



# Consumer Convenience and the Availability of Retail Stations as a Market Barrier for Alternative Fuel Vehicles

## Preprint

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# CONSUMER CONVENIENCE AND THE AVAILABILITY OF RETAIL STATIONS AS A MARKET BARRIER FOR ALTERNATIVE FUEL VEHICLES

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## 1 Overview

The availability of retail stations can be a significant barrier to the adoption of alternative fuel light-duty vehicles in household markets. This is especially the case during early market growth when retail stations are likely to be sparse and when vehicles are *dedicated* in the sense that they can only be fuelled with a new alternative fuel. For some *bi-fuel* vehicles, which can also fuel with conventional gasoline or diesel, limited availability will not necessarily limit vehicle sales but can limit fuel use. The impact of limited availability on vehicle purchase decisions is largely a function of geographic coverage and consumer perception. In this paper we review previous attempts to quantify the value of availability and present results from two studies that rely upon distinct methodologies. The first study relies upon stated preference data from a discrete choice survey and the second relies upon a station clustering algorithm and a rational actor value of time framework. Results from the two studies provide an estimate of the discrepancy between stated preference cost penalties and a lower bound on potential revealed cost penalties.

Analysis of the stated preference survey data suggests that household consumers may perceive a purchase price penalty ranging from \$750 to \$4,000 for retail station coverage at 1 to 10 percent of existing gasoline stations within metropolitan (urban) areas. In contrast, the station clustering analysis suggests a cost penalty range of \$250 to \$1,500 for coverage at 1 to 10 percent of existing stations. In addition, stated preference results suggest very high penalties for a lack of long-distance coverage along interstates connecting urban areas, ranging from \$2,000 to \$9,000, and penalties ranging from \$1,500 to \$3,000 for limited medium-distance coverage, defined as 5 to 100 stations within 150 miles of the metro area. We discuss the significance these results may pose to early market growth, investments in retail station networks, and potential means of reducing this market barrier.

## 2 Background

Several studies have attempted to characterize the challenge posed by refuelling station coverage for early markets of dedicated alternative fuel vehicles (AFVs). Results from a survey of diesel vehicle owners in California (Sperling and Kurani, 1987) suggested that when 10-15 percent of stations provided diesel most drivers were less concerned about refuelling station coverage. This percentage was later readjusted down to 10 percent after more careful evaluation of the baseline number of stations in California (Nicholas, Handy et al. 2004). Similarly, a 1992 study by Kurani (Kurani 1992) determined that most compressed natural gas (CNG) vehicle owners in New Zealand were less concerned about refuelling coverage after approximately 10 percent of stations in their local area provided CNG. Based upon results from a preference survey of Canadian drivers, Greene (1998) estimated cost penalties for reduced station coverage, concluding that coverage of greater than 20 percent of stations significantly reduces the cost barrier to purchasing a dedicated AFV and estimating the degree to which a fuel price advantage might reduce this percentage.

Relying upon spatial and demographic metrics for U.S. urban areas and interstates, rather than survey results, Melaina (2003) estimated that between 9,000 and 12,000 stations would be required to support early markets for dedicated hydrogen vehicle markets, providing sufficient coverage in both urban areas and along interstates. Given estimates of 120,000 to 160,000 total gasoline stations in the United States during that time period, this estimate represents 6-10 percent of existing stations. In another analytic study, Nicholas et al. (2004) employed a traffic flow model to estimate average driving times associated with different levels of coverage, concluding that coverage at 5 percent of stations would be associated with an average driving time of approximately 4 minutes for work-based commuters refuelling their vehicles in Sacramento, California. This compares to an average travel time of just under 2 minutes when fuel is available at all 319 existing stations in Sacramento. Most studies therefore tend to confirm Kurani's proposed 10 percent "rule of thumb" or suggest that even lower percentages could be adequate. However, it has been demonstrated that station densities (stations per square mile) vary significantly between U.S. urban areas (Melaina and Bremson 2008), with cities in California having relatively low station densities. This tends to weaken the usefulness of the 10 percent rule of thumb and suggests a more precise metric is needed, such as station density. It has also been noted (Melaina 2009) that among the studies discussed above, as well as the preference study by Tompkins et al. (1998), analytic estimates tend to predict significantly lower cost penalties than stated preference studies, including Greene (1998).

### **3 Methods**

The methodology of each study is reviewed separately in sections 3.1 and 3.2 below.

#### **3.1 Methods for the Discrete Choice Study**

The discrete choice study relies upon a series of surveys administered by NREL, PA Consulting, and Knowledge Networks between 2007 and 2009 (Welch 2007; Melaina, Welch, et al. 2008; Melaina 2009). Three versions of the survey were fielded, with each new version including improvements based upon results (and shortcomings) from the previous version. Given this progression, data from the final survey are considered the most meaningful. In the final survey approximately 500 surveys were completed in four cities: Los Angeles, CA, Atlanta, GA, Minneapolis, MN, and Seattle, WA. Panel members in each city responded to a series of introductory questions and then to 10 hypothetical vehicle purchase decisions. The introductory questions acquainted the respondents with the setup of the survey, the definitions used to describe vehicle and refuelling attributes, and the maps used to represent refuelling availability. These maps capture three levels of refuelling availability: (1) short-distance trips within the respondent's metropolitan area, (2) medium-distance trips within the metropolitan region (defined as the area within 150 miles of the metro area), and (3) long-distance trips nationwide along interstate highways connecting major cities (see Figure 2, 3, and 4). Introductory questions also inquired about the make, model, and year of the vehicle most recently purchased by the respondents, and this information was used later in the survey to remind respondents—by labelling the different alternatives—that the hypothetical vehicle purchase decisions they were making were associated with a vehicle having the same attributes as their most recently purchased vehicle.

Each of the 10 hypothetical vehicle purchase decisions included a side-by-side comparison of two vehicles, one running on conventional fuel and one running, exclusively, on an unspecified alternative fuel. Vehicle attributes were displayed side-by-side as the respondents scrolled down through the survey (see Figure 1), which was fielded through representative panels maintained by Knowledge Networks. Weighting factors were then applied to the resulting data to correct for deviations from the general population. Vehicle attributes include: vehicle purchase price (as five percentages of the conventional vehicle purchase price: equal, +/-15%, and +/- 35%), fuel costs (\$/month), vehicle range (miles), and three levels of station coverage (within the metropolitan area, within 150 miles of the metro area, and along interstates connecting multiple urban areas). These attributes and levels are summarized in Table 1. Consumer attributes include: if the respondent's home is located very near to an alternative fuel station shown on a map (yes or no); if the respondent identifies climate change as a major concern (yes or no); and if the respondent self-identifies as an early adopter of new technologies (yes or no). The vehicle attributes varied between choices, according to a discrete choice algorithm developed by Zwerina, Huber, and Kuhfeld (2005). The algorithm employs a search strategy to generate balanced, efficient designs for choice experiments where multiple choices are presented.

Significant effort was devoted to developing visual representations of retail station coverage. A series of maps was developed to indicate different levels of coverage for each of the four urban areas where the survey was fielded. For example, among the 10 hypothetical decisions posed, respondents in Seattle would have responded to the metropolitan area coverage attribute being presented as zero coverage (a map showing no alternative fuel stations), a map with minimal coverage, a map with moderate coverage, and a map with station coverage equivalent to the existing conventional gasoline station network. Maps representing multiple levels would also be shown for medium-distance coverage and long-distance coverage. For each decision posed, a map indicating “full” coverage would be shown for conventional stations as an attribute for the conventional vehicle. An example of the survey as viewed by respondents is shown in Figure 1 and all of the maps used for the three levels of refuelling availability in Los Angeles are shown in Figures 2, 3 and 4. Station coverage levels for the three types of spatial coverage were refined to be sufficiently distinct from one another, visually, based upon results from previous iterations of the survey. For example, in one of the earlier surveys respondents were ambivalent between levels 1 and 2 for medium-distance coverage, so these were made more distinct in the final survey by adding more stations to level 2.

**Table 1. Attributes and levels of the Discrete Choice Survey**

#	Attribute	Variables for Utility Function	Description for Consumer	Units	Number of Levels	Levels (for consumer description)
1	Metro Area Coverage	MAC	Average Distance to the nearest Metro Area Refueling Station	miles	4	2.7 / 1.1 / 0.5 / 0.1
2	Medium Distance Coverage	MDC	Number of stations within 150 mile of the metro area.	Ln(number of stations)	4	Varies by market: 4 to 12; 12 to 38; 26 to 79; 2,400 to 8,300
3	No Long Distance Coverage -- Level 1	LDC <sub>1</sub>	Long Distance Trips that are Possible	true/false	2	No destinations beyond 150 miles
4	Long Distance Coverage -- Level 2	LDC <sub>2</sub>	Long Distance Trips that are Possible	true/false	2	Nearby cities
5	Long Distance Coverage -- Level 3	LDC <sub>3</sub>	Long Distance Trips that are Possible	true/false	2	Regional cities
6	Long Distance Coverage -- Level 4	LDC <sub>4</sub>	Long Distance Trips that are Possible	true/false	2	Same as conventional vehicles
7	Vehicle Purchase Price	VPP	Vehicle purchase price	\$1000/vehicle	5	-35%, -15%, 0%, +15%, +35%

Original analysis results from the final survey have been presented previously (Melaina, Welch, et al., 2008; Melaina 2009). In the present study the survey data results have been revisited with a more refined modeling approach, relying upon newly formulated logit model and mixed logit models. Lexidyne, LLC performed this more recent round of analysis. The primary analytic approach employed was a traditional logit regression analysis that establishes coefficients for each of the previously identified key variables. The mixed logit analysis utilizes a unique constant by respondent, with a normal distribution of all constants plus coefficients for each of the variables. While the results are comparable to those of the previous analysis, greater confidence has been attained given the similarity of results across all methods employed. In addition, the Lexidyne analysis includes an estimate of uncertainty ranges for each parameter. Results of this new round of analysis are compared to the earlier results in the results section below.

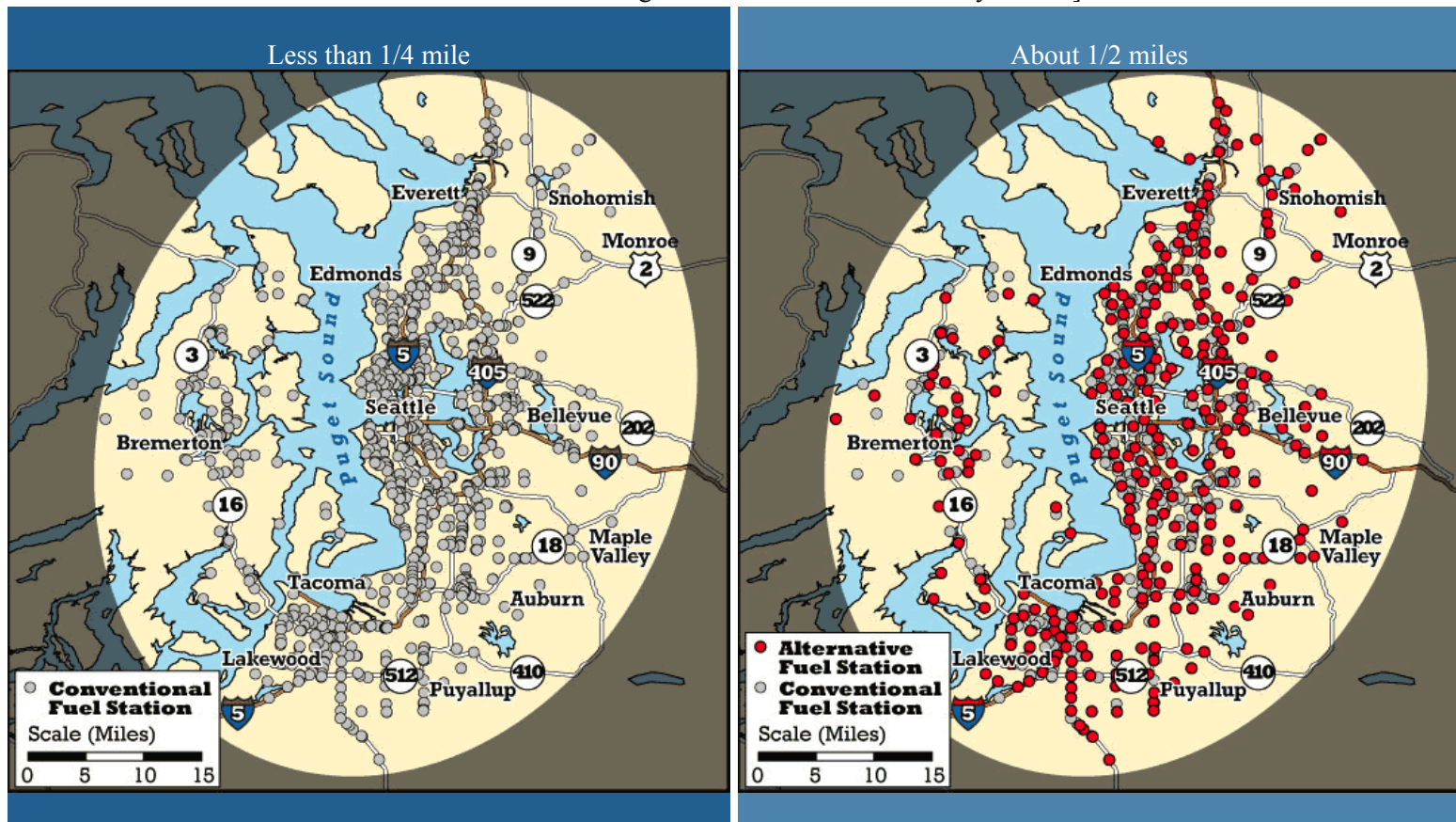
Figure 1. Screenshot of the final version of the Discrete Choice Survey as presented to participants. Multiple labels are hyperlinks in the display, shown as underlined font below. The text that appears when the hyperlink is selected is shown in parentheses.

Gasoline Vehicle (Similar to INSERT MAKE/MODEL)      Alternative Fuel Vehicle (Similar to INSERT MAKE/MODEL)

*Please click on the map thumbnails to see a bigger map*

[Average Distance to the nearest Metro Area Refueling Station](#)

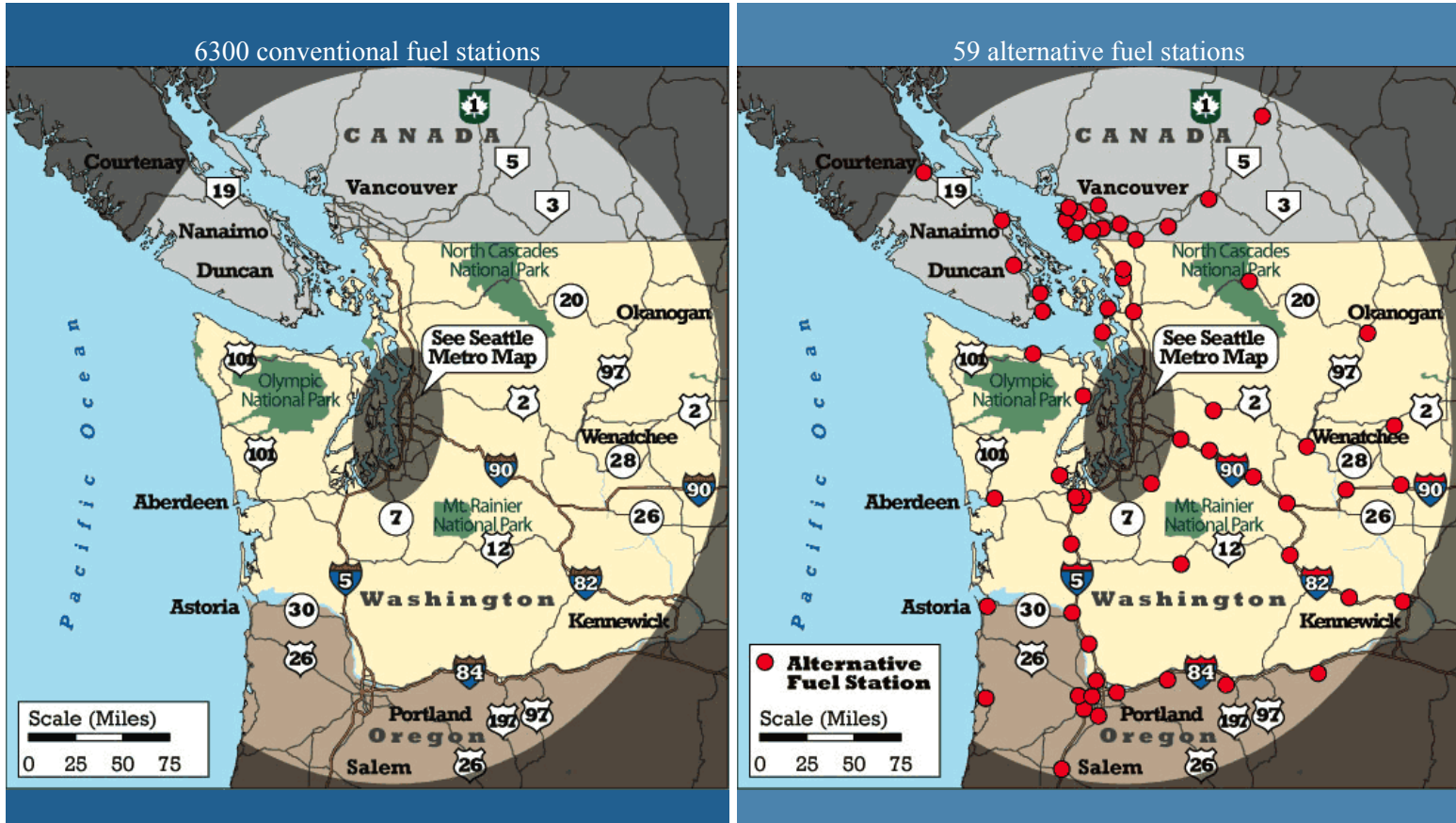
[The average distance to the nearest metro area refueling station is the distance you would have to travel, on average, to refuel your vehicle while remaining within the metro area where you live.]





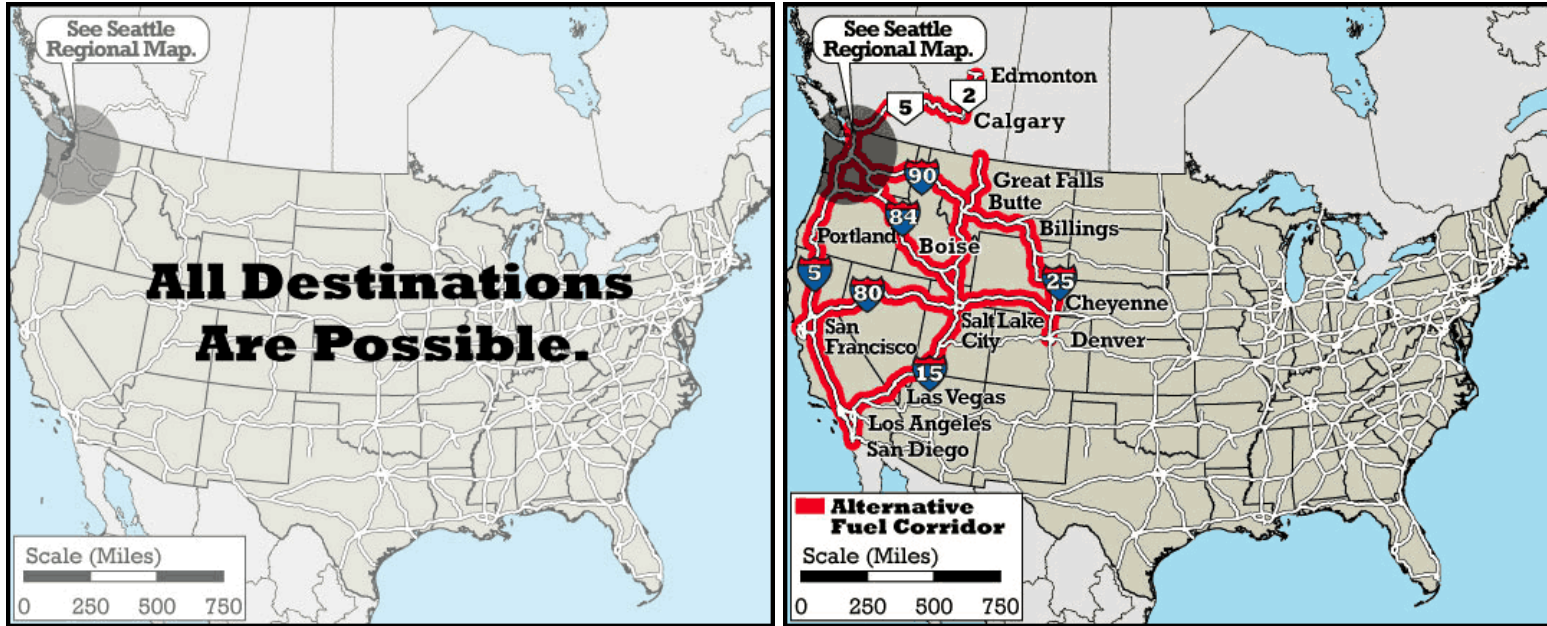
Number of stations within 150 miles of the metro area

[Number of stations in the region within 150 miles of the metro area. With an alternative fuel vehicle, all trips within this region would be possible, but some destinations would require advance planning.]



[Long Distance Trips that are Possible](#)

[Long distance trips are trips outside the 150-mile radius surrounding the metro area where you live. Some long distance trips will not be possible with the alternative fuel vehicle due to limited station coverage along interstate routes.]





Fuel Cost

[This is the amount per month you spend to put fuel in the vehicle.]

Same as your INSERT MAKE/MODEL	Same as your INSERT MAKE/MODEL
--------------------------------	--------------------------------

Other Attributes

Same as your INSERT MAKE/MODEL	<ul style="list-style-type: none"><li>• <u>Virtually NO oil used or imported</u> [The alternative fuel is not gasoline or diesel, and virtually no oil is used or imported to produce the alternative fuel.]</li><li>• <u>No smog emissions</u> [Zero smog-causing emissions (which affect local air quality) are emitted from the alternative fuel vehicle.]</li><li>• <u>50% fewer Greenhouse Gas emissions</u> [Greenhouse gas emissions (which contribute to global warming) from the alternative fuel vehicle are reduced by 50%.]</li></ul>
--------------------------------	---

Purchase Price

[This is the "net price" of the vehicle and already takes into account possible tax incentives or credits.]

\$XX,XXX	\$XX,XXX
----------	----------

Vehicle you are MOST likely to purchase

Gasoline Vehicle (Similar to INSERT MAKE/MODEL)	Alternative Fuel Vehicle (Similar to INSERT MAKE/MODEL)
	

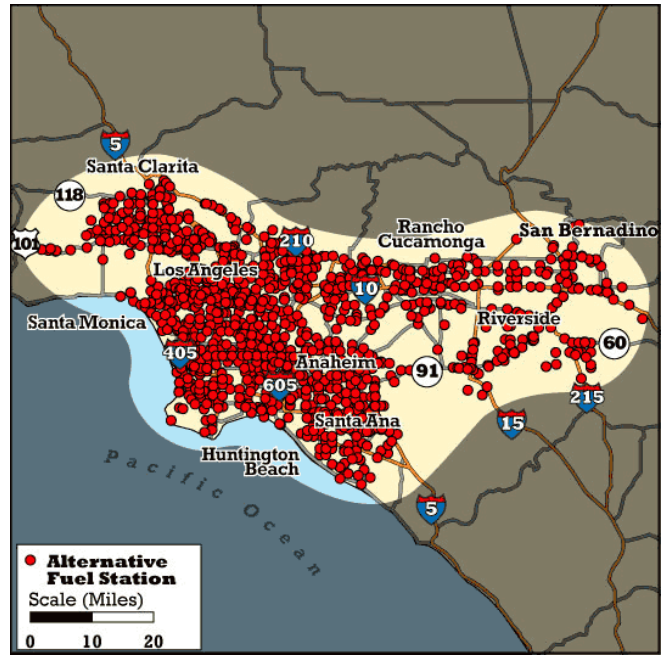
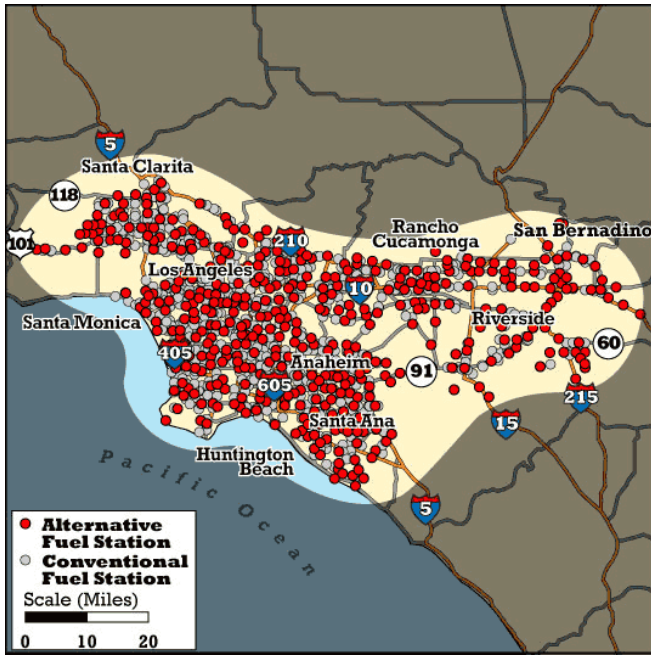
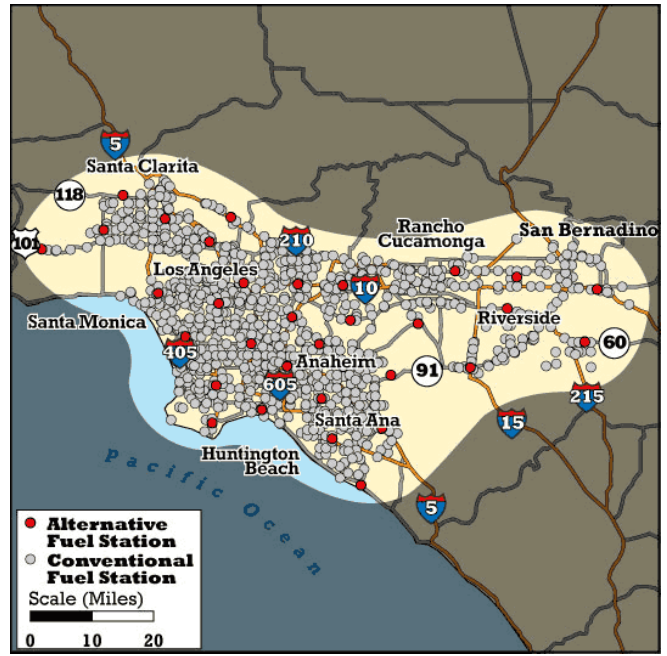


Figure 2. Maps for four levels of Metropolitan Area Coverage (MAC) in Los Angeles.



Figure 3. Maps for five levels of Medium-distance Coverage (MDC) in Los Angeles.



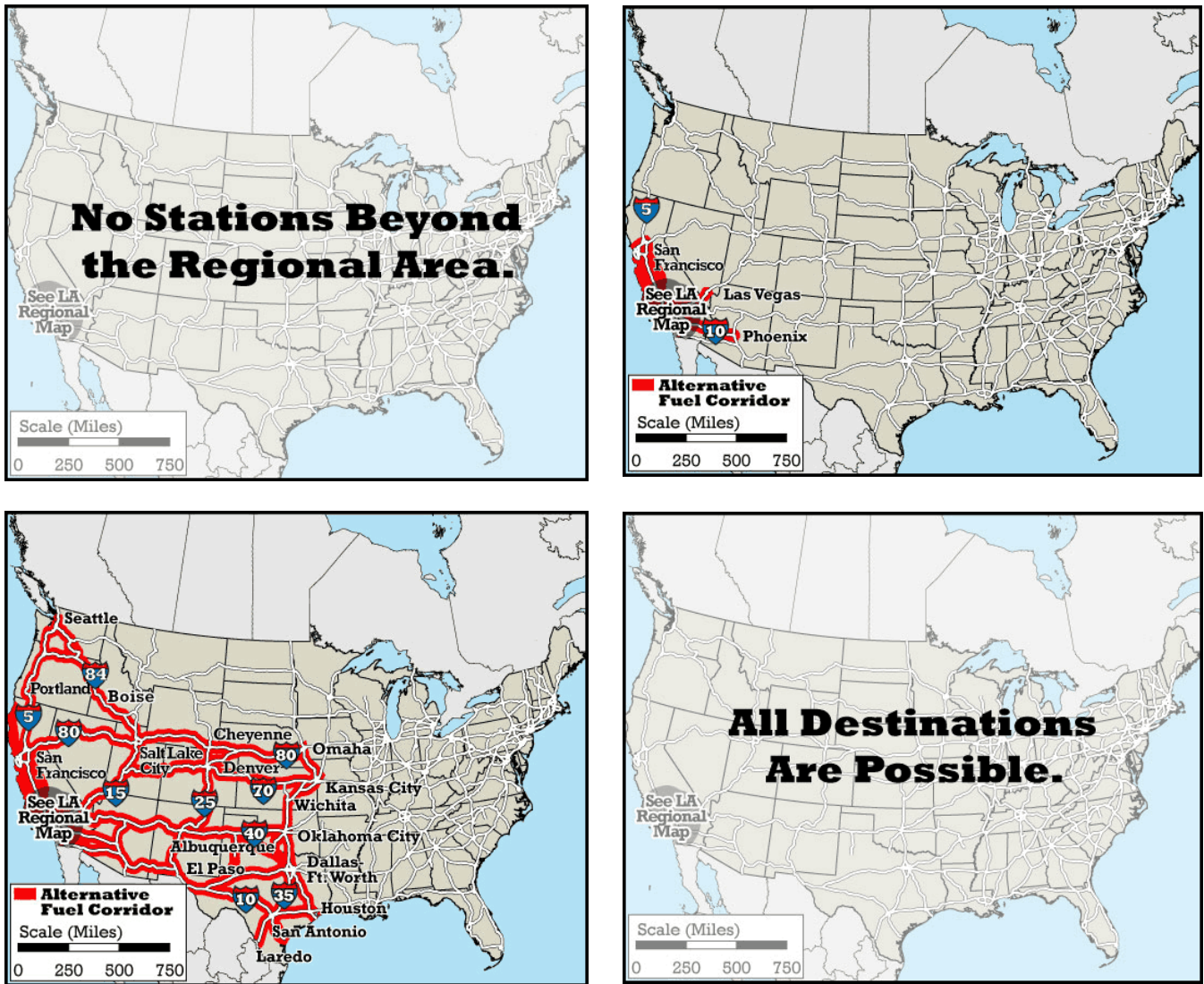


Figure 4. Maps for four levels of Long-distance Coverage (LDC) from Los Angeles.

### 3.2 Methods for the Clustering Algorithm Study

The methodology for the second study is based upon a clustering algorithm applied to data on existing gasoline station locations and average fuel dispensing volumes (gallons per month). This data was acquired from MPSI for over 100 U.S. urban areas, and includes all stations within each urban area. The clustering algorithm involves identifying the two stations in closest proximity to each other and then collapsing the smaller station into the larger station, resulting in a new fuel volume (the sum of the two previous volumes) being dispensed from the original location of the larger station. When applied iteratively, this algorithm produces a series of theoretical station networks that dispense the same total volume of fuel through a successively smaller number of stations. As more and more stations are eliminated, the network approaches uniform geographic coverage while maintaining variation in station sizes that reflect the intensity of local fuel demand. A continuous distribution of theoretical networks is developed for each city using this algorithm, ranging from the original network minus one station to a station network as sparse as 10 or 20 uniformly dispersed stations (in theory the algorithm can reduce the network to a single station, but results with less than 10-20 stations are less meaningful for our purposes). The resulting clustering simulation can be run forwards or backwards.

The resulting distances between stations and fuel volumes in a clustered network can be used as a proxy for estimating how many consumers would need to drive further to refuel if served by a network with fewer stations. Incorporating a travel time or nuisance cost, in dollars per minute spent driving to the next closest station, results in an estimated cost of inconvenience to consumers for each network at any level of clustering. The guiding equation for these calculations is indicated in Equation 1, where  $C_A$  is the (undiscounted) additional time cost associated with an AFV to reach a station. This is calculated as the average additional distance required to reach an AF station, which is a function of the percent of conventional stations ( $d_{p\%}$ ), the weight function ( $W_A$ ), which allocates a cost per mile to the additional distance travelled, and the factor of 1.27, which is a rectilinear distance adjustment accounting for the geometry of traveling through an urban street grid rather than across Euclidean (linear) distances.

$$C_A = 1.27 d_{p\%} w_A \quad (1)$$

Methodological details are discussed in the three sections below in the following sequence: Additional Distance Traveled ( $d_{p\%}$ ), rectilinear distance adjustment (1.27), and the cost per mile weight function ( $w_A$ ).

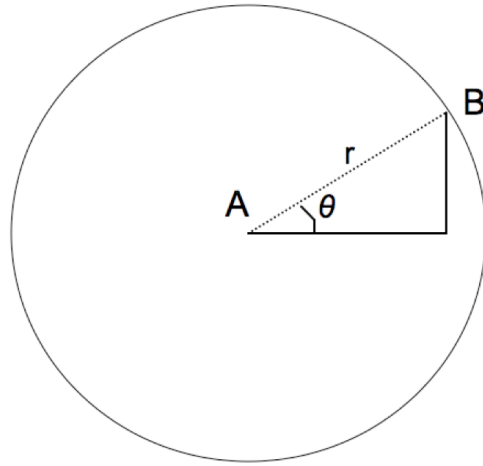
### 3.2.1 Average Additional Distance Traveled ( $d_{p\%}$ )

The clustering methodology used to determine average additional distances traveled relies upon survey data for conventional refueling stations in 100 major urban areas in the contiguous United States. The data consist of station location coordinates and average monthly gasoline dispensing volumes for each station. In total, the data set includes approximately 39,000 stations, with an average of 357 stations per city and 2,600 people per station. The data were purchased from MPSI, a petroleum fuel market consulting firm, recently acquired by KSS Fuels. The urban areas were selected to form a representative sample of U.S. cities in terms of size and region. Analyses of these data are discussed by Melaina and Bremson (2006; 2008).

As discussed above, the clustering methodology involves identifying the two stations in a given city separated by the smallest linear distance, which is easily calculated based upon station coordinates. These two stations are then clustered into a single station that has a monthly gasoline dispensing volume equal to the sum of the volumes from the two original stations and the geographic location of the larger of the two stations. Figure 5 provides a hypothetical example of two stations, A and B, with A dispensing a smaller monthly volume of gasoline than station B, and  $r$  being the linear Euclidean distance between the two stations. We assume that the drivers utilizing station A are uniformly distributed around the station at the time that they begin their diversion away from their normal driving routine to refuel. Conceptually, because most urban networks are relatively dense, and the distance from station A to the next nearest station is not significantly larger than  $r$ , this symmetrical distribution tends to be within a distance from station A that is less than half of distance  $r$ . The angle  $\theta$  is the angle of diversion. The rectilinear distance pathways are the solid black lines. Since  $r$  is known and  $\theta$  has been estimated, the rectilinear distance pathway can be easily estimated without knowing the particulars of the geometry.

If station A is eliminated from the network, we assume that drivers would begin their diversion from their normal driving routines from the same location, but would now drive to station B rather than station A. With station A at the center of the symmetrical distribution of these diversion locations, the shorter additional driving distances for diversion locations closer to B (i.e., within the hemisphere between stations A and B) would be offset by diversion locations further from B (i.e., within the hemisphere on the far side of station A away from station B). A somewhat more sophisticated variation on this clustering methodology would be to allocate the volume of the eliminated station (station A in this case) among more than one station (e.g., among the three nearest stations B, C and D) based upon proximity. Such an analysis may be pursued in future work, but preliminary calculations suggest only small changes to the final results.





**Figure 5. Station A elimination example.**

### 3.2.2 Rectilinear Distance Adjustment (1.27)

The distance between stations is calculated using Equation 2.

$$d_{ij} = \sqrt{x^2 + y^2}$$

where

$$x = 69.1 \cdot (lat2 - lat1)$$

$$y = 69.1 \cdot (lon2 - lon1) \cdot \cos(lat1/57.3)$$
(2)

The distance as calculated by this equation is the linear distance between the station locations. As vehicles in an urban area are typically limited to a grid style matrix of streets it is clear that the linear distance is an underestimate of the on-the-road distance between two station sites. The under-biased distance estimate is corrected by converting it to a rectilinear distance measure (Krause 1986). The rectilinear distance between two points is defined using equation 3.

$$d([x_1, y_1], [x_2, y_2]) = |x_2 - x_1| + |y_2 - y_1|$$

equivalently, in polar coordinates

$$d(r, \theta) = r(\sin \theta + \cos \theta) \quad (\text{in quadrant 1})$$
(3)

This can be thought of as the distance a taxicab would cover traveling between two points on a street grid (it is alternatively known as ‘taxicab’ distance (Krause 1986)).

### 3.2.3 Weight Function ( $W_A$ )

Equation 4 is used to determine the valuation of each additional mile travelled by consumers at the network is clustered. The first term accounts for time costs due to travel to a more distant station than the consumer would have used for a CFV. The coefficient 1.27 is used to convert the Euclidean distance  $d$  to an approximate rectilinear distance (covered in Methodology). Rectilinear distance is a more likely representation of on the road distance in urban areas than Euclidean distance. Dividing VMT by RNG (range) provides a lower bound of the number of refueling trips that will be made in a year.

$$w_A = \frac{TC}{MPH} \frac{VMT}{RNG_A}$$

where

$w_A$  is the weight function (\$/mile)

$TC$  is the average time cost (\$/hr) for drivers

$MPH$  is the average network speed (mph)

$VMT$  is the annual vehicle mile travelled

$MPH$  is the average network speed (mph)

$RNG_A$  is the range (mi.) of the AFV

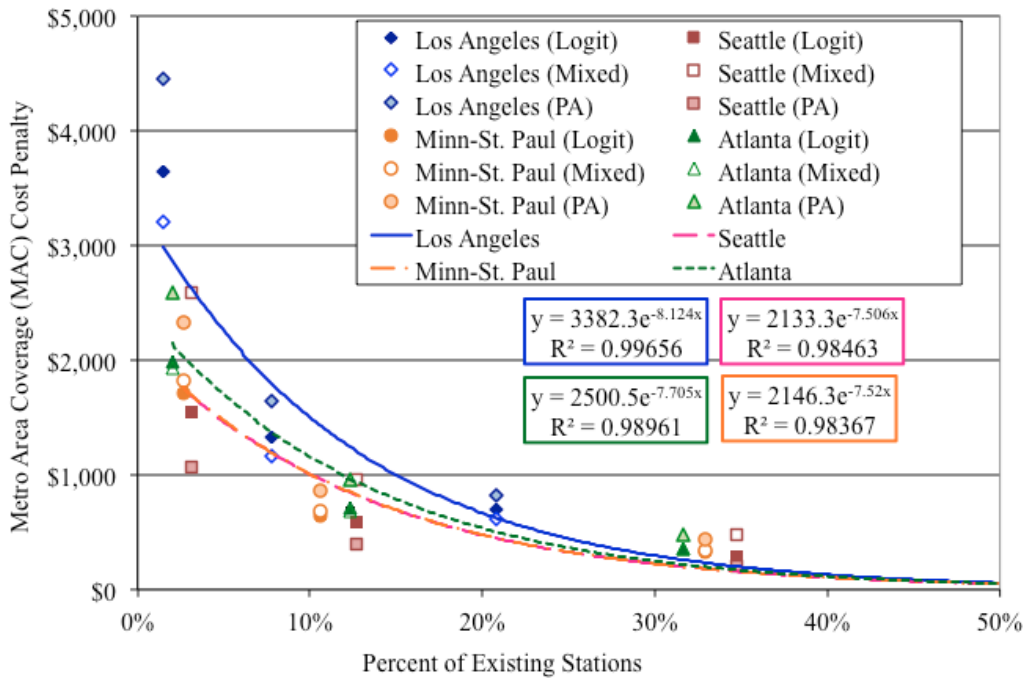
(4)

Two distance models were developed for the data. The first is for large (LRG) urban areas with station networks of over 1,000 stations. The second distance model is for the full set (FULL) of stations and includes the large urban areas. Results are presented below for both distance models to explore the variation between larger urban areas and more typical urban areas.

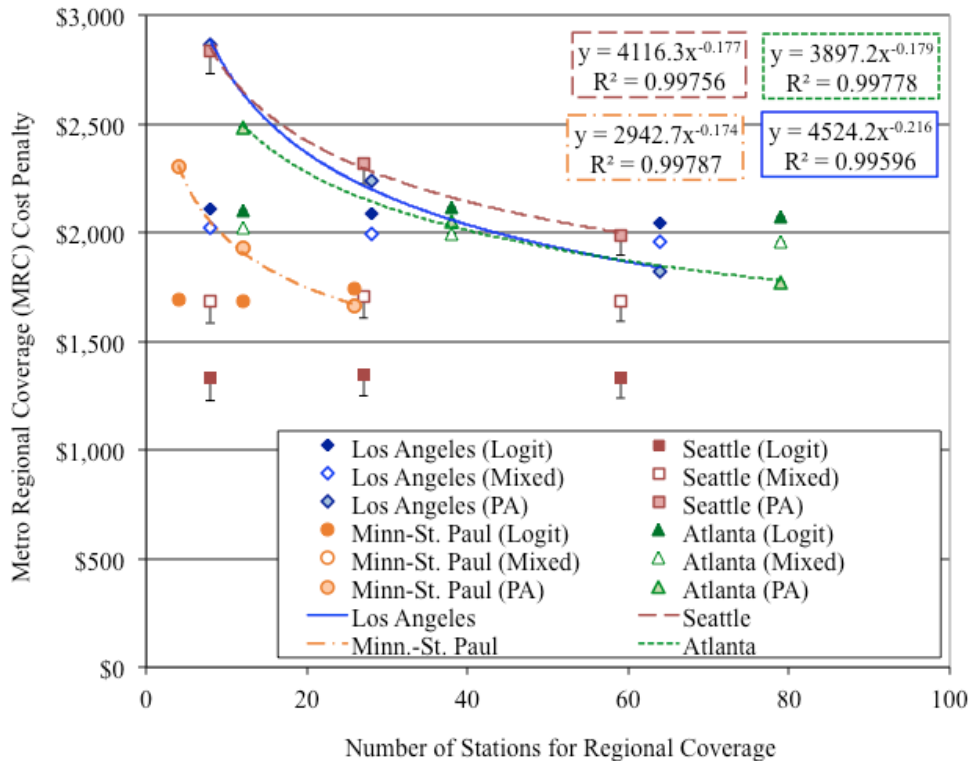
## 4 Results

### 4.1 Results from the discrete choice survey

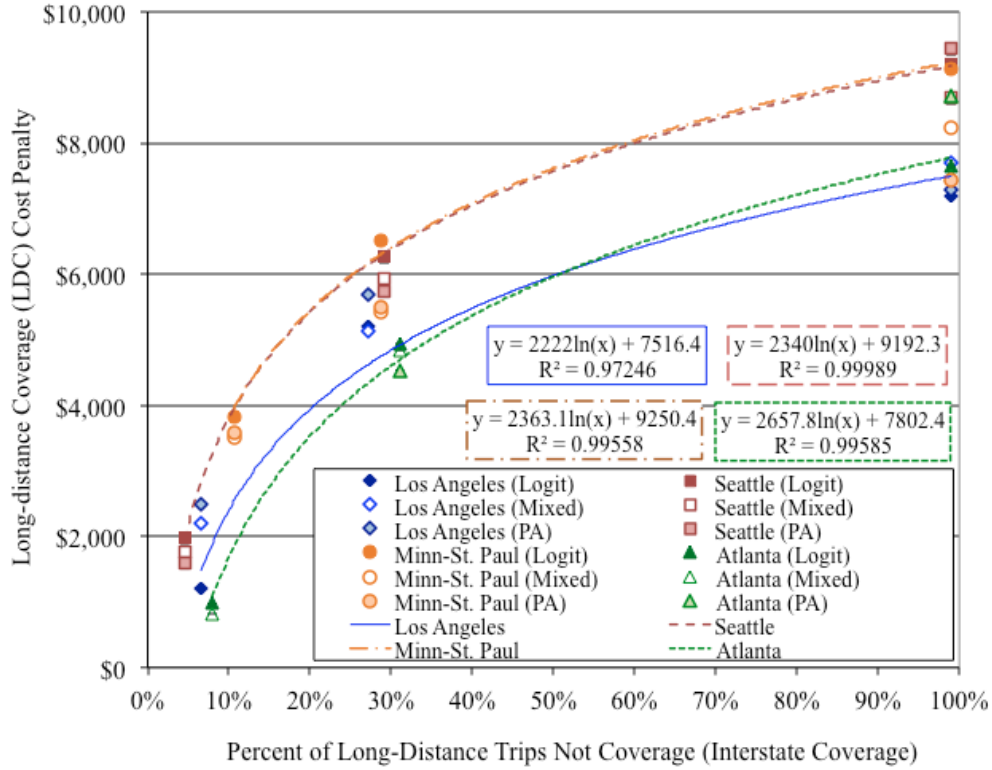
Results from the two studies can be compared using multiple metrics of station coverage. The most intuitive metric is the number of alternative fuel stations available expressed as a percent of existing conventional stations in a given urban area. However, the spatial density of conventional stations, measured in stations per 100 square miles, can range from 50 to 125 across different major U.S. urban areas (Melaina and Bremson, 2008). It can therefore prove insightful to express results in absolute terms as well as in terms of the percent of existing stations. For the case of consumer preference results from the discrete choice study, a percentage basis is more consistent given that respondents compared, both visually and quantitatively, alternative fuel station coverage to existing station coverage when making decisions. Some variations were seen across the four urban areas where the survey was fielded (Atlanta, Los Angeles, Minneapolis-St. Paul, and Seattle), but the general an approximate result is that urban area coverage at 4%, 12% and 30% corresponds to penalties of approximately \$2,500, \$1,000, and \$300 against the price of a new vehicle. These results are summarized in Figure 6 for each of the models employed (Logit, Mixed and PA), with exponential functions shown for the value from the Logit model, which was considered the most representative. Dollar values were determined using the Vehicle Purchase Price coefficient result from each model. Limited coverage within 150 miles of an urban area, medium-distance coverage, results in cost penalties ranging from \$1,500-\$3,000, as shown in Figure 7. In this case the original model from PA Consulting provided the best representation, and power functions fitting those results are shown in the figure. For the third level of coverage examined, long-distance coverage along interstates between urban areas, the penalties shown in Figure 8 suggest \$1,000-\$2,000 for a lack of stations along interstates connecting the consumer to very distant urban areas (i.e., connectivity to the East Coast if they lived on the West Coast), \$4,000-\$6,000 for coverage to urban areas within about 1000-1500 miles, and \$7,000-\$9,000 for no interstate coverage outside the consumer's metropolitan region. The basis for this level of coverage, percent of long-distance trips not coverage, is based upon long-distance trip data for each urban area from the American Travel Survey (see Figure 4).



**Figure 6. Cost penalties for limited Metropolitan Area Coverage (MAC)**



**Figure 7. Cost penalties for limited medium-distance coverage (MDC) as a function of the number of stations within 150 miles of the metro area center.**



**Figure 8. Cost penalties for limited long-distance coverage (LDC) as a function of the number of long-distance trips not covered.**

#### 4.2 Results from the Station Clustering Analysis

Results from the travel time study only inform coverage at the urban area level, but can be more readily expressed as a continuous function and are derived from data for a much larger number of cities. The clustering algorithm was applied to a subset of larger urban areas with station networks of over 1000 stations (LRG) as well as to the full set of all urban areas (FULL). Results are shown as average diversion miles for LRG and FULL sets, along with standard deviations, in Figure 9. The horizontal axis is the degree of clustering, determined by Equation 5.

$$x = 100 * s / S$$

where

$x$  is the % cluster

$s$  is the number of stations remaining in the network

$S$  is the original number of stations in the network

(5)

The trend lines for the LRG and FULL sets are very similar. The LRG set is slightly steeper than the FULL set at clusters of less than 2% but the functions quickly converge for higher degrees of clustering. The standard deviations also converge for the sets as the clustered network increases in size.

To calculate the present value the researchers assumed a 10% discount rate and a four-year ownership period. Time cost (TC) was set at \$15/hr, VMT to 15000 miles/year, range to 300 miles and network speed at 25 mph. The set of assumptions assigns the value \$30/mile to  $w_A$ . Results are shown as a function of the degree of clustering in Figure 10.

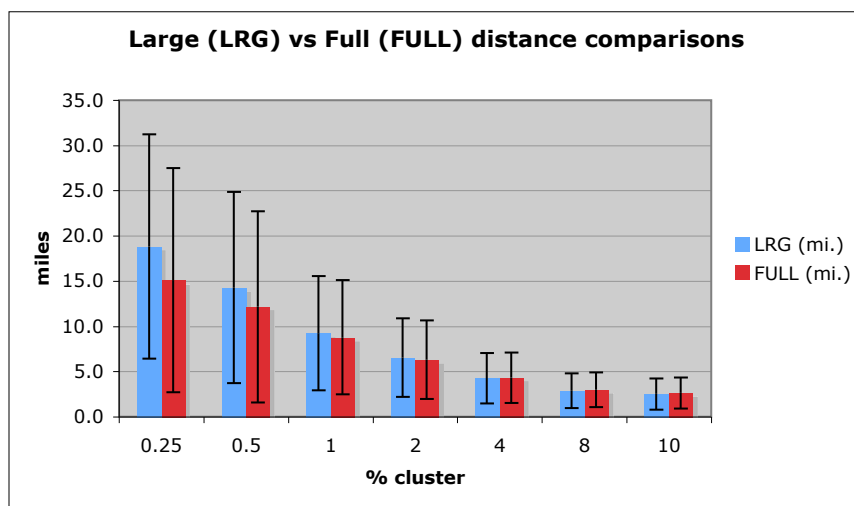


Figure 9. Average distances for large networks and all networks.

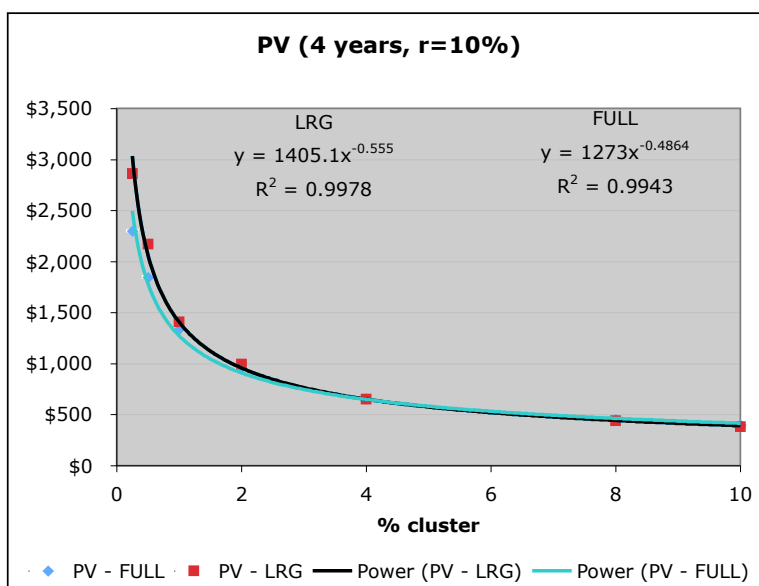
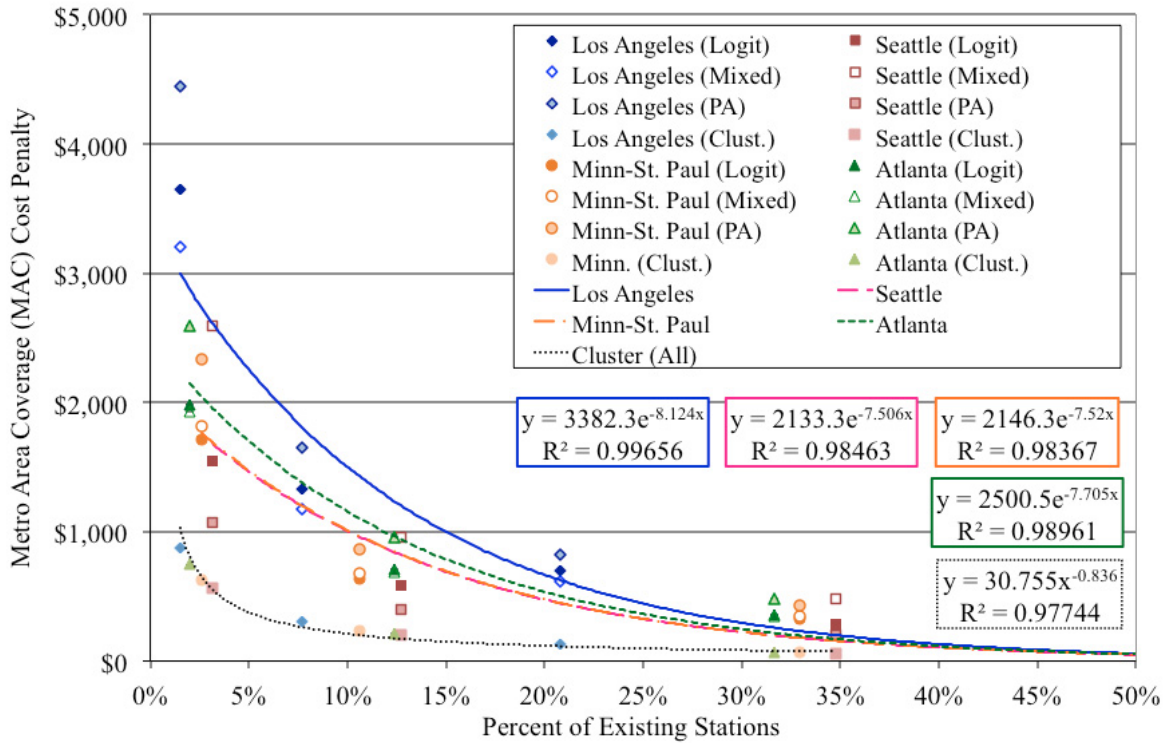


Figure 10. Present value of penalty costs for AFVs at coverage levels up to 10% clustering.

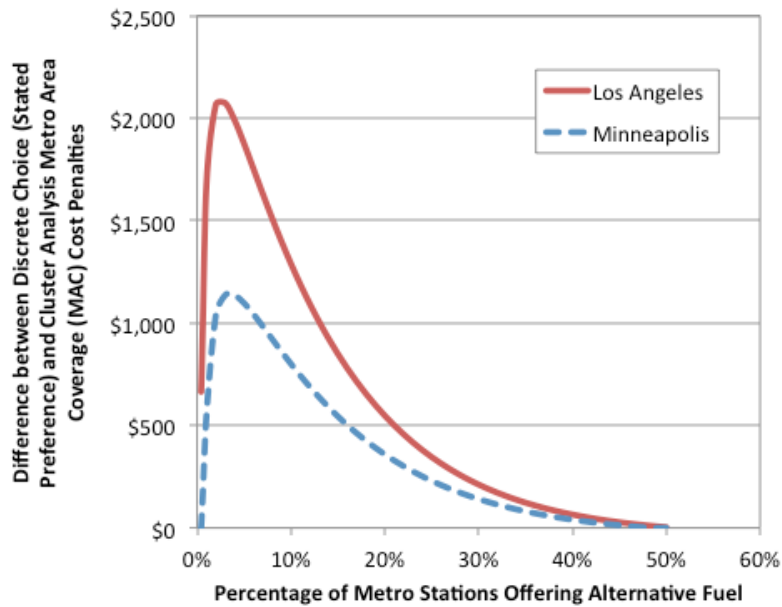
### 4.3 Comparison of stated preference and cluster algorithm results

Results for metropolitan area coverage can be compared between the two studies (the clustering algorithm, as defined here, does not apply to regional and interstate coverage). Figure 11 includes the clustering algorithm results in Figure 10 along with the survey results shown in Figure 6. Though many factors should be considered in interpreting the discrepancies among survey results in each city, we consider here the Los Angeles results to be the high end of the stated preference results and the Minneapolis-St. Paul results to be more indicative of an “average” U.S. metropolitan area (based upon relative populations and population densities). The difference in cost penalties between stated preference results for these two cities and the ALL results from the clustering algorithm are shown in Figure 12. If the cluster algorithm results are indeed a lower bound on where revealed preferences may fall, as a simulation of consumers with full information about the actual level of inconvenience, and if the stated preference results are a high estimate, this difference may represent an upper bound on a perceived level of inconvenience that could be reduced by providing consumers with additional information.





**Figure 11. Comparison of metro area coverage (MAC) penalties for both survey results and central value results from the clustering algorithm.**



**Figure 12. Difference between high and low stated preference penalties (Los Angeles and Minneapolis-St. Paul, respectively) and central value results from the ALL clustering algorithm.**

## 5 Discussion and Conclusions

Our results suggest that a significant discrepancy exists between the value of convenience perceived by consumers, implied by stated preference survey results, and the value estimated through a theoretical station clustering algorithm and travel time model using a cost penalty in dollars per minute of additional driving time. In general, the cost penalties estimated by the two studies reviewed here are on the same order as the incremental cost increases anticipated for advanced, dedicated light duty vehicles, such as battery electric, CNG or fuel cell electric vehicles, over conventional internal combustion or hybrid electric gasoline vehicles. This result suggests that a lack of retail stations may pose a market barrier as significant as the incremental costs of the advanced vehicles. Given that these vehicles are often incentivized by state or federal programs with the goal of accelerating market adoption and accruing social benefits, the availability of retail stations may also warrant a targeted policy approach. However, the details of any such policy must be tailored to the unique characteristics of the market barrier. The present study suggests that improving consumer perception or awareness of coverage may play a large role in overcoming this market barrier.

Results from the stated preference survey suggest significant cost barriers for a lack of refuelling availability serving medium- and long-distance trips, where medium-trips are within a 150 mile radius of the metro area (roughly 300 miles round trip, or on a single tank) and long-distance trips are along interstates to distant urban areas. The context of these results was a vehicle with significant range, rather than a plug-in electric vehicle with range less than 100-200 miles. We interpret the high perceived cost barriers against the purchase price of a vehicle for lack of coverage for longer trips (\$3,500 to \$12,000 when adding medium- and long-distance penalties) as a clear indication that consumers expect full (range) utility from an alternative fuel vehicle. By comparison, cost penalties are relatively low for a lack of metropolitan area coverage (\$750 to \$4,000), and the clustering analysis suggests that these penalties may be lower if consumers are provided with additional information about coverage and actual travel patterns. This could be achieved through onboard information systems that track vehicle travel patterns and convey to consumers potential deviations from normal driving routes when refuelling is required.

This being said, the pattern of cost penalties at the metropolitan level is exponential for very low coverage, suggesting significant benefits, in terms of potential market share growth, for investments in station coverage in the range of 5% to 10% of existing metropolitan area stations. In addition, it appears that a significant level of coverage at the regional and interstate level may also yield significant benefits in terms of increased early market growth. In terms of reducing cost barriers per vehicle, these benefits are on the same order as large vehicle subsidies or incentives that are already in place or propose at the Federal and State level. Though investments in early retail fueling infrastructure may prove to be high risk from an investment perspective, the benefits to consumers, as well as automakers intent on increasing market growth, are on the order of multiple thousands of dollars per vehicle for increase refuelling availability at metropolitan, regional and interstate geographic scales.

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