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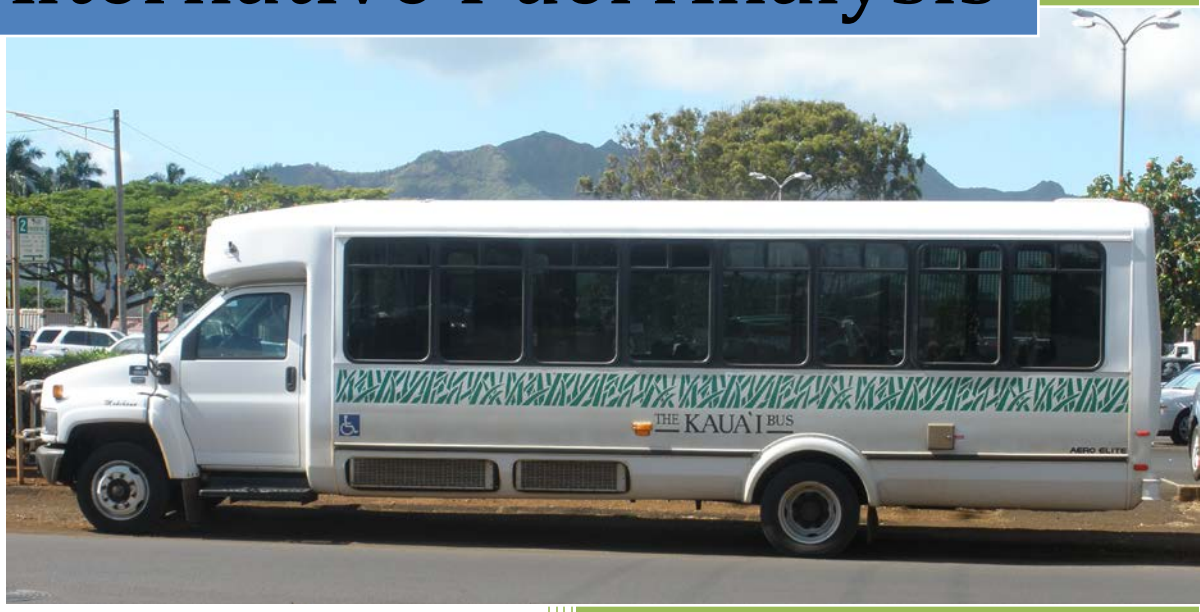
Kaua‘i
Multimodal Land Transportation Plan

APPENDIX G THE KAUA‘I BUS ALTERNATIVE FUEL ANALYSIS

Kauaʻi Multimodal Land Transportation Plan

January, 2012

The Kauaʻi Bus
Alternative Fuel Analysis



Prepared by:

Charlier Associates, Inc.

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Introduction

The Kaua'i Bus, like many other transit agencies around the country, is interested in the potential benefits of transitioning its fleet from conventional diesel fuel to one or more alternative fuels. The primary concerns that motivated The Kaua'i Bus to explore alternative fuels have to do with threats to the long term availability of petroleum fuel and its increasing cost. Petroleum will not be sustainable long term in Kaua'i as it must be imported, and diesel prices, which are already inflated in Kaua'i, are expected to double by 2035.[1] In 2011, 15% of The Kaua'i Bus's operations budget was spent on fuel.[2] In addition to these concerns, The Kaua'i Bus is also interested in other potential benefits from converting to alternative fuels including lowering vehicle emissions and reducing its reliance on foreign imports. This is supported by existing Federal programs and State initiatives aimed at decreasing vulnerability in energy supplies during an emergency. [3]

Evaluation Criteria

Evaluation criteria used in this analysis were based on the needs specific to The Kaua'i Bus. These include cost, sustainability criteria, environmental impacts, and feasibility in Kaua'i. Costs, include the cost of vehicles, maintenance, and fuel (now and in the future). Sustainability criteria include how much of the fuel is from non-renewable resources and whether that fuel must be imported or can be locally produced in a sustainable manner in Hawai'i. Environmental impacts were measured primarily by vehicle emissions. These include greenhouse gas (GHG) emissions as well as emissions regulated by the EPA, including particulate matter (PM), nitrous oxide (NOx), and non-methane hydrocarbons (NMHC). Feasibility in Kaua'i was measured by the supply of fuel available in Kaua'i (both short and long term), and how well that fuel would work given The Kaua'i Bus's route structure. Given that alternative fuel technology is expected to continue to evolve over the next 10-20 years and the fact that The Kaua'i Bus fleet is recapitalized every ten years or so, both short term (1-9 years) and long term (10+ years) viable fuel alternatives are recommended at the end of this report.

Alternative Fuels Overview

There are many types and variations of what are often grouped together as "clean fuels" or "alternative fuels." The FTA prepared an alternatives fuel study in 2006 that provides a comprehensive introduction to this topic.[4] The report defines several fuels, noting that these fuels "designated by the Energy Policy Act of 1992 or the Department of Energy after that date, are considered alternative fuels." Each fuel type is summarized in the sections to follow.

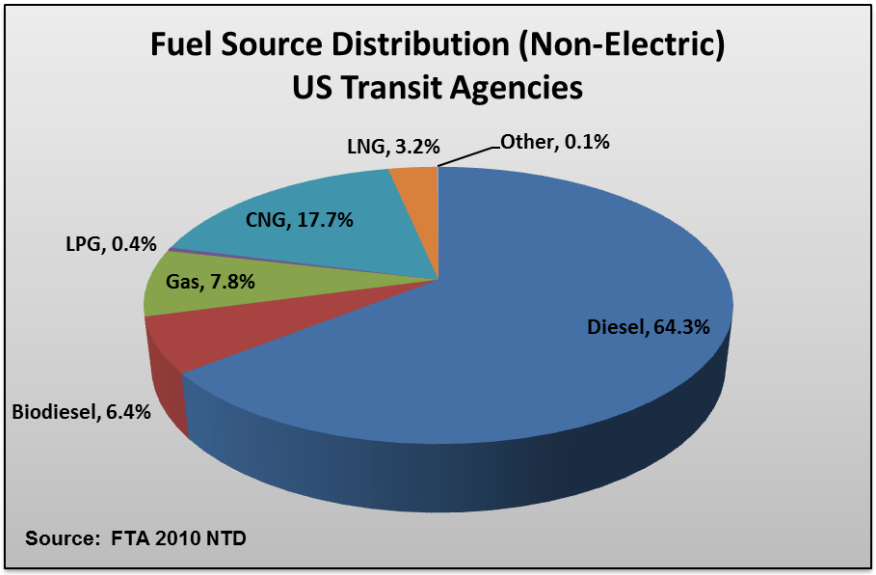
National Landscape

The national landscape for alternative transit fuels has generally focused on experimentation, research, and incentives rather than regulation. For example, the FTA provides research, support, and grant funding regarding clean fuels. Among FTA's discretionary grant programs are the Clean Fuels and TIGGER (Transit Investments for Greenhouse Gas and Energy Reduction) programs.[5] These programs provide capital, but not operating assistance with buying clean fuel buses, building clean fuel and recharging facilities, and other capital investments that reduce transit system energy reduction and

[1] *U.S. Energy Outlook 2011*. Energy Information Agency. September, 2011.
[2] Provided by Kaua'i County Transportation Agency
[3] For federal program, see: www.energyassurance.us. For state initiatives and policies, see: www.hawaiicleanenergyinitiative.org
[4] Alternative Fuels Study: A Report to Congress on Policy Options for Increasing the Use of Alternative Fuels in Transit Vehicles, available here: www.fta.dot.gov/12907_9187.html
[5] FTA summarizes its discretionary grant programs here: http://fta.dot.gov/grants/13094.html

greenhouse gas (GHG) emissions. Additionally, many transit agencies across the country have fully or partially transitioned their vehicle fleet to different types of alternative fuels. Lessons learned are discussed in more detail later in this document.

FTA's current (2010) National Transit Database (NTD)[6] was analyzed to determine transit agency fuel source distribution as a nationwide average. The NTD reports fuel consumption by type for each transit mode operated by federally-funded transit agencies comprising its database. To conduct this analysis, fuel source distribution was computed by fuel type for each transit mode and then combined to create a nationwide average for fixed route and para-transit buses shown below.



While diesel fuel continues to be the most common fuel source, it only comprises about two-thirds nationwide. Compressed natural gas (CNG) is the second most-used fuel source (18 percent), while gasoline is third with about eight percent.

A few important points about this analysis:

- The NTD does not specifically track hybrid-electric usage, or even the number of transit agencies with hybrid-electric buses in their fleet. While many transit agencies now use hybrid-electric buses, it is a technology, not a distinct fuel consumption source.
- Similarly, the NTD annually tracks the amount and type of fuel consumed, which is different from *fuel efficiency*, another reason hybrid-electric data is not included in fuel consumption statistics.
- The analysis above uses proportional consumption as a means to illustrate fuel type sources. The NTD groups fuel consumption data by gallons consumed and kilowatt hours (KWH) used, meaning that liquid and electric fuel consumption cannot be directly compared.
- Even so, the NTD does track the number of KWH to charge batteries and KWH of propulsion power, *though only for transit mode vehicles for which electricity is the primary fuel source*. For the bus-based transit service types used in this analysis (fixed route and demand response), the

[6] Source: www.ntdprogram.gov/ntdprogram/pubs/dt/2010/excel/T17_Energy_Consumption.xls

NTD lists only five transit agencies that have battery electric buses as part or all of their fleet (this list excludes trolley buses that use an overhead catenary): Los Angeles, Santa Barbara and Anaheim, CA; Anderson, Indiana; and Chattanooga, TN.

Evaluation of Alternative Fuels:

Petroleum Diesel

Description: A petroleum based fuel and the standard fuel used by trucks and buses throughout the nation.
National Examples: Petroleum diesel is the most commonly used fuel by transit bus fleets in the nation, making up 64.3% of fuel used.
Use in Hawai'i: The majority of the truck and bus fleets in Hawai'i are diesel powered, including nearly all of The Kaua'i Bus fleet.
Pros: Diesel buses are relatively inexpensive and mass production of buses makes procurement straightforward. Maintenance of vehicles is well understood and facilities are well established. Supply stations are numerous on Kaua'i.
Cons: Between January, 2006 and December, 2011 diesel prices in Hawai'i increased from $3.27 a gallon to $4.78 per gallon,[7] and mid-range projections show petroleum doubling in price by 2035 (excluding inflation).[8] Diesel fuel must be imported and therefore Kaua'i is vulnerable to disruptions in supply due to natural disasters or political unrest. Diesel emissions also contribute significantly to greenhouse gases (GHG's) and contain high levels of air pollutants including PM, NOx, and NMHC.
Bottom Line: While petroleum diesel is currently widely available in Kaua'i and diesel buses are relatively inexpensive to purchase and maintain as compared to other types of buses, diesel is not a sustainable fuel source for The Kaua'i Bus. Petroleum diesel is a non-renewable resource that must be imported and is therefore susceptible to supply disruptions. It is expected to become prohibitively expensive in Hawai'i over the next 10-25 years, and diesel buses emit high levels of GHGs and other EPA regulated air pollutants.

Clean Diesel Buses

Description: Clean diesel engines typically use petroleum based fuel, but emit fewer air pollutants meeting stricter EPA emissions standards.
National Examples: Most new diesel buses made for transit service today are clean diesels.
Use in Hawai'i: O'ahu has begun transitioning clean diesel buses into their fleet. They find them to be much more cost effective for long haul routes than hybrid buses because clean diesel buses are much cheaper than hybrids and nearly as fuel efficient.[9]
Pros: Clean diesels emit lower levels of GHGs and significantly lower levels of other air pollutants including PM, NOx, and NMHC, than older diesel buses.
Cons: Clean diesels still rely on imported petroleum fuel.
Bottom Line: While clean diesel buses produce fewer emissions than standard diesel buses, if the buses are fueled by petroleum diesel, this does little to address projected diesel price increases and potential supply disruptions that are the primary concerns of The Kaua'i Bus.

[7] Hawaii Department of Business, Economic Development and Tourism (DBEDT). Monthly Energy Trends. Dec., 2011. Available at: http://hawaii.gov/dbedt/info/economic/data_reports/energy-trends
[8] *U.S. Energy Outlook 2011*. Energy Information Agency. September, 2011.
[9] Report by *Oahu Transit Services, Inc.* "Rehab Transit Buses as an Alternative to Purchasing New Diesel Hybrid or Clean-Diesel Buses," April, 2009. Available at: http://the.honoluluadvertiser.com/dailypix/2009/May/10/bus_study09.pdf

Biodiesel Blend (B20)

Description: A mix of non-petroleum fuels and petroleum-diesel that can be used in most diesel engines. Biodiesel is derived from vegetable oils or animal fats, and is typically blended with petroleum diesel at a 20 percent biodiesel concentration to achieve a good balance of emissions benefits, cost, and risk. Known as B20, it is commonly used in diesel engines with no modifications. Another type of biodiesel is Fischer-Tropsch diesel, which is a synthetic fuel made from coal, natural gas, or biomass feedstock via the Fischer-Tropsch process. It can be used alone or mixed with petroleum diesel; neither requires engine modifications. A third type of biodiesel is a diesel-alcohol blend, which consists of a mix petroleum diesel with up to 15 percent ethanol or methanol. Such low ethanol-mixed blends can be used in existing engines without modifications.

National Examples: Biodiesel is the fourth most common fuel type used by transit agencies nationally, making up 6.4% of fuel used.

Use in Hawai'i: A biodiesel blend (a mix of petroleum diesel and biodiesel) is the most widely used alternative fuel available in Hawai'i (primarily in Maui and O'ahu). One manufacturer, Pacific Biodiesel in Maui produces biodiesel from waste restaurant oils and imported feed stock from Texas.[10] They supply the vehicle fleet of the City and County of Honolulu with B20 as well as B20-B99 to two gas stations on Maui and O'ahu. There is at least one organization on Kaua'i that is producing locally made biodiesel. Kaua'i Farm Fuel, started in 2008 in Hanapēpē, is currently converting small quantities of used oil and grease to biodiesel.[11] As of 2008 they were producing enough biodiesel to supply the County's vehicle fleet, but not the bus fleet. As described earlier, using the Fisher-Tropsch process biodiesel can be made from biomass, often called biofuel. Most biofuel production in Hawai'i today are from small scale, experimental operations primarily used to generate electricity and not to produce biodiesel. Hawai'i Electric will be getting algae based biofuel through a recently started pilot program. Phycal, Inc. will grow and convert the algae in O'ahu (provided by a USDOE $3 million grant) and Cellana LLC will do the same in Kailua-Kona on the Big Island ($9 million grant).[12] Hawai'i BioEnergy also recently contracted with Hawai'i Electric to produce, harvest and convert crops to biofuel on Kaua'i for use in O'ahu.[13] Most of the funding for biofuel plants and farming has come from the private sector and federal government, not the state.[14]

Pros: Biodiesel can be locally produced from renewable resources such as crops, excess vegetable oil, or animal fats. Biodiesel emits fewer GHG's than petroleum diesel. Blends that use 20% biodiesel and 80% petroleum diesel (B20) can be used in standard diesel engines.

Cons: Biodiesel is slightly less powerful and has a lower fuel economy than petroleum diesel.[15] Using a biodiesel blend still necessitates importing petroleum diesel fuel. Biodiesel production/availability is also limited in Kaua'i and as of October, 2011 average nationwide prices for biodiesel were slightly higher

[10] Article on Biofuel use in Hawaii. From: http://www.hawaiisenergyfuture.com/articles/Biofuels.html

[11] Eagle, Nathan. "County to explore using biodiesel for its vehicles." The Garden Island. March, 16, 2008. Available at: http://thegardenisland.com/news/article_b337bbe6-9a75-5a23-b78d-eacb7a1d0daa.html

[12] Conroe, Joan. "Biofuels: Boom or Bust?" Honolulu Weekly, Dec. 1, 2010. Available at: http://honoluluweekly.com/cover/2010/12/biofuels-boom-or-bust/

[13] Press Release. "Hawaiian Electric selects Hawaii BioEnergy to supply sustainable local biofuel for Kahe Power Plant" Sep. 12, 2011. Available at: http://www.hawaiisenergyfuture.com/articles/20110912_Hawaiian_Electric_selects_Hawaii_BioEnergy_to_supply_biofuel_for_Kahe_PP.pdf

[14] Conroe, Joan. "Biofuels: Boom or Bust?" Honolulu Weekly, Dec. 1, 2010. Available at: http://honoluluweekly.com/cover/2010/12/biofuels-boom-or-bust/

[15] Eagle, Nathan. "County to explore using biodiesel for its vehicles." The Garden Island. March, 16, 2008. Available at: http://thegardenisland.com/news/article_b337bbe6-9a75-5a23-b78d-eacb7a1d0daa.html

than petroleum diesel prices. While biodiesel emissions contain slightly lower levels of PM and NMHC as compared to petroleum diesel, emissions contain slightly higher levels of NOx.
Bottom Line: A biodiesel/petroleum diesel blend would be a feasible alternative fuel source for The Kauaʻi Bus. However, there are currently no biodiesel supply stations in Kauaʻi, and because current biodiesel production in Hawaiʻi is so small in scale, further research is needed to determine if there are large enough supplies available in Hawaiʻi for The Kauaʻi Bus fleet. Further discussion with Kauaʻi Farm Fuel and Pacific Energy may help clarify the costs and feasibility of using a locally produced biodiesel blend for The Kauaʻi Bus. A more in-depth analysis on transit agency experience using biodiesel can be found in a 2007 TCRP report,[16] and biodiesel supply opportunities can be found at www.biodiesel.org.

Straight Biodiesel (B100)

Description: Biodiesel that is unblended with any petroleum based diesel. See description for biodiesel blend above for detail on the different types of biodiesel and how they are produced.
National Examples: There are no known examples of a transit agency's bus fleet using straight biodiesel that is not blended with petroleum diesel, although some agencies, such has COTA in Ohio use blends up to B90.
Use in Hawaiʻi: There are no published examples of using straight biodiesel (B100) as a source of fuel in Hawaiʻi. However, biodiesel has begun to be more widely produced and is used in Hawaiʻi when blended with petroleum diesel to quantities up to B99 (see above). The *Kauaʻi Energy Sustainability Plan* recommends testing straight vegetable oil in older buses to see how well this could work as an alternative fuel option, which typically requires very minor vehicle modifications.[17]
Pros: Biodiesel can be locally produced from renewable resources including crops, recycled vegetable oil, or animal fats. Since straight biodiesel can, in theory, be entirely produced in Kauaʻi, this would make the fuel supply for The Kauaʻi Bus less susceptible to petroleum diesel price fluctuations or supply disruptions. If The Kauaʻi Bus were to use Biodiesel produced through locally grown biofuel, The Kauaʻi Bus would be contributing to the local agriculture business in Hawaiʻi. Biodiesel also emits far fewer GHG's, PM, and NMHC than petroleum diesel and is biodegradable, so is safer to work with and not as hazardous when spilled.
Cons: In some cases vehicle modifications may be necessary for buses to be able to run on straight biodiesel, although newer diesel buses are having fewer problems using higher percentages of biodiesel. The average national costs of biodiesel as of October, 2011 ($4.18/gal) are slightly higher than petroleum diesel ($3.81/gal), which is further heightened by the lower fuel efficiencies of biodiesel.[18] However, the price advantage of petroleum diesel over biodiesel will likely decrease in the future as diesel prices increase, and there can be local differences in price. For example, COTA (the Columbus, OH transit agency) estimated a savings of $534,000 in 2006 by using biodiesel.[19] The Kauaʻi Bus would also need to ensure a consistent supply of biodiesel is available in Hawaiʻi for their fleet. Additionally, there may be some negative environmental effects of growing biofuels locally, such as land and resource consumption and the potential displacement of locally grown food. Biodiesel actually emits higher

[16] TCRP Synthesis 72. "Use of Biodiesel in a Transit Fleet." 2007. Available at: http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_syn_72.pdf
[17] Sentech Hawaii, LLC. *Kaua'i Energy Sustainability Plan*. "Section 4: Recommendations for the Ground Transportation Sector." April, 2010. Available at: http://www.Kaua'inetwork.org/energy-sustainability/
[18] U.S. DOE. "Clean Cities Alternative Fuel Price Report." October, 2011. Available at: www.afdc.energy.gov/afdc/price_report.html
[19] TRCP Synthesis 72. "Use of Biodiesel in a Transit Fleet." 2007. Available at: http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_syn_72.pdf

amounts of NOx than petroleum diesel. Because B100 gels, it does not work well in cold weather, but this would not be a problem in Kaua'i.

Bottom Line: Using straight biodiesel as a fuel source for The Kaua'i Bus may be impractical in the short term. The cost of vehicles modifications and fuel are expected to be higher than using petroleum diesel today, and more importantly The Kaua'i Bus would need to establish a consistent supply of biodiesel before converting to this fuel. However, straight biodiesel would be a strong long term candidate for an alternative fuel source if local production becomes more widespread and cost effective. A natural way to begin this transition would be for The Kaua'i Bus to start using a biodiesel blend (B20 or lower) in the near term, which is currently used in other parts of Hawai'i (see above) and can be used without modifying current diesel buses. Another transitioning approach would be to start a pilot program whereby some buses are modified to run off straight biodiesel (as suggested in the *Kaua'i Energy Sustainability Plan*). This would provide lessons on operational/cost challenges that would set the stage for a potential fleet conversion to biodiesel.

Natural Gas (CNG or LNG)

Description: Natural gas comes in two forms – compressed (CNG) and liquefied (LNG). Compressed gas is typically transported via utility pipeline, while LNG is typically transported by tanker truck or ship.

National Examples: Natural gas is the second most common fuel type used by transit agencies nationally, making up 21.9% of fuel used (17.7% CNG and 3.2% LNG). The Los Angeles and Fort Worth transit agencies are some of the largest users of CNG powered buses.

Use in Hawai'i: Natural gas is not currently available in Hawai'i. However, a 2007 study conducted by the State of Hawai'i found that LNG would likely be cheaper and cleaner than diesel,[20] but the state has yet to take the steps necessary to import natural gas. This would almost certainly be necessary before The Kaua'i Bus could consider this fuel option. Liquid Natural Gas (LNG) is the only form of natural gas that could be used in Hawai'i because Compressed Natural Gas (CNG) is only cost effective when transported by pipeline.

Pros: Natural gas is currently less expensive than almost any other alternative fuel source, although prices are projected to increase in the near future. Natural gas vehicles emit far fewer PM, and slightly lower amounts of NOx and GHGs than diesels, and because natural gas burns cleaner, buses can operate longer between maintenance overhauls.[21]

Cons: The Kaua'i Bus would need to import LNG, which offsets its cost saving advantage. Natural gas vehicles also have lower fuel efficiencies (also offsetting the savings from lower fuel prices) and are generally more expensive to operate than diesel vehicles. Fueling and maintenance facilities would have to be retrofitted to accommodate LNG vehicles.

Bottom Line: It is not possible to import CNG to Kaua'i, and because LNG is not currently available in Hawai'i, The Kaua'i Bus would need to import LNG itself, which is not practical. It is possible that Hawai'i could begin importing LNG for other uses in the future. However, even in this scenario, the price premiums associated with importing LNG to Hawaii, the operational challenges mentioned, and the fact that The Kaua'i Bus would still be importing a non-renewable fuel outweigh any advantages of using LNG. Because of these challenges, natural gas is not a viable alternative fuel for The Kaua'i Bus.

[20] Facts, Inc. "Evaluating Natural Gas Import Options for the State of Hawaii." April, 2007. Available at: www.eere-pmc.energy.gov/states/Hawaii_Docs/FGE-Evaluating_Natural_Gas_Import_Options_for_Hawaii-Revised.pdf

[21] Roman, Alex, ed. "Transit Fleet Comes Clean as Alternative-Fuel Technology Comes of Age." *Metro Magazine*. April, 2011. Available at: http://www.metro-magazine.com/Article/Story/2011/04/Transit-Fleets-Come-Clean-as-Alternative-Fuel-Technology-Comes-of-Age.aspx

Liquefied Petroleum Gas (LPG)

Description: LPG, or propane, is a by-product of petroleum refining and natural gas processing. Most propane in the US comes from natural gas processing plants and must be put under moderate pressure to liquefy.
National Examples: LPG is used by only a handful of transit agencies nationally, making up only 0.4% of total fuel used by buses.
Use in Hawai'i: LPG is the third most common fuel source (after gasoline and diesel) used to power vehicles in Hawai'i.[22] Hawai'i has 4 LPG refueling stations, but none in Kaua'i.[23]
Pros: LPG powered buses emit slightly lower amounts of GHGs and other air pollutants.[24] LPG is also currently available as a fuel source in Hawai'i.
Cons: LPG requires a larger fuel storage area for the same energy produced as diesel, is typically more expensive than diesel fuel, cannot be locally produced in Hawai'i, is petroleum based, and would require that bus fueling and maintenance facilities be retrofitted to accommodate LPG vehicles. Transit agencies that have used LPG buses have also experienced operational challenges that have made LPG a largely unattractive fuel alternative.
Bottom Line: LPG is not commonly used as a fuel source for transit vehicles nationally due to the numerous operational challenges it presents. More importantly LPG would not address long term sustainability needs for Kaua'i, and it generally presents very few (or no) cost saving advantages over diesel.

Ethanol Blend (E85)

Description: Also known as ethyl or grain alcohol, ethanol is fermented from grains, typically corn. The type used in transportation is E85, which is a mixture of 85 percent ethanol and 15 percent gasoline and requires engine modifications. Most retail gasoline now includes 10 percent ethanol, known as E10, or (less commonly) gasohol, which does not require engine modifications. As of January 1st, 2012, Congress allowed the 30-year-old federal ethanol subsidy to expire. This could have serious consequences on the production of ethanol and calls into question the long term viability of ethanol as a fuel source.[25]
National Examples: A number of transit agencies experimented using ethanol in the 1990's, and most found the high fuel costs and reduced vehicle power were not worth the reduced emissions.[26] Most transit agencies have instead pursued other alternatives including CNG, diesel hybrid, biodiesel blends and battery-electric buses.
Use in Hawai'i: In April, 2006 Hawai'i enacted a requirement that 85% of gasoline made available in the state contain at least 10% ethanol. The hope was that ethanol would be produced locally, contributing to local jobs and reducing the state's reliance on foreign imports, but after five years this has yet to come to fruition, and Hawai'i currently imports all its ethanol.[27] Pacific West Energy, LLC is planning at some point to grow biomass and produce ethanol in Kaua'i, but this has yet to occur, which means the future supply of ethanol in Hawai'i is at best questionable.[28]

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[22] Hawaii Department of Business, Economic Development and Tourism (DBEDT). Monthly Energy Trends. Dec., 2011. Available at: http://hawaii.gov/dbedt/info/economic/data_reports/energy-trends
[23] See: http://www.altfuelprices.com/stations/LPG/
[24] TRCP Report. "Guidebook for Evaluating, Selecting and Implementing Fuel Choices for Transit Bus Operations" 1998. Available at: http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_38-a.pdf
[25] For an informative summary of the ethanol subsidy expiration and potential impacts: http://content.usatoday.com/communities/driveon/post/2012/01/end-of-ethanol-subsidy-could-raise-gas-prices-for-2012/1
[26] See: www.travelmatters.org/about/fuels-ethanol
[27] Yonan Jr., Alan. "Isle ethanol efforts stall." Star Advisor. June 27, 2010. Available at: www.staradvertiser.com/business/20100627_Isle_ethanol_efforts_stall.html?id=97255609
[28] See: http://pacificwestenergy.com/Kaua'iProject.aspx

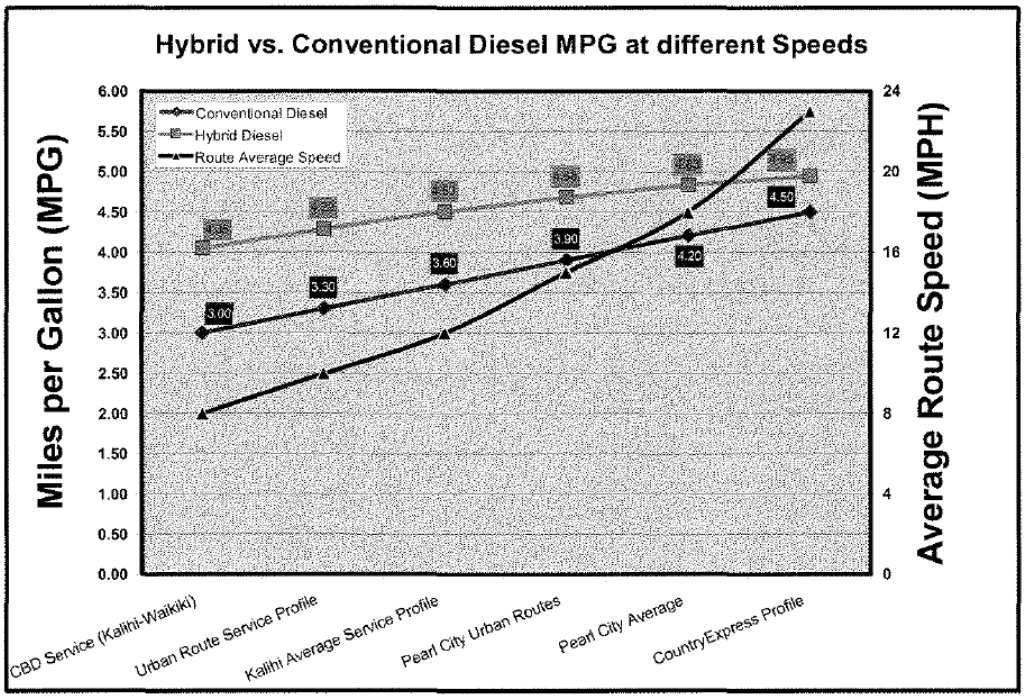
Pros: Ethanol emits fewer GHGs than diesel, is a renewable resource that can be produced in Hawai'i, and has lower capital costs than some other alternative fuel options.
Cons: E85 fuel is typically much more expensive than diesel (and even biodiesel - B100), its supply is limited (there are currently no E85 supply stations in Hawai'i, and ethanol is not yet being produced in Hawai'i), and it consists of 85% petroleum-based gasoline.
Bottom Line: Because ethanol is not yet made locally in Hawai'i (and its future production is questionable), it has high fuel costs, a poor track record when tested by previous transit agencies, and the fact that it still requires substantial amounts of imported fossil fuels, E85 is not a viable fuel alternative for The Kaua'i Bus.

Hybrid Electric

Description: Hybrid electric buses typically use diesel or gasoline to power the engine to generate electricity to drive the wheels. This electricity is stored in a battery, and regenerative braking captures kinetic energy.
National Examples: Diesel hybrids have become increasingly common among transit agencies nationwide, and make up a significant portion of some agencies' bus fleets.
Use in Hawai'i: The O'ahu Bus has expanded its fleet of hybrid-electric buses to 70 out of a total of 530. Their goal is to eventually convert half their fleet to hybrids.[29] However, O'ahu's experience with hybrids has not been entirely positive. Hybrid buses cost nearly twice as much as conventional buses and a recent report conducted by O'ahu Bus found that they only provide a 20% fuel savings.[30] This report also found that hybrids only have a marginal fuel savings/emissions advantage over conventional buses on long haul routes. However, their advantage is greater in congested areas where average speeds are 8mph or less. The study also found that hybrids produce about 25% fewer pollutants than conventional diesel buses, but are only nominally better than clean diesel buses. O'ahu has found that because they cost more, purchasing hybrids may reduce the County's ability to adequately replace its aging bus fleet, further contributing to the number of inefficient and high pollutant buses in its fleet. The Kaua'i Bus currently has one hybrid bus in its fleet.
Pros: Hybrid buses are more fuel efficient (especially in congested areas), emit fewer GHGs and particulates, and can, at times, be quieter than conventional diesel buses.
Cons: Hybrid buses are nearly twice as expensive as diesel buses, and their fuel savings over conventional diesel buses is marginal on long haul routes. A 2007 report found that, while the O&M costs of hybrids are roughly the same as clean diesels (lower fuel costs balanced by higher battery replacement costs), the life cycle costs over 12 years (assuming an average speed of 12mph) are about 35% higher for hybrids than clean diesels primarily due to increased capital costs.[31] Additionally, while hybrid buses are more fuel efficient they still require diesel.
Bottom Line: Hybrids could have advantages over standard diesel buses on some of the shorter shuttle routes operated by The Kaua'i Bus. Further research is needed to determine if average speeds on some of the shuttle routes are low enough to warrant hybrids. In general, because their purchasing costs are so much higher, it is unlikely hybrids would save The Kaua'i Bus any money, and may even increase costs. The 2009 report by O'ahu Bus found that the only scenario under which hybrids would be more cost effective than standard diesels are if diesel prices increase to nearly $30 a gallon, which is nearly

[29] Hao, Sean. "Honolulu's switch to hybrid buses stalled by realities of cost." *Honolulu Advertiser*. May 10, 2009. Available at: http://the.honoluluadvertiser.com/article/2009/May/10/ln/hawaii905100367.html
[30] Report by *Oahu Transit Services, Inc.* "Rehab Transit Buses as an Alternative to Purchasing New Diesel Hybrid or Clean-Diesel Buses," April, 2009. Available at: http://the.honoluluadvertiser.com/dailypix/2009/May/10/bus_study09.pdf
[31] FTA Report. "Transit Bus Life Cycle Cost and Year 2007 Emissions Estimations." July, 2007. Available at: www.proterra.com/images/WVU_FinalReport.pdf

double the high projection by EIA for 2035. Unless congestion rapidly increases in Kaua'i or hybrids become substantially less expensive, the fuel saving advantages of hybrids are not going to be worth their costs in Kaua'i where the majority of the buses operate long haul routes.



Hybrids have little fuel economy advantage over conventional diesel buses when average speeds are higher (20+ mph). Source: O'ahu Transit Services, Inc., 2009.

Battery Electric

Description: Battery electric buses run entirely on stored electricity and must be charged regularly.
National Examples: Five U.S. cities currently operate battery electric buses, typically on short-haul/shuttle type routes. Santa Barbara operates the largest fleet of battery electric powered buses (20).
Use in Hawai'i: Battery-electric buses are not currently used in Hawai'i. However, as of December, 2011 there were 577 plug-in electric vehicles owned by individuals in Hawai'i, including 19 in Kaua'i.[32] The *Kaua'i Energy Sustainability Plan* found that there is a potential for electric vehicle use to become more widespread in Kaua'i. The plan also points out that electric vehicles in Kaua'i could be charged using excess grid electricity.[33]
Pros: Because most of Kaua'i's electricity is petroleum based, there is very little excess grid electricity. If, however, wind and solar generated electricity became more widespread, buses could be charged during times of the day when excess electricity was available (at night or on weekends), which means buses could potentially be powered by electricity that is already being produced. Additionally, if the grid was powered by these technologies, The Kaua'i Bus would also be powered using locally produced renewable energy. Electric buses themselves produce no emissions, although power plants that generate the electricity they use may produce emissions. Battery electric buses can also capture 30% of their energy from regenerative braking. Finally, because power can be produced at power plants more

[32] Hawaii Department of Business, Economic Development and Tourism (DBEDT). Monthly Energy Trends. Dec., 2011. Available at: http://hawaii.gov/dbedt/info/economic/data_reports/energy-trends
[33] Sentech Hawaii, LLC. *Kauai Energy Sustainability Plan*. "Section 4: Recommendations for the Ground Transportation Sector." April, 2010. Available at: www.kauainetwork.org/energy-sustainability/

efficiently than by individual vehicles, electric vehicles can go three times farther on one dollar of electricity than one dollar of gas.[34]

Cons: The biggest drawback to using electric buses is that current buses can only operate up to around 50 miles before needing to be recharged. This would not work well for the majority of buses in Kaua'i that travel 200-300 miles per day to cover their routes. Charging itself, also takes approximately 30 minutes.[35] Additionally, because of the limited power storage, only 22-foot battery electric buses are currently available for purchase. There would also be costs involved in overhauling maintenance facilities and training mechanics to maintain and operate battery powered electric buses.

Bottom Line: Due to the limited range of battery electric buses between charges, this technology is currently not a viable option for the majority of The Kaua'i Bus routes that often operate 200-300 miles per day. However, The Kaua'i Bus may be able to use battery electric buses on some of their shorter shuttle routes. Additionally, given that this is a developing technology, it's possible that the range of electric buses could increase and/or charge times could decrease in the future, which would make battery electric buses a more viable alternative for more of The Kaua'i Bus's routes.

Hydrogen Fuel Cells

Description: An emerging technology, fuel cells are powered by hydrogen and have the potential to replace the internal combustion engine.

National Examples: Several transit agencies around the country have experimented by operating hydrogen fuel cell buses in regular service. As of 2009, there were 10 hydrogen fuel cell buses in service and 11 more planned.[36]

Use in Hawai'i: Hickam Air Force Base (AFB) in Honolulu has operated two hydrogen powered fuel cell buses since 2004. Hydrogen is produced at a hydrogen fueling station on site and is powered by solar panels. Hawai'i is also at the forefront of two major initiatives involving hydrogen powered vehicles. First, The Gas Company (TGC), based in O'ahu already produces enough hydrogen to power up to 10,000 fuel cell vehicles. They are planning to add 20-25 hydrogen fueling stations in Hawai'i by 2015 using an existing 1,000 mile utility pipeline between islands. As part of the initiative, General Motors will produce hydrogen fuel cell vehicles for use in Hawai'i. Secondly, Hawai'i Volcanoes National Park (HVNP) plans to put two hydrogen fuel cell buses in operation in 2012. Through a $2 million grant from DOE, Hawai'i Natural Energy Institute (HNEI), is leading an initiative to produce hydrogen on the big island using power from the island's geothermal plant, which will supply HVNP's two fuel cell buses.[37]

Pros: Hydrogen fuel cells are cleaner, quieter and more efficient than diesel engines. They are considered a zero emission vehicles because their only emissions are water vapor. However, emissions can be produced during the production of electricity which is needed to manufacture hydrogen. Using electrolysis, hydrogen can be produced by extraction from water, making hydrogen production possible in Kaua'i.[38] Additionally, hydrogen is already being produced in Hawai'i.

Cons: There are a number of significant barriers to making this technology more widespread. Vehicles typically cost 2-3 times that of diesel buses (or more), hydrogen itself is expensive to produce, and storage space required for hydrogen currently limits the range of buses to 150-200 miles.[39] Hydrogen is

[34] Hawaii's Energy Future Website. Available at: www.hawaiisenergyfuture.com/articles/ElectricVehicle.html
[35] EBus website. Available at: www.ebus.com
[36] NREL Technical Report. "Fuel Cell Buses in U.S. Transit Fleets: Current Status 2009." October, 2009. Available at: www.nrel.gov/hydrogen/pdfs/46490.pdf
[37] Fuel Cells 2000, June 2011. Available at: http://www.fuelcells.org/info/StateoftheStates2011.pdf
[38] U.S. DOE. See Quick Links at: www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/ca_transit_agencies.html
[39] U.S. DOE Report. "Fuel Cell Transit Buses. ThunderPower Bus Evaluation at SunLine Transit Agency." 2003. Available at: www.nrel.gov/docs/fy04osti/34379.pdf

also currently not available in Kaua'i, although this could change in the near future as TGC plans to add fueling stations and could pipe hydrogen from their plant in O'ahu.

Bottom Line: Due to the high cost of hydrogen fuel cell buses, the cost of producing hydrogen, the lack of hydrogen currently available in Kaua'i, and the unknowns involved in this emerging technology, this is not a viable short term option for The Kaua'i Bus. However, significant research is being invested into this technology and given the high payoffs (zero vehicle emissions, and the fact that hydrogen is produced in Hawai'i and could be in Kaua'i), there is potential for this to be a long term option for The Kaua'i Bus.

Summary of Analysis

Table 1 summarizes the results of this analysis. The table includes nine different alternative fuel types evaluated for use by The Kaua'i Bus, the primary criteria used for evaluation, and the short and long term recommendations. The primary criteria used to evaluate alternative fuel types were cost, sustainability (availability of a long term supply and whether the fuel can be locally produced), environmental impacts, and feasibility given Kaua'i's remote location and available resources.

	Costs		Sustainability	Env. Impacts		Feasibility		Recommendations	
Fuel Type	**Vehicle Costs**	**Fuel Costs**	**Fuel Locally Produced**	**GHG Vehicle Emissions**	**Other Vehicle Emissions**	**Currently Feasible in Kaua'i?**	**Long Term Feasibility in Kaua'i?**	**Short Term Solution**	**Long Term Solution**
Petroleum Diesel	Low	Med.	No	High	High	Yes	Questionable		
Clean Diesel	Low	Med.	No	High	Moderate	Yes	Questionable		
Biodiesel Blend (B20)	Low	Med.	Partially	Moderate	Moderate	Maybe	Questionable	✓	
Straight Biodiesel (B100)	Med. to Low	Med/ High	Yes	Low	Mixed	Maybe	Likely		✓
Natural Gas (LNG)	Low	Low	No	Moderate	Moderate	No	Unlikely		
Propane (LPG)	Low	High	No	Moderate	Moderate	Yes	Questionable		
Methanol/ Ethanol Blend	Low	High	No, but could be	Moderate	Moderate	Maybe	Questionable		
Hybrid Electric	High	Med.	No	Moderate	Moderate	Yes	Questionable		
Battery Electric	Med.	Low	Partially	Low	Low	Maybe	Questionable		✓
Hydrogen Fuel Cells	High	High	Yes	Low	Low	No	Questionable		✓

Table 1. This table illustrates the strengths and weaknesses of various fuel alternatives for The Kaua'i Bus organized by evaluation criteria. Source: Varies (see written section of each fuel type above), current fuel prices from U.S. DOE. "Clean Cities Alternative Fuel Price Report." October, 2011. Available at: www.afdc.energy.gov/afdc/price_report.html

Conclusion

While CNG and hybrid-electric buses are the most widely used alternative fuels by transit agencies in the U.S, neither would work very well in Kaua'i. CNG is not available in Hawai'i, and the rural nature of the island negates the fuel efficiency advantage hybrids have over diesel buses. Based on the criteria used, a biodiesel blend (B20) is the most viable short alternative fuel option for The Kaua'i Bus. B20 is locally

produced in Hawai‘i, including by a small operation in Kaua‘i. The advantages of using B20 instead of petroleum diesel are that it would reduce reliance on foreign imports, contribute to the local economy, and cut emissions. In addition, using B20 would not require any modifications of the existing bus fleet. The main hurdle involved in transitioning to B20 would be securing a reliable local supply that is cost effective.

This study produced three primary long term alternative fuel recommendations for The Kaua‘i Bus. These options include straight biodiesel (B100), battery electric vehicles, or hydrogen fuel cell vehicles. These alternatives were chosen primarily because all these fuel types have the potential to be produced in Hawai‘i and the vehicles themselves produce very low (or no) emissions. However, none of these alternatives are currently viable for The Kaua‘i Bus, and certain things would need to happen over the next several years to make them more viable alternatives.

To use straight biodiesel, The Kaua‘i Bus would need to establish a price competitive, reliable local supply. A pilot program, using a few converted buses would be a great starting point. Battery-electric vehicles could potentially work on shuttle bus routes operated by The Kaua‘i Bus, but there would need to be advances in technology that expand the range of vehicles and/or reduce the charging time before this could be a viable alternative on longer routes. It would also be desirable for a higher percentage of Kaua‘i’s grid to be produced from renewable resources, although even if this did not happen, battery electric vehicles would still have substantial advantages over diesel vehicles on shorter routes. Finally, before investing in hydrogen fuel cell vehicles, The Kaua‘i Bus would need to establish a cost-effective source of hydrogen in Kaua‘i. At present times, hydrogen production techniques can be prohibitively expensive. Additionally, because there are no hydrogen fuel cell vehicle fleets in operation as large as The Kaua‘i Bus’s fleet, The Kaua‘i Bus would be taking a big risk by investing in hydrogen before the technology has been adequately tested. A more viable option (if hydrogen fuel were to become available in Kaua‘i) would be to use a federal grant to start a pilot program with one or two buses. Some smaller challenges, as outlined in this paper, would also exist if The Kaua‘i Bus chose to convert their fleet to these alternative fuels.

Because most alternative fuels are still evolving technologies and are not widely used, the cost of implementation can be high. However, as these technologies become more widely used, and as diesel fuel becomes scarcer, the economics are likely to better favor alternative fuels. This will probably happen even sooner in Hawai‘i given that diesel prices tend to be 20% higher than in the mainland U.S. Additionally, there are a number of grants or funding options that could make purchasing alternative powered vehicles more affordable. Sources for these include the DOE, and the FTA’s Clean Fuels and TIGGER programs mentioned earlier, each of whom have incentive programs to increase the use of alternative fuel.

Despite the hurdles, many transit agencies have begun pursuing alternative fuels, not only because of the environmental benefits and cost savings, but because of the positive community perception that can come out of these conversions. Santa Barbara began converting part of their transit fleet to battery-electric buses to attract more riders and as a result they have seen tremendous support from the community.[40] There is potential for The Kaua‘i Bus to not only reduce its dependence on expensive

[40]NREL. “Challenges and Experiences with Electric Propulsion Transit Buses in the U.S.” U.S. DOE Technical Report, November, 2003. Available at: www.afdc.energy.gov/afdc/pdfs/34323.pdf

imported fuel, but to reduce its environmental impacts and gain ridership and further support from the community as an added benefit of converting its bus fleet to alternative fuels.

Appendix Tables

Fuel	PM (g/bhp-hr)	NO_X (g/bhp-hr)	NMHC (g/bhp-hr)
2007-2010 EPA Standards	*0.01*	*0.2*	*0.14*
Current diesel (baseline)	0.026	2.36	*0.11*
O_2Diesel™	0.021	2.32	*0.083*
B20	0.023	2.41	*0.087*
B100	0.014	2.60	*0.036*
Fischer-Tropsch	0.023	2.15	*0.086*
Ethanol	0.026	1.77	0.45
Methanol	0.026	1.18	*0.11*
Propane	*0.01*	1.18	0.5
CNG	*0.006*	1.24	*0.13*
LNG	*0.006*	1.24	*0.13*
Hydrogen ICE	*Trace*	*Low*	*Trace*
Hydrogen Fuel Cell	*0*	*0*	*0*
Electricity	*0*	*0*	*0*

Emissions levels of various bus engines in 2006 as compared to EPA standards (does not included GHG's). Source: Alternative Fuels Study: A Report to Congress on Policy Options for Increasing the Use of Alternative Fuels in Transit Vehicles, available here: www.fta.dot.gov/12907_9187.html

	Nationwide Average Price in Gasoline Gallon Equivalents	*Nationwide Average Price in Diesel Gallon Equivalents*	*Nationwide Average Price in Dollars per Million Btu*
Gasoline	$3.46	$3.85	$29.94
Diesel	$3.42	$3.81	$29.62
CNG	$2.09	$2.33	$18.08
Ethanol (E85)	$4.51	$5.02	$39.04
Propane	$4.23	$4.71	$36.62
Biodiesel (B20)	$3.57	$3.98	$30.96
Biodiesel (B99-B100)	$4.12	$4.59	$35.68

October, 2011 Nationwide Average Fuel Prices on Energy-Equivalent Basis. Source: U.S. DOE. "Clean Cities Alternative Fuel Price Report." October, 2011. Available at: www.afdc.energy.gov/afdc/price_report.html