogen-powered vehicle fleet adoptions, were published in the 2010s.

As for the scope of vehicle classes, only six articles solely concentrate on HDV fleets (Anderhofstadt and Spinler, 2019; Blynn and Attanucci, 2019; Mohamed et al., 2018; Pfoser et al., 2018; Seitz et al., 2015; Walter et al., 2012) while most of other articles focus on LDV fleets. For methodologies used, out of the 34 reviewed articles, 15 articles employed qualitative approaches such as focus groups and interviews, 18 used quantitative approaches by conducting online or mail surveys, and 1 was based on a review of demonstration projects. As for the study participants, 26 articles (76%) targeted fleet purchase decision-makers such as fleet managers and organization representatives, while 6 studies targeted fleet vehicle drivers with an emphasis on the acceptance of drivers for successful implementation of AFVs (e.g., Johns, Khovanova, & Welch, 2009; Wikström, Hansson, & Alvfors, 2015, 2016). Two studies targeted both fleet purchase decision-makers and vehicle drivers. Finally, the study areas of most literature (22 articles, 65%) were in Europe while the U.S. is represented with 7 articles (21%). Two articles involve both Europe and the U.S., two articles were carried out in Asia, and the other in Canada.

Table 2-2. Comparison of the Reviewed Studies

Publication Year	before 2010	*6(1)*	**Main Methodology**	Interview/Focus group	*15*
	after 2010	*28*		Online/Mail Survey	*18*
Scope: Fuel Type	Alternative fuels in general	*5(2)*		Reviews of projects	*1*
	Electricity	*23*	**Study Participants**	Fleet purchase decision makers	*26*
	E85 (flex-fuel)	*1*			
	Hydrogen	*3*		Fleet drivers	*6*
	Liquid petroleum gas	*2*		Both	*2*
	Methanol	*1*	**Location**	US	*7*
	Natural gas or biogas	*7*		EU	*22*
Scope: Vehicle Class	LDV	*19*		US/EU	*2*
	HDV	*6*		Canada	*1*
	Mixed or Not specified	*9*		Asia	*2*

[Note] (1) The numbers represent the number of reviewed studies out of a total of 34 publications. (2) The sum of the numbers may not be a total of 34 because one article can correspond to multiple categories.

2.4. Comparisons of Methodologies and Frameworks

2.4.1. Qualitative Research Approach

Among the reviewed studies, 15 were based on qualitative approaches such as interviews (Altenburg et al., 2017; Boutueil, 2016; Morganti and Browne, 2018; Nesbitt and Davies, 2014; Rolim et al., 2014; Saukkonen et al., 2017; Sierzchula, 2014), focus group

(Wikström et al., 2016), or both combined (Kirk et al., 2014; Nesbitt and Sperling, 1998). The focus group method is a form of group interview in which several participants, with the presence of a moderator or facilitator, discuss about a particular topic and may argue with and challenge one another (Bryman, 2012). The benefit of using focus groups is that it enables the participants to interact with each other and elaborate on the topic (Morgan, 1997) and provides the researcher the opportunity to explore the topic in the way where participants collectively develop and construct meanings regarding the topic (Bryman, 2012).

In contrast, interviews are conducted individually to gain in-depth understanding of each respondent's view of a certain topic. Compared to structured interviews that use a strict guidelines with a fixed range of answers offered to interviewees so that the interviewing should be standardized (Bryman, 2012), semi-structured or unstructured interviews give more emphasis on the flexibility for the interviewer to explore the context and content of the interview and allow much more space for interviewees to answer (Edwards and Holland, 2007). Most of interview-based studies in this review conducted semi-structured interviews (e.g., Altenburg et al., 2017; Morganti & Browne, 2018; Nesbitt & Davies, 2014; Saukkonen et al., 2017; Sierzchula, 2014) with a set of around 4-7 questions or themes. Overall, those studies based on a qualitative approach tended to target a relatively small number of fleet operators (e.g., 4 to 59 in the reviewed studies) who already adopted or tested AFVs (e.g., (Altenburg et al., 2017; Morganti and Browne, 2018; Nesbitt and Davies, 2014; Rolim et al., 2014; Saukkonen et al., 2017; Sierzchula, 2014; Wikström et al., 2016)) and aimed to obtain a deeper understanding of AFV fleet adoption behaviors through rich and detailed narrative answers. This qualitative research approach is associated with an inductive strategy of generating a theory from data (Bryman, 2012).

To analyze the qualitative data, the content analysis (Krippendorff, 2004), the grounded theory analysis (Goulding, 2002), or the thematic analysis (Boyatzis, 1998) methods can be employed. For example, Sierzchula (2014) used the content analysis to examine eleven interview data and three project reports. After developing textual categories from the data, researchers coded the existence, strength, and sign of textual categories and then calculated the Krippendorff's α (Krippendorff, 2004) as the most general agreement measure. Kirk et al. (2014) employed the grounded theory method to analyze the total of fifteen one-on-one and two group interviews. The grounded theory involves a series of tasks including initial open coding, drawing out concepts, and constant comparative analysis throughout data collection and across data sets until theoretical saturation was achieved (Kirk et al., 2014). The detailed explanations and comparisons about these two techniques can be found in (Cho and Lee, 2014). In addition, Skippon & Chappell (2019) used the thematic analysis to investigate four in-depth case studies with U.K. fleets. Thematic analysis is a method for identifying, analyzing and reporting patterns and themes across qualitative data (Braun and Clarke, 2006).

2.4.2. Quantitative Research Approach

A quantitative research entails a deductive approach in which the emphasis is placed on the testing of theories or hypotheses (Bryman, 2012). Studies based on a quantitative approach tend to have a large sample size so that their findings can be generalized to larger populations. In the reviewed studies, the survey participants are varied from 30 to 2,131, with a mean of 508. Out of the 18 survey-based studies, 12 employed either of two stated preference (SP) techniques: choice modelling (CM) for the 5 articles (Golob et al., 1997; Koetse and Hoen, 2014; Loo et al., 2006; van Rijnsoever et al., 2013; Walter et al., 2012) and contingent valuation (CV) methods for the 7 articles (Bennett, 2015; Globisch et al., 2018a, 2018b; Johns et al., 2009; Kaplan et al., 2016; Pfoser et al., 2018; Seitz et al., 2015). CV seeks to measure willingness to pay through direct questions while CM seeks to secure rankings and ratings of alternatives from which willingness to pay (WTP) can be inferred (Pearce et al., 2002).

Choice modelling is based on microeconomic consumer theory which assumes that consumers are rational decision-makers who try to maximize their utility from their purchase decisions and that attributes of a product are what generate benefits of the product (Lancaster, 1966). While CV usually does not have predictive accuracy in markets, CM have the experimental design features of conjoint analysis that allow extensive tests for the structure and consistency of stated preferences (Ben-Akiva et al., 2015). In choice experiments, each survey respondent is provided with a set of alternative products (e.g., conventional diesel, CNG/biogas, and hydrogen driven vehicles in (Walter et al., 2012)) with a variety of levels of their attributes and then asked to choose one of the options or rank the options among the competing alternatives. Depending on a designed choice task, various statistical models, such as multinomial logit model (e.g., (Koetse and Hoen, 2014; Loo et al., 2006)), multinomial conditional logit model (e.g., (Golob et al., 1997)), ordinal logit model (e.g., (van Rijnsoever et al., 2013)) or hierarchical Bayesian analysis (e.g., (Walter et al., 2012)), can be applied to analyze the survey results.

Contingent valuation method "relies indirectly on the links between preferences, market demands, and valuations" and is not involved with an experimental design (Ben-Akiva et al., 2015, p.7). In CV surveys, respondents are typically asked to express their willingness to pay for a given improvement or a market good. Accordingly, the seven CV-based articles in this review adopted a dependent variable of willingness to pay for a particular type of AFV or alternative fuel technologies in general. Hypotheses were constructed based a theoretical framework (that will be briefly explained in the next subchapter), and then a statistical model, such as regression models (e.g., (Globisch et al., 2018b; Johns et al., 2009; Seitz et al., 2015)) or structural equation modelling (SEM) (e.g., (Globisch et al., 2018a; Kaplan et al., 2016; Pfoser et al., 2018)), was used to evaluate those hypotheses. The SEM is particularly useful when a model needs to consist of multiple equations and to incorporate observed as well as latent variables that are measured by one or more indicators (Kline, 2010).

2.4.3. Theoretical Frameworks

Several types of theoretical frameworks were used in the reviewed studies.

Theory of Reasoned Action (TRA) (Fishbein and Ajzen, 1975)

According to TRA, one's behavior is determined by behavioral intentions, attitudes toward a behavior (one's positive or negative attitude about performing a behavior), and subjective norms (beliefs about what others will think about the behavior). Johns et al. (2009) employs a behavioral model based on TRA to examine factors that facilitate or hinder adoption of alternative fuels by fleet vehicle drivers in a local government.

Theory of Planned Behavior (TPB) *(Ajzen, 1991)*

Theory of Planned Behavior is an extension of TRA. In addition to considering attitudes, subjective norms, and intentions, TPB takes perceived behavioral control (PBC) (beliefs about the presence of factors that may facilitate or impede performance of the behavior and the perceived power of these factors) into account. Kaplan et al. (2016) proposed a behavioral framework based on TPB for understanding motivations and barriers to procurement intentions of electric vehicle fleets. The researchers examined relationship between four constructs (i.e., positive attitudes, subjective norms, familiarity, and perceived operational ease) and procurement intentions of EVs. Also, Bennett (2015) employed extended theory of planned behavior (ETPB) (Conner and Armitage, 1998), a further extension of TPB. Among many variables additionally posited in ETPB, Bennett (2015) considered pre-existing beliefs, self-efficacy, moral obligation, and environmental self-identity along with attitude, subjective norm, and PBC, in order to identify factors that might encourage fleet managers to purchase EVs.

Technology Acceptance Model (TAM) *(Davis, 1989)*

Technology Acceptance Model is one of the most influential extensions of TRA. This model was introduced to explain acceptance of an information system, but has been applied to several other technologies, including AFV fleet adoptions (e.g., (Globisch et al., 2018a; Pfoser et al., 2018; Wikström et al., 2016)). The TAM suggests two main factors determining one's acceptance of technology: perceived usefulness (perception that using system leads to enhanced personal performance) and perceived ease of use (perception that using system will be free from physical or mental effort).

Technology–Organization–Environment framework (TOE) (Tornatzky and Fleischer, 1990)

While TRA and its extended models focus on an individual level behavior, a few frameworks explain innovation adoption behavior at the organization level. As an example, the TOE framework identifies three contextual aspects that influence the process of an organization's technological innovation decision: technological context (e.g., technology availability and characteristics), organizational context (e.g., size, slack, communication process, managerial structure), and external task environmental context (e.g., industry characteristics, technology support infrastructure, and government regulations). Seitz et al. (2015) employed TOE to develop hypotheses for organizational heavy-duty AFV adoption decisions in Germany.

2.5. Insights Obtained from the Literature Review

An overview of the factors that were found to influence AFV fleet adoption behavior in the reviewed articles is presented in Table 2-3. Those factors are classified into fourteen sub-groups under three main categories: 1) AFV characteristics (monetary costs, vehicle performance, refueling/recharging infrastructure, and environmental benefits); 2) Organizational characteristics (sector and size, decision-making process, business strategic motives, intrinsic belief and values, fleet operational aspects, awareness of and experience with AFV, and individual attitudes); and 3) External environment context (governmental policy instruments, suppliers' supporting effort, and social influences). Though each factor is indicated as a motivator or a barrier to AFV fleet adoption based on the literature review

(Table 2-3), it should be noted that, this overview is unable to be interpreted as generalized results due to a sparse distribution of the reviewed articles across numerous combinations made from various dimensions (e.g., fuel types, business types, vehicle vocations, location, AFV adoption status, etc.).

Table 2-3. Factors Influencing Organizational AFV Fleet Adoption in Reviewed Studies

AFV Characteristics	Organizational Characteristics		External Environment Context
Monetary costs for AFVs	**Sector and size**	**Decision-making process**	**Governmental policy instruments**
TCO (*1, 13*)(+) (*5, 16*)(-) (*2, 3, 8, 10, 12, 19, 23, 25*)(n) Vehicle purchase price (*1, 2, 7, 8, 12, 13, 16, 19, 21, 25, 27, 28, 30, 34*)(-) (*31*)(.) (*22*)(d-) Fuel costs (*16, 21, 27, 31*)(+) (*2, 8, 12*) (n)(*1*)(-) (*4*)(.) Maintenance costs (*2, 4, 16*)(+) (*8, 12*)(n) (*3*)(-) Operating costs (*13*)(+) (*28*)(-) Residual value (*3, 13, 16, 21, 23*)(-) (*33*)(.) Other costs (*1, 2, 4, 22*)	Public vs. private status (*25, 33, 34*)(n) Business types and fleet vehicles' vocation types (*8, 9, 14, 27, 31, 33, 34*)(n) Size (e.g., the number of employees or vehicles) (*14, 19, 25, 33*)(+) (*16*)(-) (*18*)(.)	Collective dimension and complexity of the process (*5, 8, 13, 23, 32*)(-) Fleet purchase criteria (without relying on TCO) (*8, 23, 32, 33*)(-)	Government regulations (*5, 8, 23, 25*)(+) (*3*)(-) (*30*)(n) Financial incentives (*4, 5, 7, 8, 16, 25, 31*)(+) (*3*)(-) (*2*)(n) (*22*)(d+) Non-monetary incentives (*1, 10, 16, 21, 31*)(+) (*22*)(d+) Other supports (*2, 3, 5*)
Vehicle performance	**Business strategic motives**	**Intrinsic belief and values**	**Supplier supporting effort**
Driving range (*4*)(+) (*3, 5, 7, 8, 10, 11, 27, 34*)(-) (*1, 15–17*)(n) (*31*)(.) (*22*)(d-) (*6*)(d.) Payload (*3, 7, 21*)(-) (*16*)(n) Noise level (*2, 5, 13, 16, 23, 25, 28*)(+) (*16, 26*)(d+) Safety/Reliability (*12*)(+) (*2, 3, 5*)(-) (*9*)(.) Other characteristics (*5, 8, 17*)	Environmentally friendly and innovative image (*4, 8, 10, 12, 13, 16, 19, 23, 25, 33*)(+) (*5, 18*)(.) (*24*)(d+) (*6*)(d.) First-mover advantage (*10, 11, 16, 25*)(+)	Curiosity towards new technologies (*11, 12, 25*)(+) CSR (with environmental concerns) (*10–12, 18, 19, 25, 33*)(+) (*5*)(-) c.f., attitude-action gap (*18*)(-) Independence of energy source (*12*)(+)	Available vehicle models (*2, 3, 8, 9, 12, 16, 21, 30*)(-) (*1*)(n) (*22*)(d-) After-sales support (*3, 4, 16*)(-) Driver training (*10*)(+) (*16*)(d+) (*29*)(d.) Information provision (*12*)(+) (*4*)(-)
Environmental benefits	**Fleet operational aspects**	**Awareness/Experience**	**Social influences**
Greenhouse gas and tailpipe emissions (*1, 2, 5, 8, 10, 12, 21, 27, 28*)(+) (*1, 3*)(n) (*6, 16, 24*)(d+)	Fixed routes (*25*)(+) (*31*)(.) Centralized fueling (*25*)(+) (*33*)(.) In-house maintenance capabilities (*33*)(.) Other operational issues (*2, 5, 16–18, 22, 33*)	Awareness of AFVs tech (*12, 14, 15, 18, 21, 33*) (n) AFV adoption status (*10–12, 14, 15, 18, 19, 25, 31*) (n) AFV driving experiences (*15*)(+) (*16, 20, 26*)(d+)	Interconnectedness (*31, 33*)(+) Informal communication exchange between drivers (*29*)(d+) Subjective norm (*2, 14, 18*)(+) (*5*)(-) (*6*)(d+) (*29*)(d.)
Refueling infrastructure	**Individual attitudes**		
Fuel availability (*1–3, 7, 8, 13, 16, 17, 21, 27, 28, 30, 31, 33, 34*)(-) (*12*)(n) (*22*)(d-) Time to refuel/recharge (*5, 8, 25, 27, 34*)(-) (*22*)(d-) Risk of queuing (*3, 7*)(-) Other issues (*8, 13, 16, 23, 29*)	Key-decision makers' attitudes toward AFV (*2, 5, 9, 14, 15, 18, 25*)(+) Drivers' attitudes toward AFV (*8, 30*)(-) (*29*)(d.)	*Note: (1) **(+)**: motivators or facilitators to AFV fleet adoption, **(-)**: barriers to AFV fleet adoption, **(n)**: motivators or barriers depending on each own circumstance (e.g., estimated costs, alternative fuel types, operating conditions, etc.) **(.)**: neither motivators nor barriers **(d+/d-/d.)**: factors positively/negatively/insignificantly influencing acceptance of fleet drivers	

Based on the literature reviews, the following seven main insights were gained with considerations of design of the qualitative interviews (e.g., sampling strategies and selection of interview questions) and building the theory for heavy-duty AFV fleet adoption (e.g., selection of an appropriate reference theoretical framework).

1) Compared to household AFV adoption cases, a number of inherently different traits were found to affect AFV fleet adoption behavior in organizations. Total Cost of Ownership (TCO) (e.g., Altenburg et al., 2017; Morrison et al., 2018; Nesbitt & Davies, 2014; Saukkonen et al., 2017; Seitz et al., 2015; Sierzchula, 2014), operating vehicles on fixed routes (e.g., Sierzchula, 2014), first mover advantage (e.g., Altenburg et al., 2017; Sierzchula, 2014), and Corporate Social Responsibility (CSR) (e.g., Bennett, 2015; Seitz et al., 2015) are some of those examples of the factors which could be applied only to AFV fleet adoption behavior in organizations (c.f., Rezvani et al., 2015; Turcksin et al., 2013). As addressed by Seitz et al. (2015), it would be attributed to the major structural distinction between passenger car and fleet vehicle markets (e.g., business-to-consumer features for the former vs., business-to-business characteristics for the latter). Along with the different decision criteria, fleet purchase decision processes typically entail a higher complexity than household car purchase decisions – unless the organization has an autocratic decision making style –, because of its constraints such as group decisions and procedural rules (Nesbitt and Sperling, 2001). Therefore, the interchangeability of the findings from those two sectors – households vs. vehicle fleets in organizations – may be restricted.

At the same time, the reviewed articles, in some cases by assuming an autocratic decision-making style (e.g., Kaplan et al., 2016), tended to employ theoretical models that explain an individual level adoption behavior such as Theory of Reasoned Action (Fishbein and Ajzen, 1975), and its extensions, TPB (Ajzen, 1991), ETPB (Conner and Armitage, 1998), or TAM (Davis, 1989) (e.g., see Bennett, 2015; Pfoser et al., 2018). One exception is the study by Seitz et al. (2015) based on Technology–Organization–Environment framework (Tornatzky and Fleischer, 1990) which identifies three contextual aspects– technological, organizational, and external task environmental contexts – that influence innovation adoption process of an organization. This insight necessitates the use of organizational innovation adoption frameworks such as (Frambach and Schillewaert, 2002; Rogers, 1983b; Tornatzky and Fleischer, 1990) for more comprehensive investigation into the heavy-duty AFV fleet adoption behavior in organizations.

2) Great heterogeneities are observed in AFV fleet adoption behavior depending on various dimensions such as organizational sector, size, vehicle vocation, and adoption status. As an example, substantial differences among fleet market segments were found by Golob et al. (1997) in preferences for fuel types (e.g., schools were less negative toward EVs and CNG vehicles relative to the other sectors). Different driving patterns per vehicle vocation – in terms of driving distance, refueling behavior, and whether vehicles are operated on fixed routes – can also affect preference towards AFV fleet adoption (Loo et al., 2006; Sierzchula, 2014). In addition, size of an organization (e.g., fleet size or the number of employees) could affect AFV fleet adoption behavior (Sierzchula, 2014).

Another dimension which could shape different structures of influencing factors is adoption status. In the reviewed articles, the interview-based studies tended to target AFV adopters who would possibly fall into the '*innovators*' or '*early adopters*' groups according to the DOI theory (Rogers, 1983a) because of their propensity for adventurous curiosity (e.g., testing new technologies (Saukkonen et al., 2017; Sierzchula, 2014)) or taking leadership roles (e.g., CSR (Altenburg et al., 2017; Saukkonen et al., 2017; Sierzchula, 2014), first-mover advantages (Altenburg et al., 2017; Sierzchula, 2014)). In contrast, non-adopters tended to be the subjects in most of the survey-based studies (exceptions: (Globisch et al., 2018a; Johns et al., 2009; Morrison et al., 2018; Wikström et al., 2015, 2014)) and especially those who emphasized economically rational purchasing behavior would be the '*late majority*' or '*laggards*' groups (if they will purchase AFV someday). These findings provide some insights into design and analysis of the qualitative interviews: a stratified sampling technique would be necessary to capture the major variances across different segments. It will be also interesting to map one dimension (e.g., fleet size) onto another dimension (e.g., sector) and then compare structures of influencing factors across various segments.

3) Research findings focusing on LDV fleets may also not be simply translated into HDV fleets. Diverse application areas of fleet vehicles are differentially applied to LDV fleets (e.g., taxi, vans, and delivery trucks) and HDV fleets (e.g., long-haul/short-haul trucks, transit buses, refuse trucks, sweepers, and vocational trucks) under different market circumstances, fleet operational aspects, and governmental policy contexts. Thus, the results of the studies on LDV fleets may not fully explain AFV adoption behavior of HDV fleets, which justifies the necessity of building a stand-alone theory for heavy-duty AFV fleet adoption behavior.

4) Various forms of governmental policy instruments could influence AFV fleet adoption behavior. As Sierzchula (2014) reported, government regulations affected two organizations out of 14 interviewees who procured EVs. Financial incentives such as government grants, rebates, and tax credit, were found to be largely used to reduce the high upfront costs of AFVs (Morrison et al., 2018; Quak et al., 2016; Sierzchula, 2014). Although non-monetary incentives, such as parking privileges and access to high occupancy lanes, were rarely mentioned as crucial factors in AFV fleet adoptions, such benefits were perceived to be helpful and stimulating (Altenburg et al., 2017; Quak et al., 2016). Given that some portion of HDV fleet operators in California could be influenced by regulations such as South Coast Air Quality Management District (SCAQMD) Fleet Rules (SCAQMD, n.d.) and incentive programs (e.g., Natural Gas Vehicle Incentive Project (UCI-ITS, 2015)), it will be essential to incorporate a component of policy instruments into the theoretical framework after interviewing how those policy instruments have affected heavy-duty AFV fleet adoption in California.

5) There are only a few studies focusing on heavy-duty AFV fleet adoption behavior, but the results centering on different regions, a specific single vocation, and/or a single fuel technology may not fully explain AFV adoption behavior in California HDV sector. Only recently have academic researchers started to address alternative fuel adoption behavior in HDV fleets. For example, Walter et al. (2012) conducted a choice experiment in Switzerland and Germany to assess fleet operator preferences for hydrogen-powered sweepers, finding two monetary attributes – vehicle purchase price and running costs – to have the most profound influence on the purchasing decision. Another study in Germany by Seitz et al. (2015) was based on the TOE framework

(Tornatzky and Fleischer, 1990) and used a multiple linear regression analysis with their quantitative survey results, finding the CSR with environmental attitudes to be the most prevalent factors for heavy-duty AFV adoption (Seitz et al., 2015). Pfoser et al. (2018) developed a structural equation model based on their online survey results in European Rhine-Main-Danube axis areas, estimating that accessibility/availability of technology and refueling infrastructure, attitude towards AFVs, expected usability, and expected usefulness significantly determined an acceptance of liquefied natural gas for heavy-duty long distance transport operators. Mohamed et al. (2018) conducted 11 in-depth interviews with transit service providers in Canada to identify the factors that hinder the implementation of electric buses, highlighting risk mitigation, operational capabilities, and cost reductions as the potential measures for electric buses to penetrate the marketplace. Another recent study by Blynn and Attanucci (2019) also investigated the factors that affect electrification of transit bus fleets in California, Kentucky, and Massachusetts, finding environmental benefits as the top motivation factor, and high first cost and charging infrastructure costs as the most cited substantial obstacles by all 12 agencies interviewed. Anderhofstadt and Spinler (2019) employed the Delphi method to examine the factors affecting adoption of heavy-duty AFVs in Germany, finding the key factors to be truck reliability, available fueling infrastructure, the possibility to enter low-emission zones, and current and future fuel costs. Though informative, these previous studies present results centering on a specific single vocation (e.g., Mohamed et al., 2018; Walter et al., 2012), single fuel technology (e.g., Pfoser et al., 2018), or alternative power trains in general (e.g., Seitz et al., 2015). Therefore, such previous research may not fully explain heavy-duty AFV fleet adoption behavior, which justifies the need for further research probing alternative fuel adoption behavior by HDV fleet operators from various vocational sectors across diverse fuel technologies.

6) There has been a lack of studies about revealed non-adoption cases where potential adopters considered purchasing an AFV but decided not to buy it. In the reviewed articles, most of the interviews focused only on adopters and most of the surveys relied on a stated preference approach. Addressing which factors affect those reveled rejections can provide a clearer understanding of critically perceived weaknesses of and barriers to heavy-duty AFV fleet adoption. It will be therefore necessary to consider those non-adoption cases for the sampling strategies for the interviews and then to incorporate those cases in the finalized theory.

7) Lastly, acceptance of fleet vehicle drivers towards AFV use was addressed as a key for successful implementation of AFVs in several studies (Johns et al., 2009; Wikström et al., 2016, 2015). Because drivers are responsible for using and fueling AFVs as end-users, their actions could heavily influence the implementation process (Johns et al., 2009). In this context, two studies reported that confronting the problems related to end-users' acceptance about AFVs was perceived as a concern by fleet operators (Morrison et al., 2018), and sometime even limited AFV purchases (Rahm and Coggburn, 2007). Although the degree to which drivers are involved in decision-making processes varies across organizations, the feature of the acceptance at the individual level towards AFV within an organization needs to be considered when interviewing the HDV fleet operators and developing the theoretical framework.

Acknowledgements

Bae, Youngeun, Mitra, Suman K. and Ritchie, Stephen G. “Building a Theory of Alternative Fuel Adoption Behavior of Heavy-duty Vehicle Fleets in California: An Initial Theoretical Framework.” *98th Annual Meeting of the Transportation Research Board*. Washington, D.C., Jan 2019. Poster presentation

Bae, Youngeun, Mitra, Suman K., Rindt, Craig R., and Ritchie, Stephen G. “Factors Influencing Alternative Fuel Adoption Decisions in Heavy-duty Vehicle Fleets.” *Transportation Research Part D. Transport and Environment*, Under review.

CHAPTER 3: Initial Theoretical Framework of AFV fleet Adoption Behavior in Organizations

In this chapter, an initial theoretical framework is developed to explain AFV fleet adoption behavior in organizations. The literature review results imply that organizational AFV fleet adoption behavior can be inherently different from individual adoption cases in terms of both decision criteria and decision processes. Accordingly, existing theories and frameworks centering on an organization's innovation adoption behavior were referred to such as, 1) *Innovation in Organizations* in the DOI theory (Rogers, 1983b); 2) *Technology–Organization–Environment* framework (Tornatzky & Fleischer, 1990); and 3) *a multi-level framework of organizational innovation adoption* (Frambach and Schillewaert, 2002). This chapter first provides a summary of such existing frameworks.

After examining and re-designing the existing frameworks and by synthesizing the findings from the literature review, it was attempted to develop a conceptual two-level initial framework at the decision-making unit level and individual acceptance level, which is elaborated in the remaining part of this chapter,

3.1. Existing Theories and Frameworks

3.1.1. Innovation in Organizations (in the DOI theory)

Diffusion of innovations (DOI) is a theory of how a new idea or technology (called "*innovation*") is spread over time among a members of a social system by being communicated through certain channels (Rogers, 1983a). Of many sub-topics in the DOI theory – most of which are concerned with diffusion of innovations to individuals –, one topic, "Innovation in Organizations" (Rogers, 1983b), focuses on innovation adoption by organizations. According to Rogers (1983b), when innovation-decisions are made by consensus among the members of a system (collective innovation-decisions) or made by relatively few individuals in a system who possess power, status, or technical expertise (authority innovation-decisions), the organizational innovation adoption decision will lie in a different context from an individual adoption decision.

As depicted in Figure 3-1, the DOI theory suggests that organizational innovativeness can be influenced by three categories of independent variables: individual (leader) characteristics, internal characteristics of organizational structure, and external characteristics of the organization.

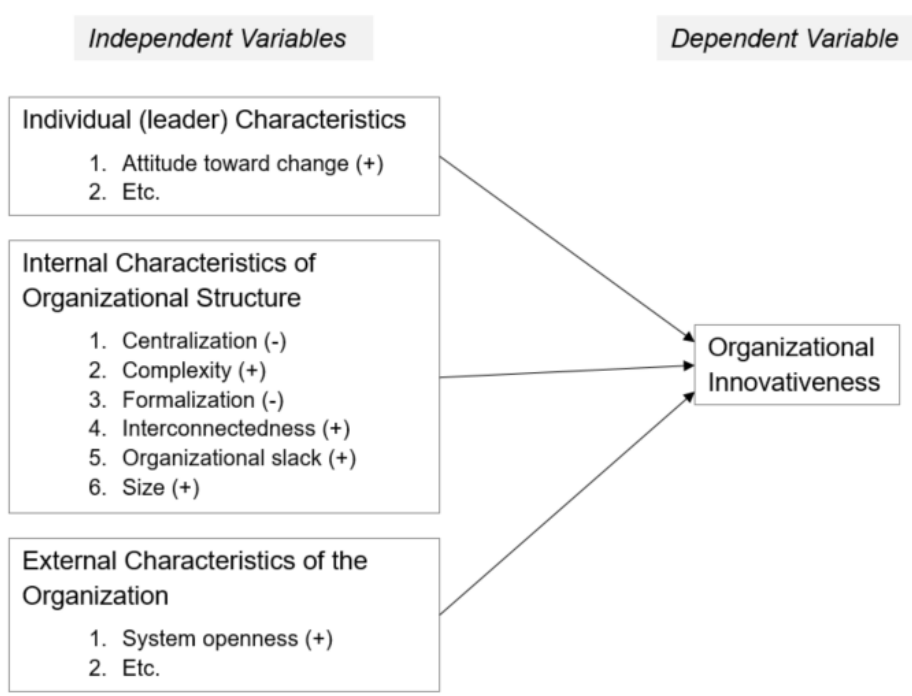

Figure 3-1. DOI: Independent Variables Related to Organizational Innovativeness (Rogers, 1983b)

1) *Individual characteristics* explains the leader's attitude toward change (Rogers, 1983b).

2) *Internal characteristics of organizational structure* include six variables: "centralization is the degree to which power and control in a system are concentrated in the hands of relatively few individuals"; "complexity is the degree to which an organization's members possess a relatively high level of knowledge and expertise"; "formalization is the degree to which an organization emphasizes following rules and procedures in the role performance of its members"; "interconnectedness is the degree to which the units in a social system are linked by interpersonal networks"; "organizational slack is the degree to which uncommitted resources are available to an organization"; and "size is the number of employees of the organization" (Rogers, 1983b).

3) *External characteristics of organizational* indicates system openness, "the degree to which the members of a system are linked to others who are external to the system" (Rogers, 1983b).

However, Rogers (1983b) highlighted that numerous previous studies reported rather low correlations between independent variables and the innovativeness of organizations. One of the basic reasons would be that each of the organizational structure variables is related to innovation in one direction during '*initiation*', and in the opposite direction during '*implementation*' (Rogers, 1983b) [7]. To help illuminate this paradox, Rogers (1983b) recommended a process research which brings the initiation and implementation sub-processes into an analysis of organizational innovation adoption

[7] "Low centralization, high complexity, and low formalization facilitate initiation in the innovation process, but these same structural characteristics make it difficult for an organization to implement an innovation" (Sapolsky, 1967; Zaltman et al., 1973 as cited in Rogers, 1983b).

behavior. In this context, the following sequence of five stages is suggested by Rogers (1983b) as an innovation process of an organization (see Figure 3-2):

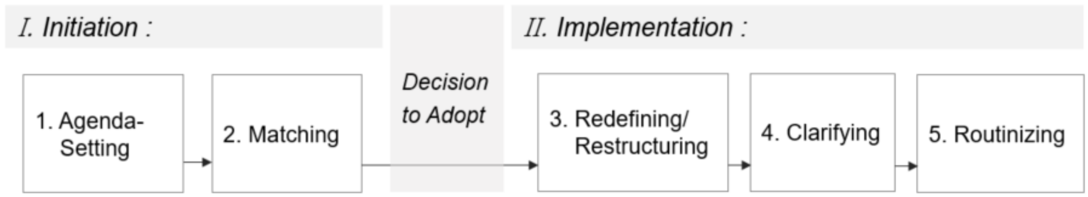

Figure 3-2. DOI: Stages in the Innovation Process in Organizations (Rogers, 1983b)

1) *Agenda-setting* stage where "general organizational problems, which may create a perceived need for an innovation, are defined and the environment is searched for innovations of potential value to the organization" (Rogers, 1983b, p.363);

2) *Matching* stage where "a problem from the organization's agenda is considered together with an innovation, and the fit between them is planned and designed" (Rogers, 1983b);

3) *Redefining/restructuring* stage where "the innovation is modified and re-invented to fit the situation of the particular organization and its perceived problem and organizational structures directly relevant to the innovation are altered to accommodate the innovation" (Rogers, 1983b, p.363);

4) *Clarifying* stage where "the relationship between the innovation and the organization is defined more clearly as the innovation is put into full and regular use" (Rogers, 1983b, p.363); and

5) *Routinizing* stage where "the innovation eventually loses its separate identity and becomes an element in the organization's ongoing activities" (Rogers, 1983b).

The first two stages form the '*initiation*' sub-process which leads to the decision to adopt. After the decision, the '*implementation*' sub-process consists of the last three stages. While these five stages may typically occur in the order presented, it may backtrack when any unnoticed problems are identified (Rogers, 1983b).

3.1.2. Technology–Organization–Environment Framework

Tornatzky and Fleisher (1990) developed the TOE framework which identifies three contextual aspects – technological, organizational, external environmental – that influence the process of an organization's technological innovation decision (see Figure 3-3):

1) *Technological context* describes both the internal and external technologies relevant to an organization. This includes current practices and equipment internal to the firm (Starbuck, 1976), as well as the set of available technologies external to the firm (Hage, 1980; Khandwalla, 1970; Thompson, 1967).
2) *Organizational context* refers to descriptive measures about the organization such as scope, size, and managerial structure.
3) *External task environmental context* is the arena in which a firm conducts its business—its industry, competitors, and dealings with the government.

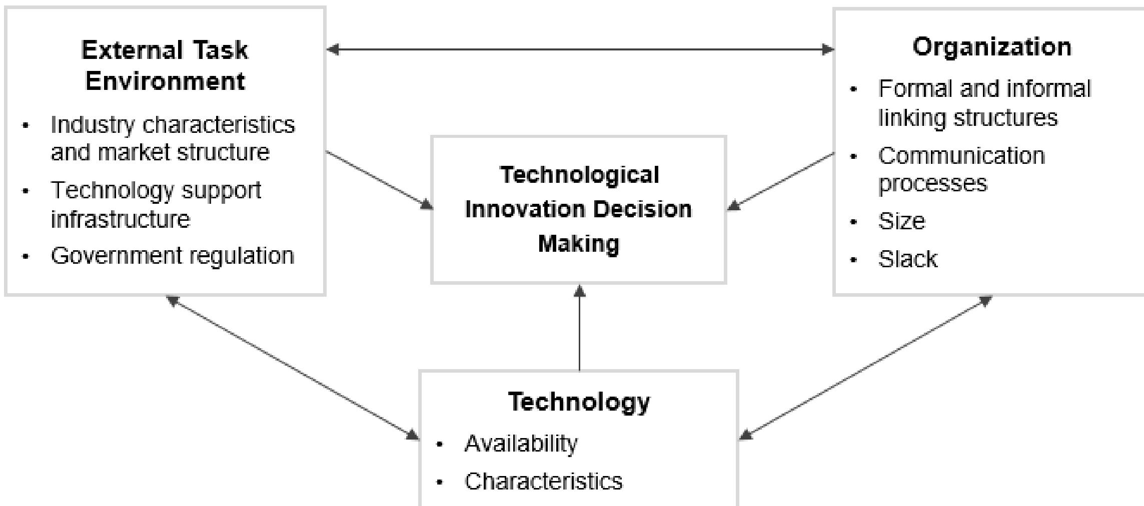

Figure 3-3. Technology, Organization, and Environment Framework (Tornatzky & Fleischer, 1990)

Compared to Rogers' theory, the TOE framework more explicitly addresses the *external environmental context*, which allows one to explain both constraints and opportunities made by government regulations, infrastructure support, and business competitors (Hsu et al., 2006). The TOE framework has been broadly applied for many different types of technological innovations such as e-business (e.g., Zhu, Kraemer, & Xu, 2006), cloud computing (e.g., Borgman, Bahli, Heier, & Schewski, 2013), and AFV fleet adoption (e.g., Seitz et al., 2015).

3.1.3. A Multi-Level Framework for Organizational Innovation Adoption

Frambach and Schillewaert (2002) developed a multi-level framework of organizational innovation adoption behavior that incorporates two levels: 1) the organizational level and 2) the individual acceptance level within an organization. This framework is based on more than 40 relevant studies published from 1970s to 1990s, as well as Rogers' DOI theory (1983a). While the DOI theory and the TOE framework focus on a leader or a decision-making unit (DMU) in an organization, this multi-level framework highlights the importance of the acceptance of innovation within an organization as well as the DMU's decision making process. This is because, as Frambach and Schillewaert (2002) explained, the innovation process can only be considered a success when the innovation is integrated into the organization and the target adopters demonstrate *commitment* by continuing to use the product over a period of time (Bhattacherjee, 1998). Accordingly, a two-level conceptual framework is proposed for the organizational level and for the individual acceptance level within an organization.

Organizational level of Innovation Adoption *(Frambach and Schillewaert, 2002)*

The first part of the multi-level framework (Frambach and Schillewaert, 2002) describes the factors that have been found to affect innovation adoption at the organizational level. This framework includes both direct and indirect effects of influencing factors: the perceived characteristics of the innovation, organizational adopter characteristics, and environmental influences directly drive the adoption process while the perceived innovation characteristics mediate the supplier, social network, and other environmental influences on adoption behavior. Each component affecting an innovation adoption decision at the organizational level is briefly described below (see Frambach & Schillewaert (2002) pp.164-167 for details).

1) *Perceived innovation characteristics* include the perceived net benefit (i.e., relative advantage provided by the innovation), perceived compatibility, complexity,

observability, trialability, and uncertainty (Rogers, 1983a, as cited in Frambach and Schillewaert, 2002).[8]

2) *Adopter characteristics* include organization size, structure and organizational innovativeness (i.e., "the degree to which an organization is receptive to new products or ideas") (Frambach and Schillewaert, 2002, p.165).

3) *Supplier marketing efforts* consist of three main factors: (a) "targeting" by which selected potential adopters are targeted for facilitating innovation acceptance in the market; (b) "communication" which creates awareness and influences potential customers' perception of the innovation; and (c) "risk reduction activities" which aim to reduce the risks – including implementation, financial and operation risk – associated with early adoption of an innovation and to stimulate the adoption of innovation (Frambach and Schillewaert, 2002, pp.165-166).

4) *Social network* can facilitate the adoption rate of innovation throughout the market. For example, the interaction between members through informal networks can enhance the speed of information spread about an innovation, which may increase awareness of the innovation and affect adoption decisions (Frambach and Schillewaert, 2002, p.166). In the DOI theory, the same concept is addressed as the "interconnectedness" (Rogers, 1983a).

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[8] According to Rogers (1983a, pp.238-240), each concept is defined as follows. The compatibility is "the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters"; the complexity is "the degree to which an innovation is perceived as relatively difficult to understand and use"; the observability is "the degree to which the results of an innovation are visible to others"; the trialability is "the degree to which an innovation may be experimented with on a limited basis"; and the uncertainty is "the degree to which a number of alternatives are perceived with respect to the occurrence of an event and the relative probabilities of these alternatives and the uncertainty implies a lack of predictability of the future."

5) *External environment* influences adoption behavior in two different ways: (a) positive "network externalities" may exist when increased utility is obtained by adopting an innovation if other interrelated entities such as suppliers, consumers, competitors, or any others also adopt the innovation. (b) "competitive pressures" by which an organization may consider adopting an innovation in order to maintain their market position (Frambach and Schillewaert, 2002, p.167).

After the DMU decides to adopt an innovation, its target user groups must realize the intended benefits and accept the innovation. Otherwise, desired consequences cannot be realized and the organization may eventually discontinue the intended adoption (Frambach and Schillewaert, 2002). As an example, even if a DMU of a freight trucking company decides to purchase alternative fuel trucks to gain financial benefits resulted from low fueling costs, the operation of these new trucks could be ceased when their drivers do not accept the new trucks due to performance issues such as a low power, a low maximum speed, and a maintenance complexity.

Individual acceptance level within an organization *(Frambach and Schillewaert, 2002)*

Frambach and Schillewaert (2002) also developed a conceptual framework for understanding individual acceptance toward an innovation within an organization. A brief description of each component affecting the individual acceptance is provided below (see Frambach & Schillewaert (2002), pp.167-172 for details).

1) *Attitude toward an innovation* is formed by "perceived beliefs and affects held towards the innovation", which is an important underlying factor for the individual acceptance.

A person's attitudes mediate the influence of external variables such as organizational facilitators and internal marketing activities (Frambach and Schillewaert, 2002, p.171).

2) *Organizational facilitators* such as organizations' management strategies, policies, and actions regarding their innovation adoption – for example, through training, education, and incentive structures – may affect a person's attitudes toward innovation (Frambach and Schillewaert, 2002, p.171).

3) *Personal innovativeness* refers to "the tendency of a person to accept an innovation independently of the communicated experience of others" (Frambach and Schillewaert, 2002, p. 171). If an individual member of an organization has personal innovativeness, they reveal more positive acceptance towards the innovation adoption. Personal innovativeness would be influenced by socio-demographics and personal values (Frambach and Schillewaert, 2002, p.171).

4) *Social influences* could also affect individual acceptance towards innovations. For example, the acceptance by peers of an individual may signal its benefits, by which the individual could be motivated to use the innovation (Frambach and Schillewaert, 2002).

Overall, the three existing frameworks embrace organizational characteristics and external influences on innovation adoption at an organization while the multi-level framework (Frambach and Schillewaert, 2002) provides a further expanded framework acknowledging the multi-level nature of innovation adoption behavior at the organizational level and the individual acceptance level within an organization. At the same time, Frambach and Schillewaert (2002) pointed out that, a model of organizational innovation adoption would follow its own idiosyncratic characteristics and thus their proposed framework needs to be adapted to the specifics of the innovation and the organizational situations.

3.2. Initial Theoretical Framework

In this subsection, an initial theoretical framework is proposed in order to conceptually understand organizational behavior of AFV fleet adoption, which serves as theoretical background for this research. Based upon existing theories (Frambach and Schillewaert, 2002; Rogers, 1983a, 1983b; Tornatzky and Fleischer, 1990) as well as findings from a comprehensive literature review of light-duty and heavy-duty AFV fleet adoption studies (Bae et al., 2019), the proposed initial framework consists of a five-stage adoption process and two levels of sub-frameworks, at both the DMU level and the individual (e.g., vehicle driver) acceptance level. This initial framework can help organize concepts and explain phenomena that would exist in such fleet behavior, which theoretically contributes to understanding of the research topic.

3.2.1. Adoption Process

To help understand the conceptual nature of an innovation adoption process, relevant descriptions in the existing frameworks were referred to. According to Rogers (1983a, p.20), the innovation-decision process is defined as “the process through which an individual (or a DMU) passes from first knowledge of an innovation to forming an attitude toward the innovation, to a decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision." Also, the innovation-decision process is "an information-seeking and information-processing activity in which an individual (or a DMU) obtains information in order to decrease uncertainty about the innovation" (Roger, 1983a, p.21). While the existing frameworks (Frambach and Schillewaert, 2002; Rogers, 1983b, 1983a) present slightly different naming of the decision processes (see Table 3-1), the main concepts seem consistent with each other. Accordingly, for this research, it is suggested to use the most comprehensive naming for each stage (see the last column of Table 3-1) as far as the concept of each stage is consistent with the previous frameworks.

Table 3-1. Comparison of the Innovation Adoption Decision Process Between Different Frameworks

DOI (individual adoption) (Rogers, 1983a)	**DOI** (organizational adoption) (Rogers, 1983b)	**A Multi-level framework** (Frambach & Schillewaert, 2002)	**For This Research**
1. Knowledge	*(initiation)* 1. Agenda-setting	1. Awareness	1. Awareness
2. Persuasion	2. Matching	2. Consideration	2. Consideration
		3. Intention	
3. Decision	*(decision)*	4. Adoption decision	3. Adoption decision
4. Implementation	*(implementation)*		4. Implementation
	3. Redefining/ restructuring 4. Clarifying		
5. Confirmation	5. Routinizing	5. Continued use	5. Confirmation

The adoption process of AFV fleets in organizations is conceptually described by the following five stages, based on Frambach and Schillewaert (2002) and Rogers (1983b, 1983a).

• **Stage 1 Awareness:** An organization acknowledges alternative fuel technology(ies), which may create a perceived need for adopting AFV(s).

• **Stage 2 Consideration:** A DMU of the organization may evaluate the AFV(s) and formally consider it with the purpose of achieving their goals or solving a problem.

• **Stage 3 Adoption Decision**: The DMU decides whether or not to adopt the AFV(s).

• **Stage 4 Implementation**: If the DMU decides to adopt, they might modify and reinvent the vehicle(s), and/or alter fleet operational particularities, if necessary, to fit a particular situation of the organization.[9]

• **Stage 5 Confirmation:** The DMU of the organization seeks consolidation of the decision already made with the organization, but they may reverse the adoption decision if they observe conflicting messages about the heavy-duty AFV(s).

During this process, a failure of adoption occurs when a subsequent stage is not completed. According to the DOI theory, there are two different groups of rejections ((Eveland, 1979) as cited in Rogers, 1983b): 1) an active rejection case which occurs when an organization considers adopting an innovation, but later decides not to adopt it; and 2) a passive rejection case which happens when an organization does not think about adopting the innovation at all. The middle part of Figure 3-4 presents such an adoption and non-adoption process.

[9] For example, a fleet operator could consider adding more CNG tanks for their trucks to increase their driving range. Also, they could consider modifying an operating schedule of the fleet to accommodate their new AFVs.

3.2.2. Initial Theoretical Framework at the Decision-making Unit Level

The first level sub-framework is depicted at the DMU level in an organization. In this framework, both direct and indirect effects of influencing factors on adoption process are assumed: perceived technology characteristics, organization characteristics, and external environmental influences could directly drive the adoption process while the perceived technology characteristics could mediate the impacts of suppliers, social influences, governmental policies, and organizational characteristics on the adoption process. The sub-framework of AFV fleet adoption at the DMU level is depicted in the top of Figure 3-4. A number of factors, which were found to influence AFV fleet adoption in the reviewed articles, are classified into the following components and defined as follows:

• ***Perceived heavy-duty AFV technical characteristics*** A higher purchase cost of AFV than conventional vehicles is one of the major relative disadvantage to AFV fleet adoption (Golob et al., 1997; Kirk et al., 2014; Morrison et al., 2018; Walter et al., 2012). Nevertheless, for some organizations, AFV fleet would be favored over conventional one, on the basis of TCO approach in which fuel costs saving is taken into account (Boutueil, 2016). In addition, a reduced noise can be a perceived operational advantage, especially of EVs (Boutueil, 2016; Quak et al., 2016; Sierzchula, 2014). Obviously, low tailpipe emissions and GHG emissions (U.S. DOE, 2014) can be perceived relative advantages of AFVs (van Rijnsoever et al., 2013; Walter et al., 2012). Perceived AFV compatibility would be obtained when an organization's business needs are satisfied in terms of AFV driving range and vehicle performance (Quak et al., 2016). Whereas, perceived complexity of AFV operation, for example, attributed to inadequate refueling infrastructure (Kirk et al., 2014; Morganti and Browne, 2018; Morrison et al., 2018; Rahm and Coggburn, 2007) and a longer time to refuel AFVs (Morrison et al., 2018; van Rijnsoever et al., 2013), would discourage AFV fleet adoption. Furthermore, perceived uncertainty associated with AFVs' residual value (Kirk et al., 2014; Nesbitt and Davies, 2014; Quak et al., 2016), safety concerns and operational risks (Morrison et al., 2018; Wikström et al., 2016) can be a barrier to facilitating AFV fleet adoption decision process.

• ***Organizational characteristics*** Various features of an organization – such as sector, size, vehicle vocation, and AFV adoption status – can affect AFV adoption behavior. Another important factor is about whether or not an organization has business strategic motives with regard to AFV adoption such as pursuing the first-mover advantage (Altenburg et al., 2017; Sierzchula, 2014) or environmentally friendly and/or innovative images (Altenburg et al., 2017; Boutueil, 2016; Morrison et al., 2018; Quak et al., 2016; Sierzchula, 2014). Intrinsic belief and values possessed by an organization, such as curiosity towards new technologies (Globisch et al., 2018b; Saukkonen et al., 2017; Sierzchula, 2014) or CSR (Altenburg et al., 2017; Seitz et al., 2015; Sierzchula, 2014), also could motivate them to adopt AFV fleet. On the other hand, a collective dimension of decision-making process, which requires coordinating across personnel from different departments and various hierarchical levels (Boutueil, 2016; Morrison et al., 2018; Nesbitt and Davies, 2014), and fleet purchase criteria without relying on TCO (Nesbitt and Davies, 2014; Nesbitt and Sperling, 1998) could become internal barriers to AFV fleet adoptions.

Furthermore, the external environmental context created by technology suppliers, governments, and social networks also affect AFV adoption behavior in organizations.

• ***Technology supplier supporting efforts*** Along with the limited availability of vehicle models on the market (Kirk et al., 2014; Morrison et al., 2018; Saukkonen et al., 2017), the limited model features – that would hinder fleet vehicles from serving specific operational needs required in the B2B context (Saukkonen et al., 2017) – were addressed as the barriers to AFV fleet adoptions. In addition, unreliable aftersales support (e.g., limited availability of spare parts and skilled servicemen, and a very long repair time) was reported as another main challenges faced by EV fleet operators (Quak et al., 2016). At the same time, providing an opportunity to use AFVs as a trial (trialability) would help lower uncertainty of AFV operations (Rogers, 1983a).

• ***Government policies*** Governmental policy instruments, such as government regulations (Rahm and Coggburn, 2007; Sierzchula, 2014), financial incentives (Morrison et al., 2018; Quak et al., 2016; Sierzchula, 2014), and non-monetary incentives (Altenburg et al., 2017; Kirk et al., 2014; Quak et al., 2016), can influence organizational AFV fleet adoption decisions.

• ***Social influences*** Despite only a few studies which discussed the roles of social networks (Bennett, 2015; Kaplan et al., 2016; Loo et al., 2006; Nesbitt and Sperling, 1998), the referred frameworks (Frambach and Schillewaert, 2002; Rogers, 1983a) along with other studies dealing with social influences on private AFV adoption (Pettifor et al., 2017) would imply a possibility of those social effects on organizational AFV fleet adoption behavior. For example, a connection through interpersonal networks between DMU members and other organizations particularly those who have already adopted AFVs (i.e., interconnectedness (Rogers, 1983a)) would be likely to decrease the uncertainty of AFV adoption (Loo et al., 2006; Nesbitt and Sperling, 1998). Also, when the organization has chances to observe AFVs operating near their location (i.e., neighborhood effect (Pettifor et al., 2017)), there is a possibility of reducing uncertainty. In addition, as found by Kaplan et al. (Kaplan et al., 2016) and Bennett (Bennett, 2015) the intent to conform with a social norm would affect AFV adoption decisions when the social norm is prevalent among referent social groups (Pettifor et al., 2017).

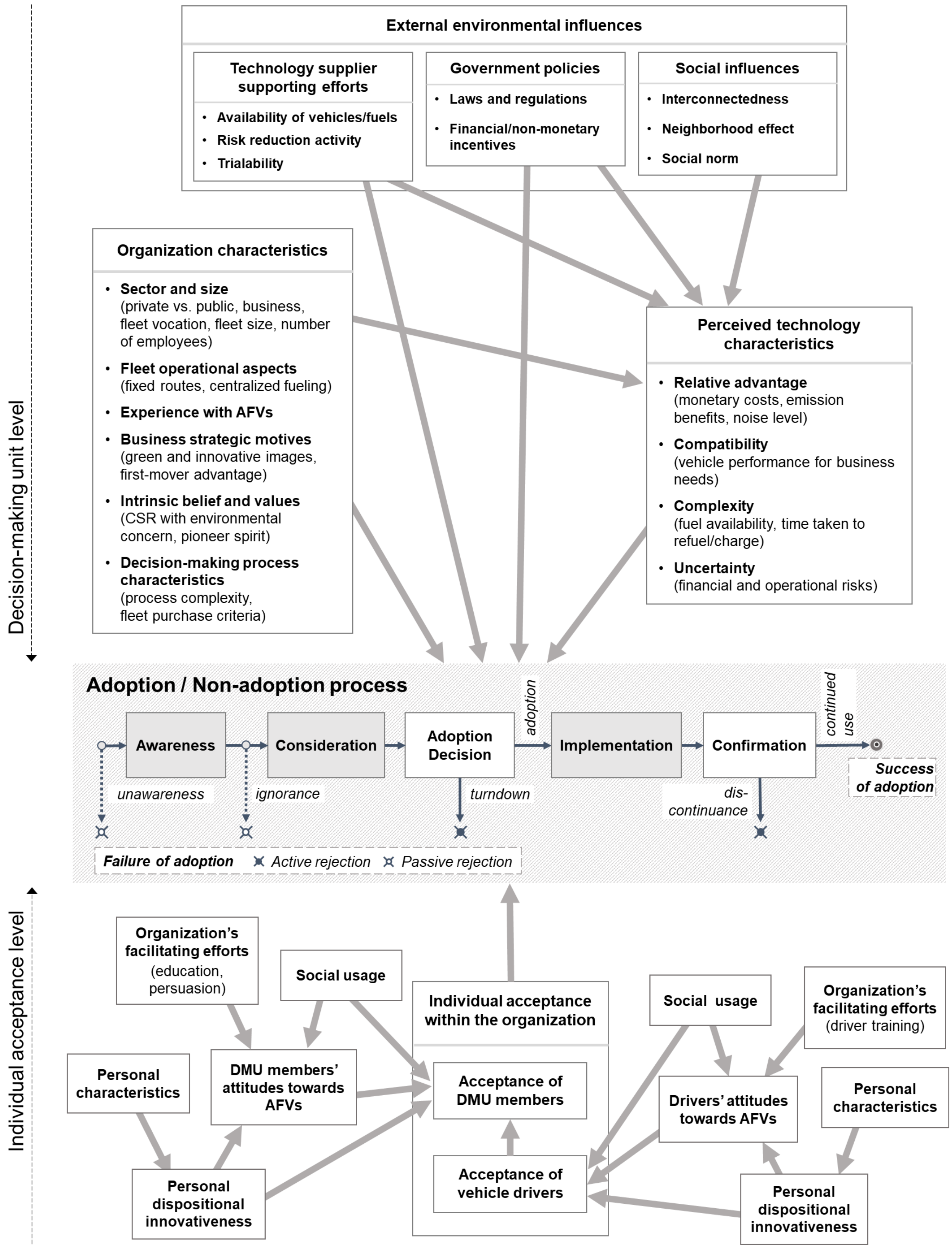


Figure 3-4. An Initial Framework of AFV Fleet Adoption Behavior in Organizations

3.2.3. Initial Theoretical Framework at the Individual Acceptance Level

The sub-framework for AFV fleet adoption at the individual acceptance level is depicted in the bottom of Figure 3-4. Two categories of individuals are considered: any individuals involved in the decision-making process (DMU members) and end users of AFVs (vehicle drivers). If an individual belongs to the DMU, their acceptance will directly influence the decision process. If not, the individual acceptance would indirectly affect the process by delivering their opinions to the DMU members. The factors, which were found to influence the individual acceptance in the reviewed articles, are classified into the following components and defined as follows:

• ***Attitude towards AFVs*** For vehicle drivers, attitudes towards AFVs are shaped by various factors, such as perceived AFV usefulness (Globisch et al., 2018a), perceived environmental benefits (Globisch et al., 2018a; Rolim et al., 2014), and perceived ease of use (e.g., refueling convenience) (Globisch et al., 2018a; Johns et al., 2009), and interest in improving company image (Rolim et al., 2014). In order to promote drivers' use and acceptance of AFVs, ***organizational facilitating efforts*** could be taken, for example, training aiming to familiarize drivers with technical and operational particularities of AFVs (Quak et al., 2016). In addition, several studies highlighted an importance of ***drivers' experience with AFVs***, observing that after utilizing AFVs for some time, drivers acceptance, satisfactions, and even driving behavior (e.g., optimize EV range (Wikström et al., 2014)) were improved (Quak et al., 2016; Wikström et al., 2015, 2014).

• ***Personal dispositional innovativeness*** The individuals, who possess a tendency to buy new products at an early stage, would be likely to have more favorable acceptance towards AFVs. The study results from Globisch et al. (2017) support this assertion: fleet managers' interest in EVs due to *technophilia* was found to significantly increase the intention to campaign for EV procurement in their company.

• ***Social usage*** When individuals' peers, who already have experience with AFVs, signal (dis)advantages to them, those social interactions could also influence individual acceptance toward AFVs. For example, subjective norms (i.e., reactions of other members in an organization to AFVs adoption) by Globisch et al. (2018) and informal communication exchange (e.g., regarding their vehicles and maintenance) between drivers by Johns et al. (2009) were highlighted as significant factors affecting fleet drivers' acceptance or use of AFV.

Meanwhile, development of a conceptual theoretical framework for AFV fleet adoption was also pursued by Mohammed et al (2020) based upon a comprehensive review of 53 peer-reviewed articles. In the resulting framework, a set of ten constructs – perceived risk, management involvement, training for innovation, performance expectancy, effort expectancy, social influence, environmental factors, organizational factors, attitudes, and emotion – is proposed to explain a firm's intention and their decision to adopt AFVs. While almost all of the concepts inherent in such explanatory constructs concur between the frameworks in this work and that of Mohammed et al (2020), the initial framework presented in this dissertation accounts for additional elements and mechanisms, including the five-stage adoption process as well as the two separate levels of sub-frameworks at the DMU and the individual acceptance levels.

However, as recognized by (Mohammed et al., 2020), frameworks based upon literature reviews should be examined, refined, and tested with empirical data. Furthermore, our literature reviews on AFV fleet adoption revealed a sparse distribution of the reviewed articles across numerous combinations made from various dimensions including fuel types, sectors, vehicle vocations, locations, and AFV adoption status (Bae et al., 2019), which may prevent this preliminary framework from being interpreted as generalized results. Moreover, the scant literature regarding heavy-duty AFV adoption may restrict the capability of this framework to properly explain HDV fleet behavior. Therefore, this initial framework first needs to be scrutinized and refined by investigating with empirical data from heavy-duty fleet operators who made an adoption or non-adoption decision regarding AFVs.

In the next chapter, this initial framework for AFV fleet adoption behavior will be further explored based on empirical data from heavy-duty AFV fleet operators in California. At the same time, the relationship between the DMU and the individual acceptance levels should be examined. Although the original conceptual framework (Frambach and Schillewaert, 2002) consists of a sequential process of those two levels, for the case of heavy-duty AFV adoption, fleet drivers' acceptance after a trial period may be counted during the DMU-level decision process. When those cases are prevalent, a simultaneous consideration of the two levels of sub-frameworks would be required.

Acknowledgements

Bae, Youngeun, Mitra, Suman K. and Ritchie, Stephen G. “Building a Theory of Alternative Fuel Adoption Behavior of Heavy-duty Vehicle Fleets in California: An Initial Theoretical Framework.” *98th Annual Meeting of the Transportation Research Board*. Washington, D.C., Jan 2019. Poster presentation

Bae, Youngeun, Mitra, Suman K., Rindt, Craig R., and Ritchie, Stephen G. “Factors Influencing Alternative Fuel Adoption Decisions in Heavy-duty Vehicle Fleets.” *Transportation Research Part D. Transport and Environment*, Under review.

CHAPTER 4: Building a Theory of Heavy-duty AFV Fleet Adoption Behavior

To empirically improve the initial theoretical framework, organizations that operate HDVs in the State of California were investigated via in-depth qualitative interviews and project reports. A total of 29 adoption and 42 non-adoption cases were probed across various alternative fuel technologies, including natural gas, propane, electricity, hydrogen, biodiesel, and renewable diesel options. In this chapter, the qualitative research approach is first explained, and the analysis results of the qualitative data are presented.

4.1. Qualitative Research Approach

Given the lack of studies on heavy-duty AFV adoption behavior, a qualitative research approach is more appropriate than a quantitative method in that the former is suited to exploring a complicated phenomenon with a more detailed analysis (Bryman, 2012; Creswell, 2003; Yin, 2009). A qualitative research approach is associated with an inductive strategy of generating a theory from data, which is in contrast to quantitative research entailing a deductive approach where the emphasis is placed on testing of theories or hypotheses already developed (Bryman, 2012). Of several possible qualitative research methods, semi-structured interviews were used to obtain a thorough understanding of each fleet operator's AFV adoption behavior, by allowing flexibility for interviewers to explore the context of the topic and providing much more space for interviewees to answer from their own perspectives and in their own words (Edwards and

Holland, 2007). In case interviews were not achievable, inclusion of other qualitative materials (e.g., project reports) was attempted in order to reinforce the analysis.

4.1.1. California as a Case Study

Out of the 50 United States, California is the most populous state with over 39.5 million residents (U.S. Census Bureau, 2019). The State is the second largest GHG emitter among the 50 states, with a share of 7% in 2017 (U.S. EIA, 2021). In the California's transportation sector, which accounts for 41% of the state's GHG inventory, HDVs are a major contributor with 21% of the sector's GHG emissions (CARB, 2020a). Meanwhile, the freight transportation system, in which HDVs are one of the main components, is responsible for one-third of the jobs in the California economy (State of California, 2015a). Therefore, it is imperative to execute mitigation strategies for reducing HDV-generated emissions that do not constrain economic growth.

The State of California is recognized as a national leader with its progressive goals, plans, and actions in reducing emissions. California has established near- and long- term goals to reduce GHG emissions to 1990 levels by 2020, and to 40 and 80 percent below 1990 levels by 2030 and 2050, respectively (State of California, 2015b, 2006, 2005). The State has also implemented multiple plans, for example, aiming for 80 percent reduction in NOx by 2031 under the Clean Air Act (CARB, 2016), 85 percent reduction in diesel PM by 2020 directed by the Diesel Risk Reduction Plan (CARB, 2000), and a transition to zero emission HDVs everywhere feasible and near-zero emission technologies powered by clean, low-carbon renewable fuels everywhere else under the Advanced Clean Trucks program (CARB, 2021a).

The State comprises 35 local air districts, which are called Air Pollution Control Districts (APCD) or Air Quality Management Districts (AQMD). Those air districts have primary responsibility for controlling regional air quality (CARB, 2021b). There are many incentives and regulations implemented by the State and local air districts to encourage or require HDV fleets to use alternative fuels (U.S. DOE, 2021b).

Table 4-1. Registered Heavy-duty Vehicles in California as of 2018 December

Fuel	HDVs [(a)]	Percentage		HDV Fleets [(b)]	Percentage	
		of Total HDVs	of Total AFVs		of Total HDV Fleets [(b)]	of Total AFV Fleets [(b)]
Diesel	513,160	80.3%		156,327	83.7%	
Gasoline	97,814	15.3%		41,193	22.1%	
Natural Gas	20,112	3.2%	70.6%	1,747	0.9%	49.9%
Ethanol (E85)	2,899	0.5%	10.2%	753	0.4%	21.5%
Propane (LPG)	2,702	0.4%	9.5%	352	0.2%	10.0%
Hybrid Diesel	1,411	0.2%	5.0%	626	0.3%	17.9%
Electricity	1,337	0.2%	4.7%	245	0.1%	7.0%
Methanol	15	0.0%	0.1%	10	0.0%	0.3%
Butane	5	0.0%	0.0%	5	0.0%	0.1%
Total	**639,455**	**100.0%**				
Total Number of AFVs / AFV Fleets	**28,481**	**4.5%**	**100.0%**	**3,504**	**1.9%**	

[Note] (a) The HDVs in this table include those vehicles with a GVWR over 14,000 lbs. (b) The sum of the HDV fleets using each fuel (201,258) is greater than the total number of fleets (186,857) as some fleets use more than one fuel type. For the same reason, the percentages also sum to more than 100%. Totals are omitted to avoid confusion.

Table 4-1 summarizes the number of HDVs in California using commercial vehicle registration data provided by the California Energy Commission (CEC). As of December 2018, over 28,000 heavy-duty AFVs are registered in California. Of the various alternative fuels, 20,112 natural gas vehicles are represented with 3.15% of the registered HDVs, followed by E85 (2,899, 0.45%), propane (2,702, 0.42%), and hybrid diesel (1,411, 0.22%) HDVs. Electric HDVs are very limited only with 1,337 (0.21%) registrations out of the total of 639,455 HDVs. In addition, the number of unique fleets was estimated, each of which consists of the vehicle(s) with the same organization name and the same registered address. Since various abbreviations were observed across the registered names and addresses, address standardization algorithms and heuristics were used to capture common variations for address components, and executed string matching to identify unique fleets. This analysis identified a total of 186,857 unique commercial fleets with a GVWR greater than 14,000 lbs. Of these California HDV fleets, 3,504 (1.88%) use one or more alternative fuels. There are 1,747 fleets (0.93%) that have at least one compressed or liquified natural gas vehicle, 753 (0.40%) with E85 vehicles, 626 (0.34%) with hybrid diesel vehicles, 352 (0.19%) with propane vehicles, and 245 (0.13%) with electric vehicles.

4.1.2. Sampling

The main sampling criterion was to select HDV fleet operators who considered alternative fuel adoption and then made a decision of either adoption or non-adoption. By referring to Rogers' DOI theory (Rogers, 1983a), the categorization of adoption and non-adoption was formed for this work. Particularly for non-adoption, active rejection cases were focused on rather than passive rejections in this study. This is because passive rejections might be mainly due to unawareness of alternative fuel technologies or sheer disinterest in evaluating them while active rejections can provide more specific reasons for non-adoptions in terms of how the technologies are evaluated in an organization's decision criteria.

Based on the insights gained from the comprehensive literature review, an initial hypothesis was formed that the structure of influencing factors would vary depending on diverse parameters: 1) public vs. private status; 2) business types or fleet vocations (e.g., organizations that are likely to pursue an environmentally friendly image, such as waste management or educational services vs. others); 3) fleet size; and 4) whether or not the organization is subject to any regulations requiring AFV purchases (e.g., the fleet rules of South Coast AQMD (SCAQMD, n.d.)). From these hypotheses, the second strategy for the sampling was designed to include various fleet sectors across those different dimensions.

Using data from vehicle incentive programs in California, basic characteristics of the fleets in participating organizations were identified, such as locations, business sectors, fleet vocations, fleet sizes or numbers of AFV purchased, and relevant air quality management district (for AQMD constraints)[10]. Further efforts were made to collect project reports that described California organization adoption decisions of alternative fuels for their HDV fleets. Moreover, to collect information about active rejection cases, a screening process was conducted for those organizations by asking a question about any alternative fuels considered but rejected.

After identifying the basic information about the organizations, stratified purposeful sampling was employed. In contrast to representative sampling where the sample is

[10] The data from Natural Gas Vehicle Incentive Project (NGVIP) was used for this analysis. A summary of NGVIP applicant analyses is provided in Appendix B.

chosen to be representative of a population, a purposeful sample consists of information-rich cases selected to productively answer the research questions (Marshall, 1996; Patton, 1990). Of various strategies in purposeful sampling, stratified purposeful sampling is employed so as to capture major variations across different strata (Patton, 1990). Accordingly, a wide diversity of HDV fleet segments was recruited. Table 4-2 presents the characteristics of participating fleets. Consequently, a total of 20 organizations, consisting of 18 in-depth interviews and two project reports, were investigated for this work, from which 29 adoption and 42 non-adoption cases were analyzed across various alternative fuel options. Although no attempt was made to obtain a statistically representative sample of HDV fleets given the small sample size for qualitative research, it was sought to recruit fleets exhibiting as much variability as possible per each dimension. For example, in comparison to California heavy-duty AFV adopter fleets (c.f., Table 4-1), which comprises natural gas adopters with 49.9%, E85 with 21.5%, hybrid diesel with 17.9%, propane with 10.0%, and electricity with 7.0%, the participating organizations consist of 18 natural gas adopters (90%), propane with 4 adopters (20%), and electric/hydrogen with 3 (15%).

Table 4-2. Characteristics of Participating HDV Fleets

Classification	Number of organizations (n = 20)		Classification	Number of organizations (n = 20)	
Public vs. private			**Heavy-duty AFV adoption status** [a]		
Public	11	(55%)	CNG	18	(90%)
Private	9	(45%)	LNG	3	(15%)
HDV fleet size			LPG	4	(20%)
> 100	13	(65%)	Electricity	2	(10%)
20 to 100	5	(25%)	Hydrogen	1	(5%)
≤ 20	2	(10%)	Renewable diesel	4	(20%)
Fleet vocation			**Heavy-duty AFV non-adoption status**		
Various public services	7	(35%)	CNG	1	(5%)
Refuse trucks	5	(25%)	LNG	9	(45%)
School buses	2	(10%)	LPG	5	(25%)
Transit buses	2	(10%)	Electricity	11	(55%)
Local delivery	2	(10%)	Hydrogen	6	(30%)
Freight trucking	1	(5%)	Biodiesel	8	(40%)
Paving work	1	(5%)	E85	2	(10%)
Number of alternative fuel types adopted			**Refueling/Recharging facilities**		
One	10	(50%)	Have their own on-site facilities	14	(70%)
Two	7	(35%)			
Three or more	2	(10%)	Rely only on off-site station(s)	5	(25%)
None	1	(5%)			
Year of the 1st heavy-duty AFV purchased			Will build their own on-site facilities	4	(20%)
After 2015	3	(15%)			
Before 2015	17	(85%)	**Subject to AQMD or CARB fleet rules** [b]		
			Yes	13	(65%)
			No	7	(35%)

[Note] (a) CNG: compressed natural gas, LNG: liquefied natural gas, LPG: liquid petroleum gas, E85: ethanol or flex fuel. Renewable diesel: the organizations are using renewable diesel for their conventional diesel HDV operations. (b) For example, the fleet rules 1186.1 and 1191-1196 by South Coast AQMD (SCAQMD, n.d.) require government fleets and private contractors under contract with public entities to purchase non-diesel lower emission and alternative fuel vehicles. Also, the California Air Resources Board (CARB)'s fleet rule for transit agencies (CARB, 2019a) requires for an advanced zero-emission bus demonstration for the large transit agencies with 200 or more buses.

4.1.3. Data

The eighteen one-on-one interviews were conducted between July 2018 and April 2019 with key individuals who participate in the fleet purchase decision-making process. The interview participants were fleet managers in most cases, but also included company presidents, project engineers, and energy analysts. Each interview consisted of a set of thirteen standard interview questions, which is presented in Table 4-3. Each interview was conducted via a phone or in person, and lasted 1 hour 12 minutes on average. Prior to each interview, a detailed information package including consent forms and a study information sheet was sent to the participants.[11] All study materials and interview protocols were approved by the Institutional Review Board of UC Irvine. Out of the 18 completed interviews, 16 interviews were recorded and professionally transcribed. The other two sets of interview data were collected via an electronic document since the interviewees did not want to communicate verbally or did not allow recording. To increase consistency of the interview procedure across all participants, multiple follow-up questions were asked for those non-recording cases. In addition to the 18 interviews, two recent project reports, which were published after 2017, were included to reinforce the analysis, particularly for investigations of adoption and non-adoption decisions. These project reports address heavy-duty AFV deployment cases in California organizations, and included basic fleet information, what factors and which regulations affected their alternative fuel adoption decisions, and how they evaluated the fuel technologies. Although investigations through these written reports could not be as interactive as the interviews, the reports was selected

[11] In Appendix C, the study information sheet and consent form used for interviewees recruitment are provided.

after examining that their contents address our main interview questions and sufficiently described the organization's alternative fuel adoption decision.

Table 4-3. Interview Questions for Heavy-duty AFV Adopters and Non-adopters

Interview Sub-topics	**For Adopters**	**For Non-adopters** (1)	**Questions**	**Analysis Methods**
Q1 (Basic information)	X	X	"How many vehicles does your organization own or operate?; Among those vehicles, do you have alternative fuel vehicles in your fleet?; What are the vocations of the vehicles in your fleet?"	Short summary (2)
Q2 (Key decision-makers)	X	X	"Who are the key people for making fleet purchase decisions?; Who is involved the decision process?; What role do they play?"	Thematic analysis (4)
Q3 (Decision-making process)	X	X	"What decision process does your organization follow in purchasing vehicles?" "During the decision-making process, did you use any written rules or any detailed cost analysis?" "How does your alternative fuel vehicle purchase decision process differ from your routine or conventional vehicle purchase decisions?"	
Q4 (Influencing factors)	X	X	"What factors influenced your fleet purchase decisions?; Were there any factors which made you more willing to or more hesitant to purchase AFVs?"	Content analysis (3)
Q5 (Laws or regulations)	X		"What laws or regulations affected your AFV purchase decision?"	
Q6 (Other alternatives considered)	X	X	"During the decision-making process of purchasing [the AFVs mentioned in Q1], were there any other fuel technologies you considered??"	
Q7 (Satisfaction about AFV operations)	X		"Given your experiences with the AFVs, how satisfied or dissatisfied are you with the AFVs?" "Can you explain why you are satisfied / dissatisfied?"	Content analysis
Q8	X		"Were there any educational training programs that your organization received	Thematic analysis

Interview Sub-topics	For Adopters	For Non-adopters (1)	Questions	Analysis Methods
(Adoption supporting/ facilitating efforts)			from AFV manufacturers or fuel providers?" "Were there any driver training programs that were provided to your AFV drivers?" "Have you ever received any feedback from the vehicle drivers about AFVs operations?"	
Q9 (Refueling behavior)	X		"What kind of fueling stations do you use for AFVs?" "How satisfied or dissatisfied are you with the AFV refueling?"	Short summary Content analysis
Q10 (Repurchase intent)	X	X	"Do you have a plan to expand your fleet of AFVs?" "(In case the answer is "No") If you need to purchase new vehicles, how likely are you to purchase AFVs?"	Short summary
Q11 (Recommendation received & recommendation intent)	X	X	"Have you ever received any recommendations or feedback from other fleet operators about AFVs purchases?" "Have you ever recommended AFVs to others? (In case the answer is "No") How likely are you to recommend AFVs to other fleet managers?"	Thematic analysis
Q12 (Incentive programs)	X	X	"How did you learn about the Natural Gas Vehicle Incentive Project (NGVIP)?" "If it were not for NGVIP, would you still consider buying NGVs?" "Could you please provide us with some suggestions which can improve NGVIP?"	Thematic analysis
Q13 (Perspectives on viable alternative fuel options in 2030s)	X	X	"If you look 10 to 20 years down the road, what do you think about viable options of alternative fuel vehicles in the heavy-duty sector?"	Thematic analysis

[Note] 1) For NGV non-adopters (i.e., those who considered NGV purchase but decided not to adopt it), a part of the list of questions were asked (i.e., Questions 1-4, 6, 10-13). 2) The answers with simple and short information were summarized using summary tables (e.g., Questions 1 and 10). 3) When the concepts described in the interview data have a direction (e.g., positively or negatively stated) and strength (e.g., implied, explicitly stated, and emphasized), content analysis was employed (e.g., Questions 4 and 7); and 4) For the other cases where the interview data contains narrative descriptions about their experiences and perspectives (e.g., Questions 3, 12-13), thematic analysis was employed.

4.1.3. Content Analysis

Of the interview transcriptions and written documents, a major portion of the answers – regarding the factors that influenced heavy-duty AFV adoption decisions (Questions 4 to 6) and satisfactions about heavy-duty AFV operations (Questions 7 and 9) – were analyzed using content analysis (Krippendorff, 2004). Content analysis involves a systematic coding process, extracting categories, and identifying themes from these categories so as to answer the research questions (Cho and Lee, 2014) and to make replicable and valid inferences from texts (Krippendorff, 2004). For this, the data were initially coded using *ATLAS.ti* (ATLAS.ti, 2018) a qualitative analysis tool that assists in managing numerous codes (i.e., discrete units of meaning) and their associated quotations. Among a long list of codes[12], those with related meanings were combined into discrete textual categories, by which an interview data abstraction sheet was created. Then, two researchers (called coders) independently filled in the data abstraction sheet using their own notes and the interview data. When filling in this data sheet, each coder identified the existence of each category, and wrote down its sign (i.e., "+" being positively stated as motivators or facilitators, and "–" being negatively stated as barriers) along with its strength (i.e., "1" being implied or indirectly affected, "2" explicitly mentioned, and "3" emphasized as overarching factors, following (Carley, 1993; Sierzchula, 2014)), and collected the relevant quotations. In case an opinion for a textual category was neutrally stated, the rating "n" was given. The list of categories for the data abstraction sheet was almost finalized using a preliminary analysis with seven interviews (35% of the data). To

[12] See Appendix D for the ATLAS.ti code list.

ensure inter-coder reliability of the findings, Krippendorff's α (Krippendorff, 2004) was computed, as the most general agreement measure in content analysis. A general formula of α is $1 - D_o/D_e$ where D_o is the observed disagreement among the coding results from different coders and D_e is the disagreement one would expect when the coding results are attributable to chance. Krippendorff's α has a value between 0 (indicating perfect reliability) and 1 (indicating the absence of reliability) with a common threshold of 0.9 used for data reliability (Neuendorf, 2002).[13] The outcomes from the two coders' work resulted in a Krippendorff's α of 0.902, which confirmed the reliability. The remaining discrepancies between the two coders were resolved by a third coder who participated in this study. Through a series of discussions between the coders with agreed categories and relevant quotes, themes and hypotheses were identified to address the research questions. Consequently, both quantitative and qualitative analyses were in agreement and verified by the researchers participating in this study.

4.1.4. Thematic Analysis

For the other subset of interview data, such as decision-making processes (Question 3) and perspectives on viable alternative fuel options in 2030s (Question 13), thematic analysis was used because of narrative traits of the data with a limited capability of being scored. Thematic analysis (Boyatzis, 1998) is a method for identifying, analyzing and reporting patterns and themes across qualitative data, for which Braun and Clarke (2006)'s six-phase approach is widely executed: 1) familiarizing with the data, 2) generating initial

[13] Refer to (Krippendorff, 2011) for the detailed calculation procedure of Krippendorff's α.

codes, 3) searching for themes, 4) reviewing themes, 5) defining and naming themes, and 6) producing the report. Following (Braun and Clarke, 2006), in the first step, the interview contents were cross-checked among the multiple participating researchers. For the second and third steps, the interview data was initially coded using *ATLAS.ti*. Among a long list of codes, those with related meanings were combined into discrete textual categories, by which an interview data abstraction sheet was created. Then, the data abstraction sheet was filled in using the interview data and notes. When filling in this data sheet, the existence of each textual category was identified along with its sign (e.g., "+" being positively addressed, "–" being negatively described, and "n" being neutrally stated), and the relevant quotations were collected. An initial list of categories for the interview data abstraction sheet was developed using a preliminary analysis with seven interviews (39% of the data). For the fourth and fifth steps, a series of discussions between the participating researchers was held to identify, review, and refine and finalize the resulting themes and hypotheses in order to address the research questions.

Consequently, based on the themes and hypotheses both from content and thematic analyses, the initial theoretical framework was empirically improved to explain AFV fleet adoption behavior in the California HDV sector. Figure 4-1 elaborate the connections between the results from the qualitative data analysis (i.e., Chapters 4.3 through 4.10) and their corresponding parts of the initial theoretical framework. In addition to the improvement of the initial framework, the interview data was also obtained to gain insights for an additional subtopic: HDV fleet operator perspectives on viable alternative fuel options in 2030s (Chapter 4.5).

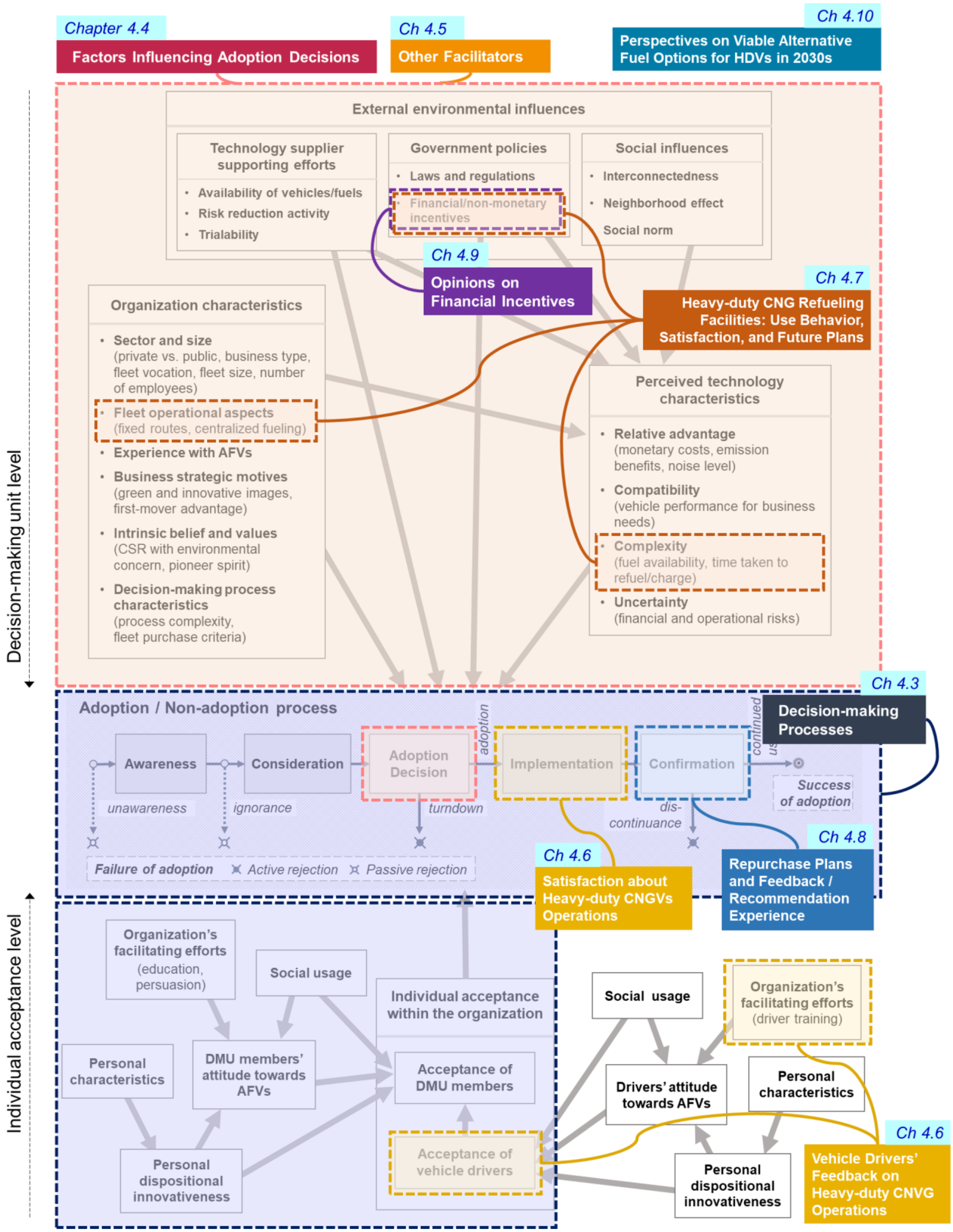


Figure 4-1. Connections between Qualitative Research Results and Initial Theoretical Framework

4.2. Basic Information of Participating Fleets

In each interview, basic fleet information was collected, which is summarized in Table 4-4, with fleet sizes, public/private status, fleet vocations, numbers of heavy-duty AFVs, year of the first heavy-duty AFV purchased, and refueling/recharging facilities. Figure 4-2 shows a visual summary of alternative fuel adoption and non-adoption status of each participating HDV fleet. Of the 20 participating fleets, 18 organizations are operating heavy-duty CNG vehicles while one organization considered but then rejected the adoption of CNG. Along with heavy-duty CNG vehicles being operated, three organizations adopted LNG vehicles, two adopted electric HDVs, and four adopted LPG vehicles. One organization adopted hydrogen transit buses. Many organizations evaluated multiple alternative fuel options and then rejected most of them except one or two fuel(s). In contrast, a few organizations with large fleets (e.g., Organization 10) adopted three or more types of alternative fuels.

Table 4-4. Participating HDV Fleets

Organi-zation	HDV fleet size [(a)]	Public vs. private	Vehicle vocation	Number of heavy-duty AFVs [(b)]	Number of heavy-duty AFVs to be expanded	Year of the 1st heavy-duty AFV purchased [(c)]	Refueling/recharging facilities [(d)]
Org. 01	51	public	school buses	19 CNGVs	15 CNGVs	2002	CNG on-site (slow-fill/fast-fill)
Org. 02	27-29	public	tractor, sewer trucks, crew trucks	9 CNGVs	11 CNGVs	2009	CNG off-site *(On-site facilities will be built)*
Org. 03	650	public	various (street maintenance, water trucks, truck tractors, etc.)	80 CNGVs RD*	9 CNGVs	≈ 1997	CNG on-site (fast-fill) and off-site
Org. 04	70	private	local delivery	2 CNGVs	9 CNGVs	2017	CNG off-site *(On-site facilities will be built)*
Org. 05	22	private	local delivery	32 CNGVs	Will expand CNGVs if business grows	1973	CNG on-site (slow-fill)
Org. 06	105	private	solid waste collection	≈ 100 CNGVs	2 CNGVS	≈ 2013	CNG on-site (slow-fill/fast-fill)
Org. 07	900+ (all classes)	private	waste collection, recycling material collection	400 CNGVs, 8 LPGVs	50+ CNGVs	2004 (CNG), 2004 or 2007 (LPG)	CNG on-site (slow-fill/fast-fill) / LPG wet-hosing [(e)]
Org. 08	16	private	hauling (biosolids, diatomaceous earth, wine grapes, compost gypsum, gravel, etc.)	2 CNGVs	4 CNGVs	2016	CNG off-site *(On-site facilities will be built)*

Organi-zation	HDV fleet size [a]	Public vs. private	Vehicle vocation	Number of heavy-duty AFVs [b]	Number of heavy-duty AFVs to be expanded	Year of the 1st heavy-duty AFV purchased [c]	Refueling/recharging facilities [d]
Org. 09	129	public	various (construction, refuse collection, sewer and drain cleaning vehicles, and firefighting)	41 CNGVs	25 CNGVs, ≈ 124 HDVs will eventually be AFVs	2007	CNG on-site (slow-fill)
Org. 10	2400 (all classes)	public	various (public works activities, park maintenance, law enforcement, sheriff, social services, and refuse trucks)	15 CNGVs, LNGVs (being migrated to CNGVs), 20-30 LPGVs, RD*	50 CNGVs, 2 EVs	2000 (LNG), 2014 (CNG)	CNG/LNG on-site (slow-fill/fast-fill) / LPG off-site stations (a contract through the propane provider) / Electric on-site station planned
Org. 11	38	private	waste collection	36 CNGVs	none	2000	CNG off-site *(On-site facilities will be built)*
Org. 12	35000 (in the U.S.)	private	school buses	22 CNGVs, ≈ 2000 LPGVs	Will expand CNGVs and LPGVs	2017 (CNG), ≈ 2015 (LPG)	(not specified for CNG) / LPG on-site and off-site stations and wet-hosing
Org. 13	615 (all classes)	public	various (sewer jetter trucks, street maintenance, refuse trucks, pickup trucks, etc.)	256 CNGVs RD*	Will expand CNGVs	1998	CNG on-site (slow-fill/fast-fill)
Org. 14	900+	private	waste collection	≈ 400 CNGVs, 10 LPGVs	≈ 500 CNGVs	2002	CNG on-site (slow-fill/fast-fill) / LPG wet-hosing

Organi-zation	HDV fleet size [(a)]	Public vs. private	Vehicle vocation	Number of heavy-duty AFVs [(b)]	Number of heavy-duty AFVs to be expanded	Year of the 1st heavy-duty AFV purchased [(c)]	Refueling/recharging facilities [(d)]
Org. 15	800	public	various (refuse, street sweeping, fire department, police, public works, parks, beach maintenance, gas department, etc.)	60 CNGVs, 75 LNGVs (being migrated to CNGVs), RD*	80 CNGVs	2015 (CNG), 2005 (LNG)	CNG/LNG on-site (slow-fill) and off-site (fast-fill)
Org. 16	179	public	various (mobile service, trucks, utility, tractors, lowboy, etc.; CNG vehicles' applications: pick-up and delivery)	3 CNGVs	Will expand CNGVs	≈ 2012	CNG off-site (fast-fill)
Org. 17	721	public	solid waste collection	310 CNGVs, 282 LNGVs	Will expand CNGVs	1994 (duel fuel LNG)	CNG/LNG on-site (slow-fill/fast-fill)
Org. 18	10+	private	dump trucks, tankers, tow trucks (paving company)	0 (i.e., non-adopter)	none	n/a	n/a
Org. 19	370	public	transit buses	17 EVs	All buses will eventually be EVs by 2030	2002 (CNG), 2010 (EV)	Electric on-site and off-site
Org. 20	1,000+	public	transit buses	13 FCEVs	n/a	2010 (FCEV)	Hydrogen on-site

[Note] (a) While different definitions of HDVs exist across various agencies, the vehicles with a GVWR over 10,000 lbs was focused on the interviews. In the case that the interviewee did not have the record of the number of HDVs, the whole fleet size (including light-duty vehicles) was collected. (b) CNGVs: Compressed Natural Gas Vehicles, LNGVs: Liquefied Natural Gas Vehicles, LPGVs: Propane Vehicles, EVs: Electric Vehicles, FCEVs: Fuel Cell Electric Vehicles (running on hydrogen), and RD*: Renewable diesel is being used for all diesel vehicles. (c) The year when the first heavy-duty AFV was purchased since the interviewee had started working at the organization unless the interviewee had their previous record. (d) On-site: the organization is using their own refueling/recharging station at their fleet site. Off-site: the organization is using off-site station(s) which is(are) close to their site or en route for their daily route. (e) The organization has an arrangement with a propane vendor to come and bring a propane tank and fill up the LPGVs on site.

Organizations vocations	01 school bus	02 various	03 various	09 various	10 various	13 various	15 various	16 various	17 refuse	19 transit bus	20 transit bus	08 truck-ing	18 paving	04 delivery	05 delivery	11 refuse	06 refuse	07 refuse	14 refuse	12 school bus
Fleet Characteristics (a): Sector	Public											Private								
Fleet size	Medium		Large									Small		Medium			Large			
On-site fueling/ charging	CNG	*(CNG)*	CNG	CNG	CNG, LNG, ELEC	CNG	CNG, LNG		CNG, LNG	ELEC	H2	*(CNG)*		*(CNG)*	CNG	*(CNG)*	CNG	CNG	CNG	LPG
< 15 AFVs or New								< 15 AFVs			< 15 AFVs	< 15 AFVs, New		< 15 AFVs, New						New
Alternative Fuels																				
CNG	A[b]	A	A	A	A	A	A	A	A	A		A	N	A	A	A	A	A	A	A
LNG	N		N	N	A→N	N	A→N	N	A			N				N				
Electricity	N		N	N	A	N	N	N		A		N		N			N	N	N	
Hydrogen	N		N				N	N			A	N								N
Propane (LPG)	N	N	N		A			N				N						A	A	A
Ethanol								N										N		
Biodiesel				N	N	N	N	N				N						N		N
Renewable diesel			A		A	A	A													
Any other alternative fuels than CNG	N	N		N		N								N	N	N				

[Note] (a) "large fleets": >100 vehicles, "medium fleets": 20-100, "small fleets": ≤ 20, "parentheses" for on-site fueling/charging: on-site facilities will be constructed, "<15 AFVs": the total number of heavy-duty AFVs, including both those are being currently operated and those to be expanded, will less than 15, "New": the year of the first heavy-duty AFV purchased was after 2015. (b) "A": an alternative fuel adopted, "N": not adopted after consideration, "A→N": adopted before, but being migrated to another fuel option.

Figure 4-2. Alternative Fuel Adoption Status of Participating HDV Fleets

4.3. Decision-making Processes of Heavy-duty AFV Adoption

Alternative fuel adoption in organizations can be regarded as a strategic decision in the circumstances where conventional gasoline/diesel adoption dominates (Nesbitt and Sperling, 2001). Strategic decisions involve committing considerable resources to achieving organizational goals (e.g., purchase of AFVs as assets); the top management being a critical role; an organizational long-range planning (e.g., refueling/recharging plans); complex and dynamic sets of problems (e.g., fleet operational changes); and significant implications on all the major functions in the organization (Harrison, 1996; Shrivastava and Grant, 1985). Hence, decision-making processes as well as decision criteria for AFV fleet adoption can be distinct from the case of conventional vehicle adoption that follows a pre-established routine procedure.

The previous studies for heavy-duty AFV adoption behavior have typically centered on the investigation of *the decision criteria* (or *the factors*) that affect adoption decisions of heavy-duty AFVs (e.g., Seitz et al., 2015; Blynn and Attanucci, 2019). Meanwhile, only a few researchers have explored organizational *decision-making processes* of AFV adoption for light-duty vehicle (LDV) fleets (Boutueil, 2016; Nesbitt and Sperling, 2001; Skippon and Chappell, 2019). A seminal study was conducted by Nesbitt and Sperling (2001) two decades ago, which developed a framework for categorizing and characterizing decision-making processes of AFV fleet adoption, based upon focus group and interviews, followed by a quantitative survey performed in 1996 with 2,117 LDV fleet decision-makers in California. The authors (Nesbitt and Sperling, 2001) proposed four different decision-making structures – namely, autocratic, bureaucratic, hierarchic, and democratic –

depending on centralization and formalization of the process, built on which implications of each structure were explored for their distinct behavior of AFV adoption. Boutueil (2016) studied fleet management processes using decision-maker interviews in 22 organizations in the Paris, of which findings included internal challenges of the processes with respect to electric vehicle adoption, such as a complexity of decision-making process, a lack of sufficient familiarity with electric vehicles, and shortcomings of information on fleet use and fleet costs. More recently, Skippon and Chappell (2019) performed in-depth case studies with four organizations in the U.K to explore decision-making processes and selection criteria of electric vehicle acquisition and usage. Few other studies also indicated some barriers inherent in the decision-making processes of AFV fleet adoption, including a collective dimension of the processes that requires coordinating across many personnel from diverse departments and various hierarchical levels (Morrison et al., 2018; Nesbitt and Davies, 2014), and fleet purchase criteria without relying on TCO (Nesbitt and Davies, 2014). However, the knowledge about AFV fleet adoption decision-making processes in organizations still largely remain as a black box, particularly in the HDV sector (Bae et al., 2019).

Accordingly, a subset of the qualitative interview questions was allocated for exploring the decision-making processes of heavy-duty AFV adoption, which includes:

- **Q2 (Key decision-makers)**: “Who are the key people for making fleet purchase decisions, who else is involved the decision process, and what role do they play?”
- **Q3 (Decision-making process)**: “What decision process does your organization follow in adopting the heavy-duty AFVs?”

In addition, many follow-up questions to these open-ended questions were asked, including: whether they use any written rules or detailed cost analyses; whether their vehicle drivers participate in decision- making; and whether there are any differences in the processes between AFV and diesel vehicle purchase decisions. A thematic analysis was performed on the interview data. One or more discrete textual categories can represent each specific step in the decision-making processes, which was identified during the discussions between the multiple participating researchers. Subsequently, a series of discussions using the agreed list of categories, steps, and relevant quotes were held to construct a general model of decision-making processes and to distinguish any patterns of the processes with their own facilitators and barriers.

4.3.1. Analysis Plans

To organize and identify key outputs of the analysis results, some existing knowledge and frameworks were referred to. For instance, organizational structural dimensions have been found to influence strategic decision-making processes (Fredrickson, 1986; Nesbitt and Sperling, 2001; Shrivastava and Grant, 1985). Of many structural variables (e.g., formalization, integration, centralization, and complexity (Fredrickson, 1986; Miller et al., 1988)), centralization and formalization can be good indicators for fleet decision-making processes (Nesbitt and Sperling, 2001). Centralization refers to "*the degree to which the right to make decisions and evaluate activities is concentrated*" (Fredrickson, 1986, p.282). Formalization refers to "*the extent to which an organization uses rules and procedures to prescribe behavior*" (Fredrickson, 1986, p.283). At the same time, centralization and formalization are also some of the main variables characterizing whether an organizational structure is mechanistic or organic (Burns and Stalker, 1961). Mechanistic structure involves the use of the formal hierarchy with vertical communications, centralized authority, and specialized functional tasks, whereas organic structure is characterized with an informal control and authority, lateral communications, and contribution of individual tasks through interactions with others (Burns and Stalker, 1961). Building on the previous research (Burns and Stalker, 1961; Fredrickson, 1986; Nesbitt and Sperling, 2001; Shrivastava and Grant, 1985), the first task was to examine general characteristics of decision-making processes based upon the two dimensions of centralization and formalization.

Next, detailed decision-making steps emerged from the thematic analysis were discussed. Unique characteristics of the processes were compared across the four patterns arising from different combinations of whether it is centralized/less centralized and formalized/less formalized. To characterize the conceptual nature of the innovation adoption process, the resulting specific steps were mapped onto the five stages of decision-making process in the initial theoretical framework, consisting of Stage 1) Awareness; Stage 2) Consideration; Stage 3) Adoption Decision; Stage 4) Implementation; and Stage 5) Confirmation. Finally, various catalysts and barriers inherent within the decision-making processes were identified. In addition, potential recommendations that would help facilitate the processes were addressed accordingly.

4.3.2. Centralization and Formalization of Decision-Making Processes

In this study, centralized decision-making processes refer to the processes in which AFV adoption decisions are made only by one or two key individuals (or groups) at upper management levels (e.g., a fleet manager and executive committee). Otherwise, the fleets in which decision processes were controlled by three or more key individuals and/or user departments are characterized as being less centralized. Formalized decision-making processes are defined as the processes entailing detailed cost analyses and/or written protocols, whereas less formalized processes utilize intuitive reasoning and subjective judgement. Table 4-5 summarizes the key decision-makers in the participating fleets and whether they use detailed analyses in the processes.

About half the participating organizations (7 out of 18), mostly with small and medium fleets, were found to have centralized processes in that their key decision-makers consist of a fleet manager and/or top management personnel (e.g., a company owner, executive committee, and board members). The fleet managers typically lead the processes while the top level is usually in charge of reviewing and confirming the final decision. In contrast, the other organizations (11 out of 18), primarily with large fleets, appeared to have less centralized decision-making processes. For example, some fleets operating vehicles in multiple vocational areas (e.g., Org. 2 and 10) have department managers (e.g., from construction, waste collection, and mechanical service departments) as one of the key participants in the process. In another case with less centralized processes, several managers, technicians, or engineers in different positions took part in the decisions along with the upper-level management (e.g., Org. 3, and 14). Across both centralized and less centralized cases, a wide range of positions were involved in the processes, including fleet supervisors and mechanics (Org. 1), tax directors (Org. 12), sustainability committees (Org. 13), and city managers and councils (Org. 15).

As to the roles of vehicle drivers in the decision-making processes, half the organizations stated that their drivers do not participate in the processes: "*Not typically the drivers. […] It's not the folks driving. It's the folks managing the drivers*" (Org. 9). However, for the other organizations, vehicle drivers were partly involved in the processes by providing their feedback (Org. 1, 3, 7, 10, and 17) or sometime deeply involved with their inputs regarding vehicle types and manufacturers (Org. 2 and 6) when developing the vehicle specification (Org. 15 and 16). One organization explained, "*Part of our company culture is we want feedback and input from the drivers. […] when it comes to the types of vehicles, the manufacturer of vehicles, the success rate of the maintenance on trucks, we very much include their input. What's comfortable, what's a safer vehicle to use […]*" (Org. 6).

Many participating fleets (12 out of 18), across various segments dispersed public/private and small/medium/large fleets, were found to have formalized processes with detailed cost analyses and/or written rules. Most of those formalized fleets reported that they conducted detailed cost analyses when making AFV purchase decisions: "*It's all cost analysis. […] If it doesn't affect your bottom dollar in a positive way, then it doesn't make sense to do*" (Org. 8). Meanwhile, only a few organizations, particularly with large fleets, reported that they maintain "*a formalized rule within the company*" (Org. 6) or "*administrative regulations*" (Org. 9), as well as cost analyses. Some organizations appeared not to have an established written procedure (Org. 10 and 17) or even addressed a sort of impracticality to have prescribed written rules due to length of time vehicles are held (e.g., 10 to 15 years) (Org. 16), although they utilized detailed cost analyses. On the other hand, there were several organizations with less formalized processes (5 out of 18) that relied neither on detailed cost analyses nor written protocols. This was because their "*driving force is [already] alternative fuel,*" which made it unnecessary to compare one fuel versus the others (Org. 13); their decision is "*all pretty subjective*" (Org 14); or they have a tendency to seek the same dealership in their previous purchases (Org. 18).

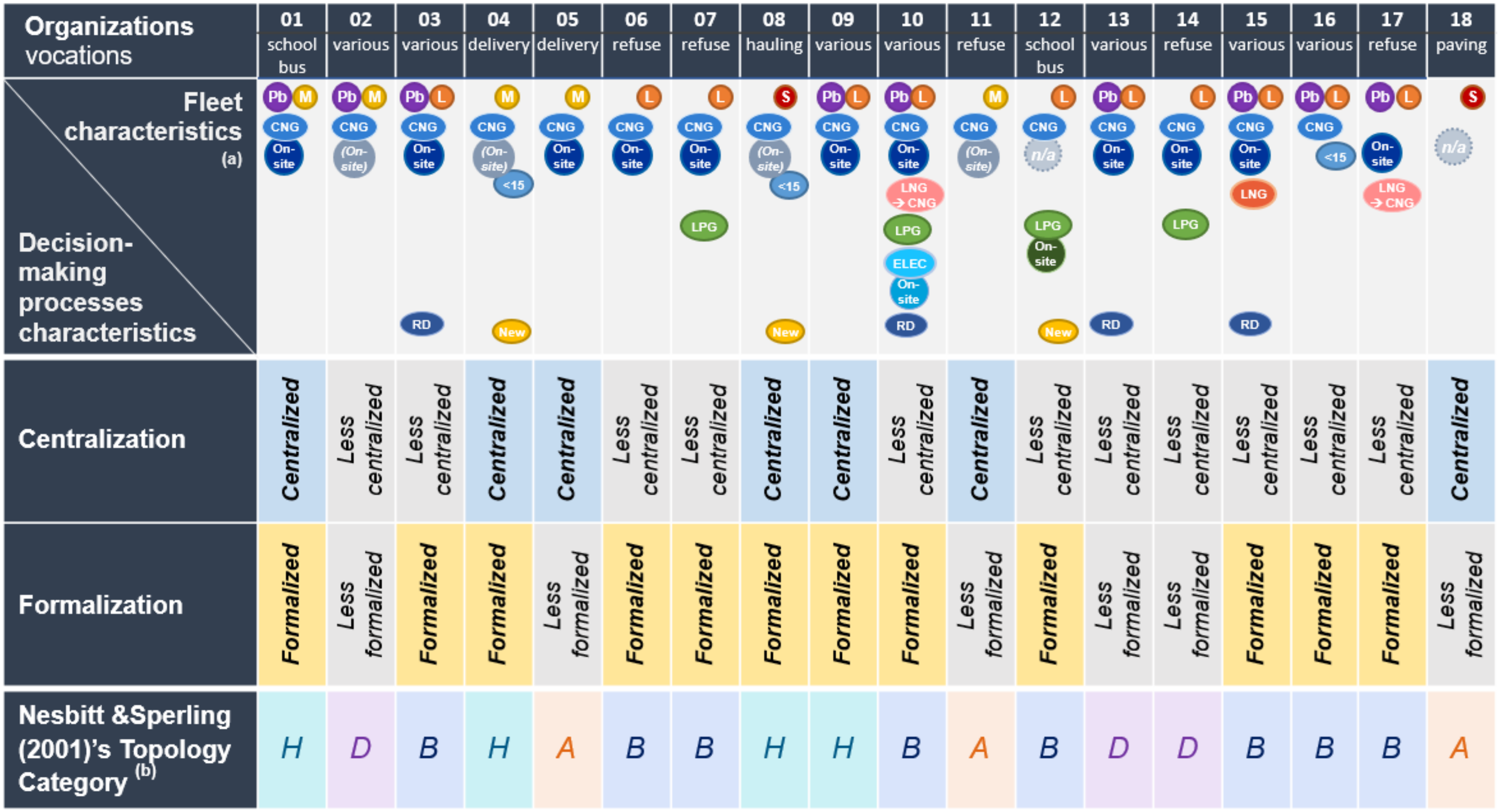
Based on the centralization and formalization characteristics of the decision-making processes, the participating organizations are classified into the four categories: 1) *Centralized and formalized*; 2) *Less centralized and formalized*; 3) *Centralized and less formalized*; and 4) *Less centralized and less formalized* decision-making processes. Figure 4-3 presents a visual summary of the fleet classifications of the participating organizations along with their basic fleet characteristics. Of the four categories, the *less centralized and formalized* processes, accounting for the largest portion of 44% (8 out of 18), are characterized as large fleets (i.e., 100+ vehicles) including both public and private entities. The *centralized and formalized* processes are the second largest portion (22%, 4 out of 18) with diverse fleet sizes from small, medium, to large fleets both across public and private sectors. Each of the other two categories is represented with three fleets (17% each). The *centralized and less formalized* processes were observed only from private organizations with small or medium fleet sizes. Lastly, the *less centralized and less formalized* processes were found only from medium or large fleets either in public or private organizations.

Table 4-5. Key Decision-makers and Detailed Analyses for Decision-making Processes in Participating Fleets

Organi-zation	People Participating in Heavy-duty AFV Adoption Decisions		Formalized Analysis or Rules in Decision-making Processes	
	Key people / (others involved)	**Vehicle drivers' participation**	**Detailed cost analysis is used?**	**Written rules or protocols are used?**
Org. 01	Fleet manager, board members / (fleet supervisor, mechanics)	A little bit	Yes (*I submitted all the documents with the costs and that went to our board for approval*)	n/a [(a)]
Org. 02	Fleet manager, user department managers	A little bit (*but sometimes deeply involved about type of vehicles*)	n/a	No (*no specific written criteria; based on need.*)
Org. 03	Fleet manager, fleet engineering technician, board of directors / (user departments)	Yes (*they provide input)*	Yes (*we did cost analysis*)	No
Org. 04	Fleet managers, CEO / (user departments, COO)	No	Yes (*it was a cost analysis; we bid four different manufacturers*)	No
Org. 05	Company owner	No	No	No
Org. 06	Location management team, regional team, corporate team / (controllers and finance people)	No (*about fuel choice*); but partly involved (*about types of vehicles, vehicle make*)	Yes (*I would say it's a formalized rule within the company based upon the capital investment.*)	Yes (*a formalized rule within the company*)
Org. 07	Fleet manager, a small group of senior managers, company owners / (a board of directors)	Yes (*we'll have our drivers give us their thoughts or feedback*)	Yes (*I put together RFDs, and proposals, and do comparative analysis*)	n/a
Org. 08	Fleet manager (=vice president), CFO, business owner	No	Yes (*it's all cost analysis: any grant available; incremental costs; maintenance costs; etc.*)	n/a
Org. 09	Fleet manager, program manager / (fleet operations department, climate department)	No	Yes (*the process for us is cost driven*)	Yes (*we have an AR, administrative regulation, …)*
Org. 10	Division chief of the fleet services division, customer departments, board of supervisors	A little bit (*but we receive their feedback*)	Yes (*we look at total cost of ownership, and what that incremental cost, …*)	Partially Yes (*the rules are in a very generic policy*)
Org. 11	Company president, CPA accountant / (consultant person)	No	No (*I wish I did. But, no.*)	n/a

Organi-zation	People Participating in Heavy-duty AFV Adoption Decisions		Formalized Analysis or Rules in Decision-making Processes	
	Key people / (others involved)	**Vehicle drivers' participation**	**Detailed cost analysis is used?**	**Written rules or protocols are used?**
Org. 12	Maintenance people at the site, finance team / (procurement team, tax director)	No	We do some (*financial analysis*).	n/a
Org. 13	Fleet maintenance superintendent, fleet manager, the director of public works / (sustainability committee)	No	No (*no cost analysis (one fuel vs. the other) because our driving force is alt fuel*).	n/a
Org. 14	Shop manager, executive committee (i.e., CEO, COO, CFO), project engineer	No	No (*we don't have to do analysis because we already know*)	No (*there's no computer generation in this thing. It's all pretty subjective.*)
Org. 15	Acquisitions superintendent, fleet manager, internal customer / (city manager and city counsel)	Yes, sometimes (*when developing the specification, doing a pilot test*)	Yes (*we make sure that we do have sufficient budget at the vehicle level; we will look at the ROI*)	n/a
Org. 16	Fleet manager, custodian, organization managers, group manager, finance department, board directors / (vehicle drivers)	Yes (*when developing the specification list for operational review*)	Yes (*we did a detailed cost analysis.*)	No (*the 'written rules' may not fit with our operation*)
Org. 17	Sanitation executive, CFO, city administrative officer, the board	Yes (*we have a meeting with driver union*)	Yes (*…whether the technology will generate any advantage, cost savings or any other economic …*)	Partially No (*we don't have a written policy, but that is the procedure that's in place, …*)
Org. 18	Production manager, company owner	No	No	No (*we normally try to stick to the same people that we purchased from in the past.*)

[Note] (a) n/a: If the interviewees already provided their answer regarding one of "written rules" and "detailed cost analysis", they tended to skip the answer for the other. Since the decision-making processes with "written rules" *and/or* "detailed cost analysis" are classified into the formalized processes in this work, such unattained answers were not sought during the interview.



[Note] (a): Each symbol represent a specific fleet characteristic: "Pb": public entities (c.f., private entities, otherwise unmentioned), "L": large fleet size (>100 vehicles), "M": medium fleet size (20-100), "S": small fleet size (≤ 20), "CNG": currently operating heavy-duty CNG vehicles, "On-site" (right below "CNG"): has their own on-site CNG station(s) (c.f., use off-site CNG stations, otherwise unmentioned), "(On-site)": will build their own on-site CNG stations, although they currently rely only on off-site station(s), "n/a": information about CNG fueling stations unavailable, "<15 NGVs": the total number of NGVs, including both those are being currently operated and those to be expanded in the near future, will less than 15 NGVs, "LNG→CNG": heavy-duty LNG vehicles adopted before are being migrated to CNG vehicles, "LPG": operating heavy-duty LPG vehicles, "On-site" (right below "LPG"): has their own on-site LPG station(s) (c.f., use off-site LPG stations or LPG wet-hosing, otherwise unmentioned), "ELEC": operating Electric HDVs, "On-site" (right below "ELEC"): planning to build their own on-site electric heavy-duty charging stations, "RD": using renewable diesel for their conventional diesel HDVs, and "New": the year of the first heavy-duty AFV purchased was after 2015. (b) H: hierarchic, A: autocratic, B: bureaucratic, and D: democratic decision-making processes, according to Nesbitt and Sperling (Nesbitt and Sperling, 2001)(2001) fleet taxonomy.

Figure 4-3. Centralization and Formalization of Decision-making Processes in Participating Fleets

4.3.3. Decision-making Processes of Heavy-duty AFVs Adoption

Detailed decision-making steps emerged from the thematic analysis of the interview data. Figure 4-4 presents the list of the steps and their corresponding stages. It should be noted that those steps do not necessarily occur in the listed order; some subsequent steps may be reversed, and some may occur simultaneously. In this study, for the first three stages (i.e., awareness, consideration, and adoption decision stages), alternative stage names are additionally suggested with more fleet-specific concepts: **fleet-level plan** and **vehicle-level decision**. For the last two stages, the same names are used as introduced in the initial theoretical framework: **implementation** and **confirmation**. While the entire list of steps could comprise an inclusive model of the decision-making processes of heavy-duty AFV adoption, the within-case and cross-case analyses implied variations of the model depending mainly on their centralization/formalization characteristics. Figures 4-5 to 4-8 visually elaborate the examples of those four patterns along with relevant quotations.

First, a **fleet-level plan** has to do with decisions regarding how many existing vehicles should be replaced with new ones (*replacement plans*) and/or how many new vehicles should be purchased (*expansion plans*) (step *a*). As to the replacement plans, a follow-up question was asked about variables or criteria guiding the replacement decisions, of which summary is presented in Table 4-6. Vehicle age was the most frequently mentioned by most organizations (14 out of 18) as one of the primary variables. The ranges of criteria age varied from 5 to 20 years. Vehicle conditions or maintenance need also commonly mentioned by a half of the organizations.[14] In some cases, vehicle mileage was also used for the criteria. Other variables include vehicle size, vocations, utilization, available budget, and business opportunity (e.g., a contract requiring AFVs). During fleet-level planning, a DMU of an organization typically checks if there are any regulations they should comply with (step *b*). They also examine whether to use existing refueling/recharging infrastructures (e.g., on-site facilities if they already built, or off-site stations) or to build their own facilities (step *c*). In some cases, a fuel choice is made in this stage. For example, if an organization is subject to a regulation requiring the use of AFVs and there is only one available alternative fuel option in terms of the infrastructures, they will have the only option to adopt that alternative fuel.

[14] One fleet operator elaborated, "*There comes a point in time when they start nickel-and-diming you, and you start end up paying more in maintenance than the truck is worth. [...] And when it starts giving us more and more issues is when it goes to the chopping block, and we just get rid of it*" (Org. 8).

Table 4-6. Fleet Replacement Criteria

Organization (vocation)	**Vehicle age**	**Mileage**	**Vehicle condition**	**Other criteria**
Org. 01 (school bus)	X (15-20 years)	.	.	.
Org. 02 (various)	X (20 years)	.	X	.
Org. 03 (various)	X (5-14 years)	.	.	vehicle size, vocations
Org. 04 (delivery)	.	.	.	.
Org. 05 (delivery)	X (max 15 years)	.	.	.
Org. 06 (refuse)	X (10 years)	.	.	.
Org. 07 (refuse)	X	.	X	business opportunity
Org. 08 (trucking)	X (5-8 years)	X (≈800K miles)	X	.
Org. 09 (various)	X (6-8 years)	0	.	vehicle vocations
Org. 10 (various)	X (12 years)	X (120K-150K miles)	.	available budget
Org. 11 (refuse)	X (10-15 years)	.	X	.
Org. 12 (school bus)	X (10 years)	X	X	.
Org. 13 (various)	.	.	.	.
Org. 14 (refuse)	X (10-12 years)	.	X	.
Org. 15 (various)	.	.	X	.
Org. 16 (various)	X	X	X	service types, reliability, utilization
Org. 17 (refuse)	X (7 years)	.	.	available budget
Org. 18 (paving)	.	.	X	.

[Note] “X”: the variable was addressed as replacement criteria.

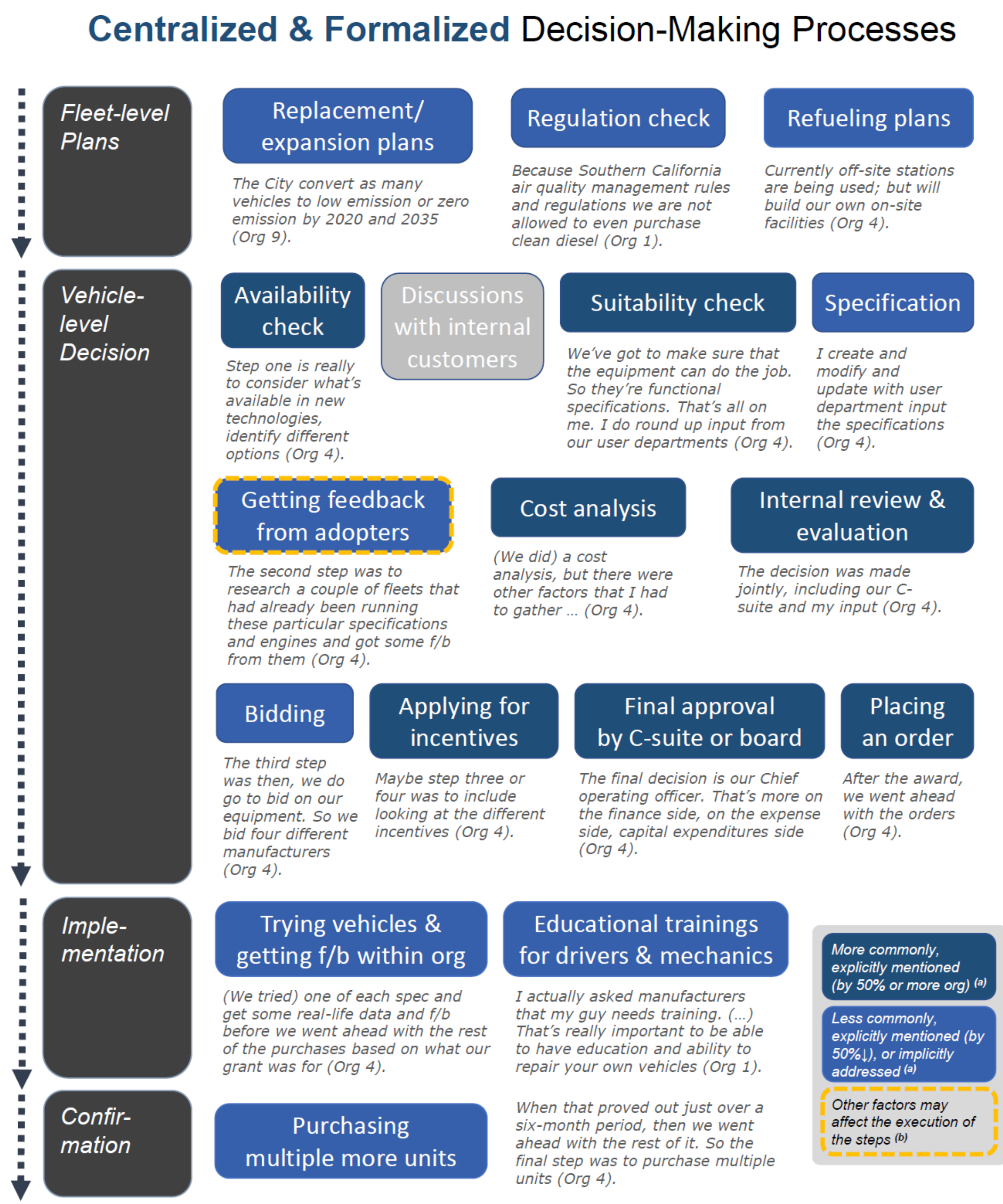
Adoption process stages: For this study	Adoption process stages: Rogers (37); Frambach & Schillewaert (38)	Structural dimensions / Decision-making steps [(1)]	Formalized: Centralized	Formalized: Less centralized	Less formalized: Centralized	Less formalized: Less centralized
		Nesbitt & Sperling's (21)	*Hierarchic*	*Bureaucratic*	*Autocratic*	*Democratic*
		Burns & Stalker (36)	*Mechanistic*	← *in between*	→	*Organic*
Fleet-level Plan	*Awareness*	**(a) Replacement/ expansion plans**	V	V	V	V
		(b) Regulation check	V	V	V	V
		(c) Fuel availability check / Refueling/recharging plans	V* [(2)]	V*	V*	V*
Vehicle-level Decision		**(d) Vehicle availability check**	V	V		V
	Consi-deration	**(e) Discussion with internal customers**		V		V
		(f) Suitability check	V	V	V	V
		(g) Specification	V	V		V
		(h) Getting feedback from adopters [(3)]	V	V*	V*	
		(i) Cost analysis	V	V		
		(j) Internal review and evaluation	V	V	V	V
	Adoption Decision	**(k) Bidding**	V	V		V
		(l) Applying for incentives	V	V	V*	V*
		(m) Final approval (by C-suite or board)	V	V		
		(n) Placing an order	V	V	V	V
Imple-mentation	*Imple-mentation*	**(o) Trying vehicles and getting feedback within org.**	V	V*	V*	V*
		(p) Educational trainings for fleet mechanics & drivers	V*	V*	V*	V*
Confir-mation	*Confir-mation*	**(q) Purchasing multiple more vehicles**	V	V*	V*	V*

[Note] (1) It should be noted that those steps do not necessarily occur in the listed order; some steps may be reversed, and some may occur simultaneously (e.g., fleets could set up a replacement plan while checking regulations requiring the use of AFVs). (2) While the steps with 'V' were explicitly stated, the steps with 'V*' were addressed in other interview questions (e.g., factors influencing their decisions, refueling behavior, repurchase intent, etc.). (3) Rather than formalization/centralization characteristics, other factors may affect the execution of the step h (e.g., how experienced they are with the heavy-duty AFVs, and how interactive they are with other fleet operators).

Figure 4-4. Decision-making Processes of Heavy-duty AFV Fleet Adoption

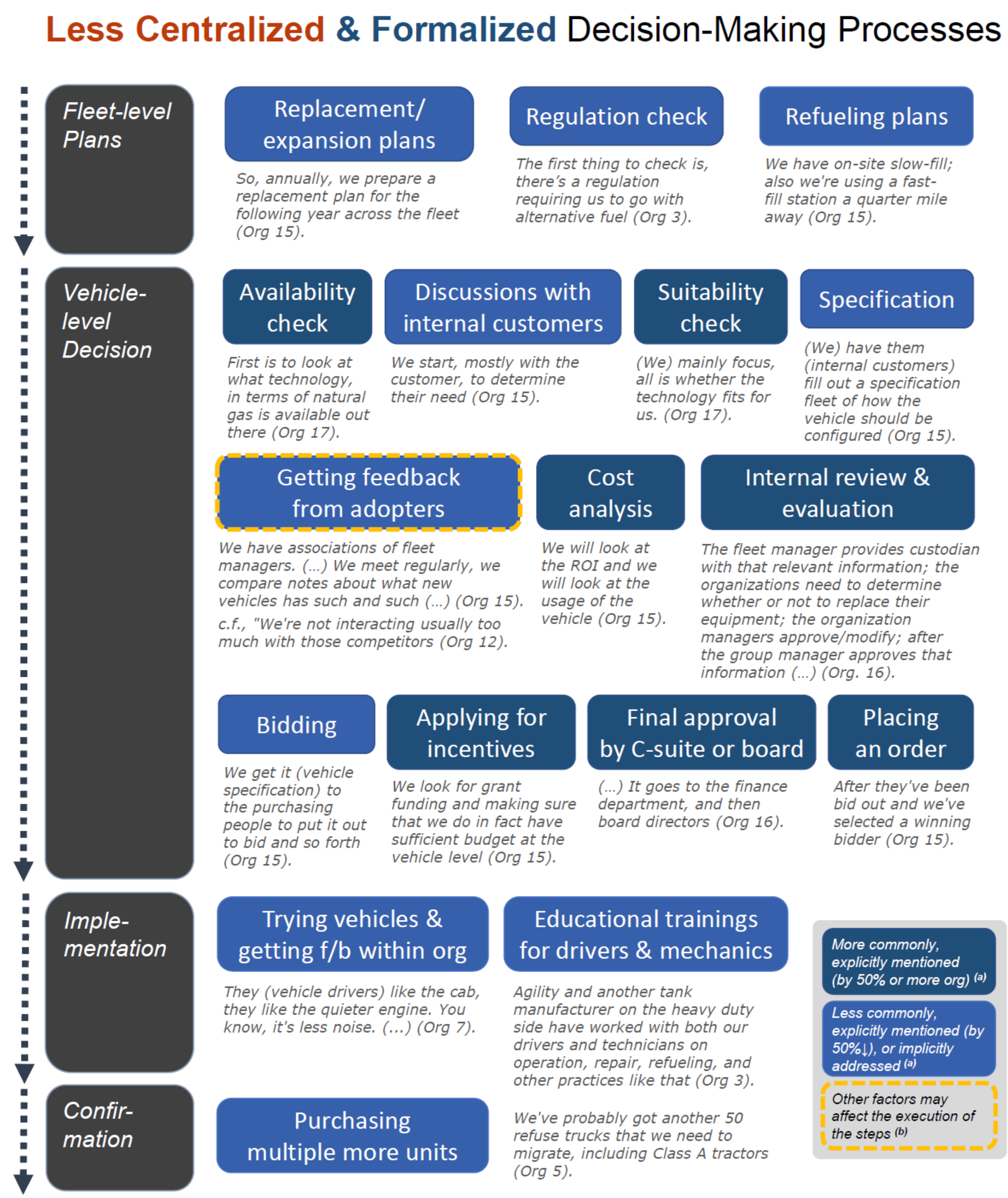
Second, a **vehicle-level decision** is related to choices about vehicle manufacturers and vehicle models as well as fuel options, in case the fuel choice is still undecided during the fleet-level plan. In this stage, the DMU of the organization searches for what AFVs are available in the market (step *d*). While checking the availability of different fuel options, either in step *c* or *d*, the organization *becomes aware of* alternative fuel technologies. Then, the DMU *considers* purchasing the heavy-duty AFVs through their own evaluations. If the heavy-duty AFVs are supposed to be used in specific departments, the DMU may discuss with those internal customers to determine their need (step *e*). The functional suitability of the vehicles (e.g., in terms of power, payload, and/or range) needs to be examined in order to make sure that the equipment suits their needs (step *f*). Then, they develop a specification of the vehicles' configuration (step *g*). In some cases, but not always, the DMU seeks feedback on the operation of heavy-duty AFVs from other organizations who already adopted it (step *h*). Some organizations conduct detailed cost analyses by evaluating not only incremental costs but total cost of ownership (step *i*); others consider only upfront costs; and the others would skip such analyses. Not only the suitability and costs analyses, but other factors can also be used: for example, whether the vehicle has any safety/reliability issues, and whether the organization possesses any intrinsic motives such as CSR. By reviewing all the inputs collected, the DMU evaluates the heavy-duty AFVs (step *j*) in order to *make a decision* either of adoption or non-adoption. If they decide to adopt, some organizations seek bids from different manufacturers (step *k*) while others would request a quote to their existing connections (e.g., a trusted dealer). If the organization looks for any opportunities to reduce the incremental costs, they apply for financial incentive programs available (step *l*). Particularly in formalized processes, a final approval of the purchase might be needed by the executive-level managers and/or the board directors (step *m*). Then, the DMU places an order of the heavy-duty AFVs (step *n*).

During **implementation** of the heavy-duty AFVs purchased, the DMU solicits feedback on the vehicle operations within the organization, including their vehicle drivers (step *o*). In addition, the organizations receive educational trainings, regarding vehicle operation, refueling, and maintenance, from manufacturers and fuel providers, or provide the trainings in-house to support their fleet mechanics and vehicle drivers (step *p*). Once the **confirmation** is made that the adoption of heavy-duty AFVs has been proved satisfactory, the organization would order multiple more units of the vehicles (step *q*).



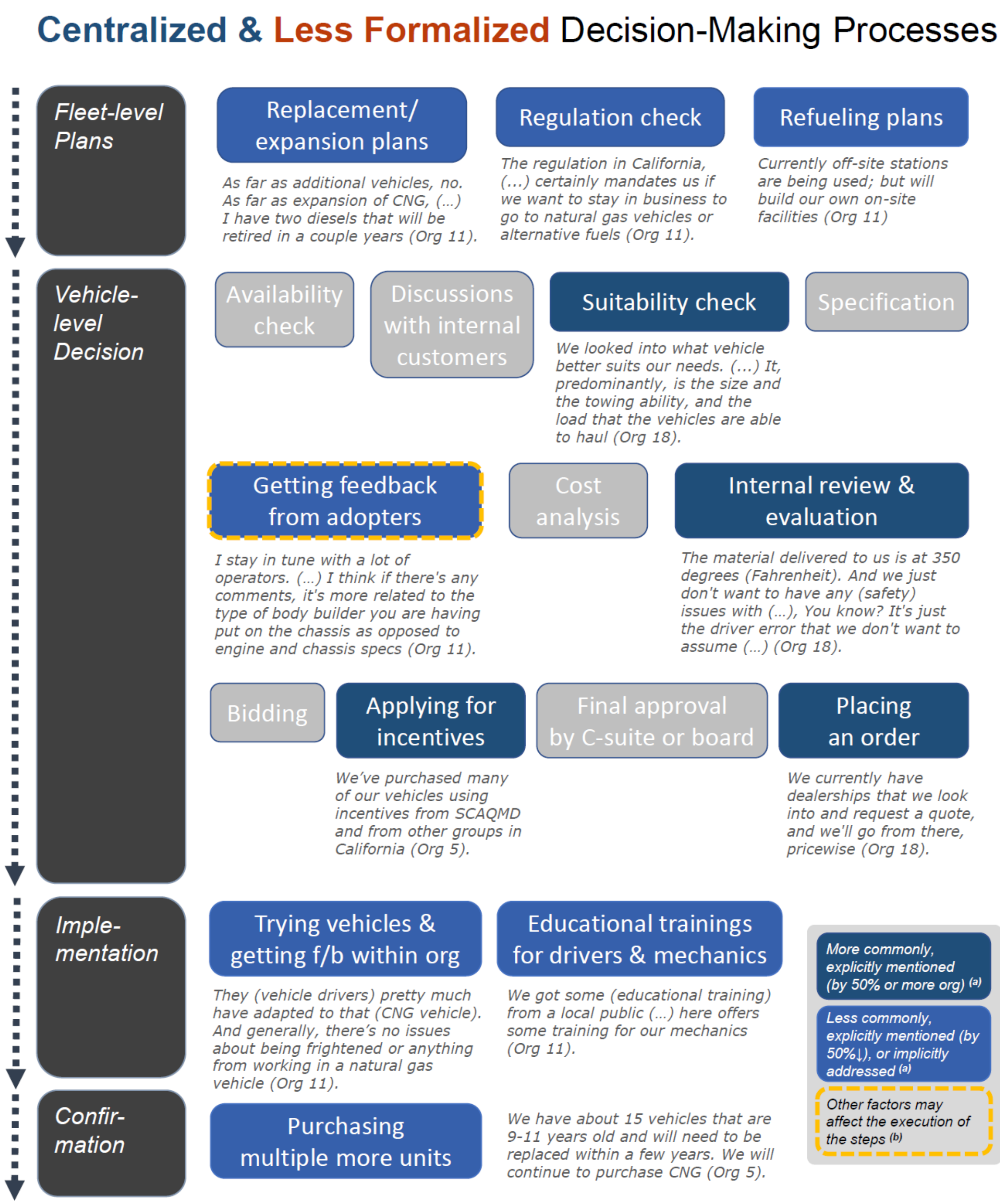
[Note] (a) Careful attention must be exercised in the interpretation of how commonly each step was mentioned, because 1) the frequency could be affected by interviewees' communication style, and thus would not be directly linked to an indication of importance; and 2) each pattern was derived based on a limited number of the participants (e.g., four organizations for centralized and formalized decision-making processes). (b) Other factors may affect the execution of the steps (e.g., how experienced they are with the heavy-duty AFVs; and how interactive they are with other fleet operators).

Figure 4-5. An Example of Centralized and Formalized Decision-Making Processes



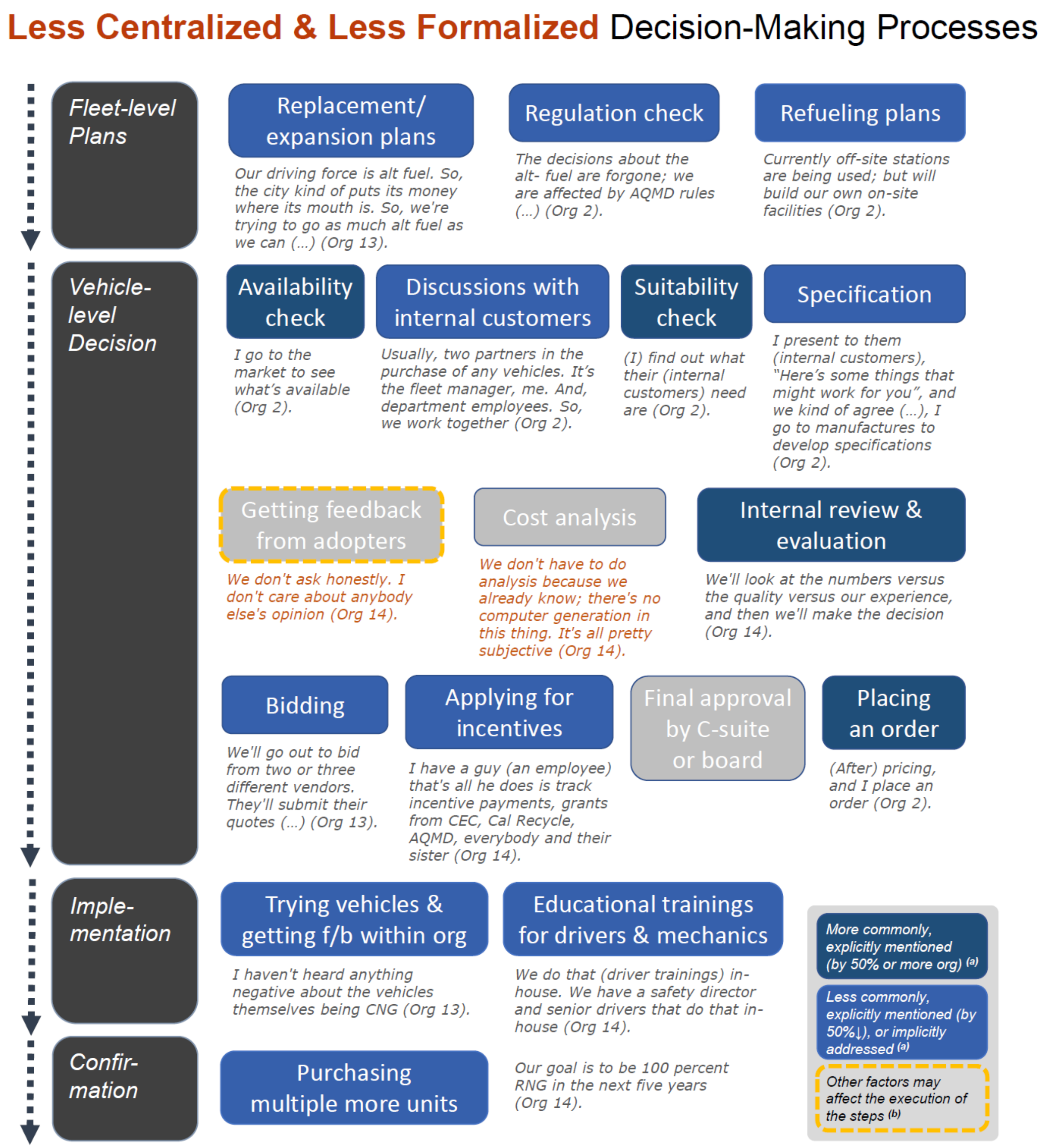
[Note] Eight participating organizations were found to have less centralized and formalized decision-making processes. For (a) and (b), the same notes are applied as in Figure 4-5.

Figure 4-6. An Example of Less Centralized and Formalized Decision-Making Processes



[Note] Three participating organizations were found to have centralized and less formalized decision-making processes. For (a) and (b), the same notes are applied as in Figure 4-5.

Figure 4-7. An Example of Centralized and Less Formalized Decision-Making Processes



[Note] Three participating organizations were found to have less centralized and less formalized decision-making processes. For (a) and (b), the same notes are applied as in Figure 4-5.

Figure 4-8. An Example of Less Centralized and Less Formalized Decision-Making Processes

4.3.4. Facilitators and Challenges in the Decision-making Processes

Based on the unique characteristics in the four distinct patterns of organizational decision-making processes for heavy-duty AFV adoption, various facilitators and challenges inherent in the processes, along with potential recommendations are addressed.

Leadership of key decision-makers with expertise (Facilitator) – Fleet managers with expertise in many participating organizations took the lead throughout the entire decision-making stages. First, participating fleet managers are "*well informed about the greenest solution*" (Org. 15) and "*focus on environmentally friendly opportunities*" (Org. 4), which made them "*head that up*" for the initiation of the discussion (Org. 4 and 16). A fleet manager's effort in gathering lots of necessary information, such as "*all the different fueling systems, manufacturers, the new engines*" (Org. 8), substantially assisted the evaluation stage. Persuasion of other key decision-makers was made by such fleet managers, which facilitated the adoption decision (Org. 4 and 8). Furthermore, their efforts to support vehicle drivers with educational trainings assisted implementing the heavy-duty AFVs: "*I individually train each driver. I go over some safety procedures [...]*" (Org. 4). Particularly for those organizations which are not subject to any mandates requiring AFV purchase (e.g., Org. 4 and 8), the fleet managers played the role of a *catalyst* in initiating and proceeding the whole processes. As such, targeted education for HDV fleet managers is recommended to enhance awareness and knowledge about alternative fuel options, which should be a stimulus for AFV adoption.

Complexity due to multifaceted criteria in formalized processes (Challenge) – Detailed cost analyses along with internal evaluations within the DMU are critical in the formalized decision-making processes. Each DMU member's acceptance of the AFV analysis, therefore, is primarily required to lead to the adoption decision. In many cases, however, members with different roles rely on different acceptance criteria: for instance, a financial team might permit an expense that financially makes sense within an available budget, whereas fleet engineers might focus on reliability and performance of the vehicles, and a sustainability group might favor a technology that ensures environmental benefits. Such multifaceted criteria inherently require demanding analyses relying on large amounts of data, particularly nowadays when "*there are many other options, whether it be CNG, LNG, LPG, electric […]*" (Org. 8). In order to streamline the complexity of the process, it may be helpful to support the development and promotion of analytical tools (e.g., *39*) for evaluation of different fuel options, for example, based on a customizable list of monetary (e.g., purchase costs, TCO) and non-monetary components (e.g., functional suitability, emission benefits).

Complexity due to many people involved in less centralized processes (Challenge) **–** Multiple people participate as key-decision makers (e.g., six entities for Org. 16) and/or various user departments are deeply involved (e.g., Org. 10) in the less centralized processes. Overall awareness regarding heavy-duty AFVs among those different participants are thus fundamental to facilitate the discussion. Coordinating across multiple personnel can be challenging, as elaborated by one organization: "*we needed to go to talk to the folks in charge of the transportation and street maintenance, and some other areas where - water resources and maintenance, where we've convinced these departments that they can save money on fuel and they can have a greener vehicle*" (Org. 10). Therefore, advertising and promotion of the benefits of the technologies can be suggested for those people involved in the processes as a means to increase their awareness and acceptance towards heavy-duty AFVs.

Inertia to follow previous purchases in centralized and less formalized processes (Challenge) – The decision behavior dominated by a limited number of people without systematic comparison in different fuel options characterizes the centralized and less formalized processes. Even if some of those organizations adopted a single type of alternative fuel (e.g., CNG adopted in Org. 5 and 11), those process-specific characteristics would pose an internal barrier to exploring other alternative fuel technologies such as electricity or hydrogen. One stated, "*We are a small company and we are very comfortable with our current [CNG] arrangement […] We have never considered another type of fuel. We will continue with CNG*" (Org. 5). Furthermore, such inertia following their previous purchases, which should be prevalent among a certain portion of diesel-only fleets (Nesbitt and Sperling, 2001), can be an obstacle to a wider adoption of heavy-duty AFVs. One fleet operator pointed out: "*If you look at the trucking companies and the commercial fleets in this state, look at the average age of the owners […] You're looking at 60-plus, right. They're set in their ways. New technology scares people a lot […] as long as they're not big corporate fleets*" (Org. 8). The key recommendation for those organizations with entrenched, risk-adverse decision behavior is to actively deliver educational programs or materials to increase their consciousness of benefits of various alternative fuel options. Mandating the use of AFV can be another measure together with financial incentives to ease the pain of forced transition.

Vehicle drivers' acceptance towards heavy-duty AFVs (Challenge) – Although vehicle drivers are typically not key-decision makers, their inputs and feedback are often used in the adoption decision, particularly in the less centralized processes, and the confirmation of the continued use of the vehicles in most processes. Fleet managers explained, they "*have their drivers give their thoughts or feedback*" when they "*do have companies demo a certain new type of truck*" (Org.7), and they "*have a meeting with driver union and get the support, the feedback, and any issues, concerns*" (Org. 17). However, in some cases, the organizations reported that "*there's some weird myths (e.g., CNG leaking out overnight), frustration or missed perception about tank capacity and range*" (Org. 3), and "*some trepidation regarding safety issues*" (Org. 4) among drivers. To assist and facilitate the drivers' acceptance toward heavy-duty AFVs, it is thus suggested to offer educational materials and trainings to adopter organizations via the support of technology suppliers.

Information shared by other adopters for inexperienced organizations (Facilitator) – For potential new adopters, information shared by other adopters should be a practical help in evaluating and implementing the new technologies. Many organizations (e.g., Org. 4, 9 and 16) stated that they visited or had informal discussions with "*municipalities and private haulers*" to obtain feedback about CNG use in general, and detailed operational and maintenance particularities (e.g., "*operational power and range*", "*configuration of CNG gas detection systems*"). Despite the merits of exchanging information as it lowers the adoption uncertainty of the unfamiliar technologies, some fleet operators appeared to be intentionally inactive in sharing their knowledge and experiences (e.g., Org 7 and 12) since they regard other fleets as business competitors. Slow dissemination of relevant information can be an obstacle to extensive adoption of the technologies for those business sectors. Networking and information-sharing events, targeting experienced fleets and potential adopters in diverse business sectors, might be helpful to facilitate rapid distribution of in-depth information about heavy-duty AFVs.

Support from technology providers for inexperienced organizations (e.g., vehicle testing opportunities and educational trainings) (Facilitator) – For new adopters, vehicle and engine manufacturers, and fuel providers can provide helpful supports in facilitating their decision processes. One recent CNG adopter stated, they "*rented a CNG truck from a vehicle manufacturer and tested it for two months*," after which they realized "*these trucks are outperforming*" some of their diesel trucks and they "*determined that it would work*" in their applications (Org. 8). In addition, many participating organizations (11 out of 17 CNG adopters) mentioned that they received educational training for fleet mechanics and technicians from manufacturers and fuel providers, focusing on vehicle operation, refueling, maintenance, and repair. When fleets did not receive such support, organizations tried to provide "*in-house trainings*" (e.g., Org. 8). Therefore, technology suppliers' support such as vehicle testing opportunities and educational trainings can be desirable to expedite the decision processes encompassing consideration and implementation stages.

4.3.5. Summary and Recommendations

In this chapter, the organizational decision-making processes of alternative fuel adoption in HDV fleets were probed based on 18 empirical cases in California. Using qualitative interviews and thematic analysis, characteristics and distinct patterns of the decision-making processes were explored, by which various challenges and facilitators inherent in the processes were discussed. The main qualitative insights gained in this research are summarized as follows:

- [**INSIGHT 1**] Key decision-makers (e.g., fleet managers)' leadership is critical throughout the entire decision-making stages.
- [**INSIGHT 2**] For formalized and/or decentralized decision-making behavior, the decision-making processes are inherently complex because of multiple people involved from different positions and/or many steps need to be passed.
- [**INSIGHT 3**] For some centralized and less formalized fleets, inertia to follow previous purchases of a specific fuel option without any cost analysis can be an internal barrier to adoption of other heavy-duty AFV option.
- [**INSIGHT 4**] Although vehicle drivers are typically not key-decision makers, their input and feedback can be often used in adoption decision and/or confirmation stages particularly in less centralized fleets.
- [**INSIGHT 5**] For potential new adopters who have never tried heavy-duty AFVs, practical information shared by other adopters and supporting efforts from technology suppliers (e.g., testing AFVs) may facilitate their decision-making processes.
- [**INSIGHT 6**] With respect to fleet replacement criteria, vehicle age, mileage, and vehicle conditions/maintenance need were commonly addressed in the participating organizations. Other criteria include vehicle size, vocations, utilization, available budget, and business opportunity.

The study findings suggest many policy implications for facilitating the decision-making processes of heavy-duty AFV adoption in organizations, which include:

- Targeted education for key decision-makers (e.g., fleet managers) to increase their awareness of alternative fuel technologies in HDV operations and to provide critical information useful for the decision-making process

- Development of a detailed evaluation tool which is able to analyze multiple fuel options (e.g., a tool enabling a user to analyze and compare monetary (e.g., TCO) and non-monetary components (e.g., functional suitability, emission benefits) with a customizable list of cost/functionality elements) and to provide information about available vehicles models/manufacturers and available fuels vendors
- Promotion of heavy-duty AFVs and their benefits to the people involved in decision-making processes (e.g., C-suites, user department managers, vehicle drivers) to increase their acceptance
- Educational training for vehicle drivers to increase their acceptance towards AFVs, and to help their safe operation of vehicles and fueling practice
- Networking events facilitating information exchange between adopters and potential adopters regarding heavy-duty AFV operations
- Provision of vehicle testing opportunity during enough period (e.g., a couple of months) for potential adopters

This research may have several limitations. First, generalization of the study findings cannot be made given the small sample size, although it is the nature of qualitative research approach (Bryman, 2012). Therefore, caution must be exercised for the interpretation of the findings. Second, some decision-making processes with extra complications were beyond the scope of recruitments, such as companies operating multiple fleets through separate branch offices in different locations. Revealing the personnel and procedures used for complex organizational decision processes will be worthwhile for creating a more complete picture of heavy-duty AFV fleet decisions. Third, there might be other indicators, beyond centralization/formalization characteristics, that can influence strategic decision processes, such as decision urgency, complexity, and DMU members' characteristics (e.g., age, education) (Rajagopalan et al., 1993). It can thus be suggested for future studies to explore additional indicators by incorporating them into the methodology. Lastly, the participants of this study tend to be more informed than average given that most of them are adopters of one or more types of alternative fuels. This suggests room for investigations of facilitators that can assist the *initiation* of decision processes for those who are unaware of, or never considered alternative fuels (e.g., late majority and laggards (Rogers, 1983a)).

Acknowledgements

Bae, Youngeun, Rindt, Craig R., Mitra, Suman K., and Ritchie, Stephen G. "Organizational Decision-making Processes of Alternative Fuel Adoption: An Empirical Study with Heavy-duty Vehicle Fleets in California." *The 100th Annual Meeting of the Transportation Research Board*, Online conference, Jan 2021. Poster presentation.

4.4. Factors Influencing Heavy-duty AFV Fleet Adoption Decisions

In the Chapter 4.4, the factors that have affected adoption decisions of heavy-duty AFVs are explored. This work seeks to address the following research questions: 1) What are the motivating or facilitating factors that have influenced alternative fuel adoption decisions made by HDV fleet operators; 2) What are the barriers or discouraging factors that have affected fleet operator non-adoption decisions of alternative fuels; and 3) How have these factors influenced such decisions and what are the potential relationships between them? Accordingly, the following interview questions were asked:

- **Q6 (Alternative considered)**: "During the decision-making process of purchasing [the AFVs mentioned in Q1], were there any other fuel technologies you considered?"
- **Q4 (Influencing factors)**: "What factors influenced your purchase decisions for [AFVs mentioned in Q1 and Q6]? Were there any factors which made you more willing to or more hesitant to purchase these vehicles?"
- **Q5 (Laws or regulations)**: "What laws or regulations affected your AFV purchase decision?"

In addition to the 18 interviews, two project reports, which address what factors and which regulations affected AFV deployment cases in California organizations, were included to reinforce the analysis. The qualitative data from the interviews and the reports were analyzed using content analysis. Both quantitative (as shown in Figures 4-10 to 4-14) and qualitative analyses (as explained in subsequent subchapters) were agreed between the participating researchers and verified to address the research questions.

4.4.1. Overview of Results

As a part of content analysis results, the factors that affected each organization's adoption or non-adoption decision of each fuel were identified with the signs and strengths, and relevant quotations were collected (See Figures 4-10 to 4-14 and Table E-1).[15] A further summary of those factors is provided in Tables 4-7 and 4-8 regarding adoption and non-adoption cases, respectively. A total of 38 factors were classified into the three large categories of technology characteristics, organizational characteristics, and external environmental influences (following the TOE Framework by Tornatzky and Fleischer (1990), with three groups representing the most recurring factors, other important but less common factors, and the least common factors.[16]

With regard to alternative fuel adoption decisions, the most recurring factors were: functional suitability, fuel price, fuel infrastructure, environmental consciousness regarding vehicle emission (or CSR), availability of vehicles, fleet regulations by the SCAQMD and CARB, and financial incentives. Other important but less common factors include overall costs (or TCO), vehicle purchase price, maintenance issues, vehicle reliability/safety, demonstrating technologies, contracts with municipalities, promoting environmental sensitivity, and attitudes of decision-makers. Each factor can be differently evaluated either

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[15] See Figures 4-10 through 4-14 for the scoring results of the factors, and Table E-1 in the Appendix for the list of factors and example quotations.

[16] To sort out the factors into the three groups – the most recurring factors, other important but less common factors, and the least common factors – we used the 80th percentiles (e.g., mentioned by 10 cases for adoption, 5 cases for non-adoption) and the 60th percentiles (e.g., 4 cases for adoption and 3 cases for non-adoption) of the frequency distribution of the factors addressed (with any scores). For example, the most recurring factors in the adoption decisions are the ones addressed by 10 or more adoption cases; other important but less common factors stated by 4 to 9 cases; and the least common factors by 1 to 3 cases. However, care should be taken when interpreting the categorization results because these are not generalized results given the small sample size.

as a motivator or a barrier depending on a fuel option being considered and a fleet vocation, which is attribute to each own technological, regulatory, fleet-specific circumstances. Among those common factors, the motivators frequently emphasized (i.e., with "+3" symbols)[17] were: environmental consciousness/CSR, regulations by the SCAQMD, financial incentives, and vehicle availability.

With respect to non-adoption decisions, the most recurring barriers were: unavailability of vehicles, functional unsuitability, insufficient fuel infrastructure, and commitment already made to other fuel option(s). Other major but less common barriers included: overall costs, maintenance issues, and vehicle reliability/safety. Among the discouraging factors, the barriers frequently emphasized (i.e., with "–3" symbols) included: functional unsuitability, commitment already made to other fuel option(s), and unavailability of vehicles.

Based upon the factors identified along with the relationships between each other, themes and hypotheses were formulated, by which the initial theoretical framework (Figure 3-4) was scrutinized and refined with more specific constructs that account for current circumstances in the California HDV sector. Figure 4-9 depicts the updated framework for heavy-duty AFV fleet adoption decisions in California. All 38 factors identified from the content analysis were found to fit well with the components previously described in the initial theoretical framework. Compared to the initial framework, many specific factors which may account for California-specific circumstances were newly

[17] The 90th percentile of the frequency distribution of the factors with "±3" scores (e.g., 4 cases for adoption, 2 cases for non-adoption) was used to select the frequently emphasized motivators or barriers. For example, the motivators frequently emphasized in the adoption decisions are the ones addressed with "+3" scores by 4 or more adoption cases.

identified (e.g., ‘contract with municipalities’, ‘AQMD/CARB regulations’, ‘fuel security issue’, ‘technologies proven in the industry’, etc.) while only a few factors in the initial framework were not observed in this analysis (e.g., ‘neighborhood effect’). In addition, more specific relationships between the components were observed. Basic characteristics of fleets, including sector, fleet size, fleet vocation, location operational aspects, and experiences with AFVs, were found to moderate the relationships between those components and the adoption decision.

Table 4-7. Factors Influencing Alternative Fuel Adoption Decisions by Participating HDV Fleets

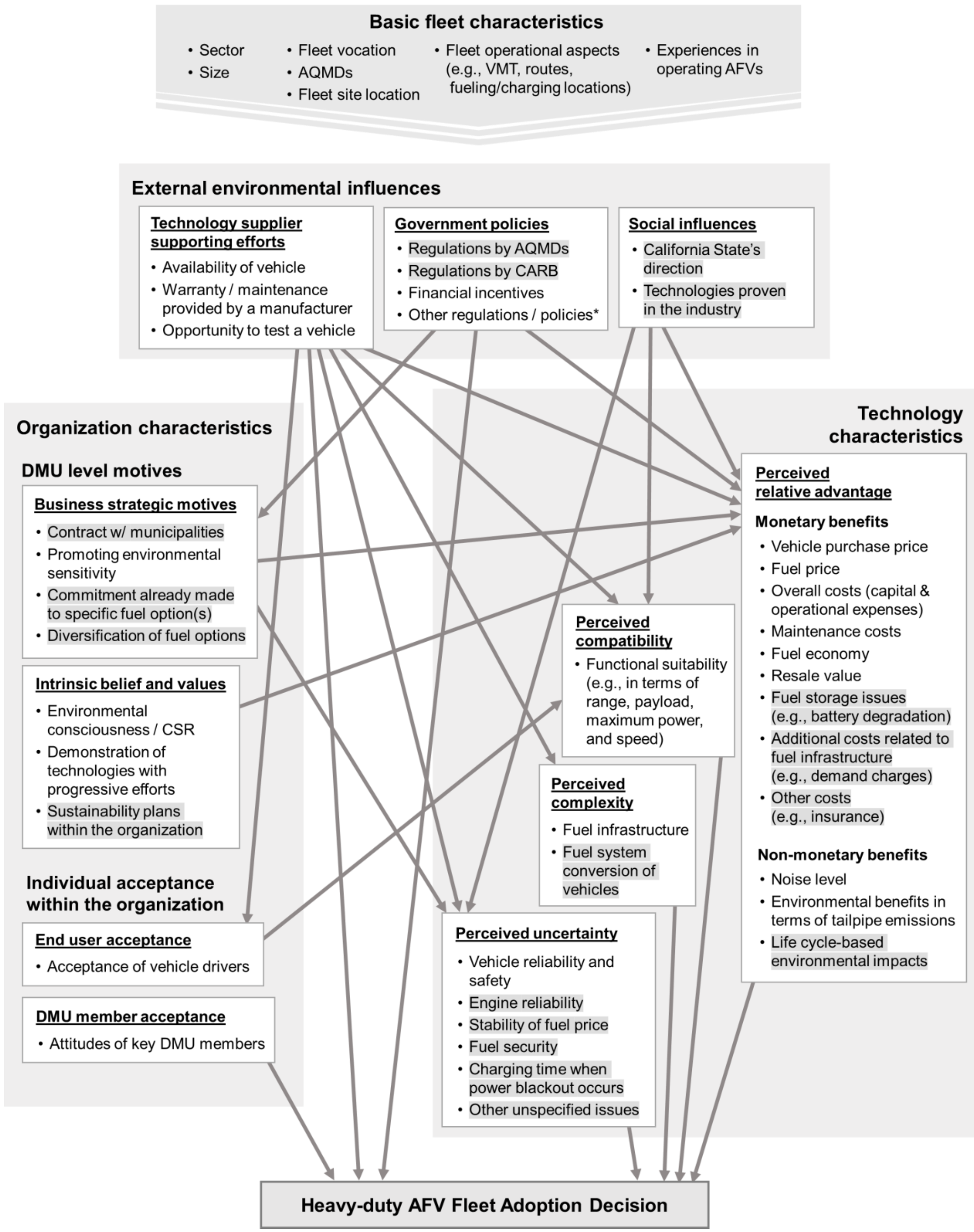
	Technology characteristics	**Organization characteristics**	**External environmental influences**
Most Recurring Factors	• Functional suitability (e.g., in terms of max power, payload, and range) (+, n) • Fuel price (+,–) • Fuel infrastructure (+,–)	• <u>Environmental consciousness/CSR</u> (+)	• <u>The only available/viable option</u> (+) • <u>Regulations by AQMDs</u> (+) • Regulations by CARB (+, –) • <u>Financial incentives</u> (+)
Other Important but Less Common Factors	• Overall costs (capital and operational expenses) (+,–) • Vehicle purchase price (–) • Maintenance costs (+,–) • Fuel economy (+,–) • Vehicle reliability and safety (+,–) • Engine reliability (+,–)	• Demonstration of technologies (+) • Contract w/ municipalities (+) • Promoting environmental sensitivity (+) • Attitude of key members of decision-making unit (+)	• Warranty/maintenance provided by a manufacturer (+,–)
The Least Common Factors	• Resale value (n) • Other costs (+) • Noise level (+) • Additional costs related to fuel infrastructure (–) • Fuel security (–) • Stable fuel price (+) • Fuel storage issues (+) • Fuel system conversion of vehicles (+)	• Sustainability plans within the organization (+) • Commitment already made to specific fuel option(s) (+) • Diversification of fuel options (+) • Acceptance of drivers (+, n)	• Other regulations/policies (+, n) • Opportunity to test a vehicle (+) • California State's direction (+) • Technologies proven in the industry (+)

[Note] (+): positively stated, (–): negatively mentioned, n: neutrally stated, (**+,–**): positive stated by some organizations while being negatively addressed by others. The motivators frequently emphasized are underlined.

Table 4-8. Factors Influencing Alternative Fuel Non-Adoption Decisions by Participating HDV Fleets

	Technology characteristics	**Organization characteristics**	**External environmental influences**
Most Recurring Factors	• Functional suitability (–) • Fuel infrastructure (–)	• Commitment already made to other fuel option(s) (–)	• Unavailability of vehicle (–)
Other Important but Less Common Factors	• Overall costs (capital and operational expenses) (–) • Maintenance issues (–) • Vehicle reliability and safety (–) • Other unspecified issues (–)		
The Least Common Factors	• Vehicle purchase costs (–) • Fuel prices (–) • Uncertain environmental benefits (–) • Life cycle-based environmental impacts (–) • Additional costs related to fuel infrastructure (–) • Unstable fuel price (–) • Charging time when power blackout occurs (–) • Fuel storage issues (–) • Fuel system conversion of vehicles (–) • Engine reliability (–)		• Regulations by AQMDs (–)

[Note] (–): negatively mentioned. The barriers frequently emphasized are underlined.



[Note] (1) The factors newly found compared to the initial theoretical framework are indicated with gray shading. (2) There are two factors included in the initial framework but not observed in this analysis: 'neighborhood effect' and 'non-monetary incentives.' (3) Basic fleet characteristics can moderate the relationships between external environmental influences, organization characteristics, perceived technology characteristics, and decisions to adopt heavy-duty AFVs.

Figure 4-9. A Framework for Heavy-duty AFV Fleet Adoption Decisions in California

While a number of insights stem from a combination of the qualitative and quantitative analyses, the following 11 main themes[18] are explained in this paper, under the three main categories: technology characteristics, organization characteristics, and external environmental influences (for reasons of space, the least common factors are less discussed).

4.4.2. Technology Characteristics

Various technological characteristics of heavy-duty AFVs are simultaneously considered and evaluated during the decision-making processes in organizations. Those traits are in line with a range of attributes previously described in the initial theoretical framework, namely perceived compatibility, perceived relative advantage – which includes monetary and non-monetary benefit, perceived complexity, and perceived uncertainty. Perceptions on such technological attributes directly influence adoption and non-adoption decisions.

1) Perceived Compatibility

Perceived compatibility is one of the most recurring themes among the participating fleets across diverse vocations. In other words, the vehicles need to be ***functionally suitable*** in terms of vehicle power, payload, and/or driving range so as to "*fit and work in the areas that we need it*" (Org. 7). In case where such functional suitability is unfulfilled, the organizations tend to decide not to adopt the fuel. For example, electric HDVs for

[18] See Table E-2 for the definitions of the themes in the Appendix E.

certain vocations were often "*ruled out*" particularly due to their unmet operational requirements. Fleet managers stated, *"[electric vehicles] don't have range*" needed for a school bus (Org. 1), "*they are so heavy*" with a limited payload (Org. 8), and "*the capacity it can haul is insufficient*" for refuse trucks (Org. 15).

2) Perceived Relative Advantage

Perceived relative advantage that can be brought by adopting an alternative fuel instead of conventional one was found as another important theme. Such relative advantages can be divided into monetary and non-monetary benefits. Monetary benefits were addressed either as a concept of TCO or specific cost components such as vehicle purchase costs, fuel prices, and maintenance costs. Some participating fleets assessed ***overall costs*** incurred by adopting heavy-duty AFVs (e.g., "*CAPEX and OPEX – how much does it cost and what it costs to run*" (Org. 14)). Such TCO evaluations can be differently estimated depending not only on fleet characteristics (e.g., fleet size, annual vehicle mileage, etc.) but on fuel technologies, which thus may lead to contrasting decisions. For example, overall monetary benefits were commonly addressed as a reason for CNG adoption (e.g., Org. 8) while several organizations rejected LNG as they evaluate the fuel as "*not cost effective to operate*" (e.g., Org. 3 and 15).

Some organizations described separate components of overall costs, among which a ***purchase price*** was commonly perceived as highly disadvantageous. For example, an expensive purchase price of a heavy-duty CNG vehicle was identified as a discouraging factor by many CNG adopters across small, medium, and large fleet size. One hauling truck fleet manager noted, "*The [CNG] vehicles that we're purchasing are about $225,000 a piece.*

Our standard conventional diesel trucks are about $115,000 to $125,000. So, it's almost two to one" (Org. 8). Electric or hydrogen HDVs are also more expensive than diesel vehicles. For example, a hydrogen transit bus costs around $1.3 million, compared to $890,000 for an electric bus, $560,000 for a CNG bus, and $480,000 for a diesel bus (NREL, 2020, 2019). If such a huge purchase cost does not financially make sense to an organization, they regard that fuel option as a "*non-starter*" when they began with their decision-making process (Org. 9).

For specific fuel options, a lower ***fuel price*** than diesel was emphasized as one of the most motivating factors. More than half the CNG adopters mentioned the advantage of lower fuel prices. One organization, which operates electric transit buses, also reported electricity ($0.41/mile) to be more cost-saving even than CNG option ($0.50/mile) (Org. 19). However, not all alternative fuels have lower prices than diesel. Hydrogen and E85 were evaluated as much more expensive (Org. 20) or gainless (Org. 7) compared to diesel, respectively.

Maintenance costs were also addressed by several participating fleets. Some CNG adopters favorably addressed the vehicles' maintenance costs due to "*less frequent oil change*" and "*no need for additional emissions control equipment*" (Org. 15). However, more maintenance issues were also noted by other CNG adopters such as due to training needs for safety precautions (Org. 12 and 16). Meanwhile, as to the use of LNG, a noticeable trend was observed. Most of the organizations who considered LNG decided not to adopt or to discontinue using it, of which main reason was due to its a lot of maintenance issues that render LNG vehicles impractical and unprofitable (e.g., Org. 3 and 9).

In addition, an improved ***fuel economy*** can substantially reduce operating costs and TCO. Such benefits were reported particularly by the adopters of zero-emission vehicles (ZEVs). For example, the battery electric transit bus operator (Org. 19) noted that their buses had an overall fuel economy of 17.35 miles per diesel gallon equivalent (mpdge), which is more than 8 times higher than that of a CNG bus. Another organization operating hydrogen fuel cell transit buses (Org. 20) also reported an improved fuel economy of 6.12 mpdge which is 45% higher than that of a diesel bus.

Non-monetary benefits can also act as a facilitator or an impediment to alternative fuel adoption for some organizations. A few participants stated that a lower ***noise level of vehicles*** was perceived as advantageous as it can help mitigate driver fatigue and improve operational efficiency (e.g., CNG adoption by Org. 8). Some fleet operators also mentioned ***environmental impacts*** of heavy-duty AFVs as one of the factors influencing their decisions. While environmental benefits gained from lower or zero emissions motivated them to favorably evaluate the adoption, dubious or unpromising assessment of environmental impacts, in terms of tailpipe emissions and/or life cycle-based analysis, affected their rejection decisions. One organization explained, "*I look at the whole picture for electric vehicles. The pollutions they are causing to the environment, those lithium batteries, and all the other environmental impacts that are happening in producing those batteries*" (Org. 1).

3) Perceived Complexity

Insufficient ***fueling/charging infrastructure*** increases complexity in adopting heavy-duty AFVs. The lack of infrastructure was frequently cited not only as a main reason for non-adoption decisions (e.g., LNG rejection by Org. 16, and electricity rejection by Org. 1), but also a main obstacle to those who proceeded the adoption: "*The main issue that I've run into is lack of [CNG] infrastructure. That's a huge issue*" (Org. 8). Moreover, the tendency was observed from the participating adopter organizations: most of them did not have a desire to solely rely on off-site stations and therefore they already built, or are planning to build their own on-site stations. One of the main reasons for building their own on-site facilities is because limited accessibility to the infrastructure causes operational disparities and greater complexity of fleet operations. One described, "*We have to make sure our tanks are full, especially if we have some longer routes. [...] The availability of gasoline or diesel is still, even in a state like California, so much more available than what it would be for propane or CNG*" (Org. 12).

4) Perceived Uncertainty

Perceived uncertainty of heavy-duty AFV technologies was found as one of the important themes. One fleet operator emphasized, the vehicle "*should be going to be there to carry out the purpose that's required of for its duty cycle*," and "*be operated safely for the life cycle of the vehicle*" (Org. 10). Participating organizations described their concerns regarding uncertainty from various angles such as ***reliability or safety of vehicle/engine technologies*** as well as ***predictability of fuel supply***. Any cases of failure in obtaining such assurance can lead to a rejection decision of an alternative fuel. For example, one paving company rejected adopting CNG and one of their main reasons was its safety concern: "*When we did look into [CNG vehicles], the way they were configured [...] didn't seem safe for our work, because we pick up asphalt that is 350 degrees [Fahrenheit]*" (Org. 18). As another example, LNG vehicles were rejected by several fleet operators due to its safety issues related to dealing with the cryogenic fuel (e.g., Org. 9). Biodiesel was also cited as problematic for engine reliability by several organizations, stating "*It's just completely destroying those engines*" (Org. 8). Accordingly, some organizations (e.g., Org. 10 and 13) decided to use renewable diesel, which would be expected not to cause such issues, while they "*stay away from*" biodiesel.

In addition, a lack of predictability of fuel supply was addressed as a barrier to the adoption in that this would be associated with unpredictable fuel prices (e.g., E85 non-adoption by Org. 7) or even fuel security issues. One organization described, "*If there is a big earthquake and power goes out […] my [CNG vehicle] fleet is gonna run for a day […] The fuel security, it's the issue*" (Org. 2).

4.4.3. Organization Characteristics

Intrinsic belief and values, or business strategic motives possessed by an organization can affect their perceptions of heavy-duty AFV technologies, which in turn influences their adoption decision. In these cases, such intrinsic or strategic motives assist the organization in defeating the obstacles associated with adopting heavy-duty AFVs (e.g., insufficient infrastructures, higher purchase costs). At the same time, for not all but some organizations, vehicle driver acceptance of AFVs are taken into account for the evaluation of the vehicles, in a way of examining whether the technology is satisfied with its required functional compatibility. In addition, key decision-maker attitudes towards AFVs can directly impact on the adoption decision. Such observations at the theme level overall conform to the initial framework while more specific factors are identified from the analysis.

1) Intrinsic Belief and Values

Environmental consciousness regarding diesel HDV harmful emissions was often pinpointed, by about half the adoption cases across diverse AFV technologies, and various public and private sectors. Some fleet operators emphasized their ***corporate social responsibility***, and explained it as the primary motivator for their adoption decisions: "*Everybody's concerned about global warming and pollution and environment, so, you know, just doing the right thing is probably the biggest driver*" (Org. 14). Another intrinsic motivation possessed by the adopter organizations is an inclination toward green, innovative technologies. While leading a ***demonstration of novel technologies***, those organizations tried to evaluate if the heavy-duty AFVs could meet their fleets' operational requirements. Such progressive efforts were noticeable with some large fleets who adopted zero-emission HDVs (e.g., Org. 10, 19, and 20). These organizations perceived adopting AFVs as highly advantageous as those green and innovative technologies can fulfill their intrinsic motivations.

2) Business Strategic Motives

For private sector fleets pursuing ***contracts with municipalities***, alternative fuel adoption can be perceived as advantageous because the "*municipalities are more receptive to people that are running green vehicles*" (Org. 8). Some refuse truck or school bus fleet operators also highlighted their contractual conditions requiring them to introduce or continue using alternative fuels, which made them operate CNG and/or LPG vehicles (e.g., Org. 7, 11, and 12). In addition, ***a good public image sensitive to environmental influences***, which could be earned by operating AFVs, can be regarded as an additional benefit of an organization's business strategy (e.g., Org. 16). Pursuing such business strategic motives contributes to more positive evaluations of relative advantages brought by adopting AFVs.

Meanwhile, a large ***investment that has already been made to a specific fuel option***, including on-site fueling/charging facilities, can make an organization willing to reject any other alternative fuels (e.g., Org 1, 5, and 7) because adopting an additional fuel is not perceived as financially beneficial. For example, one explained, "*Because we purchased and spent a lot of money on this CNG station here and CNG fast-fill, [...] I am not willing to take the budget for electric vehicles right now. That will not make sense*" (Org. 1).

At the same time, in case where a fleet can afford ***to diversify fuel technologies being operated***, adopting an additional fuel can be regarded as a way to alleviate operational risk (i.e., lower perceived uncertainty). As an example, one organization presented a continuing willingness to use their LNG vehicles as well as the CNG vehicles because of their LNG fueling infrastructure already invested along with a desire to operate multiple types of fuels in preparation for any emergency events (Org. 17).

3) End User Acceptance

Driver acceptance of AFVs was recognized by a few organizations (Org. 10 and 16) to be important for the adoption decision as it can confirm the compatibility of the technology: "*If we invest the money, […] if the user isn't going to use it, and they say it's not* *going to do the job for them, then we've failed in our responsibilities of specifying the right vehicle to carry out their mission*" (Org. 10).

4) Decision-making Unit Member Acceptance

Of many different characteristics of decision-making processes in organizations, the ***attitude of key decision-makers in the DMU*** (e.g., a fleet manager/engineer, a company owner, etc.) was addressed by several organizations as a factor affecting their adoption decisions. For example, some fleet managers, who were favorable toward AFV purchase with sufficient knowledge, initiated discussions and persuaded other key decision-makers, which substantially contributed to leading to the adoption decisions (e.g., Org. 4 and 8).

4.4.4. External Environmental Influences

External circumstances created by governmental policies, technology supplier support, and social influences can play another important role in an organization's decisions of alternative fuel adoption and non-adoption. While some external environments such as governmental regulations and limited vehicle availability directly affect the decisions, most of such external influences can have an impact on the decisions mediated through perceived technology characteristics and/or organization properties. Compared to the initial framework, several particular factors accounting for the California context were newly identified and more specific relationships were observed between the external environmental factors and the other attributes.

1) Technology Supplier Supporting Efforts

The more supportive vehicle manufacturers and fuel providers are, the more favorably heavy-duty AFVs can be evaluated, such as with more competitive purchase costs, more compatible vehicle functionality, less complex fueling planning, and improved guarantee for vehicle operations. Of the factors related to such technology supplier support, the most frequently cited was the fact (or the perception) of commercial ***unavailability of the vehicles***, which directly led to the non-adoption decisions across various alternative fuels and heavy-duty vocations (e.g., rejection of electric refuse trucks by Org. 14).

Meanwhile, ***warranty and maintenance*** provided by a manufacturer was reported by several participating organizations as one of the facilitators for making the decisions. Whether "*the companies have field service technicians that come to the site, work with our mechanics, and do repairs*" is essential because that will allow the adopters "*to keep the trucks on the road every day*" (Org. 7). When adopters are faced with unreliable aftersales support, such as a long lead time for delivery of spare parts (Org. 20), that can impose challenges to reliable fleet operations. In addition, provision of ***an opportunity to test a vehicle*** also facilitates the adoption decisions in that it can help a potential adopter (and their vehicle drivers) recognize functional compatibility of the vehicle (e.g., CNG adoption by Org. 8).

2) Governmental Policies

The ***regulations implemented by South Coast AQMD in Southern California and/or CARB*** were frequently cited by many participating organizations as the most influential factors leading to their heavy-duty AFV adoptions. The South Coast AQMD fleet rules (SCAQMD, n.d.) require government fleets and private contractors under contract with public entities (e.g., school bus, refuse hauler) to purchase alternative fuel vehicles (e.g., CNG, LNG, LPG, methanol, electricity, or fuel cell). Such fleet rules by the AQMD together with a limited availability of AFV options at the time of purchase were commonly addressed as the overarching reasons for CNG adoption (e.g., Org. 2 and 11). In addition, the CARB's fleet rule for transit agencies (CARB, 2019a), which requires advanced zero-emission bus adoption for large transit agencies with 200 or more buses, was pinpointed as the primary driver for demonstrations of battery electric (Org. 19) and fuel cell electric buses (Org. 20).[19]

In addition, ***governmental financial incentives*** can be used to offset initial capital costs, one of the biggest financial barriers to AFV adoption. Many adopter organizations addressed they sought funding from various agencies and programs. Some of those emphasized the incentives as an overarching factor in their decisions: "*because of the grants that were available here locally through our air district, that enabled [our organization] to do a lot of migration [to alternative fuel vehicles]*" (Org. 10). Furthermore, several organizations highlighted that unavailability of financial incentives would make it difficult to continue with AFVs or at least slow down the replacement of diesel.

3) Social Influences

[19] The actual effect of regulations seems to vary depending on organization-specific characteristics such as fleet size and refueling/recharging facilities being used. For example, one organization with a medium fleet size and using off-site fueling stations noted, if there were no such rules, they would buy diesel due to the incremental costs. Another organization with a medium fleet size but equipped with on-site fueling facilities stated, they would diversify fuel options so that they could use both alternative and conventional fuels. In contrast, several organizations with large fleet sizes (100+ vehicles) and their own on-site refueling facilities expressed a consistent commitment to using the fuel even without regulations.

Social influences were noted by a few participating fleets. For example, ***the intent to conform with the State of California's direction*** motivated an organization adopt renewable diesel instead of conventional diesel as they might have become aware of relative advantages of using that fuel[20]: "*When the state went out for their renewable diesel, we jumped on that*" (Org. 13). In addition, ***the belief that a certain heavy-duty vehicle technology has already been proven in the industry***, can drive the organization to adopt that AFV because such belief will help them possess functional compatibility and relieve operational uncertainty (e.g., CNG refuse truck adoption by Org. 9).

4.4.5. Summary and Recommendations

Because available theory about alternative fuel adoption behavior in HDV fleets is insufficient, this work investigated AFV adoption and non-adoption decisions made by HDV fleet operators. As a result, 38 motivators or barriers were identified for adoption and non-adoption decisions across various alternative fuels, including CNG, LNG, propane, electricity, hydrogen, E85, biodiesel and renewable diesel. The further analysis of these factors and their relationships served to formulate themes and hypotheses, by which a refined and improved framework was established to account for heavy-duty AFV fleet adoption decisions in California. Some of the key findings are summarized below.

For the fuel diversification behavior:

[20] According to U.S. Energy Information Administration (2018), carbon intensity of renewable diesel is approximately 20 gCO_2e/MJ, whereas ultra-low sulfur diesel, which accounts for most of the diesel supplied in California, has a carbon intensity of 102 gCO_2e/MJ. Under the Low Carbon Fuel Standard program (LCFS), renewable diesel therefore generates a large amount of LCFS credits relative to other fuels (U.S. EIA, 2018).

- [**INSIGHT 7**] While many participating organizations evaluated multiple alternative fuel options and then rejected most of them except one or two fuel(s), a few organizations with large fleets adopted three or more types of alternative fuels.

For the on-site and off-site fueling/charging facilities:

- [**INSIGHT 8**] Electric or hydrogen HDV adopters have built their own on-site stations. Meanwhile, some CNG HDV adopters had an option to use off-site stations when they purchased the CNG vehicles.

For the adoption decisions:

- [**INSIGHT 9**] Perceived technology characteristics, mainly in terms of functional suitability, monetary costs, fuel infrastructures, and reliability/safety of the vehicles and engines, were evaluated in a comprehensive approach for heavy-duty AFV adoption decisions.
- [**INSIGHT 10**] Organizational intrinsic values, such as corporate social responsibility, environmental consciousness regarding diesel HDV emissions, or progressive efforts in demonstrating new technologies, as well as business strategic motives, such as contracts with municipalities, were strong motivators to overcome the major barriers (e.g., financial obstacles, uncertain functionality) to heavy-duty AFV adoption.
- [**INSIGHT 11**] Governmental regulations requiring AFV or ZEV purchases in California, combined with a narrow range of available AFV models, have created constrained fuel choice circumstances toward a certain fuel option for some HDV fleets.
- [**INSIGHT 12**] Financial incentives have assisted HDV fleet alternative fuel adoption by reducing costs for purchasing the vehicles and supporting construction costs of on-site fueling/charging facilities.

For the non-adoption decisions:

- [**INSIGHT 13**] Any unmet criteria found for a heavy-duty AFV, including unsuitable functionality, reliability/safety issues, unacceptable financial costs, or increased operational complexity due to insufficient refueling/charging infrastructures, resulted in non-adoption decisions.
- [**INSIGHT 14**] If an organization has already committed to a specific fuel option, typically with a large investment in fueling/charging facilities, it may reject any other alternative fuel options – except for a few large fleets which desire to diversify fuel options.

- [**INSIGHT 15**] Perception of the commercial unavailability of some AFVs for certain HDV vocations (e.g., electric refuse trucks, hydrogen hauling trucks) was cited as one of the primary reasons for non-adoption decisions.

The findings of this study have many implications for heavy-duty AFV technology improvements and policy suggestions. First, many technological weaknesses of heavy-duty AFVs – which may be vocation-specific or fuel-specific – were identified by the non-adopter participating fleets (e.g., limited range of electric school buses, limited power/payload of electric hauling trucks, maintenance issues of LNG trucks, safety issues of CNG paving trucks, etc.). Such unmet functionality, reliability, and/or safety issues may be based on incorrect or outdated perceptions, and need to either be substantiated and more generally acknowledged, or refuted. In the former case, government policies about AFV adoption may need to be modified to acknowledge the more limited AFV choice sets faced by HDV fleet decision-makers, while at the same time targeted government research and development assistance could be made available to suppliers to overcome such technology issues. In the latter case, misinformed perceptions might be addressed through educational programs targeting fleet managers, as well as the provision of opportunities to use heavy-duty AFVs in a trial.

Financial support from governments should also be continued in order to help alleviate the major barriers of high purchase costs and insufficient fuel infrastructure. Expensive upfront costs were cited as a major obstacle, which negatively affects TCO evaluations. At least until mass production results in more affordable purchase prices, financial incentives will be needed to help offset the incremental costs and help make TCO competitive. Another major barrier, insufficient fueling/charging infrastructure was frequently addressed both in the adoption and the non-adoption decisions across several fuels including natural gas and electricity. Almost all of the adopter organizations interviewed had already built or were planning to build their own on-site fueling/charging facilities, rather than relying on off-site stations. Once organizations have invested in such facilities, they tend not to revert or switch that fuel option to another, at least in the short-term. Therefore, under long-term and stable visions and directions, provision of funding along with technical guidance for constructing on-site fueling/charging facilities could help attract new adopters and secure them in the long term.

Increasing awareness of the advantageous aspects of heavy-duty AFVs would likely lead the other non-adopter segments (i.e., those who passively rejected alternative fuels) to become potential adopters. For example, lower fuel price (e.g., for CNG trucks), fewer maintenance issues (e.g., for electric buses), and improved fuel economy (e.g., for electric and hydrogen buses), can substantially lower TCO of an alternative fuel adoption for certain organizations (e.g., with a large fleet size and a larger vehicle miles traveled). Educational programs designed to enlighten such benefits may then help to initiate the decision-making processes for those passive non-adopters. Some organizations potentially would more readily consider the adoption than others once they recognize the merits of heavy-duty AFVs. The findings regarding organizational characteristics can be used to develop targeted educational programs for certain organizations (e.g., those who are likely to possess CSR, to afford to demonstrate innovative technologies, or to pursue an environmentally-friendly image).

Lastly, regulatory requirements may be a way of increasing alternative fuel penetration rates among those fleet sectors that are too indifferent to the benefits of alternative fuel adoption. Provision of contractual advantages or implementation of contractual requirements for the private fleets that serve public agencies (e.g., school buses, refuse haulers, sweepers) would also lead to enhanced recognition of alternative fuel technologies among those private fleet sectors.

Fuels adopted	CNG																
Organizations Vocations	01 school bus	02 vari-ous	03 vari-ous	04 deliv-ery	05 deliv-ery	06 refuse	07 refuse	08 truck-ing	09 vari-ous	10 vari-ous	11 refuse	12 school bus	13 vari-ous	14 refuse	15 vari-ous	16 vari-ous	17 refuse
• Functional suitability			n	+2		+2	+2	+2	+2	+2		+,-2			+3	+2	+2
• Overall costs (capital & operating costs)			n					+3	+3	+2			n	n	+2	n	
• Vehicle purchase price	-2	-2		-2				-2		-2		-2		n			
• Fuel price	+1			+2	+2		+3	+3	+3	+2				+1			+2
• Maintenance issues	+2							+2				-2			+2	-2	
• Resale value				n													
• Other costs								+2									
• Fuel economy	-2																+1
• Noise level								+2									
• Fuel infrastructure			+2	+2	+2			-3	+2		+2	-2			+1	+,-2	
• Fuel security		-2															
• Stable fuel price					+1												
• Vehicle reliability and safety				+2		+2			+1	+3			n		+2	-2	
• Engine reliability			n	-2		+1											
• Environmental consciousness / CSR	+2			+3				+2	+1	+2		+3	+2	+3	+2		+3
• Sustainability plans within organization													3				+2
• Demonstration of technologies			+2														
• Contract with municipalities						+2	+2	+2			+3	+2		+2			
• Promoting environmental sensitivity	+1													+1		+2	+1
• Attitudes of DMU members				+2				+2							+1	+1	
• Acceptance of vehicle drivers										+2						n	
• Regulations by AQMDs	+3	+3	+2				+2				+3			+3	+3	+2	+2
• Regulations by CARB				n		+2	+2	n		n		n	-2				+2
• Other regulations/ policies			+2									n					
• Financial incentives	+3			+3	+2			+2		+3		+3					+2
• The only available / viable fuel option	+3	+3		+2		+2	+2	+3			+3		+2		+2	+1	+2
• Opportunity to test a vehicle								+2							+1		+1
• Warranty / maintenance provided by manufacturers				n			n			+2							
• Technologies proven in the industry									+2								

[Note] +: positively stated, –: negatively mentioned, +,–: positive or negative influences depending on certain conditions (e.g., vocations and locations for which vehicles are dispatched), 1: implied, 2: explicitly mentioned, 3: emphasized, n: neutrally stated due to some reasons, including inability to identify their influence during the interviews, and relatively minimal impacts on the decisions.

Figure 4-10. Factors Influencing Heavy-duty AFVs Adoption Decisions: Cases of CNG

Fuels adopted	LNG	Propane				Electricity		H2	Renewable diesel			
Organizations vocations	17 refuse	7 refuse	10 vari-ous	12 school bus	14 refuse	10 vari-ous	19 transit bus	20 transit bus	3 vari-ous	10 vari-ous	13 vari-ous	15 vari-ous
• Functional suitability			+2				n	n				
• Overall costs (capital & operating costs)								-2				
• Vehicle purchase price							-2	-2				
• Fuel price							+2	-2		+1		
• Maintenance issues				+2			+2	-2				
• Other costs								+1				
• Fuel economy							+2	+2				
• Noise level					+2							
• Fuel infrastructures	+1		+2				-1	n		+2		
• Additional costs related to fuel infrastructures							-1					
• Fuel system conversion of vehicles									+2			
• Vehicle reliability and safety							n	n				
• Engine reliability												-2
• Fuel storage issues (e.g., battery degradation)							+1					
• Environmental consciousness / CSR				+2	+2		+2					
• Sustainability plans within organization									+2			
• Demonstration of technologies						+3	+3	+3				
• Contract with municipalities		+2		+3								
• Commitment already made to specific fuel option(s)	+2											
• Diversification of fuel option(s)	+2											
• Regulations by AQMDs		+2			+1							
• Regulations by CARB							+3	+3				
• Other regulations / policies							+1					
• Financial incentives				+2			+2	+2				
• The only available / viable fuel option					+2		+2					
• Warranty / maintenance provided by manufacturers								-2				
• California State's direction											+2	

[Note] +: positively stated, –: negatively mentioned, 1: implied, 2: explicitly mentioned, 3: emphasized, n: neutrally stated.

Figure 4-11. Factors Influencing Heavy-duty AFVs Adoption Decisions: LNG, LPG, Electricity, Hydrogen and Renewable Diesel Cases

Fuels rejected	CNG	LNG									Propane				
Organizations / Vocations	18 paving	01 school bus	03 vari-ous	08 truck-ing	09 vari-ous	10 vari-ous	11 refuse	13 vari-ous	15 vari-ous	16 vari-ous	01 school bus	02 vari-ous	03 vari-ous	08 truck-ing	16 vari-ous
• Functional suitability	-3				-2					-2	-2				
• Overall costs (capital & operating costs)			-3			-1			-2						
• Maintenance issues			-3		-2					-1					
• Fuel infrastructure				-2				-1		-2					
• Fuel system conversion of vehicles		-1													
• Vehicle reliability and safety	-2			-2			-2								
• Commitment already made to other fuel option(s)		-2													
• Unavailable / nonviable fuel option									-3		-2	-2	-2	-2	-2

[Note] –: negatively mentioned, 1: implied, 2: explicitly mentioned, 3: emphasized.

Figure 4-12. Factors Influencing Heavy-duty AFV Non-adoption Decisions: CNG, LNG, and LPG Cases

Fuels rejected	Electricity											Hydrogen					
Organizations / Vocations	01 school bus	03 vari-ous	04 deliv-ery	06 refuse	07 refuse	08 truck-ing	09 vari-ous	13 vari-ous	14 refuse	15 vari-ous	16 vari-ous	01 school bus	03 vari-ous	08 truck-ing	12 school bus	15 vari-ous	16 vari-ous
• Functional suitability	-3		-2	-2	-2	-2				-2							
• Vehicle purchase price							-3										-3
• Life cycle-based environmental benefits	-2																
• Fuel infrastructure							-1										
• Additional costs related to fuel infrastructure	-3					-2											
• Charging time when power blackout occurs	-2																
• Fuel storage issues (e.g., battery degradation)	-2																
• Commitment already made to other fuel option(s)	-3																
• Regulations by AQMDs											-2						
• Unavailable / nonviable fuel option		-1	-2		-2	-2	-1	-2	-2		-2	-3	-2	-3	-2	-2	

[Note] –: negatively mentioned, 1: implied, 2: explicitly mentioned, 3: emphasized.

Figure 4-13. Factors Influencing Heavy-duty AFV Non-adoption Decisions: Electricity and Hydrogen

Fuels rejected	E85		Biodiesel							
Organizations Vocations	07 refuse	16 various	07 refuse	08 trucking	09 various	10 various	12 school bus	13 various	15 various	16 various
• Fuel price	-2									
• Uncertain environmental benefits	-2									
• Unstable fuel price	-2									
• Vehicle reliability and safety										-2
• Engine reliability				-3						
• Other unspecified reasons						-2	-1	-2	-2	
• Regulations by AQMDs			-2							
• Unavailable / nonviable fuel option		-2			-1		-2			

[Note] –: negatively mentioned, 1: implied, 2: explicitly mentioned, 3: emphasized

Figure 4-14. Factors Influencing Heavy-duty AFV Non-adoption Decisions: E85 and Biodiesel

Acknowledgements

Bae, Youngeun, Mitra, Suman K. Rindt, Craig R., and Ritchie, Stephen G. “Factors Influencing Alternative Fuel Adoption Decisions in Heavy-duty Vehicle Fleets in California.” *The 99th Annual Meeting of the Transportation Research Board.* Washington, D.C., Jan 2020. Poster presentation.

Bae, Youngeun, Mitra, Suman K., Rindt, Craig R., and Ritchie, Stephen G. “Factors Influencing Alternative Fuel Adoption Decisions in Heavy-duty Vehicle Fleets.” *Transportation Research Part D. Transport and Environment*, Under review.

4.5. Other Facilitators: Technology Suppliers and Social Influences

Support provided by technology suppliers, such as vehicle/engine manufacturers and fuel providers, as well as social influences through interpersonal networks or social norm could facilitate the decision process of heavy-duty AFV adoption, not only including *Adoption Decision* stage but also *Consideration* and *Implementation* stages. In that regard, two relevant questions were asked during the interview regarding such facilitating influences:

- **Q8 (Adoption supporting/facilitating efforts)**: "Were there any educational training programs that your organization received from AFV manufacturers or fuel providers? If so, what kinds of educational programs did you receive? Were there any driver training programs that were provided to your vehicle drivers?"
- **Q11 (Recommendation received)**: "Have you ever received any recommendations or feedback from other fleet operators about the purchase of [the AFVs adopted]? If so, what recommendations or feedback did you receive?" (one of the questions in Q11)

The answers to these two questions were analyzed using thematic analysis. A summary of the responses are presented in Table 4-9. Based on the discussions between the participating researchers, the qualitative insights were identified as below.

4.5.1. Results

1) Technology Supplier Support

Opportunities to test a heavy-duty AFV – Several organizations, across both new and existing CNG adopters, tested heavy-duty AFVs over a period (e.g., six months) in order to "*have the drivers do some operation and give us feedback*" (Org. 15), "*to get some real-life data and feedback before we went ahead with the rest of the purchases*" (Org. 4), and to make sure "*not to have issues that we had before*" (Org. 17). Trying the vehicles, particularly for new adopters, can provide the opportunity to apparently realize advantageous aspects of the technology: "*we go and rent one and try it out pulling and pulling other things, and these trucks are outperforming some of our diesel trucks. And now you start seeing the benefits behind them as well, it starts opening eyes*" (Org. 8).

Warranty/maintenance services – A warranty, "*product support after the sale*", was addressed as one of the important considerations for the purchase decisions. One stated, "*Do they have any areas, many of the companies have field service technicians that are actually out in the field? They come to the site, work with our mechanics, do repairs. That allows us to keep the trucks on the road every day*" (Org. 7). The warranty provided by manufacturers should the support to ensure *vehicle safety and reliability* which is one of the important factors mentioned by more than a third of the participants: "*We are never going to purchase a vehicle where we are dependent upon a dealer or a manufacturer that's not locally based to maintain it, and to support it*" (Org. 10).

Educational training programs – A majority of the participating organizations received educational trainings from manufacturers and/or fuel providers (11 out of 17

CNG adopters), provided those trainings in-house (5 out of 17), or received from other institutes (2 out or 17). The trainings were provided to technicians with the focus on "*operation, repair, refueling, and other practices*" (Org. 3), offered to both mechanics and vehicle drivers for the "*maintenance (e.g., CNG tank inspections) and repair*" (Org. 7), or aimed to educate fleet managers as well as technicians about "*the fuel systems*" (e.g., inspections of tanks and cylinders) (Org. 4). Even if some of the AFV adopters did not receive any educational trainings from technology suppliers, the fleet operators tried to provide it in-house (e.g., Org. 17). These observations indicate that educational trainings play an essential role for those individuals who use, maintain, or repair a heavy-duty AFV within an organization, to implement those "*new assets*". One fleet operator emphasized the importance of those training, "*I actually asked manufacturers that my guy needs training. I want you to send somebody here [...] The education part is really big. That's really important to be able to have education and ability to repair your own vehicles*" (Org. 1).

Driver training – Many CNG adopters (12 out of 17) provided trainings to vehicle drivers with the support of the manufacturers and/or in-house. In driver trainings, an emphasis was typically placed on "*how to operate the truck safely*" because the drivers operate the "*heavy vehicles in neighborhoods, around schools, often with heavy traffic*" (Org. 7). Also, the drivers were trained "*how to use fast-fuel stations*" and "*how to report problems if there are any*" (Org. 7). One fleet operator stated they developed the training program with the help of the fuel providers and manufacturers: "*we went over all the things we need to train the drivers on, from a technical perspective, what to do if you smell gas, what to shut off, how to fuel*" (Org. 9). In case the fleets did not receive driver trainings from manufacturers, some fleet operators developed those training in-house (e.g., Org. 4 and 14).

Meanwhile, additional benefit gained from the driver trainings was turned out to increase acceptance of drivers toward heavy-duty AFV adoption. One fleet operator described, "*All that training had to be done. [...] I would say the vehicle drivers are more interested in getting CNG vehicles than they were when we first brought them onboard*" (Org. 9). Another also mentioned, "*After they were educated how to operate the vehicles, the initial concerns (natural human apprehensiveness regarding some something new/different) went away very quickly*" (Org. 16).

Table 4-9. Technology Supplier Support and Social Influences on Adoption Decisions

Organization (vocation)	**Technology Supplier Support**				**Social Influences**	
	Testing vehicles [(a)]	**Warranty/ maintenance** [(a)]	**Educational training for mechanics / technicians**	**Driver training**	**Interpersonal channels** [(b)]	**Social norm**
Org. 01 (school bus)			Received			
Org. 02 (various)			Will provide in-house			
Org. 03 (various)			Received	Received	Yes (Neutral, CNG)	Positive, CNG/ Negative, LNG
Org. 04 (delivery)	Facilitator	Factor	Received	Provided in-house	Yes (Neutral, CNG)	
Org. 05 (delivery)			Received from other institutes	Provided in-house	No	
Org. 06 (refuse)			Received	Received	Yes (Positive, CNG)	
Org. 07 (refuse)		Factor	Received	Received	No	
Org. 08 (trucking)	Facilitator		Provided in-house	No	Yes (Negative, LNG)	
Org. 09 (various)				Provided in-house w/help of suppliers	Yes (Neutral, CNG)	Negative, LNG
Org. 10 (various)		Facilitator	Received	Received	Yes (Neutral, CNG)	
Org. 11 (refuse)			Received from other institutes	No	Yes (Neutral, CNG)	Negative, LNG
Org. 12 (school bus)			Received; Also provided in-house	Provided in-house	No	

Organization (vocation)	**Technology Supplier Support**				**Social Influences**	
	Testing vehicles [(a)]	**Warranty/ maintenance** [(a)]	**Educational training for mechanics / technicians**	**Driver training**	**Interpersonal channels** [(b)]	**Social norm**
Org. 13 (various)			No	No	No	
Org. 14 (refuse)			Received	Provided in-house	No	
Org. 15 (various)	Facilitator		Received; Also provided in-house	Received or Provided in-house	Yes (Neutral, CNG)	
Org. 16 (various)			Received	Received	Yes (Neutral, CNG)	
Org. 17 (refuse)	Facilitator		Received; Also provided in-house	Provided in-house	Yes (Neutral, CNG)	
Org. 18 (paving)						Negative, CNG

[Note] (a) The data regarding "testing a vehicle" and "warranty/maintenance" presented in this table were re-collected from the answer from Q3 (decision-making process) and Q4 (influencing factors). "Facilitators" denote that the corresponding support was positively addressed, and "Factors" were neutrally mentioned. (b) An example of the interpersonal channels is whether they received feedback on AFV operations from other fleet operators.

2) Social Influences

Feedback from other adopter fleets – Many organizations (10 out of 18) stated that they received feedback or opinions from other fleet operators who already adopted heavy-duty natural gas vehicles. Those experiences shared by other adopters helped facilitate the Consideration stage of the decision-making process. One fleet operator described, "*Our engineers visited municipalities, [...], and private haulers, and got some feedback about CNG use in general. [...] They've been extremely helpful. We visited their maintenance facility. We looked at the configuration of their CNG gas detection system. We had maintenance staff talk to their maintenance staff about the differences between maintaining a diesel truck versus a CNG truck. I mean their help has been enormous in this process*" (Org. 9). While almost all of the feedback received from others tended to be neutral on a basis of sharing information, one received negative opinions on LNG vehicles: "*I've spoken with a lot of people that have had LNG trucks. [...] But for some reason they're having issues with [...] not being able to fill their tanks completely, things like that*" (Org. 8).

Meanwhile, some fleet operators, particularly in the industry, tended to be intentionally inactive in sharing information with other fleet operators, stating that they "*not care about anybody else's opinion*" (Org. 14) or "*not interact too much with competitors*" (Org. 12). One fleet operator explained, "*Being in the waste business, we're very competitive. [...] We don't have a lot of sharing we do. [...] if we do have something that gives us an advantage, we're likely not to be too quick to let everybody else know. [...] I think sometimes we tend to keep things to ourselves a little more than we probably should*" (Org. 7).

Social norm – For several organizations, the intent to conform with a social norm (e.g., perception about whether a specific technology option is proven and accepted among referent social groups) has affected their decisions, both for adoption and non-adoption decisions. One CNG non-adopter explained, "*I couldn't find a paving company that already had them. [...] That's kind of like a big indicator for us that it's not suited for our industry*" (Org. 18). One organization, that had operated LNG vehicles, but retired them, also stated, "*we kind of retired all those assets [LNG vehicles] over the last five plus years and, yeah, we're definitely seeing a direction where less people are using LNG and more people going to CNG*" (Org. 3). Another further elaborated, "*Because many of our local, private refuse collection companies [...], all had a similar configuration. It was very easy to sell it to decision makers. This is what EDCO is doing. This is what Waste Management is doing. This is what the industry is doing. The industry in general was not doing LNG*" (Org. 9).

4.5.2. Summary and Recommendations

In this chapter, it was explored how technology suppliers and social influences have facilitated the decision process, not only the *Adoption Decision* stage but the *Consideration* and *Implementation* stages. The findings are summarized as follows:

- [**INSIGHT 16**] Opportunities to test a heavy-duty AFV and warranty/maintenance services provided by vehicle and engine manufacturers would positively affect the process of decision-making, particularly the Consideration and Adoption Decision stages.
- [**INSIGHT 17**] Educational training programs provided by vehicle/engine manufacturers, fuel providers or other institutes have essentially helped the Implementation stage right after heavy-duty AFV adoptions.

- [**INSIGHT 18**] Though driver trainings tended to be provided in a less extensive way than technicians / mechanics trainings, drivers would become not only better aware of how to use the vehicles but more acceptable toward the vehicle adoption, with the support of the trainings.
- [**INSIGHT 19**] Social Networks can affect heavy-duty AFV purchase decisions in a way of obtaining feedback from other fleet operators who already have experiences in operating the vehicles and/or of following a social norm prevalent in the industry.
- [**INSIGHT 20**] Some fleet operators, particularly in an industry, would be intentionally inactive in sharing information with other fleet operators – potential competitors – regarding heavy-duty AFVs.

Based on these insights, several recommendations, in addition to the ones previously addressed in Chapter 4.3, are be suggested:

- Provision of opportunities to test a heavy-duty AFV to potential adopters
- Provision of a sufficient period of warranty and maintenance services for heavy-duty AFVs for potential adopters and new adopters
- Educational training programs for adopter fleets to facilitate the implementation of the vehicle operations
- Educational training for vehicle drivers to increase their acceptance towards AFVs, and to help their safe operation of vehicles and fueling practice
- Targeted pilot testing (and encouragement of early adoption) of heavy-duty AFVs for "big and well-known companies" and active promotion of those companies to other non-adopter fleets
- Networking events to facilitate information exchange between adopters and potential adopters regarding heavy-duty AFV operations

- Targeted education for key decision-makers in entrenched, risk-adverse fleets to increase their awareness of alternative fuel options

4.6. Satisfaction about Heavy-duty CNGVs and Driver Feedback

Once a DMU in an organization decides to adopt AFV(s), they implement the operations of the vehicle(s) to make them serve the fleet operational duties. In this *Implementation* stage, the DMU would evaluate the AFV operations from various aspects and would seek to obtain feedback from individuals (e.g., vehicle drivers), within the organization. This Chapter explores how the DMU would evaluate AFV operations, what feedback they would receive from vehicle drivers, and how they would manage such end user acceptance. Since a majority of the participating organizations were CNG adopters, the analysis of this Chapter is focused on those 17 CNG adopter cases. The relevant interview questions are:

- **Q7 (Satisfaction about AFV operations)**: "Given your experiences with the heavy-duty CNG vehicles, how satisfied or dissatisfied are you with the vehicles? Can you explain why you are satisfied/dissatisfied?"
- **Q8 (Driver feedback)**: "Have you ever received any feedback from the vehicle drivers about CNGV operations? If so, what feedback did you receive?" (one of the questions in Q8)

The answers from Q7 were analyzed using content analysis. A quantitative portion of the analysis results is presented in Figure 4-15, with the existence of each category (i.e., specific reasons for dis/satisfaction), its sign (i.e., "+" being positively stated, "–" being negatively stated), and its strength (i.e., "1" being implied or indirectly stated, "2" explicitly mentioned, and "3" emphasized as overarching reasons). For the "overall satisfaction," each sign and strength indicate the following meanings: "+3" being very satisfied overall, "+2" satisfied, "+1" somewhat satisfied, "n" neither satisfied nor dissatisfied, "−1" somewhat dissatisfied, "−2" dissatisfied, and "−3" very dissatisfied. Through a series of discussion between the researchers, both quantitative and qualitative analyses were agreed and verified. In addition, the thematic analysis was used to analyze the answers regarding the driver feedback (Q8)[21], based on which a summary table was presented in Figure 4-16. Subsequently, qualitative insights were identified after discussions between the participating researchers.

4.6.1. Results

1) Satisfaction on Heavy-duty CNVGs

Main strengths of heavy-duty CNGVs: engine reliability, environmental benefits, and low noise levels – More than two thirds of the CNG adopters (12 out of 17) expressed the highest level of satisfaction (i.e., "+3") about the CNGV operations and several adopters (3 out of 17) presented a moderate level of satisfaction (i.e., "+2"). One stated, "*If I had to put it between a one and a 10, right now, I'm at a 10*" (Org. 4). Among various advantages of the heavy-duty CNGVs, the strengths that were consistently addressed as positive aspects, were: engine reliability (7 out of 17), environmental benefits (5 out of 17), and a low noise level (3 out of 17). Regarding CNG engine reliability, fleet managers stated, "*the Cummins ISL G is totally reliable*" (Org. 10); "*we have had almost no down time with the any of these CNG engines*" (Org. 2); and "*the engine certainly improved*

[21] Only in the cases where the interviewees have received any feedback from vehicle drivers, and could recall the feedback during the interviews, the data was able to be collected.

after 2007 with a lot of components that were vastly improved from Cummins' side" (Org. 11). Lower level of tailpipe emissions (e.g., in terms of NOx and PM) were also addressed as another major satisfactory aspect: "*We're not emitting the emissions that we were with diesel. So it's a feel-good from an environmental perspective as well*" (Org. 6). In addition, a lower noise level was regarded as additional strength of CNGVs: "*One of the biggest strengths, for us, is the noise. It's the quiet operation of the CNG engine. All diesel Vactors that are screaming away on a cul-de-sac in the middle of the day or at middle of night in an emergency repair. [...] In an emergency repair, these new machines are just so quiet. That's the strong suit*" (Org. 2).

Other strengths of heavy-duty CNGVs: promoting environmental sensitivity, contractual advantage, complying with regulations, and lowered insurance costs – A few CNG adopters stated they are satisfied with that they can "*promote our Green Status*" because they "*fuel the vehicles with clean burning CNG*" (Org. 5). Furthermore, for some private fleet operators, CNG adoption helped them obtain or extend a contract with municipalities in a competitive market. One fleet operator explained, "*we're proud that we're able to get extensions on our contracts based upon deploying CNG trucks. [...] It gives us a good track record and a good bidding position, if you will, as we chase new business*" (Org. 6). Also, in case an organization is subject to any regulations requiring AFV operation, adopting CNGV(s) can provide an apparent benefit of *"regulatory compliance*" (Org. 16). In addition, one organization stated that "*getting a discount on our insurance for natural gas trucks*" was additional satisfactory aspect (Org. 8).

Weakness of heavy-duty CNGVs: high purchase costs, potential performance/ maintenance issues, and shorter engine longevity than diesel vehicles – A higher vehicle purchase cost than a diesel vehicle is an obvious weakness of CNGVs, which was commonly mentioned by several CNG adopters: "*The only negative was a CNG-powered truck cost more than diesel-powered truck*" (Org. 6). Another common weakness was addressed as a potential problem in terms of their performance or maintenance issues. Such potential problems include a cold start issue (e.g., "*when it's cold out, it will not start out*" (Org. 1)) and a possibility of "*being underpowered when traveling highway grades*" (Org. 16). In that regard, a few fleet managers highlighted that they were on the learning curve and had to pay attention to any such latent issues: "*I would say my biggest concern right now is on the learning curve of our shop technicians. And a little bit further down the road when we do begin to experience maybe drivability issues or performance issues with the vehicle*" (Org. 4). Another also elaborated, "*they [CNGVs] are not perfect. And they've got a lot more moving parts on them than a diesel engine. And you have to be watching. You have to be paying attention to what it is and the trends that you're seeing [...]*" (Org. 7). Lastly, one organization mentioned a shorter longevity of CNG engine as additional weakness (Org. 17).

Organizations (vocations)	01 school bus	02 vari-ous	03 vari-ous	04 deliv-ery	05 deliv-ery	06 refuse	07 refuse	08 truck-ing	09 vari-ous	10 vari-ous	11 refuse	12 school bus	13 vari-ous	14 refuse	15 vari-ous	16 vari-ous	17 refuse
Fleet characteristics (a)	Pb M On-site	Pb M (On-site)	Pb L On-site	M (On-site) <15 NGV New	M On-site	L On-site	L On-site other AFV	S (On-site) <15 NGV New	Pb L On-site other AFV	Pb L On-site ELEC On-site other AFV	M (On-site)	L n/a other AFV New	Pb L On-site	L On-site other AFV	Pb L On-site other AFV	Pb L <15 NGV	Pb L On-site
• Overall satisfaction	+3 (b)	+3	+2	+3	+3	+3	n	+3	+2	+3	+3	+3	+1	+3	+3	+3	+2
• Functional suitability		+2	-2	+2					-3	+2		+,-2			n	+2	
• Vehicle purchase price	-2					-2	-2										
• Fuel price	+2	-2		-2		+2	+2	+3	+2	+2				+1	+2		
• Overall fuel economy (c)									+1								
• Maintenance issues	+2	-2					-2	+2				+2			+2		
• Resale value						-1		+1									
• Other costs (e.g., insurance)								+2									
• Noise level		+3						+2			+2						
• Environmental benefits						+2				+1	+2				+2	+2	
• Vehicle reliability and safety	+2			-2		-2		+2	-1		+2	+2				+,-2	
• Engine reliability	+2	+2				+2	+2	+2		+2	+2						
• Engine longevity																	-2
• Potential performance/ maintenance issues	-2			-2			-2		-1							-1	
• Contract w/ municipalities						+2	+2										
• Promoting environmental sensitivity					+2						+2						
• Acceptance of users (drivers)																+1	
• Regulatory compliance											+1					+2	
• Policy about increased payload								+2									
• Past issue (e.g., functionality, maintenance issues)							-2				-1						

[Note] (a) Symbols represent specific fleet characteristics. "Pb": public entities (c.f., private entities, otherwise unmentioned), "L": large fleet size (>100 vehicles), "M": medium size (20-100), "S": small size (≤ 20), "On-site": has their own on-site CNG station(s) (c.f., use off-site CNG stations, otherwise unmentioned), "(On-site)": will build their own on-site CNG stations, although they currently rely only on off-site station(s), "n/a": information about CNG fueling stations unavailable, "<15 NGVs": the total number of NGVs, including both those are being currently operated and those to be expanded in the near future, will less than 15, and "New": the year of the first heavy-duty AFV purchased was after 2015. (b) +: positively stated, –: negatively mentioned, 1: implied, 2: explicitly mentioned, 3: emphasized. (c) Overall fuel economy by considering fuel efficiency per unit volume and CNG storage.

Figure 4-15. Satisfaction about Heavy-duty CNGVs

The strengths and weaknesses of heavy-duty CNGVs above mentioned were consistently addressed by the CNGV adopters. However, other aspects of CNGVs operations were evaluated either favorably or unfavorably, depending on many other factors, including: vehicle application areas, types of fueling facilities being used, accumulated experiences with the CNGVs adopted, model years of the vehicles, and personal perception about the technologies. Such mixed dis/satisfactory aspects of CNGVs are discussed as follows.

Mixed evaluations of functional suitability of heavy-duty CNGVs depending on vehicle application areas, operational routes, and locations – Several CNG adopters explained that their specific application areas fit in with the CNGVs, for example, "*internal pickup and delivery activities*" (Org. 16), "*vocational trucks those are parked"* during a major portion of its job cycle of 10 to 12 hour – which does not cause a range issue (Org. 2) –, and operations in the area where "*we don't have quite the hilly terrain*" (Org. 12). In contrast, some organizations provided negative remarks on CNGV functional suitability. One fleet manager expressed a concern regarding additional weight and possible visibility issues created by CNG tanks (Org. 3). Regarding a driving range of CNGVs, one stated that "*they [CNGVs] can't meet range requirements [for a specific route]. It requires them to buy fuel from a private station which is essentially double the cost of what we can pump it for*" (Org. 9). Another also mentioned, they are "*not usually inclined to use a CNG-powered bus on a commercial charter trip*" because "*those trips are longer and sometimes they can even cross a state line - from California to Nevada or et cetera*" where there is "*the fueling limitations for a CNG-powered bus*" (Org. 12).

Mixed evaluations of reliability and safety of heavy-duty CNGVs – While several organizations addressed positive remarks on CNGV reliability and safety (e.g., Org. 1, 11, and 12), some fleet operators expressed their safety concerns regarding CNGVs because they should be "*working with pressure and flammable gas*" (Org. 4) and "*CNG's explosive while Diesel's not necessarily; and CNG's a gas that you can inhale*" (Org. 6). One fleet manager further described, "*I would say as a potential negative is the nature of our [refuse collection] vehicles [...] if they are unable to dump their final load of trash by the end of the day [...] there's always the possibility of a combustible being inside of the vehicle. [...] that's a slight negative*" (Org. 9). In that regard, the other organization addressed that they "*may have safety concerns for certain activities (e.g., welding on CNG utility trucks)* while their "*CNG vehicles work very well under proper application, proper routes and proper operations*" (Org. 16).

Mixed evaluations of CNG fuel prices depending on refueling facilities – Fleet operators who owned their on-site fueling facilities tended to perceive CNG prices as cheaper than diesel: "*the fuel costs are obviously significantly lower. So that's good for our budget analysis*" (Org. 9). In contrast, negative remarks on CNG prices came from those who were using off-site stations. One fleet operator stated, "*It [CNG price] is not cheap. The whole calculus will be different if I was pumping my own*" (Org. 2). Another also addressed differences in CNG prices offered from different off-site stations, "*[...] This particular station. The owner of the station seems to know and keep their finger on the pulse of what diesel sells for, and that's what they sell it for. [...]*" (Org. 4). Further detailed analysis will be provided in the next Chapter 4.7 regarding CNG refueling behavior and the fleet operators' satisfaction on the facilities.

Mixed evaluations of CNGV maintenance costs – Several organizations satisfied with CNGV maintenance costs. For example, one school bus operator explained, "*[The CNG buses required] least maintenance, you know. We change oil once a year so there's a little bit less as far as that cost goes in maintenance. As far as the engine goes, we have a very good luck with them so far*" (Org. 1). Similarly, one public organization stated, "*I think there's a savings in maintenance cost, as the fuel is generally cleaner and the engine therefore runs cleaner and has less issues*." (Org. 15). In contrast, a few fleet managers stated that their CNGVs require more maintenance than they expected. One public fleet operator described, "*They advertise a lot lower maintenance costs, my maintenance costs really are not lowered [...]*" (Org. 2). Another refuse truck operator explained, "*We do a lot of preemptive preventative maintenance in between maintenance cycles beyond the manufacturer's requirements because we can't have our trucks down*" (Org. 7).

Mixed evaluations of resale opportunity of heavy-duty CNGVs – Only a few CNG adopters addressed resale opportunity of heavy-duty CNGVs. One freight trucking company implied a positive opinion on the resale market for heavy-duty CNGVs: "*Fortunately now we can take 2010 and newer compliant trucks and trade those in or find somebody that's got an older truck [...] So, that's one thing that's helped us out now […]*" (Org. 8). However, one refuse truck operator addressed that, from the viewpoint of a seller, there are limited recipients who can take their old CNG trucks: "*And I'd have to say this. Other than California, you're not really seeing CNG in our fleet. So, as we move trucks around the system, there's only a certain set of recipients that can take these 10-year-old CNG trucks and continue to use them. […] There's limited potential homes for them. If that's a detriment, which is a small one, but a detriment nonetheless*" (Org. 6).

Organizations (vocations)	01 school bus	02 vari-ous	03 vari-ous	04 deliv-ery	05 deliv-ery	06 refuse	07 refuse	08 truck-ing	09 vari-ous	10 vari-ous	11 refuse	12 school bus	13 vari-ous	14 refuse	15 vari-ous	16 vari-ous	17 refuse
Fleet characteristics (a)	Pb, M, On-site	Pb, M, (On-site)	Pb, L, On-site	M, (On-site), <15 NGV, New	M, On-site	L, On-site	L, On-site, other AFV	S, (On-site), <15 NGV, New	Pb, L, On-site, other AFV	Pb, L, On-site, ELEC On-site, other AFV	M, (On-site)	L, n/a, other AFV, New	Pb, L, On-site	L, On-site, other AFV	Pb, L, On-site, other AFV	Pb, L, <15 NGV	Pb, L, On-site
• Performance equivalent to a diesel vehicle			X[b]	X	X		X										
• Lower noise							X	X									
• Fueling convenience					X				X	X							
• Overall positive feedback										X	X		X				
• Safety concern				X													(X)
• Performance issues with power or speed				X*			(X)		X								
• Range issue			X*	X					X								
• Difficulty to find off-site stations												X					
• On-site facilities-related issues (c)	(X)									X			X				
• Effort needed to learn CNGV operations						X		X									
• Drivers' acceptance became favorable							X	X	X						X	X	X

[Note] (a): Symbols represent specific fleet characteristic: "Pb": public entities (c.f., private entities, otherwise unmentioned), "L": large fleet size (>100 vehicles), "M": medium fleet size (20-100), "S": small fleet size (≤ 20), "On-site": has their own on-site CNG station(s) (c.f., use off-site CNG stations, otherwise unmentioned), "(On-site)": will build their own on-site CNG stations, although they currently rely only on off-site station(s), "n/a": information about CNG fueling stations unavailable, "<15 NGVs": the total number of NGVs, including both those are being currently operated and those to be expanded in the near future, will less than 15 NGVs, and "New": the year of the first heavy-duty AFV purchased was after 2015. (b) X: the feedback by drivers was received by fleet operators (X): the feedback was received but is currently not an issue. X*: driver feedback was received but found it unsubstantiated. (c) For example, insufficient number of dispensers, and inconvenience when facilities are temporality suspended.

Figure 4-16. Vehicle Drivers' Feedback on Heavy-duty CNGVs

2) Vehicle Driver Feedback on Heavy-duty CNGVs

Fleet operators have experienced in hearing various feedback from their heavy-duty CNGV drivers – In many participating organizations (15 out of 17), fleet operators heard and collected their drivers' opinions on CNGV operations. Those feedback from vehicle drivers tended to be a mix of positive and negative opinions rather than utterly positive or negative, which is summarized in Figure 4-16. Of various feedback from the drivers, some opinions recurred from the dis/satisfactions on CNGVs addressed by the fleet operators themselves, of which examples included satisfactory vehicle performance, lower noise, safety concern, and a range issue. For example, one organization mentioned, "*They [drivers] are happy with CNG. No real loss of power*" (Org. 5). With respect to a lower noise level, a few organizations highlighted it as a satisfactory aspect perceived by their drivers: "*We've noticed a big difference in driver fatigue while driving natural gas vehicles versus driving your conventional diesel trucks, because you don't have the noise fatigue that comes along with a diesel truck. [...] This is what I'm getting reported back from my drivers*" (Org. 8). At the same time, one fleet operator reported safety concerns possessed by drivers, which affected their willingness to drive a CNGV: "*Sometimes there's some trepidation by drivers in thinking, is this safe? You've got this high-pressure flammable gas. So, I have seen that affect drivers' willingness to participate [...]"* (Org. 4). Another fleet operator explained a weird perception, possessed by the drivers, regarding a leak of CNG overnight, which created a range concern on CNGVs (Org. 3). At the same time, the range issue was sometimes reported by drivers who drive a specific route: "*[For] longer routes, they [drivers] don't see the same range that they do with the diesel trucks, so they begin running out of fuel quicker*" (Org. 9). For such negative feedback, fleet managers would tend to withhold judgement until they are substantiated. For example, one fleet manager stated that they heard about a power issue which made a driver unable to drive a certain speed. However, after the performance comparison between CNGV and a diesel truck by *"tracking* *the speeds using telematics on that certain route*," they found the claim unsubstantiated (Org. 4). In the cases of unsubstantiated, negative feedback or any hesitation in using a CNGV, fleet managers would put their efforts to increase driver acceptance toward CNGVs by persuading them or providing education.

Detailed feedback on CNGVs by drivers: vehicle performance, refueling dis/advantages, and learning effort for new technologies – Drivers, as end users, tended to provide more detailed feedback on the vehicle use than those by fleet managers, including vehicle performance in a specific driving condition and convenience of using refueling facilities. For example, some organizations with on-site fueling facilities cited their drivers' satisfaction in terms of fueling convenience. One stated, "*They [drivers] plug in at the end of their route and leave for the day, so the fact that they fuel overnight I know is beneficial. It saves a little bit of time*" (Org. 9). However, in case using off-site stations, a negative feedback reported from drivers is regarding a lack of fueling stations: "*I have heard feedback that sometimes it is very difficult to find CNG or propane fuel at certain sites. And so that's why they try to avoid the longer trips*" (Org. 12). Meanwhile, since the use of CNGVs can be perceived new and unaccustomed by vehicle drivers, some fleet operators highlighted that effort should be needed to learn CNGV operation. One explained, "*For them [drivers], probably the most difficult part was knowing how much CNG fuel was in their trucks and how much of their route they could run. That was their big learning curve, really, quite honestly*" (Org. 6). Another also elaborated, "*Because a diesel engine is combustion, whereas a CNG engine is ignition. So, with a CNG engine, you're not getting that back pressure to where you can use an exhaust brake and come down a hill or slow down a heavy load faster. Your* *drivers have to learn how to utilize the transmission and downshift to different points and things like that. That's my biggest issue with the CNG engines*" (Org. 8).

Drivers became favorable toward CNGVs after having operational experiences and/or receiving educational trainings – More than a third of CNG adopters (6 out of 17) addressed that their drivers initially had various negative concepts towards CNGVs. Fleet operators cited, "*[When] we're putting them [drivers] in natural gas, they weren't real happy*" (Org. 7); "*At first, the users [drivers] were apprehensive about CNG operations*" (Org. 16). Those unfavorable attitudes were attributed to various reasons, including the fact that their drivers were accustomed only to diesel vehicles (Org. 7); any negative postulations created by past unsuccessful experiences in other alternative fuels (Org. 9); past drawbacks of CNGs (Org.15); natural human apprehensiveness for something new and different (Org. 16); and any other misconceptions along with safety concerns (Org. 8 and 17). As an example, one explained, "*There's a lot of misconceptions about natural gas vehicles, especially when you start talking to drivers. They think they're driving around a giant bomb and there's just a whole lot of rumors about the trucks that aren't actually true*" (Org. 8).[22] However, the participating organizations stated that driver acceptance toward CNGVs became favorable as they experienced in driving the vehicles. One described, "*What we found, once we get a driver in these trucks, […] they realize, you know what? No, this isn't*

[22] Other relevant quotations regarding drivers' initial unfavorable perceptions include: "*for those drivers that had been here a number of years and dealt with the diesel LNG fueled vehicles, it was a very negative connotation associated with any sort of AFV*" (Org. 9); "*CNG has a reputation from 15-20 years ago when some of the conversions were not good and parts were not available and they seemed underpowered compared to the diesel version and so forth. So, there's a lot of folks that have been around since then and that's what they remember and that's their expectation with a CNG vehicle today*" (Org. 15); "*they [drivers] believe that, you know, the natural gas vehicle unsafe to operate*" (Org. 17).

what I've been told by another driver or whatever it may be" (Org. 8). Furthermore, educational training was addressed by several organizations as a means of alleviating drivers' concerns and improving their knowledge on the vehicles. One organization explained, "*To ease the [driver] concerns, we brought in the expertise from the industry, […] Also, we would make sure that any issue that they encounter during the operation of the vehicles will be immediately conveyed to us, and we will - working with the engine manufacturer as well as other natural gas industry to address the issue […]*" (Org. 17). After putting such efforts, some fleet operators found that "*drivers are more interested in getting CNG vehicles than they were when we first brought them onboard*" (Org. 9) and the use of CNGVs "*just becomes the norm*" for drivers (Org. 7).

4.6.2. Summary and Recommendations

This chapter explored how heavy-duty AFVs would be evaluated in the *Implementation* stage, based on heavy-duty CNG adopter cases. Specifically, this work investigated how satisfied the participating organizations were with the heavy-duty CNGVs, whether they received feedback from their vehicle drivers, if they received, what feedback were reported, and how they handled driver acceptance towards the new technologies. The main qualitative insights obtained in this work are summarized as follows.

For the satisfaction on heavy-duty CNVGs:

- **[INSIGHT 21]** Almost all of the CNG adopters were satisfied with the vehicle operations. Main strengths of the heavy-duty CNGVs, which were commonly and consistently addressed, included CNG engine reliability, environmental benefits, and low noise levels.

- **[INSIGHT 22]** Other strengths of the heavy-duty CNGVs were addressed by a few of the fleet operators, including: being able to promote environmental sensitivity, to obtain a contract with public entities, to easily comply with regulations, and to benefit from any discount offers (e.g., lowered insurance costs).
- **[INSIGHT 23]** Several weaknesses of CNGVs were addressed by one to five CNG adopters, including: high purchase costs, potential performance/maintenance issues, and shorter engine longevity than diesel vehicles.
- **[INSIGHT 24]** The functional suitability of heavy-duty CNGVs was either favorably or unfavorably evaluated depending on a vehicle application area with its own performance requirements (e.g., in terms of driving range, maximum power, speed, and payload) and its operational routes and locations.
- **[INSIGHT 25]** Depending on a fleet operator's perception and experiences about the technologies, some CNG adopters stated that they were satisfied with the CNGVs' reliability and safety while some expressed their concerns on working with the flammable or explosive gas.
- **[INSIGHT 26]** Many fleet operators with their own on-site CNG refueling facilities stated that they were satisfied with CNG fuel prices; in contrast, others relying on off-site stations tended to be dissatisfied with the fuel prices.
- **[INSIGHT 27]** Some organizations favorably stated CNGV maintenance costs, while a few others addressed that their CNGVs have required more maintenance than they expected.
- **[INSIGHT 28]** A resale opportunity of heavy-duty CNGVs was either positively or negatively addressed by a few CNG adopters, of which different opinions would depend on their experiences with the resale market for a specific vocational area.

For the vehicle driver feedback on heavy-duty CNGVs:

- **[INSIGHT 29]** Across almost all of the participating organizations that adopted CNGVs, fleet managers have experienced in hearing various feedback from the CNGV drivers on use of the vehicles – whether it is positive, negative, or both –, and some of which would affect fleet managers' evaluation on CNGVs.

- **[INSIGHT 30]** As end-users, drivers' feedback on CNGVs contain detailed aspects of the vehicle use, including perceived vehicle performance, refueling dis/advantages, and learning effort for such new technologies.
- **[INSIGHT 31]** Many CNG adopters reported a change of drivers' acceptance toward the vehicles: they initially had negative perceptions but became favorable after having operational experiences and/or receiving educational trainings.

Based on these insights, several recommendations are suggested:

- Promotion of main strengths of heavy-duty AFVs, which have been perceived by adopters, to potential adopters
- Resolving or alleviating the weaknesses of heavy-duty AFVs reported by adopters (e.g., financial incentives to offset incremental costs, warranty and maintenance services to alleviate potential performance/maintenance issues)
- Investigation into different requirements of functional suitability (e.g., in terms of driving range, maximum power, speed, and payload) across diverse vocational areas in HDV applications, and matching those requirements with current status of heavy-duty AFV technologies, so as to identify the areas needed for improvements
- Investigation into negative perceptions of heavy-duty AFV operations, which have been reported by adopters (e.g., shorter longevity of CNG engine, safety and reliability, maintenance costs, and resale market of heavy-duty CNGVs)
- Targeted education for key decision-makers (particularly to resolve negative, unsubstantiated concerns)

- Promotion of main strengths of heavy-duty CNGVs, which have been perceived by vehicle drivers, to other drivers at potential and new adopter organizations
- Educational training for vehicle drivers (particularly to resolve negative, unsubstantiated concerns)
- Provision of vehicle testing opportunities to drivers

4.7. Heavy-duty CNG Refueling Facilities: Use Behavior and Satisfaction

Refueling/charging heavy-duty AFVs is a fundamental task to operate the vehicles. Once a DMU in an organization decides to adopt the vehicles and implements the operations, they would evaluate how satisfied they are with the refueling/charging facilities being used. This Chapter intends to probe how the participating organizations use the infrastructure in terms of facility types and amount of time spent in fueling, and how satisfied they are with the facilities being used. In case an organization has a plan to build on-site fueling facilities, the reasons for their decisions are further explored. Given that many participating organizations adopted CNG (17 out of 18), the analysis in this Chapter is focused on those CNG adopters. The interview questions for this work are as follows:

- **Q9 (Refueling facility/Refueling time):** "What kind of fueling stations do you use for CNG vehicles?"; "(If they are using off-site facilities) How long does it take to travel to that station from your fleet site?"; "How long does it take to refuel your vehicles?" (a subset of the questions in Q9)
- **Q9 (Satisfactions about the current refueling facilities):** "How satisfied or dissatisfied are you with the NGV refueling?"; "Can you explain why you are satisfied/dissatisfied?" (a subset of the questions in Q9)

The answers regarding satisfaction about refueling facilities were analyzed using content analysis. A quantitative portion of the content analysis results is presented in Figure 4-17, with the existence of each category (i.e., specific reasons for dis/satisfaction), its sign (i.e., "+" being positively stated, "−" being negatively stated), and its strength (i.e., "1" being implied or indirectly stated, "2" explicitly mentioned, and "3" emphasized as overarching reasons). For the "overall satisfaction," each sign and strength indicate the following meanings: "+3" being very satisfied overall, "+2" satisfied, "+1" somewhat satisfied, "n" neither satisfied nor dissatisfied, "−1" somewhat dissatisfied, "−2" dissatisfied, and "−3" very dissatisfied. Meanwhile, the other answers (e.g., regarding facility types and refueling time) were summarized in Table 4-10. Through a series of discussion between the researchers, the analysis results were agreed and verified, by which the following insights were identified.

4.7.1. Results

1) Use Behavior of CNG Refueling Facilities

Large fleets being more likely to build on-site refueling facilities – An organization with a larger number of CNG vehicles would be more likely to build their own on-site refueling facilities than a fleet with a smaller number of the vehicles. Table 4-10 summarizes the types of CNG refueling facilities which are being used by the participating organizations along with the number of the vehicles. A comparison between the types of fueling facilities (i.e., on-site vs. off-site) and the ultimate numbers of CNG vehicles (including both the ones currently being operated and to be purchased), the following rough trends were captured:

a) Almost all the organizations with 30 or more CNG vehicles have already built their own on-site refueling facilities (11 out of 12 organizations).

b) Almost all the organizations with more than 5 and less than 30 CNG vehicles are using off-site stations but planning to build on-site facilities (at least 3 out of 4 organizations).

c) An organization with less than 5 CNG vehicles is relying only on off-site stations.

However, careful interpretation should be exercised given that these trends were found based on a too small sample to be generalized. Further research may be needed with a sufficient size of sample[23] to precisely investigate how the number of AFVs would affect a preferred refueling or recharging facilities.

[23] For example, a large sample from diverse vocational areas and various locations with different levels of accessibility to off-site refueling/charging stations.

Table 4-10. CNG Refueling Facility and Use Behavior of Participating Fleets

Org. (vocation)	Number of CNGVs / Fleet size	Number of CNGVs to be expanded	Year of 1st CNGV adopted	Refueling facilities	Location of off-site stations	Amount of time taken to fuel		Add information	
						Fast-fill	Slow-fill	On-site facilities	RNG
Org. 01 (school bus)	19 / 51	15	2002	On-site (slow-fill/fast-fill)		•5 min		•Fast-fill was built in 2017 •Construction costs: $2M-5M •Semi-public •Will upgrade the facility with additional storage	•We'll use RNG
Org. 02 (various)	9 / ≈28	11	2009	Off-site (but, on-site facilities will be built)	•Clean Energy fuel station			•On-site station to be built might be private facilities	
Org. 03 (various)	80 / 650	9	≈ 1997	On-site (fast-fill) and Off-site	•Off-site stations close to their facilities	•40 min (old facilities)		•Two on-site stations (owned by themselves, operated by Clean Energy, outside from their fleet sites)	
Org. 04 (delivery)	2 / 70	9	2017	Off-site (but, on-site facilities will be built)	•About a mile away	•12 min on average		•On-site station to be built will have separate access between themselves and public	
Org. 05 (delivery)	32 / 32	Will expand if business grows.	1973 (*after the Iran embargo of oil)	On-site (slow-fill)				•Slow-fill facilities were built in the 1980s •4 slow-fill on-site facilities	
Org. 06 (refuse)	≈100 / 105	2	≈ 2013	On-site (slow-fill/fast-fill)			•5 to 6 hours	•Fast-fill was built in 2015	
Org. 07 (refuse)	400 / 900+ (all classes)	50+	2004	On-site (slow-fill/fast-fill)		•12 to 15 min for two trucks	•Over night	•Will build one or two more stations	•We're using RNG

Org. (vocation)	Number of CNGVs / Fleet size	Number of CNGVs to be expanded	Year of 1st CNGV adopted	Refueling facilities	Location of off-site stations	Amount of time taken to fuel		Add information	
						Fast-fill	Slow-fill	On-site facilities	RNG
Org. 08 (trucking)	2 / 16	4	2016	Off-site (but, on-site facilities will be built)	•en route for everyday route (15-20 min from our yard)	•Less than 10 min		•On-site station to be built will be run from 2019	
Org. 09 (various)	41 / 129	25	2016 (CNG), 2007 (LNG dual fuel)	On-site (slow-fill)			•6 to 7 hours	•Will build additional on-site fueling stations	
Org. 10 (various)	15 / 2400 (all classes)	50	2000 (LNG), 2014 (CNG)	On-site (slow-fill/fast-fill)	•(before 2015) Some private CNG stations run by Clean Energy	•5-7 min	•A couple of hours	•Fast-fill was built in 2015 •Construction cost: $1.8M-2M	•We're using RNG
Org. 11 (refuse)	36 / 38	No (now almost at a 100% NGVs)	2000	Off-site (but, on-site slow-fill facilities will be built)	•A local facility by Clean Energy •Less than 5 min	•30 to 35 min		•Slow-fill station will be built between 2019 to 2020	
Org. 12 (school bus)	22 / 35,000	Yes	2017	n/a					
Org. 13 (various)	256 / 615 (all classes)	Yes	1998	On-site (slow-fill/fast-fill)		•no more than 5 min	•overnight	•On-site facilities have 34 slow-fill hoses and 2 fast-fill	•We're about to use RNG
Org. 14 (refuse)	≈ 400 / 900+	500	2002	On-site (slow-fill/fast-fill)	•A CNG station had been used	•15 min at max	•4 to 6 hrs (but it really	•All sites have fast- fill just for emergencies •All facilities are private	•We make our own RNG

Org. (vocation)	**Number of CNGVs / Fleet size**	**Number of CNGVs to be expanded**	**Year of 1st CNGV adopted**	**Refueling facilities**	**Location of off-site stations**	**Amount of time taken to fuel**		**Add information**	
						Fast-fill	**Slow-fill**	**On-site facilities**	**RNG**
					before building our own slow-fill station		doesn't matter because of 10 hrs of downtime)		
Org. 15 (various)	60 (& 75 LNGVs) / 800	80	2015 (CNG), 2005 (LNG)	On-site (slow-fill) and Off-site (fast-fill)	•A fast-fill station a quarter mile away		•4-5 hours		
Org. 16 (various)	3 / 179	Yes	≈ 2012	Off-site (fast-fill)	•Public station (fast-fill) •Within 5 miles away	•Depends on circumstances (e.g., queue at the site, time of day)			
Org. 17 (refuse)	310 / 721	Yes	1994 (duel fuel LNG)	On-site (slow-fill/fast-fill)		•Less than 10 min	•overnight		•We are using RNG

[Note] (a) The cases with 30 or more CNG vehicles (both the ones currently being operated and to be expanded) are indicated in blue background. The other cases with 5 to 30 CNGVs, and less than 5 CNGVs are indicated in yellow and red background, respectively.

(b) Org. 12 did not have available information about types of CNG refueling facilities during the interview.

Refueling behavior: on-site vs. off-site stations – The participating CNG adopters' refueling behavior is presented in Table 4-10, including where they refuel the vehicles, and how long it takes to refuel. Of the fleets with on-site stations, more than half fleets have both slow-fill hoses and fast-fill dispensers (7 fleets out of 11) while the others have either only slow-fill (3 out of 4) or fast-fill facilities (1 out of 4). When on-site slow-fill facilities are used, CNG vehicles are typically refueled overnight, after the end of the operations. Though approximately 4 to 7 hours were reported as their refueling hours, one fleet manager mentioned, "*it really doesn't matter to us, whether it takes 4 hours, 6, or 8, because I've got 10 hours of downtime*" (Org. 14). In other cases when on-site fast-fill dispensers are used, typically 5 min to 15 min (c.f., 40 minutes for old facilities (Org. 3)) were reported as refueling time. As a short amount of time is needed, one organization stated that the fast-fill can be used for emergencies while the slow-fill is a typical way to refuel (Org. 14).

At the same time, for the off-site CNG stations, which are equipped with fast-fill dispensers, it was reported by some portion of the participating fleets to take less than 10 min to 35 min to refuel. Meanwhile, one organization also answered, the refueling time at off-site stations "*depends on circumstances (e.g., queue at the site, time of day),*" and addressed "*waiting time*" as an unsatisfactory aspect of using off-site facilities. In most cases, those off-site stations are located nearby their fleet sites (e.g., a mile away, a quarter mile away, within 5 min to travel) while one organization is using an off-site station located en route for their everyday route (15-20 minutes from the fleet site).

Construction and maintenance of on-site fueling facilities – Most of those organizations, that already built or are planning to build their own on-site CNG fueling facilities, provided several pieces of additional information regarding building and maintaining on-site fueling facilities (see Table 4-10). Several organizations stated that they had put slow-fill facilities first, and then recently built fast-fill stations (e.g., Org. 1). Construction costs for building the fast-fill stations were reported from 1.8 million to 5 million dollars. After building the on-site fueling facilities, some organizations (e.g., Org. 1, 7, and 9) stated that they are proceeding with upgrading facilities with expanded storage and building additional fueling stations.

As to whether to allow for public access to on-site fueling facilities, different decisions were observed between fleet sectors. For example, Org. 1 (school bus) and Org. 4 (delivery trucks) considered semi-opening the facilities to public (e.g., with separate access). In contrast, Org. 2 (various public vocations) and Org. 14 (refuse trucks) preferred keeping their facilities private, because they do not have the enough space in their yard (Org. 2), or they do "*not want to sell anything to anybody else*" (Org. 14).[24]

Previously LNG, currently CNG, and being transitioned to RNG – One distinctive trend, that was observed by many organizations with on-site fueling facilities, is common interest in using renewable natural gas (RNG) (6 out of 11 fleets). Four of those fleets are currently using RNG (Org. 7, 10, 14, and 17) and two more fleets stated they are going to use RNG (Org. 1 and 13). Regarding motivations to using RNG, one fleet manager explained, "*because [...] we are able to purchase from the renewable sources, the price is even cheaper than the natural gas fuel from the petroleum sources. [...] As far as lifecycle analysis, it has a*

[24] It should be noted that, not all interviewees provided detailed information regarding their on-site refueling facilities. When a large sample can be accessible from the fleets equipped with on-site fueling facilities, more solid investigation could be conducted to produce generalizable findings.

negative carbon footprint. That is, environmental benefits" (Org. 17). In addition, another organization implied the trend toward the use of RNG, which was followed a previous transition from LNG to CNG. "*When we started with refuse we were using liquefied natural gas, and now we're migrating to compressed natural gas. And all the natural gas we use is 100 percent renewable natural gas*" (Org. 10). Furthermore, one organization reported that they are even producing RNG (Org. 14): "*We have a large anaerobic digestion facility in XXX, California. [...] I collect all the green waste and food waste, and then I digest it onsite, and then I upgrade it to pipeline quality, and I inject it in the pipeline. [...] We make our own RNG*" (Org. 14).

Organizations (vocations)	01 school bus	02 vari-ous	03 vari-ous	04 deliv-ery	05 deliv-ery	06 refuse	07 refuse	08 truck-ing	09 vari-ous	10 vari-ous	11 refuse	12 school bus	13 vari-ous	14 refuse	15 vari-ous	16 vari-ous	17 refuse
Fleet characteristics [(a)]	Pb M	Pb M	Pb L	M <15 NGV New	M	L	L other AFV	S <15 NGV New	Pb L other AFV	Pb L other AFV ELEC On-site	M	L other AFV New	Pb L	L other AFV	Pb L other AFV	Pb L <15 NGV	Pb L
Refueling facilities [(b)]	On-S On-F	(On-site) Off	On-F Off	(On-site) Off	On-S	On-S On-F	On-S On-F	(On-site) Off	On-S	On-S On-F	(On-site) Off	n/a	On-S On-F	On-S On-F	On-S Off	Off	On-S On-F
• Overall satisfaction	+3[(c)]	-2	-2	+2	+3	+3	+3	+2	+3	+3	+1	+3	+2	+3	+3	+3	+3
• Time taken to drive to refueling facilities	+2	-2										+2					
• Waiting time at refueling facilities															+,-2 (on/off)	-2	
• Fuel price	+2	-2		-2		+2	+2	+3	+2	+2				+1	+2		
• Fueling convenience									+2			+2			+2		
• Not always a 100 % full in a CNG fuel tank		-2									-2						
• Costs for building facilities (e.g., code compliant natural gas facility)										-2							
• Fuel security	-2	-3															
• Consistency of the fuel being provided						+3											
• Facility/equipment reliability								+2	-1						+2		
• Easiness of facility maintenance					-2		+2						-1				
• Complexities involved with building facilities							-2										
• Complexity increased w/ fleet routing											-2						
• Fuel availability								-3		-2	+2	-2		-2			
• Org.-specific issues (e.g., capacity of CNG storage)	-2																

[Note] (a) Symbols represent fleet characteristics. "Pb": public entities (c.f., private entities, otherwise unmentioned), "L": large fleet size (>100 vehicles), "M": medium size (20-100), "S": small size (≤ 20), "<15 NGVs": the total number of NGVs, including both those are being currently operated and those to be expanded in the near future, will less than 15, "Other AFV": AFV other than CNGV being operated, "ELEC on-site": planning to build on-site electric heavy-duty charging station, and "New": the year of the first heavy-duty AFV purchased was after 2015. (b) Symbols represent specific types of fueling facilities: "On-S": on-site slow-fill hoses, "On-F": on-site fast-fill dispenser(s), "Off": off-site station(s), and "(On-site)": Will build their own on-site CNG stations, although they currently rely only on off-site stations. (c) "+": positively stated as satisfactory aspects, "-": negatively stated as unsatisfactory aspects. "1": implied or indirectly stated, "2": explicitly mentioned, and "3": emphasized as overarching aspects.

Figure 4-17. Satisfaction about CNG Refueling Facilities

2) Satisfaction on CNG Refueling Facilities

Overall satisfaction on refueling facilities: on-site vs. off-site – Almost all of the fleets with their own on-site fueling facilities (9 out of 11) expressed a high level of overall satisfaction (i.e., "+3") regarding their facilities. (See Figure 4-17). For example, one stated, "*We're very satisfied. The stations are mature, the equipment is reliable*" (Org. 15). In case that on-site fueling systems are so old that more maintenance and an upgrade are needed, fleet operators expressed a moderate level satisfaction (i.e., "+2") or dissatisfaction (i.e., "–2"). One addressed, "*It's an almost 20 year old system now, so I mean we're having a lot more maintenance and downtime which is affecting us. With the replacement that will all go away*" (Org. 13). In a sharp contrast, only one of the fleets using off-site stations (1 out of 5) was very satisfied with the facilities, though they needed to seek multiple locations for off-site stations. The fleet manager explained, "*Very satisfied [with the off-site stations]. One issue occurs when the facilities are closed, for example, for maintenance or when the sites are busy. So, we've identified multiple sites*" (Org. 16). The other four fleets expressed a moderate or minimal level of satisfaction, or explicit dissatisfaction. Specific unsatisfactory aspects of using off-site stations included a complexity of fleet routing (e.g., "*our drivers may have to come in in the middle of the day to refuel during the course of their route*" (Org. 11)), and a higher fuel price (e.g., "*When we put in our own station, I'll be going from paying $2.20 a gallon to about $1.80*" (Org. 8)).

Advantages of having on-site refueling facilities: saving time for driving and waiting, lower fuel prices, and reduced uncertainty in refueling fleets – Many benefits of having on-site refueling stations were reported by the participating fleets, as shown in

Figure 4-17. First of all, an apparent advantage is that there is no need to drive to any off-site stations, which would allow for saving time and associate financial expenses. In addition, potential waiting time at an off-site station can be saved. One fleet operator described, "*[If we didn't have a plant] I would be paying drivers, half hour go there, half hour come back, that could be twice during a day*" (Org. 1). Another also explained, "*In the CNG time-fill scenario, [...] you're going to bring your vehicle in at the end of the day [...] it's going to refuel all night […]. So, there's not that time of chatting and waiting to refuel*" (Org. 15). Moreover, CNG fuel prices from on-site stations would be lower than those at off-site stations, which was reported by 7 out of 11 organizations: "*If we didn't have a plant, our cost would be so much higher. […] Because we would be paying whatever market prices for CNG"* (Org. 1). One organization that produces RNG by themselves further highlighted: *"We make our own fuel [RNG] […] even if electricity would save me a couple dollars, I probably wouldn't switch"* (Org. 14). Furthermore, the organizations with on-site fueling facilities expressed their satisfaction in terms of reducing uncertainty in fueling the fleets, not only by increased convenience of fueling, but by consistency of the fuel (Org. 6), facilities reliability (Org. 15), and easiness of facilities maintenance (Org. 7)[25].

Unsatisfactory aspects of having on-site fueling facilities: construction costs, complexities associated with the construction, and maintenance issues – Even though almost all the fleets with on-site fueling stations were highly satisfied with their facilities,

[25] Example quotes include: "*We're very satisfied with the amount of fuel we're able to acquire […], the consistency of that fuel*" (Org. 6); "*CNG, it's mature and the stations are mature, the equipment is reliable. […] the station design and the redundancy of compressors and all that sort of thing is well established*" (Org. 15); "*CNG compressor technology's been around a long time. It's not something new. [...] [the maintenance] is a fairly simplistic process.*" (Org. 7).

each fleet often expressed a disadvantageous aspect – which was mainly about the costs associated with building the facilities or maintenance needs. One organization stated the costs needed to build a code compliant facility: "*Many of our technicians have to work outside [...] there's a cost associated with trying to get that facility replaced so we have a Code compliant natural gas facility […]*" (Org. 10). In addition, a long and complex process to deal with the necessary utilities was addressed as a disadvantage: "*The only dissatisfaction I have is […] when you're dealing with the utilities to get it done, like the gas company or the power company […] It's just ridiculous. It takes forever and you really got to be ahead of it if you're planning on doing one*" (Org. 7). Once they build the on-site refueling facilities, the equipment should be monitored and maintained. For example, when the system "*goes offline*", they need to "*be able to resolve the issue quick enough*" so that they "*can still fuel the trucks overnight*" (Org. 9). A few organizations also reported a need to replace their old equipment. One explained, "*Our equipment is getting rather old […] It also takes a lot of record keeping ensuring our tanks, pressure valves, etc. are inspected and replace according to requirements*" (Org. 5).

Unsatisfactory aspects of using off-site stations: time taken for driving and waiting, expensive fuel prices, and complexity increased with fleet routing – All the fleets that were relying on off-site stations addressed unsatisfactory aspect(s). First, the time taken to drive to off-site stations, wait and complete fueling, and return back, would cause expensive labor costs. One explained, "*It's the labor cost […] So, the drive time from here to the station, the waiting time, the time taken to complete to drive back, […] two people, so, it costs me three men hour a day per truck. [...] I kind of calculated how many hours a year that costs me, and it was mind-boggling [...] We were spending 700,000 dollars a year for* *labor costs getting back and forwards*" (Org. 2). Another main disadvantage was CNG fuel prices which would be more expensive than those from on-site stations. Though CNG prices can be lower than diesel (Org. 8), some organizations pinpointed that "*there was no measurable savings*" when using off-site stations (Org. 2). Other disadvantages mentioned by the participating fleets was the inability to obtain a full tank of CNG. One fleet operator explained, "*It [the off-site station] is a fast-fill station, which means that […] depending on the outside temperature, ambient temperature, you're going to get, 75 to 85 percent of a full tank*" (Org. 11). This fleet operator additionally mentioned that this issue may increase the complexity of fleet routing: "*[...] Which does mean our drivers may have to come in in the middle of the day to refuel during the course of their route. And so, we are looking at possibly putting a slow-fuel station in our facility here so that we can get a full tank to start in the morning*" (Org. 11).

CNG fuel security and limited fuel availability being common concerns in both fleets with and without on-site fueling facilities – Some organizations expressed their concern regarding fuel security, for example, when "*there is a big earthquake and power goes out.*" In such emergencies, those organizations could "*only fill up a couple of buses from the storage I have*" (Org. 1) or "*run my fleet just for a day*" (Org. 2). One organization particularly emphasized the fuel security issue: "*In the earthquake, Southern California gases line breaks, I am out of fuel. [...] In that kind of natural disaster scenario, I'm really concerned. The fuel security, it's the issue. […] If the earthquake interrupts CNG flow, here for weeks, we're not gonna help the public*" (Org. 2). Another common concern addressed by several organizations was limited fuel availability (e.g., "*a severe lack of fueling infrastructure*" (Org. 8)). The issue of limited fuel availability would be more serious for those fleet vocations requiring a longer trip. One fleet operator explained, "*we are not usually inclined to use a CNG-powered bus on a commercial charter trip [...] cross a state line - from California to Nevada or et cetera. [...] because of the fueling limitations*" (Org. 12). Another also addressed, "*the only risk with CNG, and I'm sure you – the other truckers will tell you this – if you long haul, let's say you're going to haul from here to Phoenix, Arizona, there's tons and tons of diesel stations. But, there's not that many CNG stations*" (Org.14).

Decisions about building on-site fueling facilities – Almost all the fleets that were relying on off-site stations (4 out of 5) were planning to build their own on-site fueling facilities. The main motivations for building on-site facilities were in taking advantages from lowered CNG fuel price (Org. 2, 4, and 8), saving labor costs of driving off-site stations (Org. 2), and lowering complexity with the fleet routing (Org. 11). At the same time, barriers were addressed, including a physical space required for on-site facilities and the construction costs. Financial incentives can be used to alleviate the cost barrier. All these four organizations already applied (or plan to apply) for multiple sources of financial incentive programs. In the Appendix F, the fleet responses regarding their decisions about building on-site fueling facilities are summarized.

4.7.2. Summary and Recommendations

Based on 17 CNG adopter cases, it was explored how they use the refueling facilities and how satisfied they are with the infrastructure. Their perspectives are contrasted between those with equipped with on-site facilities versus the others using off-site stations. The main qualitative insights gained in this work are summarized as follows.

For the use behavior of CNG refueling facilities:

- [**INSIGHT 32**] A fleet with a larger number of CNGVs would be more likely to build their own on-site CNG refueling facilities than a fleet with a smaller number of CNGVs.
- [**INSIGHT 33**] The time taken to refuel a CNGV were reported longer for on-site slow-fill stations than off-site stations. Such longer on-site refueling time would not matter in case that the vehicles are refueled overnight, while off-site refueling time would sometimes pose uncertainty (e.g., due to queue at the site, time of day).
- [**INSIGHT 34**] Some of those organizations with on-site fueling facilities stated that they began with slow-fill hoses first, and recently built fast-fill stations. Others also stated they are proceeding with upgrading their on-site facilities to expand the storage or to construct additional stations. Depending on fleet operators' decision, those on-site facilities are either semi-open to public or operated as private facilities.
- [**INSIGHT 35**] Renewable natural gas was a common attention among many participating organizations equipped with on-site CNG fueling facilities. In addition, a few organizations implied a trend: from previously LNG to currently CNG, being now transitioned to RNG.

For the satisfaction on CNG refueling facilities:

- [**INSIGHT 36**] Most organizations with on-sites refueling stations are satisfied with their facilities while those are using off-site stations tend to be less satisfied or dissatisfied with the facilities.
- [**INSIGHT 37**] Major advantages of having on-site refueling stations were reported by the participating fleets, including: saving time – and associated financial expenses – required to drive to any off-site stations, lower CNG fuel prices, and reduced uncertainty in refueling fleets – which were attributed to fueling convenience, fuel consistency, facilities reliability, and easiness of facilities maintenance.
- [**INSIGHT 38**] Disadvantageous aspects of having on-site fueling stations were reported as costs and complexities associated with building the facilities, and maintenance issues for old equipment.
- [**INSIGHT 39**] Although a few of fleets using off-site stations were satisfied with the refueling facilities, all of them reported one to multiple

unsatisfactory aspects including longer time taken to drive to off-site stations, waiting time, uncompetitive fuel prices, and complexity increased with fleet routing.

- [**INSIGHT 40**] CNG fuel security and limited fuel availability were addressed as common concerns by both fleets with and without on-site fueling facilities.
- [**INSIGHT 41**] Several participating organizations were planning to build on-site CNG refueling facilities in order to take advantages from lowered CNG fuel price, to save labor costs of driving to off-site stations, and to lower complexity with the fleet routing. While limited space and construction costs were addressed as barriers to building the facilities, all of them applied (will apply) for financial incentives to alleviate the cost barrier.

Based on these insights, the following recommendations are suggested:

- Provision of sufficient guidance and educational programs about building, maintaining, and upgrading on-site fueling/charging facilities for those who wish to have such on-site facilities
- Provision of financial incentives for those who plan to construct on-site fueling/charging stations
- Investments of off-site fueling/charging stations for those who are unable to build on-site facilities
- Cost-benefit analysis of different scenarios of infrastructure investment on a region or state-wide basis, which would be created with various combinations of public, private, and shared stations
- Resolving or alleviating the weaknesses of using off-site stations reported by adopters (e.g., waiting time, uncompetitive fuel price)

- Investigation into the fuel security issue (e.g., for CNG or any other alternative fuels, how negatively fleet operations would be affected in case the issue really arises)

4.8. Heavy-duty CNGVs Repurchase Plans and Feedback/ Recommendation Experiences

After starting the operation of heavy-duty AFVs, an adopter organization would decide whether or not to purchase more AFVs. Such repurchase decisions would be affected by several aspects, including their evaluations on the AFV operation, how much they invested in that technology (e.g., on-site fueling/charging facilities), and what outlook they would possess on that fuel technology. Meanwhile, if the organization confirms about their adoption decision, they would be likely to provide feedback or even recommendation to other non-adopter organizations. The extent to which such feedback/recommendation activities occur, might depend on how connected the DMU members are with other fleet operators, as well as how satisfied they are with the AFV operation. Overall, both the repurchase and feedback/recommendation behavior would further boost the diffusion of the technology throughout the entire market. In that sense, this Chapter aims to explore the repurchase plans and feedback/recommendation experiences of the participating organizations, particularly in relation to their overall satisfaction on the technology (in Chapter 4.6) and investment status of refueling facilities (in Chapter 4.7). Since a majority of the organization interviewed adopted CNG (17 out of 18), the analysis is focused on those CNG adopters. The interview questions for this work are as follows:

- **Q10 (Repurchase plans/intent)**: "Do you have a plan to expand your fleet of CNGVs? (In case the answer is "No") If you need to purchase new vehicles, how likely are you to purchase CNGVs?", and

- **Q11 (Recommendation experiences/intent)**: "Have you ever recommended CNGVs to others? (In case the answer is "No") How likely are you to recommend CNGVs to other fleet managers?" (ones of the questions in Q11)

The interview data was analyzed using thematic analysis. Through a series of discussion between the multiple researchers, the following insights were identified.

4.8.1. Results

1) Repurchase Plans

First, a summary of the CNGV repurchase plans of the participating organizations is presented in Table 4-11 along with other associated information such as fleet size, refueling facilities, and satisfaction on CNGV operation. In addition, ultimate penetration rates of CNGVs in each fleet were estimated based on the numbers of CNGVs being operated, the numbers of CNGVs to be additionally purchased, and the assumption that those new CNGVs will replace other existing vehicles within the fleet. The estimated, ultimate penetration rates of CNGVs per fleet are classified into the following broad categories[26]:

a) Very High penetration (90 or more percentage of CNGVs in a fleet)

b) High penetration (50 to 90 percentage)

c) Medium penetration (10 to 50 percentage)

d) Low penetration (less than 10 percentage)

[26] For some cases, those classifications could not be made due to unavailability of an exact HDV fleet size (e.g., Org. 10, 13) or an exact number of CNGVs to be purchased (e.g., Org. 12, 13), for which the data are indicated with grey background.

Based on these estimations, a rough trend is depicted in Figure 4-18 between three variables: the overall satisfaction on heavy-duty CNGV operations, the investment status in refueling facilities, and the ultimate penetration rates of CNGVs. Then, Figures 4-19 and 4-20 were created by modifying Figure 4-18: Figure 4-19 was drawn only with the cases where fleet operators are satisfied both with CNGVs and their refueling facilities (i.e., "+1", "+2", or "+3" symbols), and Figure 4-20 was created only with the cases where investment was already made in on-site refueling facilities. Subsequently, the following insights were identified regarding satisfactions on heavy-duty CNGV operations, investment in refueling facilities, and CNGV repurchase plans.

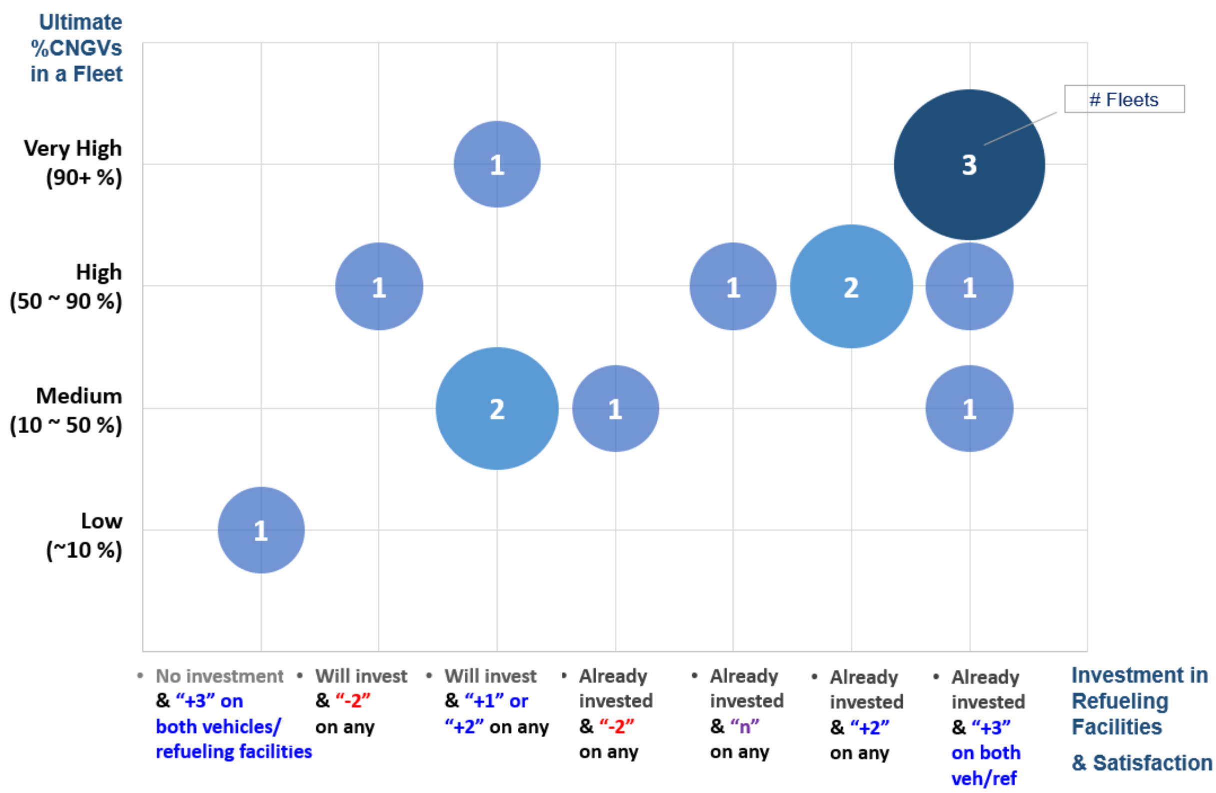


Figure 4-18. A Rough Trend between Investment in Refueling Facilities, Satisfaction, and Ultimate Penetration Rates of CNGVs in a Fleet

Table 4-11. Heavy-duty CNGVs Repurchase Plans and Feedback/Recommendation Experiences

Org. (vocation)	**Public vs. Private**	**Number of CNGVs / Fleet size**	**Refueling facilities**	**Overall satisfaction** (a)		**Number of CNGVs to be expended**	**Ultimate % CNGVs in the fleet** (b)	**Feedback provided to other fleet operators**	**Recommendation /education provided to other fleet operators**
				CNGVs	**Refueling facilities**				
Org. 01 (school bus)	public	19 / 51	On-site (slow-fill/fast-fill)	+3	+3	15	67%	Yes (Positive)	
Org. 02 (various)	public	9 / ≈28	Off-site (but, on-site facilities will be built)	+3	-2	11	71%	Yes (Positive)	
Org. 03 (various)	public	80 / 650	On-site (fast-fill) and Off-site	+2	-2	9	14%	Yes (Neutral)	
Org. 04 (delivery)	private	2 / 70	Off-site (but, on-site facilities will be built)	+3	+2	9	16%	Yes (Neutral)	
Org. 05 (delivery)	private	32 / 32	On-site (slow-fill)	+3	+3	Will expand if business grows	100%	Yes (Neutral)	
Org. 06 (refuse)	private	≈100 / 105	On-site (slow-fill/fast-fill)	+3	+3	2	97%	Yes (Positive)	
Org. 07 (refuse)	private	400 / 900+ (all classes)	On-site (slow-fill/fast-fill)	n	+3	50+	50+ %	No	
Org. 08 (trucking)	private	44243	Off-site (but, on-site facilities will be built)	+3	+2	4	38%	Yes (Positive)	Yes (recommendation & education)
Org. 09 (various)	public	41 / 129	On-site (slow-fill)	+2	+3	25	51%	No	
Org. 10 (various)	public	15 / 2400 (all classes)	On-site (slow-fill/fast-fill)	+3	+3	50	3+ %	Yes (Positive)	Yes (recommendation & education)

Org. (vocation)	**Public vs. Private**	**Number of CNGVs / Fleet size**	**Refueling facilities**	**Overall satisfaction** (a)		**Number of CNGVs to be expended**	**Ultimate % CNGVs in the fleet** (b)	**Feedback provided to other fleet operators**	**Recommendation /education provided to other fleet operators**
				CNGVs	**Refueling facilities**				
Org. 11 (refuse)	private	36 / 38	Off-site (but, on-site facilities will be built)	+3	+1	No (already almost at 100% CNGVs)	95%	Yes (Neutral)	
Org. 12 (school bus)	private	22 / 35,000	n/a	+3	+3	Yes (b)	0.1+ %	No	
Org. 13 (various)	public	256 / 615 (all classes)	On-site (slow-fill/fast-fill)	+1	+2	Yes	42+ %	No	
Org. 14 (refuse)	private	≈400 / 900+	On-site (slow-fill/fast-fill)	+3	+3	500	100%	Yes (Neutral)	
Org. 15 (various)	public	60 / 800	On-site (slow-fill) and Off-site (fast-fill)	+3	+3	80	18%	Yes (Neutral)	
Org. 16 (various)	public	3 / 179	Off-site (fast-fill)	+3	+3	Yes	2+ %	Yes (Neutral)	
Org. 17 (refuse)	public	310 / 721	On-site (slow-fill/fast-fill)	+2	+3	Yes	82+ %	Yes (Neutral)	
Org. 18 (paving)	private	0 / 10+	n/a	n/a	n/a	No	0%	n/a	

[Note] (a) For the 'overall satisfaction' each number means the following: "+3": very satisfied, "+2": satisfied, "+1": somewhat satisfied, "n": neither satisfied nor dissatisfied, "-1": somewhat dissatisfied, "-2": dissatisfied, and "-3": very dissatisfied. (b) The 'yes' regarding the 'number of CNGVs to be expanded' represent the cases where a fleet operator has a willingness to expand their CNGV fleet although an exact size was not mentioned during the interview. (c) For the 'ultimate percentages of CNGVs', the data with dark blue background indicate 50 or more percentage of CNGVs penetrations (i.e., Very High penetration); and blue, yellow, and red background indicates 50 to 90% (i.e., High), 10 to 50% (i.e., Medium), and less than 10% (i.e., Low) of penetrations, respectively. In case being unable to be classified into those four categories - due to unavailability of exact HDV fleet size or exact number of CNGVs to be purchased, the data are indicated with grey background.

Fleets with investment already made in on-site refueling facilities would be likely to plan higher penetration rates of CNGVs – As seen in Figure 4-19, many participating fleets (7 out of 11 satisfactory fleets) already built their on-site fueling facilities and almost of them (6 out of 7) were aiming High or Very High penetration rates of CNGVs (i.e., 50+%)[27]. Meanwhile, two out of those three (Org. 4 and 8) – which were using off-site refueling stations but planned to build their own on-site facilities – are represented with Medium penetration rates (i.e., 10 to 50 %) while the other (Org. 11) plans a Very High penetration rate (95%). Given that those two organizations with Medium penetrations were new CNG adopters (i.e., their first CNGV was purchased after 2015), this observation would reasonably imply that new adopters tend to be less committed to the repurchase than experienced adopters. At the same time, Org. 11 with a Very High penetration rate was turned out to be subject to the SCAQMD fleet rules, which made them plan active repurchases of CNGVs although they have not made the infrastructure investment yet. Lastly, one organization (Org. 16) – that was relying on off-site fueling stations and had no plan to build their own facilities – aimed the lowest penetration rate of CNGVs (2%). Overall evidence would imply that HDV fleets with investment already made in CNG on-site refueling facilities tend to plan higher penetration rates of CNGVs than others using off-site fueling stations [28].

[27]One organization (Org. 15) – with a Medium penetration rate (i.e., 10 to 50 %) despite their investment made in CNG refueling facilities – adopted other alternative fuels such as LNG (9.4% penetration rate) and renewable diesel (47.5%) along with CNG. Therefore, this organization can be classified as a High penetration case (50+%) of 'alternative fuels'.

[28] However, it also should be noted that the CNGVs penetration rates computed in this analysis are not based on maximum possible numbers of CNGVs in a fleet – with the consideration of vocational composition in each fleet and availability of heavy-duty AFV models in each vocation. Once those data are available and a large sample size becomes accessible, a more precise relationship can be investigated.

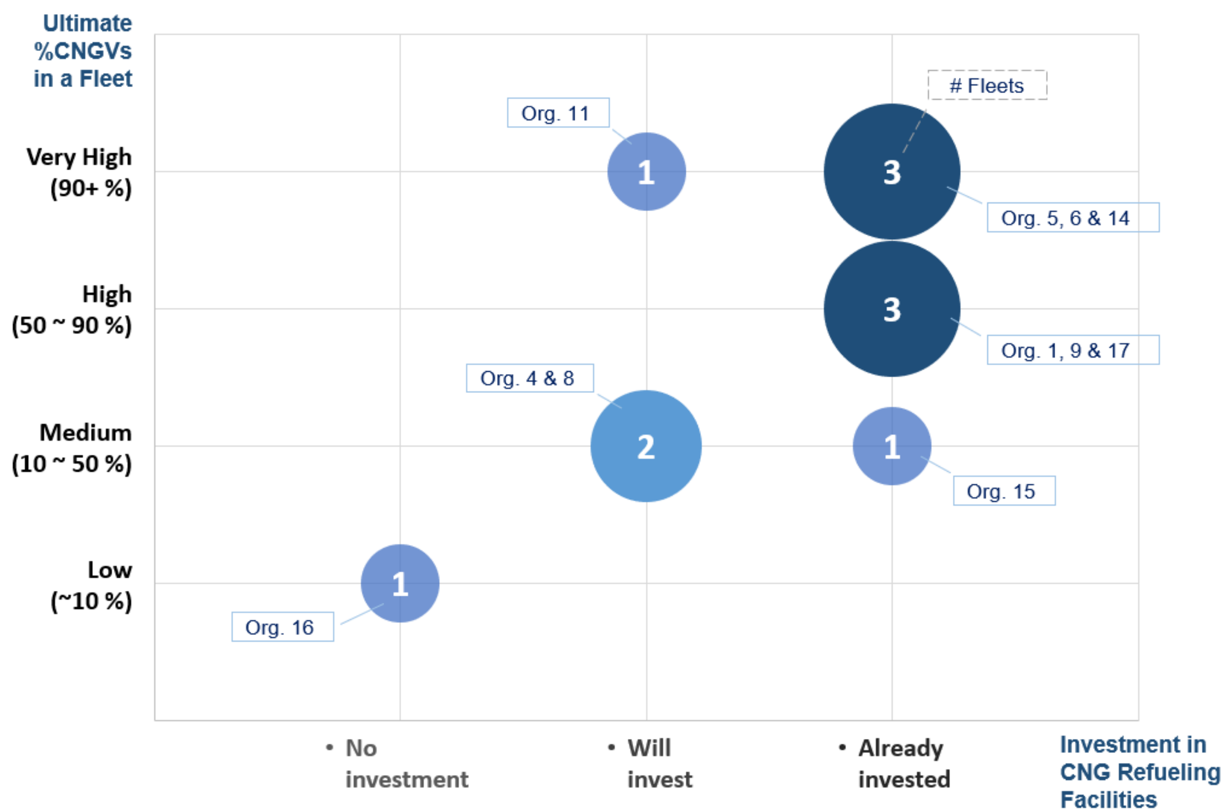


Figure 4-19. A Rough Trend between Investment in Refueling Facilities and Penetration Rates of CNGVs: Only with the Satisfactory Cases

Fleets satisfied with CNG operations would be likely to plan higher penetration rates of AFVs – Out of those fleets already invested in on-site refueling facilities, several organizations that are highly satisfied with CNGVs and their refueling facilities (Org. 5, 6, and 14) aimed Very High penetration rates of CNGVs (90+ %) (See Figure 4-20). Meanwhile, several organizations planed High penetration rates (50 to 90%) (Org. 1, 7, 9, and 17): all of them were highly satisfied ("+3") with their refueling facilities but their satisfaction on CNG vehicles varied across neutral ("n") to high ("+3") levels. Only two organizations (Org. 3 and 15) in this analysis are represented with Medium penetration rates of CNGVs (10 to 50%). It should be noted that Org. 15 diversified their fuel options by adopting LNG (9.4% penetration rate) and renewable diesel (47.5%) along with CNG. Therefore, they can be classified as a fleet with High penetration rates of 'alternative fuels.' Lastly, one organization (Org. 3) planed a Medium penetration rate (14%). This organization is the only one that expressed dissatisfaction on their on-site refueling facilities (i.e., "-2").[29] Overall evidence would imply that HDV fleets highly satisfied with CNGV operations - in both terms of the vehicles and refueling facilities - tend to plan higher penetration rates of CNGVs than other less-satisfied fleets.[30]

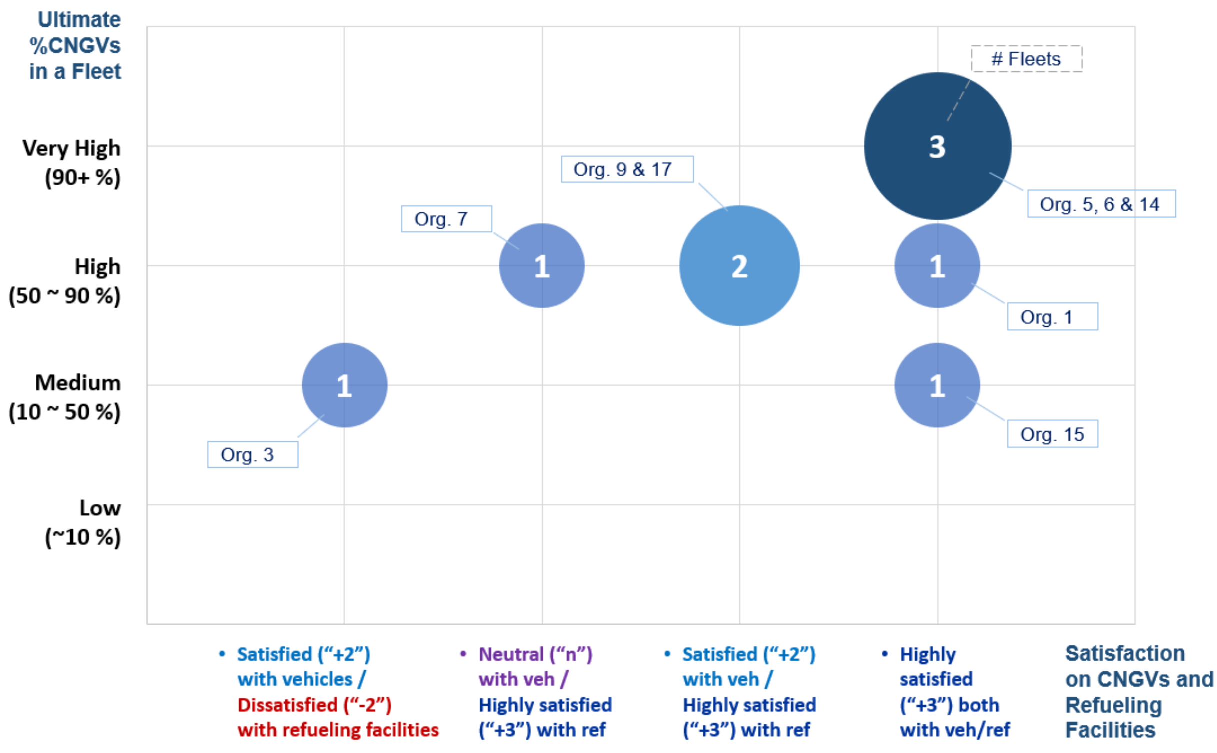


Figure 4-20. A Rough Trend between Satisfaction and Penetration Rates of CNGVs: Only with the Cases Already Invested in Refueling Facilities

29 "*They [the on-site facilities] are very old and dated, and the technology from compresses to the dispensing equipment is definitely in need of an upgrade*" (Org. 3).

30 However, it should be underlined that the sample used for this work is too small to elicit generalized findings. When a large sample becomes available with a more varied distribution in satisfaction levels (e.g., ranging from highly unsatisfactory cases ("-3") to highly satisfactory cases ("+3")), a more accurate relationship can be examined.

2) Feedback and Recommendation Experiences

The participating organizations stated their experiences in providing feedback and recommendation about heavy-duty CNG vehicle operations to other organizations, which is summarized in Table 4-11. This table also presents other relevant information such as public vs. private status, CNGVs penetration rates in their fleets, and satisfaction on CNGV operations. A majority of CNG adopters interviewed (13 out of 17) had experiences in giving positive (5 organizations) or neutral (8 organizations) feedback on CNGV operations to other fleet operators. Two of those have even offered recommendations of adopting CNGVs and provided education regarding the operation to other fleets. Meanwhile, four organization have no experiences in sharing such information with others.

It was attempted to explore if there are any patterns between the several variables presented in Table 4-11. Two variables, a) public vs. private status, and b) satisfaction on CNGV operations, were found to imply some trends associated with feedback/ recommendation experiences.[31] Then, two graphs were created to visually explore patterns between CNGV satisfaction and feedback/recommendation experiences for either public organization cases (Figure 4-21) or private organization cases (Figure 4-22).

**Fleets highly satisfied with CNG vehicles, both across public and private organizations, would be likely to provide positive or neutral feedback to other fleets – **Almost all those fleets with highly satisfied with CNGVs (i.e., "+3") (11 out of 12) – both across public and private organizations – had experiences in providing positive (5 out of

[31] No apparent patterns were captured between the ultimate CNGVs penetration rates and the feedback/ recommendation experiences within this data.

11) or neutral (6 out of 11) feedback on CNGV operations to other fleet operators (see Figures 4-21 and 4-22). In a related quote, a public fleet operator stated, "*I personally do a lot of speaking [...] I've gone out and talked a lot about what we've done here in California […]*" (Org. 10). Another private fleet manager also explained, "*I get a lot of phone calls that say, how's this working? [...] Since the diesel prices have started climbing about 12 to 14 months ago [...] I'm getting more and more people that are calling interested in alternative fuels[...]"* (Org. 8). While some of such highly satisfied organizations (e.g., Org. 8 and 10) tended to distribute their favorable opinions toward CNGVs, some others tended to be neutral in sharing the information with others: "*Just on an informal basis, it's just been sharing information. We don't go out and tout it or anything publicly*" (Org. 4). On the other hand, among those fleets with relatively less satisfied (i.e., "+2" or less), only a few organizations (2 out of 5) have provided neutral feedback (e.g., Org. 3) whereas the others (e.g., Org. 7) had no experiences in offering feedback or could not recall if they did. At the same time, the organization that was slightly satisfied with CNGVs (i.e., "+1") stated that they have not recommended anyone for CNG adoption.[32]

Some private fleets would be intentionally inactive in sharing their CNGV experiences with others – A tendency was observed that some private fleet operators seemed to be intentionally inactive in sharing information on CNGV operation with other fleet operators, even if they were satisfied with CNGVs. One private organization addressed,

[32] (a) Meanwhile, no clear pattern was observed between satisfaction on refueling facilities and feedback/recommendation experiences, with the data used for this analysis.

(b) Given that this analysis was based on a relatively small sample which is biased toward those fleets which installed CNG refueling facilities and are more likely to be satisfied with CNGVs, further investigation should be needed with a sufficient sample size to probe more accurate relationships.

“*We don’t have a lot of sharing we do. [...] if we do have something that gives us an advantage, we’re likely not to be too quick to let everybody else know*” (Org. 7). The reason for such tendency was also pointed out by another interviewee: “*[such private fleet operators] are pretty tight-lipped when it comes to talking about [AFVs, as they can] beat out their competitors because of the simple fact that they’re running alternative fuel*” (Org. 8).

Some organizations would actively disseminate information about the new technologies by providing recommendation and even education to others – There were a few public or private organizations (e.g., Org. 8 and 10) who actively took a leadership role in disseminating the information on such new technologies by providing strong recommendation and/or education through their interpersonal networks. In a related quotation, one fleet operator addressed, *“I’m helping educate people and teach them how to do the maintenance and the basic stuff that they can work on their fuel systems in their trucks, tank replacement, just preventive maintenance and all that stuff because there's a huge hole in the industry*” (Org. 8). Those recommendation and education efforts could create a positive impact on adoption decisions of other organizations by alleviating uncertainty associated with the new technologies and facilitating the decision processes.

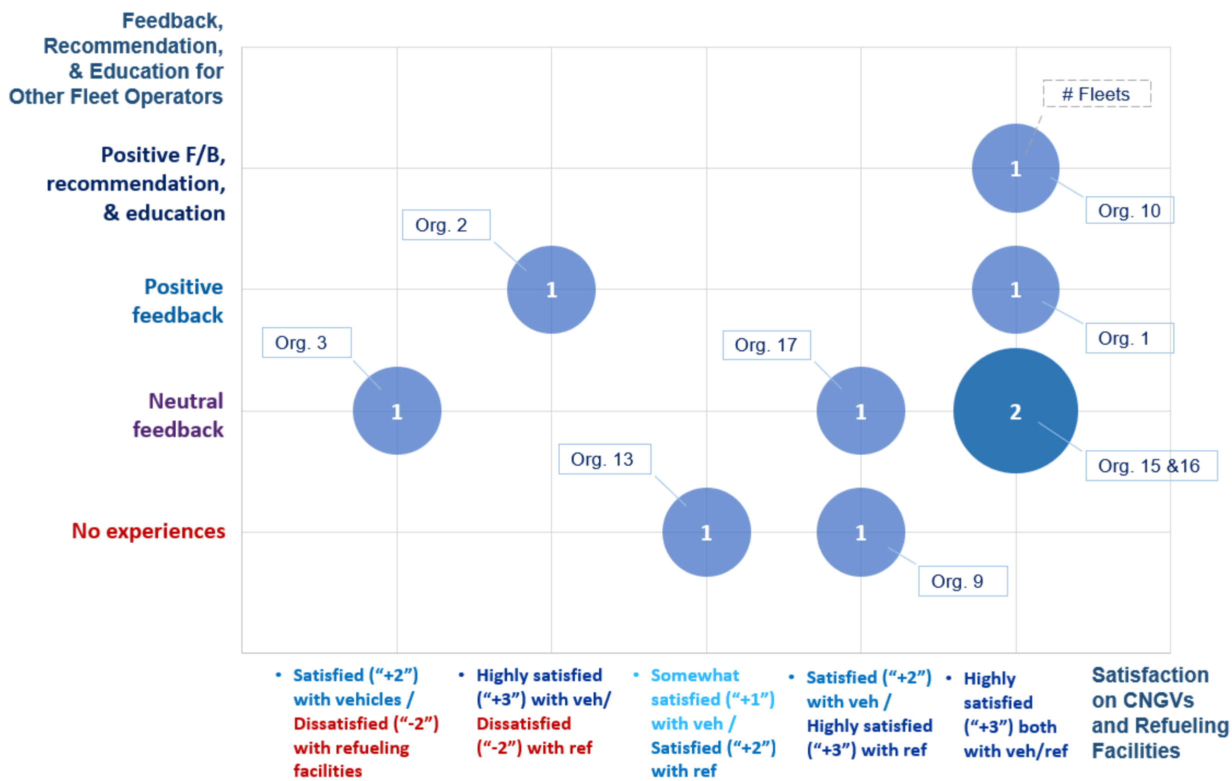


Figure 4-21. A Rough Trend between Satisfaction and Feedback/Recommendation Experiences for Other Fleet Operators: Only with the Cases of Public Organizations

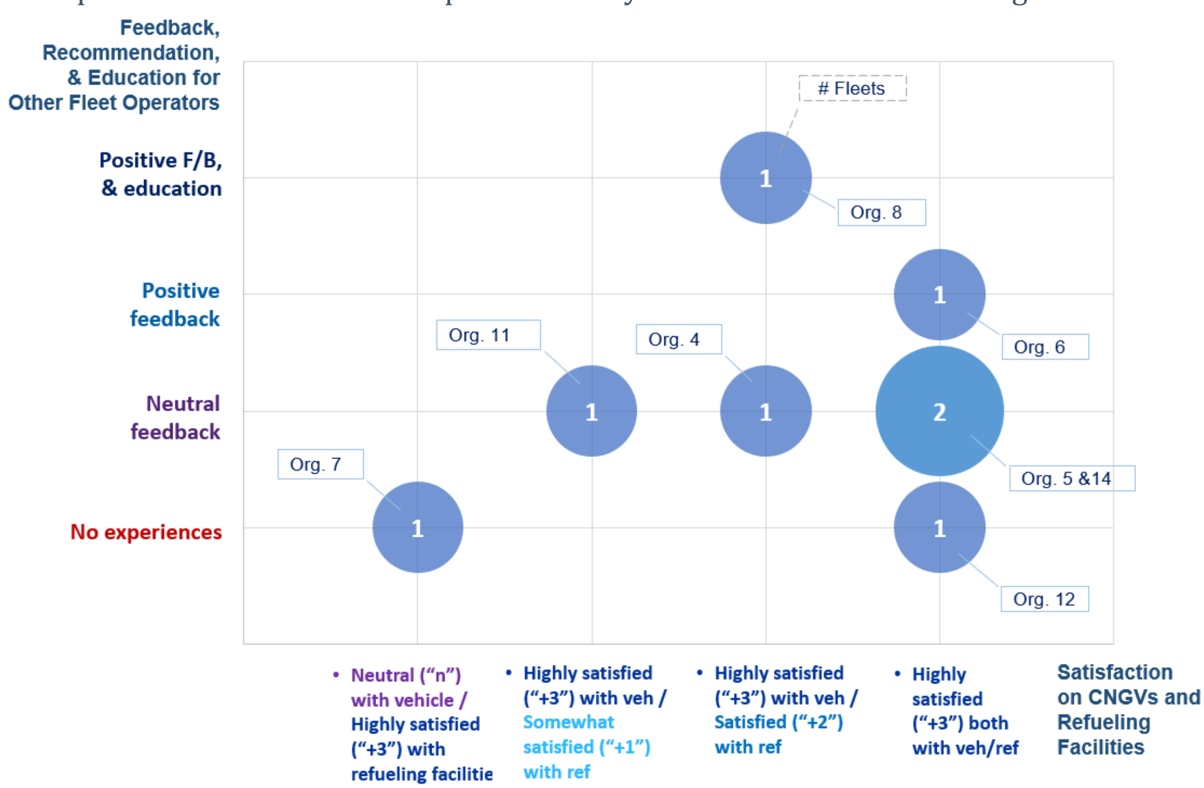


Figure 4-22. A Rough Trend between Satisfaction and Feedback/Recommendation Experiences for Other Fleet Operators: Only with the Cases of Private Organizations

4.8.2. Summary and Recommendations

In this Chapter, it was explored what would affect the participating organizations' repurchase plans for heavy-duty CNGVs and their feedback/recommendation experiences to other fleets, particularly in relation to their overall satisfaction on the technology and their investment status of refueling facilities. The main insights obtained are summarized below.

- [**INSIGHT 42**] HDV fleets with investment already made in CNG on-site refueling facilities tend to plan higher penetration rates of CNGVs within their fleets than others those are using off-site fueling stations.
- [**INSIGHT 43**] Those HDV fleets that are highly satisfied with CNGV operations - in both terms of CNGVs and refueling facilities - tend to plan higher penetration rates of CNGVs than other less-satisfied fleets.
- [**INSIGHT 44**] Most of the HDV fleets those are highly satisfied with CNG vehicles - both across public and private organizations - tend to provide their positive or at least neutral feedback to other fleet operators.
- [**INSIGHT 45**] Some private fleet operators seemed intentionally inactive in sharing their CNGV experiences with other fleet operators – despite their satisfactory experiences in CNGV operations –, whereas there are some public/private organizations who try to actively disseminate information about the new technologies by providing recommendation and even education.

Accordingly, the following recommendations are suggested:

- Investigation into a more accurate relationship between investment status in refueling/recharging facilities and fleet-level penetration rates of AFVs, and how such fleet-level penetration rates would affect the overall AFV market share in the HDV sector

- (If the AFV market share turns out to significantly rely on whether to have on-site fueling facilities) The same recommendations provided in Chapter 4.7 (e.g., provision of sufficient guidance and financial incentives for building on-site fueling/charging facilities)
- Investigation into a more accurate relationship between dis/satisfaction on heavy-duty AFVs and fleet-level penetration rates of AFVs, and how such fleet-level penetration rates would affect the overall AFV market share in the HDV sector
- (If the ultimate heavy-duty AFV penetration rates turn out to significantly rely on the satisfaction levels) The same recommendations in Chapters 4.6 and 4.7 to facilitate AFV operations and increase satisfaction
- Investigation into how information-sharing activities (e.g., providing feedback/recommendation to others) would affect the overall AFV market share in the HDV sector
- Provision of events intending to disseminate practical information on heavy-duty AFV operation between adopters and non-adopters
- Targeted education for key decision-makers in certain industries with inactive interaction with other fleet operators
- Incentives to support those organizations who try to actively disseminate information about heavy-duty AFVs by providing recommendation and education for other fleets

4.9. Opinions on Financial Incentives

Financial incentives can be used to offset the incremental costs between conventional diesel and alternative fueled HDVs, and to reduce construction costs of refueling/charging infrastructure – if an organization would plan to build such infrastructure on site. This chapter intends to explore the effect of financial incentives on heavy-duty AFV adoption of the participating organizations. Given that a majority of the participants adopted CNG, and they applied for Natural Gas Vehicle Incentive Project (NGVIP), the analysis in this work is mainly focused on the CNG adopters and the NGVIP, although it was attempted to obtain data other incentive programs they utilized. Accordingly, the data on the following interview questions were collected and analyzed:[33]

- **Q12 (Incentive programs) (a)**: "Along with the NGVIP, are there any other incentive programs that you received financial incentives from?"
- **Q12 (b)**: "If it were not for NGVIP, would you still consider buying NGVs?"
- **Q12 (c)**: "Did NGVIP encourage you to buy more NGVs than what you initially planned?"

The answers from the participating organizations are summarized in Tables 4-12. After a series of discussion between the multiple researchers, the following insights were identified and verified.

[33] In addition to that, other interview questions were asked regarding how they became aware of the incentive program, and if they have any suggestions for improvement of the incentive program, of which analyses are provided in Appendix F.

Table 4-12. Incentive Programs Used for Heavy-duty AFV Adoption and Effect of NGVIP on Vehicle Purchase

Org. (vocation)	**Public vs. Private**	**Fleet size**	**Incentive programs used or applied** [a]		**Effect of NGVIP on heavy-duty NGV purchases**		
			For vehicle purchases	**For refueling infrastructure construction**	**Buy vs. Not buy w/o incentives** [b]	**Buy more thanks to incentives?** [b]	**Effect of NGIVP on CNGV purchases** [c]
Org. 01 (school bus)	public	medium	Carl Moyer, NGVIP, SCAQMD & DERA (for 1st NGVs)	CEC, SCAQMD	n/a	n/a	n/a
Org. 02 (various)	public	medium	Only NGVIP	MSRC	Yes	No	Low
Org. 03 (various)	public	large	NGVIP, other incentives	MSRC and some grant funding	Yes	Yes	Medium
Org. 04 (delivery)	private	medium	NGVIP, Prob 1B	Carl Moyer	Depends on	Yes	High
Org. 05 (delivery)	private	medium	Carl Moyer, NGVIP, SCAQMD, CEC, other incentives, Fed gas tax rebate	n/a	Would make it difficult	Yes	Very High
Org. 06 (refuse)	private	large	Only NGVIP	n/a	Yes	No	Low
Org. 07 (refuse)	private	large	Carl Moyer, CARB HVIP, NGVIP, SCAQMD	No (that was all internally funded)	Would make it difficult	Yes	Very High
Org. 08 (trucking)	private	small	Carl Moyer, CARB VIP, Prob 1B	Will apply for incentives	Depends on	Yes	High
Org. 09 (various)	public	large	NGVIP (*n/a whether they applied for others)	CEC	Yes	No	Low
Org. 10 (various)	public	large	DERA, NGVIP, other incentives	No (that was all internally funded)	Would make it difficult	Yes	Very High
Org. 11 (refuse)	private	medium	Only NGVIP	Will apply for incentives	Yes	No	Low

Org. (vocation)	**Public vs. Private**	**Fleet size**	**Incentive programs used or applied** [(a)]		**Effect of NGVIP on heavy-duty NGV purchases**		
			For vehicle purchases	**For refueling infrastructure construction**	**Buy vs. Not buy w/o incentives** [(b)]	**Buy more thanks to incentives?** [(b)]	**Effect of NGIVP on CNGV purchases** [(c)]
Org. 12 (school bus)	private	large	NGVIP (*n/a whether they applied for others)	n/a	Yes	Yes	Medium
Org. 13 (various)	public	large	CVRP, NGVIP	n/a	Yes	No	Low
Org. 14 (refuse)	private	large	NGVIP (*n/a whether they applied for others)	Carl Moyer, SCAQMD	Would make it difficult	Yes	Very High
Org. 15 (various)	public	large	NGVIP, Other incentives	Some grant funding	Depends on	Yes	High
Org. 16 (various)	public	large	Only NGVIP	n/a	Yes	Yes	Medium
Org. 17 (refuse)	public	large	NGVIP, other incentives	Some grant funding	Yes	Yes	Medium
Org. 18 (paving)	private	small	Only NGVIP (but cancelled due to their rejection decision)	n/a	n/a	n/a	n/a

[Note] (a) CARB HVIP: Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (https://www.californiahvip.org); Carl Moyer Program (https://www.arb.ca.gov/msprog/moyer/apply/apply.htm); CVRP: California Vehicle and Replacement Program; DERA: Diesel Emissions Reduction Act (federal DERA Funding); MSRC: Mobile Source Air Pollution Reduction Review Committee; NGVIP: Natural Gas Vehicle Incentive Project; Prob 1B: Goods Movement Emission Reduction Program (Proposition 1B); n/a: the relevant information was not available during the interviews. (b) The answers to these questions are summarized: Q12(b) for "Buy vs. Not buy w/o incentives", and Q12(c) for "Buy more thanks to incentives" (c) The effect of NGVIP on CNGV purchase are summarized with the four categories. "Very High": the incentives highly motivated the organization to buy CNGVs, and made them buy more than initially planned, "High": the incentives helped them buy the vehicles, and made them buy more, "Medium": the incentives did not motivate them to buy, however helped them buy more, and "Low": the incentives did neither make them buy nor buy more.

4.9.1. Results

Financial incentives extensively used for heavy-duty CNGV purchases and fueling infrastructure construction – Multiple financial incentive programs were utilized for heavy-duty CNGV purchases by more than half the CNG adopters to alleviate the incremental costs (see Table 4-12). To reduce the cost barrier to building on-site refueling facilities, many participating fleets (at least 10 out of 16, those who already built or will build the facilities) also utilized or plan to apply for financial incentives from one or multiple funding sources. Those organizations mentioned many incentive programs, including NGVIP, Carl Moyer Program, Prop 1B Program by SCAQMD, and CARB HVIP (Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project).

In contrast, some organizations (4 out of 17 CNG adopters) stated that they used only NGVIP, which might be affected by several possible reasons including unawareness of other incentive programs, being not allowed to apply for those programs (e.g., due to a limited scope), or being unnecessary to apply for those programs (e.g., thanks to sufficient internal funds). In case of unawareness of other incentive programs was only the reason for not utilizing those incentive opportunities, more active distribution of the information on those incentive programs might be needed.

Unavailability of financial incentives would make it difficult for some fleets to purchase CNGVs – For the question Q12 (b), "*If there were no financial incentives available, would you still consider buying NGVs?*", several organizations stated that the unavailability of financial incentives would make it difficult to continue with CNGVs or at least slow down the replacement of old diesel with CNGVs: "*We'll consider it, but it's going to be an uphill* *battle to come up with the incremental costs*" (Org. 10); "*It would slow us down for sure*" (Org. 14). This would imply a high impact of the financial incentives on the adoption decision at the timing they prefer. Such a high effect of the incentives was more often stated by private companies (3 out of 8) than public organizations (1 out of 8). At the same time, about a half of the organizations (9 out of 16 respondents) expressed a confirmed willingness to pay for CNGVs regardless of the availability of incentives. Such confirmed willingness to purchase without incentives was more commonly mentioned by public entities (6 out of 8 public CNG adopters) than private companies (3 out of 8 private CNG adopters). Meanwhile, some organizations neutrally addressed: their WTP without incentives would depend on whether "*the additional expense can be justified*" (Org. 4) when considering other factors such as the capital available, return on investment (ROI), and the usage of the vehicles (Org. 15).

Financial incentives would help some fleets purchase more CNGVs than what was initially planned – For the question Q12(c), "Did NGVIP encourage you to buy more NGVs than what you initially planned?", about two thirds of the respondents (11 out of 16) stated that the incentives made them buy more CNGVs or accelerated the replacement of their old diesel vehicles with CNGVs. In related quotes, one stated, "*We probably would have purchased less had the financial incentives offered by NGVIP not been in place*" (Org. 12). Another also addressed, "*It helps us expedite it, so [...] additional funds, we could potentially buy more and, you know, replace more vehicles sooner rather than later*" (Org. 3). Such positive impact of the financial incentives on the replacement plan were often addressed by both public (5 out of 8 public adopters) and private organizations (5 out of 8 private adopters), across small, medium, and large fleets. On the other hand, for about a third of the respondents (5 out of 16), the incentives did not seem to influence their replacement plan: "*In our case, it did not. We didn't deviate from our replacement plan at all, because NGVIP was available [...]*" (Org. 2).

The overall data obtained regarding the effect of financial incentives on heavy-duty CNGV purchases are summarized in Table 4-12. Various levels of such effect could be grouped into the following categories:

a) Very High (the cases where the incentives highly motivated the organization to buy CNGVs, and made them buy more than initially planned)
b) High (the incentives helped them buy the vehicles, and made them buy more)
c) Medium (the incentives did not motivate them to buy, however helped them buy more)
d) Low (the incentives did neither make them buy nor buy more).

While various effectiveness levels of the incentives tend to be spread across the 16 respondents[34], different fleet characteristics tended to be captured between the various effectiveness levels. For example, compared to the fleets with a less impact of incentives (i.e., Medium or Low levels), the fleets with a higher impact of incentives (i.e., Very High or High levels) tend to comprise a larger number of small fleets and private organizations.

However, it should be underscored that the sample used for this analysis is too small to produce generalized findings. When a large sample of fleet operators becomes available from those who have applied for financial incentives, more accurate and

[34] Very High effect: 4 organizations, High effect: 3 organizations, Medium: 4 organizations, and Low effects: 5 organizations.

comprehensive investigation can be conducted to examine the effect of such incentives on heavy-duty AFV adoption decisions.

4.9.2. Summary and Recommendations

In this Chapter, the various levels of the effect of financial incentives were explored regarding the heavy-duty CNGV adoption by the participating organizations. The findings are summarized below.

- [**INSIGHT 46**] Financial incentives were extensively used for heavy-duty CNGV purchases and fueling infrastructure construction among the participating organizations
- [**INSIGHT 47**] Unavailability of financial incentives would make it difficult for some fleets to purchase heavy-duty CNGVs
- [**INSIGHT 48**] Financial incentives would help some fleets purchase more CNGVs than what was initially planned

Based on these insights, the following recommendations are suggested:

- Provision of financial incentives to offset incremental costs between diesel and alternative fueled HDVs
- Provision of financial incentives to reduce construction costs for building fueling/charging infrastructure
- Further research to examine the effect of existing financial incentive programs on heavy-duty AFV adoption decisions across various fleet characteristics (fleet size, sector, vocation, etc.) in order to determine better-targeted fleets

- Further research to estimate a market share of heavy-duty AFVs in the future between multiple scenarios - with and without financial incentives, certain levels of incentive amounts - in order to explore better incentive schemes resulting in more AFV penetrations

4.10. Perspectives on Viable Alternative Fuel Options for HDVs in 2030s

In the previous Chapter 4.4, the work focused on the revealed behavior of HDV fleet operators regarding their adoption or rejection decisions that have already been made, which provides insights into promising or discouraging factors affecting their decisions in the current era. However, fleet operator attitudes or potential behavior toward future heavy-duty AFV market may or may not be fully consistent with their current adoption behavior; that would depend on their perspectives on technology advancement status and government guidance/support in the future. The investigations into this topic are provided in this Chapter 4.10.

Previous studies tended to investigate *what factors* would affect or have influenced adoption decisions of alternative fuels (e.g., Seitz et al., 2015; Pfoser et al., 2018; Mohamed et al., 2018; Blynn and Attanucci, 2019 as well as Chapter 4.4). Meanwhile, some studies explored not only influencing factors but *perspectives on viable alternative fuel options* in the future (Anderhofstadt and Spinler, 2019; Parker et al., 1997; Walter et al., 2012). Walter et al. (2012) performed a choice experiment targeting Swiss and German fleet operator to assess their preferences for hydrogen-powered sweepers, highlighting a potential market niche for hydrogen sweepers with an approximately 7% preference share notwithstanding diesel sweepers being by far the most preferred (around 71% share) followed by CNG/biogas (around 22%). The researchers also found two monetary attributes – vehicle purchase price and running costs – to have the most substantial influence on the purchasing decisions while polluting emissions also occupy an important position among a set of six attributes they experimented (Walter et al., 2012). Another study by Anderhofstadt and Spinler (2019) employed the Delphi method to determine promising alternative fuel options for the German HDV sector and to examine the factors affecting heavy-duty AFV adoption. The authors addressed battery electric, hydrogen, CNG and LNG as promising, and identified truck reliability, available fueling infrastructure, the possibility to enter low-emission zones, and current and future fuel costs as the key factors (Anderhofstadt and Spinler, 2019). On the other hand, the study by Parker et al. (1997) conducted a questionnaire survey over two decades ago, in which 139 U.S. trucking fleet operators responded. The authors found that fleets believed that the most viable fuel options by the year of 2000 would be clean diesel/reformulated gas (90.6% of responses) and natural gas (CNG, 4.3% and LNG, 2.2%) with electricity perceived as nonviable (0%) (Parker et al., 1997). Though informative, these study findings focused on the European HDV sectors (Anderhofstadt and Spinler, 2019; Walter et al., 2012) which limits their transferability to other regions due to different culture, policy context, and market conditions. Other outdated results (e.g. (Parker et al., 1997)) have limited applicability as the heavy-duty AFV market has significantly changed from then to now.

In that sense, this work seeks to explore the perspectives HDV fleet operators on viable alternative fuel options in 2030s, and investigate main motivators for and barriers to the adoption of such fuels in the future. Accordingly, the following interview question was asked:

- **Q13** (Perspectives on viable alternative fuels in 2030s): “If you look 10 to 20 years down the road, what do you think about viable options of alternative fuel vehicles in the heavy-duty sector?”

To analyze the interview data, thematic analysis (Boyatzis, 1998) was employed. After filling in a data abstraction sheet using the interview data, a series of discussions between the participating researchers was held to identify, review, refine, and finalize the resulting themes and hypotheses in order to address the research questions.

4.10.1. Overview of Results

As a part of the thematic analysis results, Figures 4-23 to 4-25 present a visual summary of the answers obtained from the participating organizations. For the interview question, "*If you look 10 to 20 years down the road, what do you think about viable options of alternative fuels for your heavy-duty vehicles*?", the participants' positive opinions are marked with a symbol of "**+**", negative remarks are with "**–**", and neutral statements with "*n*". In Figure 4-23, the organizations' basic fleet information such as sector, fleet size, and vocation, and their experiences in heavy-duty AFVs are presented along with these abstracted symbols of their perspectives on viable fuel options. Seventeen out of 18 participating organizations are CNG adopters while one organization stated that they considered but rejected the adoption of a CNG vehicle. Along with CNG, three organizations adopted LNG, four adopted propane, and one adopted electric refuse trucks. In addition, four organizations use renewable diesel instead of conventional diesel.

An interesting feature observed from this visual overview is that many fleet operators appeared to have perspectives that seem inconsistent with their current AFV adoption status. For example, although most of the organizations interviewed have rejected the adoption of an electric HDV, many of them expressed their opinions on electric HDVs

(14 out of 18), including very positive remarks from four, positive or neutral comments from four, and mixed viewpoints from three organizations. One organization, which adopted electric trucks, presented rather some negative opinions. Of many CNG adopters, less than two thirds of those (10 out of 17) regarded CNG as promising or foreseeable in 2030s though three of them added a somewhat neutral remark that the fuel would be transitional. Despite none of the participants being hydrogen adopters, five organizations expressed opinions about hydrogen HDVs, including three fleets with positive/neutral remarks and two with negative statements. Lastly, only one propane adopter explicitly expressed their positive opinion while the other three propane adopters did not address the fuel as a viable option.

Aside from electric, hydrogen, CNG, propane, and hybrid HDVs, no participants addressed other alternative fuels such as LNG, biodiesel, and ethanol. Some organizations explained their non-adoption decisions of those fuels by citing several reasons, including as numerous maintenance problems (e.g., LNG non-adoption by Org. 9), engine reliability issues (e.g., biodiesel non-adoption by Org. 8), and uncertain environmental benefits and unpredictable fuel price (e.g., E85 non-adoption by Org. 7) in other interview questions (see Chapter 4.4 for more details). Such adverse experiences would cause disinterest in those fuels as a future option.

While probing into the complicated contexts underlying the perspectives of participating fleet operators toward viable fuel options, 24 textual categories were identified across the diverse fuels above mentioned. Figures 4-24 and 4-25 show the list of positive (with "**+**" symbols), negative ("**–**"), and neutral remarks ("n") made by the corresponding organizations about each fuel technology in 2030s. The following subchapters discuss the main motivators for, and barriers to the future adoption of electric, hydrogen, CNG, propane and hybrid HDVs, using with relevant quotations to illustrate specific points.

Organizations	01	12	11	06	07	14	17	08	04	05	16	02	09	03	13	15	10	18
Sector / Fleet size [a]	Pb M	L	M	L	L	L	Pb L	S	M	M	Pb L	Pb M	Pb L	Pb L	Pb L	Pb L	Pb L	S
Vocation	School buses		Refuse trucks					Freight trucking	Local delivery		Various public services							Paving work
Experiences in AFV operations [b]	CNG*	CNG LPG* New	CNG(*)	CNG*	CNG* LPG	CNG* LPG	CNG* LNG*	CNG(*) New	CNG(*) New	CNG*	CNG	CNG(*)	CNG*	CNG* RD	CNG* RD	CNG* LNG* RD	CNG* LNG* LPG ELEC(*) RD	none
Opinions on viable fuels in 2030s [c]: Electricity	+	+	–	+/–		+/n	+/–	–	+		n	+		+/–	+/n	+/n	–	
Hydrogen								–	+		–					+/n	+	
CNG	–				+		+	+			+	+/n	+	+	+/n	+	+/n	
Propane		+													–			
Hybrid [d]								n	+		+	+						

[Note] (a) Pb: public entities (c.f., private entities, otherwise unmentioned), L: large fleet size (>100 vehicles), M: medium fleet size (20-100), S: small fleet size (≤ 20). (b) Fuel: currently operating HDVs running on that fuel, Fuel*: have their own on-site fueling/charging facilities for that fuel, Fuel(*): will build their own on-site fueling/charging facilities for that fuel, CNG: compressed natural gas, LNG: liquefied natural gas, LPG: liquid petroleum gas or propane, ELEC: electricity, RD: renewable diesel, New: the year of the first heavy-duty AFV purchased was after 2015. (c) +: positive remarks were addressed, –: negative aspects were explained, n: remarks were neutrally stated, +/– or +/n: both different aspects were addressed. Org. 5 did not have any opinions. Org. 18 addressed a general remark rather than a fuel-specific opinion. (d) A vehicle that uses two or more types of power.

Figure 4-23. A Summary of Perspectives on Viable Alternative Fuel Options for HDVs

4.10.2. Electric HDVs in 2030s

Electric HDVs can draw electricity from the grid or other external sources by plugging the vehicle into the source, store electricity in batteries, and are powered solely by the electric batteries (U.S. DOE, 2020a). The vehicles are also called battery electric vehicles or all-electric vehicles (c.f., hybrid electric and plug-in hybrid electric HDVs have both a diesel-powered engine and an electric motor to drive the vehicle, which is discussed in a later subchapter). As of 2021 March, more than 20 manufacturers are offering electric HDVs in the U.S. across various fleet vocations including transit/school/shuttle buses, tractor trucks, sweepers and refuse trucks (U.S. DOE, 2021a). As outlined in Figure 4-24, many participating organizations regarded electric HDVs as promising because the technologies are advancing, produce zero tailpipe emissions, and are in line with the state's direction. Nonetheless, various concerns and uncertainties were reported relating to the vehicle's functional suitability, required charging infrastructure, vehicle availability, total life cycle emissions, and total cost of ownership.

(+) Emerging and advancing technologies – The most common positive opinion across diverse vocational areas was the electric HDV technologies being "*advancing very fast*", which made the fleet operators "*keep an eye on electric*" (Org. 3). As a related quotation, one refuse truck operator stated, "*I think [an electric HDV] is going to have adequate power to operate all the functions necessary to operate a collection vehicle where it packs its load as it goes, et cetera. I think everything will be battery-operated 20 years from now*" (Org. 6).

(+) Environmental benefits with zero tailpipe emissions – A crucial need of zero emission vehicles (ZEVs) for the future was emphasized by both public and private fleet operators. For example, one addressed, "*My priority would eventually get that zero emissions, whether it's electric or some other, hydrogen, [...] I'm aware of the change over the years and the bottom line for companies now threefold. It used to be all profit, and then it became profit and people, and now it's profit, people, and planet. [...] I believe [all electric] is the way that we need to go*" (Org. 4).

(+) The state's and industry's direction – Some public organizations emphasized that there is "*the big push right now towards electric vehicles*" (Org. 13). One city fleet operator described, "*Maybe, in five to ten years, the industry [of refuse trucks and street sweepers] will be going electric*" (Org. 13). One school bus operator stated, "*It's just the matter of the time, before we get some electric buses, the state wants all electric by 2030*" (Org. 1).

(–) Functional unsuitability – Many fleet operators perceived functional suitability of electric HDVs as still unresolved. Several organizations addressed that "*heavy batteries*" caused "*range issues*", which requires "*a need for learning*." For example, one described, "*There's a lot of added weight to get the range that you need [...] I think electric is coming a long way just once again with batteries*" (Org. 3). Another stated, "*There's a lot yet to be learned in that alternative style of power [due to heavy batteries]*" (Org. 11). In addition, uncertain functionality in payload capacity or vehicle power was addressed by refuse and hauling truck operators: "*[Electric HDVs] are certainly are in a need of capacity to haul* *payloads of waste*" (Org. 11); "*[Electric HDVs] would work great for drayage at ports or local delivery, but they wouldn't work in an application like what I'm doing [hauling]*" (Org. 8).

(–) Insufficient infrastructure – The organization that adopted electric HDVs highlighted "*a lot of feasibility problems*" associated with insufficient charging infrastructure, which made them perceive widespread deployment of the vehicles "*in the near term*" less promising: "*From a practicality standpoint, heavy-duty electrification, it's going to be a hard sell any time soon, because of the charging infrastructure and demand charges potentially from our electric utilities [...]*" (Org. 10).

(–) Perceived unavailability of electric HDVs – A limited number of available vehicle models for certain vocations (e.g., only a couple of models for electric refuse trucks at the time we were interviewing) made some fleet operators think that electric HDVs are still commercially unavailable: "*As far as HDV application, we have not seen widespread application of that yet. We saw a few demonstration projects here and there, but none to commercialization as we are aware of*" (Org. 17).

(n) Total cost of ownership – The willingness to pay (WTP) for electric HDVs would depend on "*whether it's cheaper and pays for itself, that makes good business sense*" (Org. 14) and "*what the ROI [return on investment] is*" (Org. 15) from a business standpoint.

(n) Total life cycle emissions – The WTP would also be based on the evaluation of life cycle analysis of carbon intensity. One explained, "*I want to say [sustainability group] look at the total fuel cycle analysis [...] where they consider the carbon intensity of the entire process*" (Org. 13).

Organizations vocations		01 school bus	02 vari-ous	03 vari-ous	04 deli-very	05 deli-very	06 refuse	07 refuse	08 truck-ing	09 vari-ous	10 vari-ous	11 refuse	12 school bus	13 vari-ous	14 refuse	15 vari-ous	16 vari-ous	17 refuse	18 paving
Electric HDVs	+ Emerging and advancing technologies			X			X						X		X	X		X	
	+ Environmental benefits with zero tailpipe emissions		X		X														
	+ The state and industry's direction	X												X					
	- Functional/ operational unsuitability			X			X		X			X		X			X		
	- Insufficient infrastructure										X								
	- Perceived unavailability of electric HDVs																	X	
	n Total cost of ownership														X	X			
	n Total life-cycle emissions													X					
Hydrogen HDVs	+ Emerging and advancing technologies															X			
	+ Environmental benefits with zero tailpipe emissions				X						X								
	+ Practical/economical fuel production from renewable sources										X								
	- Higher incremental cost of the vehicle purchase																X		
	- Insufficient infrastructure																X		
	- Perceived unavailability of hydrogen HDVs								X										
	n Total cost of ownership															X			
CNG HDVs	+ Continued use of CNG due to the investment already made			X				X	X	X									
	+ Viable fuel option (though transitional)		X*								X*			X*		X	X	X	
	- Not being in line with the State's direction	X																	

[Note] X: the textual categories were stated by the corresponding organizations, X*: a neutral remark was added that CNG would be a transitional fuel option, though foreseeable.

Figure 4-24. Perspectives on Viable Alternative Fuels for HDVs in 2030s: Electricity, Hydrogen, and CNG

4.10.3. Hydrogen HDVs in 2030s

Hydrogen HDVs (a.k.a., fuel cell electric HDVs) use hydrogen in a fuel cell to generate electricity to power the electric motor (U.S. DOE, 2020a). As of 2021 March, Only few manufacturers provide hydrogen HDVs for shuttle and transit buses, step van, and tractor trucks in the U.S (U.S. DOE, 2021a). Given that hydrogen HDVs are in the early stages of implementation, the hydrogen option received relatively less attention than electric HDVs from the organizations interviewed. Several organizations addressed hydrogen's positive or negative aspects equivalent to those of electric HDVs. Meanwhile, hydrogen HDVs were positively viewed as a practical and economical fuel option when being produced from renewable sources.

(+) Emerging and advancing technologies – One organization recognized that hydrogen HDVs technologies will be more advanced, along with the electric option: "*Electric and hydrogen HDVs remains to be seen [in the 10-20 years down the road]*" (Org. 15).

(+) Environmental benefits with zero tailpipe emissions – As hydrogen HDVs emit only water vapor and warm air, they thus produce no tailpipe emissions. Moreover, when producing from renewable energy sources (e.g., biomass, wind, and solar), hydrogen HDVs can avoid the emissions associated with energy production (U.S. DOE, 2020a). Some public and private fleet operators emphasized such environmental benefits from the ZEVs: "*Certainly a lot of emissions benefits from a well-to-wheels perspective [...] Hydrogen is the true zero emissions if you're getting it from renewable sources*" (Org. 10).

(+) Practical and economical fuel production from renewable sources – An additional promising remark on hydrogen (e.g., in terms of "*practical*" and "*economical*" fuel production) was emphasized by the most progressive alternative fuel adopters among those interviewed (Org. 10). The participant stated, "*10 or 20 years down the road, I think we're going to have hydrogen. Because it's a practical fuel, it's already coming to market. We just have to have more of it produced from renewable sources regionally, not just trucked in like it is now. It can be produced economically*".

(–) Higher incremental cost of the vehicle purchase – Another major barrier is the "*huge purchase cost*" of the vehicle (Org. 16). For example, a hydrogen transit bus costs around $1.2 million, compared to $750,000 for an electric bus, and $500,000 for a diesel bus (Maloney, 2019; Webb, 2018).

(–) Insufficient infrastructure – Despite the increased number of hydrogen fueling stations in California (e.g., 41 stations in 2020 compared to 25 in 2016) (U.S. DOE, 2020b), fleet operators still regard the infrastructure as extremely restricted (e.g., "*no infrastructure [for hydrogen]*" (Org. 16)).

(–) Perceived unavailability of hydrogen HDVs – Due to only few vehicle models available in the market, some fleet operators perceive the hydrogen option as commercially unavailable. Furthermore, the hydrogen option is not provided for several heavy-duty vocations (e.g., refuse trucks and street sweepers) in the U.S (U.S. DOE, 2021a). One explained, "*[Technology providers] are just scratching the surface on the hydrogen. [Only t]he concept vehicles out*" (Org. 8).

(n) Total cost of ownership – "*What the ROI is for those [hydrogen HDVs]*" are one of the aspects that should be evaluated (Org. 15).

4.10.4. CNG HDVs in 2030s

CNG HDVs use compressed natural gas which is stored onboard a vehicle (U.S. DOE, 2020a). CNG vehicles are commercially mature technologies which are used in diverse heavy-duty applications including transit, school, and shuttle buses, tractor trucks, refuse trucks, and street sweepers (U.S. DOE, 2021a). As of 2021 March, around 100 vehicle models available from about 31 manufactures (U.S. DOE, 2021a). Many participating fleets, particularly those already adopted CNG, regarded the fuel as a viable choice in 2030s, mainly due to the fact that they previously invested in the vehicles and on-site fueling facilities. However, some organizations offered partially neutral remarks that CNG would be a transitional fuel, ultimately towards electricity. Meanwhile, one pointed out that CNG is not in line with the state's direction.

(+) Continued use of CNG due to the investment already made – Both in small and large fleets across various vocational sectors, several organizations of those who already built on-site CNG fueling facilities, stated that CNG will still be in their plan "*for the next 10, 15, maybe even 20 years*" (Org. 3). One further explained, "*In refuse collection services, I'm under the assumption that we would only be heavily using CNG vehicles only because we have invested in the infrastructure, and we've invested in the conversion. I can't see in the next 10 to 20 years switching to a different type of alternative fuel*" (Org. 9).

(+) Viable fuel option (though transitional) – Even fleets that had not made investments in on-site fueling facilities anticipated continued use of CNG with one organization predicting "*increased use of CNG in HDVs*" (Org. 16). Another fleet operator further described promising aspects of CNG such as "*relatively inexpensive and pretty clean with the near zero engines*" (Org. 15). However, there was a neutral opinion that CNG is a transitional option towards electric solutions. One stated, "*I think that the natural gas is a real transitional fuel. I think it's gonna get us from really dirty diesel to cleaner electric, hybrid type solutions. […but…] The foreseeable alternative fuels for me are still CNG*" (Org. 2).

(–) Not being in line with the State's direction – One fleet operator indicated that they perceived CNG as disaccord with the state's plans: "*[Regarding] what future funding is, right now, [...] CNG vehicles and CNG Infrastructure are not on the radar*" (Org. 1). For instance, the Clean Transportation Program by California Energy Commission (CEC, 2020a), which had allocated around $14 million on annual average for natural gas vehicle incentives or infrastructure projects until 2018, has not provided the funding since the program began to prioritize ZEVs. Nevertheless, one organization underscored the need for CNG until the feasibility problems with electrification are resolved: "*If our state doesn't put all of their eggs in one basket with electric trucks, we're going to continue to buy CNG. [...] There's just a lot of feasibility problems with thinking that we're going to get there [electrification] in the near term, and we've got to do something in the meantime*" (Org. 10).

Organizations / vocations		01 school bus	02 vari-ous	03 vari-ous	04 deli-very	05 deli-very	06 refuse	07 refuse	08 truck-ing	09 vari-ous	10 vari-ous	11 refuse	12 school bus	13 vari-ous	14 refuse	15 vari-ous	16 vari-ous	17 refuse	18 paving
Propane HDVs	+ Continued use of propane due to the investment already made												X						
	- Perceived lower viability (compared to CNG and electric options)													X					
Hybrid HDVs	+ Improved uncertainty in fueling costs and fleet routing		X														X		
	+ Drivers' favorable acceptance																X		
	+ Environmental benefits with low tailpipe emissions				X														
	n Functional/ operational suitability and total cost of ownership								X										
Other remarks	n Potential safety issues																		X
	n Any types of fossil fuel vehicles will be closing up				X				X										
	n Heavy-duty AFV market will not change much from now							X											
	n I have no opinions					X													

[Note] X: the textual categories were stated by the corresponding organizations.

Figure 4-25. Perspectives on Viable Alternative Fuels for HDVs in 2030s: Propane, Hybrid, and Others

4.10.5. Propane HDVs in 2030s

Propane (a.k.a. liquid petroleum gas) is produced as a by-product of natural gas processing and crude oil refining. In a propane HDV, the fuel is stored onboard in a pressurized tank which makes it liquid (U.S. DOE, 2020a). As of 2021 March, there are over 30 propane HDV models available from about 10 manufacturers for several fleet applications such as school buses, shuttle buses, and vocational trucks (U.S. DOE, 2021a).

Compared to electricity, hydrogen, or CNG, propane HDVs received limited attention from the participating organizations as a viable fuel option.

(+) Continued use of propane due to the investment already made – One organization, who already built on-site propane stations for more than 2,000 propane buses being operated in the U.S., expressed the commitment to their continued use of propane: "*I would hope to think that 20 years from now […] 90 percent of our fleet would either be propane or electric. And I'm fairly confident that that will occur*" (Org. 12). In contrast, the other three propane adopters (e.g., Org. 7, 10, and 14) – those who rely on off-site propane stations or wet-hosing (i.e., an arrangement with a propane vendor to come and bring a propane tank and fill up the vehicles on site) – did not mention propane as a future fuel option, presumably due to lack of interest or perceived unviability.

(−) Perceived lower viability – One organization explicitly commented that "*propane would be our least viable option*" (Org. 13). Though the organization has experience in operating light-duty propane vehicles, they "*were actually trying to get away from propane*" as they favored electricity and CNG options.

4.10.6. Hybrid HDVs in 2030s

Hybrid HDVs use two or more types of power (CEC, 2020b). For example, plug-in hybrid electric vehicles (PHEVs) have a diesel-powered engine together with an electric motor that uses energy stored in a battery. PHEV batteries can be charged by being plugged in to an electric power source, or through regenerative braking (U.S. DOE, 2020a). Hybrid electric vehicles (HEVs) also use both diesel and electricity to drive the vehicles, but they can recharge their batteries only through regenerative braking (U.S. DOE, 2020a).[35] As of 2021 March, only a couple of manufacturers provide hybrid HDVs in the U.S (U.S. DOE, 2021a). Some participating organizations addressed hybridization as a viable option while reporting a few unique advantages such as potential economic savings, which could result from less uncertainty in fueling costs and fleet routing, and increased acceptance from drivers.

(+) Improved uncertainty in fueling costs and fleet routing – Alternative fuel prices are not always lower than those of conventional fuels (e.g., average retail fuel prices for CNG in the U.S. was $2.30/diesel gallon equivalent vs. $1.90/gallon for diesel in 2016 April (U.S. DOE, 2020c)). Moreover, an additional markup is sometimes applied at some off-site fueling stations (Org. 2 and 4). Furthermore, alternative fuel stations are not as abundant as gas stations, which increases complexity of fleet routing plans that must incorporate refueling stops. Taken together, in some cases, these aspects can lead to uncompetitive operational costs of the vehicles running only an alternative fuel. Hybridization could resolve these drawbacks to some extent as the vehicle can run on either alternative or conventional fuels: "*Hybridization will result in real economic savings. […] Look, I have hybrid [light-duty electric vehicles] in my fleet. We're doing maximizing [driving of] those hybrids [… in contrast…] We never really realized the cost savings on our [dedicated] CNG trucks, another point*" (Org. 2).

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[35] There are various types of hybrid HDVs, including PHEVs, HEVs, and other emerging technologies such as CNG hybrid trucks (e.g., (HYLIION, 2021)). Though such different hybrid types are technically different with distinct benefits and concerns, the participating fleet operators tended to address those vehicles as a common general concept of vehicles that can run on either a conventional fuel or an alternative fuel.

(+) Drivers' favorable acceptance – Hybrid vehicles can potentially receive favorable acceptance from vehicle drivers (Org. 16), mainly owing to diminished range anxiety.

(+) Environmental benefits with low tailpipe emissions – Hybrid vehicles can bring environmental benefits with reduced tailpipe emissions particularly when running on alternative fuels (Org. 4).

(n) Functional/operational suitability and TCO – The WTP for a hybrid HDV would depend on whether it satisfies the functional suitability required for a certain application, and the resulting overall costs. One trucking company explained, "*It's going to depend on the weight of the vehicle. Because those [hybrid] electric vehicles are so heavy that you just start cutting into your bottom line. […] We're saving money over here, but we're not making as much on the payloads*" (Org. 8).

4.10.7. Other Remarks

One fleet operator in a paving company stated that viability of any fuel options will depend on whether the fuel and vehicle technologies can "*assure no safety concerns*" for their vocational application (Org. 18). On the other hand, some organizations noted that the use of "*any type of fossil fuel vehicles [will be] sort of closing up in time*" (Org. 4) and "*there's no reason for me to go back to diesel as long as the alternative fuels keep progressing*" (Org. 8). Nevertheless, there was an opinion that the heavy-duty AFV market in the U.S. will not change much from now without other states' participation and more effective market actions that can attract fleet operators to purchase AFVs: "*If you look at how, where we've* *come in the last ten years – it's all market driven. […] I just don't see a huge demand anywhere else other than California. […] So, in the next 20 years if nothing changes? I see things very much the same. You know, maybe, they'll be a few improvements […] But, I don't see the landscape changing significantly unless other states are purchasing a lot more trucks and the market opens up and other people jump in*" (Org. 7).

4.10.8. Summary and Recommendations

Despite the aggressive policy goals to reduce HDV-generated emissions, such as the Advanced Clean Trucks and Fleets regulations in California aiming to accelerate a large-scale transition of zero-emission HDVs by 2045 everywhere feasible (CARB, 2021a, 2021c), the demand-side understanding regarding alternative fuel adoption in HDV fleets is still limited. This work investigated HDV fleet operator perspectives on viable alternative fuel options in 2030s using in-depth qualitative interviews followed by thematic analysis. Electric, hydrogen, CNG, and hybrid options were commonly perceived as viable to some extent by the participating organizations. Across 24 textual categories identified for those alternative fuel options, many motivators were addressed, including advancing technologies and emission reduction benefits (electric/hydrogen), continued commitments due to their investment already made (CNG), and alleviated uncertainty in fleet routing along with drivers' favorable acceptance (hybrid options). However, many concerns were also reported, including functional unsuitability (electric), expensive upfront costs (hydrogen), unready infrastructure, perceived unavailability, uncertain TCO (electric/hydrogen), and diminishing support from state governments (CNG). The main insights in this work are summarized below:

- [**INSIGHT 49**] (Electric HDVs in 2030s) Electric HDVs received the most popular attention from the organizations interviewed. Most of them perceive electricity as a promising fuel option for HDVs in 2030s; because the technologies are advancing, produces zero tailpipe emissions, and are line with the state's and industry's direction. However, many organizations were unsure about the vehicle's functional suitability and the feasibility regarding charging infrastructures.
- [**INSIGHT 50**] (Hydrogen HDVs in 2030s) Hydrogen HDVs received less attention than battery electric HDVs from the organizations interviewed. While its positive or negative opinions were similar to electric HDVs to some degree (e.g., the technologies being advanced, zero emission vehicles needed for the future, functional unsuitability for HDV applications), one distinct remark was that hydrogen can be a practical and economical option when producing from renewable sources.
- [**INSIGHT 51**] (CNG HDVs in 2030s) With the second most popular attention from the interviewees, CNG HDVs were positively addressed by almost all those organizations as a foreseeable fuel option which they are being committed to at least for 10 to 20 years. At the same time, some fleet operators stated that CNG is not in line with the state's direction: it would be a transitional option towards electricity.
- [**INSIGHT 52**] (Hybrid HDVs in 2030s) Only a few organizations provided their attention to hybrid options (e.g., hybrid electric or hybrid CNG HDVs) as a viable fuel for the future. The advantages of hybrid vehicles were addressed as being economic, good acceptance by users, and lower emissions than diesel vehicles. However, one organization possesses a neutral position in which their WTP for hybrid HDVs will depend on its functional suitability for a specific vocation.
- [**INSIGHT 53**] (Other Remarks on Viable Alternative Fuel Options for HDVs) LPG received a little attention from the participating organizations and the other alternative fuels (e.g., LNG, biodiesel, and ethanol) had no attention from them. While a few organizations presented their opinions that the use of fossil fuels will be ended in the future, another opinion was stated that alternative fueled HDV market in the U.S. will not be changed much from

now without other states' participation and more effective market actions – which can attract fleet operators to purchase alternative fueled HDVs.

The findings in this work are an important initial step toward supporting policy makers who seek to facilitate AFV adoptions among HDV fleet operators. Although there is a common optimism anticipating heavy-duty AFV technologies (particularly electric drivetrains) to continue advancing, decision-making processes of the adoption would hardly initiate without being assured of vehicle availability, functional/operational suitability for their fleet applications, and infrastructure availability. There is a variety of fleet vocations in HDV sector where each vocation has their own functional and operational requirements in terms of range, power, speed, and many other traits. Assisted by government research and development support together with fleet customers' extensive feedback, vehicle manufacturers should prepare and provide sufficient vehicle models that fulfill such vocational requirements particularly for those fleet applications where its limited availability is substantiated.

Moreover, insufficient infrastructure is another big challenge to the adoption by fleets. Recalling the hardship with many feasibility problems experienced by the organization that was constructing on-site electric charging facilities, not only financial supports but adequate technical assistances should be essential for those who build on-site fueling/charging facilities. Furthermore, off-site fueling and charging stations for heavy-duty AFVs might need to be available and accessible for those fleets that are unable to build on-site facilities due to, for example, a limited space (Tetra Tech and Gladstein Neandross & Associates, 2019). Given the aggressive transition targets toward zero-emission by the year of 2045 (CARB, 2021a, 2021c) and a severe lack of infrastructure, a well-designed infrastructure planning needs to be established by vigorous cooperation between fuel providers, manufacturers, governments, fleet operator communities, and other relevant agencies.

In addition, financial supports should continue to be offered with the intention to reduce expensive vehicle purchase costs along with other TCO components (e.g., fuel costs, maintenance costs, etc.), if needed, so as to ultimately make a TCO evaluation attractive. Provision of educational guidance regarding TCO calculations should certainly be preceded.

Lastly, the effort to increase awareness of alternative fuel options and their advantageous aspects should be more actively delivered to diverse fleet segments. It is worth noting that there was absence of attention for hydrogen as a viable fuel option by around two thirds of the participating organizations (despite they being assumed to be innovator or early adopter groups). Also, even some organizations perceived neither electric nor hydrogen options viable. Effective educational approaches should be therefore designed and implemented for comprehensive fleet categories including current adopters as well as non-adopters (i.e., from innovators to laggards). Furthermore, any resolutions of vehicle and/or fuel technological issues, if they previously caused concerns, should be rapidly communicated throughout fleet communities so that any misconceptions do not impede their decision-making processes.

Acknowledgements

Bae, Youngeun, Rindt, Craig R., Mitra, Suman K., and Ritchie, Stephen G. "Perspectives on Viable Alternative Fuels for Heavy-duty Vehicles in 2030s: Qualitative Interviews with California Fleet Operators." *The 100th Annual Meeting of the Transportation Research Board*, Online conference, Jan 2021. Poster presentation.

4.11. Limitations and Future Work

The qualitative research studies presented in Chapter 4 have several limitations. First, a sample size of around 20 organizations restricts the ability to generalize the findings, although it should be noted that small sample sizes are also typical of the labor and time-intensive qualitative research approach (Bryman, 2012). However, ongoing research involves a quantitative survey of a large representative sample in an effort to validate the qualitative inferences from this study and thus obtain more generalized findings (see Chapter 6.2.1 for an overview of the survey design and Appendix G for the survey item listing).

Second, beyond acknowledging the adoption barriers addressed by the participating fleets, it is essential to precisely examine how improved demand would be actualized with potential technology strategies for overcoming such barriers (e.g., upgraded vehicle functionality, more prevalent infrastructure, and enhanced vehicle availability). In addition, the effect of governmental policies, such as mandates or incentive programs, on heavy-duty AFV adoption decisions were explored in this study, but cannot be precisely estimated under such a qualitative approach. Further experimental investigations based on a stated preference survey are therefore needed to estimate the effect of such technology strategies and policy instruments on heavy-duty AFV adoption and to determine better-targeted fleets and improved policy schemes stimulating more AFV penetrations. The investigations into these areas are in progress with a case study of drayage fleets in California (See Chapter 6.2.2 and Appendix H for more details).

Third, non-adoption of heavy-duty AFVs in this research focused only on active rejection cases. While this study investigated what factors as decision criteria have led to such non-adoption, the mechanism of how fleet operators passively reject alternative fuel(s) was beyond the scope of this research. Therefore, further research needs to explore how passive non-adopters can become aware of alternative fuel technologies, how they can begin evaluating them as an alternative, and what are triggers and obstacles in such processes.

Fourth, a state-wide transition plan toward ZEVs could not be easily facilitated, considering the fleets who already invested a certain type(s) of AFVs and the fueling facilities. Further research is therefore suggested in order to explore flexible sets of transitional scenarios toward ZEVs with consideration of not only transition timing and fuel technology status, but required vocational functionalities and any investment status.

Finally, the findings from this research, with a broader range of topics – not only including factors affecting the decisions, but also decision-making processes, vehicle driver acceptance of AFV within an organization, satisfaction on vehicles and refueling facilities, and repurchase plans and recommendation experiences to other fleets – offer an enhanced understanding of heavy-duty AFV adoption behavior in organizations. This addresses a key knowledge gap in AFV adoption research regarding HDV fleet operator perspectives. Such improved understanding can serve as the basis for developing effective technological and policy suggestions with the purpose of aiding the success of AFV diffusion throughout the HDV market in the long run, ultimately ensuring greater benefits from reduced emissions and public health impacts.

CHAPTER 5: Conceptual Modelling Framework for Demand Analysis of Heavy-duty AFVs

The second objective of this dissertation research is to develop a model that is capable of performing a demand analysis for heavy-duty AFVs under different policy and technology advancement scenarios. The demand analysis in this research is defined as "*the analysis of fuel preferences and AFV share estimates under different policies and technology advancement scenarios which would vary in a medium- and long-term future*" (e.g., from the 2020s through 2030s). Ideally, the shares of AFVs are defined as "*the shares of a particular fuel type of HDVs in the total HDV population in a study area in a certain year*" (e.g., vehicle shares in the registrations for the California Department of Motor Vehicles). However, in case relevant data acquisition is unachievable, a narrower definition could be used instead, such as "*the shares of yearly sales for a particular fuel type of HDVs in a study area in a certain year*."

To this objective, use is first made of the qualitative research findings, presented in Chapter 4, to develop a conceptual modelling framework for analyzing demand of heavy-duty AFVs. Chapter 5.1 summarizes the qualitative inferences that were used for this modelling. Then, an overall model structure is presented in Chapter 5.2, followed by descriptions of specific modules and components in Chapter 5.3. Lastly, advantages and limitations of this modelling approach are discussed in Chapter 5.4.

5.1. Summary of Qualitative Inferences

The first task in developing a conceptual demand model was to review the qualitative analysis results and extract major inferences that need to be considered for the modelling. Table 5-1 presents the main qualitative inferences and key modelling insights under the following categories:

1) Fleet replacement/expansion plans
2) AFV choice behavior
3) Refueling/charging infrastructure choice behavior
4) Relationships between fleet replacement/expansion plans, AFV choices, and refueling/charging facility choices
5) Satisfaction on AFV operations
6) Fleet confirmation influencing their next decisions
7) Fleet confirmation influencing other fleet adoption decision
8) Decision-making processes

Table 5-1. Qualitative Inferences Used for Demand Modelling

Main Qualitative Inferences	Key Takeaways
Fleet replacement/expansion plans	
• [INSIGHT 6] Vehicle age, mileage, and vehicle conditions/maintenance need were commonly addressed as fleet replacement criteria. Other criteria include vehicle size, vocations, utilization, available budget, and business opportunity. • [INSIGHT 47] Unavailability of financial incentives would make it difficult for some fleets to purchase heavy-duty CNGVs.	• When an organization ends up paying more in maintenance than a truck is worth, they replace the truck with a new (or used) one. The timing of the replacement would be determined based on vehicle age, mileage, or vehicle conditions/maintenance needs. • The proxy criteria for replacement (e.g., certain ages or mileages) would differ

Main Qualitative Inferences	Key Takeaways
• [INSIGHT 48] Financial incentives would help some fleets purchase more CNGVs than what was initially planned.	across vehicle size, vocations, and utilization. • Depending on available budget and business opportunities, an organization would also plan to expand or shrink their fleet size. • Policy instruments would affect replacement/expansion plans: for example, financial incentives would help some fleets accelerate their replacement so that they could purchase more AFVs earlier than what was initially planned.
AFV choice behavior	
• [INSIGHT 9] Perceived technology characteristics, mainly in terms of functional suitability, monetary costs, fuel infrastructures, and reliability/safety of the vehicles and engines, were evaluated in a comprehensive approach for heavy-duty AFV adoption decisions. • [INSIGHT 10] Organizational intrinsic values, such as corporate social responsibility, environmental consciousness regarding diesel HDV emissions, or progressive efforts in demonstrating new technologies, as well as business strategic motives, such as contracts with municipalities, were strong motivators to overcome the major barriers (e.g., financial obstacles, uncertain functionality) to heavy-duty AFV adoption. • [INSIGHT 11] Governmental regulations requiring AFV or ZEV purchases in California, combined with a narrow range of available AFV models, have created constrained fuel choice circumstances toward a certain fuel option for some HDV fleets.	*[AFV choice behavior]* • Perceived technology characteristics, organization characteristics, and governmental policies would affect heavy-duty AFV adoption decision. • Technology supplier support and social influences could also have an impact on the decisions mediated through perceived technology characteristics. *[Quantities of AFVs to be purchased]* • Fuel diversification behavior should be carefully considered when converting estimated fuel choice probabilities into estimated quantities of AFVs to be purchased because some fleets (typically large fleets) would diversify while the others would adopt only a sinlgle type. *[For the choice experiment design to analyze AFV preferences]* • A set of attributes that could be used for the experiment design includes: several main technology characteristics (e.g.,

Main Qualitative Inferences	Key Takeaways
• [INSIGHT 12] Financial incentives have assisted HDV fleet alternative fuel adoption by reducing costs for purchasing the vehicles and supporting construction costs of on-site fueling/charging facilities. • [INSIGHT 27] Depending on an organization's experiences accumulated with the AFVs adopted, their perceptions on the AFVs would differ in terms of technological aspects and cost evaluations. • [INSIGHT 16] Opportunities to test a heavy-duty AFV and warranty/maintenance services provided by vehicle and engine manufacturers would positively affect the process of decision-making, particularly the Consideration and Adoption Decision stages. • [INSIGHT 19] Social networks can affect heavy-duty AFV purchase decisions in a way of obtaining feedback from other fleet operators who already have experiences in operating the vehicles and/or of following a social norm prevalent in the industry. • [INSIGHT 7] While many organizations evaluated multiple alternative fuel options and then rejected most of them except one or two fuel(s), a few organizations with large fleets adopted three or more types of alternative fuels. • [INSIGHT 49] (Electric HDVs in 2030s) Many participating organizations regarded electric HDVs as promising because the technologies are advancing, produce zero tailpipe emissions, and are in line with the state's direction. Nonetheless, various concerns and uncertainties were reported relating to the vehicle's functional suitability, required charging infrastructure, vehicle availability, total life	functional suitability, costs, infrastructure) and fleet characteristics (e.g., fleet size, sector, vocation), and several major policy instruments (e.g., regulations and incentives). • A specific choice task design, which can allow for analyzing the impact of a AFV mandate, should be needed: for this, a dual-response design could be considered (see Appendix H for details). • For an analysis of the impact of financial incentives on AFV choice, different levels of purchase incentive amounts could be included as attributes in the choice experiment design. • Electric, hydrogen, and CNG options could be considered for the set of alternatives in the experiment design.

Main Qualitative Inferences	Key Takeaways
cycle emissions, and total cost of ownership. • [INSIGHT 50] (Hydrogen HDVs in 2030s) Given that hydrogen HDVs are in the early stages of implementation, they received less attention than battery electric HDVs from the organizations interviewed. While its positive or negative opinions were similar to electric HDVs to some degree (e.g., the technologies being advanced, zero emission vehicles needed for the future, functional unsuitability for HDV applications), one distinct remark was that hydrogen can be a practical and economical option when producing from renewable sources. • [INSIGHT 51] (CNG HDVs in 2030s) CNG HDVs were positively addressed by almost all those organizations as a foreseeable fuel option which they are being committed to at least for 10 to 20 years. At the same time, some fleet operators stated that CNG is not in line with the state's direction: it would be a transitional option towards electricity.	
Refueling/charging infrastructure choice behavior	
• [INSIGHT 32] A fleet with a larger number of CNGVs would be more likely to build their own on-site CNG refueling facilities than a fleet with a smaller number of CNGVs. • [INSIGHT 33] The time taken to refuel a CNGV were reported obviously longer for on-site slow-fill stations than off-site stations. Such longer on-site refueling time would not matter in case that the vehicles are refueled overnight, while off-site refueling time would sometimes pose	*[On-site vs. off-site infrastructure choice behavior]* • Fleet characteristics (e.g., fleet size, space available for building on-site facilities) would affect their choice between on-site vs. off-site fueling facilities. • Various fueling infrastructure characteristics, such as the time taken to refuel (including time for travelling, waiting, and at-station-time), labor costs associated with fueling activity, construction costs (for on-site), space requirements (for on-site), fuel prices, and

Main Qualitative Inferences	Key Takeaways
uncertainty (e.g., due to queue at the site, time of day). • [INSIGHT 37] Major advantages of having on-site refueling stations were reported by the participating fleets, including: saving time – and associated financial expenses – required to drive to any off-site stations, lower fuel prices, and reduced uncertainty in refueling fleets – which were attributed to fueling convenience, fuel consistency, facilities reliability, and easiness of facilities maintenance. • [INSIGHT 38] Disadvantageous aspects of having on-site fueling stations were reported as costs and complexities associated with building the facilities, and maintenance issues for old equipment. • [INSIGHT 39] Although a few of fleets using off-site stations were satisfied with specific traits of the refueling facilities, all of them reported one to multiple unsatisfactory aspects including longer time taken to drive to refueling stations, waiting time, not inexpensive fuel prices, and complexity increased with fleet routing. • [INSIGHT 40] CNG fuel security and fuel availability were addressed as common concerns by both fleets with and without on-site fueling facilities. • [INSIGHT 41] Several participating organizations are planning to build on-site CNG refueling facilities in order to take advantages from lowered CNG fuel price, to save labor costs of driving off-site stations, and to lower complexity with the fleet routing. While limited space and construction costs were addressed as barriers to building the facilities, all of	complexity in fleet routing, would affect the choice for on-site vs off-site fueling facilities. • Government policies, such as financial incentives for on-site infrastructure construction, would help alleviate the barrier to building the facilities. *[For the survey items to analyze on-site vs. off-site facility choice behavior]* • Comprehensive information should be provided when asking respondents to choose on-site vs. off-site facilities, including: ○ the minimum space required for on-site infrastructure construction ○ fuel prices (note that lower fuel prices may need to be assumed for on-site facilities than for off-site stations) ○ construction costs for on-site facilities ○ the shortest distance to off-site stations ○ amount of time taken to refuel (on-site vs. off-site) ○ any governmental incentives (e.g., provided for on-site facility construction) • Potential follow-up questions include: ○ Preferred fueling/charging equipment (e.g., slow vs. fast charging) ○ Preferred timing for fueling/charging (e.g., overnight, en route in the daytime) ○ Preferred access (public, private, vs. shared)

Main Qualitative Inferences	**Key Takeaways**
them applied (will apply) for financial incentives to alleviate the cost barrier. • [INSIGHT 46] Financial incentives were extensively used for heavy-duty CNGV purchases and fueling infrastructure construction among the participating organizations. • [INSIGHT 34] Some of those organizations with on-site fueling facilities stated that they began with slow-fill hoses first, and recently built fast-fill stations. Others also stated they are proceeding with upgrading their on-site facilities to expand the storage or to construct additional stations. Depending on fleet operators' decision, those on-site facilities are either semi-open to public or kept as private facilities.	
Relationships between fleet replacement/expansion plans, AFV choice, and refueling/charging facility choice	
• [INSIGHT 7] While many organizations evaluated multiple alternative fuel options and then rejected most of them except one or two fuel(s), a few organizations with large fleets adopted three or more types of alternative fuels. • [INSIGHT 6] Vehicle age, mileage, and vehicle conditions/maintenance need were commonly addressed as fleet replacement criteria. Other criteria include vehicle size, vocations, utilization, available budget, and business opportunity. • [INSIGHT 32] A fleet with a larger number of CNGVs would be more likely to build their own on-site CNG refueling facilities than a fleet with a smaller number of CNGVs. • [INSIGHT 8] Electric or hydrogen HDV adopters have built their own on-site	*[Replacement/expansion plans → AFV and Fueling facility choice]* • If a fleet plans to replace/expand a larger number of vehicles, they would be more likely to consider purchasing AFVs, diversifying fuels, and constructing on-site fueling/charging facilities. *[AFV and Fueling facility choice → Replacement/expansion plans]* • If a fleet already made AFV choice, that would likely to affect their vehicle replacement criteria (e.g., because a part of the criteria would be vehicle conditions and maintenance needs, which could be distinguished across different fuel technologies). • In case a fleet already chose to build or use their on-site station previously installed,

Main Qualitative Inferences	Key Takeaways
stations. Meanwhile, some CNG HDV adopters had chosen to use off-site stations when they purchased their CNG vehicles. • [INSIGHT 42] HDV fleets with investment already made in CNG on-site refueling facilities tend to plan higher penetration rates of CNGVs within their fleets than others those are using off-site fueling stations.	they would be more likely to smoothly proceed with their fleet replacement schedule, or even could accelerate it. *[AFV choice → Fueling facility choice]* • In case a fleet already made AFV choice, that would affect their choice between on-site and off-site stations given that different alternative fuel options have different circumstances in their infrastructure. *[Fueling facility choice → AFV choice]* • In case a fleet already chose to build or use the on-site station previously built, they would be likely to be more favorable towards the fuel technology for which they wish to build or already built the station.
Satisfaction on AFV operations	
• [INSIGHT 17] Educational training programs provided by vehicle/engine manufacturers, fuel providers or other institutes have helped the Implementation stage right after heavy-duty AFV adoptions. • [INSIGHT 18] Though driver trainings tended to be provided in a less extensive way than technicians / mechanics trainings, drivers would become not only better aware of how to use the vehicles but more acceptable toward the vehicle adoption, with the support of the trainings. • [INSIGHT 29] Fleet managers have experienced in hearing various feedback from their vehicle drivers on use of the vehicles – whether it is positive, negative, or both –, and some of which would affect fleet managers' evaluation on the vehicles.	*[Technology supplier supports]* • With the support from technology suppliers, educational trainings could be provided to fleet managers, technicians, mechanics, as well as drivers, which would help increase their acceptance towards AFV operations in the *Implementation* stage. *[Driver feedback on AFVs]* • Some of driver feedback on AFV operations, if substantiated, would affect decision-making unit (DMU) member evaluation on AFV operations. *[DMU member satisfaction on vehicle use]*

Main Qualitative Inferences	Key Takeaways
• [INSIGHT 30] As end-users, drivers' feedback on CNGVs contain detailed aspects of the vehicle use, including perceived vehicle performance, refueling dis/advantages, and learning effort for such new technologies. • [INSIGHT 31] Many CNG adopters reported a change of drivers' acceptance toward the vehicles: they initially had negative perceptions but became favorable after having operational experiences and/or receiving educational trainings • [INSIGHT 21] Almost all the CNG adopters were satisfied with the vehicle operations. Main strengths of the heavy-duty CNGVs, which were commonly and consistently addressed, included CNG engine reliability, environmental benefits, and low noise levels. • [INSIGHT 23] Several weaknesses of CNGVs were addressed by one to five CNG adopters, including: high purchase costs, potential performance/maintenance issues, and shorter engine longevity than diesel vehicles. • [INSIGHT 24] The functional suitability of heavy-duty CNGVs was either favorably or unfavorably evaluated depending on a vehicle application area with its own performance requirements and its operational routes and locations. • [INSIGHT 25] Some CNG adopters stated that they were satisfied with the CNGVs' reliability and safety while some expressed their concerns on working with the flammable or explosive gas. • [INSIGHT 28] A resale opportunity of heavy-duty CNGVs was either positively or negatively addressed by a few CNG	• DMU member would evaluate various technological aspects of AFV operations, including vehicle performance, operating costs (e.g., fuel costs, maintenance costs), engine reliability and longevity, vehicle reliability and safety, noise levels, and resale opportunities. • Such evaluations would differ across fleet vocation and fleet-specific experience in operating AFVs. *[DMU member satisfaction on fueling facilities]* • DMU member would evaluate various aspects of fueling facilities, including amount of time taken to fuel vehicles (including travel time, waiting time, fueling time), labor costs associated with fueling, costs of fuel, costs and complexity of construction/maintenance of the equipment (for on-site), any operational complexities involved in fueling and routing, and any uncertainty associated with fuel security and fuel consistency. • Such evaluations would differ between not only on-site vs. off-site but specific fueling facilities being used (e.g., specific equipment types and locations, etc.)

Main Qualitative Inferences	Key Takeaways
adopters, of which different opinions would depend on their experiences with the resale market for a specific vocational area. • [INSIGHT 36] Most organizations with on-sites refueling stations are satisfied with their facilities while those are using off-site stations tend to be less satisfied or dissatisfied with the facilities. • [INSIGHT 26] Many fleet operators with their own on-site CNG refueling facilities stated that they were satisfied with CNG fuel prices; in contrast, others relying on off-site stations tended to be dissatisfied with the fuel prices. • [INSIGHT 33] The time taken to refuel a CNGV were reported obviously longer for on-site slow-fill stations than off-site stations. Such longer on-site refueling time would not matter in case that the vehicles are refueled overnight, while off-site refueling time would sometimes pose uncertainty (e.g. due to queue at the site, time of day). • [INSIGHT 37] Major advantages of having on-site refueling stations were reported by the participating fleets, including: saving time – and associated financial expenses – required to drive to any off-site stations, lower CNG fuel prices, and reduced uncertainty in refueling fleets – which were attributed to fueling convenience, fuel consistency, facilities reliability, and easiness of facilities maintenance. • [INSIGHT 38] Disadvantageous aspects of having on-site fueling stations were reported as costs and complexities associated with building the facilities, and maintenance issues for old equipment.	

<table>
<tr><th>Main Qualitative Inferences</th><th>Key Takeaways</th></tr>
<tr><td>[INSIGHT 39] The fleets using off-site stations reported unsatisfactory aspect(s), including longer time taken to drive to refueling stations, waiting time, not inexpensive fuel prices, and complexity increased with fleet routing.
[INSIGHT 40] CNG fuel security and fuel availability were addressed as common concerns by both fleets with and without on-site fueling facilities.</td><td></td></tr>
<tr><td colspan="2">Fleet confirmation influencing their next decisions</td></tr>
<tr><td>[INSIGHT 43] Those HDV fleets that are highly satisfied with CNGV operations - in both terms of CNGVs and refueling facilities - tend to plan higher penetration rates of CNGVs than other less-satisfied fleets.

c.f., Several organizations had adopted LNG but they were migrating LNG vehicles to CNG ones because of negative experiences in LNG.
[INSIGHT 41] Several participating organizations, that were using off-site stations, were planning to build on-site CNG refueling facilities in order to take advantages from lowered CNG fuel price, to save labor costs of driving off-site stations, and to lower complexity with the fleet routing. All of them are highly satisfied with the use of vehicles.</td><td>[Confirmation and the next decisions]
For adopter fleets satisfied with AFV operations, they confirm their adoption decision and their choice probability for choosing that fuel option in their next round decisions would be higher than other less-satisfied fleets due to their favorable perceptions on the technology characteristics.
Such satisfied fleets would likely to plan a larger number of diesel vehicle replacement with the AFVs than dissatisfied fleets.
For those fleets who are using off-site stations and satisfied with the use of AFVs, their next round choice probability for building on-site infrastructure would be higher than other dissatisfied fleets.
[For the demand analysis modelling]
Relationships between the degree to which adopter fleets are satisfied with AFV operations, and their next round decisions such as AFV choice, fueling facility choice, and replacement plans, should be quantitatively investigated and</td></tr>
</table>

Main Qualitative Inferences	Key Takeaways
	incorporated into the relevant modelling components.
Fleet confirmation influencing other fleet adoption decision	
• [INSIGHT 44] Most of the HDV fleets those are highly satisfied with CNG vehicles - both across public and private organizations - tend to provide their positive or at least neutral feedback to other fleet operators. • [INSIGHT 45] Some private fleet operators seemed intentionally inactive in sharing their CNGV experiences with other fleet operators – despite their satisfactory experiences in CNGV operations –, whereas there are some public/private organizations who try to actively disseminate information about the new technologies by providing recommendation and even education. • [INSIGHT 5] For potential new adopters who have never tried heavy-duty AFVs, practical information shared by other adopters and supporting efforts from technology suppliers may facilitate their decision-making processes. • [INSIGHT 19] Social Networks can affect heavy-duty AFV purchase decisions in a way of obtaining feedback from other fleet operators who already have experiences in operating the vehicles and/or of following a social norm prevalent in the industry.	*[Confirmation and social influences]* • Adopter fleets with an active interpersonal channel would be likely to be influential to non-adopter fleet decisions in a way of disseminating their un/satisfactory experiences to others. • The degree to which fleets are engaged in such social activities (e.g., sharing their AFV experiences with others, providing recommendations and education) would differ across various sectors, industry, and DMU member personal traits. • Confirmation of AFV operations among adopter fleets would contribute to forming the social norm that the technology is proven in the industry, which would affect potential decisions by non-adopter fleets. *[For the demand analysis modelling]* • Relationships between the degree to which adopter fleets in certain sectors/industries are satisfied with AFV operations, and their influences on other fleet decisions (e.g., in various ways via interpersonal channels, social norms, and neighboring effects), should be quantitatively investigated and incorporated into the relevant modelling components.
Decision-making processes	
• [INSIGHT 1] Key decision-makers (e.g., fleet managers)' leadership is critical	*[Survey respondent eligibility]*

Main Qualitative Inferences	Key Takeaways
throughout the entire decision-making stages. • [INSIGHT 2] For formalized and/or decentralized decision-making behavior, the decision-making processes are inherently complex because of multiple people involved from different positions and/or many steps need to be proceeded. • [INSIGHT 4] Although vehicle drivers are typically not key-decision makers, their input and feedback can be often used in adoption decision and/or confirmation stages particularly in less centralized fleets.	• In case of using survey data for the modelling, only key decision-makers would be eligible to provide necessary data. *[Potential limitation of the modelling]* • Depending on characteristics of their decision-making structure, the key decision-maker willingness to adopt AFVs may or may not be smoothly materialized: If personnel in different positions are invited in the process, their acceptance could be an internal barrier. For that case, modelling results could potentially overestimate AFV shares.

5.2. Overall Conceptual Structure of Demand Modelling

A conceptual demand modelling framework for heavy-duty AFVs was developed based upon the insights gained from the qualitative research results. The primary intent of this framework is to provide a conceptual structure which can contribute to the analysis of demand of heavy-duty AFVs under various policies, technology advancement status, and presumably different fleet responses to these conditions. This conceptual structure explains only a preliminary design for the demand modelling in this Chapter. The overall structure is depicted in Figure 5-1 with seven integrated modules:

- Module 1) Replacement/expansion plans
- Module 2) AFV choice
- Module 3) Refueling/charging facility choice
- Module 4) Satisfaction on AFV operations

- Module 5) Influences on the next decision
- Module 6) Influences on other fleet decisions
- Module 7) Decision-making process

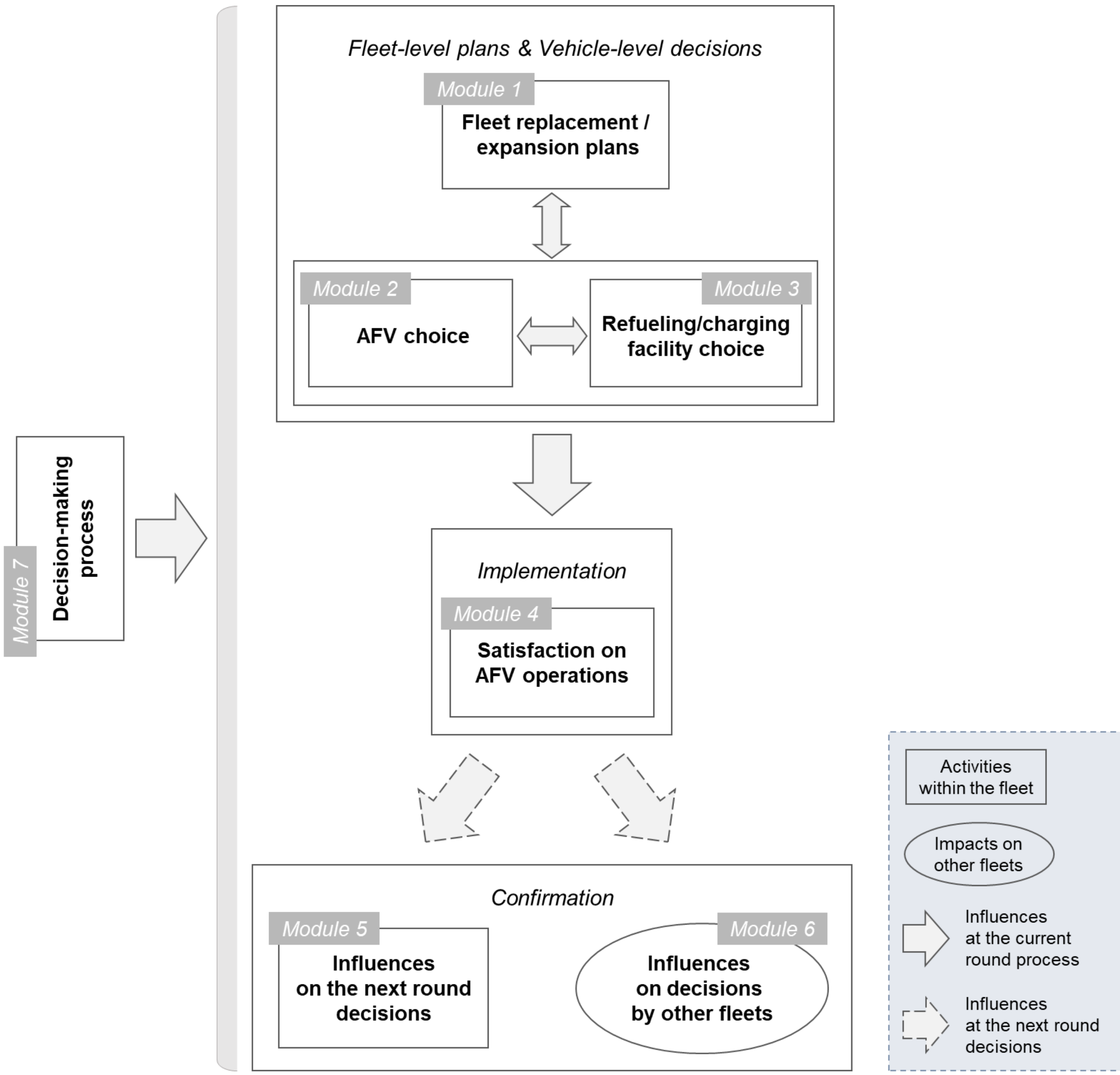

Figure 5-1. Overall Structure of Demand Modelling

First, the fleet-level plans and vehicle-level decisions are represented with the three modules, *replacement/expansion plans*, *AFV choice*, and *refueling/charging facility choice* modules, and the interrelationships between them. The *fleet replacement/expansion plans* module would estimate the total number of vehicles to be purchased in a fleet at a specific time duration for the purpose of either replacing existing vehicles or expanding the fleet size (Module 1). The *AFV choice* module would estimate choice probabilities of different fuel technologies for the fleet at that period, by which the number of AFVs to be purchase could be predicted (Module 2). Probabilities whether the fleet refuels/charges their AFVs at an on-site facility or an off-site station would be estimate in the *refueling/charging facility choice* module (Module 3).

The outcomes resulting from Modules 1 to 3 could influence one another. First, a choice of what fuel type of vehicles to be purchased, and a decision whether to use off-site stations or build on-site facilities would be interrelated to each other, and even become a constraint on the other. It is because infrastructure circumstances could be one of the factors guiding the fuel choice, and the fuel option chosen will inherently characterize fuel infrastructure conditions. An example typically observed for natural gas vehicle adopters interviewed was the case where a fleet who already chose to use an on-site station previously built would be more favorable towards that fuel technology for which they had the station. As another example, a fleet that decided to buy electric trucks had no choice but to build on-site charging facilities due to the lack of off-site infrastructure.

Meanwhile, replacement/expansion plans could also affect the fuel and fueling/charging facility choices. For example, if a fleet plans to replace or expand a larger number of vehicles, they would be more likely to consider purchasing AFVs and constructing on-site facilities. An opposite direction of the influence could also occur. For example, if a fleet already made an AFV choice, that would likely affect their vehicle replacement criteria, because a part of the criteria would be vehicle conditions and maintenance needs, which could be distinguished across different fuel technologies.

Once the fleet completed their series of decisions including replacement/expansion plans, AFV choice, and fueling facility choice, they would implement the AFV operations. DMU members in the organization would evaluate *how satisfied they are with the operations* based upon their own analysis as well as feedback received from individuals within the organization (Module 4). Whether they confirm or reverse their decision should then *influence their next round of decisions* on alternative fuel adoption (Module 5). Their confirmation or discontent would also directly or indirectly *affect other fleet decisions* regarding alternative fuel adoption (Module 6). Finally, the *decision-making process* module delineates who, within the organization, would play what roles throughout these modules under what organization-specific influences (Module 7). Detailed components and mechanisms for these modules are discussed in the next Chapter.

5.3. Modules and Components

For each module, this section provides its objective and main outputs, describes the components and their interrelationship comprising the module, and suggests potential research required for operationalizing the module.

5.3.1. Module 1: Fleet Replacement and Expansion Plans

The objective of the *fleet replacement/expansion plans* module is to estimate the total number of vehicles to be purchased in a fleet m at a given time duration t ($\Delta N_{m,t}^{A}$)[36]. The number of vehicles to be purchased would consist of the number of vehicles needed to replace some existing vehicle(s) ($\Delta N_{m,t}^{A,R}$) and the number of vehicles to be additionally needed to expand the fleet ($\Delta N_{m,t}^{A,E}$).

$$\Delta N_{m,t}^{A} = \Delta N_{m,t}^{A,R} + \Delta N_{m,t}^{A,E}$$

The number of replacement vehicles would be identified based on several components. One of them would be a cost-benefit analysis, which could be performed based upon fleet-specific turnover criteria (e.g., certain vehicle age or mileage criteria), determining whether to retain or replace existing vehicle(s). Turnover criteria would vary depending on different fleet characteristics, such as fleet vocation, sector, location, and fleet-specific operational characteristics. Also, model year distribution of vehicles and engines would affect the replacement plans (e.g., older vehicles/engines would be more likely to be retired than newer ones).

Government policies are another component, such as regulations requiring a certain model year engine[37] which necessitates replacing old vehicles with newer ones (if a fleet wishes to keep its fleet size), or financial incentives provided to AFV purchases, which

[36] The length of the time duration would depend on a time interval at which an organization plans replacement/ expansion of their fleet as well as a time unit that an analyst is interested in. Typically, the interval might be a year, several years, or so.

[37] For example, according to the CARB Truck and Bus Regulation (CARB, 2017), nearly all trucks and buses will need to have 2010 model year engines or equivalent by January 1, 2023,

could, for some potential AFV adopters, help accelerate replacement cycle of diesel vehicles so that fleets could purchase more AFVs earlier than what was initially planned.

Economic conditions would also affect the number of vehicles not only for replacement but also for fleet expansion or reduction. Depending on economic situations, a fleet would decide whether to expand, shrink, or keep their fleet size. If they wish to maintain the size, they will purchase as many vehicles as their retiring vehicles. If they expect their business would grow or decline, they will plan to purchase more or fewer vehicles than the number of vehicles to be retired.

Along with these components, potential disruptive technologies might also affect $\Delta N_{m,t}^{A}$, such as commercial availability of autonomous trucks which can impact operational efficiency and allow for fleets to attempt to modify fleet sizes.

Further research may be required to precisely estimate $\Delta N_{m,t}^{A}$, including 1) investigation of fleet turnover criteria, which would vary across fleet vocations and operational characteristics, 2) exploration of fleet responses, in terms of vehicle replacement plans, to specific governmental policies being or to be implemented, 3) estimation of how fleets manage fleet sizes under potentially different future scenarios of economic conditions, and 4) exploration of how the disruptive technologies would change fleet operational efficiency, when and which fleets would adopt the technologies, and how this would affect their fleet size.

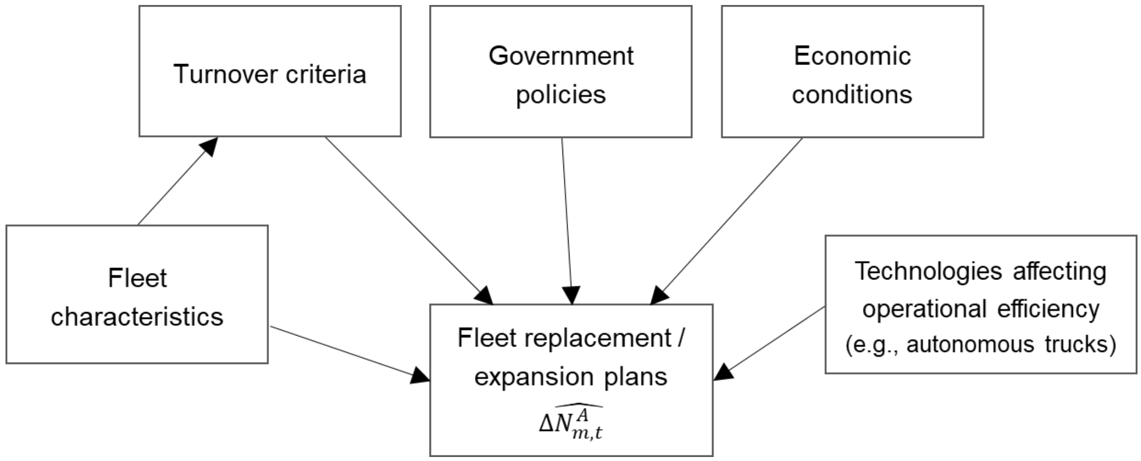

Figure 5-2. Replacement/expansion plans (Module 1)

5.3.2. Module 2: AFV Choice

The *AFV choice* module would predict the number of vehicles for a fuel technology f to be purchased for the fleet m at the time t ($\Delta N_{m,f,t}^{A}$). This module would first estimate choice probabilities for different fuel technologies ($P_{m,f,t}$).

There are many components that would affect the fuel choice probabilities, such as perceived technology characteristics (e.g., in terms of functional suitability, monetary costs, fuel infrastructures, and vehicle reliability/safety), fleet characteristics (e.g., sector, size, vocation, experiences in AFV operations, whether they possess intrinsic values for environmental consciousness, or pursue business strategic motives), and governmental policies such as regulations and financial incentives. In addition, technology supplier support (e.g., providing available models for AFVs, warranty/maintenance services) and social influences (e.g., social norm that the technology is proven in the industry) could also have an impact on the choice behavior mediated through perceived technology characteristics.

Estimations of the AFV choice probabilities could then be converted into the number of AFVs to be purchased by considering whether or not a fleet diversifies its fuels, and using the output from the *Module 1* (i.e., $\Delta N^{A}_{m,,t}$).

One of the ways to operationalize this module would be to employ choice modelling based on stated preference choice experiments (See Chapter 2.4.2 or Appendix H for more details about choice modelling). For the design of the choice experiments, region-specific contexts should be taken into account for selection of a set of alternatives (e.g., promising fuel technologies in the medium- and long-term future in the study area of interest), a set of attributes (i.e., several main factors that would significantly affect the decisions by the fleet operators for the fleet vocation of interest in that study area), and choice tasks (e.g., region-specific choice circumstances, if any, should be provided to respondents). These issues are discussed further in Appendix H.

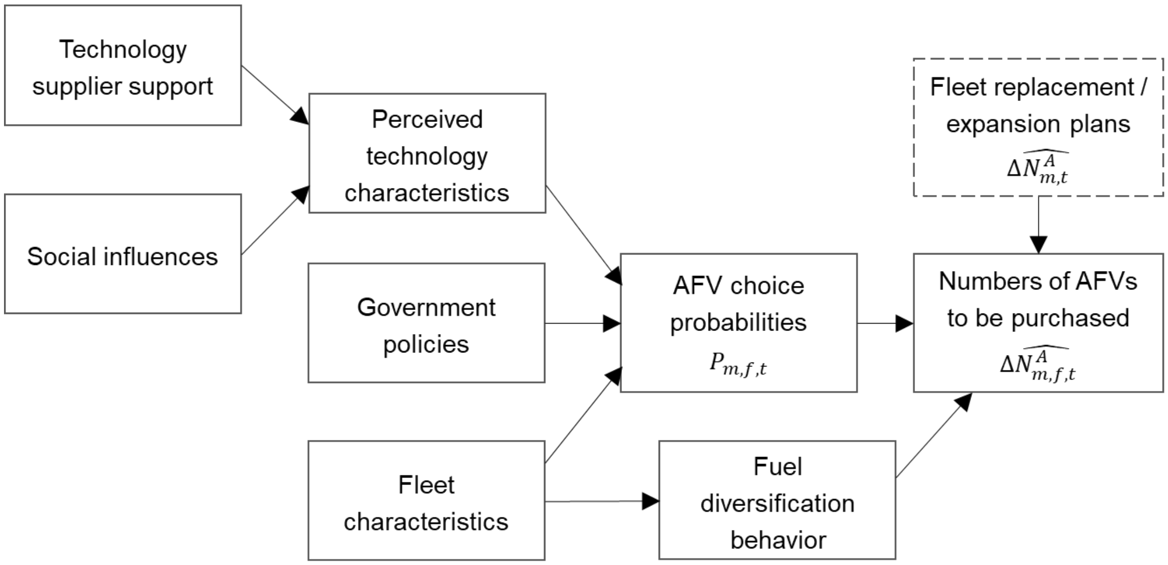

Figure 5-3. AFV choice (Module 2)

5.3.3. Module 3: Refueling/charging Facility Choice

Some fleets would prefer to use off-site stations while others would prefer to build on-site stations. This choice would be determined in the *refueling/charging facility choice* module. For this module, the choice is broadly defined as the selection between on-site and off-site stations. Meanwhile, more specific choices would be also made, such as which equipment (e.g., slow-fill vs. fast-fill) to be installed and who to allow for access (for on-site), and what specific locations to visit to fuel and which equipment to be used (for off-site). In addition, choices on fueling behavior such as when and how frequently to fuel vehicles would be formed. Such specific fueling decisions should be important for not only fleet-level but regional-level infrastructure cost analysis as well as fuel demand analysis in a geographical and temporal domain. Nevertheless, this module mainly focuses on the broad definition, the selection between on-site and off-site facilities, given the overall focus of this modelling framework being centered on the estimate shares of AFVs.

Several components would affect the fueling facility choice. Perceived infrastructure characteristics are one of those, such as construction and maintenance costs for on-site facilities, travel time and labor costs for off-site stations, fuel costs which would differ between on-site vs off-site stations, and reliability and complexities involving the use of facilities.

Government policies, such as monetary incentives offered for on-site facility construction and investment in providing off-site stations, could influence the decision. Fleet characteristics, such as fleet size, vocation, and space available at the site, could also affect the decision. In addition, technology supplier support (e.g., providing relevant infrastructure technologies, offering education for facility construction and/or equipment use) and social influences could affect the decision behavior mediated through perceived technology characteristics.

The infrastructure choice probabilities ($P_{m,i,t}$) could be converted into a binary variable whether a fleet would build on-site facilities or use off-site stations ($I_{m,t}$). Using choice experiments, this module could be operationalized. In addition, supplementary data about more specific preferences about equipment types (those with different amounts of time taken to fuel), access permissions (public, private, vs. shared), and fueling/charging behavior could be attempted to be collected and analyzed.

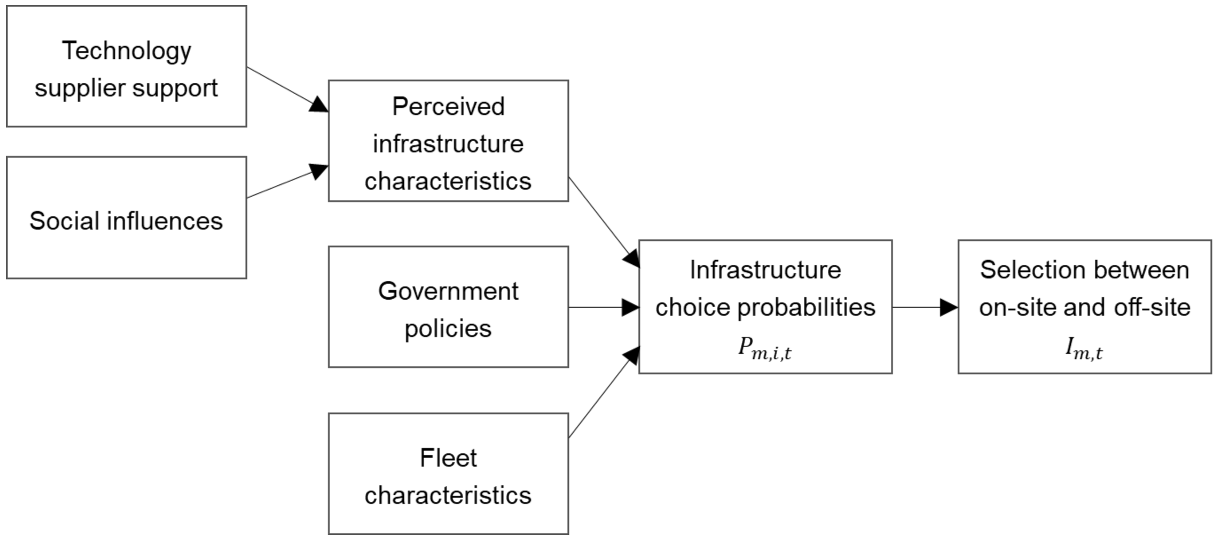

Figure 5-4. Refueling/charging facility choice (Module 3)

5.3.4. Module 4: Satisfaction on AFV Operations

Once the organization completed the series of decisions, replacement/expansion plans, AFV choice, and fueling facility choice, they would implement the AFV operations. The implementation refers to having the vehicles perform their vocational duty requirements while driving, fueling/charging, and maintaining them. The DMU members would evaluate how satisfied they are with the operations not only in terms of vehicle use but also the fueling/charging facilities. Feedback from vehicle drivers (i.e., end users) could affect the DMU evaluations, if substantiated. In addition, with support from technology suppliers, educational training could be provided to fleet managers, technicians, mechanics, as well as drivers, which would help increase their satisfaction with AFV operations.

As to AFV use, various technological aspects would be evaluated, including vehicle performance (e.g., range, speed, power), operating costs (e.g., fuel costs, maintenance costs), vehicle/engine reliability, safety, longevity, noise levels, and resale opportunities.

Such evaluations would differ across fleet vocation and fleet-specific experience in operating AFVs.

Aspects of fueling/charging facilities would be also evaluated, such as, amount of time taken to fuel vehicles (including travel time, waiting time, fueling time), labor costs associated with fueling, fuel costs, complexity and costs associated with construction/ maintenance of the equipment (for on-site), operational complexities involved in routing, and any uncertainty associated with fuel security and fuel consistency. Such evaluations would differ between not only on-site vs. off-site but specific fueling facilities being used (e.g., specific locations and equipment types, etc.)

Research is needed to quantitatively establish the relationships between specific satisfactory and unsatisfactory aspects of AFV operations, an overall satisfaction by DMU members, and the influence of vehicle driver acceptance on DMU satisfaction. Furthermore, the role and impact of technology supplier support on AFV implementation, and acceptance of both DMU members and drivers, should be quantitatively modeled.

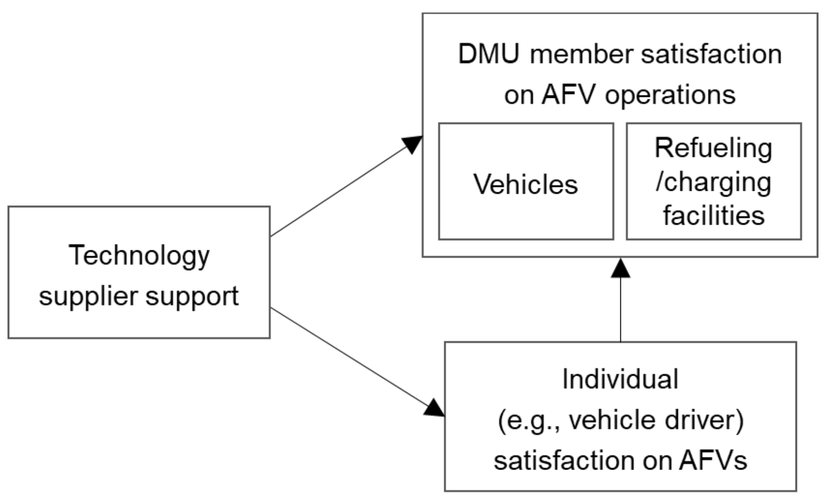

Figure 5-5. Satisfaction on AFV operations (Module 4)

5.3.5. Module 5: Confirmation Influencing Next Decisions

After evaluating AFV implementation, satisfied fleets would be willing to continue their adoption decisions while dissatisfied fleets would be willing to retract their choices in their next round decisions. Module 5 aims to assess how the degree of satisfaction on AFV operations would influence such next round decisions.

For example, adopter fleets satisfied with AFV operations would be likely to have a higher probability to choose that fuel option in their next round decision than other less-satisfied fleets due to their favorable perceptions on the technology characteristics (influence on AFV choice). Also, the fleets that are using off-site stations and satisfied with the use of AFVs would be more likely to build on-site fueling/charging facilities than other less-satisfied fleets, if they perceive financial and operational advantages of having on-site facilities (influence on fueling facility choice). In addition, such satisfied fleets would be more likely to accelerate diesel vehicle replacement with the AFVs than dissatisfied fleets (influence on turnover plans).

To operationalize this module, research may be required to quantitatively investigate the relationships between the degree to which adopter fleets are satisfied with AFV operations, and their next round decisions such as AFV choice, fueling facility choice, and replacement plans, of which results should also be incorporated into the relevant modelling components in Modules 1 through 3.

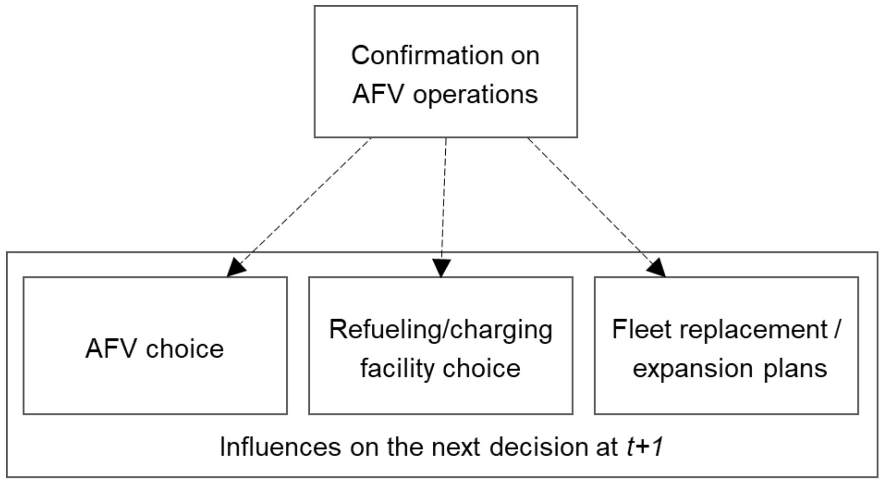

Figure 5-6. Confirmation influencing the next decisions (Module 5)

5.3.6. Module 6: Confirmation Influencing Other Fleet Decisions

Fleet confirmation or discontent on their AFV operations would directly or indirectly affect other fleet decisions regarding alternative fuel adoption, which is referred to as social influence. For example, adopter fleets actively engaged in an interpersonal channel (e.g., via an association that they belong to, and they meet other fleet operators and exchange information) would be likely to be influential to other non-adopter fleet decisions in a way of disseminating their un/satisfactory experiences to them. Also, strong confirmation of AFV operations among adopter fleets would contribute to forming the social norm that the technology is proven in the industry, which would affect potential decisions by non-adopter fleets. The impacts of such social influences on other fleet decisions would differ across various sectors, industry, and DMU member personal traits (c.f., some private organizations would be intentionally inactive in sharing with others their experiences regarding AFVs, if they perceive the AFV adoption brings competitive advantages for their business).

Though indirectly influential, an increased adoption rate in a certain geographical area, which makes the vehicles observable on roads, would be also likely to positively affect other non-adopter fleet decisions (i.e., neighborhood effect).

Relationships between the degree to which adopter fleets in certain sectors, industries, and locations are satisfied with AFV operations, and their influences on other fleet decisions, in various ways via interpersonal channels, social norms, and neighboring effects, should be quantitatively investigated and incorporated into the relevant modelling components.

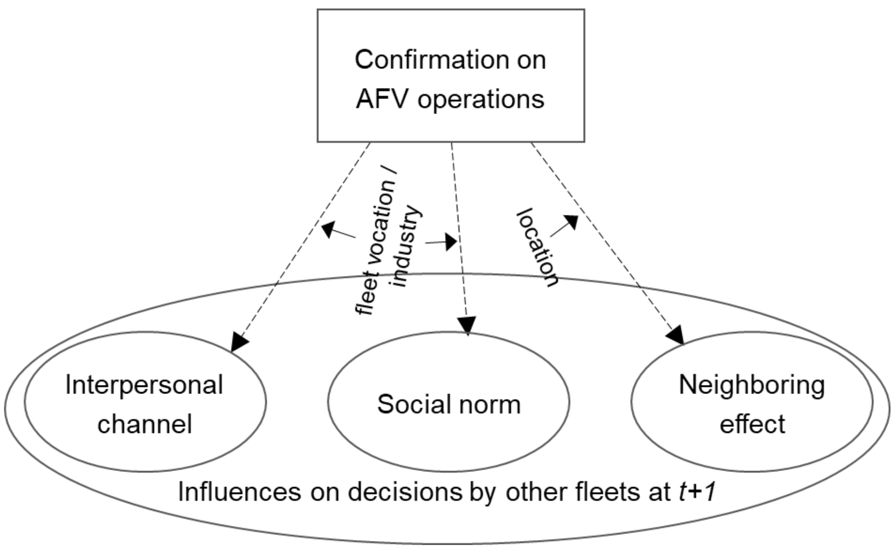

Figure 5-7. Influences on other fleet decisions (Module 6)

5.3.7. Module 7: Decision-making Process

Finally, the *decision-making process* module delineates who, within the organization, would play what roles throughout all these modules under what organization-specific influences (Module 7). The decision-making process refers to a series of certain steps associated with alternative fuel adoption in an organization – which can be expressed as a set of modules and components in this modelling, related to *fleet-level plans*, *vehicle-level decisions*, *implementation*, through *confirmation* – where one or multiple people in the organization are involved with their particular roles.

A range of people with different positions could participate in the decision-making process. As previously described in Chapter 4.3, for example, only one or two key individuals (or groups) at upper management levels would participate (e.g., executive committee and a fleet manager) in a centralized process. In contrast, three or more key individuals and/or user departments would get involved in a less centralized process (e.g., executive committee, a fleet manager, fleet technicians, directors of user departments). Furthermore, the process where end users (i.e., vehicle drivers) take part along with other upper positions would be characterized as being decentralized.

Roles and acceptance of the decision process participants, including key decision-makers, other people involved in the decisions/operations, and vehicle drivers, would guide the whole or a part of the decision-making process within the organization, such as from Module 1 through Module 5. Typically, lower-level positions would indirectly influence the process by delivering their opinions to upper positions. However, depending on the characteristics of the decision-making process such as how centralized and formalized it is, as well as what specific relationships are held between the participants (e.g., motor carriers and independent contractor drivers in drayage operations[38]), the structural characteristics of the process could vary.[39]

In addition, the individuals participating in the decision-making process would also play a role in influencing other fleet decision processes. Not only DMU members but vehicle drivers could have a social influence on individuals in other fleets regarding their perspectives on AFVs (see Module 6 for details). Such outward influences would vary in terms of its strength and direction, either positive or negative, per fleet industry as well as personal traits.

Research may be needed to identify key positions being involved in each module and their specific roles. In a situation where too many positions participate, which makes the modelling further complicated and requires intensive data collection efforts, it might be necessary to select a few key individuals by assuming that their behavior could represent the collective behavior of all participants in an organization[40]. However, in such cases, it must be aware of the potential limitations regarding the accuracy of modelling results because data from a few selective respondents may or may not fully represent an actual group of decision participants. For example, in case of many personnel in different

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[38] A motor carrier is referred to as an entity who hold their own operating authority, the permission given by the Federal Motor Carrier Safety Administration to operate a commercial motor vehicle to transport goods or passengers for compensation. Independent contractor drivers are those who provide driving services to a motor carrier under a lease for a contracted period and operate under that carrier's authority. Some of such contractor drivers might lease a truck from the motor carrier, and might or might not participate in the process.

[39] The simplest case would be owner-operators (for which the components in the middle of Figure 5-8 are combined into one) while a complex case would be large companies that collectively make decisions with multiple branches in different locations.

[40] For example, a survey data could be collected from fleet managers or executive committee to operationalize the *AFV choice* module under the assumption that their decision would represent the *organization*'s decision.

positions being involved in an organization's AFV choices, modelling results relying only on key-decision maker responses would not necessarily guarantee accurate estimates of AFV shares: due to potential internal barriers, the shares would likely be overestimated.

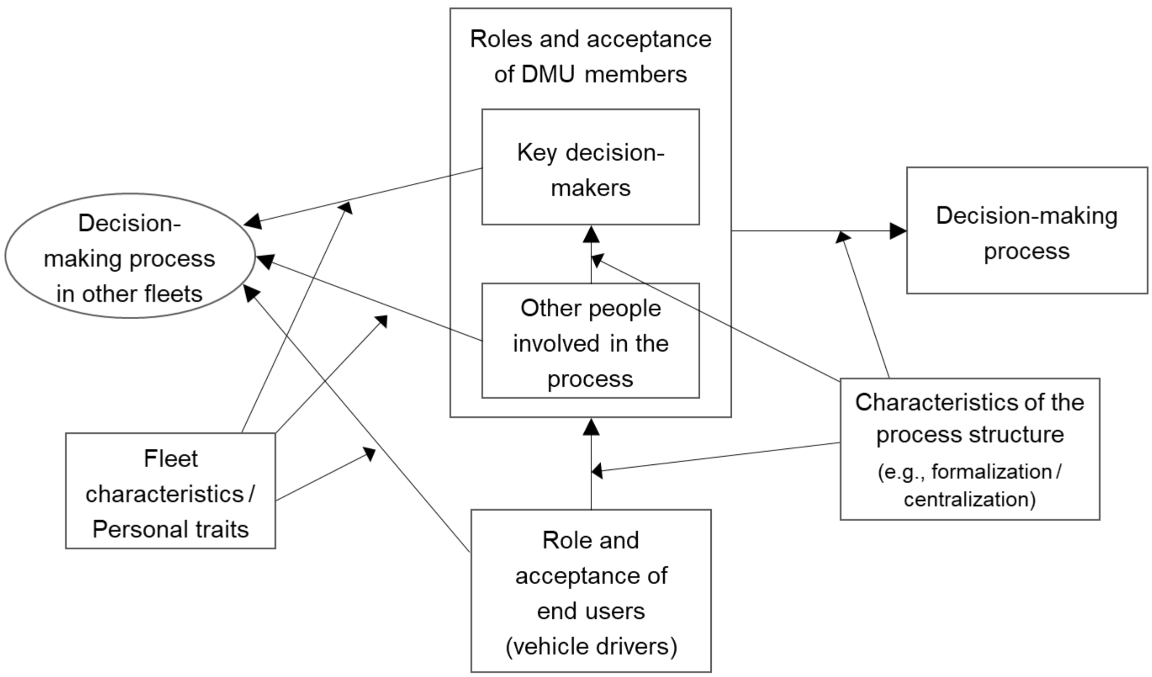

Figure 5-8. Decision-making process (Module 7)

5.4. Advantages and Limitations

In this Chapter, a conceptual modelling framework was proposed for estimating the demand of heavy-duty AFVs, based upon extensive insights obtained from the qualitative research results. This comprehensive modelling framework, which considers not only the factors affecting a series of the fundamental decisions regarding alternative fuel adoption (i.e., AFV choice, refueling/charging facility choice, and replacement/expansion plans) but also the process-specific characteristics (e.g., different adoption stages, organizational decision process structures), can provide theoretical background for AFV demand modelling in HDV fleets. This framework is the first step towards a more accurate, comprehensive and realistic models for analyzing AFV demand.

However, this conceptual modelling framework has limitations in that it does not fully address how to operationalize the overall structure and each module. Though the operationalization of *Module 2 (AFV choice)* is addressed in Appendix H, the other modules and the entire structure remain in the conceptual stage. Their mathematical representations, computational methods to calibrate parameters, validation procedure, and identifying potential sources for necessary data are reserved for future work. Nevertheless, previous studies such as (Kieckhäfer et al., 2017, 2014) based on agent-based modelling and system dynamics model provide insightful clues.[41]

[41] According to (Kieckhäfer et al., 2014), in agent-based modelling, consumers (e.g., organizations operating HDV fleets in the case of this dissertation research) are modeled as agents who perform adoption decisions, into which discrete choice models can be integrated. In the meantime, some characteristics (e.g., vehicle purchase costs, fuel infrastructure availability) that partly guide agent decision behavior should be updated endogenously. For example, the more AFVs are adopted by agents based on their decisions, the lower vehicle costs and the more fueling stations should be available, with a more mature market and technology status, which in turn affect the agent's decisions. System dynamics approach can model such interdependencies between individual agent choice and technology advancement on the macro level over time. See Kieckhafer et al. (2014) for more details. Also, see (Rand and Rust, 2011) for validation procedure.

CHAPTER 6: Conclusions

6.1. Summary and Contributions

Understanding HDV fleet operator behavior with respect to adoption of AFVs is critically important for accelerating diffusion of these innovative technologies, and for achieving societal benefits through reduced emissions and improved public health. However, fleet operator perspectives have thus far received limited attention, leaving a key knowledge gap. This dissertation aimed to fill this gap in AFV adoption research by investigating HDV fleet operator perspectives and behavior toward alternative fuels through two main objectives: to build a theory regarding heavy-duty AFV adoption behavior from HDV fleet operator point of view, and to develop a conceptual modelling framework that could be used in future research to analyze the demand for heavy-duty AFVs under different policy and technology advancement scenarios. The contributions of this dissertation are summarized below.

Initial Theoretical Framework for AFV Adoption Behavior in Organizations – This research proposed an initial theoretical framework to facilitate a conceptual understanding of organizational behavior of AFV fleet adoption, to serve as theoretical background for this research. Built based upon existing theories (Frambach and Schillewaert, 2002; Rogers, 1983a, 1983b; Tornatzky and Fleischer, 1990) as well as findings from a comprehensive literature review of light-duty and heavy-duty AFV fleet adoption studies (Bae et al., 2019), the proposed initial framework consists of a five-stage adoption process and two levels of sub-frameworks, at both the DMU level and the individual (e.g., vehicle driver) acceptance level. This initial framework can help organize concepts and explain phenomena that would exist in such fleet behavior, which theoretically contributes to understanding of the research topic.

Building a Theory of Heavy-duty AFV Adoption Behavior as a Case study with California – It was attempted to empirically improve the initial theoretical framework given that this initial framework was mostly based on light-duty AFV fleet adoption studies and potentially had a limited capability to appropriately explain heavy-duty AFV fleet adoption. As a case study focusing on the California HDV sector, 18 to 20 organizations that operate HDVs in California were investigated via in-depth qualitative interviews and project reports. A total of 29 adoption and 42 non-adoption cases were probed across various alternative fuel technologies, including natural gas, propane, electricity, hydrogen, biodiesel, and renewable diesel options. A broader range of topics associated with heavy-duty AFV adoption behavior was addressed, including factors affecting the adoption and non-adoption decisions, decision-making processes, vehicle driver acceptance of AFV within an organization, satisfaction with vehicles and refueling facilities, repurchase plans and recommendation experiences to other fleets. The findings from this qualitative research study demonstrated the empirical contributions of this California case study to the limited body of literature in this area, offered an enhanced understanding of heavy-duty AFV adoption behavior in organizations, and identified technology and policy implications useful for stimulating the diffusion of AFVs in the HDV sector.

Conceptual Modelling Framework for Demand Analysis of Heavy-duty AFVs – As an initial step to perform the demand analysis of heavy-duty AFVs, the conceptual modelling framework was developed based upon the extensive insights obtained from the qualitative research findings. The overall structure consists of seven integrated modules: 1) *replacement/expansion plans*, 2) *AFV choice*, 3) *refueling/charging facility choice*, 4) *satisfaction on AFV operations*, 5) *influences on the next decision*, 6) *influences on other fleet decisions*, and 7) *decision-making process*. This comprehensive conceptual framework, which includes not only a series of the fundamental decisions regarding alternative fuel adoption but also process-specific characteristics, can provide theoretical background for AFV demand modelling in HDV fleets under various policies, technology advancement status, and presumably different fleet responses to these conditions. This framework is the first step towards a more accurate, comprehensive and realistic models for analyzing AFV demand.

Finally, the overall research findings address the key knowledge gap in AFV adoption research regarding HDV fleet operator perspectives. Increasing AFV uptake in HDV fleets is currently an important issue for achieving local, state, and national policy goals (e.g., CARB, 2021a; The White House, 2021). Therefore, the results from this research can help policymakers develop effective strategies to promote AFV adoption by HDV fleet operators, particularly in California and in the other US states that follow California's environmental policies.

6.2. Future Research

Research limitations and recommendations for further research are addressed in detail in each chapter. In this section, ongoing and future work are summarized below.

6.2.1. Generalized Theory of Heavy-duty AFV Adoption Behavior

The qualitative research findings with a sample size of around 20 organizations are unable to be interpreted as generalized results, although small sample sizes are appropriate for a qualitative research approach (Bryman, 2012). Future investigation, therefore, will be directed toward quantitative survey research with a larger, more representative sample in an effort to validate or invalidate the qualitative inferences, and thus obtain more generalized findings. Based on the extensive analyses of the qualitative research data along with literature reviews on relevant statistical modelling, more than 50 survey items have been created with over 100 questions across six parts with 14 specific sub-topics:

- **Part A**: Fleet Characteristics
  1. AFV adoption/rejection profile
  2. Fleet turnover behavior
  3. Fleet operational characteristics
- **Part B**: Decision-making Processes
  4. Decision-making processes of AFV adoption
- **Part C**: Factors Influencing Heavy-duty AFV Adoption Decisions
  5. Choice sets in the latest adoption/rejection decision
  6. Effect of regulations
  7. Factors that have influenced AFV adoption / rejection decisions
  8. Effect of incentives
  9. Social influences on AFV adoption
  10. Technology suppliers' support
- **Part D**: Satisfaction, Repurchase, and Recommendation
  11. Satisfaction, repurchase, and recommendation
- **Part E**: Stated Preference Choice Experiments
  12. AFV preference in 2030s (stated preference choice experiment)

- **Part F**: Refueling/Charging Behavior
  13. AFV refueling behavior (e.g., natural gas HDVs)
  14. Potential charging/refueling behavior (e.g., electric/hydrogen HDVs)

A list of the survey items is provided in Appendix G (see Table G-1). To implement survey administration, subsets of those within the long list will need to be prioritized by considering an appropriate length of questionnaire, potential usefulness for policy and technological recommendations, and recruitment status. While investigation of Topic 12 (AFV preference in 2030s) is currently prioritized, subsets of other topics are reserved for future work.

6.2.2. AFV Choice Analysis of HDV Fleets Based on Stated Preference Choice Experiment with a Case Study of Drayage Fleets in California

As a case study with California drayage fleets, the stated preference choice experiment for analyzing preferences for alternative fuel technologies in HDV fleets is in its design stage. This ongoing work intends to quantitatively operationalize the *AFV choice* module to estimate alternative fuel choice probabilities in HDV fleets under various policy and technology scenarios. Class 8 drayage fleets in California were selected as a case study in that drayage fleets play an important role for the goods movement economy in California and nationally, but account for harmful emissions which threaten public health particularly in disadvantaged communities.[42] Accordingly, the State of California has established aggressive goals for transitioning drayage fleets to be zero-emission by 2035 (State of California, 2020).

The previous qualitative research findings, additional data collection for drayage truck characteristics and relevant policies, and a review of relevant literature on choice experiments guided the initial design of the stated preference choice experiment (see Appendix H). As subsequent tasks, ongoing and future work includes: interviewing drayage fleets with the intention to ensure the modeling feasibility, pre-testing and finalizing the survey questionnaire, data collection, and data analysis. While the subsequent tasks are in progress, the final research findings will include heavy-duty AFV choice probability estimates under diverse scenarios, and the effect of policy instruments, such as a ZEV mandate or different amounts of financial incentives, on heavy-duty AFV adoption. The study results will ultimately yield empirical contributions to the heavy-duty AFV adoption research area, and effective policy recommendations to stimulate fleet transition towards clean HDV sector. Details about this ongoing work is addressed in Appendix H.

6.2.3. Quantitative Demand Modelling for Heavy-duty AFVs

The modelling framework presented in Chapter 5 for demand analysis for heavy-duty AFVs remains in a conceptual stage, except for Module 2 (AFV choice). To

[42] Disadvantaged communities refers to "the areas throughout California which most suffer from a combination of economic, health, and environmental burdens. These burdens include poverty, high unemployment, air and water pollution, presence of hazardous wastes as well as high incidence of asthma and heart disease" (State of California, 2021).

quantitatively operationalize the overall structure and each module, further literature reviews and research are needed, although previous studies such as (Kieckhäfer et al., 2017, 2014) based on agent-based modelling and system dynamics model provide valuable clues. In agent-based modelling, according to (Kieckhäfer et al., 2014), consumers (e.g., fleet operators in the case of this dissertation research) are modeled as agents who perform adoption decisions, and discrete choice models can be integrated into the consumer agents. Meanwhile, some technology characteristics such as vehicle purchase costs, fuel infrastructure availability that partly guide agent decision behavior should be updated endogenously. In other words, the more AFVs are adopted by agents based on their decisions, the lower vehicle costs and the more fueling stations should be available (due to the market and technology stage being more mature), which in turn affect the agent's decisions. A system dynamics approach can model such interdependencies between individual agent choice and technology advancement on the macro level over time (Kieckhafer et al., 2014). The overall mathematical representations, computational methods to calibrate parameters, validation procedure (see Rand and Rust (2011), and identifying potential sources for necessary data are reserved for future work.

GLOSSARY

AFDT: alternative fueled drayage truck

AFV: alternative fuel vehicle

APCD: air pollution control districts

AQMD: air quality management district

AVC: asymptotic variance-covariance

B20: a blend of biodiesel and petroleum diesel with 6% to 20% biodiesel

CAAP: San Pedro Bay Ports Clean Air Action Plan

CARB: California Air Resources Board

CEC: California Energy Commission

CM: choice modelling

CMP: Carl Moyer Memorial Air Quality Standards Attainment Program

CNG: compressed natural gas

CO: carbon monoxide

CSR: corporate social responsibility

CTP: Clean Truck Program

CV: contingent valuation

CVRP: California Vehicle and Replacement Program

DERA: Diesel Emissions Reduction Act

DMU: decision-making unit

DOI: Diffusion of Innovation theory

DTR: Drayage Truck Regulation

E85: a blend of ethanol and gasoline that contains no more than 85% ethanol

EPA Phase 2: US EPA Phase 2 GHG regulation

ETPB: Extended Theory of Planned Behavior

EV: all-electric vehicle

FHWA: Federal Highway Administration

GHG: greenhouse gas

GVWR: gross vehicle weight rating

HDV: medium and heavy-duty vehicle with a gross vehicle weight rating of more than 10,000 lbs by FHWA, or 8,500 lbs by U.S. EPA

HEV: hybrid electric vehicle

HVIP: Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project

IIA: independence of irrelevant alternatives property

LADWP: Los Angeles Department of Water and Power

LCFS: Low Carbon Fuel Standard program

LDV: light-duty vehicle

LNG: liquefied natural gas

LPG: liquefied petroleum gas or propane

MMNL: mixed multinomial logit model

MNL: multinomial logit model

MSRC: Mobile Source Air Pollution Reduction Review Committee

MY: model year

NGVIP: Natural Gas Vehicle Incentive Project

NOx: nitrogen oxides

NREL: National Renewable Energy Laboratory

PBC: perceived behavioral control

PDTR: Ports Drayage Truck Registry

PHEV: plug-in hybrid electric vehicle

PM: particulate matter

PoAK: Port of Oakland

PoLA: Port of Los Angeles

PoLB: Port of Long Beach

RNG: renewable natural gas

ROI: Return on Investment

RP: revealed preference

SCAQMD: South Coast Air Quality Management District

SEM: structural equation modelling

SP: stated preference

SP: stated preference

TAM: Technology Acceptance Model

TCO: total cost of ownership

TOE: Technology–Organization–Environment framework

TPB: Theory of Planned Behavior

TRA: Theory of Reasoned Action

TRID: Transportation Research International Documentation

U.S. DOE: U.S. Department of Energy

U.S. EIA: U.S. Energy Information Administration

U.S. EPA: U.S. Environmental Protection Agency

UCI-ITS: Institute of Transportation Studies at the University of California, Irvine

WTP: willingness to pay

ZEV: zero-emission vehicles

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APPENDIX A: Available Heavy-duty AFV Models and Makes

See Table A-1.

Table A-1. Available AFV Models and Manufacturers (As of 2020 January) (U.S. DOE, 2021a)

Fuels and Vocations	Number of Models	Number of Manufacturers	Manufacturers
CNG	**100**	**34**	
Refuse truck	10	4	Heil Environmental, McNeilus, Mack, Autocar
Street Sweeper	11	6	TYMCO, Elgin, Global, Schwarze Industries, Autocar, Nitehawk
School Bus	5	2	Thomas Built, Blue Bird
Shuttle Bus	13	5	Turtle Top, Thomas Built, Blue Bird, Hometown Trolley, Champion Bus
Transit Bus	17	7	COBUS Industries LP, Gillig, New Flyer, ENC, MCI, Nova Bus, Cummins Westport, ENC
Tractor	12	9	Kenworth, Capacity, Freightliner, Autocar, Mack, Kalmar, Peterbilt, TICO, Volvo
Vocational/ Cab Chassis	32	12	Ford, Crane Carrier, Freightliner, Peterbilt, Autocar, Chevrolet, Kenworth, Greenkraft, GMC, Isuzu, Mack, McNeilus, Ford
LNG	**32**	**10**	
Refuse truck	6	3	McNeilus, Mack, Autocar
Street Sweeper	1	1	Autocar
Transit Bus	3	1	ENC, ENC
Tractor	11	8	Kenworth, Capacity, Autocar, Freightliner, Mack, Kalmar, Peterbilt, Volvo
Vocational/ Cab Chassis	11	6	Autocar, Kenworth, Peterbilt, Mack, McNeilus, Freightliner, Freightliner
EV/HEV/PHEV[(a)]	**68**	**18**	
Step Van	5	4	US Hybrid, BYD, Zenith Motors, Workhorse
Refuse truck	2	1	BYD

Street Sweeper	2	1	Global
School Bus	7	4	Blue Bird, Lion Electric, Thomas Built, GreenPower Bus
Shuttle Bus	7	5	GreenPower Bus, Lion Electric, Zenith Motors, Ford, US Hybrid
Transit Bus	27	8	BYD, COBUS Industries LP, GreenPower Bus, Proterra, New Flyer, Nova Bus, eBus, Gillig
Tractor	4	3	BYD, Orange EV, US Hybrid
Vocational/ Cab Chassis	14	4	Ford, Zenith Motors, BYD, ZeroTruck
Hydrogen	**5**	**2**	
Step Van	1	1	US Hybrid
Shuttle Bus	2	1	US Hybrid
Transit Bus	1	1	ENC
Tractor	1	1	US Hybrid
Propane	**35**	**12**	
Street Sweeper	2	1	Nitehawk
School Bus	5	3	Blue Bird, Thomas Built, IC Bus
Shuttle Bus	12	5	Turtle Top, Blue Bird, Hometown Trolley, Thomas Built, IC Bus
Tractor	1	1	TICO
Vocational/ Cab Chassis	15	6	Ford, Freightliner Custom Chassis, Chevrolet, Greenkraft, Ford, GMC
E85	**6**	**3**	
Vocational/ Cab Chassis	6	3	Ford, GMC, Chevrolet
Biodiesel	**15**	**7**	
Shuttle Bus	1	1	Hometown Trolley
Vocational/ Cab Chassis	14	6	Hino, Ford, Chevrolet, Isuzu, GMC, RAM

[Note] (a) EV: all-electric vehicle; HEV: hybrid electric vehicle, PHEV: plug-in hybrid electric vehicle.

APPENDIX B: Summary of Incentive Program Applicant Analyses

Since the Institute of Transportation Studies at the University of California, Irvine (UCI-ITS) has administered the Natural Gas Vehicle Incentive Project (NGVIP), the UCI-ITS has an opportunity to access recent NGV fleet adopters and non-adopters sampled from NGVIP applicants. Based on the insights gained from the literature review, along with the descriptive analysis of NGVIP applicants, the sampling strategy for the qualitative research study (presented in Chapter 4) was developed. Although the majority of the interviewees were heavy-duty NGV operators, further efforts were made to fill the gap between NGV and other AFV adoption behavior, such as asking interviewees relevant questions about adoptions of other types of AFV.

To build up the sampling strategy, I conducted the analysis of NGVIP applicants which began with desk research to identify basic fleet characteristics (e.g., locations, business sectors, numbers of natural gas vehicle purchased, and relevant air quality management district. The inventory of NGVIP applicants as of May 2018 was used. The main findings are summarized below.

- 142 applicants and 1,832 incentives in total
- 53 withdrawers (those who cancelled NGVIP applications)

- 99.4 % of incentives are paid to HDVs
  (78.6% for the vehicles ≥ 26,001 lbs;
  20.8% for the vehicles between 8,501 and 26,000 lbs)

- 58% applicants from Southern CA
- 27% from Northern CA
- 15% are outside CA

- Public organizations account for 18% of the total applicants

Of private organizations:

- The highest portion of the business sector being waste management (31% of the total applicants)
- The second highest being freight trucking (10%)

Of private organizations:

- The highest portion of the number of incentives being paid to waste management (35% of the total applications)
- The second highest being paid to vehicle leasing/rental services (11%).

- Mandatory purchase cases (due to SCAQMD rules and/or California laws) would potentially account for up to 30% of the total applicants

APPENDIX C: Study Information Sheet and Consent Form used for Interviewee Recruitment

University of California, Irvine
Study Information Sheet

A Study of Factors Influencing Natural Gas Vehicles (NGVs) Fleet Adoption

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Youngeun Bae, PhD Candidate
Institute of Transportation Studies, Irvine
(949) 394-7162 / youngeub@uci.edu

Study Sponsor: California Energy Commission

- You are being asked to participate in a research study to explore what factors influence NGVs fleet adoptions and non-adoptions in California; to understand what aspects of NGVs are considered strengths, weaknesses, or uncertainty; to grasp how those properties are linked to satisfaction or dissatisfaction in NGVs use; and to comprehend how those satisfaction or dissatisfaction would affect NGVs repurchase intent.

- You are eligible to participate in this study if you have considered purchasing a new Natural Gas Vehicle after July 2015 for use in the State of California and made a decision of either adoption or non-adoption, are an adult 18 years or older, and are able to communicate in English.

- The research procedures involve an audio-taped interview that will last approximately 30-60 minutes at a location convenient for you or via a phone interview.

- Possible risks/discomforts associated with the study are an invasion of your privacy and the possibility of a breach of confidentiality. However, these risks are considered to be minimal as we will protect your private data with industry standard encryption and delete it within one (1) year of collection or completion of the project (whichever occurs first).

- There are no direct benefits from participation in the study. However, this study may provide a novel insight into the recent NGVs market in California from its demand-side. The study results also may help California transportation planners elicit policy recommendations which would increase alternative fuel vehicle market penetration. Ultimately, this study may contribute to air quality improvement and help California achieve its greenhouse gas reduction goals.

- You will not be compensated for your participation in this research study.

- All research data collected will be stored securely and confidentially on encrypted and password protected networks.

- The research team, authorized UCI personnel, and the study sponsor may have access to your study records to protect your safety and welfare. Any information derived from this research project that personally identifies you will not be voluntarily released or disclosed by these entities without your separate consent, except as specifically required by law.

- If you have any comments, concerns, or questions regarding the conduct of this research please contact the researchers listed at the top of this form.

- Please contact UCI's Office of Research by phone, (949) 824-6662, by e-mail at IRB@research.uci.edu or at 141 Innovation Drive, Suite 250, Irvine, CA 92697 if you are unable to reach the researchers listed at the top of the form and have general questions; have concerns or complaints about the research; have questions about your rights as a research subject; or have general comments or suggestions.

- **What is an IRB?** An Institutional Review Board (IRB) is a committee made up of scientists and non-scientists. The IRB's role is to protect the rights and welfare of human subjects involved in research. The IRB also assures that the research complies with applicable regulations, laws, and institutional policies.

- Participation in this study is voluntary. There is no cost to you for participating. You may choose to skip a question or a study procedure. You may refuse to participate or discontinue your involvement at any time without penalty. You are free to withdraw from this study at any time. **If you decide to withdraw from this study you should notify the research team immediately**.

UNIVERSITY OF CALIFORNIA, IRVINE
CONSENT TO ACT AS A HUMAN RESEARCH SUBJECT

A Study of Factors Influencing Natural Gas Vehicles (NGVs) Fleet Adoption

You are being asked to participate in a research study. Participation is completely voluntary. Please read the information below and ask questions about anything that you do not understand. A researcher listed below will be available to answer your questions.

RESEARCH TEAM

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Study Sponsor: California Energy Commission

WHY IS THIS RESEARCH STUDY BEING DONE?

The purpose of this research study is to explore what factors influence NGVs fleet adoption and non-adoption and to understand what aspects of NGVs are considered strengths, weaknesses, or uncertainty.

This interview is being conducted by the Institute of Transportation Studies at the University of California, Irvine which is administering the Natural Gas Vehicle Incentive Project (NGVIP) on behalf of the California Energy Commission. The study results will be one of the components of the research tasks in the NGVIP.

HOW MANY PEOPLE WILL TAKE PART IN THIS STUDY?

This study will consist of individual in-depth interviews. There will be approximately 20 – 24 participants. Each interview will be conducted at a location convenient for you or via a phone interview.

WHAT PROCEDURES ARE INVOLVED WITH THIS STUDY AND HOW LONG WILL THEY TAKE?

Based on a set of 13 standard questions, a semi-structured interview will be conducted with the flexibility for the interviewer to explore particular areas of interest. Each interview will take approximately 30 to 60 minutes.

The list of 13 questions are:

Items	For Adopters	For Non-adopters	Questions
Q1 (Basic information)	X	X	"How many vehicles does your organization own or operate?; Among those vehicles, do you have alternative fuel vehicles (AFVs) in your fleet?" "What are the vocations of the vehicles in your fleet?"
Q2 (Key decision-makers)	X	X	"Who are the key people for making fleet purchase decisions?; Who is involved the decision process?; What role do they play?"
Q3 (Decision-making process)	X	X	"What decision process does your organization follow in purchasing vehicles?; How does your NGV purchase decision process differ from your routine or conventional vehicle purchase decisions?"
Q4 (Influencing factors)	X	X	"What factors influenced your fleet purchase decisions?; Were there any factors which made you more willing to or more hesitant to purchase NGVs?"
Q5 (Laws or regulations)	X		"What laws or regulations affected your NGVs purchase decision?"
Q6	X	X	"What kinds of fuel types of vehicles did you consider when you decided to purchase NGVs?"

(Other alternative considered)			
Q7 (Satisfaction about NGV operations)	X		"Given your experiences with the NGVs, how satisfied or dissatisfied are you with the NGVs? Can you explain why you are satisfied/dissatisfied?"
Q8 (Adoption supporting/facilitating efforts)	X		"Were there any educational training programs that your organization received from natural gas vehicle manufacturers or fuel providers?; Were there any driver training programs that were provided to your NGV drivers?"
Q9 (Refueling facilities)	X		"What kind of fueling stations do you use for NGVs?; How satisfied or dissatisfied are you with the NGV refueling?"
Q10 (Repurchase intent)	X	X	"Do you have a plan to expand your fleet of NGVs? (In case the answer is "No") If you need to purchase new vehicles, how likely are you to purchase NGVs?"
Q11 (Recommendation received & recommendation intent)	X	X	"Have you ever received any recommendations or feedback from other fleet operators about NGVs purchases?" "Have you ever recommended NGVs to others? (In case the answer is "No") How likely are you to recommend NGVs to other fleet managers?"
Q12 (NGVIP)	X	X	"How did you learn about the Natural Gas Vehicle Incentive Project?; Could you please provide us with some suggestions which can improve NGVIP?"
Q13 (Opinions on future technologies)	X	X	"If you look 10 to 20 years down the road, what do you think about viable options of alternative fuel vehicles?" "Have you heard about autonomous or driverless vehicle technologies? (In case the answer is "Yes") What do you think about using the autonomous vehicles in your fleet?"

For NGV adopters, those 13 questions above will be asked. For NGV non-adopters − those who considered NGV purchase and decided not to adopt NGVs −, a part of the set of questions (i.e., Questions 1-4, 6, 10-13) will be asked.

We will be recording this interview because we do not want to miss any of your valuable comments. Although we will be taking some notes during the interview, we cannot possibly write fast enough to get it all down.

WHAT ARE THE POSSIBLE DISCOMFORTS OR RISKS RELATED TO THE STUDY?

There are no known harms or discomforts associated with this study beyond those encountered in normal daily life.

ARE THERE BENEFITS TO TAKING PART IN THE STUDY?

Participant Benefits

You will not directly benefit from participation in this study.

Benefits to Others or Society

The information obtained from this study may provide us a novel insight into the recent NGVs market in California from its demand side. The study results also may help California transportation planners elicit policy recommendations which would increase NGVs market penetration either by promoting drivers or removing barriers. Ultimately, this study may contribute to air quality improvement and help California achieve its greenhouse gas reduction goals.

WILL I BE PAID FOR TAKING PART IN THIS STUDY?

Compensation

You will not be compensated for your participation in this research study.

Reimbursement

You will not be reimbursed for any out of pocket expenses, such as wireline or wireless telephone service fees, parking, or transportation fees.

WHAT HAPPENS IF I WANT TO STOP TAKING PART IN THIS STUDY?

You are free to withdraw from this study at any time. **If you decide to withdraw from this study you should notify the research team immediately.** The research team may also end your participation in this study if you do not follow instructions, miss scheduled visits, or if your safety and welfare are at risk.

HOW WILL MY PERSONAL INFORMATION BE KEPT?

Subject Identifiable Data

All identifiable information collected about you will be kept with the research data, because we might need to refer the original interview data during further analysis.

To transcribe the interview audio recordings, we will use a transcription service. Although non-UCI researchers, such as a typist, an editor, and a project manager in the transcription service company, can temporarily access the interview data, the following protocol will be implemented with the transcription service company to minimize potential breach of confidentiality: 1) Use of 128-bit Secure Socket Layer encryption security in transit and 256-bit AES encryption at rest; 2) Deletion of each audio/transcript immediately upon completion; 3) Not using the audio files/transcripts for any kind of secondary purposes; and 4) Not storing the audio files/transcripts on portable drives.

All responses will be kept confidential. We will ensure that any information we include in any report or publication does not identify you as the respondent.

Data Storage

Research data will be stored electronically on a laptop computer in an encrypted file and is password protected.

The audio recordings will also be stored in a secure location; then transcribed and erased at the end of the study.

Data Retention

The researchers intend to keep the research data within one (1) year of collection or completion of the project, NGVIP (whichever occurs first).

WHO WILL HAVE ACCESS TO MY STUDY DATA?

The research team, authorized UCI personnel, and regulatory entities such as the Office of Human Research Protections (OHRP), may have access to your study records to protect your safety and welfare.

Any information derived from this research project that personally identifies you will not be voluntarily released or disclosed by these entities without your separate consent, except as specifically required by law. Study records provided to authorized, non-UCI entities will not contain identifiable information about you; nor will any publications and/or presentations without your separate consent.

While the research team will make every effort to keep your personal information confidential, it is possible that an unauthorized person might see it. We cannot guarantee total privacy.

ARE THERE OTHER ISSUES TO CONSIDER IN DECIDING WHETHER TO PARTICIPATE IN THIS STUDY?

No one on the study team has a disclosable financial interest related to this research project.

WHO CAN ANSWER MY QUESTIONS ABOUT THE STUDY?

If you have any comments, concerns, or questions regarding the conduct of this research, please contact the research team listed at the top of this form.

Please contact UCI's Office of Research by phone, (949) 824-6662, by e-mail at IRB@research.uci.edu or at 141 Innovation Drive, Suite 250, Irvine, CA 92697, if you are unable to reach the researchers listed at the top of the form and have general questions; have concerns or complaints about the research; have questions about your rights as a research subject; or have general comments or suggestions.

What is an IRB? An Institutional Review Board (IRB) is a committee made up of scientists and non-scientists. The IRB's role is to protect the rights and welfare of human subjects involved in research. The IRB also assures that the research complies with applicable regulations, laws, and institutional policies.

HOW DO I AGREE TO PARTICIPATE IN THIS STUDY?

You should not sign this consent form until all of your questions about this study have been answered by a member of the research team listed at the top of this form. You will be given a copy of this signed and dated consent form to keep. **Participation in this study is voluntary**. You may refuse to answer any question or discontinue your involvement at any time without penalty or loss of benefits to which you might otherwise be entitled. Your decision will not affect your future relationship with UCI or your quality of care at the UCI Medical Center. Your participation in this study will not impact your eligibility for incentives under the NGVIP or any other CEC incentive programs.

_____ Yes, I agree to allow the research team to audio record my interview.
_____ No, I do not agree to allow the research team to audio record my interview.

Your signature below indicates you have read the information in this consent form and have had a chance to ask any questions you have about this study. In the case of phone interviews, an oral consent will be obtained.

I agree to participate in the study.

____ _____________________

Subject Signature **Date**

____

Printed Name of Subject

____ _____________________

Researcher Signature **Date**

____

Printed Name of Researcher

APPENDIX D: ATLAS.ti Code List

Using *ATLAS.ti*, a qualitative analysis tool, approximately more than 300 initial codes were created under nine categories:

1) Basic information (BSI, an abbreviation for codes));
2) Decision-making process (PRC);
3) Factors influencing heavy-duty AFV adoption decisions (DM);
4) Feedback from vehicle drivers (DRV);
5) Adoption supporting or facilitating efforts from technologies providers (EFF);
6) Social influence on heavy-duty AFV adoption decision (e.g., recommendation or feedback shared with other fleet operators) (REC);
7) Satisfaction about heavy-duty AFV operations (SAF);
8) Opinions on NGVIP (NGVIP)
9) Opinions about viable options for alternative fuels in 2030s (AFV2030s).

The code list is provided in Table D-1.

Table D-1. ATLAS.ti Code List

Category		Code
Q1 (Basic information) **Q10 (Repurchase intent)** **Q9 (Refueling behavior)** **► BSI**	●	BSI_1st AFV-year
	●	BSI_1st NGV-year
	●	BSI_AFV-expand
	●	BSI_CNG engine
	●	BSI_Costs-CNG tank replacement
	●	BSI_Costs-CNG vehicles
	●	BSI_Driving patterns
	●	BSI_Driving range
	●	BSI_ELEC Recharging
	●	BSI_In-house maintenance
	●	BSI_Interviewees
	●	BSI_LCFS credit
	●	BSI_Lifespan-CNG tank
	●	BSI_Lifespan-CNG Vehicle
	●	BSI_LPG Refueling

Category		Code
	●	BSI_LPG Refueling-time
	●	BSI_NGV-expand
	●	BSI_NGV-ngvip
	●	BSI_Num-AFV
	●	BSI_Num-NGV
	●	BSI_Others_Incremental cost
	●	BSI_Procurement plan
	●	BSI_Refueling-offsite-stations
	●	BSI_Refueling-offsite-stations-had been used
	●	BSI_Refueling-offsite-travel time
	●	BSI_Refueling-onsite
	●	BSI_Refueling-onsite-construction costs
	●	BSI_Refueling-onsite-decision process
	●	BSI_Refueling-onsite-fast-fill-built-year
	●	BSI_Refueling-onsite-fuel costs
	●	BSI_Refueling-onsite-planned
	●	BSI_Refueling-onsite-private
	●	BSI_Refueling-onsite-private and public
	●	BSI_Refueling-onsite-semi public
	●	BSI_Refueling-onsite-upgrade plans
	●	BSI_Refueling-time-fast fill
	●	BSI_Refueling-time-slow fill
	●	BSI_RNG
	●	BSI_RNG-production facilities
	●	BSI_Size-employees
	●	BSI_Size-fleet
	●	BSI_Size-others
	●	BSI_Turnover
	●	BSI_Turnover-Age
	●	BSI_Turnover-Budget available
	●	BSI_Turnover-Business opportunity
	●	BSI_Turnover-Miles
	●	BSI_Turnover-TCO
	●	BSI_Turnover-Vehicle condition
	●	BSI_Vocation
Q2 (Key decision-makers) Q3 (Decision-making process) ► PRC	●	PRC_Centralized or decentralized
	●	PRC_Compared to diesel: people involved in the process are the same
	●	PRC_Compared to diesel: process is the same or different
	●	PRC_Formality
	●	PRC_Frequency of reassessment of fuel choice decision
	●	PRC_Key people
	●	PRC_Other people involved
	●	PRC_Process
	●	PRC_STEP-Applying for incentives
	●	PRC_STEP-Availability
	●	PRC_STEP-Bidding
	●	PRC_STEP-Business strategies
	●	PRC_STEP-Cost analysis
	●	PRC_STEP-Discussions with internal customers
	●	PRC_STEP-Getting feedback from adopters
	●	PRC_STEP-Placing an order

Category		Code
	●	PRC_STEP-Specifications
	●	PRC_STEP-Suitability
	●	PRC_Vehicle drivers
Q4 (Influencing factors) **Q5 (Laws or regulations)** **Q6 (Other alternatives considered)** **► DM**	●	DM_Adoption-CNG-Others-Decision of vehicle
	●	DM_Adoption-CNG-Attitude of DMU members-pioneer
	●	DM_Adoption-CNG-Contract w municipalities
	●	DM_Adoption-CNG-Cost overall
	●	DM_Adoption-CNG-Engine reliability
	●	DM_Adoption-CNG-Environmental consciousness regarding veh emissions
	●	DM_Adoption-CNG-Factors prioritized
	●	DM_Adoption-CNG-Fuel costs: lower
	●	DM_Adoption-CNG-Fuel economy
	●	DM_Adoption-CNG-Functionality
	●	DM_Adoption-CNG-Incentives
	●	DM_Adoption-CNG-Incentives requirement: replacing old veh
	●	DM_Adoption-CNG-Infrastructure
	●	DM_Adoption-CNG-Insurance costs: lower
	●	DM_Adoption-CNG-Longevity
	●	DM_Adoption-CNG-Maintenance costs
	●	DM_Adoption-CNG-Maintenance provided by a manufacturer
	●	DM_Adoption-CNG-Noise level lowering driver fatigue
	●	DM_Adoption-CNG-Only available option
	●	DM_Adoption-CNG-Promoting environmental sensitivity
	●	DM_Adoption-CNG-Purchase price
	●	DM_Adoption-CNG-Regulation-CARB
	●	DM_Adoption-CNG-Regulation-SCAQMD
	●	DM_Adoption-CNG-Regulations-Others
	●	DM_Adoption-CNG-Reliability
	●	DM_Adoption-CNG-Resale value
	●	DM_Adoption-CNG-Suitability
	●	DM_Adoption-CNG-Trialability
	●	DM_Adoption-CNG-User Acceptance
	●	DM_Adoption-CNG-Warranty
	●	DM_Adoption-ELEC-Demonstration of the tech w progressive efforts
	●	DM_Adoption-ELEC-LDVs-Regulations associated w installing elec charging stations
	●	DM_Adoption-LPG-Contracts
	●	DM_Adoption-LPG-Ease of maintenance and operation
	●	DM_Adoption-LPG-Environmental consciousness regarding veh emissions
	●	DM_Adoption-LPG-Infrastructure
	●	DM_Adoption-LPG-Lower noise level
	●	DM_Adoption-LPG-Only available option-region specific
	●	DM_Adoption-LPG-Regulation-SCAQMD
	●	DM_Adoption-RD-Fuel price
	●	DM_Adoption-RD-Infrastructure
	●	DM_Compared to diesel: factors are different
	●	DM_Compared to LPG: factors are different
	●	DM_CouldAdopt-Clean Diesel-Purcase price
	●	DM_CouldAdopt-Clean Diesel-Range

Category		Code
	•	DM_CouldAdopt-Clean Diesel-To diversify in case of emergency
	•	DM_General-Age group of DMU members
	•	DM_General-Competitors-lack of info exchange
	•	DM_General-Complex fuel choice
	•	DM_General-Finding useful info about ELEC veh was the toughest
	•	DM_General-Indenpendence of foreign sources of oil
	•	DM_General-Lack of information and awareness
	•	DM_General-Regulation-lack of education
	•	DM_General-Size of company
	•	DM_General-Vehicle emissions: little benefits CNG vs diesel
	•	DM_IF-No-Incentives: depends on the capital
	•	DM_IF-No-Incentives: still buy NGVs
	•	DM_IF-No-OnsiteRefueling plus No-Regulation: wouldve stayed w diesel
	•	DM_IF-No-Regulation: buy diesel
	•	DM_IF-No-Regulation: buy some clean diesels
	•	DM_IF-No-Regulation: others
	•	DM_IF-No-Regulation: stick w CNG
	•	DM_NonAdoption-Biodiesel-Availability
	•	DM_NonAdoption-Biodiesel-engine issues
	•	DM_NonAdoption-Biodiesel-Not allowed by AQMD
	•	DM_NonAdoption-Biodiesel-Other or unmentioned reasons
	•	DM_NonAdoption-ELEC-additional costs for battery backup systems
	•	DM_NonAdoption-ELEC-Already built CNG on-site station
	•	DM_NonAdoption-ELEC-Battery degradation issues
	•	DM_NonAdoption-ELEC-Cost to upgrade power grid to charge
	•	DM_NonAdoption-ELEC-Less payload
	•	DM_NonAdoption-ELEC-Life cycle based environmental impact
	•	DM_NonAdoption-ELEC-Limited range
	•	DM_NonAdoption-ELEC-Long charge time in case of the power blackout
	•	DM_NonAdoption-ELEC-Not viable option
	•	DM_NonAdoption-ELEC-Purchase price
	•	DM_NonAdoption-Ethanol-Fuel price is not low
	•	DM_NonAdoption-Ethanol-Fuel price is unstable
	•	DM_NonAdoption-Ethanol-Not sure about emission benefits
	•	DM_NonAdoption-Hydrogen-Availability
	•	DM_NonAdoption-LNG-Infrastructure
	•	DM_NonAdoption-LNG-Maintenance issues
	•	DM_NonAdoption-LNG-Reliability issues
	•	DM_NonAdoption-LNG-Suitability
	•	DM_NonAdoption-LNG-The number of fuels is saturated
	•	DM_NonAdoption-LPG-Availability
	•	DM_NonAdoption-LPG-Limited range
	•	DM_NonAdoption-LPG-Lower power
	•	DM_NonAdoption-LPG-The number of fuels is saturated
	•	DM_NonAdoption-Others-Already committed CNG
	•	DM_NonAdoption-Others-Infrastructure

Category		Code
	•	DM_NonAdoption-Others-Suitability
	•	DM_OnsiteRefuel-Business purpose
	•	DM_OnsiteRefuel-Fuel price: lower
	•	DM_OnsiteRefuel-Incentives
	•	DM_OnsiteRefuel-Labor cost savings
	•	DM_OnsiteRefuel-LCFS credits
	•	DM_OnsiteRefuel-Lower complexity w fleet routing
	•	DM_OnsiteRefuel-Space
Q7 (Satisfaction about NGV operations) **Q9 (Satisfaction about NG refueling facilities)** **► SAF**	•	SFN_CNG-InfraCons-CNG storage diminishing return
	•	SFN_CNG-InfraCons-Fuel security
	•	SFN_CNG-InfraCons-Lack of infrastructure (in general)
	•	SFN_CNG-InfraCons-Long time taken to deal with utilities when building stations
	•	SFN_CNG-InfraCons-Maintenance
	•	SFN_CNG-InfraCons-Offsite-Complexity increased w fleet routing
	•	SFN_CNG-InfraCons-Offsite-Labor cost
	•	SFN_CNG-InfraCons-Offsite-No measurable fuel cost saving
	•	SFN_CNG-InfraCons-Offsite-Not 100 percent fuel in a full tank
	•	SFN_CNG-InfraCons-Onsite facilities-issue-offline
	•	SFN_CNG-InfraCons-Onsite fueling facility capacity
	•	SFN_CNG-InfraPros-Consistency of the fuel
	•	SFN_CNG-InfraPros-Driver costs saving thanks to onsite fueling facilities
	•	SFN_CNG-InfraPros-Maintenance is a fairly simplistic process
	•	SFN_CNG-InfraPros-Offsite-Accessibility
	•	SFN_CNG-InfraPros-Onsite facilities lowering fuel price
	•	SFN_CNG-InfraPros-Onsite facilities-Fueling convenience
	•	SFN_CNG-InfraPros-Onsite-Refilling convenience of tanks by monitoring systems
	•	SFN_CNG-Overall infra
	•	SFN_CNG-Overall vehicles
	•	SFN_CNG-Past-InfraCons-Low psi issue
	•	SFN_CNG-Past-VehCons-Didnt work
	•	SFN_CNG-VehCons-Cold start issue
	•	SFN_CNG-VehCons-Cost required to build a code compliant natural gas facility
	•	SFN_CNG-VehCons-Engine piston failure issue
	•	SFN_CNG-VehCons-Fuel efficiency
	•	SFN_CNG-VehCons-Maintenance costs are not really lower than diesel
	•	SFN_CNG-VehCons-Potential performance issues
	•	SFN_CNG-VehCons-Purchase price
	•	SFN_CNG-VehCons-Range issue
	•	SFN_CNG-VehCons-Resale value
	•	SFN_CNG-VehCons-Safety concern
	•	SFN_CNG-VehPros-Dont need to buy diesels w emission controls
	•	SFN_CNG-VehPros-Engine reliability
	•	SFN_CNG-VehPros-Fuel cost saving
	•	SFN_CNG-VehPros-Help get a contract
	•	SFN_CNG-VehPros-Insurance discount
	•	SFN_CNG-VehPros-Lower env impact

Category		Code
	•	SFN_CNG-VehPros-Lower maintenance costs
	•	SFN_CNG-VehPros-No range issues: due to vocation-specific aspects
	•	SFN_CNG-VehPros-Noise level
	•	SFN_CNG-VehPros-Performance
	•	SFN_CNG-VehPros-Policy about increased payload
	•	SFN_CNG-VehPros-Promoting green status
	•	SFN_CNG-VehPros-Resale value
	•	SFN_CNG-VehPros-Storage of CNG
	•	SFN_CNG-VehPros-Vehicle reliability
	•	SFN_LPG-InfraCons-Inefficient clipboard transactions
	•	SFN_LPG-Overall infra
	•	SFN_LPG-Overall vehicles
	•	SFN_LPG-VehPros-Engine reliability
	•	SFN_LPG-VehPros-Little more energy than NGV
	•	SFN_LPG-VehPros-Lower maintenance costs
	•	SFN_LPG-VehPros-Performance
	•	SFN_LPG-VehPros-Vehicle Reliability
Q7: f/u (Drivers feedback on AFV operations) ► DRV	•	DRV_Acceptance: became favorable
	•	DRV_Acceptance: education is important
	•	DRV_Cons-Concerns but unsubstantiated
	•	DRV_Cons-Difficulty to find off-site stations
	•	DRV_Cons-Efforts needed to learn CNG operations
	•	DRV_Cons-Fueling inconvenience
	•	DRV_Cons-Performance when fuel begins to run out
	•	DRV_Cons-Range issue w tractor
	•	DRV_LPG_None
	•	DRV_None
	•	DRV_Others: how to identify the drivers for CNG vehicles
	•	DRV_Past-Negative-Incorrect nozzle connection
	•	DRV_Past-Negative-Less power than diesel
	•	DRV_Past-Negative-Not enough hoses to fill over buses
	•	DRV_Pros-Fueling convenience
	•	DRV_Pros-Lower noise
	•	DRV_Pros-Overall
	•	DRV_Pros-Performance equivalent to diesel
Q8 (Adoption supporting/ facilitating efforts) ► EFF	•	EFF_Dealership-Lack of awareness-Education needed
	•	EFF_Fuel Provider-Maintenance program
	•	EFF_General-Education for fleet operators about AFVs-Important
	•	EFF_General-Lack of collaboration btw fuel-veh manufacturers
	•	EFF_LNG-Manufacturer-Educational training-None
	•	EFF_Manufacturer-Driver training-None
	•	EFF_Manufacturer-Driver training-Received
	•	EFF_Manufacturer-Educational training-None
	•	EFF_Manufacturer-Educational training-Received
	•	EFF_Manufacturer-Test driving-Just did
	•	EFF_Others-Educational training-Received
	•	EFF_Themselves-Driver training-Provided
	•	EFF_Themselves-Educational training-Provided
	•	EFF_Themselves-Safety training for drivers-Provided

Category		Code
	●	EFF_Themselves-Safety training for mechanics-Provided
Q11 (Recommendation received & recommendation intent) ► REC	●	SOC_AFV-Edu-Provided
	●	SOC_CNG-Edu-Provided
	●	SOC_CNG-FB-Provided-Neutral-Vehicle overall
	●	SOC_CNG-FB-Provided-None
	●	SOC_CNG-FB-Provided-Positive-Vehicle brand
	●	SOC_CNG-FB-Provided-Positive-Vehicle overall
	●	SOC_CNG-FB-Received-Neutral-Vehicle overall
	●	SOC_CNG-FB-Received-None
	●	SOC_CNG-FB-Received-Positive-Vehicle overall
	●	SOC_CNG-REC-Provided
	●	SOC_CNG-REC-Would like to give-Onsite refueling
	●	SOC_Fleet manager associations
	●	SOC_General-Associations-resource for helping the DM process
	●	SOC_General-Gas company-ideal resource for helping the DM process
	●	SOC_General-Lack of information exchange between competitors
	●	SOC_LNG-FB-Received-Negative-Having issues in the LNG systems
	●	SOC_LNG-Social norm-The industry was not doing LNG
Q12 (Opinions on NGVIP) ► NGVIP	●	NGVIP_Access
	●	NGVIP_Encouraged you to buy more NGVs
	●	NGVIP_IF-No-Incentives
	●	NGVIP_Opinion-incentive amount
	●	NGVIP_Opinion-thanks
	●	NGVIP_Other incentives-CARB VIP
	●	NGVIP_Other incentives-Carl Moyer
	●	NGVIP_Other incentives-Prob1B
	●	NGVIP_Other incentives-Others
	●	NGVIP_Other incentives-none
	●	NGVIP_Other incentives-Infra-Carl Moyer
	●	NGVIP_Other incentives-Infra-MSRC
	●	NGVIP_Other incentives-Infra-SCAQMD
	●	NGVIP_Other incentives-Infra-Others
	●	NGVIP_Other incentives-Infra-none
	●	NGVIP_Pros-easy process
	●	NGVIP_Suggestion-long time to get approval
	●	NGVIP_Suggestion-time frame
	●	NGVIP_Suggestion-allowing for early sitting on a reservation-unfair
	●	NGVIP_Suggestions by Admin-allowing vehicle purchase before receiving reservation
	●	NGVIP_Suggestions by Admin-asking early applicants to return it at some point if they do not have a contract to buy
Q13 (Opinions on viable alternative fuel options in 2030s) ► AFV2030s	●	AFV2030s_CNG
	●	AFV2030s_Diesel
	●	AFV2030s_Electricity
	●	AFV2030s_Hybrid
	●	AFV2030s_Hydrogen
	●	AFV2030s_LPG

APPENDIX E: Quotation Examples and Definition of Themes

As supplementary materials for Chapter 4.4, Table E-1 provides the quotation examples for the factor found influencing heavy-duty AFV adoption decisions in the participating organizations. Table E-2 provides the definitions of themes emerged by the analysis.

Table E-1. List of Factors and Quotation Examples

Factors	Quotation Examples
<u>Technology characteristics</u>	
• Functional suitability	"*We have to take into consideration this, you know, certain things with the size of the vehicle and whether or not it'll fit and work in the areas that we need it to.*" (Org. 7)
• Overall costs (capital and operational expenses)	"*CAPEX and OPEX - how much does it cost and what's it cost to run.*" (Org. 14)
• Vehicle purchase price	"*It's almost two [a CNG truck] to one [a diesel truck]. I wish we could get the price of these CNG trucks down a little bit.*" (Org. 8)
• Fuel price	"*As far as the fuel cost, it's cheaper.*" (Org. 17)
• Maintenance issues	"*The CNG right now, as of today, are a bit more onerous to maintain and operate and in training our mechanics*." (Org. 12)
• Resale value	"*Secondary would be resale value and how do we remarket these when we're done with [...]*" (Org. 4)
• Other costs	"*We also get a discount on our insurance for natural gas trucks, [...]*" (Org. 8)
• Fuel economy	"*The battery electric bus fuel economy is more than 8 times higher than that of a CNG bus [...]*" (Org. 19)
• Noise level	"*We've noticed a big difference in driver fatigue while driving natural gas vehicles versus driving your conventional diesel trucks, because you don't have the noise fatigue [...]*" (Org. 8)
• Environmental benefits	"*Ethanol, you know, I'm not sure that we can get the same footprint with emissions as we can with a near-zero Cummins with renewable gas.*" (Org. 7)

Factors	Quotation Examples
• Life cycle-based environmental impacts	"*I look at the whole picture for electric vehicles. The pollutions, the destructions they are causing to the environment, those lithium batteries, and all the other environmental impacts that are happening in producing those batteries.*" (Org. 1)
• Fuel infrastructures	"*Probably the only operational issue that we have to be cognizant of at these five sites that have the CNG buses is just the availability of fuel. So, we have to make sure our tanks are full, especially if we have some longer routes.*" (Org. 12)
• Additional costs related to fueling/charging infrastructure	"*Time of use and demand charges factor into the cost of electricity […].*" (Org. 19)
• Fuel system conversion of vehicles	"*We're in the process of converting over our diesel to renewable diesel at the moment. I mean, that's pretty straight transition. There's no real changes needed to convert if it's a renewable diesel.*" (Org. 3)
• Fuel security	"*If there is a big earthquake and power goes out […] my fleet is gonna run for a day […]*" (Org. 2)
• Charging time when power blackout occurs	"*There's also a problem with electric vehicle, the blackout of the power over night. […] You're not moving them. You're dead, and then you get to take 68 hours to charge them [17 buses] up.*" (Org. 1)
• Stable fuel price	"*After the Iran embargo of oil, [the DMU of my organization] thought that CNG duel fuel would be more reliable in the future.*" (Org. 5)
• Vehicle reliability and safety	"*The most important factor is safety and reliability, that the vehicle is going to be there to carry out the purpose that's required of it, its duty cycle, and that it can be operated safely for the life cycle of the vehicle.*" (Org. 10)
• Engine reliability	"*I mean, [engine] reliability, I think that there was a lot of early issues with the 12 liter [CNG] engine. […] [However] I think they're on par, CNG and diesel, at the moment in regards to reliability.*" (Org. 3)
• Fuel storage issues (e.g., battery degradation)	"*Proterra reports that the high voltage batteries are showing little to no signs of capacity degradation to date, and current estimates show they may last for up to 12 years.*" (Org. 19)
• Other unspecified issues	"*Well, we've used biodiesel in the past. Of course, we may have had the same problems everybody else did.*" (Org. 13)
<u>Organization characteristics</u>	
• Environmental consciousness/CSR	"*I would say, if I prioritize [the factors], number one would be the environmental impact that [the vehicles] have […]*" (Org. 4)

Factors	Quotation Examples
• Sustainability plans implemented within the organization	"*I do know that we have a sustainability plan and directive from our city council that we are going to be, I want to say 80 percent alt[ernative] fuel by a certain year.*" (Org. 13)
• Demonstration of technologies with progressive efforts	"*Because we have a reputation as a very progressive and green public fleet, and they know we've implemented a lot of things, and kind of been on the leading edge of a lot of fleet sustainability efforts, so they really wanted us to demonstrate the technology.*" (Org. 10)
• Contract with municipalities	"*In the trash business, when you run a municipal fleet, they're requiring you to run CNG.*" (Org. 14)
• Promoting environmental sensitivity	"*Public perception, from a company standpoint, [is one of the factors].*" (Org. 16)
• Commitment already made to a specific fuel option(s)	"*Right now, what happened is, because we have the LNG fueling infrastructure and we would like to utilize it for - to make our investment worthwhile.*" (Org. 17)
• Diversification of fuel options	"*We want to diversify the fuel option for our fleet, so in the event that we have an issue with one particular fuel type like CNG, then we still have a portion of fleet running or operating on other fuel types.*" (Org. 17)
• Attitude of key DMU members	"*My role, I've been in fleet for 40+ years, so I am pretty well informed about what's on the market, and where we should be looking in terms of new technology. And, I take a particular interest in the sustainability of the vehicles [...]*" (Org. 15)
• Acceptance of users (drivers)	"*And then user acceptance - if we invest the money [...] if the user isn't going to use it, and they say it's not going to do the job for them, then we've failed in our responsibilities of specifying the right vehicle to carry out their mission.*" (Org. 10)
External environmental influences	
• Regulations by AQMDs	"*Because of SCAQMD rules and regulations we are not allowed to even purchase clean diesel or else I would.*" (Org. 1)
• Regulations by CARB	"*There's state CARB requirements. [...] So, it was advantageous for us from a CARB requirement to convert this fleet to CNG.*" (Org. 6)
• Other regulations/policies	"*I know California recently approved a state level some potentially increases under 80,000 pound limit for CNG. [...] That 2,000 pounds is a big deal. That's a big step forward.*" (Org. 3)
• Financial incentives	"*I would say because of the grants that were available here locally through our air district. That enabled the county to do a lot of*

Factors	Quotation Examples
	migration and put in the original liquefied natural gas station." (Org. 10)
• Availability of vehicles	"*The only alternative in 2009 was CNG vehicle. There's really no alternatives in that category other than natural gas.*" (Org. 2)
• Opportunity to test a vehicle	"*We go and rent one and try it out pulling and pulling other things, and these trucks are outperforming some of our diesel trucks. And now you start seeing the benefits behind them as well, it starts opening eyes.*" (Org. 8)
• Warranty/maintenance provided by manufacturers	"*We are never going to purchase a vehicle where we are dependent upon a dealer or a manufacturer that's not locally based to maintain it, and to support it.*" (Org. 10)
• California State's direction	"*When the state went out for their renewable diesel, we jumped on that.*" (Org. 13)
• Technologies are already proven in the industry (social norm)	"*CNG vehicles have proven to be an acceptable heavy-duty application for refuse and recycling collection […] That was the driver.*" (Org. 9)

Table E-2. Definitions of Themes

Themes	Definitions
Technology characteristics	
• Perceived compatibility	The degree to which AFVs are "perceived as consistent with the existing values, past experiences, and needs of potential adopters." (Rogers, 1983b, p.223)
• Perceived relative advantages	The degree to which AFVs are "perceived as being better than the idea it supersedes." (Rogers, 1983b, p.213)
• Perceived complexity	The degree to which AFVs are "perceived as relatively difficult to understand and use." (Rogers, 1983b, p.230)
• Perceived uncertainty	"the degree to which a number of alternatives are perceived with respect to the occurrence of an event and the relative probability of these alternatives." (Rogers, 1983b, p.6)
Organization characteristics	
DMU level's motives	

Themes	Definitions
• Business strategic motives	Extrinsic motives that an organization strives for improving their competitive position in the market and industry (Seitz et al., 2015)
• Intrinsic belief and values	Certain belief and values that an organization intrinsically possesses and pursues (Seitz et al., 2015)
Individual acceptance	
• Acceptance of end users	The degree to which AFVs are accepted and used by end users within an organization (Frambach and Schillewaert, 2002)
• Acceptance of DMU members	The degree to which key decision-makers form a favorable or unfavorable attitude towards AFVs within the DMU, along with the degree to which other DMU members accept AFVs (Rogers, 1983a)
External environmental influences	
• Supplier supporting efforts	Support provided by technology suppliers (e.g., vehicle manufacturers and fuel providers) to increase technology availability (Tornatzky and Fleischer, 1990), to reduce risks associated with the adoption, which includes implementation, financial, and operation risks (Frambach and Schillewaert, 2002), and to facilitate the adoption via offering trialability (Rogers, 1983a), marketing and communication activities (Frambach and Schillewaert, 2002)
• Government policies	A course of action adopted and implemented by governments, such as via regulations and incentives, to facilitate or strongly encourage to purchase and use AFVs (Tornatzky and Fleischer, 1990)
• Social influences	Direct or indirect social interactions between a member in an organization and others, which influences AFV fleet adoption in organizations, such as via information sharing activities (Rogers, 1983a) and social norm (Frambach and Schillewaert, 2002)

[Note] DMU: decision-making unit.

APPENDIX F: Supplementary Materials for Chapter 4

See Tables F-1 and F-2 for Chapter 4.7 (Heavy-duty CNG Refueling Facilities).

Table F-1. Decisions about Building On-site Refueling Facilities

Organization [(a)]	**Org. 02**	**Org. 04**	**Org. 08**	**Org. 11**
Vocation	various	delivery	trucking	refuse
Public vs. Private	public	private	private	private
Fleet size [(b)]	medium	medium	small	medium
Lower fuel price	Motivator	Motivator	Motivator "*Because I'll be going from paying $2.20 a gallon to about $1.80, so now I'm saving another 40 cents a gallon.*"	Motivator
Labor cost savings	Motivator "*We were spending, 700,000 dollars a year and labor costs getting back and forwards*"			
Lower complexity with fleet routing				Motivator "*[...] our drivers may have to come in in the middle of the day to refuel during the course of their route*"
Space	Barrier "*Space is another barrier along with the costs*"			
Construction costs				
Incentives	Facilitator	Facilitator	Facilitator	Facilitator

[Note] (a) All these organization were using off-site CNG fueling stations, but planning to build on-site facilities. (b) large fleet size: >100 vehicles, medium fleet size: 20-100 vehicles, and small fleet size: $\leq$ 20 vehicles.

Table F-2. Financial Incentives Used to Build On-site Refueling Facilities

Organization	Vocation	Public vs. Private	Fleet size	Incentives for refueling Infrastructure [(a)]
Org. 01	school bus	public	medium	CEC, SCAQMD
Org. 02	various	public	medium	MSRC
Org. 03	various	public	large	MSRC and some grant funding
Org. 04	delivery	private	medium	Carl Moyer
Org. 05	delivery	private	medium	n/a
Org. 06	refuse	private	large	n/a
Org. 07	refuse	private	large	No (that was all internally funded)
Org. 08	trucking	private	small	Will apply for incentives
Org. 09	various	public	large	CEC
Org. 10	various	public	large	No (that was all internally funded)
Org. 11	refuse	private	medium	Will apply for incentives
Org. 12	school bus	private	large	n/a
Org. 13	various	public	large	n/a
Org. 14	refuse	private	large	Carl Moyer, SCAQMD
Org. 15	various	public	large	Some grant funding
Org. 16	various	public	large	n/a (using only off-site stations)
Org. 17	refuse	public	large	Some grant funding
Org. 18	paving	private	small	n/a

[Note] (a) Carl Moyer Program (https://www.arb.ca.gov/msprog/moyer/apply/apply.htm), MSRC: Mobile Source Air Pollution Reduction Review Committee, n/a: the relevant information was not available during the interviews.

In Chapter 4.9 (Opinions on Financial Incentives), in addition to the interview questions on the effect of the incentives on heavy-duty AFV adoption decisions, the following questions were additionally asked.

- **Q12 (d)**: "How did you learn about the Natural Gas Vehicle Incentive Project (NGVIP)?"

- **Q12 (e)**: "Do you have any opinions about NGVIP? Could you please provide us with some suggestions which can improve NGVIP?"

The answers to Q12(d) and Q12(e) are summarized in Figures F-1 and F-2, respectively. After discussions between participating researchers, the relevant insights were identified below.

Organizations (vocations)	01 school bus	02 vari-ous	03 vari-ous	04 deliv-ery	05 deliv-ery	06 refuse	07 refuse	08 truck-ing	09 vari-ous	10 vari-ous	11 refuse	12 school bus	13 vari-ous	14 refuse	15 vari-ous	16 vari-ous	17 refuse	18 paving
• Internet (e.g., Google search, social media) (a)			X	X			X	X	X			X	(b)	(c)		X	X	
• Email subscriptions		X					X								X			
• Vehicle dealers					X						X						X	
• Fuel vendors					X	X			X			X						
• Interpersonal network (e.g., a contact at another agency)				X		X										X		
• Through associations/ coalitions (e.g., Clean Fleets)						X	X			X					X			X
• Events (e.g., conference, expo)	X		X															

[Note] (a) Each background color for access paths represents a certain category of those paths: yellow (through the Internet), red (through technology suppliers), and purple (via a social network or social event). (b) The relevant information could not be recalled during the interview. (c) The information on incentive programs was delivered by an employee within the organization.

Figure F-1. Access Path to NGVIP

Various paths used to become aware of NGVIP such as through the Internet, a social network/event, and vehicle/fuel vendors – The participating organizations addressed various paths by which they were able to learn about the NGVIP (see Figure F-1), including the following categories: 1) through the Internet (e.g., Google search, social media, email subscriptions to AQMD), 2) via a social network/event such as an interpersonal network (e.g., a contact at a gas company), relevant associations (e.g., fleet manager associations, Clean Cities Coalition), social events (e.g., conference, expo), and 3) through the technologies suppliers (i.e., vehicle dealers, fuel vendors). Among those categories, the most popular way was through the Internet (11 out of 18), followed by a social network/event (9 out of 18). Tech suppliers were least mentioned by the participating organizations (6 out of 18). If there are any fleet segments that would be unable to access such information, it may be recommended to design better strategies for distributing the information about incentive programs for HDV fleets.

Organizations	01 school bus	02 vari-ous	03 vari-ous	04 deliv-ery	05 deliv-ery	06 refuse	07 refuse	08 truck-ing	09 vari-ous	10 vari-ous	11 refuse	12 school bus	13 vari-ous	14 refuse	15 vari-ous	16 vari-ous	17 refuse	18 paving
• Thank you for the financial support [(a)]	X [(b)]		X	X	X	X	X		X	X		X	X				X	
• Easy and simple process	X			X					X		X					X		
• A more appropriate time frame	X		X					X	X	X		X					X	
• Higher incentive amounts							X	X		X								
• A shorter time to get an approval						X		X										
• Expanding the scopes of incentives							X										X	
• More user-friendly notifications of the status of the incentive program									X							X		
• Reducing an unfair advantage to those who are early sitting on a reservation and not using it		X																

[Note] (a) Opinions with blue background indicate positive comments. The other opinions with purple background present the interviewees' suggestions for improving the incentive program. (b) The specific opinion was addressed by the corresponding organization.

Figure F-2. Opinions on NGVIP

Various opinions on NGVIP were reported by the participating organizations, ranging from the application process (e.g., simple and straightforward process), the implementation process (e.g., time frame issue, time to get an approval), to the incentive scheme (e.g., incentive amount and scope) – Various opinions on the incentive program were reported, as summarized in Figure F-2. First of all, many of the participating organizations (11 out of 18) thanked the NGVIP for helping them with their NGV adoptions by the financial support: "*We very much appreciate and enjoy that we made the decision [of buying CNG vehicles]. I appreciate that your program exists. I appreciate that California's leading edge*" (Org. 6). Along with the financial support, the straightforward and easy process of NGVIP was acclaimed by many interviewees (5 out of 18): "*I would just like to also say thank you for keeping the process simple. I found it to be a very simple process in comparison to what we had gone through with what we call our primary source [another incentive program they applied for*" (Org. 4).

Meanwhile, possible improvements were suggested which could be considered for any other incentive programs. The most commonly addressed suggestion (7 out of 18) was about an appropriate time frame. For example, one fleet operator explained, *"There's somewhat of a restriction on delivery schedule, but it seems like the delivery of natural gas vehicles keeps getting pushed out longer and longer. […] we've got board approvals and other type applications to fill out, so sometimes […] the six months I think, is hard to meet*" (Org. 3). Due to the time frame issue, some organizations mentioned that they were unable to take advantage of the funding because "*[the delivery of vehicles] fell outside the six-month window*" (Org. 12).

In addition, another recommendation was reported that the program expand the scope of funding so as to "*enable fleet operators to have the opportunity to receive funding for both implementation of the new natural gas fueling infrastructure, as well as expansion of existing fueling stations*" (Org. 17). Also, one organization mentioned about the scope of vehicle vocations: "*HVIP now, they're going to exclude refuse and transit. [...] I just, you know, if California wants to eliminate as much as they can of pollutants into the atmosphere [...] They gotta give it to everybody*" (Org. 7). Regarding the incentive amount, some organizations stated that the amount is "*not enough to cover the incremental costs*" (Org. 7). Furthermore, regarding the time taken to get an approval, a few organizations addressed, they "*go a long period of time before we know whether we're actually going to get the benefit from it*" (Org. 6). Lastly, some organizations recommended more user-friendly notifications of the funding status of the incentive program on the website.

Some of those suggestions particularly regarding administrative processes of an incentive program could be considered when designing application and implementation processes of any future incentive programs. For the other suggestions – such as the incentive amount and the scope of the incentives –, a further research based on a quantitative analysis should be needed with a sufficient size sample in order to examine which incentive scheme (i.e., with what incentive amounts, what target fleet vocations and sectors) would bring the maximum benefits to California in terms of a resulted market share of heavy-duty AFVs and its emission reduction benefits.

APPENDIX G: Survey Item List

See Table G-1.

Table G-1. List of Survey Items with Specific Research Topics

Survey Items	#Questions [(a)]	Specific Topics [(b)]													
		PROF	TURN	OPER	DMP	SETS	REG	FACT	INC	SOC	SUPP	STFN	CHEX	RFL	CHR
Part A: Fleet Characteristics															
[A1] Business sector	2-3	V	V	V	V	V	V	V	V	V	V	V	V	V	V
[A2] The number of employees	1	V	V	V	V	V	V	V	V	V	V	V	V	V	V
[A3] Vehicle vocation type	1	V	V	V	V	V	V	V	V	V	V	V	V	V	V
[A4] Fleet size	1	V	V	V	V	V	V	V	V	V	V	V	V	V	V
[A5] The number of vehicles for each fuel type	2	V	V	V	V	V	V	V	V	V	V	V	V	V	V
[A6] Major vocation type for each fuel type	1	V	V	V	V	V	V	V	V	V	V	V	V	V	V
[A7] Past experiences of heavy-duty AFV operations	1-5	V													
[A8] Current plan to expand / purchase heavy-duty AFV(s)	1-5	V													
[A9] Vehicle turnover criteria	3		V												
[A10] Operating time	1-3			V											
[A11] Operating distance	1-3			V											
[A12] Operating start locations	2-n			V											
Part B: Decision-making Processes															
[B1] People involved in the decision-making processes	1				V										
[B2] Key decision-makers	1				V										

Survey Items	#Ques-tions [(a)]	Specific Topics [(b)]													
		PROF	TURN	OPER	DMP	SETS	REG	FACT	INC	SOC	SUPP	STFN	CHEX	RFL	CHR
[B3] Respondents' job position	1				V										
[B4] Formalization of the process	1				V										
[B5] Specific steps included in the process	1-2				V										
[B6] Difference from conventional decisions: in terms of "decision-makers"	1-2				V										
[B7] Differences from conventional decisions: in terms of "steps of process"	1-2				V										
[B8] Any difficulties in proceeding the process & possible supports	1-3				V										
Part C: Factors Influencing Heavy-duty AFV Adoption Decisions															
[C1] Alternatives in choice set	3-4					V		V							
[C2] Laws or regulations affecting heavy-duty AFV adoption	2-6						V								
[C3] Motivators and barriers affecting AFV adoption and non-adoption decisions	L							V							
[C4] Differences from conventional decisions: in terms of "list of factors"	1-2							V							
[C5] Incentive programs affecting heavy-duty AFV fleet adoption	3-7								V						

Survey Items	#Ques-tions [(a)]	Specific Topics [(b)]													
		PROF	TURN	OPER	DMP	SETS	REG	FACT	INC	SOC	SUPP	STFN	CHEX	RFL	CHR
[C6] Social influences on the decisions	L / 2-5									V					
[C7] Adoption support received from technology providers	L / 2										V				
Part D: Satisfaction, Repurchase, and Recommendations															
[D1] Overall satisfaction on heavy-duty AFV operations	1											V			
[D2] Satisfactory & unsatisfactory aspects	L / 0-5											V			
[D3] Expansion plans & willingness to expand their heavy-duty AFV(s)	2											V			
[D4] Recommendation & feedback experiences	2-3											V			
Part E: Stated Preference Choice Experiments															
[E1] Choice Tasks	TBD												V		V
Part F: Refueling/Charging Behavior															
[F1] Type of refueling facilities	1-2													V	
[F2] Access of the refueling facilities	1-2													V	
[F3] Types of fueling equipment	1-2													V	
[F4] Time taken to travel to off-site stations (in case of "off-site" from F1)	1													V	
[F5] Time taken to refuel the vehicles	1													V	
[F6] When to refuel	1													V	
[F7] Fueling frequency	1													V	

Survey Items	#Questions (a)	Specific Topics (b)													
		PROF	TURN	OPER	DMP	SETS	REG	FACT	INC	SOC	SUPP	STFN	CHEX	RFL	CHR
[F8] Fuel price	1													V	
[F9] Whether they engage in the LCFS market? (in case of "on-site" from F1)	1													V	
[F10] Preferred place to refuel	1-2														V
[F11] Preferred access	1														V
[F12] Preferred fueling equipment	1														V
[F13] Preferred time to refuel	1														V

[Note] (a) Numbers present approximate minimum to maximum numbers of questions for survey items. "L" indicates a Likert scale question comprising multiple statements to be included along with other survey questions (e.g., 45 statements for [C3], 28 statements for [D2]). For [E1], the number of choice tasks will be determined based on the design complexity of the experiments and a potential number of survey respondents. (b) Various specific research topics can be explored by using survey items marked with "V"s. The following abbreviations are used to specific topics: PROF = Heavy-duty AFV adoption/rejection profile, TURN = Fleet turnover behavior, OPER = Fleet operational characteristics, DMP = Decision-making processes of AFV adoption, SETS = Choice sets in the latest adoption/rejection decision, REG = Effect of regulations, FACT= Factors that have influenced AFV adoption, INC = Effect of incentives, SOC = Social influence on AFV adoption, SUPP = Tech suppliers' support, STFN = Satisfaction, repurchase, and recommendations, CHEX = Stated preference choice experiments for heavy-duty AFV in 2030s, RFL = AFV refueling behavior (e.g., CNG HDVs), CHR = Potential charging/refueling behavior (e.g., electric/hydrogen HDVs).

APPENDIX H: AFV Choice Analysis of HDV Fleets Based on Stated Preference Choice Experiment: A Case Study with Drayage Fleets in California

In this Appendix, the ongoing work, the AFV choice analysis of HDV fleets based on stated preference choice experiment, is further described about its initial design. For this work, drayage fleets in California are selected as a case study. The following contents are provided:

1) Overview of drayage fleets in California
2) Stated preference choice experiment with its design components, including: a set of alternatives, a set of attributes and attribute levels, choice tasks, experimental design, and examples of model specification and estimation methods

APPENDIX H.1. Overview of Drayage Fleets in California

The CARB defines drayage trucks as any in-use on-road vehicle with a GVWR greater than 26,000 pounds that is used for transporting cargo, such as containerized, bulk, or break-bulk goods, that operates on, transgresses through, or off a port or intermodal railyard property (CARB, 2011). Similarly, the U.S. EPA defines drayage trucks as “heavy-duty Class 8 trucks that transport containers and bulk freight between the port and intermodal rail facilities, distribution centers, and other near-port locations” (US EPA, 2021). According to the CARB Drayage Truck Inventory (CARB, 2020b), as of 2019, a total of 22,262 Class 8 drayage trucks are registered in California.[43]

These drayage trucks comprise 16,721 trucks at the Port of Los Angeles (PoLA) and/or Port of Long Beach (PoLB) (75.1%), 4,088 trucks at the Port of Oakland (PoAK) (18.4%), and 1,453 trucks at other ports (6.5%). Almost all these drayage trucks are running on diesel fuel (e.g., 94.8% of the trucks at PoLA (PoLA, 2021)), and alternative fueled trucks are very limited (e.g., 3% for LNG and 2% for CNG at PoLA (PoLA, 2021)). Drayage trucks not only play a vital role for the goods movement economy but also account for harmful emissions which threaten health conditions of residents particularly in disadvantaged communities (CARB, 2020b). Meantime, in the U.S. more than eight manufacturers provide CNG and LNG tractors (U.S. DOE, 2021a) (see the Appendix A), and several manufacturers (e.g., Freightliner, Volve, Peterbilt) have started or plan to offer battery electric or hydrogen options (CARB, 2020b).

In line with the aggressive goal of the State of California to transition all drayage trucks to be zero-emission by 2035 under Executive Order N-79-20 (State of California, 2020), there are many regulations and incentive programs to which drayage fleets are subject. Tables H-1 and H-2 present summaries of some examples of these regulations and incentive programs, respectively. These policies can influence alternative fuel adoption behavior of drayage fleets in various ways, across multiple Modules described in the demand modelling framework presented in Chapter 5.

[43] There are 202 drayage trucks registered as Class 4-7 in the inventory, therefore about 99.1% of heavy-duty drayage trucks are Class 8.

Some regulations restrict fuel choice options, which is associated with Module 2 (AFV choice). For example, under the proposed Advanced Clean Fleet (ACF) regulation (CARB, 2020b), beginning in 2023, any truck added to the CARB Drayage Truck Registry must be zero-emission. Some other regulations affect fleet replacement plans (Module 1) by requiring a particular model year or newer engine, such as the San Pedro Bay Ports Clean Air Action Plan (CAAP) (Clean Air Action Plan, 2021) and the CARB Drayage Truck Regulation (CARB, 2021d).[44] In addition, other regulations, such as US EPA Phase 2 GHG regulation (U.S.EPA, 2021) and CARB Low-NOx Heavy-duty Omnibus regulation (CARB, 2020c), would give a penalty for operating diesel trucks by imposing incremental compliance costs, which is related to Module 2.

Financial incentive programs for vehicle purchases such as the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (California HVIP, 2021) and Volkswagen Environmental Mitigation Trust (CARB, 2021e) can help offset the incremental costs between AFVs and diesel trucks, which would affect AFV choice (Module 2) and replacement plans (Module 1). Incentive programs for fueling/charging infrastructure construction such as the Carl Moyer Program (CARB, 2021f) and Charge Ready Transport Program by Southern California Edison (Southern California Edison, 2021) would mainly affect Module 3 (refueling/charging facility choice). Such potential impacts by various policy instruments should be incorporated into the demand analysis for alternative fueled drayage fleets.

[44] Under the CAAP, new trucks entering the Ports' Drayage Truck Registry must have a 2014 engine model year (MY) or newer. Under the CARB Drayage Truck Regulation, starting Jan 2023, trucks must have 2010 MY or newer engines to continue entering ports.

Table H-1. Regulations for Drayage Trucks in California

Regulations	Ports	Overall Goals	Specific Strategies (some examples)	References
San Pedro Bay Ports Clean Air Action Plan (CAAP)	PoLA/ PoLB	• The CAAP presents an overall strategy to systematically reduce harmful emissions from five key goods movement sectors – ships, trucks, trains, cargo-handling equipment and harbor craft.	• Advancing the CTP to phase out older trucks and transition to near-zero emissions in the early years and zero-emission trucks by 2035 with a truck rate. • Beginning in mid-2018, new trucks entering the Ports' Drayage Truck Registry (PDTR) must have a 2014 engine model year (MY) or newer. • Beginning in 2020, all heavy-duty trucks will be charged a rate to enter the ports' terminals, with exemptions for trucks that are certified to meet this near-zero standard or better. • Starting in 2023, or when the state's proposed low-NOx heavy-duty engine standard will be required for new truck engine manufacturers, new trucks entering the PDTR must have engines that meet this near-zero emissions standard or better. • A modification of the truck rate that, by 2035, exempts only those trucks that are certified to meet zero-emissions.	(Clean Air Action Plan, 2021)
2017 CAAP Update		• The CAAP Update further defines emissions reduction targets and strategies. • It calls for an accelerated timeline to transition the San Pedro Bay Ports drayage fleet to adopt zero- or near-zero-emission trucks.		
Clean Truck Program (CTP)		• The CTP was designed in the original CAAP to generate truck-related emissions reduction strategies.		
CARB Drayage Truck Regulation (DTR)	Statewide	• The DTR is part of CARB's efforts to reduce PM and NOx emissions from diesel-fueled engines and improve air quality associated with goods movement.	• Owners of drayage trucks with 2007 MY or newer are fully compliant until Dec. 31, 2022, for ports in California. • Starting Jan. 1, 2023, trucks must have 2010 MY or newer engines to continue entering ports.	(CARB, 2021d)
Sustainable Freight Action Plan (SFAP)	Statewide	• To meet the State's 80 percent GHG emission reduction target by 2050, freight will need to be moved more efficiently with zero-emission	• The 2016 SFAP established a target of deploying over 100,000 freight vehicles and equipment capable of zero-emission operation.	(CARB, 2021g)

Regulations	Ports	Overall Goals	Specific Strategies (some examples)	References
		technologies wherever possible and near zero-emission technologies paired with renewable fuel use everywhere else.		
US EPA Phase 2 GHG regulation (EPA Phase 2)	USA	• The EPA Phase 2 aims to improve fuel efficiency and cut carbon pollution to reduce the impacts of climate change, and to bolster energy security and spur manufacturing innovation.	• The EPA Phase 2 promotes a new generation of cleaner, more fuel-efficient trucks by encouraging the development and deployment of new and advanced cost-effective technologies. • Estimated incremental compliance cost for tractors: $6,464 for 2021-2023 MY, $10,101 for 2024-2026 MY, $12,442 for 2027+ MY	(U.S.EPA, 2021)
Low-NOx Heavy-duty Omnibus Regulation	Statewide	• It aims to dramatically reduce NOx emissions by comprehensively overhauling exhaust emission standards, test procedures and other emissions-related requirements for 2024 and subsequent model year California-certified heavy-duty engines	• This rulemaking will lower NOx emissions by lowering tailpipe NOx standards, establishing a new low-load test cycle to ensure emissions reduction are occurring in all modes of operation, strengthening durability, lengthening warranty and useful life, and in-use testing provisions. • Estimated incremental compliance cost for tractors: $3,761 for 2024-2026 MY, $7,423 for 2027-2030 MY, $8,478 for 2031+ MY	(CARB, 2020c)
Advanced Clean Truck Regulation (ACT)	Statewide	• The proposed ACT Regulation is part of a holistic approach to accelerate a large-scale transition of zero-emission medium-and heavy-duty vehicles from Class 2b to Class 8.	• Manufacturers would be required to sell zero-emission trucks as an increasing percentage of their annual California sales from 2024 to 2035. • By 2035, zero-emission truck/chassis sales would need to be 75% of Class 4 – 8 straight truck sales, and 40% of truck tractor sales.	(CARB, 2021a)

Regulations	Ports	Overall Goals	Specific Strategies (some examples)	References
			• For Class 7 and 8 drayage trucks, operating at intermodal seaports or railyards, 100% ZEV sales by 2035	
Advanced Clean Fleet Regulation (ACF)	Statewide	• The ACF is the follow-up effort to the ACT Regulation to ensure the transition and market demand for zero-emission medium and heavy-duty vehicles	• Beginning in 2023, any truck added to the CARB Drayage Truck Registry must be zero-emissions • Model year engines older than 13 years must report mileage annually • Drayage trucks with mileage over 800,000 miles, or a maximum of 18 years from certification, will no longer be compliant in the CARB Drayage Truck Registry	(CARB, 2020b)

Table H-2. Incentives for Drayage Trucks in California

Incentive Programs	Scopes					Overall Goals	Incentive amounts (some examples)	References
	Vehicle	Infra-structure	Fuels	Vocations	Classes			
Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)	V		natural gas, hybrid, electric	trucks and buses	All	To offset the incremental cost of cleaner technologies compared to conventional diesel vehicles	• $150,000 for battery-electric Class 8 trucks; $165,000 for trucks deployed in disadvantaged communities • $300,000 for hydrogen fuel cell Class 8 trucks; $315,000 for those in disadvantaged communities • up to $45,000 for the purchase of 12L near-zero natural gas engines, when paired with renewable natural gas	(California HVIP, 2021)
Volkswagen Environmental Mitigation Trust	V	V (for light-duty)	electric, hydrogen	transit, school, and shuttle buses, trucks	Class 8	To reduce NOx emissions to offset the NOx emission impacts	• $200,000 for the replacement of a 2012 or older diesel truck with a zero-emission truck.	(CARB, 2021e)
Carl Moyer Memorial Air Quality Standards Attainment Program (CMP)	V	V	alter-native fuel, cleaner diesels	trucks, buses, school buses, transit,	Class 4 to Class 8	To incentivize the purchase of HDVs and equipment that are cleaner than state regulations, with the intent to further reduce NOx, PM and VOC emissions.	• The Carl Moyer Program grants are based on the cost-effectiveness and emission benefits of the project. • For infrastructure, up to 50% of new alternative fuel station costs.	(CARB, 2021f)

Incentive Programs	Scopes					Overall Goals	Incentive amounts (some examples)	References
	Vehicle	Infra-structure	Fuels	Vocations	Classes			
Prop 1B-Goods Movement Emission Reduction Program	V	V	natural gas, low-NOx, hybrid, or zero-emission	trucks engaged in the movement of goods within designated trade corridors	Class 5 to Class 8	To quickly decrease emissions along California's major trade corridors	• Up to $200,000 for zero-emission Class 8 trucks • For truck stop electrification, charging station and hydrogen fueling station projects, up to 50% of eligible costs in funding.	(SCAQMD, 2020)
Southern California Edison's Charge Ready Transport Program		V	electric	medium- or heavy-duty fleet used for either on-road or non-road applications	Class 3 to Class 8	To offer financial assistance to its commercial customers to install charging infrastructure for medium- and heavy-duty vehicles.	• Southern California Edison pays for all make-ready costs at customer sites • Rebate covering up to 50% of the charger cost	(Southern California Edison, 2021)
Los Angeles Department of Water and Power (LADWP): Commercial EV Charging Station Rebate Program		V	electric	transit buses, shuttle buses, commercial buses, school buses, and trucks	Class 3 to Class 8	To offset costs for both the make-ready and the charging equipment itself.	• $35,000 for a <50kW DC charger, … , $125,000 for a 150+ kW DC charger • Up to $500,000 per site	(Los Angeles Department of Water and Power, 2021)

APPENDIX H.2. Alternative Fuel Choice Analysis based on Stated Preference Choice Experiment

1) Stated Preference Choice Experiment

The objective of the AFV choice analysis is to estimate choice probabilities for drayage fleets in California to adopt various fuel technologies in a medium- and long-term future, considering the State's emission reduction goals (e.g., from 2020s through 2030s). In this regard, this work intends to address the following research questions:

A. Would a promising demand for alternative fueled drayage trucks (AFDTs) exist in California in the future (in a near-, medium-, and long-term), compared to conventional diesel?

B. If not, which improvement could be made to each type of fuel technology and infrastructure to achieve more demand?

C. Would different demand structures exist between different fleet segments (e.g., sector, size, AQMD, etc.)? If so, what strategies could be introduced for a fleet segment with relatively low demand?

D. What impact would various policy instruments (e.g., ZEV mandate and financial incentives) have on the demand for AFDTs?

Given that new vehicle models of AFDTs can be commercially available in the future (e.g., fuel cell electric tractors), the demand for those vehicles can be estimated through the stated preference (SP) method rather than the revealed preference (RP) method. In addition, compared to the RP method, the SP method can provide much deeper and broader data on the structure of consumer preferences (Ben-Akiva et al., 2015). Of the two classes of SP methods – choice modelling (CM) and contingent valuation (CV), CM is chosen for this study because its experimental design feature enables better predictive accuracy via extensive tests for the preferences structure (Ben-Akiva et al., 2015).

CM is based on microeconomic consumer theory which assumes that consumers are rational decision-makers who try to maximize their utility from their purchase decisions (subject to preferences, knowledge about alternatives and budget constraints), and that attributes of a product are what generate benefits of the product (Lancaster, 1966). In the SP choice experiment (a.k.a., choice-based conjoint elicitations), each survey respondent is provided with a hypothetical set of alternative products – a small number of realistic, relatively familiar, and fully described alternatives – with a variety of levels of their attributes (Ben-Akiva et al., 2015), and then asked to perform a certain choice task (e.g., choose one among the competing alternatives). Typically, a series of choice tasks is given to each respondent by changing the attribute levels, by which information on the relative importance of each attribute is obtained from the SP experiment.

For the SP choice experiment, many issues for the design and analysis need to be addressed across several components, which is summarized in Table H-3. Some of these issues are briefly explained in this dissertation.

Table H-3. Design and Analysis Issues in the Stated Preference Choice Experiment

Components	Design/analysis issues
A set of alternatives	• The number of alternatives • Which alternatives should be included? (e.g., which fuel technologies will be viable in 2030s?)
Attributes and attributes levels	• How many, and which attributes should be included? • How many, and what levels should be assigned to each attribute with what units?
Choice tasks	• How many choice tasks should be given per respondent? • What types of choice tasks should be designed? (e.g., how far down to explore stated preference orderings?) • What assumptions/context should be provided to respondents in the experiment?
Policies to be analyzed	• What policies should be considered for the analysis of their impact on the demand?
Data analysis	• Which statistical model should be employed with what specification? • How is the model estimated? • For the case of diversifying fuels (i.e., purchase multiple trucks across multiple fuel technologies), what model can be used? • How to deal with multiple choice tasks performed by a single respondent? • How to convert individual-level choice probabilities into aggregate measures, and how to use such measures for forecasting?
Experimental design features	• Orthogonal vs. efficient design • Software to generate the choice experiment design
Sampling and recruiting strategies	• Sampling strategies • Stratification variables • Recruiting strategies

2) A Set of Alternatives

Two main issues should be considered when selecting a set of choices: a) how many and b) which alternative fuel technologies should be included in the choice set. First, an increase in the number of choices would make the survey questionnaire complicated and may yield inconsistent responses because this would impose great demand on the patience and concentration of respondents. In the previous literature based on choice experiments (Golob et al., 1997; Loo et al., 2006; van Rijnsoever et al., 2013; Walter et al., 2012), three or four alternatives have typically been used. Thus, a restriction of less than five alternatives was made for this work.

Second, the choice set should consist of several viable alternative fuel options expected to be available on the California's HDV market within the next 5-20 years, considering the State's emission reduction goals. According to Gladstein Neandross & Associates (2017), the potential alternative fuel options in order to meet the California NOx and GHG targets could include low-NOx renewable natural gas HDVs, battery electric HDVs, and fuel cell electric HDV. Also, the CARB's analysis of pathways for heavy-duty fuel technologies (CARB, 2019b) reported that battery electric drayage trucks are in the later pilot stage and their early production capability would be achieved over the next three to five years. Fuel cell heavy-duty trucks are in the mid-pilot stage of commercialization and the development will head toward early production capability (CARB, 2019b). Moreover, the fleet operators who participated in the qualitative research phase perceived that electric, hydrogen, and CNG options would be viable in the next 10 to 20 years (See Chapter 4.10: Perspectives on viable alternative fuel options for HDVs in 2030s).

By cross-checking these sources, the set of the alternatives in the choice experiment was determined to include electric, hydrogen, and natural gas options, along with diesel.

3) A Set of Attributes and Attribute Levels

Each of the alternatives consists of its attributes with their specific levels. Decisions should be made regarding a) how many and b) which attributes should be included in the choice experiment and c) which levels should be assigned to each attribute. Some guides for selecting attributes can be found in the literature (Pearce et al., 2002).

First, the number of attributes should be properly limited so that respondents can easily understand a given choice task so as to avoid a large number of possible choice tasks. In previous studies, about 6-9 attributes were used (see Table H-4).

Table H-4. Attributes Used in the Previous CM Studies

Categories	Attributes	Lebeau et al. (2016)	van Rijnsoever et al. (2013)	Walter et al. (2012)	Loo et al. (2006)	Golob et al. (1997)
Monetary costs	Vehicle purchase price	X	X	X	X	X
	Fuel costs		X		X	
	Operating costs	X		X		X
Vehicle Performance	Driving range	X	X	X	X	X
	Noise levels	X[(a)]		X		
	Cargo capacity	X				X
	Vehicle life				X	
	Number of seats				X	
	Horse power				X	
Fuel type	Fuel type			X	X	X
Infrastructure	Time taken to refuel	X	X			X

Categories	Attributes	Lebeau et al. (2016)	van Rijnsoever et al. (2013)	Walter et al. (2012)	Loo et al. (2006)	Golob et al. (1997)
	Fuel availability		X		X	X
AFV penetration	AFV penetration					X
Environmental benefits	Polluting emissions	X[(a)]	X	X		X

[Note] In Lebeau et al. (2016), vehicle's noise level and polluting emissions (GHGs and local pollutants) are presented as a combined single measure, called the Ecoscore (Van Mierlo et al., 2003).

Second, the attributes that are included can be determined through literature reviews and focus group discussions. In this work, the qualitative research results based on fleet operator behavior (i.e., Chapter 4.4: Factors influencing heavy-duty AFV adoption decisions) was used to select major attributes. Also, attributes that are likely to be affected by a policy decision (e.g., financial incentive) could be included. It should be noted that care needs to be exercised with the specification of attributes to avoid correlation between them (Pearce et al., 2002). Accordingly, it was determined to include the following attributes for this work:

1) Purchase costs ($),

   Purchase costs with the support of financial incentives ($)

2) Operating costs ($/mile)

3) Driving range (miles)

4) Emission levels (%)

5) Distance to off-site refueling/charging stations (min)

6) On-site refueling/charging infrastructure construction costs ($)

   On-site infrastructure construction costs with the financial incentives ($)

7) Refueling/charging time (min or hrs)

Third, the attribute levels, which could include policy targets, should span over a realistic range so that respondents can be expected to have preferences (Pearce et al., 2002). In the previous literature (Golob et al., 1997; Lebeau et al., 2016; Loo et al., 2006; van Rijnsoever et al., 2013; Walter et al., 2012), around 3 to 5 levels were used for each attribute. This restriction was also considered for this work.

Through reviews of scientific studies and other literature, and inquiries to expert researchers (at CARB, UCI APEP), information was collected about what ranges of values would be in 2020s to 2030s (within the available data) for each of these attributes across the set of alternatives previously chosen. Some of the qualitative research results (Chapter 4) were also used for this attribute level design. Table H-5 summarizes the information collected for the attribute design along with the assumptions made.

Table H-5. Summary of Information Collected for Attribute Design

Attributes	Summary of the information collected	References
Purchase costs ($)	Based on (CARB, 2020d, 2020e) projections ▪ [2030] 125% (electric), 125% (hydrogen), 130% (natural gas) ▪ [2025] 144% (electric), 141% (hydrogen), 135% (natural gas) Based on (Lane, 2019) projections ▪ [2030] 149% (electric), 143% (hydrogen), 138% (natural gas) (a) ▪ [2025] 251% (electric), 206% (hydrogen), 162% (natural gas)	(CARB, 2020d, 2020e; Lane, 2019)
Purchase costs with the support of financial incentives ($)	Assuming one can receive the maximum amount of incentive (but no more than the incremental costs), the purchase costs compared to diesel trucks are: ▪ 111% (electric), 104% (hydrogen), 100% (natural gas)	(California HVIP, 2021; CARB, 2021e; SCAQMD, 2020)

Attributes	Summary of the information collected	References
Purchase costs w/tax exemption for AFVs ($)	Assuming 8.5 % of sales tax (= California's basic sales tax rate of 7.25% + district tax that differs among districts) ▪ 115% (w/tax exemption) based on 2030 purchase cost projections	(CARB, 2020d, 2020e)
Operating costs ($/mile)	Based on (CARB, 2020d, 2020e), The operating costs in 2030 compared to diesel trucks are: ▪ 72% (electric), 95%-115% (hydrogen)[(b)], 88% (natural gas) The operating costs in 2020 compared to diesel trucks are: ▪ 53% (electric), 128% (hydrogen), 67% (natural gas) Based on (Tetra Tech and Gladstein Neandross & Associates, 2019), The operating costs in 2018 compared to diesel trucks are: ▪ 39% (electric), n/a (hydrogen), 91% (natural gas) Note: fuel price, fuel efficiency, and maintenance costs are incorporated into operating costs.	(CARB, 2020d, 2020e; Tetra Tech and Gladstein Neandross & Associates, 2019)
Driving range (miles)	Driving ranges of (current & upcoming) Class 8 trucks are: ▪ 600+ miles (requirement), 70-500 miles (electric), 240-750 miles (hydrogen), 400-1000 miles (natural gas)	(CALSTART, 2021; CARB, 2020b; Di Filippo et al., 2019; Southern California Edison, 2021; Tetra Tech & GNA, 2019; TTSI, 2020)
Emission levels	Based on pump-to-wheel emissions & w/o tire and brake wear: ▪ 0% (electric), 0% (hydrogen), 25% (natural gas), 100% (diesel) Assumptions for scaling factors: - Contributions of GHG vs. criteria air pollutants = 0.3 : 0.7 - Weights applied to NOx : $PM_{2.5}$: CO_2e = 0.35 : 0.35 : 0.3	(CARB, 2021h)
Off-site refueling/ charging distance (min)	Distance to off-site natural gas stations: ▪ a quarter - a mile away, within 5 miles away, less than 5 min, or en route for our everyday route (15-20 min from the yard)	This dissertation Chapter 4.7 (the qualitative

Attributes	Summary of the information collected	References
		interview results)
On-site infrastructure construction costs	▪ For electric option, $80,000 per a 50 kW charger, $160,000 per 150 kW charger, $250,000 per a 350 kW charger, and unknown but approximately, $480,000 per a 1MW charger ▪ For hydrogen option, $2M (fast-fill station) ▪ For natural gas option, $50,000 per truck (15 or less trucks) or $25,000 per truck (for 16+ trucks) for time-fill facilities, and $2M for a fast-fill station.	(Bradley et al., 2019; California Fuel Cell Partnership, n.d.; CARB, 2020e; Smith and Gonzalez, 2014)
Financial incentives for infrastructure construction	For charger costs ▪ Typically 20% to 50% of the charger costs can be covered by incentives. ▪ Also, with the upper limit of $500,000 per site, 100% of the costs could be covered by the LADWP incentives. For installation costs (or make-ready costs) ▪ The whole costs (by SCE) or 50% of the costs can be covered (by Prob 1b or CMP).	(CARB, 2021f; Los Angeles Department of Water and Power, 2021; SCAQMD, 2020; Southern California Edison, 2021)
Refueling/ charging time (min or hrs)	▪ For battery electric vehicles: ◦ 30 min (w/350 kWh charger for 100 mile range; w/MW charger for 200, 300, or 500 mi range) ◦ 1-3 hrs (w/50 kWh charger for 100 mile range; w/150 kWh charger for 100, 200, or 300 mi range; w/350kWh charger for 200, 300, or 500 mi range) ◦ 5-9 hrs (w/50 kWh charger for 200 or 300 mi range; w/150kWh charger for 500 mi range) ▪ For hydrogen: 10 min (fast-fill) ▪ For natural gas: 10 min (fast-fill), 5-9 hrs (time-fill) ▪ For diesel: 5 min (fast-fill)	(Bradley et al., 2019; GNA, 2000; Southern California Edison, 2021; Tetra Tech & GNA, 2019), this dissertation Chapter 4.7

[Note] (a) The original values obtained from (Lane, 2019) were adjusted by considering Phase 2 & Low NOx omnibus regulations. (b) 115% by assuming the same maintenance cost for hydrogen compared to diesel, or 95% by assuming 50% maintenance cost compared to diesel.

Using the attribute information collected, a series of discussions was held within the research team to select appropriate attribute levels. After cross-checking the draft design with other expert researchers, the design was updated. The latest version of the attribute design is presented in Table H-6. It should be noted that some modifications could be made to this version after pre-testing the survey questionnaire.

Table H-6. Attribute Design for the Choice Experiment

No.	Attribute	Electric	Hydrogen	Natural gas	Diesel
1	Purchase costs ($)	125%	125%	130%	100%
		150%	150%		
		175%	175%		
	*Pivot design [(a)]	200%	200%		
1P	Purchase costs with the support of financial incentives ($)	115%	115%		
		110%	110%		
	*Pivot design [(a)]	105%	105%	105%	
2	Operating costs ($/mile) [(b)]	50%	90%	70%	100%
		70%	115%	90%	
	*Pivot design [(a)]		130%		
3	Driving range (miles)	100 miles	300 miles	700 miles	700 miles
		200 miles	500 miles		
		300 miles	700 miles		
		500 miles			
4	Emission levels (%)	0%	0%	25%	100%
5	Refueling/charging distance: off-site (min)	within 10 min	within 10 min	within 10 min	within 5 min
		within 20 min	within 20 min	within 20 min	
		no off-site	no off-site		
6	Refueling/charging on-site infrastructure construction costs [(c)]	100% [(d)]	100% [(d)]	100% [(d)]	n/a
6P		75%	75%		
		50%	50%		

No.	Attribute	Electric	Hydrogen	Natural gas	Diesel
	On-site infrastructure construction costs with the support of financial incentives	25%	25%		
7	Refueling/charging time (min or hrs)	30 min, 1-3 hrs, or 5-9 hrs (e)	10 min (fast-fill)	10 min (fast-fill), or 5-9 hrs (time-fill)	5 min (fast-fill)

[Note] (a) The attribute levels, which are expressed in a unit of % in this design, would be shown to respondent pivoted from reference value for diesel vehicles. (e.g., 100% purchase cost = $150,000, and 100% operating costs = $0.50/mile for the years of 2030). (b) Fuel price, fuel efficiency, and maintenance costs are incorporated into the attribute of operating costs. (c) If a respondent already has their own on-site facilities (from survey responses), they could use that facilities at no cost. In case they don't have, and they wish, they could build on-site facilities, but it will require some physical spaces and payment for the equipment / installation costs. (d) For simplicity, the infrastructure construction costs are expressed in a unit of % in this table. The information that will be actually provided are in a unit of $. For electric option, $80,000 per a 50 kW charger, $160,000 per 150 kW charger, $250,000 per a 350 kW charger, $480,000 per a 1MW charger. For hydrogen option, $2M for a fast-fill station. For natural gas option, $50,000 per truck (15 or less trucks) or $25,000 per truck (for 16+ trucks) for time-fill facilities, and $2M for a fast-fill station. (e) Charging time for battery electric vehicles varies depending on charger capacity and vehicle maximum range. Based on some calculations on relationship between those variables, further information should be provided: 30 min (w/350 kWh charger for 100 mile range; w/MW charger for 200,300, or 500 mile range), 1-3 hrs (w/50 kWh charger for 100 mile range; w/150 kWh charger for 100,200, or 300 mile range; w/350kWh charger for 200,300, or 500 mile range), 5-9 hrs (w/50 kWh charger for 200 or 300 mile range; w/150kWh charger for 500 mile range). (f) This draft attribute design could be modified and updated when creating its experimental design, and after pretesting with potential respondents.

4) Policies for Analysis Consideration

Using this choice experiment, this work intends to not only analyze the demand of AFDTs, but to explore the impacts of various policies on the demand. The initial set of policies of interest in this study include:[45]

- Purchase financial incentives – with different levels so that the incremental purchase costs would be 5%, 10%, or 15%

[45] It should be noted that this initial set of policies could be modified based on expert reviews of the design and interviewing results with drayage fleets. For example, if financing interest rates are considered to be an important policy instrument, that factor with a range of levels could be included in the final attribute design.

- Financial incentives for on-site infrastructure construction costs – with different levels so that the construction cost would be reduced to 75%, 50%, or 25%
- Provision of off-site fueling/charging stations – with different levels so that the shortest distance to the station from the fleet site would be within 10 min, or 20 min
- Regulations requiring fleets to purchase ZEVs

All these policies except for the mandate are incorporated into the attribute design. The ZEV mandate, which gives a restriction on the choice sets, could be incorporated in the choice task design (see the subsequent section).

5) Choice Tasks

The design of a choice task needs to decide how far down stated preference orderings are explored. Different types of choice tasks were used in the previous CM studies (see Table H-7), including the best-choice task (e.g., Lebeau et al., 2016), the best-worst choice task (e.g., van Rijnsoever et al., 2013), the rank-the-option task (e.g., Loo et al., 2006), and the filling-the-number task (e.g., Golob et al., 1997).

As seen in Table H-7, depending on the types of choice tasks, different information about the preference of given options can be obtained. All these designs can provide the most preferred option among the alternatives, but each design would provide different levels of information about competition between alternative fuel technologies.[46] In

[46] For example, while the best-worst choice task would tend to provide the least preferred AFV option (unless AFVs are preferred over diesel vehicles), the best-choice task with duel response design can provide the most preferred AFV among different AFV options.

addition, there is a tradeoff between the levels of information richness and the burden of respondents. For example, the rank-the-option or the filling-the-number tasks can provide rich information on the preferences, but these tasks would require a high level of patience of respondents; thus they would be applicable when a low number of tasks (e.g., one or two) can be given to a respondent. Ben-Akiva et al. (2019) also noted, choice experiments based on other than the best choice task, such as rating or ranking products tend to "induce cognitive "task-solving" responses different from the task of maximizing preferences." Another consideration for determining the type of choice tasks is related to an achievable sample size. For example, if a relatively smaller size would be expected, a larger number of choice tasks should be assigned to each respondent, which may require a simpler choice task.

After discussing these issues with experts as well as within the team, it was determined to use the best choice task for this work, given the uncertainty of recruiting a large number of respondents. Meanwhile, it can be also considered to assign a few numbers of filling-in-number tasks to some respondents, only in case where the respondents have sufficient knowledge to answer (e.g., fleet managers). Such data can be used to explore fuel diversification behavior.

Table H-7. Choice Tasks in the Previous CM Studies

Study	Choice tasks	An example of task description	Preference information to be obtained	Information on different AFV preferences	Information richness (burden of respondents)	The number of choice tasks per respondent	Sample size	Statistical model
Lebeau et al. (2016)	Best choice task	"Which vehicle satisfies you the most?"	The most preferred option	n/a [(a)]		10 tasks	45	Hierarchical Bayesian analysis
van Rijnsoever et al. (2013)	Best-worst choice task	"Of the four alternatives below, choose which vehicle your organization is most likely to purchase and which vehicle your organization is least likely to purchase."	The most and the least preferred options	The least or the most preferred AFV [(b)]		9 tasks	50	Ordinal logit model
Walter et al. (2012)	Best choice task (with dual response design)	"1. Choose one vehicle among three alternative fuel vehicles below. 2. Would you buy the alternative you selected in the first stage if a diesel vehicle were also available?"	The most (and the second most) [(c)] preferred options	The most preferred AFV		10 tasks	274	Hierarchical Bayesian analysis
Loo, Wong & Hau (2006)	Rank-the-option tasks	"Rank the four options of the vehicles below in order of preference (1=most favored, 4=least favored)"	Rank of each option	Rank of each AFV option		2 tasks	483	Multinomial logit models [(d)]
Golob et al. (1997)	Filling in the numbers of vehicles	"Assume that your organization must replace your entire fleet of vehicles by using the four alternatives described in the table below. Please indicate the number of vehicles you would require"	The number of vehicles for each option	The number of vehicles for each AFV option		1 or 2 tasks	2,023	Multinomial conditional logit model

[Note] (a) In Lebeau et al. (2016), battery electric vehicle is the only option aside from diesel. (b) The least preferred AFV, if diesel vehicle is preferred over at least one type of AFV, or the most preferred AFV if any AFVs are preferred over diesel. (c) The most preferred options along with the second most preferred one if diesel vehicles are preferred over any AFVs. (d) The first ranks of the respondents were taken as their discrete choices.

To incorporate the ZEV mandate into the choice experiment design, a dual response format can be considered. The dual response format has been used in some previous studies (e.g., Rose and Hess, 2009; Walter et al., 2012) to better deal with a status quo alternative (a.k.a., no-choice, reference alternative, opt-out alternative, or "choose none" alternative in the literature). In the dual response format, respondents are first asked to answer between a set of non-status quo alternatives (e.g., ZEVs) in a forced-choice task, and then are asked to choose between the previous alternatives and a status quo alternative in a second task (e.g., ZEVs and diesel options).

Compared to a standard format in which respondents are asked to answer between all the alternatives, the dual response format can provide further information. In a study by (Rose and Hess, 2009), the authors suggest that the responses in the dual response format may offer useful information on sensitivities and a better estimation of the parameters especially in the presence of large amounts of inertia in the status quo alternative. In particular, the comparison of the analysis results using the data from the first task versus the data pooled from the first and second tasks could allow for the analysis of ZEV mandate impacts.

For these reasons, the dual response format is suggested for this choice experiment design. An example of the choice tasks with the dual response format is presented in Figure H-1. In this format, respondents are forced to choose between ZEVs first, and then are asked to choose between the ZEV selected previously and the diesel option.

In this section, you will be given a total of eight choice tasks. In each task, you will see a hypothetical scenario where a set of vehicles and their characteristics are provided. Please carefully review the vehicle characteristics and answer the questions. Please assume the following context:

- Your organization will be running the current business through 2030s.
- Your organization will need to purchase one or more vehicles with the purpose of either replacing or expanding your fleet.
- The following vehicles running on certain fuel technologies will be available from major truck manufacturers such as Freightliner.
- Any other characteristics (which are not described below) will be guaranteed across all the vehicles.
- There is no option to defer the choice. You must choose the most preferred option.
- In case there are other fleet decision-makers in your organization, please answer on behalf of them.

Task 1. Please assume that the following hypothetical set of vehicles are available.

Attributes \ Vehicles	Battery electric vehicle (BEV)	Fuel cell electric vehicle (FCEV)	Diesel vehicle
Purchase costs ($) ⓘ	$225,000 (150%)	$300,000 (200%)	$150,000 (100%)
Purchase costs with incentives ($) ⓘ	$172,500 (115%)	$165,000 (110%)	n/a
Operating costs ($/mile) ⓘ	$0.35/mi (70%)	$0.55/mi (110%)	$0.50/mi (100%)
Driving range (miles) ⓘ	200 miles	700 miles	700 miles
Emission levels (%) ⓘ	0%	0%	100%
Shortest distance to off-site refueling/charging stations (min) ⓘ	20 min	n/a	5 min
On-site refueling/charging facility construction costs ⓘ	▪ $80,000 per a 50 kW charger ▪ $160,000 per 150 kW charger ▪ $250,000 per a 350 kW charger ▪ $480,000 per a 1MW charger	▪ $2M for a fast-fill station	n/a
On-site refueling/charging facility construction costs with incentives ⓘ	50% of the total costs	25% of the total costs	
Refueling/charging time ⓘ	▪ 30 min (w /MW charger), ▪ 1 hrs (w/ 350 kWh charger),	10 min	5 min

	▪ 2 hrs (w/ 150 kWh charger), or ▪ 6 hrs (w/ 50 kWh charger)		

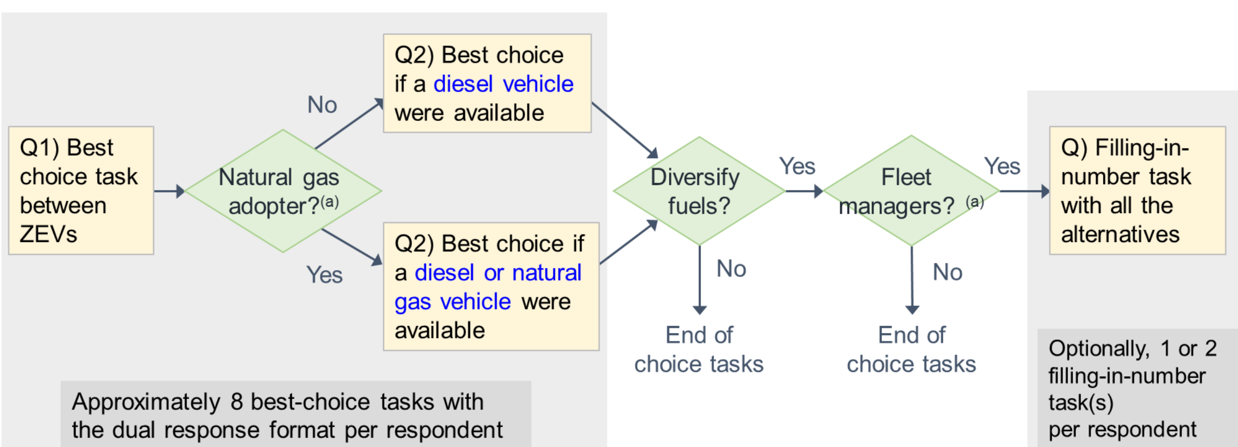
1) If you must choose only between BEV and FCEV, what is the most preferred option?
   □ BEV □ FCEV

2) If a diesel vehicle were available, would the one previously selected be still the most preferred?
   □ Yes □ No

[Note] 1) For each attribute, detailed descriptions will be provided to respondents. 1) This draft design could be modified after pretesting.

Figure H-1. An Example of Choice Task with Dual Response Format

In case of natural gas vehicle adopters, their status quo alternative would sometimes be natural gas vehicles rather than diesel. In that case, the second question in the dual response format may ask them to choose the best one between the ZEV previously selected, diesel, and natural gas options. With the consideration of such adoption status, along with some cases enabling to assign filling-in-vehicle tasks, a series of choice tasks can be modified in accordance with respondent fleet characteristics, as seen in Figure H-2.



[Note] This draft design will be reviewed during the pretesting and could be modified.

Figure H-2. Choice Task Design for the Choice Experiment

6) Experimental Design

When the attributes and their levels are determined, the number of possible choice tasks can be computed. The number of all the combinations is usually very large (e.g., more than 1,000).[47] The experimental design with all possible different choice situations is referred to as a full factorial design. However, it is typically impractical to use a full factorial design with such a large number of choice situations. Therefore, a fractional factorial design, which consists of a subset of choice situations from the full factorial design, should be used to reduce the number of combinations while capturing information useful for estimating the model. There are different types of factional factorial designs with different strategies to allocate the attribute levels to the design matrix.[48]

Of the fractional factorial designs, the most well-known type is the orthogonal design. This design aims to minimize the correlation between the attribute levels in the choice tasks (ChoiceMetrics, 2018). Many previous CM-based studies used the orthogonal design (e.g., Lebeau et al. 2016; Walter et al. 2012; Golob et al. 1997). Meanwhile, one of the limitations of the orthogonal design is the incapability to avoid choice situations in which a certain alternative is obviously more competitive (e.g., better performance, lower price) than the others, which causes inefficiency in obtaining information in the overall experiment.

[47] In the study by van Rijnsoever et al. (2013), six attributes were used with 3 or 4 levels for each, which resulted in 1,296 possible choice tasks (4*3*3*3*4*3 = 1,296). Then, a fractional factorial design with orthogonal main effects was generated using a software. Finally, the design consisting of 72 choice tasks were divided over eight questionnaire versions, by which nine tasks were given to each respondent (72/8 = 9).

[48] Each column and row of the design matrix, respectively, represent an attribute and a choice task. The element of the matrix represents a particular level of an attribute in its corresponding choice task and attribute.

The efficient design, another type of fractional factorial designs, has recently been used in choice experiment-based studies (e.g., Sheldon et al., 2017). The efficient design aims to be statistically as efficient as possible by producing the data that generates parameter estimates with as small as possible standard errors (ChoiceMetrics, 2018).[49] However, its limitation is the requirement for information on parameter estimates – which are in fact the output of the choice experiment analysis. Nevertheless, if any prior information on the parameters is available (e.g., from the literature, or pilot studies, even just about the sign of the parameters), the design can be improved with the efficient design (ChoiceMetrics, 2018).

After discussing the advantages and limitations of these different types of design with researchers who have expertise in this area, it was decided to use the efficient design for this work. Testing with various design properties using *Ngene*, a software assisting in generating a choice experiment design (ChoiceMetrics, n.d.), is in progress.

[49] See (ChoiceMetrics, 2018) for more details about the efficient design. Some basic information is summarized as follows: Given that the asymptotic variance-covariance (AVC) matrix of the parameters is the negative inverse of the expected Fisher Information matrix (which is the second derivatives of the log-likelihood function), the AVC matrix can be derived if the parameters are known. The roots of the diagonal of the AVC matrix are the asymptotic standard errors. Therefore, if prior information on parameter estimates is available, it can be attempted to find an experimental design which results in the AVC matrix with as low as possible standard errors. One of the ways of determining the AVC matrix is using Monte Carlo simulation. For this, a sample is generated, and parameters are estimated based on simulated choices, which relies on prior parameter estimate. After repeating many times of this procedure, the average AVC matrix can be computed.

7) Model Specification and Estimation

Some examples of model specification and potential estimation methods are provided below. It should be noted that a final model specification and estimation will be determined as research progresses.

7.1) Model Specification

Multinominal logit model

Suppose a respondent faces M sets of choice tasks, $\{J_m\}_{m=1}^{M}$, in which they are asked to choose one between a set J_m of mutually exclusive alternatives.[50] Assume the respondent obtains utility U_{jm} by choosing alternative j in a choice task m. Let $\boldsymbol{x}_{jm}$ denote a vector of attributes of alternative j in a choice task m for $j \in J_m$.[51] Let $\boldsymbol{s}$ denote a vector of measured attributes of the respondent characteristics in the population.[52]

Define $\boldsymbol{z}_{jm}$ as a K x 1 vector of the observed characteristics of the respondent and attributes of the alternative such that $\boldsymbol{z}'_{jm} = \left[\boldsymbol{x}'_{jm}, \boldsymbol{s}'\right]$. The respondent has a utility function that consists of a nonstochastic component, V_{jm} (which reflects the representative tastes of the population), and a stochastic component, ϵ_j (which reflects idiosyncrasies of this respondent in tastes for the alternatives) (McFadden, 1973).

$$\begin{aligned} U_{jm} &= V_{jm}(\boldsymbol{s}, \boldsymbol{x}_{jm}) + \epsilon_j \\ &= \boldsymbol{z}'_{jm}\boldsymbol{\beta} + \epsilon_j \end{aligned} \tag{1}$$

[50] For example, electric, hydrogen, and diesel options in this work.

[51] Purchase costs, operating costs, emission levels, and refueling availability are some examples of the alternative characteristics in this work.

[52] Respondent characteristics in this work include fleet size, sector, and experience in AFV operations.

where a linear transformation is assumed for the V_{jm},[53]

$\boldsymbol{\beta}$ is a K x 1 vector of parameters to be estimated which are fixed over people and alternatives,

ϵ_j is a random term that is independently identically distributed with Extreme Value Type 1 distribution, is normalized to set the scale of utility, and is assumed to be the same in every choice task.

Suppose that the respondent chooses the alternative which maximizes utility. Then, the probability that the respondent (drawn randomly from the population with attributes $\boldsymbol{s}$) will choose alternative j in a choice task m equals the probability that the utility obtained by choosing j is greater than utility obtained by choosing any other alternatives.

$$\begin{aligned} P_{jm} &= P\left(V_{jm} + \epsilon_j \geq V_{km} + \epsilon_k\right) \\ &= P\left(\epsilon_k - \epsilon_j \leq V_{jm} - V_{km}\right);\ \forall\, k \neq j \end{aligned} \tag{2}$$

Since ϵ_j are independently distributed Type-1 extreme value errors, the probability P_{jm} can be derived as below:

$$P_{jm} = \frac{\exp\left(\boldsymbol{z}_{jm}{}'\boldsymbol{\beta}\right)}{\sum_{k=1}^{J} \exp(\boldsymbol{z}_{km}{}'\boldsymbol{\beta})}\ ;\ \forall\, j \in J_m \tag{3}$$

In this multinomial logit (MNL) model, the parameters in $\boldsymbol{\beta}$ are fixed across all respondents. This MNL model exhibits the independence of irrelevant alternatives (IIA)

[53] The observed part of utility V_{jm} also contain an alternative-specific constant c_j that captures the average effect on utility of all factors unincluded in the model. To normalize the absolute levels of those constants across alternatives, $J_m - 1$ alternative-specific constants enter the model.

property: the ratio of choice probabilities for alternatives *i* and *j* is the same for every choice set C that includes both *i* and *j* (McFadden, 2001), which may imply unrealistic substitute patterns. A mixed multinomial logit model (a.k.a., random coefficients logit model) is one of the models that allows more flexible substitute patterns, introduced by (Cardell and Dunbar, 1980; Mellman and Boyd, 1980) and has been addressed with its estimation method and application examples in Brownstone and Train (1999) and McFadden and Train (2000).

Mixed multinomial logit model

In Ben-Akiva et al. (2019), taste heterogeneity in a population of the decision makers as well as across choice tasks is addressed in details, by which the restriction on fixed parameter $\boldsymbol{\beta}$ can be relaxed. By following Ben-Akiva et al. (2019), assume that the respondent a latent taste ρ_m when confronted with a choice task *m.* The taste consists of the two components: 1) permanent tastes ζ that are invariant across choice tasks, and 2) transitory whims η_m that vary across tasks. Such combination of inter-consumer and intra-consumer heterogeneity can be modeled as:

$$\rho_m = \zeta + \eta_m \tag{4}$$

where ζ represents permanent tastes with CDF $F(\zeta \mid s, \theta)$,

η_m, independently identically distributed with CDF $H(\eta_m \mid \zeta, s, \theta)$ characterizes perturbations in tastes across choice tasks,

s is a vector of measured attributes of the respondent characteristics in the population,

θ is a set of deep parameters of the CDF $F(\zeta \mid s, \theta)$ and CDF $H(\eta_m \mid \zeta, s, \theta)$.

In general, the taste ρ_m is heterogeneous across respondents and choice tasks, and thus can be treated as random effects with a joint cumulative distribution function. The joint CDF of the taste parameters is:

$$G(\rho_1, \dots, \rho_M|s) = \int_{-\infty}^{+\infty} H(\rho_1 - \zeta|\zeta, s) \dots H(\rho_M - \zeta|\zeta, s) F(d\zeta|s) \tag{5}$$

With the taste ρ_m, the utility function in Eq. (1) can be re-written as:

$$\begin{aligned} U_{jm} &= V_{jm}\left(\boldsymbol{s}, \boldsymbol{x}_{jm}\middle|\, \rho_m\right) + \sigma(\rho_m)\epsilon_j \\ &= \boldsymbol{z}_{jm}'\boldsymbol{\beta}(\rho_m) + \sigma(\rho_m)\epsilon_j \end{aligned} \tag{6}$$

where ε_j is psychometric noise[54], i.i.d. with Extreme Value Type 1 distribution, scaled by $\sigma(\rho_m) > 0$, assumed to be the same in every choice task, and

the coefficients $\sigma(\rho_m)$ and $\boldsymbol{\beta}(\rho_m)$ are predetermined transformations (e.g., linear, exponential) of the underlying taste vector ρ_m.

[54] Refer to Ben-Akiva et al. (2019) for descriptions on the disturbances ε_j : “the ε_j are interpreted as perturbations in utility that vary from one consumer and alternative to the next, and come from the psychometric difficulty consumers have in distinguishing between products and attribute levels, from whimsy, from lack of consumer attention and acuity, and from mental mechanisms consumers use to “break ties” when the utility levels of alternatives seem indistinguishable” (Ben-Akiva et al., 2019, p. 48)

Let d_{jm} denote an indicator that is one if the respondent chooses alternative j in choice task m, zero otherwise, $\boldsymbol{d}_m = (d_{1m}, \ldots, d_{Jm})$, and $\mathbf{d} \equiv (\boldsymbol{d}_1, \ldots, \boldsymbol{d}_M)$ denote a portfolio of choices for this respondent. Let $\mathbf{z}_m = (\mathbf{z}_{1m}, \ldots, \mathbf{z}_{Jm})$, and $\mathbf{z} \equiv (\mathbf{z}_1, \ldots, \mathbf{z}_M)$ denote a portfolio of the attributes of the alternatives in all the choice tasks for this respondent and the observed respondent characteristics. The probability of a portfolio $\mathbf{d}$ under the random-parameters modeling is:

$$P(\mathbf{d}|\mathbf{z}) = \int_{\zeta} \prod_{m=1}^{M} \prod_{j=1}^{J} \left[\int_{\eta_m} P_{jm}\left(\mathbf{z}_m, \zeta + \eta_m\right) H(d\eta_m|\zeta, s) \right]^{d_{jm}} \cdot F(d\zeta|s)$$

$$= \int_{\zeta} \prod_{m=1}^{M} \prod_{j=1}^{J} \left[\int_{\eta_m} \frac{\exp\left(\dfrac{\boldsymbol{z}'_{jm}\boldsymbol{\beta}(\zeta + \eta_m)}{\sigma(\zeta + \eta_m)}\right)}{\sum_{k=1}^{J} \exp\left(\dfrac{\boldsymbol{z}'_{km}\boldsymbol{\beta}(\zeta + \eta_m)}{\sigma(\zeta + \eta_m)}\right)} H(d\eta_m|\zeta, s) \right]^{d_{jm}} \cdot F(d\zeta|s) \quad (7)$$

In case $\eta_m = 0$ is assumed (i.e., a separate fixed parameter vector (ζ) for each respondent, with no intra-consumer homogeneity), Eq. (7) reduces to:

$$P(\mathbf{d}|\mathbf{z}) = \int_{\zeta} \prod_{m=1}^{M} \prod_{j=1}^{J} \left[\frac{\exp\left(\dfrac{\boldsymbol{z}'_{jm}\boldsymbol{\beta}(\zeta)}{\sigma(\zeta)}\right)}{\sum_{k=1}^{J} \exp\left(\dfrac{\boldsymbol{z}'_{km}\boldsymbol{\beta}(\zeta)}{\sigma(\zeta)}\right)} \right]^{d_{jm}} \cdot F(d\zeta|s) \quad (8)$$

The Equation (7) and (8) are mixed MNL models for portfolios of choices (Ben-Akiva et al., 2019).

If homogeneous σ and $\boldsymbol{\beta}$ are assumed across respondents and choice tasks, the Equation (7) further reduces to the below, which is in line with the case of the flat MNL model.

$$P(\mathbf{d}|\mathbf{z}) = \prod_{m=1}^{M}\prod_{j=1}^{J}\left[\frac{\exp\left(\frac{\boldsymbol{z}'_{jm}\boldsymbol{\beta}}{\sigma}\right)}{\sum_{k=1}^{J}\exp\left(\frac{\boldsymbol{z}'_{km}\boldsymbol{\beta}}{\sigma}\right)}\right]^{d_{jm}} \tag{9}$$

7.2) Model Estimation

For a flat MNL model, a traditional approach to estimating parameters is maximum likelihood estimation. Suppose that the state choice data are obtained from respondent n = 1, …, N. Then, the log likelihood function can be written as:

$$LL(\sigma,\beta) = \log L(\sigma,\beta) = \sum_{n=1}^{N}\sum_{m=1}^{M}\sum_{j=1}^{J} d_{jm}^{n}\log\left[\frac{\exp\left(\frac{\boldsymbol{z}_{jm}^{n\,\prime}\boldsymbol{\beta}}{\sigma}\right)}{\sum_{k=1}^{J}\exp\left(\frac{\boldsymbol{z}_{km}^{n\,\prime}\boldsymbol{\beta}}{\sigma}\right)}\right]$$

where d_{jm}^{n} is defined as d_{jm} associated with a respondent n, and

$\boldsymbol{z}_{jm}^{n}$ is defined as $\boldsymbol{z}_{jm}$ associated with a respondent n.

The parameters that maximize this likelihood function so that the observed data is most probable is called the maximum likelihood estimates.

$$\left(\hat{\sigma},\widehat{\boldsymbol{\beta}}\right) = \arg\max_{\sigma,\beta} LL(\sigma,\boldsymbol{\beta})$$

Numerical methods can be used to find the maximum likelihood estimate (see (Train, 2009, Chapter 10)).

However, in mixed MNL models, the computation of the choice probability (e.g., Eq. (7) and (8)) requires a relatively high-dimensional integration and cannot be performed analytically in general (Ben-Akiva et al., 2019). Accordingly, numerical approximation by simulation is usually required, such as Maximum Simulated Likelihood where simulated probabilities are used instead of the exact probabilities (see Train, 2009, Ch.10). An alternative approach is hierarchical Bayesian estimation, which does not require maximization of any function and can obtain desirable estimation properties (e.g., consistency and efficiency) under more relaxed conditions (see Train, 2009, Ch.12 for more details).

7.3) Further Considerations

Several issues should be further considered for the model specification and estimation. One issue is the case where an organization adopts multiple types of fuel technologies. To explore this case, the filling-in-number task is optionally included in the experiment design so long as a respondent can perform this relatively complicated task. In terms of model estimation, a previous study by (Golob et al., 1997) converted the number of vehicles assigned to each fuel type by the respondent to a fraction of the fleet size, and used this fraction as a weight in a maximum likelihood estimation procedure. More recent works (e.g., Bhat et al., 2014) developed a formulation to accommodate multivariate count data. Such methods will be explored in future work.

Other issues are related to forecasting of AFV penetrations from the estimated choice probabilities. First, the estimated probabilities obtained at the individual decision-maker levels should be converted to aggregate measures. For this, sample enumeration or segmentation can be used (Train, 2009). In the sample enumeration method, each sampled decision-maker n has some weight w_n that represents the size of subpopulation similar to them. Then, an estimate of the total number of decision-makers in the population who choose alternative j is the weighted sum of the individual probabilities. It would be also possible to estimate aggregate outcomes based on segmentation. For example, if there are three geographical areas of fleet site locations and two levels of AFV experiences (e.g., adopted AFV or not), the total number of different segments is six. If the data on the number of decision-makers is obtained in each segment, the aggregate outcomes can be estimated by taking the weighted sum of the choice probabilities in each segment. For forecasting of the aggregate outcomes into future years, the explanatory variables associated with decision-makers, and the weights attached to each decision-maker should be adjusted to reflect changes over time (see Train, 2009, Ch.2 for more details).

However, these AFV choice probabilities at the fleet-level do not necessarily represent vehicle-level AFV penetrations. Fleet size distribution and fuel diversification behavior should be considered for such conversions to vehicle-level penetrations. If any necessary data is unable to be collected, it should be identified as to what limitations would occur in estimation results. Detailed methods will be investigated in future work.

8) Connection with Total Cost of Ownership Approach

The last section in this Appendix introduces the recent studies by Burnham et al. (2021) and CARB (2021i) that explored Total Cost of Ownership (TCO) computations across several alternative fuel technologies and diesel option for HDVs. This section explains what cost components were considered for these TCO analyses, and how related those are with the attribute set in the choice experiment.

In the study by Burnham et al. (2021), TCO is presented as "aggregate terms over the entire span of the analysis timeframe, on an annualized basis, or on a per-mile basis as a levelized cost of driving" (e.g., 10-year cost, or average 10-year per-mile cost). As a holistic formulation of TCO, the authors (Burnham et al., 2021) considered vehicle cost and depreciation, financing, fuel costs, insurance costs, maintenance and repair costs, taxes and fees, payload capacity expenses, and labor costs. The study by Burnham et al. (2021) quantified such direct monetary costs incurred by operators of HDVs at averages or representative values on a national level. Another study by CARB (2021i) also performed TCO computations, with an assumption of 12-year life of operation, by considering a range of cost components similar to Burnham et al. (2021), except for inclusion of LCFS credit revenue, and exclusion of payload capacity expenses and labor costs. Table H-8 summarizes the cost components used in these TCO studies.

Table H-8. Cost Components in TCO Approaches

Burnham et al. (2021)		CARB, (2021i)	Included in the initial design of the attribute set?
Categories	**Descriptions (Burnham et al., 2021, p.45)**		
▪ Vehicle (purchase cost, depreciation)	"The vehicle cost includes the cost of purchase less the residual value of the sale of the vehicle at the end of the analysis window"	▪ Vehicle Price ▪ Residual values ▪ Depreciation	Yes (purchase costs only)
▪ Financing	"Financing represents the cost of interest payments beyond the retail price of the vehicle"	▪ Financing	
▪ Fuel	"Fuel cost is proportional to the driving distance, the fuel efficiency of the vehicle, and the cost of the specific fuel needed by the vehicle"	▪ Fuel cost ▪ Diesel exhaust fluid consumption ▪ Infrastructure	Yes (operating costs)
▪ Insurance	"Insurance costs cover both liability and vehicle replacement or repair"	▪ Insurance	
▪ Maintenance & Repair	"Maintenance includes the cost of scheduled vehicle repairs as the vehicle ages, as well as unscheduled services for inspection and replacement of vehicle parts. Repair accounts for unexpected costs to operate a vehicle"	▪ Maintenance costs ▪ Midlife costs	Yes (operating costs)
▪ Tax & fees	"Taxes and fees include taxes on vehicle sales and any recurring annual costs, such as registration fees, parking, and tolls"	▪ Taxes ▪ Registration fees	Yes (tax only)
▪ Payload capacity expenses [(a)]	"Additional costs due to the increased weight of new vehicle technologies"		
▪ Labor costs [(a)]	"Labor costs are representative of the typical wages and benefits for drivers, and includes additional time for charging or fueling vehicles"		Indirectly, Yes (refueling/charging time, travelling time to off-site stations)
		▪ LCFS credit revenue [(b)]	

[Note] (a) Payload capacity expenses and labor costs are included only in Burnham et al. (2021). (b) LCFS credit revenue is included only in CARB (2021i).

Compared to these studies, several major cost components are currently included in this work for the attribute set for the choice experiment, due to the fact that a restriction on the number of attributes should be necessary (Pearce et al., 2002) in order to reduce the cognitive burden of respondents and avoid a too large number of possible choice tasks (e.g., 6-9 attributes in the previous studies). In this work, the attributes associated with the costs include purchase costs, operating costs (incorporating fuel costs, fuel economy, and maintenance costs), infrastructure construction costs, amount of time taken to refuel/charge a vehicle, and travelling time to off-site stations.

Meanwhile, other important attributes associated with vehicle characteristics (e.g., functional suitability, environmental benefits), such as driving ranges and emission levels, as well as policy attributes, such as purchase incentives and infrastructure construction incentives, are included in the attribute design whereas they are not included the TCO studies. Other possibly important but unincluded attributes (e.g., vehicle/engine reliability, safety, fuel security, and others addressed in Chapter 4.4) will be captured as an alternative-specific constant with their average effect on the utility in this choice model. It should be also noted that this initial attribute set could be modified based on the interview results with drayage fleet operators[55] while maintaining an appropriate number of attributes.

Several limitations were addressed in the TCO studies. First, a variety of "soft" costs, such as value of driver preferences for comfort, performance, and corporate image were not included (Burnham et al., 2021, p.95). Second, for some cost components, there was

[55] For example, if insurance costs, financing, or payload capacity costs emerge as common important factors across drayage operators during interviews, such factors should be included in the final attribute design.

extreme data scarcity particularly for ZEV options because only CNG vehicles have seen appreciable historical sales; also, data for medium and heavy-duty vehicles is in general more scarce and often more proprietary than that for LDVs (Burnham et al., 2021, p.89, p.130), causing the researchers to rely on weak assumptions (e.g., the same depreciation between ZEVs and diesel vehicles). Furthermore, from the fleet operator perspectives, high complexity in assessing TCO particularly for unknown future vehicles was reported, in that "there is high variation and uncertainty in many variables and the appropriate value to use – which depends on the application"[56] and "many parameters are interrelated (e.g., range, vehicle utilization, and charging opportunity)" (Burnham et al., 2021, p.127). The study by Burnham et al. (2021) also noted that their analysis did not intend to model market adoption, as the adoption analyses depend on consumer behavior which is not completely tied to the cost of ownership. In sum, the holistic TCO outputs might be perceived by at least some fleets as uncertain, complex, and less relevant to a particular calculation practice used in the fleet whereas such all-inclusive TCO analyses provided promising cost estimates for ZEV or AFV options compared to a diesel option in the studies.

Therefore, some considerations could be made to a choice experiment design, to better engage the TCO analysis with the demand modelling. For example:

(a) Identify what range of cost components are taken into account for TCO analyses in a specific fleet segment with a specific vocation. Then, conduct a choice experiment by including major cost components of TCO, a few other cost components that need to

[56] For example, an organization raised a question on the TCO analysis by (CARB, 2021i) regarding what certainty exists that LCFS credits will continue in the future even though the CARB TCO analysis shows significant cost recovery through the LCFS program (CARB, 2021j).

be tested for policy sensitivity analysis, as well as a few other important non-monetary factors in its attribute design.

(b) For fleet operators who wish to be informed by a TCO estimate in each alternative in a choice situation, provide TCO estimates in accordance with their preferred unit (e.g., *n*-year cost, annual cost, monthly cost, or per-mile cost), and preferred basis of cost calculation particularities (e.g., purchasing vs. leasing, as well as specific replacement behavior of vehicles (years/miles), etc.) with the information regarding what cost components are included for the TCO and what assumptions are posed, so that the provided TCO estimates should be well-understood, familiar, and credible.

While this work currently follows option (a)[57], option (b) might require a two-step survey: the first one is to collect the basic inputs to compute a fleet specific TCO as mentioned above, and the second one is to conduct the choice experiment.

9) Tasks in Progress

To ensure the modelling feasibility, interviews with drayage fleet operators are currently being conducted. After this first round of interviews, the choice experiment design and the overall survey design will be updated. As a second round, pre-testing of the survey questionnaire will be performed with drayage fleet operators.

[57] In the interviews being currently conducted with drayage fleet operators, one interview question is about their cost calculation approaches. The initial attribute set could be modified based on the interview results.

In the meantime, development of sampling and recruiting strategies is in progress. Of various sampling strategies, stratified random sampling is considered in order to compare the model estimation results between various subpopulations. Stratification variables could include fleet sizes, sectors, air districts, and AFV adoption status. Potential recruitment sources are port drayage truck registries for PoLA and PoLB, which contain around 2,300 fleet operator email addresses (Port of Long Beach, 2020; Port of Los Angeles, 2020). Other sources, if necessary, could also be considered such as fleet data from AFV incentive programs. Based upon the exploratory analyses, specific sampling and recruiting strategies will be finalized. Financial incentives for completed surveys will be considered.

Based on the sampling and recruitment strategies, the finalized survey questionnaire will be distributed to the recruitment population. The survey data will be collected via an online survey platform. With selected statistical models, the data will be analyzed. The modelling results will include estimated choice probabilities of AFVs for a fleet with certain characteristics under various technology advancement and policy scenarios.

Meanwhile, further studies should be performed to forecast "AFV shares" under various scenarios, and to analyze the demand more accurately with the consideration of fueling/charging facility choice. Also, any limitations of this modelling approach, particularly associated with complex fleet decision-making processes, should be identified.