Hawaii Renewable Hydrogen Program Plan 2010–2020

Prepared for:
State of Hawaii
Department of Business, Economic Development, and Tourism

Prepared by:

Kolohala Holdings, LLP and Hawaii Natural Energy Institute
University of Hawaii-Manoa

Contract # 57598

August 2011

Project Title: Hawaii Renewable Hydrogen Program: 2010-2020 – Final Report

Recipient: University at Manoa - School of Ocean and Earth Science and Technology – Hawaii Natural Energy Institute

Award Number: Contract No. 57598

Working Partner:
Author: Mr. James M. Ewan – University at Manoa - School of Ocean and Earth Science and Technology – Hawaii Natural Energy Institute – Hydrogen Systems Program Manager

Acknowledgments:
The Hawaii Natural Energy Institute's contributions to this report were funded by the Hawaii Renewable Hydrogen Program Contract No. 57598. The author is solely responsible for any omissions or errors contained herein.

Executive Summary

HCEI and the Renewable Hydrogen Program

The Hawaii Clean Energy Initiative (HCEI) is a partnership between the state of Hawaii and the US DOE launched in 2008. HCEI is the top-level program initiated by the State to transform Hawaii's energy economy from fossil fuels to indigenous renewable energy. The goal of the HCEI is to meet 70% of Hawaii's energy needs by 2030 through energy efficiency (30%) and renewable energy (40%). The Hawaii Renewable Hydrogen Program supports attainment of the HCEI goals in three of four major HCEI energy sector areas: 1) electricity generation and delivery, 2) transportation, and 3) fuels.

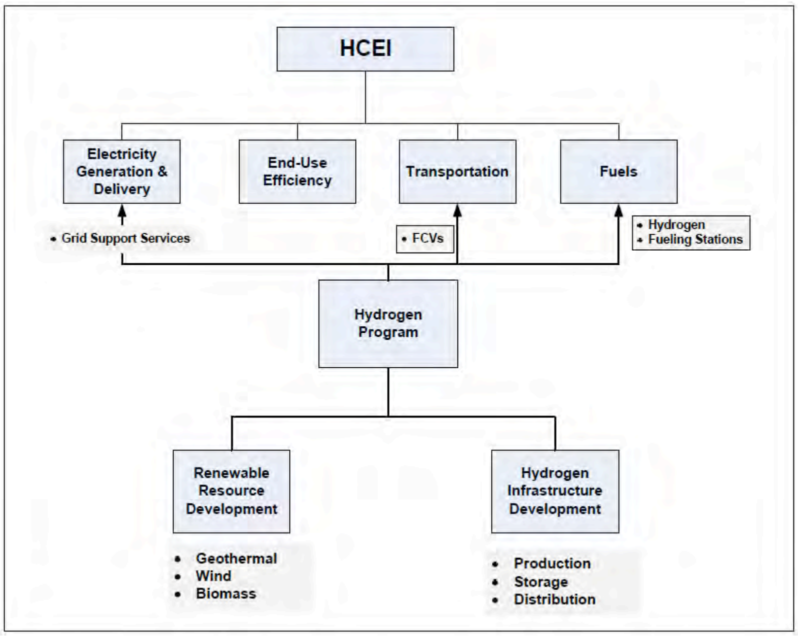


Figure E1: HCEI / H2 Plan Interface

✓ *Electricity Generation and Delivery*

HCEI calls for deploying renewable generation and grid infrastructure to meet a Renewable Portfolio Standard of 40% of delivered MWh renewable energy. Hydrogen supports meeting this objective. Hydrogen production and storage systems can be used to mitigate the impacts of a high penetration of intermittent renewable energy generation on an electrical grid. Analysis has shown these systems to be cost competitive (NREL), and pilot projects have been built and begun operation (Enertrag in Germany). Electrolyzers are used as variable load devices that can increase or decrease load as required to mitigate power surges while producing hydrogen. In addition to supporting the introduction of more renewable electricity on the grid, hydrogen produced by the system can be used for a variety of value-added products including transportation fuel, or feedstock for the production of ammonia fertilizer to support Hawaii agriculture.

✓ *Transportation*

HCEI calls for the introduction of electric vehicles (EVs) to displace fossil fuels utilizing renewable electricity to recharge their batteries. Plug-in Electric Vehicles (PEVs) are EVs using electric energy (grid and/or renewable) to charge onboard batteries. Fuel Cell

Electric Vehicles (FCEVs) are another class of EV that use hydrogen to produce electricity onboard the vehicle to power the electric drive train. FCVs do not require recharging from the grid – rather they are fueled in a manner almost identical to what consumers are familiar with today – at a "gas" station from a fueling dispenser that operates in a similar way to a gasoline pump. The fueling operation can be completed in 5 minutes rather than several hours of battery charging and is available to all consumers. Overall system efficiencies are similar to those of the electrical grid system and there may be potential capital savings in terms of electrical infrastructure and Green House Gas generation. General Motors has launched a major FCV demonstration on Oahu and there are plans to install up to 25 hydrogen fueling stations by 2015.

- ✓ *Fuels*

  HCEI calls for meeting as much of in-State demand for fuels as is feasible utilizing indigenous fuel sources. Hydrogen supports this objective in that it can be produced from all Hawaii's renewable energy sources including biomass, wind, solar, and geothermal using a variety of conversion technologies.

The Hawaii Renewable Hydrogen Program

The Hawaii Renewable Hydrogen Program was initiated in 2006, 2 years before HCEI. Hawaii's Hydrogen Investment Capital Special Fund ("Fund"), created by Act 240, Session Laws of Hawaii 2006, was established to provide seed and venture capital investments in hydrogen initiatives as well as cost-share grant opportunities. The equity and cost-share investments are intended to develop partnerships with the private sector and in federal projects for research, development, testing, and implementation of strategic renewable hydrogen technology ventures. The fund was appropriated $10 million by the State for this purpose. Of that amount, a contract for the Hydrogen Investment Capital Special Fund was awarded to Kolohala Holdings LLP ("Kolohala") effective November 18th, 2008 in the amount of $8.7 million.

The Hydrogen Program ("Program") has been developed to focus on one over-riding objective - reducing Hawaii's dependence on imported fossil fuels by using hydrogen to increase the utilization of Hawaii's renewable energy sources. The 2010-2020 Program plan defines the development and implementation of a strategy that will make use of indigenous renewable energy resources that can serve as feedstocks for hydrogen technology development, demonstration, and deployment.

The two classes of renewable resources that can be utilized in the 2010-2020 time period for meeting this objective are identified in this plan – hydrogen produced from renewable electricity generated from geothermal and wind resources, and hydrogen produced from biomass resources.

Strategies

Staying the Course. Transitioning Hawaii from a fossil based economy to energy self-sufficiency will be a challenge that will require a sustained effort from all stakeholders and sustained public financial support. The fossil fuel system took 100 years to develop. Hawaii has only 20 years to meet the HCEI 2030 objectives. Staying the course requires considerable political will and vision.

Innovative Technical and Financial Solutions. Hawaii is a small state in terms of geography and population. While a smaller geographical area is good in that it limits the overall size of the energy system, the related small population and tax base makes paying for the transition a challenge. Therefore, Hawaii must be innovative in both technology solutions and financing.

Leverage is a Key Strategy – investing Hawaii's limited financial resources to generate large returns. On the financial side it means attracting federal and private financing. The Program is a good first step in providing the required technical and financial leverage. It is unique, innovative, and is working. On the cost share side, an initial $2 million investment by the Fund has generated over $10 million of Federally supported hydrogen project activities in 2010 and laid the groundwork for attracting more.

The Program Plan

The Program described in this document provides the strategy, objectives, and actions required for its implementation over ten years from 2010 to 2020. The investment component provides equity investments in companies at both the "seed" and "venture" levels. They will be structured to provide the State equity ownership in private companies and the potential of a return on that investment. The overall objective is that over time the Program becomes self-sustaining or "evergreen". The second component - cost share - allows Hawaii to attract US DOE and Office of Naval Research program funding that builds infrastructure and capacity such as the Hawaii Hydrogen Power Park projects, and the hydrogen grid energy storage project at the Puna Geothermal Venture plant. The results of the first two years of the Program, 2009-2010, have shown the State is on the right track with equity and cost share investments making a positive impact on achieving the State's objectives.

2020 Objectives

The Plan identifies the following 2020 Program objectives:

- A fleet of 5,000 hydrogen-fueled vehicles.
  - *Supports HCEI transportation and infrastructure objectives.*
- Significant hydrogen infrastructure on Hawaii & Oahu. New infrastructure projects on Kauai and Maui.
  - *Supports HCEI electricity, transportation and fuel objectives.*
- GM + 2 additional major car company rollout FCV fleets.
  - *Supports HCEI fuel and transportation objectives.*
- 20 Oahu + 10 Hawaii hydrogen fueling stations accessible to the general public.
  - *Supports HCEI transportation and fuel objectives.*
- 1 Geothermal hydrogen production plant.
  - *Supports HCEI transportation and fuel objectives.*
- 2 Big Wind hydrogen production plants.
  - *Supports HCEI electricity, transportation and fuel objectives.*
- 1 Ammonia plant utilizing geothermal power.
  - *Supports HCEI electricity, transportation and fuel objectives.*
- 1 Rental car company renting FCVs.
  - *Supports HCEI, transportation and fuel objectives.*
- 50 Hydrogen buses on Hawaii and Oahu.
  - *Supports HCEI transportation and fuel objectives.*

Implementation Tasks

As illustrated in Figure E2, six major tasks have been identified to achieve the Plan's 2020 objectives.

Task #1: Develop Large-Scale Renewable Energy Sources – geothermal, wind, and biomass. Large geothermal resources are available now (2010), large wind may become available in 2013, and biomass resources may become available in 2014. Supports HCEI electricity, transportation and fuel objectives.

Task #2: Develop Hydrogen Infrastructure. Hydrogen infrastructure is essential to support a hydrogen industry in Hawaii. While private industry can take care of "the last mile" and end-use applications, the public sector needs to support the common infrastructure required to produce, store, and distribute hydrogen in the formative stages of industry development. Supports HCEI electricity, transportation and fuel objectives.

- ✓ *Hydrogen Production:*
  - Geothermal Hydrogen Production: A hydrogen production from geothermal resources initiative started in 2010 with an initial plant scheduled to come on line in mid 2011. The hydrogen will be used to fuel shuttle buses operated by the County of Hawaii Mass Transportation Authority (MTA) providing a Puna District feeder service to the main Hele-on bus line.
  - Wind Hydrogen Production: Use curtailed wind that would otherwise be wasted, to produce hydrogen.
  - Biomass Hydrogen Production: Municipal Solid Waste (MSW), energy crops, and crop residue converted to hydrogen by gasification, offers the nearest-term opportunity to produce low cost hydrogen in Hawaii.
- ✓ *Hydrogen Dispensing Stations*. Due to Hawaii's geographic constraints, a relative modest number of hydrogen stations on each island can meet the basic fueling requirements for hydrogen vehicles.
- ✓ *Hydrogen Delivery Infrastructure*: As demand for hydrogen increases there will be a requirement to introduce large tube trailers that can transport up to 400 kgs of hydrogen – enough for 100 fills. The Gas Company is currently investigating the viability of delivering hydrogen to dispensing station through its existing syngas pipeline on Oahu.
- ✓ *Hydrogen Storage Infrastructure:* Hydrogen bulk storage presents an expensive challenge. Current methodology utilizes high-pressure compressed gas cylinders – either steel or composites – at pressures up to 1050 bar. Other technologies such as the plastic pipe technology offer considerable promise for hydrogen bulk storage.
- ✓ *Ammonia Production:* All fertilizer is imported to Hawaii and is critical for Hawaii's food security. Liquid ammonia is used for fertilizer and could be manufactured in Hawaii utilizing geothermal power.

Task #3: Support Application and demonstration Projects. In 2010, the majority of the funding used to develop hydrogen infrastructure is being provided through federal research and demonstration projects leveraged by State funding. The State should continue to leverage federal dollars in support of the Program by providing cost share to secure the projects. These projects result in infrastructure that stays in the state after the project completes and can be used to support the Plan and leverage new projects. Supports HCEI electricity, transportation and fuel objectives.

Task #4: Policy Development: This task involves the ongoing development of legislative policies to support the introduction of hydrogen in Hawaii by removing barriers, providing incentives, and funding. Supports HCEI electricity, transportation and fuel objectives.

Task #5: Funding: This task involves providing ongoing State funding for the Hawaii Renewable Hydrogen Program. Supports HCEI electricity, transportation and fuel objectives.

Task #6: Commercialization by Private Business: We will know we have made progress when the private sector steps up to develop hydrogen projects. It is difficult to project how this will develop over the next 10 years, however there are at least 3 businesses that are prepared to start and one potential company standing in the wings. Supports HCEI electricity, transportation and fuel objectives.

- *The Gas Company:* Developing a hydrogen production and distribution business on Oahu to support the GM project and others as they come along.
- *General Motors:* GM has planned a rollout of its fuel cell vehicle program in Hawaii starting on the island of Oahu.
- *Bus Companies:* The Big Island MTA will be the first bus company operator of a hydrogen bus in Hawaii and there have been strong indications there is interest in converting over the whole Hele-On fleet to hydrogen fuel.
- *Rental Cars:* Rental car companies may consider having FCVs become a part of their fleet as a novelty item for tourists who would like to try a hydrogen FCV. This would depend on the infrastructure being in place.

This document has the following structure:

- ✓ The *Hawaii Renewable Hydrogen Program Plan 2010 - 2020* – defines the strategy and guidance for the types of projects that will be invested in the Program.
- ✓ Appendix A – *Strategic Partnerships Plan* provides a strategy and actions to attract investment and project partners to Hawaii.
- ✓ Appendix B – *Engineering & Economic Evaluation Plan* provides a strategy and actions necessary to continuously evaluate technology and related economic feasibility.
- ✓ Appendix C – *Action Plan for Grid Reliability Projects* – provides a plan for the ongoing development of the electrical grid to deliver renewable energy services to Hawaii.
- ✓ Appendix D – *Hydrogen Demonstration Projects Plan* – describes existing hydrogen demonstration projects and a plan on how they can be leveraged to meet the objectives of the Program.
- ✓ Appendix E – *Public Education Plan* – In order to obtain community acceptance and support of a hydrogen economy, we need to be able to reach stakeholders, decision-makers, and the general public with information that increases their knowledge of and comfort with hydrogen. This plan provides a strategy and actions necessary to provide information on the program to the public.

- ✓ Appendix F – *Hawaii's Renewables-to-Hydrogen Promotion Plan* – provides a plan and tasks necessary to provide information to potential investors on Hawaii's renewable resources and the programs to utilize them.
- ✓ Appendix G – *Hydrogen Systems Technologies – Characteristics, Challenges, and Opportunities* provides an overview on the development status of hydrogen technologies that are required for the implementation of the Program.
- ✓ Appendix H – *Investment Summary* provides an overview of Program investments as of January 2011.

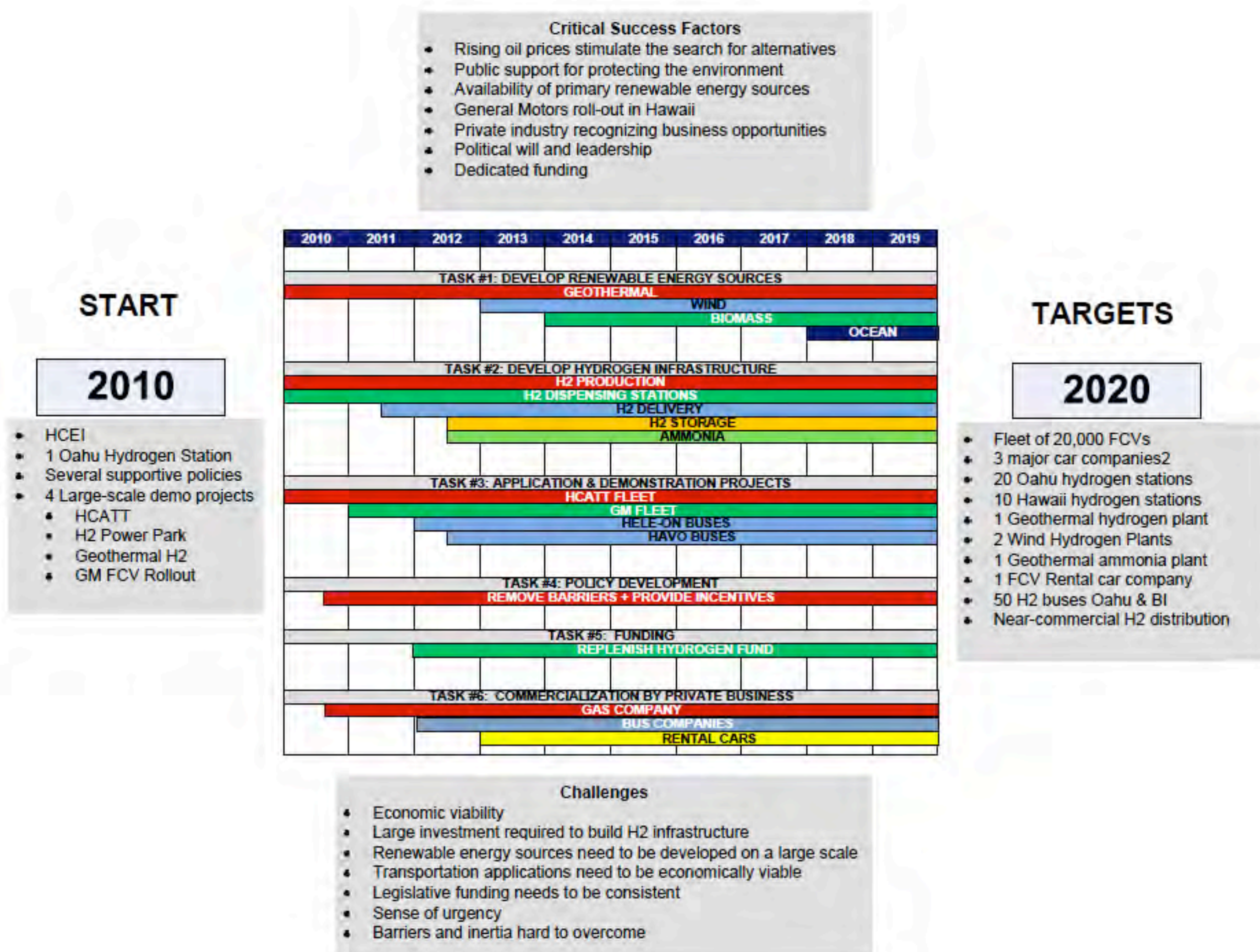


Figure E2: Hydrogen Roadmap Implementation Tasks

Table of Contents

Introduction

Hawaii: Energy & Hydrogen

For decades the Hawaii Legislature has actively promoted the utilization of the state's abundant renewable energy resources in harmony with the environment. During the oil crises of the 1970s, the threat to Hawaii's energy security and economy through the State's heavy reliance on fossil fuels was recognized and steps were taken to develop programs to replace imported fossil fuels with renewable energy. This included establishing the Hawaii Natural Energy Institute (HNEI) with the mandate of developing technologies to displace fossil fuels with Hawaii's indigenous renewable energy sources.

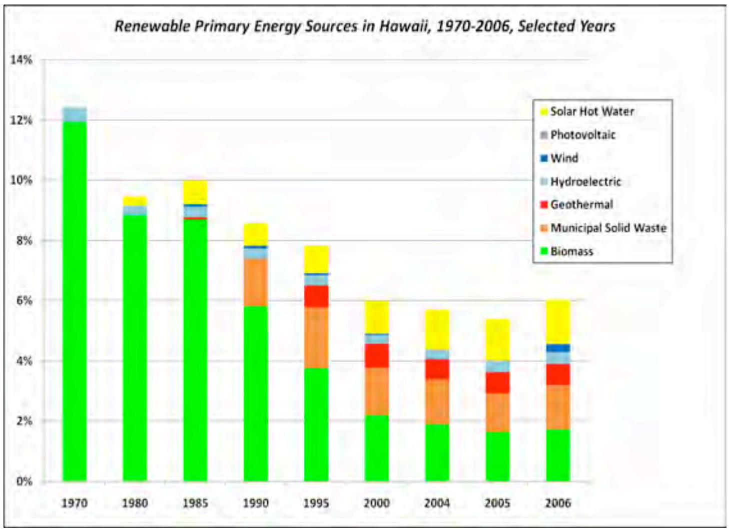


Figure 1: Negative Progress in Renewable Energy

However, converting the legislative policy into reality has proved to be difficult and as illustrated in Figure 1, circumstances such as the demise of the sugar industry, have actually caused the percentage of renewable energy utilization to regress. This negative trend appears to have bottomed out in the last four years and the trend is now moving in the right direction albeit slowly. Stimulated by the 2008 oil price shock when oil exceeded $140 per barrel, the legislature established the Hawaii Clean Energy Initiative (HCEI) to increase the percentage of renewable energy in the state to 40% by 2030 – a 30% increase. This has breathed new life into the effort to develop our indigenous resources.

The development of a robust hydrogen energy sector supports the HCEI objectives particularly in the transportation sector.

Hawaii's Renewable Energy Resources

To date Hawaii has harnessed only a small proportion - 10% - of its natural energy potential. As shown in Figure 2, Hawaii has more than enough renewable energy sources to meet all its energy requirements (150% of its energy requirements). If utilized to its full potential, these resources would be sufficient to serve the entire electricity and transportation needs of the State.

One of the first renewable energy resource development projects (a major success) was the development of the Island of Hawaii's geothermal resources and this resulted in the Puna district geothermal plant operated by Puna Geothermal Ventures (PGV). This plant provides significant electrical power to the Hawaii grid and represents up to 15% of the Big Island's electrical energy demonstrating the potential for large baseload. The geothermal plant could produce much more energy if fully exploited. It is currently permitted to produce a maximum of 60 Mega-Watts (MW) but the resource could produce over 500 MW. Recent geothermal prospecting has resulted in the discovery of significant new geothermal resources on the Kona side of Hawaii. The PGV geothermal resource is turned down at night due to a lack of demand resulting in over 100 MW-hours per day of power being available to make hydrogen.

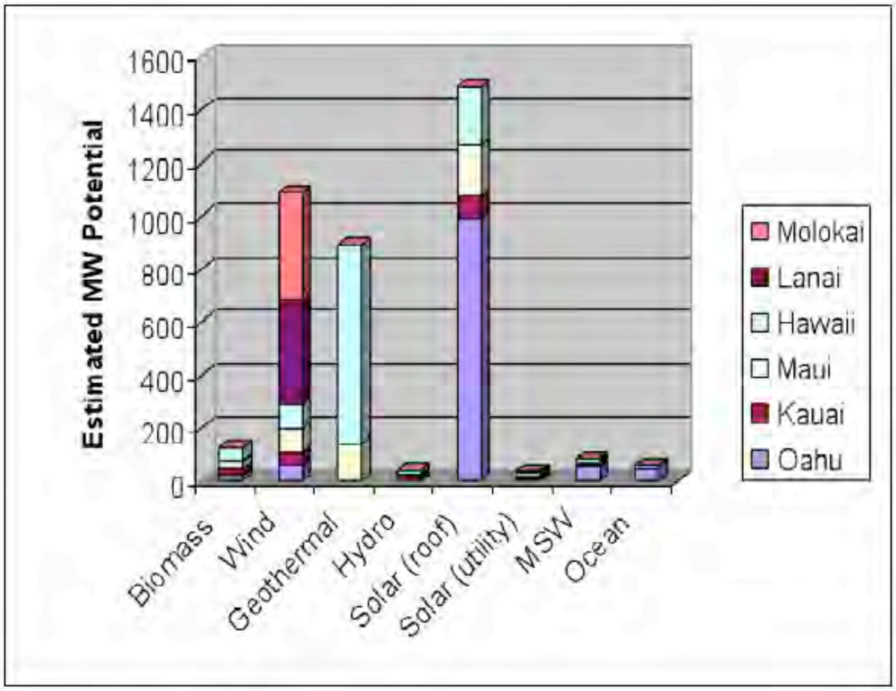


Figure 2: Hawaii renewables estimated at 150% of current installed capacity

Hawaii is currently undergoing the development of its wind resources with major wind farms on Hawaii, Maui, and most recently (2010) Oahu. There are also plans to develop the significant wind resources on Molokai and Lanai, and deliver electricity to the Oahu market by undersea cable. Unlike geothermal, wind is intermittent and this provides challenges to managing the electrical grid as the wind ramps up and down, sometimes quite quickly in gusty wind conditions. Also, the best wind tends to be at night and sometimes this is curtailed by the utility due to a lack of demand and grid management issues.

The curtailed wind and geothermal power are resources that could be used to make hydrogen that provides an energy storage capability for later use including delivering electricity back into the grid during the day, and also for transportation applications displacing fossil fuels.

The Hawaii Clean Energy Initiative

The Hawaii Clean Energy Initiative (HCEI) is a partnership between the state of Hawaii and the US DOE launched in 2008 and established in statute in 2010. The goal of the HCEI is to exceed 70% of Hawaii's energy needs by 2030 through energy efficiency and renewable energy. The hydrogen plan supports the latter goal through projects in the following areas:

- Harnessing energy from solar, wind, ocean, geothermal, and biomass resources. These renewable energy resources can be used to produce hydrogen. The hydrogen program supports the HCEI objective through the development of the renewable resources and the technologies necessary to convert them into hydrogen.

- Taking the first steps in establishing a sustainable alternative-fuel strategy. The hydrogen program supports this objective by installing hydrogen-fueling infrastructure on the Big Island and Oahu, and utilizing curtailed renewable resources to produce hydrogen.

- Embrace hybrid and electric vehicles. The hydrogen program supports this objective by supporting projects that include the deployment of plug-in hybrid electric vehicles comprised of shuttle buses at Hawaii Volcanoes National Park that utilize both batteries and hydrogen fuel cells for propulsion in a hybrid configuration.

Hydrogen Plan Strategy

The overall hydrogen plan strategy supports the HCEI and is comprised of two main components (Figure 3). The first strategy component is to focus investment on the development of Hawaii's renewable energy systems that have the potential to lead to hydrogen production. This approach's value is that the investment in developing the state's energy resources will progress Hawaii's overall goal of achieving clean energy independence, economic diversification, and workforce development even if specific hydrogen technologies are not developed as quickly as desired. The second major component is to develop hydrogen infrastructure comprised of hydrogen production, storage, and distribution systems. Infrastructure is a common requirement for all end-use applications and therefore supports public and private sector initiatives to introduce end-use hydrogen applications. For example developing hydrogen production infrastructure at the geothermal plant supports initially a Puna District bus service operated by the County of Hawaii Mass Transportation Agency and in the longer term this same infrastructure would support private bus companies.

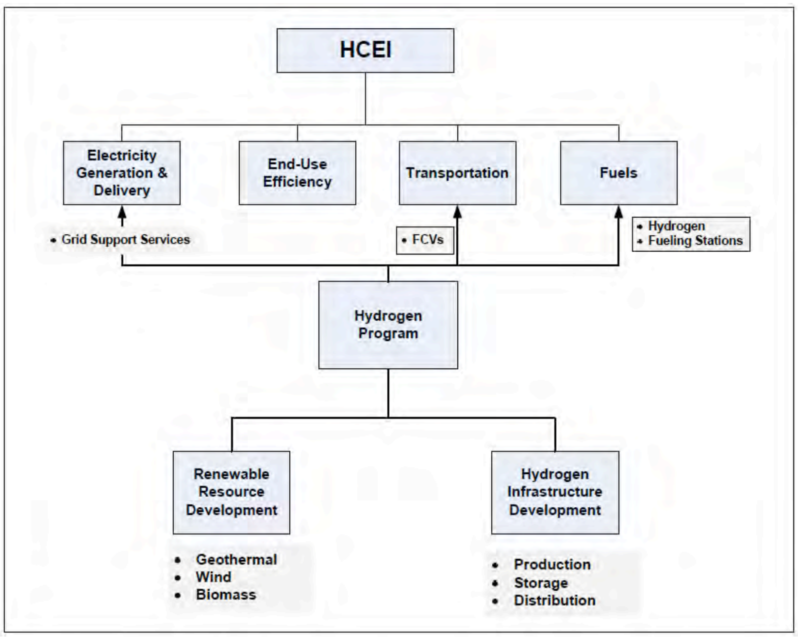


Figure 3: HCEI / H2 Plan Interface

Hydrogen in Support of HCEI Transportation and Fuels Objectives

Like the rest of the world, Hawaii uses fossil fuels to drive its motor vehicles, fuel aircraft, and operate its marine transportation fleets - all of which must be imported. Producing hydrogen using electrolyzers powered by local wind and geothermal energy, and the thermo-chemical conversion of biomass would provide Hawaii with its own source of domestically produced clean fuel, replacing a significant amount of fossil fuel imports. This would contribute to the HCEI transportation and fuels objectives.

Hawaii's tourist economy is heavily dependent on air travel and this component of the transportation sector has been generally considered to be beyond the ability of Hawaii to address and therefore has been ignored. However, stimulated by recent military requirements, there is considerable interest in producing bio-jet fuel from biomass resources using a variety of technologies such as the "made-in-Hawaii" ClearFuels gasification technology. The conversion of biomass to biojet also requires the use of hydrogen in the refining process thus presenting another pathway and incentives to developing hydrogen infrastructure.

The scale of the renewable energy resources required to displace a significant percentage of Hawaii energy requirements with hydrogen will present a significant challenge. The following estimates are based on meeting the ground transportation sector hydrogen requirements by substituting hydrogen for gasoline/diesel on a one kilogram of hydrogen to 2 gallons of diesel/gasoline basis. This conversion calculation allows for a doubling of fuel efficiency through the replacement of internal combustion engines (ICE) by more efficient fuel cell power systems that are twice the efficiency of an ICE.

To illustrate the scale of the effort required, the following figures show the amount of hydrogen and renewable energy resources required to produce the hydrogen needed to displace gasoline and diesel in the transportation sector based on the previous assumptions. For example, based on fuel consumption data from the 2008 State of Hawaii Data Book, it can be seen in Figure 4 that it would take approximately 195 million kilograms of hydrogen to meet Oahu's total annual ground transportation energy requirement of 2008.

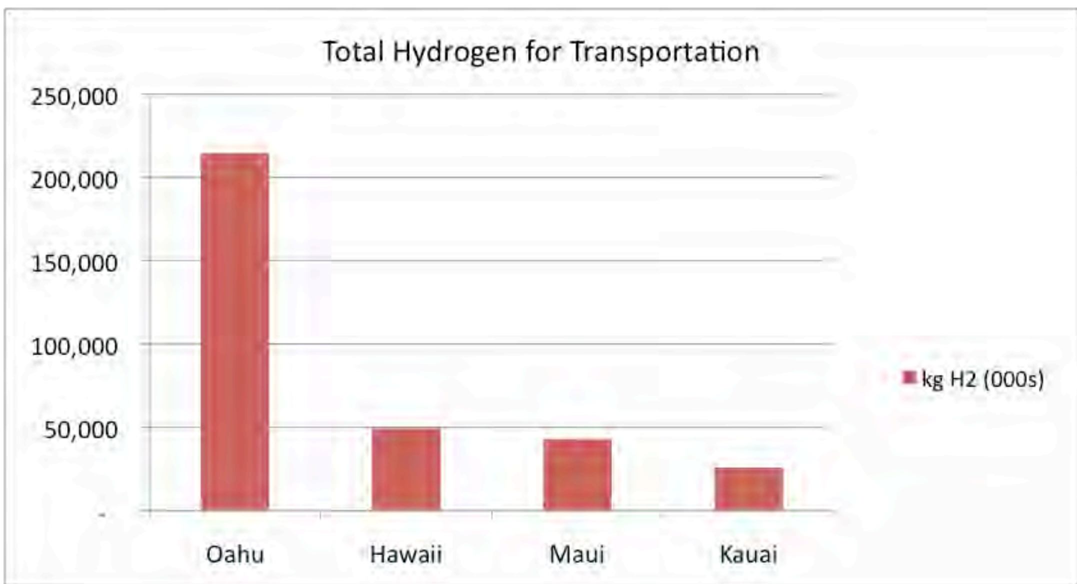


Figure 4: Total hydrogen for transportation requirement

Figures 4 & 5 provide a perspective on the magnitude of renewable energy resources required to produce this amount of hydrogen. If biomass is used, it must be grown and processed into hydrogen. For the purposes of this analysis, it was assumed that this would be accomplished by gasification. Sugar cane is assumed as the biomass feedstock. Other candidate feedstocks include banagrass and sweet sorghum, but these require further testing under Hawaii conditions. It is calculated that it would take approximately 77,000 acres of annual sugar cane production to produce the hydrogen necessary to fuel Oahu's vehicle fleet (Figure 5).

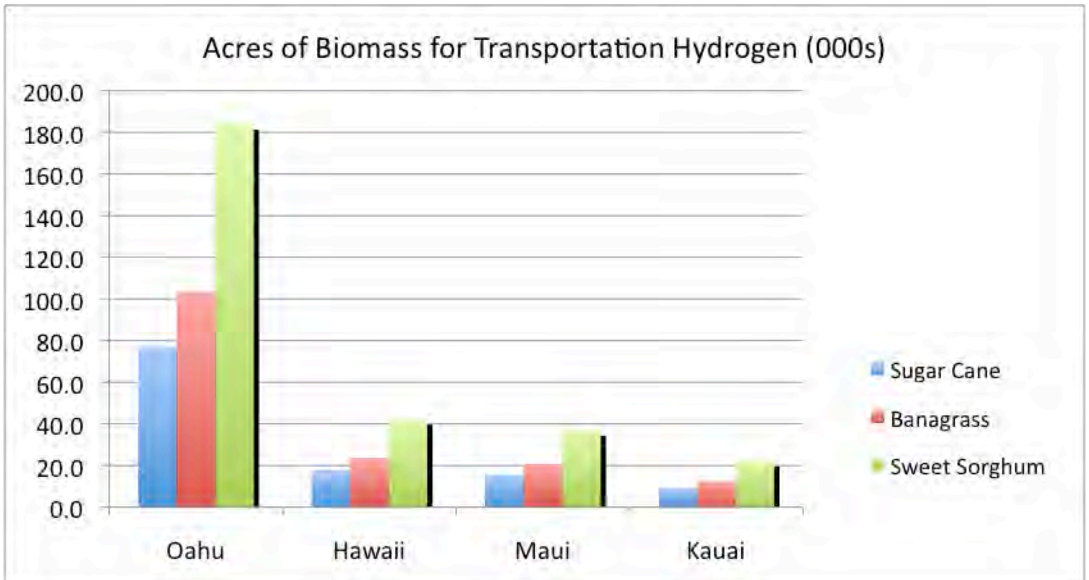


Figure 5: Land Area required to produce hydrogen for transportation

If renewable electricity were used to produce hydrogen, it would take more than 16 terawatt-hours (TWh) of electricity to produce the necessary hydrogen for the Oahu ground transportation sector. This value can be compared to total electricity currently being used on Oahu that is slightly more than 8 TWh (Figure 6).

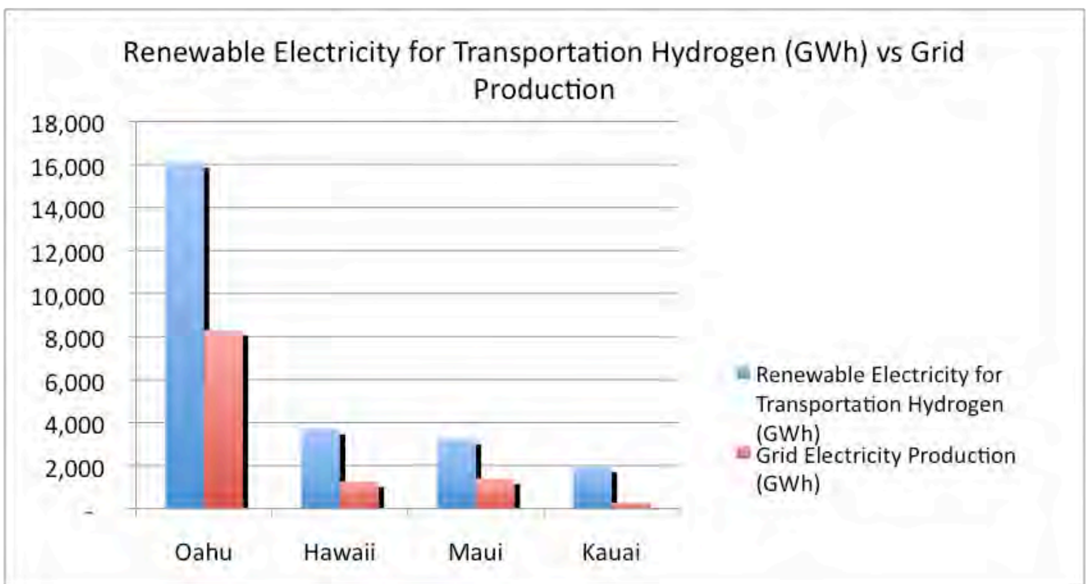


Figure 6: Renewable electricity required to produce hydrogen for transportation

As can be seen by these analyses, it will take large-scale infrastructure development to transition the ground transportation fleet to hydrogen fuel. Challenges that must be overcome include improving technological performance throughout the value chain, land-use, water availability and rights, policy and permitting support, and not the least, financing.

The Hawaii Bioenergy Master Plan Project established and funded under Part III of Act 253, Session Laws of Hawaii (SLH) 2007 called for the preparation of a bioenergy master plan to "set the course for the coordination and implementation of policies and procedures to develop a bioenergy industry in Hawaii." The "*Hawaii Bioenergy Master Plan*" project final report was completed by HNEI in December 2009. The Plan was developed to address a number of outcomes and issues prescribed by the Act, spanning a diverse range of considerations - from business partnerships and financial incentives to land and water resource issues. Toward this end, preparation of the Plan involved a wide range of stakeholders from Hawaii's agriculture, business, research, and broader communities. While not specifically focused on the production of hydrogen, the Bioenergy Master Plan addresses what will be required to develop feedstock that could be used to produce hydrogen.

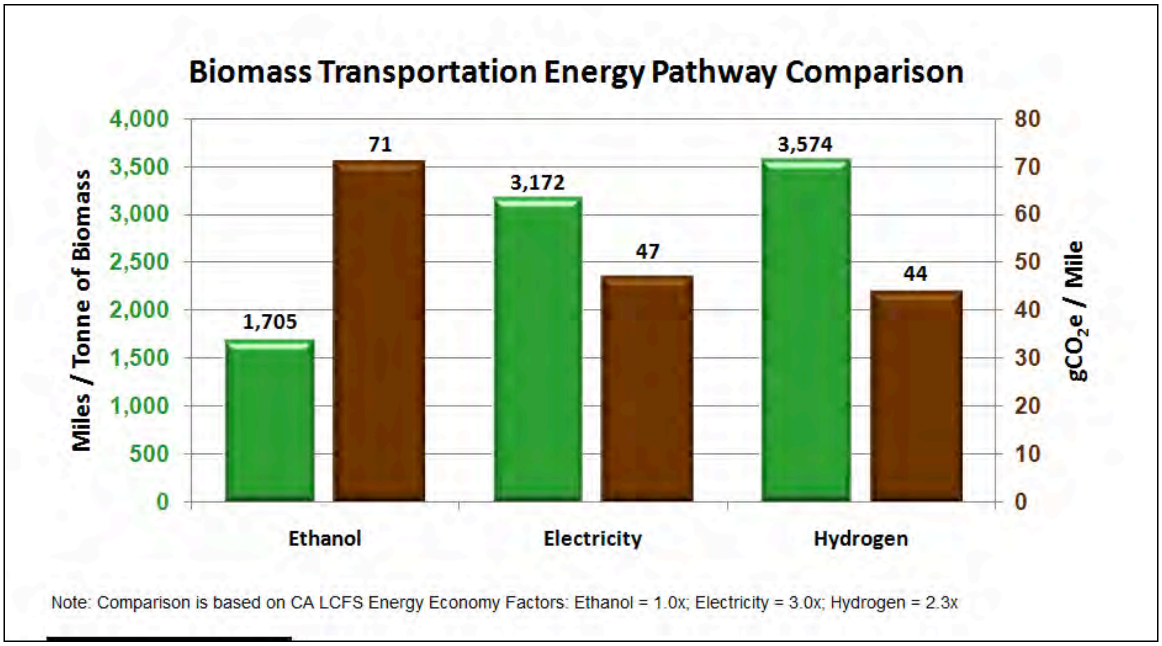


Figure 7: Biomass Transportation Energy Pathway Comparison

Figure 7 shows that hydrogen produced from biomass is the most effective use of biomass for transportation with 3,574 miles traveled per ton of biomass compared to 1,705 miles per ton of biomass converted to ethanol (green columns) and the lowest amount of carbon dioxide at 44 grams per mile vs. 47 grams per mile for grid electricity (brown columns).

Hydrogen in Support of HCEI Electricity Generation & Distribution Objectives

There are potential areas in the electricity grid sector where hydrogen technologies might be able to provide energy storage and grid management services. New experiments are being conducted at the PGV geothermal plant utilizing hydrogen electrolyzers in new ways that can both support the grid as well as utilizing the product hydrogen for transportation and as a feedstock for the production of ammonia in support of the agriculture sector thus contributing to Hawaii's food security.

The EERE Fuel Cell Technologies Program (FCT) is collaborating with the University of Hawaii's Hawaii Natural Energy Institute (HNEI) and the Naval Research Laboratory (NRL) on a hydrogen market transformation project on the Island of Hawaii that seeks to evaluate hydrogen energy systems as a potential grid management tool. The objective of this project is to evaluate the feasibility of utilizing a hydrogen production and storage system to mitigate the impacts of renewable energy generation intermittency on the Big Island electrical grid that has a high penetration of variable renewable energy sources.

A unique element of the overall program is the utilization of an electrolyzer as a controllable variable load that can provide grid services such as:

- Up regulation;
- Down regulation; and
- Off-peak load (relieving curtailment of as-available renewable energy).

In this mode, the electrolyzer would be operated at a production rate that would be determined by the demand for a combination of transportation fuels, auxiliary power, and chemical feedstock production. The electrolyzer would have the ability to reduce its load (i.e. ramp down) in response to a loss of renewable generation on the system. This capability to quickly drop load is equivalent to "up-regulation" carried by generating units on the system. The hydrogen energy system could also provide a quick transient increase in load (i.e. ramp up) that would be useful in loss-of-load events, such as a loss of transmission lines. For this service, the difference between the maximum capacity of the electrolyzer and the steady state defines the ability of the electrolyzer to provide "Down regulation."

The hydrogen energy system will be installed at the PGV geothermal plant on the Big Island of Hawaii. The project will evaluate one or more electrolyzer technologies, including alkaline or solid polymer electrolyte technologies, as well as Internet-based remote monitoring and control systems. Hydrogen produced from the system could be used for a variety of value-added products, including, in the initial phase of the project, use as a transportation fuel for two Ford E-450 shuttle buses operated by the County of Hawaii Mass Transportation Agency.

The successful deployment of hydrogen energy systems as a grid management tool offers substantial potential benefits to both stationary and transportation energy markets. The combination of hydrogen energy storage and high value products has the potential to increase the use of renewable energy resources and also reduce barriers to the introduction of further hydrogen infrastructure in Hawaii and elsewhere.

For stationary energy markets, the use of electrolyzers as controllable loads will provide "real time" grid services, including regulation (also known as frequency regulation) and curtailment downtime avoidance. Using hydrogen energy storage to provide these grid services will provide additional value streams to the power producers.

Just as important, the revenues from these grid services will also provide new value streams for hydrogen infrastructure investments, which will benefit the transportation energy market. Because reducing the cost of producing and delivering hydrogen from zero-carbon sources is a key technological challenge, the potential for hydrogen production to also attract grid service revenues offers substantial strategic value.

Hawaii – A National & International Platform for Hydrogen Research

Research related to the production of hydrogen and synthetic fuels from Hawaii's renewable resources has been conducted at HNEI for decades. This has lead to close federal co-operation in this field. Hawaii has recently become a hotbed of activity in the development of hydrogen infrastructure and biofuels with projects funded by the Department of Defense and the US Department of Energy. The recent announcement by General Motors that Hawaii was planned for a major rollout of hydrogen fuel cell vehicles has received global attention and is providing the opportunity to build up hydrogen refueling infrastructure. Because Hawaii is small and has a constrained geography, hydrogen infrastructure is easier to implement than on the mainland. This infrastructure in turn will create a favorable international platform for further research and testing within the state, based on close co-operation between the public and private sectors, and offering a unique framework for future development and collective expertise. Because Hawaii's energy costs are high, we offer a nearer term market than the mainland USA. So while

Hawaii is not capable of making major advances in this area on its own, major steps can be taken in cooperation with other agencies and key industry operators worldwide.

Consistent Long-Term Political, Policy, and Financial Support

The transition from a fossil fuel to a renewable energy economy requires consistent, long-term political and financial support over an extended period of time. The path forward can be considered a marathon – not a sprint. Progress will depend on numerous externalities including but not limited to the price of oil, technology development, the state of the economy, public support, and political will. It will also depend on the progress the Program makes and the confidence it instill in the political leadership that it is an effective program. Most of these externalities are outside the control of the Program but can have profound effect on how quickly it moves forward. The most obvious is that when the state suffers economic setbacks, discretionary funding dries up, and the Program is in danger of slowing down for a lack of funding. On the other hand, this is offset by the "pain" consumers feel at the gas pump when gasoline prices rise as they did in 2008. Many expect that our current price structure is a lull before the storm and energy prices will rise significant in the 2011-2015 time-frame. The public wants solutions – not excuses and they look to the legislature to provide them.

As we start down the 2010-2020 path, the Program continues to enjoy the consistent bipartisan support of the leadership in both the Administration and the Legislature. The Program was actually started through the initiative of the Legislature and Administration when the initial legislation established the Program was passed in 2007. Since then a similar bi-partisan effort was made to establish the Hawaii Clean Energy Initiative (HCEI) by the previous State of Hawaii administration.

Now with a change in Administration, our new governor has made the commitment in his comprehensive economic development plan – "*A New Day in Hawaii*" – to the development of the State's renewable energy resources. Governor Abercrombie wrote: "*Hawaii's most important economic enterprise right now is to pursue energy independence*" and presented the following top-level objectives that support the HCEI and Program:

- Creating an independent Hawaii Energy Authority;
- Allowing independent power producers to sell directly to end-users;
- Aligning the electric utility's success with Hawaii's clean energy goals;
- "Greening" government;
- Supporting workforce development for good "green" jobs;
- Researching, expanding, and deploying renewables with clear community benefits; and
- Reducing our dependence on fossil fuels for transportation.

Public and private cooperation work on policy formulation on hydrogen will continue. Emphasis will be on the development of renewable energy resources, establishing an effective hydrogen infrastructure, and working with government agencies and the private sector to introduce hydrogen transportation solutions to Hawaii.

Through extensive experience, expertise, and on-going commitment to innovative research on the exploitation of sustainable renewable energy resources, Hawaii energy companies, universities, and research institutes are making a major contribution towards creating a hydrogen future for Hawaii.

1.0 The Hawaii Hydrogen Program Plan 2010-2020

When starting down a path that has a starting point and an end point, it is always good to know where you are starting from and set objectives on where you want to be at the end of the road. This provides "direction" and this is a good thing.

1.1 Current Status

The Hydrogen Program and Fund ("Program") have been developed to focus on one over-riding objective - reducing Hawaii's dependence on imported fossil fuels by using hydrogen to increase the utilization of Hawaii's renewable energy sources.

The Interim Program Plan 2009-2010 provided a near-term strategy and the actions required for its implementation for the first 2 years of the Program. It set the initial strategies and framework for the first investments by Kolohala. The investment component provided equity investments in companies at both the "seed" and "venture" levels. They are structured to provide the State equity ownership in private companies and the potential of a return on that investment. The overall objective is that over time the Program becomes self-sustaining or "evergreen". The second component - cost share - allows Hawaii to attract US Department of Energy program funding that builds infrastructure and capacity.

Many of the strategies and tasks identified in the Interim Plan will continue to be carried forward in the 2010-2020 plan. Using the Interim Plan as its foundation, the Renewable Hydrogen Program Plan 2010-2020 ("Program") described in this document provides longer-term objectives, strategies, and the actions required for its implementation.

Plan Starting Point: 2010

There has been considerable hydrogen activity in the past 2 years and the momentum is starting to increase. In 2010 Hawaii was finally "discovered" as an ideal location to launch major hydrogen demonstration programs by General Motors, the DOD, and the US DOE.

Hickam AFB Hydrogen Program: At the start of the period in 2010 Hawaii had one hydrogen production and dispensing facility. It is located at Hickam Air force Base and is operated for the Air Force by the Hawaii Center for Advanced Transportation Technologies (HCATT), a state sub-agency that is part of DBEDT. HCATT has developed considerable expertise in converting a variety of military and civilian vehicles to operate on hydrogen as part of its Air Force projects, and this expertise is available to other Hawaii hydrogen projects.

State of Hawaii Policies: The State of Hawaii has introduced supportive hydrogen policies including the Hawaii Hydrogen Fund to provide financial support to the pathways identified in this plan.

HNEI Hydrogen Program: HNEI has developed its world-class Hydrogen Fuel Cell Test Facility located in downtown Honolulu, and has developed in-depth expertise in how fuel cells work in the presence of contaminants in air and hydrogen. This is the real world environment in which hydrogen vehicles will need to operate and HNEI is a leader in characterizing the performance and durability of fuel cells operating under these conditions.

Major Hydrogen Projects Underway: There are several major hydrogen projects underway including the Hawaii Hydrogen Power Park technology validation project, and the geothermal grid energy hydrogen storage project.

General Motors FCV Rollout: General Motors (GM) has selected Hawaii as a major rollout location for its Equinox Fuel Cell Vehicles (FCV) and an initial fleet of 15 vehicles is being introduced to Oahu.

Private Company Interest: The Gas Company has announced its intent to establish a commercial hydrogen production and distribution business.

Hydrogen Fueling Stations: A new hydrogen fueling station is being installed at the Marine Corps Based Hawaii (MCBH) Kaneohe base to support part of the fleet of GM FCVs. Additional stations are planned at Schofield Barracks and Camp Smith on Oahu. Stations are also planned for the Island of Hawaii at Hawaii Volcanoes National Park (HAVO) to support two (2) HAVO shuttle buses, and at the County of Hawaii Mass Transportation Agency (MTA) base yard in Hilo to support two (2) Puna District shuttle buses. The Fund has provided cost share funding in accordance with the Interim Plan.

2020 Objectives

The Plan identifies the following 2020 objectives that the roadmap drives towards:

- Fleet of 20,000 hydrogen-fueled vehicles comprised of buses and cars.
    - *Supports HCEI transportation and infrastructure objectives.*
- Significant hydrogen infrastructure on Hawaii & Oahu. New infrastructure projects on Kauai and Maui.
    - *Supports HCEO electricity, transportation and fuel objectives.*
- GM + 2 additional major car company rollout FCV fleets.
    - *Supports HCEI fuel and transportation objectives.*
- 20 Oahu + 10 Hawaii hydrogen fueling stations accessible to the general public.
    - *Supports HCEI transportation and fuel objectives.*
- 1 Geothermal hydrogen production plant.
    - *Supports HCEI transportation and fuel objectives.*
- 2 Big Wind hydrogen production plants.
    - *Supports HCEI electricity, transportation and fuel objectives.*
- 1 Ammonia plant utilizing geothermal power.
    - *Supports HCEI electricity, transportation and fuel objectives.*
- 1 Rental car company renting FCVs.
    - *Supports HCEI, transportation and fuel objectives.*
- 50 Hydrogen buses on Hawaii and Oahu.
    - *Supports HCEI transportation and fuel objectives.*
- Near-commercial hydrogen distribution.

1.2 Key Challenges & Success Factors

Key Challenges

✓ *Economic viability.* Hydrogen production and use must become economically viable in the longer term if it is to graduate from the demonstration project stage to commercial viability. In time this will happen as technology develops, and oil prices rise.

✓ *Investment is required to build hydrogen infrastructure.* Hydrogen technologies are expensive and currently do not enjoy the advantage of volume production. It took one hundred years to build the current energy system. The system is fully invested and people are reluctant to launch new infrastructure for something that is in the future.

- ✓ *Renewable energy sources need to be developed on a large scale – MW's of power vs. kW's.* We have only developed about 10% of our renewable energy resources. To meet HCEI objectives we have to increase that to 40% by 2030 – another 30% in only 20 years. The momentum is not there yet. We are still trying to get traction. And it is expensive – interisland cables are being quoted at $1-2 billion, and that is to capture just 400MW of intermittent Big Wind.

- ✓ *Transportation applications need to be economically viable.* This is a similar challenge to developing hydrogen infrastructure - hydrogen end-use applications are still very expensive. Light at the end of the tunnel? Several vehicle companies are predicting prices will drop dramatically by 2015.

- ✓ *Legislative funding is not constant or dependable.* Developing infrastructure will take public investment similar to that that was used to develop the interstate highway system. There are competing priorities and the nation and State are in poor financial shape. Long-term priorities are forgotten in the immediacy of the present.

- ✓ *Sense of urgency.* People generally react to economic "pain". At the moment (2010) fossil fuels are relatively affordable and available so while we may be "uncomfortable", we are not experiencing the economic pain that will make us change our current energy habits. It is difficult to develop urgency on what is coming down the track ("Peak Oil" and much higher oil prices) when everything seems to be normal.

- ✓ *Barriers and inertia are hard to overcome.* There are all kinds of man-made and technology barriers that have been developed to support the incumbent energy system. These need to be overcome but the difficulty of the task of changing the existing system cannot be underestimated.

Critical Success Factors

While the challenges are large and difficult, there are factors that give cause for optimism that can be termed "Success Factors". These include:

- ✓ *Rising oil prices will stimulate the search for alternatives*. Rising oil prices will motivate people to take action. "Peak Oil" is not a myth and new oil resources are becoming harder to find and produce. Many reputable organizations are projecting oil will rise to over $200 per barrel by 2015. This could be devastating for Hawaii's economy. We need to be working on alternatives now and the HCEI supported by the Hydrogen Program can mitigate the impact.

- ✓ *Public support for protecting the environment.* While not as effective as economic pain, public support for a clean environment will find a natural ally with hydrogen. Hydrogen produced utilizing renewable energy sources supports a clean environment – the only product of combustion is pure water.

- ✓ *Availability of renewable energy sources.* Hawaii does not lack renewable energy resources. In fact it is estimated we have 150% more renewable energy available than we need. Geothermal energy is the most attractive renewable energy source because we have a lot of it and it operates at steady state thus optimizing the capital investment in extracting it.

- ✓ *Department of Defense Initiatives:* The Department of Defense is a major player in Hawaii's energy system and has been historically an effective incubator of new technologies that later feed wide-scale civilian use. The Secretary of Defense recently designated energy initiatives as one of the top "transformational priorities" for the DOD. The National Defense Authorization Act (NDAA) 2009 mandated movement towards renewable energy sources for military installations. As a major energy user in Hawaii, the DOD program to increase its use of renewables will have impact on meeting HCEI goals.

- ✓ *General Motors' rollout in Hawaii:* The fact that GM has selected Hawaii for the rollout of its hydrogen vehicles has given the Hawaii Hydrogen Program a tremendous boost. The global interest and resulting public outreach has the potential to capture the imagination of Hawaii's public and its support for the Program.

- ✓ *Private industry recognizing business opportunities:* Government can only set the conditions for success. It takes private industry to carry the ball over the goal line. When private industry sees a way to make money from hydrogen, we will see their participation dramatically increase. It is interesting that in Hawaii, TGC, a major public utility, and Aloha Petroleum have announced their intentions to enter the hydrogen space.

- ✓ *Political will and leadership.* Giving priority to the Program over other competing interests will require political courage and determination but is an essential success factor particularly in the early formative stages of the Program. The establishment of the Fund was such an act of leadership and political will.

- ✓ *Dedicated funding:* Dedicated funding is an essential requirement of all successful new programs. This is a component of political will. The enactment of the "Barrel Tax" gives cause for cautious optimism that ongoing support might be available to support the Program.

1.3 Vision/Strategy

Six (6) major tasks have been identified to achieve the Plan's 2020 objectives. The tasks and their projected timelines are shown in Figure 1.1 as follows:

Task #1: Develop Large-Scale Renewable Energy Sources – geothermal, wind, and biomass. Large geothermal resources are available now (2010), large wind may become available in 2013, and biomass resources may become available in 2014. While other resources such as OTEC and wave energy may become available towards the end of the period, the Program's priority needs to be given to those resources that have the greatest potential for success in the near-term. *Supports HCEI electricity, transportation and fuel objectives.*

Task #2: Develop Hydrogen Infrastructure. Hydrogen infrastructure is essential to support a hydrogen industry in Hawaii. While private industry can take care of "the last mile" end-use applications, the public sector needs to support the common infrastructure required to produce, store, and distribute hydrogen in the formative stages of industry development. *Supports HCEI electricity, transportation and fuel objectives.*

- ✓ *Hydrogen Production:*
  - ▪ <u>Geothermal Hydrogen Production</u>: A hydrogen production from geothermal resources initiative started in 2010 with an initial plant scheduled to come on line in mid 2011 in a project funded by the US DOE through the Naval Research Laboratory

(NRL) and managed by HNEI. The hydrogen will be used to fuel shuttle buses operated by the County of Hawaii Mass Transportation Authority (MTA) providing a Puna District feeder service to the main Hele-On bus line. Subject to a successful first phase and the availability of additional funding, the second phase of the project would increase the level of hydrogen production.

- Wind Hydrogen Production: It is unlikely that in the next ten years wind farms will be built and dedicated specifically to hydrogen production, however curtailed wind that would otherwise be wasted, could be used to produce hydrogen. Should the price of oil rise dramatically as predicted, then using wind to manufacture hydrogen for use as a transportation fuels may become economically attractive.

- Biomass Hydrogen Production: Municipal Solid Waste (MSW), energy crops, and crop residue converted to hydrogen by gasification, offer the nearest-term opportunities to produce low cost hydrogen in Hawaii. A 20-ton per day facility at a commercially reliable level that could accept MSW, construction wastes, and mixed biomass for conversion to hydrogen is currently being evaluated.

✓ *Hydrogen Dispensing Stations*. Due to Hawaii's geographic constraints, a relative modest number of hydrogen stations on each island can meet the basic fueling requirements for hydrogen vehicles. This was a major reason for GM selecting Hawaii to rollout its FCVs. Several hydrogen dispensing stations are being installed in the 2010 – 2011 timeframe as components of DOD and DOE hydrogen demonstration projects. Private sector candidates include the Gas Company working with Aloha Petroleum who has announced their plans to develop a hydrogen delivery and dispensing capability on Oahu.

✓ *Hydrogen Delivery Infrastructure*: Current hydrogen projects are planning to deliver hydrogen using lightweight tube trailers that carry up to 100 kg of hydrogen and are capable of being towed by a pickup truck. These allow 25 fills per tube trailer. As demand for hydrogen increases there will be a requirement to introduce larger tube trailers that can transport up to 400 kgs of hydrogen – enough for 100 fills. These are large units that are towed with a tractor. The Gas Company is currently investigating the viability of delivering hydrogen to dispensing stations through its existing syngas pipeline on Oahu, however the TGC system only distributes to about one third of the island.

✓ *Hydrogen Storage Infrastructure:* Hydrogen bulk storage presents an expensive challenge. Current methodology utilizes high-pressure compressed gas cylinders – either steel or composites – at pressures up to 350 bars. Higher pressures can be used but it is very costly in terms of the compressors, the electricity to operate the compressors, and the high-pressure cylinders used to store the hydrogen. In the immediate term, lightweight tube trailers are being purchased using pubic money to support transportation demonstration projects. These can be used to jump-start the build-up of storage capacity until the private sector steps in. Other technologies such as the plastic pipe technology described in the hydrogen storage section of this plan offer considerable promise for hydrogen bulk storage and are worthy of investigation utilizing public funds.

✓ *Ammonia Production:* All fertilizer is imported to Hawaii and is critical for Hawaii's food security. In 2008 when the price of natural gas spiked up, Hawaii's farmers were faced with a tripling of their fertilizer costs and the prospect of business failure. As a result the agriculture community is very interested in the prospect of manufacturing ammonia locally. Ammonia is produced by combining nitrogen and hydrogen in a pressurized reaction chamber. Geothermal power could be used to produce electrolytic hydrogen, separate nitrogen from air, and power the conversion process. The ammonia can be used in its liquid form, or converted to urea by combining it with CO2. As it is unlikely that private industry will build the first ammonia plant, it is recommended the State make a strategic investment in food security by building the first plant. Building an ammonia plant supports the production of hydrogen for a transportation fuel in support of HCEI objectives.

Task #3: Support Application and demonstration Projects. In 2010, the majority of the funding used to develop hydrogen infrastructure was being provided through federal research and demonstration projects leveraged by State funding. The State should continue to leverage federal dollars in support of the Program by providing cost share to secure the projects. These projects result in infrastructure that stays in the state after the project completes and can be used to support the Program including meeting HCEI objectives. Projects currently (2010) identified include the following:

- ✓ *HCATT Hydrogen Program*. HCATT is starting the 2010 – 2020 Plan period with an existing program of deploying several FCVs for the Air Force at Hickam Air Force Base that represents the Air Force's main hydrogen transportation program. This program is expected to continue throughout the 10-year period and should continue to be given the support by the State through HCATT.

- ✓ *GM Equinox FCV fleet demonstration.* This project initially consists of 15 Equinox FCVs that utilize DOD funding. The vehicles are being deployed with the Army, Navy, and Air Force. The project includes support for infrastructure including fueling stations. GM intends this to be the first step in rolling out its FCV vehicles and intends to support HCEI objectives by displacing fossil fuel with a substantial amount of hydrogen.

- ✓ *Hele-on Buses:* The County of Hawaii MTA manages the Hele-on bus service on the Big Island. MTA is participating in the geothermal hydrogen project and will operate two (2) hydrogen-fueled shuttle buses operating as a feeder service to the main Hele-on bus line. There have been recent indications that the Mayor of Hawaii County would like to convert all the Hele-on buses to operate on hydrogen over the next ten years.

- ✓ *HAVO Hydrogen Shuttle Buses:* HAVO is planning to introduce 2 plug-in Hybrid Fuel Cell shuttle buses to transport visitors in the park to reduce the Park's carbon footprint. This project is being supported by the State with Fund cost share to develop the bus design. Hydrogen will be supplied from the geothermal plant using tube trailers and a mobile fuel dispenser located at HAVO. The buses are planned to become operational in 2012 and will operate initially for two (2) years.

Task #4: Policy Development: This task involves the ongoing development of legislative policies to support the introduction of hydrogen in Hawaii by removing barriers, providing incentives, and funding.

Task #5: Funding: This task involves the ongoing funding of the Program. The best vehicle to do this is by periodic replenishment of the Hydrogen Fund.

Task #6: Commercialization by Private Business: We will know we have made progress when the private sector steps up to develop hydrogen projects. It is difficult to project how this will develop over the next 10 years, however there are at least 2 businesses that are prepared to start and one potential company standing in the wings.

- ✓ *The Gas Company:* As previously stated TGC is teamed with Aloha Petroleum to develop a hydrogen production and distribution business on Oahu to support the GM project and others as they come along.

- ✓ *Bus Companies:* The Big Island MTA will be the first bus company operator of a hydrogen bus in Hawaii and there have been strong indications there is interest in converting over the whole Hele-on fleet to hydrogen fuel. This may in turn spawn other supporting business.

- ✓ *Rental Cars:* Rental car companies may consider having FCVs become a part of their fleet as a novelty item for tourists who would like to try a hydrogen FCV. This would depend on the infrastructure being in place. The first experiment with rental cars would probably be on Oahu utilizing the TGC/Aloha infrastructure.

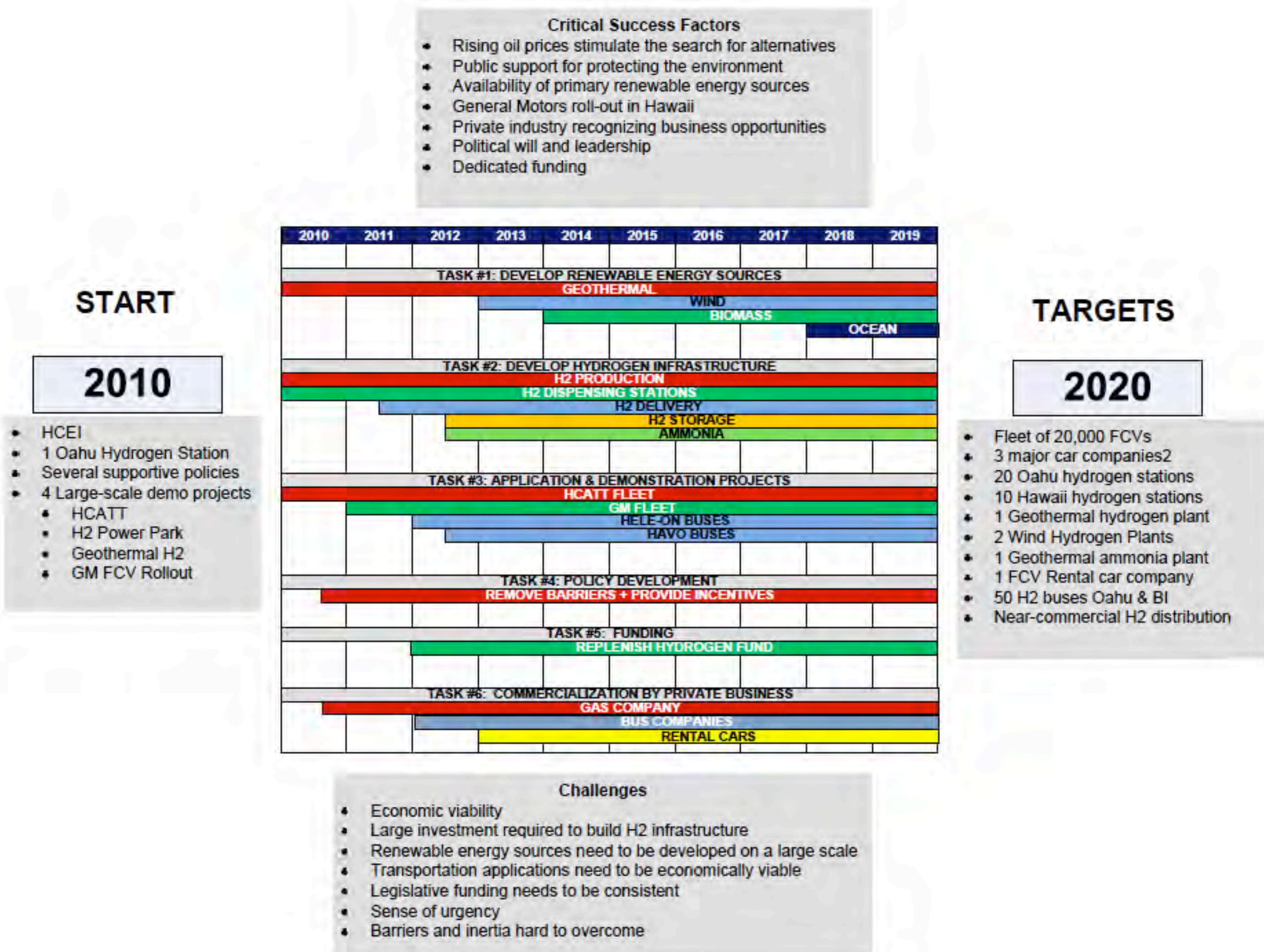


Figure 1.1: Hydrogen Roadmap Implementation Tasks

2.0 Renewable Energy Sources

Hydrogen is not an energy source but an energy carrier, and as such it requires an energy source for its manufacture. The key to developing a hydrogen economy is to develop inexpensive primary energy sources to manufacture the hydrogen.

2.1 Current Status

Energy self-sufficiency cannot be underestimated. One of the biggest concerns for the state is energy security. By developing an indigenous hydrogen-based industry, the state will be less dependent on oil from foreign countries. The development of these precursor steps for hydrogen production will provide the state with resources and technologies leading to energy self-sufficiency.

Renewable Electricity

Hawaii has a wealth of renewable electricity resources, including solar, wind, and geothermal. These resources are currently being used for electricity production. Wind and solar are intermittent and can cause problems with grid reliability and stability. The wind resource is most productive at night and can cause significant problems with grid stability when electricity demand is low. As the efficiency and economy of hydrogen electrolyzers improve, it should be possible to utilize either baseload geothermal or wind energy at night for the production of hydrogen. These approaches will enable the increased use of these renewable resources to produce hydrogen during hours of low electricity demand when production is now curtailed. The reason this is described as a "no-regrets" strategy is that improvement of these technologies for electricity production can bring down the cost of electricity and reduce the state's reliance on oil even if the pathway to hydrogen production proves difficult.

Biomass

The second set of renewable resources is biomass. The state has sufficient agricultural lands and, in many cases, water supplies to develop an energy crop industry. Currently, most of the current bio-fuels effort examines the use of biomass feedstock for the production of either ethanol or bio-diesel. However, thermal reforming can be utilized to produce hydrogen from these feedstocks. If better economic and environmental methods and processes can be found to raise biomass for energy, these processes can be used for other energy end-uses in addition to hydrogen production. Certain feedstocks may be better suited for the production of hydrogen versus the production of either ethanol or bio-diesel.

The achievement of the energy self-sufficiency objective creates a number of benefits for the state. There is an economic benefit that funds are no longer "exported" to other countries for oil. Second, the development of an indigenous industry will create local jobs and infuse funds into the state. Job creation can be beneficial as most of these will be "green" jobs that will provide long-term employment to residents. The indirect benefit is that, for every job created in the state, there is the creation of additional jobs that are needed to service the income that is provided by these jobs.

An additional benefit is environmental. The utilization of these new technologies will reduce greenhouse gas emissions, as there will be a reduction in oil use for both transportation and electricity. This benefit must be weighed against impacts associated with increased use of land and water for the production of bio-energy crops.

2.2 Key Challenges

Developing large-scale renewable energy resources

- Project financing - can be difficult in early stages due to lack of experience, market, and off-take agreements
- Viable hydrogen market
- Land-use issues
- Water issues
- Society acceptance - NIMBY
- Capital investment in developing the resource
- Available infrastructure including roads, power lines etc.
- Permitting
- Interagency coordination and cooperation
- Political will and public support

Lowering the cost of renewable energy harvesting technologies

- Developing new farming techniques
- Developing new strategies for moving the renewables to the processing facility

2.3 Vision/Strategy

The Hydrogen Program has been developed to focus on one over-riding objective - reducing Hawaii's dependence on imported fossil fuels by using hydrogen to increase the utilization of Hawaii's renewable energy sources. The development of a state-based industry in this area requires the development and implementation of a strategy that will make use of indigenous resources that can serve as feedstocks for hydrogen technology development, demonstration, and deployment. Two sets of renewable resources can be used for meeting this objective – excess electricity generated from renewable resources, and biomass resources. The strategy is to continue to develop Hawaii's primary renewable energy sources including wind, geothermal, biomass, and MSW.

2.4 Moving Forward

Moving forward it is important to tackle the key challenge facing hydrogen production in Hawaii – the supply of economically viable large-scale electricity and biomass feedstocks. Major efforts must continue to develop Hawaii's renewable energy resources. On the renewable electricity front, new wind farms need to be developed, and new technologies and strategies implemented to solve their intermittency problems. These solutions include the use of batteries and hydrogen to help manage grid reliability and harvest the wind energy. Hydrogen offers the potential to store massive amounts of energy from wind-generated electricity that would otherwise be curtailed. The geothermal resource offers large-scale baseload electrical generation potential on the Big Island. Exploratory drilling on the other islands may be useful in discovering new resources. A Geothermal Working Group has been established on the Island of Hawaii to investigate what can be done to enhance the viability of the geothermal resource. New projects funded by the US DOE are looking at utilizing geothermal power to operate utility scale electrolyzers that have the ability to quickly ramp up and down to provide grid reliability support while at the same time producing hydrogen that can be used as a transportation fuel or to produce ammonia – an important fertilizer for the agriculture industry. Also ammonia can be used as a hydrogen carrier opening up the potential of actually shipping hydrogen from the Hawaii to Oahu. The ammonia concept must be validated through technical and economic analyses.

On the biomass front, considerable effort must continue to develop biomass feedstocks to feed the thermo-chemical extraction of hydrogen. The technologies shown in Figure 2.1 include the production and conversion of biomass feedstock to a bio-fuel through gasification, conversion of syngas to a liquid bio-fuel such as ethanol and bio-diesel, and the reformation of the bio-fuels into hydrogen for use in an energy conversion technology such as a fuel cell, internal combustion engine, or gas turbine.

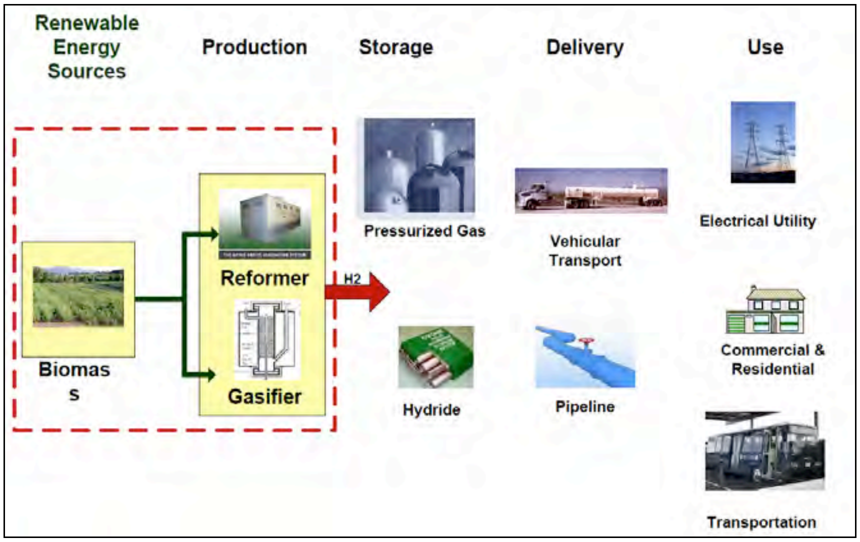


Figure 2.1: Biomass to Hydrogen Pathways

These are technologies currently being developed by Hawaii companies such as ClearFuels.

2.5 Tasks in Support of HCEI Strategies

The following tasks are proposed to increase the availability of renewable energy sources for hydrogen production in coordination and support of HCEI strategies and timeframes.

HCEI Strategy	Program Actions: Years 1-5 (2015 Target Date)
• Electricity: explore next generation technologies/new applications of existing technologies	• 2010: execute the electrolyzer grid management project at PGV to evaluate electrolyzers as a grid management tool to mitigate the effects of dynamic power fluctuations of intermittent renewable resources such as wind and PV on the grid. This has the potential to allow greater penetration of variable renewable energy sources on the grid. Complete Phase 1 in 2013. *Supports HCEI electricity, transportation, and fuels objectives*. • Design and test an autonomous automated electrolyzer grid management system that can allow the system to be remotely monitored and controlled utilizing a variety of communications systems such as the Internet. This is a component of the electrolyzer grid management project. It can be applied to all electrolyzer grid management systems. *Supports HCEI electricity, transportation, and fuels objectives*.

	• Conduct a technical and economic analysis of the PGV project data to evaluate the potential for additional intermittent renewable resources to be added to a grid utilizing electrolyzers as a grid management tool. Complete initial analysis in 2012. *Supports HCEI electricity objectives*.
• Deploy renewable generation and grid infrastructure	• "Big Wind" project – includes wind farm, inter-island cable, and Oahu grid integration components (400MW). Apply the electrolyzer grid management system to manage the frequency regulation of the grid. Utilize the hydrogen produced as a transportation fuel for the local residents and peaking power. *Supports HCEI electricity, transportation, and fuels objectives*. • Evaluate/deploy for medium scale wind projects (all islands, ~ 142 MW). Apply the results of the PGV grid hydrogen storage project results on the use of electrolyzers in managing the frequency regulation of the grid. Utilize the hydrogen produced as a transportation fuel for the local residents. *Supports HCEI electricity, transportation, and fuels objectives*. • Increase the production capacity of PGV to its maximum permitted 60 MW limit. *Supports HCEI electricity objectives*. • Utilize the new PGV production capacity for hydrogen production for transportation and to manufacture ammonia that can be used to support growing bioenergy feedstock. *This supports HCE, transportation and fuels objectives*. • Evaluate/deploy geothermal plants on Maui and Oahu. *Supports HCEI electricity, transportation, and fuels objectives*. • Deploy one ClearFuels gasification micro-system in one community on each island to produce hydrogen for transportation utilizing MSW. *Supports HCEI transportation, and fuels objectives*.

3.0 Hydrogen Production

Naturally occurring elemental hydrogen is relatively rare on earth. It is chemically bound to other atoms and this chemical bond must be broken by applying energy – either heat or electricity.

3.1 Current Status

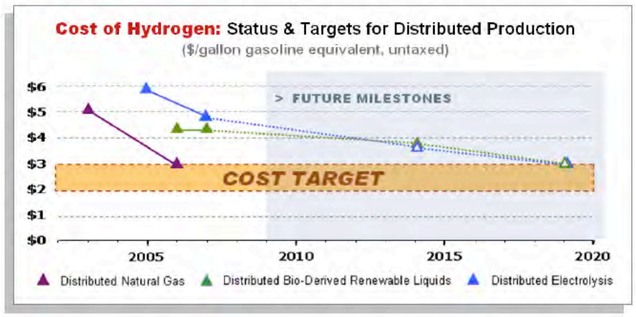


Figure 3.1: Cost of Hydrogen

Many methods have been developed for hydrogen production, but today the primary means of production is the thermo-catalytic reforming of hydrocarbons, especially of natural gas. In particular, steam reforming of methane (SMR) accounts for 95% of hydrogen production in the US, and most of the hydrogen produced is used in industrial processes of ammonia synthesis and in the refining of crude oil. The steam reforming method for producing hydrogen is undesirable since large amounts of CO2 are produced in the process. Because of this, more environmentally friendly approaches to hydrogen production are being pursued around the world. However, while undesirable in the long term, SMR is economical and provides per-mile GHG reductions of over 50% when the hydrogen is used in an FCEV. It is therefore a good transition strategy to renewable hydrogen.

In Hawaii, the two oil refineries produce hydrogen to support the refining of crude oil. The feedstock is from the petroleum itself and has been termed "black" hydrogen by local environmental groups. However black hydrogen does not support the overall objective of becoming fossil fuel independent. Therefore the two candidate processes in Hawaii are the electrolysis of water utilizing renewable electricity from geothermal, wind, and solar resources, and the gasification of biomass.

Electrolysis

In this process an electric current is used to split water into hydrogen and oxygen gases. Using an electric current to produce hydrogen from water permits the use of renewable energy sources such as solar, wind, and geothermal power. The cost of the hydrogen primarily depends on the cost of the renewable electricity resource. It requires approximately 60 kilowatt-hours of electricity to produce one kilogram of hydrogen compressed to 5,000 pounds per square inch. For curtailed electricity that cannot be utilized and is "dumped", the cost of hydrogen can be very competitive to gasoline. The capital costs of current electrolysis systems, along with the high cost of electricity in many regions, limit widespread adoption of electrolysis technology for hydrogen production. Electrolyzers are already highly efficient (nearing theoretical efficiency limits) so significant further gains are not possible. Lowering the cost of electrolyzers would reduce the capital cost of acquisition but when amortized over the life of the electrolyzer, would have marginal impact on the cost of hydrogen. Therefore a major effort should be focused on producing hydrogen utilizing curtailed renewable electricity.

Figure 3.2: Utility scale electrolyzer

Biomass Reformation, Gasification and Pyrolysis

Hydrogen can be also produced from biomass either by reformation of bio-derived liquids, or by gasification of biomass feed stocks. Significant improvements in gasification technologies need to be made to reduce the capital and operating costs for this option to become competitive. Large stocks of biomass are required to produce a significant amount of hydrogen, making it more costly than using fossil fuels (in 2010). The cost differential will be reduced as gasification CAPEX and OPEX costs lower and fossil fuel costs rise. Biomass production also requires large land areas and significant water resources. It is also an obvious requirement that farmers make money on energy crops or they won't farm.

3.2 Key Challenges

We are currently in a "chicken and egg" situation in terms of hydrogen infrastructure being able to support the HCEI objectives. Building hydrogen production infrastructure to meet a limited market demand is difficult to fund using private investment. A prerequisite for investment in hydrogen production infrastructure at the scale needed for massive hydrogen production is a stable and predictable demand for the new fuel at a price that is profitable to the producer. Today there is very limited use of hydrogen in Hawaii and significant public investment will be needed to support the initial deployment of hydrogen application technologies.

3.3 Vision/Strategy

Hydrogen will be produced by a combination of electrolysis and the gasification of biomass technologies depending on the clean energy resource available. Technologies such as Hawaii's ClearFuels gasification system, offer the promise of hydrogen from energy crops, food crop residue, and municipal solid waste (MSW). One strategy calls for distributed hydrogen production plants that can serve a local community. For example a farming community might be able to produce enough hydrogen from crop residue and MSW to meet a significant fraction of their local energy requirements. Areas of interest requiring further study for the production of hydrogen in local communities include:

- ✓ The optimal combination of plant size, storage capacity, and production phases; and
- ✓ The feasibility of using high heat combined with electricity for electrolysis.

The strategy for the 5-year period ending in 2015 is creating demand for hydrogen by continuing to attract demonstration projects such as the GM Equinox vehicle rollout, leveraging federal funding to build local hydrogen production infrastructure, and facilitate the integration of hydrogen projects and research in Hawaii.

3.4 Moving Forward

Close collaboration with global leaders in the research and development in the fields of electrolysis and gasification is important as are collaborations between Hawaii energy companies and the research community to build, test, and demonstrate various type of production facilities. To ensure demand for hydrogen, hydrogen production demonstration projects should be implemented in tandem with application demonstrations. A good example is the GM Equinox rollout project that will require considerable hydrogen production infrastructure. Demonstrations are expensive especially since there may be little initial demand for the hydrogen produced. Demonstrations that integrate production technology with other elements of hydrogen infrastructure, including market use, will be more cost effective.

For of-site electrolysis, Hawaii will need to reconsider existing laws that restrict the delivery of electricity from the electricity generation site to the hydrogen production site. The current restrictions on wheeling and the high cost of grid-delivered electricity will make electrolytic hydrogen very expensive. There is a need to intercept the electrons before they get on the grid. Power Purchase Agreements (PPA) may need to be negotiated to allow the production of hydrogen on-site at the production cost of the electricity resource for curtailed wind. It is not clear that this is currently allowed under existing PPAs.

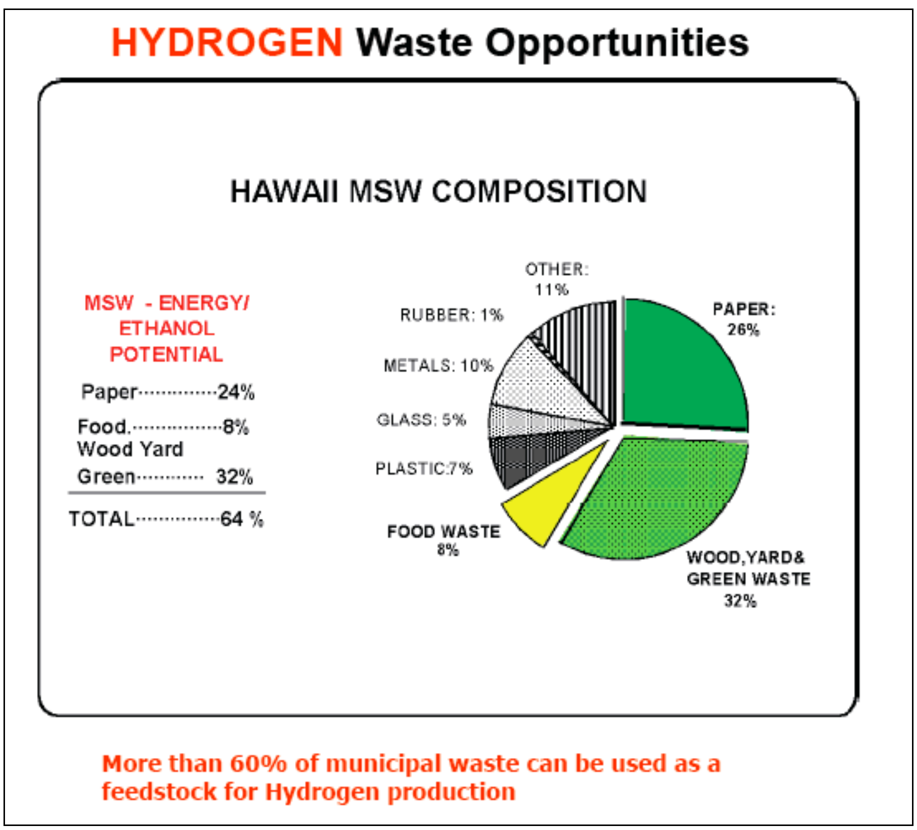


Figure 3.3: MSW composition

Biomass hydrogen production will require considerable infrastructure to deliver biomass feedstock to the gasification site or the gasifier must be installed at the biomass site. MSW is a very attractive feedstock because it is already collected and delivered to a centralized site – the landfill. Up to 64% of MSW (Figure 3.3) is comprised of materials that could be gasified into hydrogen utilizing the ClearFuels system.

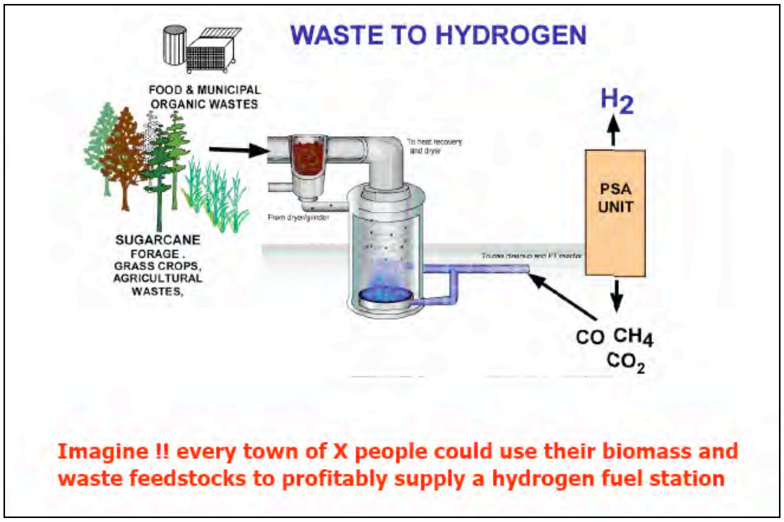


Figure 3.4: Community ClearFuels biomass hydrogen production system

3.5 Tasks in Support of HCEI Strategies

The following tasks are proposed to develop hydrogen production capacity in coordination and support of HCEI strategies and timeframes.

HCEI Strategy	Program Actions: Years 1-5 (2015 Target Date)
• Electricity: explore next generation production technologies/new applications of existing technologies. • Transportation: develop renewable fuel supply and infrastructure. • Fuels: 1) evaluate local agricultural industry/support development, 2) invest in key infrastructure at scale, 3) evaluate and develop renewable fuel processing infrastructure, 4) match potential fuels supply to sources of in-State demand.	• 2010-2013: Phase 1 electrolyzer grid management project at PGV to evaluate an electrolyzer as a grid management tool to mitigate the effects of dynamic power fluctuations of intermittent renewable resources such as wind and PV on the grid. This has the potential to develop significant hydrogen production capacity on the Big Island. Complete Phase 1 in 2013. The technology may capable of being applied at wind farm sites. *Supports HCEI transportation, and fuel objectives*. • 2013-2015: Phase 2 grid management project at PGV. Increase hydrogen production system to utilize maximum PGV permitted capacity – 60 MW. Utilize hydrogen for transportation and ammonia fertilizer production. *Supports HCEI transportation, and fuel objectives. Ammonia supports hydrogen from biomass and electricity generation*. • Design and test an autonomous automated electrolyzer grid management system that can allow the system to be remotely monitored and controlled utilizing a variety of communications systems such as the Internet or satcom. This is a component of the electrolyzer grid management project. It can be applied to all electrolyzer grid management systems. This system has the potential to reduce the operating costs of the hydrogen production system. *Supports HCEI electricity, transportation, and*

	fuels objectives. • Conduct a technical and economic analysis of the PGV project data to evaluate the potential for additional intermittent renewable resources to be added to a grid utilizing electrolyzers as a grid management tool. Complete "first-look" analysis in 2012. *Supports HCEI electricity objectives*. • 2011-2014: Develop community-sized ClearFuels gasification system focused on converting MSW and crop residue into hydrogen. Hydrogen used for local transportation fuel and heating for crop drying. *Supports HCEI transportation, and fuel objectives*.

4.0 Hydrogen Storage

Hydrogen is a gas at ambient temperatures and pressures, but it can be stored as a gas, a liquid, or as a solid. Despite these different options, the storage of hydrogen for transportation and mobile applications remains one of the greatest challenges that face the introduction of hydrogen as a mainstream fuel.

4.1 Current Status

Hydrogen storage is a key enabling technology for the advancement of hydrogen and fuel cell power technologies in transportation, stationary and portable applications. For transportation applications, the overarching technical challenge for hydrogen storage is how to store the necessary amounts of hydrogen required for conventional driving range (greater than 300 miles), within the constraints of weight, value, durability, efficiency, and total cost. Substantial improvements have been made in the weight, volume and cost of systems for vehicular applications. Durability over the performance lifetime of these systems must be verified and validated, and acceptable refueling times must be achieved. Concept vehicles have demonstrated ranges >300 miles with compressed H2 storage tanks, without compromising customer requirements. Even at present levels, onboard H2 storage system costs are significantly less than that of the batteries used in EVs and plug-in hybrids. The range of vehicles with compressed hydrogen tanks vastly exceeds the range capability of equivalent size battery powered vehicles of the same energy storage volume. It is noted that a 3-5 minute gaseous fueling protocol has been developed and is being implemented at newer hydrogen stations.

The US Department of Energy has set up a target of 6.5% hydrogen by weight or 62 kg/m3 and several storage technologies are able to meet these requirements. These technologies do not, however, show other needed features like release or filling rates at proper temperature or even reversibility.

In Hawaii the hydrogen produced today is stored as compressed gas. This is the most mature hydrogen storage technology and most car manufacturers today design their vehicles based on storage of compressed hydrogen. Cylinders that withstand pressures as high as 1200 bars are currently being tested, while the first generation of cylinders used kept hydrogen under a pressure of 350 bars. The GM Equinox being introduced to Hawaii used tanks pressurized at 700 bar and achieves an operating range of 200 miles. However, the higher the pressure, the more expensive the fueling station infrastructure. HNEI is currently procuring a dual pressure station that can fuel vehicles simultaneously at 350 and 700 bar.

Research is ongoing to look at a various options and improvements for hydrogen storage. Storage tank designs are advancing with increased strength-to-weight ratio materials and optimized structures that provide better containment, reduced weight and volume, improved impact resistance, and improved safety. Solid state storage has reached great interest and some different approached there are listed below:

- Hydrogen adsorption on solids with large surface areas, such as carbon nano-structures;
- Hydrogen storage in metal hydrides; and
- Water-based carriers.

Ammonia as a Hydrogen Storage Medium

Ammonia (NH3) is evolving as a potential hydrogen chemical storage carrier. Ammonia can be produced in an environmentally friendly and reasonably efficient process using simply water, air and electricity. Ammonia has a number of unique physical and chemical characteristics that make it an important chemical around the world. Perhaps most important to society is the ability of naturally occurring bacteria in the soil to convert NH3 and water into nitrates by a process called nitrification. The nitrates are easily absorbed by plants and aid in their growth. Other key attributes of NH3 are:

- Can be stored compactly as a liquid (much like propane) at very low pressures (~ 125 psi);
- **Highest hydrogen density of any liquid; 50% more hydrogen per volume than even cryogenic liquid hydrogen;**
- Inherently carbon-free;
- High latent heat of vaporization, resulting in excellent properties as a refrigerant;
- Flammable over a very narrow range, and has extremely high ignition energy – rated as an inflammable liquid by DOT;
- Much lighter than air; and
- Not a greenhouse gas.

Ammonia used as a fuel has unique characteristics including its ease of storage, the fact that it is carbon free, and it does not emit any greenhouse gases on combustion. Certainly if ammonia receives support and acceptance as a clean alternative fuel, for both stationary and vehicular applications, this market could easily exceed the fertilizer market over time.

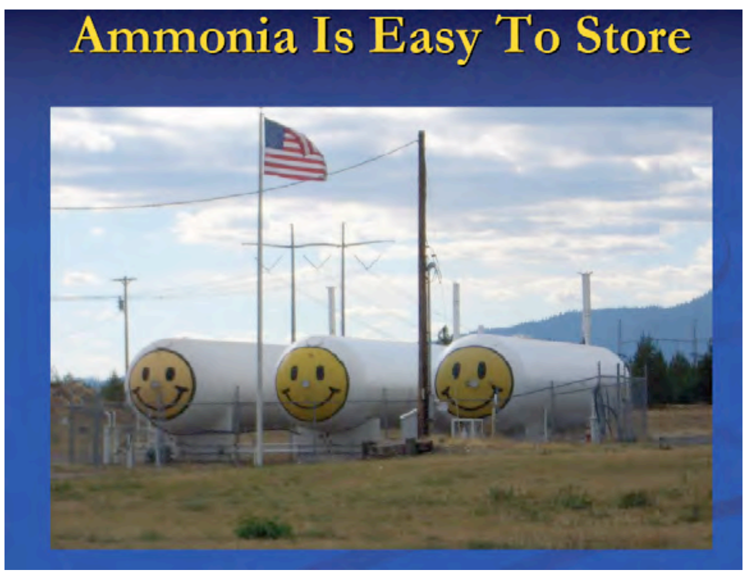


Figure 4.1: Ammonia storage tanks in the farm belt

Ammonia makes a very compact and lightweight energy storage medium. One tonne of NH3 (about 433 gallons at room temperature) has an energy content (higher heating value, HHV) of 6.25 MWh. This is roughly half the energy content for a tonne of carbon-bearing gasoline or diesel. The hydrogen is extracted from the ammonia using a simple reformer. Other relevant energy storage comparisons are:

Energy Storage Medium	Output Energy Density kWh/tonne
NH3	6,250
Lead-Acid Battery	35 – 45
Li Ion Battery	170 - 220
Vanadium Flow Battery	30 – 35
Flywheels	10 - 15

Because it is an energy storage carrier, necessarily ammonia will consume more power to manufacture than it produces. Indeed, compared to other storage technologies, the "round trip" thermodynamic efficiency is relatively low. However, ammonia's carbon-free and clean burning combustion characteristics make ammonia a viable energy storage medium candidate.

Production of ammonia at the geothermal plant provides a near-term market for hydrogen to provide fertilizer to Big Island farmers. This promotes food security in that farmers do not need to import their ammonia and are also protected from huge price swings as the result of rising natural gas prices on the mainland. Furthermore, if sufficient ammonia can be produced, it can be used as an energy carrier to transport hydrogen to support the transportation infrastructure on the Big Island and also be barged to other islands.

4.2 Key Challenges

The challenges that face hydrogen storage are dependent upon the type of storage technology. For the compressed gas and liquid hydrogen, safer and lighter designs that can meet the set US DOE goals for size and weight limits are the greatest challenges. For solid-state storage the challenges are the loading and release kinetics in addition to the great amount of heat that is released by the formation of the stable metal hydrides. This heat formation could make it necessary to include a cooling system that tends to be bulky and heavy, and adds to the cost.

Public perceptions of safe use have been raised as a potential issue around hydrogen vehicles and storage. There are some concerns that high-pressure tanks will seem undesirable to the public and this makes solid-state storage options more attractive.

For compressed hydrogen, challenges include the cost of high pressure compressors, which can be very high for the ultra-high pressure models, and the cost of the electricity required to run the compressor. Compressed hydrogen needs to be cooled for fast fill operations (under 5 minutes). Finally the cost of high pressure fueling stations remains high – in the order of $2.5 million for a basic station.

4.3 Vision/Strategy

The vision for hydrogen storage is that a selection of different, safe, clean, reusable, lightweight, low-cost, and low-volume hydrogen storage devices will be available. Hawaii will likely not be a producer of such systems but will use these for vehicle transport applications as well as storage.

Ammonia is evolving as a potential hydrogen chemical storage carrier and a small plant should be installed at the geothermal plant to demonstrate its effectiveness and economics as an energy carrier and for fertilizer, a vision strongly supported by many leaders in Hawaii agriculture community. The near-term production of ammonia provides the immediate market required to develop hydrogen infrastructure by the private sector.

4.4 Moving Forward

As for hydrogen production, close collaboration with global leaders in the research and development in the fields of hydrogen storage is important as are collaborations between Hawaii energy companies and the research community to build, test, and demonstrate various type of hydrogen storage technologies. Hawaii researchers are actively participating in this area and continuing research involvement and monitoring of all breakthrough progress in the field should be closely monitored. For example HNEI is investigating the use of Fiber Reinforced Plastic Pipe as a novel and cost effective method for storing hydrogen. Tests conducted by Oak Ridge National Laboratory have shown very positive results. The University of Hawaii chemistry department has developed novel hydride technology that has generated national and international interest. Hawaii should continue to contribute to the technology development through collaboration and facility sharing, as well as technology demonstrations by linkage to projects linked to other aspects of the hydrogen society.

Using ammonia as a hydrogen carrier is foreseen as a Hawaii field for innovation. A small plant should be installed at the geothermal plant to demonstrate its effectiveness and the economics of its use as an energy carrier and for indigenous fertilizer production. The near-term production of ammonia provides an immediate market required to develop hydrogen infrastructure by the private sector.

4.5 Tasks in Support of HCEI Strategies

The following tasks are proposed to develop hydrogen storage capacity in coordination and support of HCEI strategies and timeframes.

HCEI Strategy	Program Actions: Years 1-5 (2015 Target Date)
• Electricity: explore next generation production technologies/new applications of existing technologies. • Transportation: develop renewable fuel supply and infrastructure. • Fuels: 1) evaluate local agricultural industry/support development, 2) invest in key infrastructure at scale, 3) evaluate and develop renewable fuel processing infrastructure, 4) match potential fuels supply to sources of in-State demand.	• 2010-2013: Phase 1 electrolyzer grid management project at PGV to evaluate an electrolyzer as a grid management tool to mitigate the effects of dynamic power fluctuations of intermittent renewable resources such as wind and PV on the grid. Evaluate the use of Fiber Reinforced Plastic Pipe for bulk hydrogen storage and compare to existing pressurized steel tank hydrogen bulk storage systems. *Supports HCEI transportation, and fuel objectives*. • 2013-2015: Phase 2 grid management project at PGV. Increase hydrogen production system to utilize maximum PGV permitted capacity – 60 MW. Utilize hydrogen for transportation and ammonia fertilizer production. *Supports HCEI transportation, and fuel objectives. Ammonia supports hydrogen from biomass and electricity generation*. • 2013-2015: Build mini ammonia production plant at the PGV geothermal plant. Evaluate use of ammonia as a liquid hydrogen carrier to deliver hydrogen from the geothermal plant to hydrogen dispensing stations. *Supports HCEI transportation, and fuel objectives. Supports biomass feedstock production and therefore HCEO electricity objectives*.

5.0 Infrastructure

Hydrogen infrastructure refers to the physical links between sites where hydrogen is produced and where it is consumed. This is irrespective of the type of hydrogen production site and consumption.

5.1 Current Status

Around the world hydrogen is produced in a number of plants and is used for making chemicals or upgrading fuels. It is transported by pipeline, by road via cylinders, tube trailers, and cryogenic tankers, with a small amount shipped by rail car or barge. In Hawaii there is currently no hydrogen distribution system other than that provided by industrial gas suppliers. All hydrogen is distributed in gas bottles transported by truck. In 2010 the only hydrogen transportation project underway was at HCATT and hydrogen production occurs at the point of use so there is no production-site to end-use site hydrogen delivery requirement.

Figure 5.1: HCATT fueling station at Hickam AFB

Figure 5.2: TGC proposes to deliver hydrogen in syngas pipeline

On Oahu TheGasCompany (TGC) has a limited syngas pipeline distribution system that services the Eastern and Southern sides of the island - about 1/3 of the island. In support of the GM plan to launch its hydrogen FCVs in Hawaii, TGC is evaluating utilizing its pipeline to deliver hydrogen. This involves injecting pure hydrogen into the pipeline (up to ~ 15%) and then extracting it at a dispensing site (gas station) to fuel vehicles. Several extraction technologies are being evaluated. GM is evaluating locations for up to 25 hydrogen fueling sites on Oahu to support its planned rollout of FCVs. There will be a requirement to provide infrastructure to sites not serviced by the TGC pipeline.

A simple method for delivering hydrogen is to use hydrogen tube trailers. Tube trailers are comprised of high pressure steel or composite cylinders mounted on a trailer that can be towed over the road by a truck. HNEI plans to purchase several lightweight tube trailers (Figure 5.3) that can carry approximately 80 to 100 kilograms of hydrogen (enough to support up to 20-25 fills for the GM Equinox FCV), and hauled by a pickup truck to support its transportation projects. These include the MCB Hawaii fleet of GM Equinox FCVs, the County of Hawaii MTA shuttle buses, and the HAVO fuel cell PHEV shuttle buses at Volcanoes National Park. These trailers cost ~$200k - $300k depending on the tank pressure. As the number of FCVs increases, larger tube trailers carrying up to 350 kilograms of hydrogen can be used to support up to 70 fills. The larger tube trailers are hauled using a tractor as illustrated in Figure 5.4 and cost ~$750k (without tractor).

Figure 5.3: Lightweight hydrogen tube trailer

Figure 5.4: Full size hydrogen tube trailer

Dispensing the hydrogen is accomplished utilizing a hydrogen dispenser system that has the look and feel of a regular gasoline station pump as illustrated in Figure 5.5.

Figure 5.5: Hydrogen fueling station infrastructure

Depending on the dispensing pressure, a hydrogen fueling station can cost from $2.5 to $3 million. HNEI is installing a 700 bar production and fueling station at MCB Hawaii in support of the GM Equinox program at an overall project cost of approximately $3 million. These stations are capable of fast filling a vehicle in 5 minutes that is very similar to a gasoline station fill.

HNEI plans to support the HAVO and MTA shuttle bus fueling requirements with two mobile fuel dispensers illustrated in Figure 5.6. These units are suitable for projects where the fueling location may wish to be adjusted or where project funds are limited. These units cost approximately $500k. They are towed to new locations by a pickup truck. They perform a combination of cascade and compressor fill that can take several hours. They are suitable for fleet operations that are able to fill their vehicles overnight.

Figure 5.6: Mobile fuel dispenser

Inter-island Transportation

There is no interisland hydrogen delivery infrastructure. Industrial gases are shipped interisland by tug and barge in steel high-pressure cylinders. Gaseous hydrogen could be shipped interisland using tube trailers but the economics are likely to make this option impractical. This could change if ammonia is used as a hydrogen storage medium. Ammonia could be shipped interisland from the Big Island by tug and barge. The ammonia would then be gasified into nitrogen and hydrogen. Figure 5.7 shows an ammonia "nurse" tank that is used to dispense liquid ammonia as a fertilizer. The nurse tank has a 1250 gallon capacity, carries 534 kg of hydrogen, and can support 107 fills. It costs ~$6,300. Using ammonia for interisland transportation of hydrogen could prove to be a viable option that needs to be investigated.

Figure 5.7: Ammonia "nurse" tank

5.2 Key Challenges

It is likely that in Hawaii hydrogen production will occur via electrolysis of water and the gasification of biomass. The delivery and transport of hydrogen will be greatly impacted by where the hydrogen is produced and where it needs to be delivered. It is important that a hydrogen delivery system be flexible to accommodate new generations of hydrogen production technology and next generation applications. A central issue is the need for strategies to create hydrogen infrastructures that can grow gradually as demand increases.

Ammonia could become a viable energy carrier and considerable work is being done at various research institutes to evaluate its potential and develop delivery systems. However there are safety concerns that need to be addressed and the round trip efficiency evaluated before it can be considered ready for prime time.

5.3 Vision/Strategy

In Hawaii, the most likely method for hydrogen delivery in the near term (2011-2015) is directly from hydrogen production sites in tube trailers (Figures 5.3 & 5.4). As the inventory of hydrogen vehicles increases (2015-2020), there will be a proportional increase in the number of hydrogen tube trailers required to support the vehicle fleet. As the number of hydrogen-fueled vehicles increases further, pipelines between the hydrogen production site and high volume dispensing sites may prove to be a viable solution. The solution proposed by TGC offers an innovative alternative solution in the near-term for the Honolulu market. However, on the Neighbor Islands and the North Shore of Oahu, tube trailers will likely be the primary method over the 2011-2020 timeframe.

Our strategy is to install a system of gas stations and supporting hydrogen delivery infrastructure throughout Hawaii. The first installations need to be supported financially by the public sector until the number of vehicles is able to attract private sector investment. The State needs to provide financial support to assist in installing the infrastructure necessary for the GM FCV fleet rollout. A successful GM rollout is also likely to attract other FCV manufacturers when they are confident that the fueling infrastructure is in place. It will also attract additional Federal funding that leverages State investment. All of this activity results in displaced fossil fuel, hydrogen fueling infrastructure, and electric vehicles. This directly supports the HCEI transportation and fuels goals

5.4 Moving Forward

Hydrogen delivery and distribution is a critical step for the successful implementation of a hydrogen fuel economy. Since the introduction and growth of hydrogen fuel in the transportation sector can be expected to increase gradually it is important that the delivery and distribution system be flexible and adaptable to both initial low volumes and later growing to match the increased demand. Due to the lack of gas distribution systems (except for the most populated parts of Oahu) and low population density, building a pipeline grid to support gas distribution will not be economical in the 2011-2020 period. Federal projects should be leveraged to acquire a fleet of tube trailers that support the initial rollout of hydrogen vehicles.

5.5 Tasks in Support of HCEI Strategies

The following tasks are proposed to develop hydrogen infrastructure in coordination and support of HCEI strategies and timeframes.

HCEI Strategy	Program Actions: Years 1-5 (2015 Target Date)
• Fuels: invest in key distribution and dispensing infrastructure at scale.	• 2011-2015: Financially support the installation of hydrogen fueling stations and the acquisition of hydrogen tube trailers to support the GM Equinox FCV program on Oahu. *Supports HCEI transportation, and fuel objectives*. • 2011-2015: Financially support TGC and Aloha Petroleum in establishing hydrogen fueling infrastructure in South and East Oahu utilizing TGC syngas pipeline. *Supports HCEI transportation and fuel objectives*. • 2011-2012: investigate the feasibility of utilizing ammonia for interisland delivery of hydrogen. *Supports HCEI transportation, and fuel objectives*. • 2013-2015: Financially support the installation of an ammonia plant at a geothermal site on the Big Island. Deliver ammonia by interisland barge to other Hawaiian Islands as a pilot project. *Supports HCEI transportation, and fuel objectives*. • 2014-2015. Investigate the feasibility of utilizing ammonia as a direct fuel to power an interisland tug boat so that the delivery of ammonia interisland it totally fueled by ammonia. *Supports HCEI transportation, and fuel objectives*.

6.0 End-Use

Hydrogen can be used both in internal combustion engines and in fuel cells. Engines can combust hydrogen in the same manner as gasoline or natural gas, while fuel cells use an electrochemical process to produce electricity and thermal energy. Fuel cells are more than twice as efficient as internal combustion engines and the product of process is pure water.

6.1 Current Status

Hydrogen can be used in a variety of end-use applications from powering forklift trucks and working lights, to cars, trucks, buses, and even locomotives. It can be used to fuel an internal combustion engine, gas turbine, and fuel cell.

In 1990 there were no fuel cell powered cars, buses, or really any fuel cell powered end-use application that the public could actually see, much less operate. Hydrogen applications were very much in the laboratory but in a just a mere 20-year period we have advanced from almost zero end-use applications to the point where a major automotive manufacturer such as General Motors is ready to roll out a fleet of hydrogen fueled vehicles. GM has chosen Hawaii as one of its three test markets and intend to make a major Hawaii commitment. GM's plans call for hundreds, evolving to thousands, of vehicles per year.

Engines

The use of hydrogen in internal combustion engines is a well-developed technology. The conversion efficiency of burning hydrogen in an engine is about the same as a gasoline engine so there is no great energy advantage to hydrogen-fueled engines. However because there is no carbon in hydrogen, they do not emit CO2, a greenhouse gas. Rather they produce water and a small amount of NOx. Major advantages are that ICE's are very inexpensive when compared to fuel cells, engine technology is well known and understood, and they will support the development of hydrogen infrastructure that in turn helps in the transition to the greater use of hydrogen. Vehicles with hydrogen internal combustion engines are now in the demonstration phase. Some examples include the following:

- BMW Series 7 hydrogen car has a dual fuel engine that can switch between hydrogen and gasoline:
- Ford SUV is being tested in Hawaii by HCATT;
- The Hydrogen Energy Center develops hydrogen fueled ICE generators;
- The Ford E-450 shuttle bus with a 225 hp ICE utilizes compressed hydrogen at 350 bar and carries 12 passengers. Four of these vehicles are scheduled for deployment in Hawaii in 2011.

Figure 6.1: Ford E-450 shuttle bus

Fuel cells

For transportation applications, fuel cell technologies face stringent cost and durability requirements. In stationary power application, raising the operating temperature of PEM fuel cells to increase fuel cell performance will also improve heat and power cogeneration, and overall system efficiency. Recent technology progress illustrates that fuel cells are the most efficient known way to convert hydrogen to vehicle propulsion energy.

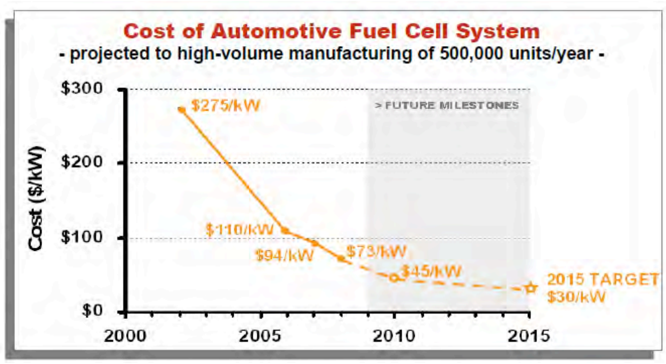


Figure 6.2: Fuel system cost curve

Performance and cost of fuel cell systems have improved remarkably in the last 5 years. While progress has tracked US DOE and industry research projections for efficiency, cost reduction and durability improvement, there are still gaps to levels that would make fuel cell technology competitive with advanced combustion engines. DOE's Technology Validation program has demonstrated 58% fuel cell efficiency, nearly meeting the 60% target. Current estimates of $60-$80/kW for fuel cell systems are still too high to meet cost targets of ~$30/kW by evolutionary design and development. The durability of vehicular fuel cell systems has improved dramatically. According to DOE's own assessment, projections of on-road durability have improved from 950 hours in 2006 to 1900 hours in 2008. The DOE hydrogen program's 2015 target is 5,000-hour durability, equivalent to approximately 150,000 miles of driving. The tolerance of fuel cell stacks to impurities has not yet been established. Tolerance to air, fuel, and system-derived impurities (including the storage system) is being addressed by the industry. SAE J2719 – hydrogen fuel quality for fuel cell vehicles – is currently out for balloting as a standard. This is based on testing of today's materials to a wide range of impurities by multiple labs.

Figure 6.3: GM Equinox FCV

6.2 Key Challenges

Hawaii needs to build the infrastructure necessary to support large-scale applications volumes. Training of technicians and experts in maintenance and safety protocols is crucial as well as training and information flow to all those who will be impacted by the changes to hydrogen fuel use. ***Most importantly***, the public – ultimately the end-users – must embrace the technology and support it in the most critical way – the marketplace. Simply stated, consumers need to purchase these vehicles and to do that, they need to enjoy the driving and ownership experience. GM and other automobile manufacturers understand that and are working hard too attain market acceptance. Part of that driving experience is a "no hassles" hydrogen infrastructure that includes convenient and fast refueling capacity that consumers are currently used to.

6.3 Vision/Strategy

It is not the place of government to select end-use technology "winners" but to provide a level playing field that supports all users. Just as the Federal government built the interstate highway system to provide for interstate commerce accessible to all, the emphasis in Hawaii should be placed on developing the infrastructure to support all end-use applications. Everyone purchasing a hydrogen fuel cell vehicle will have equal access to fueling facilities.

In Hawaii the primary use for hydrogen will be for transportation applications and potentially for manufacturing ammonia to support Hawaii's agriculture industry. For transportation applications the vision for Hawaii is that the first hydrogen vehicles will be public transportation and corporate fleet cars that will be followed with commercial private vehicles. The first steps in introducing public transportation fleets has already started in Hawaii with the Volcano National Park project, the County of Hawaii Puna shuttle buses, and HCATT projects where hydrogen buses will be used as a part of the Hickam air force base transportation system. The GM Equinox rollout in Hawaii will be a major demonstration of FCVs in a real-world environment and will demonstrate their potential to fleet operators including government. Rental cars operators may see value in differentiating themselves from their competition by offering the opportunity to drive rented hydrogen FCVs.

The strategy will be to build infrastructure – a "build it and they will come" strategy. This will be accomplished by leveraging high visibility projects such as the GM FCV project to attract federal funding. This is already happening on Oahu with the GM project, and on the Big Island with the HAVO and geothermal hydrogen projects where hydrogen infrastructure is being installed and the majority be paid with Federal money.

6.4 Moving Forward

Hawaii shall focus on federal projects that result in the development of hydrogen infrastructure. Many of these projects will require cost-share and the State needs to be prepared to provide the cost-match needed to secure these funds. Government incentives could help companies take the first steps towards building a hydrogen car fleet that will have a domino effect on other aspects such as infrastructure development.

The main players attracting Federal funds will be HNEI and HCATT. The Gas Company and Aloha Petroleum will be developing the hydrogen distribution network on Oahu that will support the planned introduction of GM and other car manufacturer FCVs. On the Big Island, there is a plan being developed to convert all county vehicles and buses to hydrogen using hydrogen produced with geothermal power and potentially wind. With the right motivation, leadership, and funding this conversion could be accomplished over the next 10 years.

Figure 6.4: Public outreach is important for acceptance

Equally important is to launch a public outreach campaign to introduce the public to hydrogen end-user applications. Many of the Federal programs have a public outreach component to them including "ride-and-drives" and visits to schools, fairs, and other public events.

Figure 6.5: GM vision for FC vehicle deployment in Hawaii

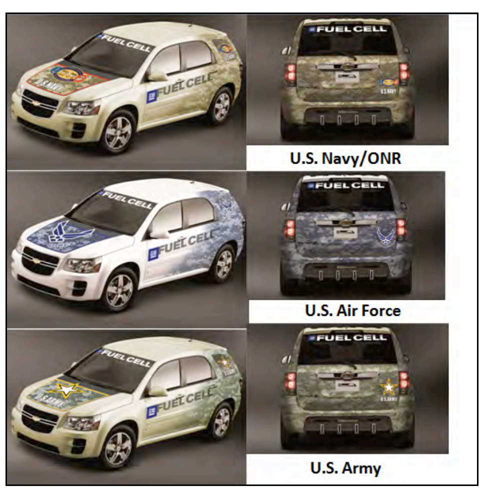


Figure 6.6: GM DOD FC vehicle deployment in Hawaii

6.5 Tasks in Support of HCEI Strategies

The following tasks are proposed to develop hydrogen end-use in coordination and support of HCEI strategies and timeframes.

HCEI Strategy	Program Actions: Years 1-5 (2015 Target Date)
• Transportation: develop renewable fuel supply and infrastructure. • Fuels: 1) invest in key infrastructure at scale, 2) match potential fuels supply to sources of in-State demand.	• The Program shall invest in common infrastructure that makes hydrogen available to all end users. • 2011-2015: Financially support the installation of hydrogen fueling stations and the acquisition of hydrogen tube trailers to support the GM Equinox FCV program on Oahu. *Supports HCEI transportation, and fuel objectives*. • 2011-2015: Financially support TGC and Aloha Petroleum in establishing hydrogen fueling infrastructure in South and East Oahu utilizing TGC syngas pipeline. *Supports HCEI transportation and fuel objectives*. • 2011-2012: investigate the feasibility of utilizing ammonia for interisland delivery of hydrogen. *Supports HCEI transportation, and fuel objectives*. • 2013-2015: Financially support the installation of an ammonia plant at a geothermal site on the Big Island. Deliver ammonia by interisland barge to other Hawaiian Islands as a pilot project. *Supports HCEI transportation, and fuel objectives*. • 2014-2015. Investigate the feasibility of utilizing ammonia as a direct fuel to power an interisland tug boat so that the delivery of ammonia interisland it totally fueled by ammonia. *Supports HCEI transportation, and fuel objectives*. • Support an aggressive outreach campaign to introduce the general public to hydrogen end-use technologies. Focus shall be on customer acceptance of the application and hydrogen safety. *Supports HCEI transportation, and fuel objectives*.

7.0 Hydrogen Research & Demonstration

The challenge of making hydrogen feasible for transportation and other applications requires developing cost-effective solutions. Developing these solutions requires extensive research, development, and technology demonstration.

7.1 Current Status

The world community recognizes the need for researching new hydrogen technology solutions and major funding in this area have been dedicated by most governments, major institutes, and international councils. In Hawaii the majority of research in hydrogen has been funded through the US Department of Energy Hydrogen Program and the US Department of Defense. HNEI and HCATT have been conducting hydrogen research and demonstration projects for over 20 years and currently have an impressive mix of demonstration and fundamental research projects on Oahu and the Big Island.

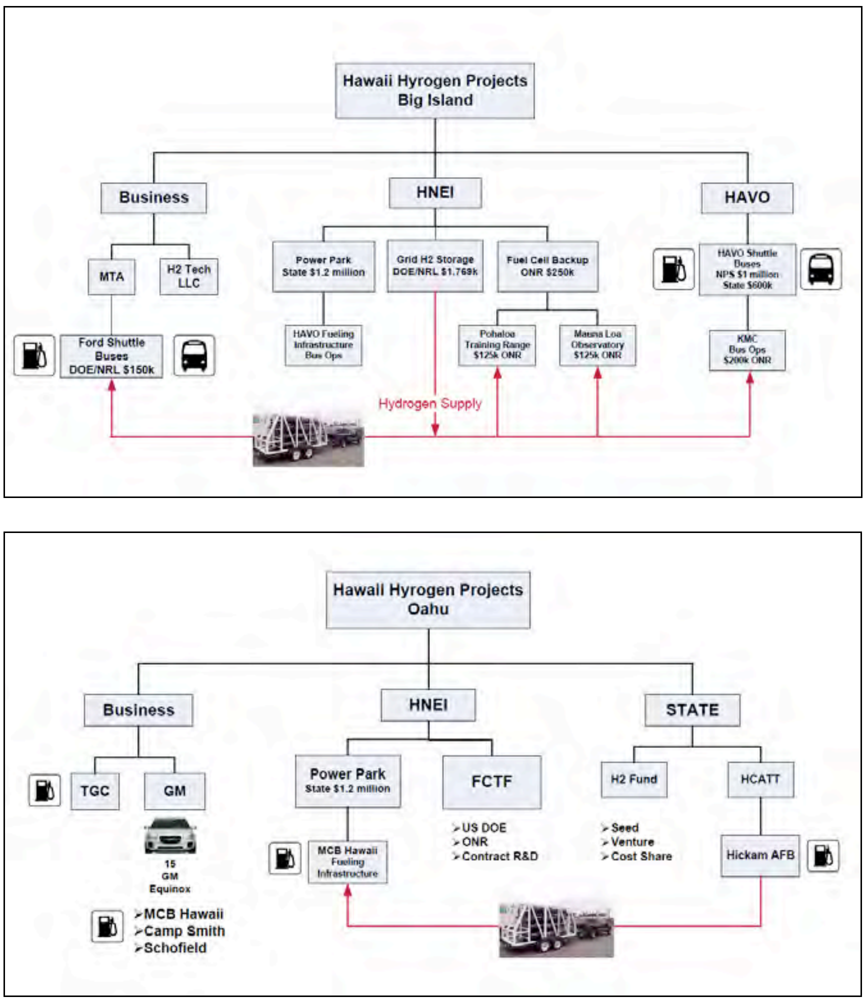


Figure 7.1: Hawaii Hydrogen Projects Overview 2010

Figure 7.2: Hawaii Hydrogen R&D Project Sites

Hydrogen Production R&D

The challenge for hydrogen production R&D is to provide hydrogen at an affordable and competitive price. It is clear that a major component of Hawaii's hydrogen production will come from the electrolysis of water utilizing geothermal and wind power. Therefore following and implementing new technologies in electrolysis will be crucial.

Developing technologies that allow the conversion of biomass, including municipal solid waste, into hydrogen are research areas where Hawaii can provide leadership that could benefit the national and international hydrogen community. A homegrown "made in Hawaii" solution is the ClearFuels gasification process. Initial technology development was supported by HNEI and is a good example of the benefits of industry and academic collaboration.

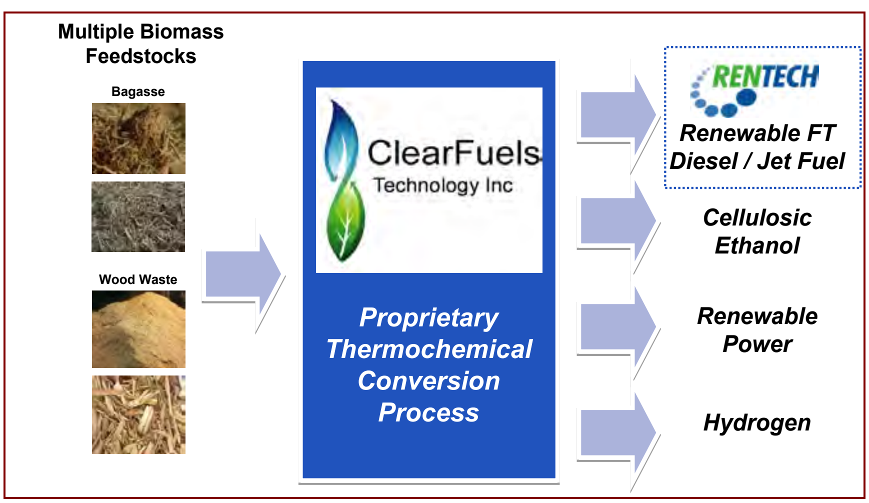


Figure 7.3: ClearFuels Process

It is equally important to produce cost effective biomass to feed the conversion process and developing the resource is an important research area. The production of biomass is a complicated systems challenge involving land-use, water, crop research, labor, harvesting, and delivery infrastructure to the production plant. In 2009 HNEI prepared the Hawaii Bioenergy Master Plan in an attempt to identify system components and their interrelationships. This plan was an excellent first start that needs to be developed further and a consensus reached on the way forward by all the stakeholders – government agencies, landowners, farmers, labor, and energy production companies.

Hydrogen Delivery and Distribution R&D

To allow a successful implementation of hydrogen as a fuel, a smooth integration with hydrogen delivery to the end-user is a critical requirement. Careful studies and system analysis of different production/end-use configurations need to be encouraged and performed. Due to Hawaii's confined geography these types of optimization studies could be used as a starting point to benefit in a larger scheme of a national hydrogen economy.

Hydrogen Storage R&D

Hydrogen storage for transportation applications is one of the biggest challenges that the hydrogen economy faces. Hawaii researchers are actively participating in this area and continuing research involvement and monitoring of all breakthrough progress in the field should be closely monitored. For example HNEI is investigating the use of Fiber Reinforced Plastic Pipe as a novel and cost effective method for storing hydrogen. Tests conducted by Oak Ridge National Laboratory have shown very positive results.

Figure 7.4: Potential new method for storing hydrogen?

7.2 Key Challenges

Setting a direction for a strategic research agenda for Hawaii requires cooperation between a broad range of stakeholders including research centers, industry, end-users, small and medium enterprises, and public authorities at all levels. With a population of approximately 1.2 million people, Hawaii has limited financial and people resources to conduct major research programs.

We must choose our research targets carefully and leverage the resources and technology of others to achieve our goals.

Two areas continue to be challenging – funding and talent. Long term and substantial funding is required to progress research projects, particularly those involving major infrastructure development. While the Hydrogen Fund was a substantial investment in terms of Hawaii's population (a similar investment on a per capita basis would have been a $300 million dollar project in California), as it makes investments, it needs to be continuously replenished to maintain a financial resource level sufficient to continue its mission. It should not be a "one shot" program. The barrel tax is also innovative and may provide funding support for research programs but it also is not enough to meet the overall infrastructure investment that will be required.

Hawaii needs to develop homegrown talent. At the moment the majority of hydrogen researchers hail from all over the world. The number of Hawaii-born researchers is small and this situation needs to be redressed. Foreign and mainland researchers eventually go home and they take their knowledge and Hawaii's investment in their personal development with them. There needs to be a more effective effort in technology transfer of their knowledge to Hawaii.

7.3 Vision/Strategy

It is essential that the University of Hawaii be developed into a hydrogen knowledge powerhouse. This knowledge base will form the core competence of a hydrogen knowledge cluster that develops technology, leverages technology from other institutions, trains Hawaii-born residents to function in this new knowledge area, and supports local entrepreneurs and industry to develop hydrogen-related ventures. All the resources of the university must be coordinated in a systematic way to cover the technical, socio-economic, business, and workforce development aspects required of a hydrogen economy.

7.4 Moving Forward

Emphasis will be placed on developing coordinated, well-funded programs that develop the Hawaii hydrogen knowledge cluster. We must continue to attract the best and brightest both from around the world and locally, and build world-class hydrogen R&D teams. HNEI and HCATT will continue to seek externally funded projects that support the development of Hawaii's hydrogen economy. Going forward there will be increased emphasis on technology transfer from other areas in the world to Hawaii. Having hydrogen infrastructure in place and a constrained geography make Hawaii very attractive to organizations that want to test their new products in the American marketplace. Their presence in Hawaii, as demonstrated by the GM project, will have far-reaching beneficial spin-off potential to help Hawaii achieve its HCEI goals.

7.5 Tasks in Support of HCEI Strategies

The following tasks are proposed to conduct research and development in coordination and support of HCEI strategies and timeframes.

HCEI Strategy	Program Actions: Years 1-5 (2015 Target Date)
• Electricity: explore next generation production technologies/new applications of existing technologies • Transportation: develop	• 2010-2013: Phase 1 electrolyzer grid management project at PGV to evaluate an electrolyzer as a grid management tool to mitigate the effects of dynamic power fluctuations of intermittent renewable resources such as wind and PV on the grid. This has the potential to develop significant hydrogen production capacity on the Big Island. Complete

renewable fuel supply and infrastructure. • Fuels: 1) evaluate local agricultural industry/support development, 2) invest in key infrastructure at scale, 3) evaluate and develop renewable fuel processing infrastructure, 4) match potential fuels supply to sources of in-State demand.	Phase 1 in 2013. The technology may be capable of being applied at wind farm sites. *Supports HCEI electricity, transportation, and fuel objectives.* • 2013-2015: Phase 2 grid management project at PGV. Increase hydrogen production capacity to fully utilize maximum PGV permitted 60 MW. Utilize hydrogen for transportation and ammonia fertilizer production. *Supports HCEI electricity, transportation, and fuel objectives. Ammonia supports hydrogen from biomass and electricity generation. Supports the agricultural community and food security.* • Design and test an autonomous automated electrolyzer grid management system that can allow the system to be remotely monitored and controlled utilizing a variety of communications systems such as the Internet or satcom. This is a component of the electrolyzer grid management project. It can be applied to all electrolyzer grid management systems. This system has the potential to reduce the operating costs of the hydrogen production system. *Supports HCEI electricity, transportation, and fuels objectives.* • Conduct a technical and economic analysis of the PGV project data to evaluate the potential for additional intermittent renewable resources to be added to the grid utilizing electrolyzers as a grid management tool. Complete "first-look" analysis in 2012. *Supports HCEI electricity objectives.* • 2011-2014: Develop community-sized ClearFuels gasification system focused on converting MSW and crop residue into hydrogen. Hydrogen used for local transportation fuel and heating for crop drying. *Supports HCEI transportation, and fuel objectives.* • 2011-2015: Support the deployment of the GM Equinox FCV. Develop the TGC hydrogen/syngas pipeline hydrogen delivery system on Oahu. *Supports HCEI transportation, and fuel objectives.* • 2011-2015: Demonstrate the use of Fiber Reinforced Plastic Pipe for bulk hydrogen storage. *Supports HCEI transportation, and fuel objectives.* • Continue to support HCATT's very successful USAF hydrogen R&D program. Leverage expertise in vehicle conversions to support other projects in Hawaii. *Supports HCEI transportation, and fuel objectives.*

8.0 Implementation

A modest plan, well executed, trumps a good plan that is poorly or, in the worst case, not executed at all. The challenge of implementing this plan, covering the period from 2010-2020, is that it requires an organization with the mandate, authority, financial resources, and the long-term enthusiastic support of the administration and legislature to see it through to fruition.

8.1 Current Status

Although it has the potential to be a significant contributor in meeting the HCEI electricity generation and delivery, transportation, and fuels goals, we find in 2011 hydrogen has not been represented in the HCEI structure. This situation needs to be remedied as soon as possible.

A major driver in providing the incentive to achieve HCEI objectives is the cost of oil. The price of oil can be either a positive or a negative incentive. In 2011 as we start down the path to 2020, we find that energy costs are low. This leads to complacency and a lack of urgency among the population to develop alternatives. While we assume that energy costs will rise in the future, we do not know when and by how much. DARPA and other government agencies are predicting oil prices will rise to over $200 per barrel by 2015, yet in 2011 we see them in the $90 range – not high enough to stimulate public reaction. From the experiences of 2008 however we know that $150 per barrel oil is a pain point and the public reacted strongly to that. We are also starting down the path in an era of economic hardship that will challenge the allocation of already scarce State and Federal financial resources. Naturally the public will be hard-pressed to understand why we need to invest in our energy future when prices are so low. However, the public also has a short memory, and when prices rise people want an instant solution.

8.2 Key Challenges

Hydrogen not on the HCEI agenda: It must be recognized from the outset that meeting the HCEI objectives is not for the faint-of-heart – it represents a significant infrastructure investment and implementation effort. While hydrogen has the potential to make a significant contribution to meeting the HCEI goals, as of 2010, it has not been considered a component of HCEI.

Assignment of Responsibility, Authority, and Resources for Executing the Plan: A plan requires a person with the responsibility, authority, and resources to implement it. This Program is no different - it will not magically implement itself – it needs someone to actually get it done. Therefore implementing the Program will require DBEDT to assign departmental responsibility to ensure it is being acted upon.

Lack of Urgency: Realistically, in 2011 we do not have the pain of high oil prices and their effect on Hawaii even though we probably all agree it is hovering over the horizon. We are complacent and lack a sense of urgency. But we do need to be working towards mitigating it when it happens.

8.3 Vision/Strategy

The vision is the State Energy Office tasked with the responsibility, the authority, and resources to implement the Program and that the hydrogen Program is recognized as an important and valued contributor to meeting HCEI objectives.

Organization

Hydrogen Implementation Authority
This plan proposes the legislature establish an Implementation Authority (IA) resident in the State Energy Office and tasked with implementing the necessary actions required to develop a hydrogen economy in Hawaii. The IA would be lead by a full time senior manager who would be designated the State Hydrogen Economy Implementation Coordinator. He would have an administrative staff to support him. The office would be funded by the legislature for a minimum of ten years so that it has the ability to conduct long-term implementation tasks without the uncertainty of losing its funding. There would also be established three additional entities that would provide policies and action plans to the IA for presentation to the legislature. The structure illustrated in Figure 1 provides the input of all stakeholders in developing the plan, implementing it, providing feedback, and making suggestions for changes.

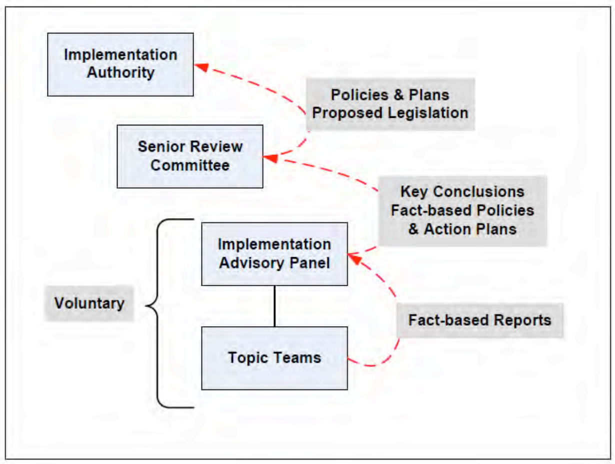


Figure 8.1: Implementation Organization

The IA would be supported by a Senior Review Committee comprised of senior state government officials representing the various stakeholder agencies that need to be consulted in the implementation process.

Implementation Advisory Panel
There would also be established an Implementation Advisory Panel, reporting to the Senior Review Committee, comprised of representatives from 1) industry, 2) state agencies, 3) federal agencies, 4) local government agencies, 5) academia, and 6) public advocacy groups. The Advisory Panel would establish Topic Teams to investigate 1) rollout strategies; 2) the economy; 3) implementation teams; 4) public education; 5) societal benefits; and 6) budgets.

Topic Team
The Topic Team would prepare fact-based reports that would be submitted to the Advisory Panel who in turn would use the reports to formulate key conclusions and propose fact-based policies and action plans.

Budget

Allocating sufficient funding to advance down the 2010-2020 Hydrogen Program roadway is a critical component of the strategy. There are several areas that can be considered for funding as follows:

- ✓ **State Budget**
  DBEDT should request, and the legislature should allocate, yearly funding to support the Hydrogen Program. There are two major areas requiring state funding: 1) the energy office needs to fund a hydrogen position for the person assigned responsibility for implementing the Program, and 2) maintaining adequate resources in the Hydrogen Fund to continue supporting hydrogen projects through cost-share, and investing in hydrogen technology companies. Just as for other public infrastructure such as roads, sewer and water systems, government will need to install basic hydrogen infrastructure. The levels of funding obviously depend on many factors including the health of the economy, the need, public support, and spending priorities.

- ✓ **Market-based Mechanism**
  Aimed at influencing the financial attractiveness of investment in the Hawaii Hydrogen Program. Mechanisms include tax credits, revenue bonding, and encouragement of dual-use applications.

- ✓ **Mandates**
  Mandates actively affect the behavior of various private or public actors. For example, growing the proportion of new state-owned vehicles and later, private vehicle fleets (including rental car fleets) fueled by alternative fuels including hydrogen.

- ✓ **Cross Subsidies**
  Transfer some of the benefits of current subsidy programs from existing recipients to new recipients - namely the participating service providers in the Hawaii Hydrogen Program. For example - transfer a portion of the existing barrel tax revenues to the Program;

- ✓ **New Subsidies**
  Involves new taxes or other new revenue sources to enable the Program (barrel tax);

- ✓ **Non Profit Organizations**
  Involves public service or philanthropic missions that embrace environmental/energy sustainability or economic development goals; and

- ✓ **Reinforcing Mechanisms**
  Awards and incentives that while not sufficient to fund the Hydrogen Program infrastructure, may contribute to the broader goal of accelerating development of the Hawaii Hydrogen Economy.

8.4 Moving Forward

The Program must be *implemented* if we are to have any chance of developing hydrogen capacity in Hawaii in the 2010–2020 timeframe. It cannot be allowed to become another piece of "shelf-ware" as is the fate of so many plans. Furthermore it must be treated as a "living document" that is adjusted based on experience and changing circumstances. This probably points to a review every two years to ensure that it is relevant to the conditions. For example, if the price of oil starts to escalate rapidly, the Program may need to become more robust in its execution and investment.

Based on conditions today (2011) the initial effort will be to obtain buy-in for the overall Program and its implementation by the legislature. There will be a new administration taking office in 2011 that must be convinced to take a leadership role in developing the necessary implementing legislation and policies. This effort must be spearheaded by DBEDT working with the new administration.

The first year's objectives are to:

1) Assign responsibility within DBEDT for implementing the plan;
2) Ensure adequate representation in the HCEI organizational structure; and
3) Start taking the necessary actions to secure an ongoing budget.

Appendices

Appendix A: Strategic Partnership Plan

Appendix B: Engineering and Economic Evaluation Plan

Appendix C: Action Plan for Grid Reliability Projects

Appendix D: Hydrogen Demonstration Projects Plan

Appendix E: Pubic Education Plan

Appendix F: Hawaii Renewable Hydrogen Promotion Plan

Appendix G: Hydrogen Systems Technologies

Appendix H: Investment Summary

Appendix A

Strategic Partnerships Plan

Introduction

HRS 196-10 established, within the Department of Business, Economic Development, and Tourism, a Hawaii renewable hydrogen program to manage the State's transition to a renewable hydrogen economy. The program calls for the design, implementation, and administration of activities that include strategic partnerships for the research, development, testing, and deployment of renewable hydrogen technologies. This plan covers the 10-year period from 2010 to 2020. HRS 196-10 directed that the plan consider the following:

- Expanded installation of hydrogen production facilities;
- Development of integrated energy systems including hydrogen vehicles;
- Construction of additional hydrogen refueling stations; and
- Promotion of building design and construction that fully incorporates clean energy assets, including reliance on hydrogen-fueled energy generation.

Objective

Identify, recruit, retain, help to form, and track progress of strategic partnerships between entities that can contribute one or more assets to specific areas of need identified in the hydrogen pathway below:

1. Funding sources
2. Technology/Intellectual property
3. Research/development/deployment expertise
4. Business development/commercial application expertise
5. Trained labor
6. Industry expertise
7. Expansion synergy
8. Support/partner network
9. Hawaii affiliation or interest

Strategy

The 2010-2020 Plan builds on the 2009-2010 Interim Program Plan and expands it over the 10-year period. The focus remains on Hawaii-based and Hawaii-engaged entities that have existing hydrogen-related plans/programs on the drawing board that can be started and implemented over the 2010-2020 time frame. The updated Strategic Partnerships Map is depicted in Figure A1 and includes new initiatives such as the GM FCV deployment that has been announced to take place over the next 20 years in support of the HCEI. The longer-term focus is on moving from demonstration projects funded by Federal and State agencies to the implementation of solid business plans by the private sector in the following areas:

1) The biomass-to-hydrogen pathway;
2) The excess renewable electricity-to-hydrogen pathway;
3) Using renewable hydrogen in commercial equipment such as a passenger bus fleet.

Specific potential partners that can be currently identified for each area of effort and demonstration project for this 2010-2020 plan are mapped against the Hydrogen Pathway in the Strategic Partnerships map below. Like any long range plan there is a lot of specificity at the start and then this becomes less defined as we march down the path. In fact, what will happen 2 or 3 years out can only be a guess at best. For example when we started the Program who would have guessed that GM and TGC would have teamed to deploy a fleet of FCV's as part of a major GM rollout strategy? Our overall strategy must be to evolve from a public funded to public-private projects and this will happen when the private sector can see that they will make money.

Strategic Partnerships Map

	Renewable Energy Sources	Production	Delivery	Storage	Use
	Renewable Electricity • Base Load • Intermittent **Bioenergy** • Waste • Biomass	Electrolysis **Gasification** **Reforming**	• Gaseous Carrier • Liquid Carrier • Solid	• Tanks • Bottles • Pipelines	• Grid Stability • Transportation • Consumer Electronics • Distributed Power
Public Strategic Partners - Federal	• US DOE • USDA • US DOD	• US DOE • US DOD	• US DOE • US DOD	• US DOE • US DOD	• US DOE • DOD – ONR • NPS
Public Strategic Partners - State	• DBEDT • HNEI • H2 Fund • State DOA	• DBEDT • H2 Fund • HNEI	• DBEDT • H2 Fund • HNEI	• DBEDT • H2 Fund • HNEI	• DBEDT • H2 Fund • HNEI
Private Strategic Prospects - Large	• PGV • HC&S • Farmers • Wind Farmers • Ulu Pono	• Ulu Pono • GasCo • CF Co-investors	• GasCo	• GasCo	• GM • HELCO • MTA • Bus Mfr
Private Strategic Prospects - Small		• Hawaii Angels • ClearFuels • BIB • RGP • KAS Co-investors			
Non-Profits/Others - Strategic Prospects					

Figure A1: Strategic Partnerships Map

Potential Strategic Partners

The different categories of strategic partners and examples of each are outlined below. Specific objectives and details of each partnership will be developed in more detail through the Demonstration Projects plan.

Public Sector

State of Hawaii

Hawaii State Legislature

The Legislature established this Renewable Hydrogen Program and has invested \$8.7M to fund the program and its direct investment fund, the Hydrogen Investment Capital Special Fund. The initial phase of the Program is approaching completion as the fund becomes fully invested in

2011. It is important that new funds be invested based on the success of this initial phase to keep the momentum moving forward.

The legislature established financial incentives that could be used to support renewable hydrogen companies and projects, such as the Act 221/215 High-Technology Investment Tax Credit and the refundable Research and Development tax credit. SB199 passed in the 2009 legislative session significantly reduced the tax credit provisions of Act 221/215 and the program expired on 31 December 2010 without replacement. The fallout of this change is still working its way through the system but the high tech community believes it will significantly reduce investment in Hawaii high tech ventures and therefore could have a negative impact on the hydrogen program.

The Legislature mandated and funded the creation of a Bioenergy Master Plan, which is intended to provide the overall structure for land use, water use, etc to support bioenergy production and use, to include hydrogen. The first plan has completed and evoked considerable comment but is currently languishing and in danger of becoming "shelf-ware". This plan needs to be followed up with a new draft based on the input on the first draft and the issues that were identified

The Office of the Governor

The Office of the Governor (Lingle Administration) established several innovative energy programs, one of which is the Hawaii Clean Energy Initiative (HCEI), a January 2008 agreement between the US Department of Energy and Hawaii Office of the Governor. It is a broad program aiming to reduce or displace Hawaii's dependence on fossil fuels by 70% by 2030. A supporting program of the HCEI is the October 2008 "accord" between the State Consumer Advocate, Office of the Governor, and the main regulated electric utility, Hawaiian Electric Industries, to revamp the electrical system of the state by implementing a feed-in tariff, decoupling, smart grid technologies, time of use metering, and other innovations to reduce electricity use and encourage development of renewable sources. Hydrogen has the potential to be a major contributor to the HCEI for energy storage to support re-use of curtailed off-peak production, grid stability, and off-grid applications. Hydrogen can be used as transportation fuel and make an important contribution to HCEI by displacing fossil fuels.

Hawaii's Congressional Delegation

Hawaii's Congressional Delegation has an interest in developing Hawaii's energy independence and economic development and has helped to fund many projects, such as the Hawaii Technology Development Venture and Hawaii Renewable Energy Development Venture. Both are a source of seed funding for promising technologies suitable for either defense or energy applications. With success, we can hope to attract ongoing support for good projects.

Federal Government Agencies:

US Department of Energy (DOE)

The Office of Electricity (OE) has invested in several projects related to grid reliability modeling and demand reduction. In addition, the Office of Electrical Efficiency and Renewable Energy (EERE) invested directly in Hawaii projects such as the Hawaii Fuel Cell Test Facility and the Hawaii Hydrogen Power Park. Navy is deploying several GM equinox fuel cell powered vehicles at the Marine Corps Base at Kaneohe. Leveraging US DOE and ONR investment, HNEI is installing a 700 bar fueling station at the base using electrolysis for hydrogen production (Figure A2). The DOE initiated a program, working in partnership with the Office of Naval Research (ONR), to develop a geothermal hydrogen production plant to be located at the PGV geothermal facility. The system is intended to study dynamic control of the electrolyzer as a grid management tool while also providing hydrogen to a variety of transportation and other high-value applications on the island. It is projected the system will be online in the fall of 2011 and there is potential for a follow-on project subject to financing and positive test results.

Figure A2: GM Equinox and HNEI Hydrogen Fueling Station

US Department of Defense (DOD)

DOD has made major investments in Hawaii's hydrogen programs throughout the years, and the level of funding is projected to dramatically increase in the following years. DOD has invested in the Hawaii Fuel Cell Test Facility through the Hawaii Energy and Environmental Technology Initiative (HEET) project, sponsors the HCATT fueling station and vehicles at Hickam Air Force Base, and most recently is supporting the Hawaii Hydrogen Power Project at HAVO. As described in the preceding paragraph there is close collaboration between the DOD and DOE in Hawaii hydrogen projects. In addition to the MCB Hawaii hydrogen fueling station, DOD is deploying a total of 15 GM Equinox FCVs in Hawaii divided equally (5 each) between Air Force, Navy, and Army. Additional hydrogen fueling stations will be installed at Camp Smith, Schofield Barracks, and the HCATT station at Hickam AFB will be upgraded.

US Department of Interior (DOI)

DOI is a partner in the Hawaii Hydrogen Power Park project through the National Park Service's plan to use hydrogen-powered shuttle buses at Hawaii Volcanoes National Park (HAVO) on the island of Hawaii. One objective of the project is to position HAVO as a hydrogen test site for the NPS and test a variety of hydrogen applications.

US Department of Agriculture (USDA)

USDA has several grant and loan programs for rural electrification, farm energy support, and rural small business energy support that could be used to support renewable hydrogen-based projects.

Private Sector

Financial Partners

As shown in Figure A3 financing innovation from the seed through the venture to the eventual full commercial deployment stage is a complicated series of handoffs from one investment partner and stage to another.

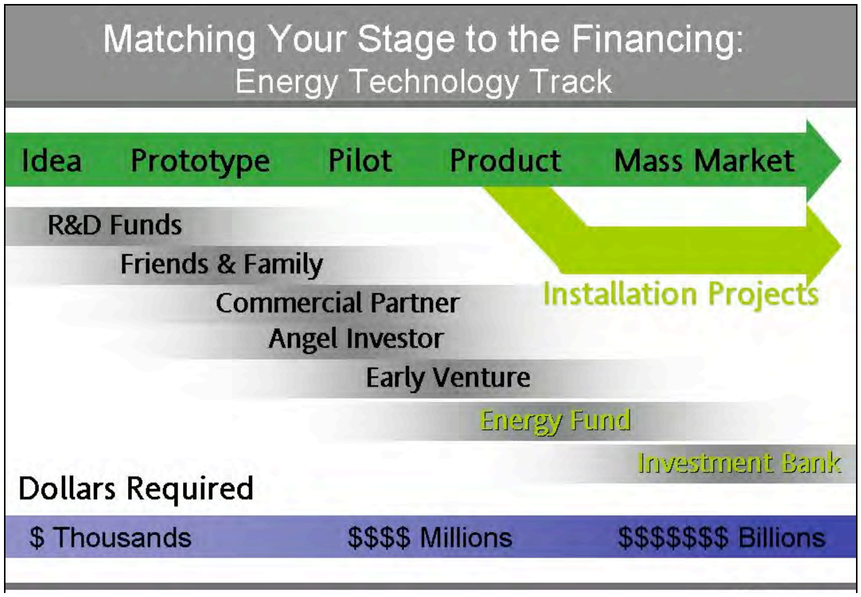


Figure A3: Progression of Financing Innovation

Energy technologies, such as hydrogen, add an additional complication in that the later stage development phases, such as demonstration and commercial-scale projects, are highly capital intensive relative to information technology and other traditional venture capital markets. Because they require much more funding than projects in these other markets, late-stage venture capital firms generally prefer not to invest directly in these projects if they do not already have a stake in the company owning the underlying technology. To fill this gap, there is a complicated and fluid landscape of commercial-stage investors:

1) Dedicated energy/cleantech funds - a small and specialized class of private equity fund - which can address only a small portion of the total capital needs for promising demonstrations;

2) Tax-motivated investors, generally top-tier investment banks investing for the applicable tax credits. This activity has fallen by over 70% since the financial crisis of 2008, and medium-tier firms are just starting to fill the gap.

3) Second-tier investment banks and industry partners using Department of Energy loan guarantees and American Recovery and Reinvestment Act Treasury-backed cost share conversions of tax credits.

Our opportunity and intent has been to use the Renewable Hydrogen Program to integrate venture-backed innovative approaches with capital-intensive infrastructure investments, in order to short-cut some of this complicated financial landscape. In doing so, the objective was to facilitate commercial product demonstration, lever other strategic partners brought into this Program, and provide government-funded hydrogen energy support infrastructure to facilitate and demonstrate innovative technologies.

The prime focus of professional venture capital firms are areas where small amounts of capital can be targeted to grow companies with unique solutions that can address large markets with high financial returns. The specific areas our venture capital partners will focus in the 2010-2020 Plan are the non-capital-intensive gaps identified in the Hydrogen Pathway diagram displayed in Figure A1 at the beginning of this Plan, such as novel renewable energy production technologies and biomass conversion technologies.

Specific Potential Venture Capital Partners

Kolohala Holdings LLP

Kolohala is the prime contractor for the Hawaii Hydrogen Investment Capital Special Fund and Hawaii State Hydrogen Program. Kolohala Holdings/Kolohala Ventures has selected this renewable energy and clean technology space as an area of focus and is making efforts to grow this sector in Hawaii. Kolohala's responsibility to Hawaii for this Program and Fund include selecting and making investments that further the state's goals as well as attracting additional capital to Hawaii.

Hawaii Angels:

Hawaii Angels was founded as UH Angels by Robert Robinson Ph.D., in February 2002. It attracted high net worth members from a variety of professions including chief executives, attorneys, physicians, and scientists, who share an enthusiasm for entrepreneurship. In September 2006, it was incorporated as a non-profit and changed its name to Hawaii Angels. The number of members has grown to over 100 and individual members have invested over $11 million in aggregate and have played a significant role in Hawaii's startup community to date. Members often mentor entrepreneurs and provide new companies with valuable business advice and important contacts.

Other Co-investors:

Another significant source of capital to leverage the State's investment in the Hydrogen Special Capital Fund include co-investors in portfolio companies that receive money from the Hydrogen fund. Examples include co-investors in ClearFuels Inc or Kuehnle AgroSystems Inc, such as California-based Garage Ventures.

Structured Finance

Specific debt/equity capital providers for specific demonstration projects, such as ClearFuels or Real Green Power have not been identified yet.

Industry Prospects - Large companies

General Motors

On the 14th of June 2010 General Motors and the Gas Company launched the Hawaii Hydrogen Initiative (H2I) with a mission to fill a strategic role that supports Hawaii's transformation to a clean energy economy by collaborating with key partners and stakeholders to create a sustainable hydrogen initiative that is necessary to support Hawaii in achieving its vision.

The Gas Company (TGC)

In June 2010 TGC announced it had partnered with GM to tap into Oahu's 1,000-mile utility pipeline and supply hydrogen gas to fueling stations that could power thousands of fuel cell vehicles. TGC currently makes the hydrogen equivalent of 7,000 gasoline gallons per day that could power as many as 15,000 fuel-cell vehicles. Between 7% and 12% of Hawaii's natural gas is hydrogen, which is added to improve the burn quality of natural gas and to reduce emissions of oxides of nitrogen. While TGC isn't separating hydrogen from its natural gas pipeline at the moment, it will do so as service station operators, such as Shell, begin building hydrogen fueling stations on Oahu over the next few years. At that time, TGC will also increase the amount of hydrogen it adds to its natural gas pipeline to 20%.

"There's been a chicken-and-the-egg issue with [fuel cell vehicles]," said Charlie Freese, executive director of global fuel cell activities for General Motors. "You can't put a vehicle in a dealership and have customers wondering where they can refuel. Similarly, you can't have a large investment go forward on the station infrastructure and have an insignificant number of vehicles in the field." TGC is already established in Hawaii, has an existing distribution system for fossil-based gas products such as synthetic natural gas, and the infrastructure and resources to be effective.

UTC Fuel Cells

UTC is a partner in the Hawaii Fuel Cell Test Facility, providing technology transfer of fuel cell testing technology to support the activities of the Hawaii Fuel Cell Test Facility operated by HNEI.

Hawaiian Electric Industries (HEI):

HEI Subsidiary Hawaii Electric Company (HECO) on Oahu is a partner in the Hawaii Fuel Cell Test Facility, providing workspace and utilities. Subsidiaries Hawaii Electric Light Company (HELCO) and Maui Electric (MECO) are partners in the grid reliability modeling projects for Hawaii Island, Oahu, and Maui. HECO and HELCO are cost share partners in the Hawaii Hydrogen Power Park as a supplier of technical support and power at a special research cost approved by the Public Utilities Commission.

Puna Geothermal Ventures (PGV):

PGV is a partner in the Hawaii Power Park and the geothermal hydrogen grid management project as a supplier of low-cost excess renewable geothermal electricity to produce hydrogen via electrolysis for storage and distribution. PGV views hydrogen projects as a potential future market for their excess electrical production. PGV has agreed to host the hydrogen production facility at its site.

Chevron & Tesoro

Similar to The Gas Company, these two petroleum refiners are well established in Hawaii. They have both existing fossil-based hydrogen production resources and existing refining/production/distribution systems for fossil fuels. They are already mandated by the State to blend 10% ethanol into gasoline, and there may be future mandates from the HCEI and other initiatives to require further displacement and restriction on the use of fossil fuels. These companies will need to find substitute renewable crude oil sources or expand to other lines of business, and renewable hydrogen production and sale could be an option.

Industry Prospects - Small Companies

Phycal

Phycal has prepared plans to construct and operate a pilot plant in Hawaii to grow algae and extract algal oil and methane gas. The plant is designed to produce up to 100,000 gals/yr. The next step to commercial success is demonstrating sustained growth and algal oil production at scale. To accomplish this goal, Phycal will construct and operate a 40-acre pilot facility in Hawai'i to develop, test and demonstrate all systems for the successful growth of algae and the extraction of commercial energy products. The Hawai'i pilot facility will include shallow ponds for growth of algae, a processing building for extraction of oil, an anaerobic digester for conversion of biomass to methane gas, and water treatment capability. Commencing operations in 2010, the facility will deliver algal oil in volumes to complete technical qualification as a commercial product and permit system development to confirm our ability to produce at acceptable cost targets.

Phycal states it chose Hawaii because energy costs in Hawai'i are the highest in the United States, and its principal source of electricity is oil-fired plants that consume more than 400 million gallons of petroleum-based fuels annually. Phycal claims its system can deliver algal oil at a competitive price for the Hawai'i market. Hawai'i offers both a market and public support for the development of biofuel. The Hawai'i

Clean Energy Initiative established clear targets for both the State and local utilities' development and use of renewable energy. Additionally, the State has established processes to facilitate regulatory approvals for development of renewable energy projects and provides tax credits to encourage investment.

On July 23rd 2010 it was announced Phycal was awarded a $24 million grant from the US DOE. The Hydrogen Fund committed $1 million in cost share to support Phycal's DOE proposal, of which $200,000 has been invested.

Big Island Biodiesel

Pacific Biodiesel is a leading pioneer and advocate for the establishment of community-based biodiesel. PBI has been converting waste vegetable oil collected from commercial eating establishments into biodiesel since 1996 in the State of Hawaii and currently operates two biodiesel production facilities in the State and two on the mainland. Pacific Biodiesel Technologies (PB Tech), the engineering, research and development subsidiary of PBI, has installed 11 biodiesel process systems ranging in size from 0.25 to 6 million gallons per year in the U.S.

PBI has formed a new company, Big Island Biodiesel, LLC (BIB) that plans to construct a new 2.6 million gallon per year biodiesel facility on the Big Island. The new facility will incorporate the latest waterless, zero-waste technology developed through PB Tech and commercially deployed at the Salem Oregon plant. In addition to biodiesel production, this technology refines the glycerin recovered from the transesterfication process into a high-grade product with minimal impurities. The $10 million facility is financed with a $5 million loan guarantee from the USDA's Rural Development Business and Industry Program, and equity investments totaling $5 million. BIB has received $800,000 from the Hydrogen Fund.

To develop a market for glycerin in Hawaii, BIB and HNEI agreed to cooperate on a glycerin transformation to hydrogen fuel project using BIB crude glycerin and technologies researched by HNEI.

Kuehnle Agrosystems Inc (KAS)

KAS is a biotech company focused on providing elite and scalable microalgae as a new agricultural crop. KAS custom-develops algae strains for industrial markets: biofuels and carbon sequestration, aquaculture feeds, and specialty chemicals and lubricants. KAS can deploy proprietary natural or genetic modification techniques for its customers, who are developing large-scale algae production systems in the US and Europe. For the purposes of the Hydrogen Program, KAS is capable of developing direct biological production of hydrogen in either liquid carrier form via methanol or gaseous form via methane, or of being an indirect source of excess biomass production through its customers in Hawaii, after essential oils are drawn off for jet fuel.

The Hydrogen Fund has invested $575,000 in KAS in a combination of seed and cost-share support.

ClearFuels Technologies, Inc.

ClearFuels Technology Inc's mission is simply stated in its name; to produce clear, clean renewable fuels such as ethanol, methanol, hydrogen and synthetic gas from sustainable cellulosic biomass using advanced thermo-chemical technologies. ClearFuels has refined a technology that can process biomass to produce a syngas that has a high percentage of hydrogen. ClearFuels has a license from Pearson Technologies Inc (PTI) who has developed a technology that can be used to processes biomass and waste materials to produce a syngas that will have a high percent of hydrogen. Work done by ClearFuels and supported by HNEI has documented that by extending the time that biomass takes to pass through a syngas production unit (residence time) the content of hydrogen in the syngas can be increased.

Since that time, ClearFuels has expended considerable time and private funds upgrading the basic reformer design from a research level to a commercial scale design. The commercial reformer design now designated as a High Efficiency Hydrothermal Reformation (HEHTR) is now being fabricated and will be integrated with the Fischer Tropsch gas to liquid fuels system, developed by ClearFuels' partner Rentech. The completed system will demonstrate the conversion of syngas produced in the HEHTR to diesel and jet fuel. The integrated commercial demonstration is partially funded by a \$22.6 M Integrated Biorefineries (IBR) grant from the US Department of Energy (DOE). The fully operational system will be constructed at Rentech's PDU demonstration facility in Colorado, and will process 20 tons per day of bagasse or wood waste to renewable diesel and jet fuel,. The design and final engineering work could provide a significant part of the basis to design of a system to process MSW to produce pure hydrogen. The diagram below provides an overview of the system of the integrated CF-RTK system.

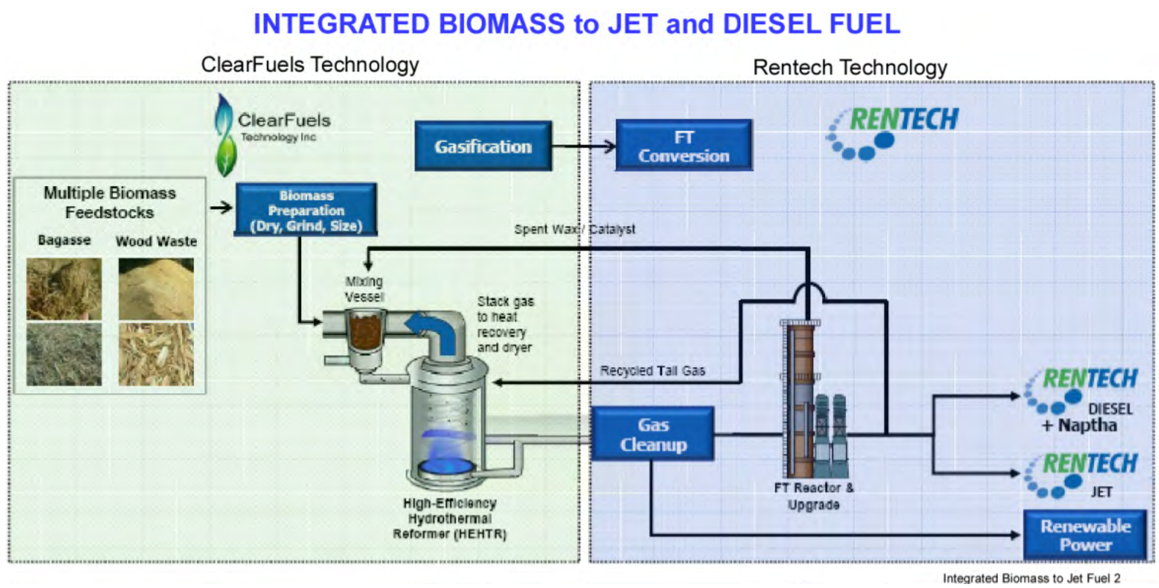


Figure A4: ClearFuels Process

The Hydrogen Fund has invested \$1,000,000 in ClearFuels and this promises to be a success story in terms of developing hydrogen production technology from biomass for Hawaii, and as a potential return on investment for the Fund.

Hawaii Hydrogen Carriers LLC (HHC)

HHC develops hydrogen storage systems using innovative metal hydrides and integrates that storage with platforms. The State's High Technology Development Corporation (HTDC) currently funds HHC and the Hawaii Center for Advanced Transportation Technologies to assemble a prototype hydrogen PEM fuel cell powered light cart for the U.S. Air Force. The key component of this device is a metal hydride based hydrogen storage system produced by HHC.

Real Green Power, Inc (RGP)

RGP utilizes a highly efficient proprietary system of anaerobic reactors, fuel cells, and gas turbines to convert the biological materials in wastewater to energy via methane (hydrogen) production. RGP's core technology is patented and exclusively licensed from the University of Hawaii, while RGP has made further improvements to the technology that it may patent or treat as trade secrets. The system is based on an engineered anaerobic bioreactor made of fiber-reinforced plastic ("FRP") containing "Bionest" structures to retain microbial content, providing high digestion efficiency even at operating temperatures as low as 20°C. It is adaptable to many types of agricultural wastewater, including waste from ethanol vinasse.

The Hydrogen Fund has invested $350,000 in RGP in a combination of seed and cost-share funding.

H2 Technologies Inc

H2 Technologies is prototyping a unique ultrasonic electrolyzer to produce hydrogen for residential and commercial applications. It is a new Hawaii start-up located on the Big Island. Its technology is in the early concept stage.

Academic Sector

Hawaii Natural Energy Institute (HNEI)

HNEI at the University of Hawaii at Manoa provides a technical foundation in support of other strategic partners. This includes technical expertise in all aspects of renewable energy resources such as resource base evaluation, conversion technologies, and end-use applications. HNEI has a significant hydrogen program ranging from fundamental research on the performance and durability of fuel cell utilizing hydrogen that has different levels of impurities, to multi-million dollar technology demonstration projects including developing hydrogen fueling infrastructure and geothermal hydrogen production. In 2011 it is projected HNEI will be installing hydrogen fueling infrastructure at the MCB Hawaii to support the GM Equinox FCV project, a geothermal hydrogen project that will support two hydrogen fueled shuttle buses operated by the Island of Hawaii Mass Transportation Authority as a feeder service to its main bus line. In 2012 it is projected new fuel cell powered shuttle buses will come on line at Hawaii Volcanoes National Park and these will be supported by HNEI hydrogen fueling systems.

Appendix B

Engineering and Economic Evaluation Plan

Introduction

HRS 196-10 established, within the Department of Business, Economic Development, and Tourism (DBEDT), a Hawaii renewable hydrogen program to manage the State's transition to a renewable hydrogen economy. The program calls for the design, implementation, and administration of activities that include engineering and economic evaluations of Hawaii's potential for renewable hydrogen use and near-term project opportunities for the State's renewable energy resources. This plan covers the 10-year period from 2010 to 2020. HRS 196-10 also directed that the plan consider the following:

- Expanded installation of hydrogen production facilities;
- Development of integrated energy systems including hydrogen vehicles;
- Construction of additional hydrogen refueling stations; and
- Promotion of building design and construction that fully incorporates clean energy assets, including reliance on hydrogen-fueled energy generation.

Objective

Develop a plan to evaluate Hawaii's ability to: 1) produce large-scale primary renewable energy sources that can be used to produce hydrogen, 2) the conversion technologies necessary to utilize these resources to produce hydrogen, 3) develop a plan for the construction of hydrogen refueling stations, and 4) develop a plan for the introduction of end-use hydrogen applications. The plan shall identify what must be accomplished in the following areas:

1. Biomass feedstock assessment and production.
2. Conversion of the biomass to biofuels.
3. Conversion of the feedstocks and/or biofuels to hydrogen.
4. Renewable electricity production.
5. Conversion of renewable electricity to hydrogen.

Strategy

For this 2010-2020 Program Plan, the focus will be on 1) biomass resource development, 2) the conversion technologies to produce biofuels and hydrogen, 3) an evaluation of the potential renewable electricity sources that will be capable of producing hydrogen, 4) the infrastructure necessary to distribute hydrogen including hydrogen fueling stations, and 5) end-use technologies such as buses and cars for transportation. The assessments will feed into the HCEI via the Fuels Working Group to evaluate the contribution hydrogen could make to meeting HCEI goals.

Hawaii Hydrogen Assessment

It is recommended that a Hawaii Hydrogen Assessment (HHA) be developed and updated every 2 years. The HHA would include the most current information on primary energy sources available in Hawaii, a status report on the technologies necessary to produce, store, deliver, and utilize hydrogen, and an economic assessment of the hydrogen system using the most current cost data.

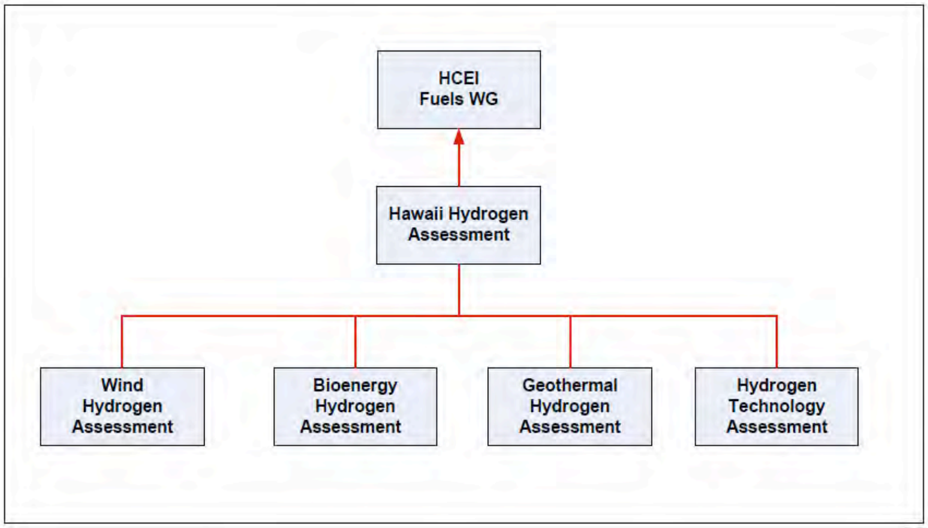


Figure B1: Hawaii Hydrogen Assessment (HHA)

Several studies that have been completed that could contribute to the HHA including the Hawaii Bioenergy Master Plan and the 2008 Big Island Geothermal-to-Hydrogen Roadmap. The HHA will provide fact-based information to assist stakeholders in understanding the potential of hydrogen to HCEI. A description of the work already completed, or underway that is germane to this plan includes:

1. *The Hawaii Bioenergy Master Plan*. Biomass was identified in a 2001 Hawaii hydrogen feasibility study[1] as one of the most economically viable potential sources of hydrogen. The increased use of the state's biomass resources for the production of fuels for transportation could diversify Hawaii's energy supplies and increase energy and economic security and sustainability. However, the development of a bioenergy industry in Hawaii poses significant challenges including limited land and water resources, adequacy of labor, lack of specialized production and distribution infrastructure, potential environmental impacts, financial risk, and the fundamental question – can farmers actually make money producing biomass resources? Recognizing the importance of increased use of renewable biomass energy resources in Hawaii Act 253, SLH 2007 called for the preparation of a Bioenergy Master Plan by DBEDT and appropriated funds to support the activity. The plan was completed by HNEI in December 2009 and identified many issues that need to be addressed.

2. *Analysis of Geothermally Produced Hydrogen on the Big Island of Hawaii – A Roadmap for the Way Forward"*: This study, completed in September 2008, analyzed the potential for geothermally produced hydrogen on the Big Island. It subsequently developed the roadmap delineating the most prudent pathways for the development of a hydrogen energy infrastructure based on the geothermal resources on the Big Island of Hawaii through 2025. Results of this study indicate that hydrogen is a potential transportation fuel on the Big Island, however a concerted effort by the state's leaders and policy makers will be necessary for hydrogen to become a significant transportation fuel before 2025.

3. *Strategic Energy Roadmap for the Big Island of Hawaii*: General Electric Global Research developed a validated power systems model of the transportation and electricity infrastructure for the Big Island of Hawaii. This analytic model is currently being used to develop a renewable

[1] *Nurturing a Clean Energy Future in Hawaii – Assessing the Feasibility of Large-Scale Utilization of Hydrogen and Fuel Cell in Hawaii*.

energy roadmap to identify the optimal path forward for increased penetration of renewable and other distributed energy technologies. This tool could provide valuable insights into the most cost effective development of hydrogen infrastructure for both the transportation and utility sectors.

Action Plan

Tasks

Task 1: **Prepare the initial Hawaii Hydrogen Assessment Study Baseline.**
Develop the first Hawaii Hydrogen Assessment. It shall be initially comprised of: 1) wind-hydrogen assessment, 2) bioenergy hydrogen assessment, 3) geothermal hydrogen assessment, and 4) hydrogen technology assessment. Other renewable-to-hydrogen pathways can be added in the future as large-scale production of those renewables becomes viable. The HHA shall be updated every 2 years and be available at the end of 2012, 2014, 2016, 2018, and 2020 to reflect the changing situation.

Task 2: **Develop a Hawaii Hydrogen Model.**
Develop a spreadsheet model that utilizes the most current: 1) technology economic and technical performance data, 2) resource assessments, and 3) transportation requirements to evaluate the economics of introducing hydrogen as a fuel in the transportation sector.

Task 3: **Formulate Scenarios and analyze them using the Hawaii Hydrogen Model.**
Develop logical scenarios that introduce hydrogen into the Hawaii transportation system and then apply the Hawaii Hydrogen Model to determine their economic impact.

Schedule

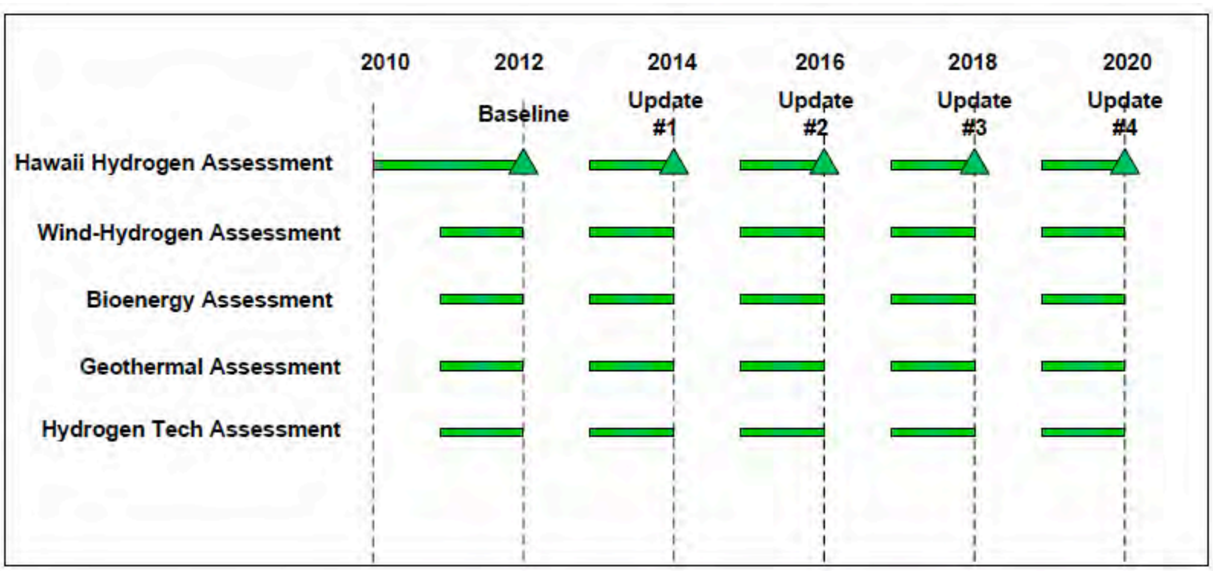


Figure B2: Hawaii Hydrogen Assessment Schedule

Appendix C

Action Plan for Grid Reliability Projects

Introduction

HRS 196-10 established, within the Department of Business, Economic Development, and Tourism (DBEDT), a Hawaii renewable hydrogen program to manage the State's transition to a renewable hydrogen economy. One of the program's objectives calls for the design, implementation, and administration of activities that include electric grid reliability and security projects that will enable the integration of a substantial increase of electricity from renewable energy resources on the island of Hawaii. This plan covers the 10-year period from 2010 to 2020.

This appendix discusses current and recently completed grid reliability projects and the action plan for the period from 2010-2020. HNEI recently completed an extensive series of grid modeling studies that analyzed significant increases in renewable energy in Hawaii's island grids. In this work, HNEI and the research team studied the integration challenges involved in adding new renewable energy sources in considerable detail. This document will summarize the studies performed on each island and the key conclusions involving grid reliability. In addition to the grid modeling studies, HNEI is currently pursuing a demonstration project on the island of Hawaii that will use an electrolyzer as a controllable load that can provide grid stability services to the local utility. Through knowledge and experience gained in both the analytical studies and demonstration projects, HNEI will develop future projects utilizing hydrogen to enhance grid reliability and security.

Existing Projects – Hawaii Grid Modeling Studies

HNEI and its subcontractor General Electric Global Research (GEGR) recently completed grid modeling studies that analyzed substantial increases in renewable energy on the islands of Oahu, Maui, and Hawaii. In addition to HNEI and GEGR, the research partners included the US Department of Energy (DOE), the Hawaii Electric Company (HECO), Maui Electric Company (MECO), and the Hawaiian Electric Light Company (HELCO). This team represents a strong public/private partnership capable of leveraging private business support and commercializing R&D activities.
The project team used two specific simulation tools in this series of studies: production cost modeling and dynamic (or transient) modeling.

- The Production Model considers the dispatch and constraints of all generation on an hourly basis and provides outputs such as the emissions, electricity production by unit, fossil fuel consumption, and variable cost of production. For example, if 10MW of wind power were added to the island, and certain assumptions were made about the spinning reserve needed to maintain system stability, how would the total variable cost of production, overall emissions and GWh by fuel type change?

- The Dynamic Model considers shorter timescales (sub-hourly). This is a necessary tool to determine if the decisions made in the longer timescales (Production Model) affect the system stability in the shorter timescale. This model can be used to determine the short timescale impacts of various decisions. For example, if 10MW of wind power were added to the island it would be necessary to determine the impact of alternative decisions for maintaining system stability (i.e., how much additional spinning reserve would be needed or how much energy storage would be needed?)

By using both a production cost and transient simulation tool to analyze "what-if" scenarios, a more thorough analysis can be performed, which will provide greater insight into the technical and economic tradeoffs of these types of technology choices. Over the past 5 years, HNEI and the research partners have used these models and refined the research methods to study integration of renewable energy on the islands of Maui, Hawaii, and Oahu. The next section will summarize these studies and the conclusions from them.

The Big Island Energy Roadmapping Study

This study analyzed three scenarios of alternative energy futures for the Big Island. The first scenario more than doubled the capacity of wind power on the island. The second scenario increased geothermal power sources and the final scenario considered the impacts of several measures to improve energy efficiency and shift load from the peak to off-peak periods.

The studied show that all of the scenarios significantly reduced oil consumption on the Big Island. The results also showed that with the large increase in wind power the system experienced frequency deviations more often and of greater magnitude. With no mitigation measures, the grid would be at greater risk of blackouts. In the final stage of the study, the team analyzed different energy storage systems and found that storage could reduce the number and extent of frequency deviations. As a direct result of this project, HNEI is now pursuing demonstration projects that will use battery energy storage and hydrogen storage to improve grid stability.

Maui Island Study

The HNEI and GE GRC study team began model development and validation for the Maui island grid. After the initial phase of the project, the electric utility and an independent power producer (IPP) chose to utilize the models to resolve a complaint filed at the Public Utility Commission (PUC). At this point, HNEI did not continue any further involvement with this project. While HNEI's role was limited, our staff did participate in the model validation and analyzed several observed events where the island's current wind project caused grid stability problems.

Oahu "Big Wind" Study

The most recent study analyzed the addition of several large wind and solar power project to the Oahu system. The island of Oahu is the most populated island in Hawaii and has a peak load of about 5-6 times of the next largest island in Hawaii. In this study, the team analyzed several scenarios of increasing amounts of wind and solar power. In the scenario with maximum renewable energy, the new power sources consisted of large wind power projects (totaling 400 MW) located on adjacent islands that transport power to Oahu using an undersea high voltage direct current (HVDC) transmission cable. The study also assumed 100 MW each of new wind and solar power located on Oahu (600 MW total of new renewable energy). This was a one year study effort involving staff from HNEI, GE GRC, HECO, and the National Renewable Energy Laboratory. The final report from the study will be available to the public in the first quarter of 2011.

Lessons from Modeling Studies

Through these studies, HNEI and its research partners have analyzed several issues utility system operators face with integrating renewable energy into their grids and the hydrogen energy system projects proposed in this plan can contribute to solving these problems in the Hawaiian Islands. In these studies, the research team studied the following challenges:

- Excess energy/curtailment
- Extra spinning reserves carried to manage ramping events
- Risks of overfrequency at low load, high wind conditions

Excess energy/curtailment – During off peak periods with low demand, utility system operators in Hawaii currently curtail output from wind power plants on the Maui and Big Island systems. These conditions occur because each of the systems maintain "must run" units online to help stabilize the system in contingency events. These units are operated at minimum levels to allow wind power into the system. If the amount of wind power available exceeds the ability of the system to accept power from this source, then output must be curtailed. As more wind power is added to the Hawaiian Island grids, which is planned for Oahu and Maui, the power producers could face more frequent curtailment. The hydrogen energy systems considered in this plan can help address this problem by increasing system load during off peak periods. In addition, as a controllable load, the demand for power can increase to help capture periods of large amounts of curtailment.

Extra spinning reserves to manage ramping events – System operators in Hawaii currently carry additional reserves from fossil fuel generating units to help manage sharp decreases in output from wind power plants (down ramping events). These additional reserve requirements result in operators committing additional units to maintain the requirement and operate them at low efficiency periodically. The hydrogen storage systems discussed in this plan can mitigate some of these requirements by providing a controllable load that can be called on during system emergencies. This resource would allow operators to relax the reserve requirements. Similarly, fast-responding generation using stored hydrogen, such as a fuel cell, could be used in a similar manner.

Risk of Overfrequency under Low Load, High Wind Conditions – In the modeling studies discussed above, one of the key conclusions from the analysis was that adding high penetrations of variable, renewable generation will require the systems to operate with conventional generating units at or near their minimum operating levels for considerable periods of time. Operating in this manner increases the risk of significant overfrequency events under unexpected decreases in load, such as loss of a major transmission line. In these conditions, system operators can benefit from rapidly increasing load. As noted earlier, this is one of the features and proposed benefits of operating an electrolyzer as a controllable load.

Objective

As noted earlier, the program will continue to identify new grid reliability and security projects that will enable the integration of a substantial increase of electricity from renewable energy resources on the island of Hawaii.

Strategy

The strategy shall be to identify and support new grid reliability projects that could be implemented over the 2010-2020 time-period.

Action Plan

Task 1: **Seek projects in the 2010-2020 timeframe that contribute to the integration of renewables into the Big Island grid.**

HNEI, the Office of Naval Research and HELCO are developing projects to utilize megawatt-sized lithium chemistry batteries to assist in the integration of wind energy into the Big Island grid. A component of this project is to utilize excess curtailed geothermal electricity to produce hydrogen utilizing an electrolyzer. The electrolyzer will be capable of ramping up and down quickly to either shed load or increase load thus acting as a buffer for the grid and providing grid regulation ancillary services. The hydrogen produced can then be used to provide electricity back to the grid or other value-added purposes such as for transportation.

Task 2: **Seek projects in the 2010-2020 timeframe that contribute to the integration of renewables into the Maui, Oahu, and Kauai grids.**

Based on a successful outcome of utilizing electrolyzers as a grid management tool on Hawaii, similar opportunities shall be sought on the other islands' respective grids. It is envisioned that the Big Island project will not be fully validated until latter half of the 2010 to 2020 Program time-frame as these projects take considerable time to set up, test, and conduct analyses of the results.

Appendix D
Hydrogen Demonstration Projects Plan

Introduction

The development of cost-effective hydrogen and fuel cells technologies and infrastructure requires time, public and private sector investment, and technology breakthroughs to achieve commercial maturity and market penetration. Concerted government strategies, long-term commitment and public research and demonstration activities are indispensable for catalyzing larger private R&D investment, for building public awareness and for facilitating the penetration of hydrogen and fuel cells technologies in the competitive marketplace. Government's current role is to focus funding on high-risk, applied research in the early phases of development to the point where the private sector can make informed decisions on whether or not, and how best to commercialize these technologies.

HRS 196-10 established, within the Department of Business, Economic Development, and Tourism (DBEDT), a Hawaii renewable hydrogen program to manage the State's transition to a renewable hydrogen economy. The program calls for the design, implementation, and administration of activities that include hydrogen demonstration projects, including infrastructure for the production, storage, and refueling of hydrogen vehicles. This plan covers the 10-year period from 2010 to 2020. The primary plan activities during this period call for funding projects that meet the Program's overall renewables-to-hydrogen objectives to include seed, venture, and cost share projects. The "Hydrogen Demonstration Projects Plan" supports projects that meet the overall objectives of the Hydrogen Fund including the development of hydrogen infrastructure and deployment of hydrogen vehicles on the Big Island.

While the original legislation provides for developing infrastructure on the Big Island, support must be provided where private industry tells us there is a market. Given the interest by GM and TGC in rolling out fuel cell vehicles on Oahu, the Plan must provide support for the Hawaii Hydrogen Initiative on Oahu as this has the greatest potential of supporting the HCEI transportation objectives. This support should be in the form of investment in the basic hydrogen infrastructure comprised of hydrogen production, delivery, and dispensing. As the number of vehicles increases and the business becomes economically viable, private industry can begin to shoulder and increasing share of the infrastructure capital investment.

In the near-term there are several existing project underway and these have the potential to expand in scope over the period of the Plan. However it is impossible to identify projects beyond a 4-year window. A case in point is the GM project. It was not even on the radar 2 years ago and it suddenly appeared. It is the hope that there are several large-scale hydrogen projects on the horizon that have not even been formulated yet. Therefore the demonstrations plan must address the conditions that make demonstration projects in Hawaii an easy choice for both federal agencies and the private sector. The most effective strategy to make that happen is to continue to focus on infrastructure projects that can support multiple projects. For example, setting up a system of hydrogen fueling stations on the Big Island an Oahu will make it easier for automobile companies such as GM, to use Hawaii as an initial launch location for their vehicles.

Projects identified to date that can begin, progress, or be completed in the 2010-2020 time frame include:

- ✓ **GM & TGC Hawaii Hydrogen Initiative**
  This is the largest and most exciting hydrogen project in Hawaii with the potential to position Hawaii on the hydrogen world map. On the 14th of June 2010 General Motors and the Gas Company launched the Hawaii Hydrogen Initiative with a mission to fill a strategic role that

supports Hawaii's transformation to a clean energy economy by collaborating with key partners and stakeholders to create a sustainable hydrogen initiative that is necessary to support Hawaii in achieving its vision.

Goals

The goals of this initiative are to:

- Help Hawaii achieve its goal of a 70% clean energy economy within a generation through the use of hydrogen;
- Increase Hawaii's energy security;
- Capture economic benefits of clean hydrogen energy for all levels of society in Hawaii;
- Foster and demonstrate innovation in renewable hydrogen energy sources:
- Set the stage to build the workforce of the future; and
- Serve as a model for the United States and the world.

The first phase of the initiative is to create the initial framework by use of modeling and the development of a business plan, and to establish momentum for the overall H2I plan.

Operational Model

The second phase of the initiative will aim to have an operational infrastructure realized and vehicle deployment in the 2015 timeframe. Elements of this phase include achieving a critical mass of hydrogen fueling stations in operation, ensuring a sufficient supply of available hydrogen fuel including sources of green hydrogen, demonstrating the capability of hydrogen to stabilize the electrical grid with increased renewable, demonstrating the economic viability of hydrogen as an energy source, and developing the third phase of the initiative.

End State

This end state of the initiative is aimed at achieving an economically and environmentally sustainable integrated hydrogen infrastructure in the state of Hawaii, by, among other things, leveraging multiple hydrogen sources, delivering low cost "green" hydrogen, delivering appealing transportation, integrating the initiative with transportation and energy sectors, creating a model for a green economy and creating an environment for green jobs. The goal is to achieve a sustainable model by the year 2030.

✓ **Volcanoes National Park Hydrogen Power Park**

The Hawaii Volcanoes National Park (HAVO) is acquiring from 2 to 5 battery-dominant fuel cell hybrid plug-in shuttle buses. These vehicles are expected to reduce congestion at the park and to provide a better (quieter and cleaner) visitor experience. The Hawaii Center for Advanced Transportation Technologies (HCATT), which currently manages a hydrogen fueling station for the US Air Force at Hickam Air Force Base on Oahu, has converted several vehicles for fuel cell use, and has been identified by HAVO to manage the vehicle conversions. It is planned to use the hydrogen infrastructure developed under Hawaii Hydrogen Power Park project to support HAVO's hydrogen fueling requirements. When the HAVO Power Park is operational, the following capabilities will be in place:

- **Hydrogen Infrastructure**

  A hydrogen production, storage and dispensing facility located at the Kilauea Military Camp (KMC). The station is being designed with the flexibility to be expanded in terms of production, storage, and dispensing capability. The system will be used initially to fuel park vehicles, but could, subject to the appropriate conditions, be used to fuel other vehicles as part of a Big Island hydrogen highway.

- **Hydrogen Vehicles:**
  A fleet of battery-dominant plug-in hybrid electric vehicle shuttle buses with a hydrogen-fueled fuel cell range extender. The vehicles will provide operational data regarding the consumption of hydrogen required on several different routes, and operational and maintenance experience in their operation.

- **Knowledge & Experience**
  An initial cadre of trained personnel who will have experience in operating and maintaining hydrogen vehicles and a fueling station in public service.

✓ **DOD Fuel Cell Vehicle demonstration model**
The DOD has acquired 15 GM Equinox FCVs and is deploying them in Hawaii. Five (5) vehicles are allocated to Navy, Air Force, and Army. Fueling infrastructure to support vehicle operations is being installed and will result in up to four (4) hydrogen fueling stations.

✓ **DOE/ONR hydrogen grid stability project**:
The DOE initiated a program, working in partnership with the Office of Naval Research (ONR) and the Naval Research Laboratory (NRL), to develop a geothermal hydrogen production plant to be located at the PGV geothermal facility. The system is intended to study dynamic control of the electrolyzer as a grid management tool while also providing hydrogen to a variety of transportation and other high-value applications on the island. It is projected the system will be online in the fall of 2011 and there is potential for a follow-on project subject to financing and positive test results. This project also has the potential to be expanded to other island grids.

✓ **HCATT Hickam AFB Hydrogen Program**
HCATT has a series of ongoing projects in support of the Air Force Advanced Power Technology Office (APTO), Robins AFB, and 15th Airlift Wing, Hickam AFB. HCATT has installed and operates a fueling station at Hickam that will be upgraded to support fueling the GM FCVs assigned to Air Force. The experience gained from this project is being leveraged by the HAVO hydrogen shuttle bus project.

Objective

The objective of the Hydrogen Demonstrations Projects Plan is to identify hydrogen demonstration projects including infrastructure for the production, storage, and refueling of hydrogen vehicles. The plan shall consider the following:

- Expanded installation of hydrogen production facilities;
- Development of integrated energy systems including hydrogen vehicles;
- Construction of additional hydrogen refueling stations;
- Promotion of building design and construction that fully incorporates clean energy assets, including reliance on hydrogen-fueled energy generation.

Strategy

Leverage strategic partnerships and existing projects

Once basic hydrogen infrastructure is in place and the initial project is considered a success, it becomes much easier to add to a project rather than starting a project from scratch. The three highest visibility existing hydrogen demonstration projects are the GM Equinox FCV deployment project, the HAVO Power Park shuttle bus project, and the HCATT Hickam AFB hydrogen project. All of these projects offer infrastructure that can be leveraged with add-on projects. For example the HAVO Power Park project has already attracted interest from the Office of Naval Research who recognized an opportunity to test vehicles in harsh terrains and high sulfur dioxide air conditions. They are also introducing highly engineered energy efficient FROG buildings in the park that will have a hydrogen component. The HCATT project continues to grow with the addition of new hydrogen-fueled equipment and PV and wind power generation added to power the electrolyzer. The Hickam system could be used to supply hydrogen to a new hydrogen-powered Wiki-Wiki shuttle bus or to an Arizona Memorial shuttle bus. The additional shuttle buses could use designs developed under the HAVO hydrogen project.

Position Hawaii for new Projects

"Success Breeds Success". Developing a strong hydrogen program with effective infrastructure makes it easier to win new projects: the entry cost is much lower, competence and experience has been demonstrated, positive relationships with funding authorities have been developed, and previous projects can be leveraged.

Action Plan

Tasks:

Task 1: DBEDT manage the demonstration programs

DBEDT shall have the primary responsibility for executing the "Hydrogen Demonstration Projects Plan".

Task 2: Support the development of hydrogen production capacity

Leverage the HAVO Power Park as a demonstration project "Magnet". With the basic infrastructure in place, a fledgling fleet of shuttle buses, and the knowledge base of operating the systems, the site has the potential to act as a "magnet" for additional projects as follows:

Task 3: Support the installation of hydrogen delivery and fueling infrastructure

Leverage HCATT's hydrogen experience and infrastructure for the supply of hydrogen shuttle buses to HAVO and other hydrogen shuttle bus demonstration projects.

Task 4: Provide substantial and ongoing funding to support tasks 1 through 3

Leverage HCATT's hydrogen experience and infrastructure for the supply of hydrogen shuttle buses to HAVO and other hydrogen shuttle bus demonstration projects.

Appendix E

Public Education Plan

Introduction

In order to obtain community acceptance and support of a hydrogen economy, we need to be able to reach stakeholders, decision-makers, and the general public with information that increases their knowledge of, and comfort with hydrogen. Safety is a dominant theme that is recognized as a critical issue with market acceptance that needs to be addressed by a comprehensive outreach program. In support of this requirement, HRS 196-10, calls for a statewide hydrogen economy public education and outreach plan focusing initially on the island of Hawaii, to be developed in coordination with Hawaii's public education institutions.

The activity that provides the most opportunity of meeting this plan’s outreach objectives is the GM/TGC Equinox FCV rollout project announced in mid 2010. This is a high visibility project located on Oahu. The vehicles will be operated in the most populated area of the state and will be highly visible. GM and TGC are expected to mount an aggressive publicity campaign that will accomplish most if not all of the objectives of the Public Education Plan. The most important role for the State is to support the GM/TGC public outreach activities in as many ways as possible. This can include financial support as well as hosting different activities.

It is not clear in the legislation who is responsible for executing the plan nor does it allocate any dedicated financial resources. Specific projects such as the HAVO Power Park do have project funding available to provide outreach on the specifics of the project although not necessarily the top-level requirement of developing a “Public Education” plan with Hawaii’s public education institutions. Therefore it is recommended that DBEDT be designated to oversee the execution of this plan.

Objective

The objective of the plan is to conduct hydrogen public education and outreach tasks to facilitate the specific projects to be undertaken during the period 2010 to 2020. The plan shall address the following:

1. Provide information to stakeholders, decision-makers, and the general public on the island of Hawaii that increases their knowledge of and comfort with hydrogen.

2. Provide outreach management to facilitate specific demonstration projects, such as the hydrogen-powered shuttle system at Hawaii Volcanoes National Park, specifically:
    a. Safety concerns about the hydrogen fueling station and vehicles;
    b. Cultural concerns;
    c. Land-use concerns; and
    d. Cost/benefit for use of taxpayer funds.

Strategy

For the 2010–2020 period the strategy is to leverage the newsworthiness, public access to, and hands-on demonstration opportunities provided by the HAVO hydrogen project.

Action Plan

Tasks:

Task 1: DBEDT manage the "Public Education Program"

Assign DBEDT the primary responsibility for executing the "Public Education Plan" in coordination with the Big Island's public education institutions.

Task 2: Identify and prioritize target audiences and outreach

Identify and prioritize target audiences and how they can best be reached including:

a. Legislators and policy makers;
b. First responders;
c. Local community;
d. Visitors/users of the HAVO hydrogen demonstration;
e. Visitor industry stakeholders;
f. Renewable/hydrogen strategic partners;
g. General Public;
h. Business leaders;
i. Investors;
j. Educators; and
k. Academia.

Task 3: Identify key talking points

Identify the key talking points to convey to priority audiences, outlined in Task 2.

Task 4: Develop outreach materials

Identify the materials required for conveying talking points and fine-tune to be audience-appropriate in the following venues:

- ✓ Face-to-face engagement: school lectures, neighbor meetings, community boards, and stakeholder meetings.
- ✓ Publications: websites, editorials, articles in local and national newspapers and magazines;
- ✓ PowerPoint presentations and printed materials to support those meetings;
- ✓ Visual content: educational video for use at the HAVO theater, signs for the hydrogen-powered buses, informational brochures and signs inside the buses and visitor's center, advertising and promotional material for conferences and industry gatherings to promote Hawaii and its renewable hydrogen program; and
- ✓ Educational material for educators and museums.

Appendix F

Hawaii Renewables-to-Hydrogen Promotion Plan

Introduction

HRS 196-10 calls for a plan for the promotion of Hawaii's renewable hydrogen resources to potential partners and investors. The plan shall consider the following:

- ✓ Expanded installation of hydrogen production facilities;
- ✓ Development of integrated energy systems including hydrogen vehicles;
- ✓ Construction of additional hydrogen refueling stations; and
- ✓ Promotion of building design and construction that fully incorporates clean energy assets, including reliance on hydrogen-fueled energy generation.

This plan covers the 10-year period from 2010 to 2020. The primary plan activities during this period call for funding projects that meet the Program's overall renewables-to-hydrogen objectives as described in the preceding plan to include seed, venture, and cost share projects.

Similar to the Public Education Plan, the activity that provides the most opportunity of meeting Hawaii's Renewables-to-Hydrogen Promotion Plan's objectives is the GM/TGC project on Oahu. This project provides global visibility to Hawaii's hydrogen programs. The strategy is very simple – work with GM/TGC to leverage their advertising and outreach to highlight the elements of the Hawaii Renewables-to-Hydrogen program.

Another project that can be leveraged to get the message out is the Hawaii Volcanoes National Park (HAVO) fuel cell PHEV shuttle bus project. This is a high visibility project located in Hawaii's largest tourist attraction with over 2 million visitors per year. It addresses the requirement for integrated hydrogen energy systems including hydrogen vehicles and hydrogen fueling infrastructure on the Big Island. It has also attracted interest from the Office of Naval Research who is planning to install buildings at the eruption site that meet the requirement for the promotion of building design and construction that fully incorporate clean energy assets, including reliance on hydrogen-fueled energy generation. The ONR is one of our first partners and investors that have been attracted by the infrastructure opportunities offered by this project. The completed HAVO transportation system will offer the opportunity to present a high profile and newsworthy demonstration project to the world.

Other opportunities to leverage the investment in the HAVO infrastructure, particularly the design of the HAVO shuttle buses include the replacement of the Wiki-Wiki shuttle at the Honolulu International Airport and providing shuttle buses at the Arizona Memorial. The buses could be refueled at the Hickam AFB hydrogen fueling station if suitable arrangements can be made with the DOD. Both of these potential future projects would provide high visibility outreach to a large audience.

It is not clear in the legislation who is responsible for executing the "Renewables to Hydrogen Promotion Plan" nor does it allocate any dedicated financial resources. Specific projects such as the HAVO Power Park do have project funding available to provide outreach on the specifics of the project although not necessarily the top-level requirement of promoting "Renewables-to-Hydrogen" to investors and partners.

The Hawaii Clean Energy Initiative (HCEI) is also promoting renewable energy sources to potential partners and investors so there is overlap between the two programs. This would be best resolved if there is one entity tasked with coordinated the promotion effort. It is recommended that DBEDT be designated to execute the plan.

Objective

Promote Hawaii's "Renewables-to-Hydrogen" Program to potential investors and partners to achieve the following:

- ✓ Expanded installation of hydrogen production facilities;
- ✓ Development of integrated energy systems including hydrogen vehicles;
- ✓ Construct additional hydrogen refueling stations;
- ✓ Promote building design & construction that fully incorporates clean energy assets including reliance on hydrogen-fueled energy generation.

Strategy

The overall strategy is to leverage the newsworthiness of high visibility hydrogen demonstration projects such as the GM/TGC and HAVO hydrogen projects, and to the extent possible, seek funding for additional high visibility demonstrations at heavily trafficked venues such as Honolulu International Airport and the Arizona memorial.

Action Plan

Tasks:

Task 1: DBEDT manage the "Renewables-to-Hydrogen Promotion Plan"

Assign DBEDT the primary responsibility for executing the "Renewables-to-Hydrogen" promotion plan and coordinating the effort with the HCEI program.

Task 2: Leverage hydrogen demonstration project publicity opportunities

Seek opportunities to leverage the promotional value of high visibility hydrogen demonstration projects such as the HAVO Hydrogen Power Park to publicize the Hawaii Renewables-to-Hydrogen Program. Potential venues include the following:

a. Invite hydrogen program managers to present their projects at State of Hawaii sponsored conferences and events;
b. Present technical papers that include information on Hawaii's Renewables-to-Hydrogen Program and HCEI at various industry-sponsored conferences such as the National Hydrogen Association annual conference;
c. Include details of the Program in hydrogen demonstration project outreach activities to the public. For example the materials presented to visitors at HAVO should include information on the Program;
d. Participate in webinars, television documentaries and radio interviews;
e. Publish articles for newspaper and magazines.

Task 3: Capture strategic partners

Target strategic partners identified in the strategic partnership plan. Develop talking points and "value propositions" specific to each target audience/stakeholder group/strategic partner.

Task 4: Develop and maintain a business support tools information database

Prepare updated information on supportive policies, tax incentives and business support tools that add value to renewable energy objectives.

Task 5: Supply chain management support

Develop a list of existing businesses in Hawaii that will support a renewables industry. This would include machine shops, labs, academic R&D facilities etc. Post this information on the DBEDT web site. Keep the information current.

Task 6: Build the business case to invest in Hawaii

Amalgamate existing research and studies on Hawaii's business climate to build the business case to attract partners to invest in Hawaii.

Appendix G

Hydrogen Systems Technologies:

Status, Challenges, and Opportunities

Technology Status

Production

The overarching technical challenge to hydrogen production is cost. Estimates of the delivered cost of hydrogen using currently available technology for all production feed stocks is currently higher than that required for hydrogen to be a cost-competitive primary energy carrier. While hydrogen is abundant in water and in many other chemical compounds, producing pure or "free" hydrogen for an energy supply is costly. Molecular "free" hydrogen can be separated or unbound from naturally occurring compounds such as fossil fuels, water, or biomass using several processes including steam reformation of natural gas, (or other fossil fuels), electrolysis of water, or gasification of biomass. As illustrated in Figure G1, the US DOE hydrogen program is making good progress in reducing the cost of hydrogen production utilizing natural gas as a feedstock but more needs to be accomplished using renewable resources. This presents an opportunity for Hawaii to make progress and attract Federal funding.

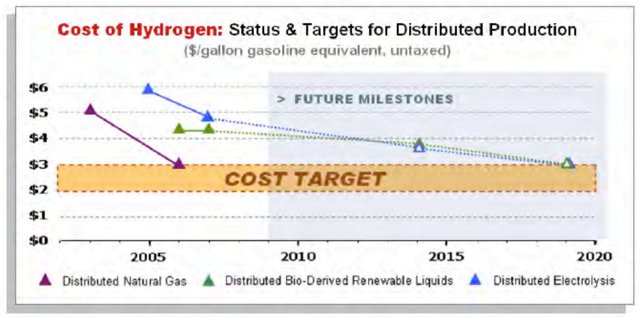
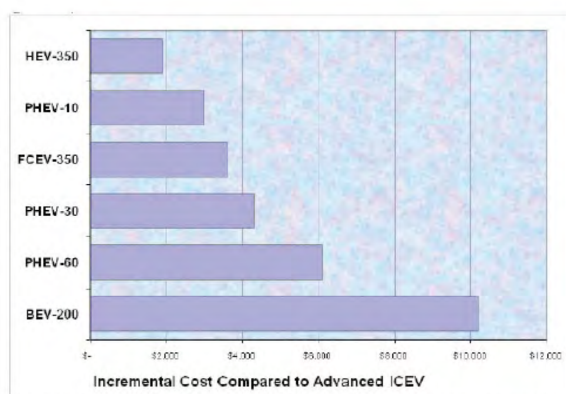


Figure G1: Cost of Hydrogen is falling

Storage

Hydrogen storage is a key enabling technology for the advancement of hydrogen and fuel cell power technologies in transportation, stationary and portable applications. For transportation applications, the overarching technical challenge for hydrogen storage is how to store the necessary amounts of hydrogen required for conventional driving range (greater than 300 miles), within the constraints of weight, value, durability, efficiency, and total cost. Substantial improvements have been made in the weight, volume and cost of systems for vehicular applications. Durability over the performance lifetime of these systems must be verified and validated, and acceptable refueling times must be achieved. Compressed hydrogen is adequate for many near and mid-term applications, though energy density and cost are still issues. Considerable progress has been made in the last 5 years for onboard H_2 storage



Ref: Kromer & Heywood, "Electric Powertrains: Opportunities & Challenges in the U.S. Light-Duty Vehicle Fleet Report # LFEE 2007-03RP, MIT, May, 2007, Table 63

Figure G2: Incremental Cost of Hydrogen Storage

methods to improve the storage density of H_2 in vehicles. DOE and industry research has achieved roughly a doubling of stored capacity in advanced systems over the last 7 years. Concept vehicles have demonstrated ranges >300 miles with compressed H2 storage tanks, without compromising customer requirements. Even at present levels, onboard H2 storage system costs are significantly less than that of the batteries used in EVs and plug-in hybrids. The range of vehicles with compressed hydrogen tanks vastly exceeds the range capability of equivalent size battery powered vehicles of the same energy storage volume. It is recognized that continued research on material based storage systems is required in order to achieve performance and cost targets for the full range of the U.S fleet model mix. The OEMs support the DOE approach to maintaining a research budget balanced across multiple material groups (metal hydrides, chemical hydrides and sorbents). A sustained effort utilizing DOE's key technical resources such as the National Labs is required to ensure these new technologies reach commercial viability.

Delivery

Hydrogen must be transported from the point of production to the point of use. It must also be compressed, stored, and dispensed at refueling stations. Due to its relatively low volumetric density, transportation, storage, and dispensing at the point of use can be one of the significant cost and energy inefficiencies associated with using hydrogen as an energy carrier. If the hydrogen is produced centrally, the longer transportation distances can increase delivery costs. To reduce this transport distance, distributed production at the point of use eliminates the transportation costs but results in higher production costs because the economies of larger scale production are lost. In all cases, the delivery costs associated with compression, storage, and dispensing at the refueling station power site are significant and need to be minimized.

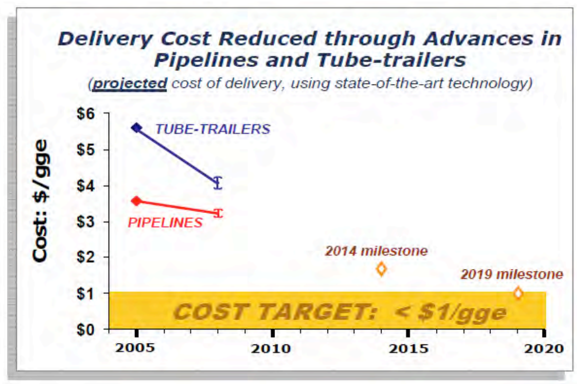


Figure G3: Hydrogen Delivery Costs are

Fuel Cells

For transportation applications, fuel cell technologies face stringent cost and durability requirements. In stationary power application, raising the operating temperature of PEM fuel cells to increase fuel cell performance will also improve heat and power cogeneration and overall system efficiency. Recent technology progress illustrates that fuel cells are the most efficient known way to convert hydrogen to vehicle propulsion energy. Performance and cost of fuel cell systems have improved remarkably in the last 5 years. While progress has tracked US DOE and industry research projections for efficiency, cost reduction and durability improvement, there are still gaps to levels that would make fuel cell technology competitive with advanced combustion engines. DOE's Technology Validation program has demonstrated 58% fuel cell efficiency, nearly meeting the 60% target. Current estimates of $60-$80/kW for fuel cell systems are still too high to meet cost targets of ~$30/kW by evolutionary design and development. The durability of vehicular fuel cell systems has improved dramatically. According to DOE's own assessment, projections of on-

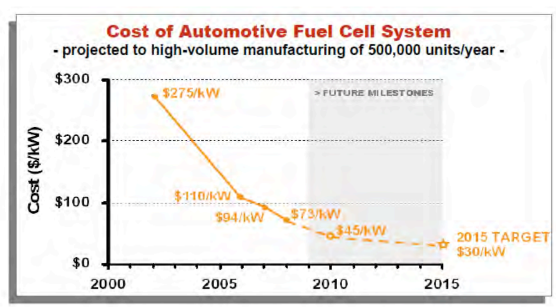


Figure G4: Fuel Cell Costs are Falling

road durability have improved from 950 hours in 2006 to 1900 hours in 2008. The DOE hydrogen program's 2015 target is 5,000-hour durability, equivalent to approximately 150,000 miles of driving. The tolerance of fuel cell stacks to impurities has not yet been established. Tolerance to air, fuel, and system-derived impurities (including the storage system) needs to be established.

Manufacturing Technology

PEM Fuel Cells – The ramp-up to high-volume production of PEM fuel cells will require quality control and measurement technologies consistent with high-volume manufacturing processes.

Hydrogen Storage – Cost is the primary issue with composite tank technology. Manufacturing carbon fiber storage tanks for both vehicular and stationary storage at forecourt stations will require dramatic reductions in unit costs and fabrication times while ensuring required quality control.

End-use Applications

Utilities

The hydrogen market is identifying applications where the value proposition of a hydrogen solution makes the product "better" than the incumbent. This is seen primarily in areas for battery replacement such as communications backup power where battery systems are found to be inadequate and customers are looking for new solutions.

Transportation

New fuels and alternative vehicles will be required to substantially cut Hawaii's dependence on imported oil and reduce our transportation sector carbon footprint. Biofuels such as biodiesel and ethanol, especially if made from cellulosic feedstocks, are promising. Hydrogen and electricity will eventually become key zero-carbon transportation fuels. In terms of alternative vehicles, gasoline-powered hybrid electric vehicles (HEVs) are already making an impact in the light duty vehicle fleet, and plug-in hybrid electric vehicles (PHEVs) that derive some of their energy from the electrical grid may soon enter the marketplace. The combination of biofuels and PHEVs will reduce oil consumption. Ultimately all-electric vehicles powered either by fuel cells or batteries could make a major contribution to achieving our long-term societal goals.

Challenges

Technical (Non-Market) Challenges and Barriers

For hydrogen to become a major energy carrier, its combination of cost and power systems, must be competitive with the alternatives available in the marketplace.

Hydrogen is Costly to Produce: The overarching technical challenge to hydrogen production is cost. Estimates of the delivered cost of hydrogen using currently available technology for all production feed stocks is currently higher than that required for hydrogen to be a cost-competitive primary energy carrier. While hydrogen is abundant in water and in many other chemical compounds, producing pure or "free" hydrogen for an energy supply is costly. Molecular "free" hydrogen can be separated or unbound from naturally occurring compounds such as fossil fuels, water, or biomass using several processes including steam reformation of natural gas, (or other fossil fuels), electrolysis of water, or gasification of biomass.

- ✓ **Biomass Reformation, Gasification and Pyrolysis**
  Hydrogen can be produced from biomass either by reformation of bio-derived liquids or through gasification or pyrolysis of biomass feed stocks. The costs of currently available bio-derived liquids such as ethanol or sugar alcohols need to be reduced. Significant improvements in reforming and improved technologies need to be developed for other bio-derived liquids to reduce the capital and operating costs for this option to become competitive. Large stocks of biomass are required to produce a significant amount of hydrogen, making it more costly than using fossil fuels. Biomass production also requires large land areas.

- ✓ **Electrolysis**
  In this process an electric current is used to split water into hydrogen and oxygen gases. Using an electric current to produce hydrogen from water permits the use of renewable energy sources such as solar, wind, and geothermal power. The cost of the hydrogen primarily depends on the cost of the renewable electricity resource. It requires approximately 60 kilowatt-hours of electricity to produce one kilogram of hydrogen compressed to 5,000 pounds per square inch. For curtailed electricity that cannot be utilized and is "dumped", the cost of hydrogen can be very competitive to gasoline[2]. The capital costs of current electrolysis systems, along with the high cost of electricity in many regions, limit widespread adoption of electrolysis technology for hydrogen production. Making efficiency improvements to electrolyzers is proving to be difficult and incremental. Lowering the cost of electrolyzers would reduce the capital cost of acquisition but when amortized over the life of the electrolyzer would have marginal impact on the cost of hydrogen. Therefore the major effort should be focused on developing hydrogen as a way to store curtailed renewable electricity production.

- ✓ **High Temperature Thermo-Chemical Production**
  Solar-driven, thermo-chemical production using water-splitting chemical cycles is at an early stage of research. Research is also needed to cost-effectively couple the thermo-chemical cycles with advanced concentrated solar energy technology. If these efforts are successful, high temperature thermo-chemical processes may provide a clean, efficient, and sustainable route for producing hydrogen from water.

- ✓ **Photo-Electrochemical Hydrogen Production (PEC)**
  PEC hydrogen production (direct water splitting), also in an early stage of development, depends on a breakthrough in materials development and could require large areas of land. Research in this area is progressing on three fronts: (1) the study of high-efficiency materials in order to attain the fundamental understanding needed develop higher-efficiency lower-cost materials; (2) the study of low-cost durable materials in order to modify higher-efficiency lower-durability materials; and (3) the development of multijunction devices incorporating multiple layers to achieve efficient water splitting.

- ✓ **Biological Hydrogen Production**
  Biological hydrogen production is in an early stage of research and presents many technical challenges, beginning with bioengineering of microorganisms that can produce

[2] One (1) kilogram of hydrogen is approximately equivalent in energy content to a gallon of gasoline. Therefore multiplying the cost per kilowatt of electricity by 60 kilowatts gives the equivalent cost of a gallon of gasoline or gasoline gallon equivalent (gge). Wind at 2 cents per kilowatt-hour will produce a kilogram of hydrogen at a gallon-gasoline equivalent (gge) cost of $1.20. **These are electrical costs only and do include CAPEX and non-electricity OPEX costs.**

hydrogen at high rates and easily collectible form. Some of the challenges are related to increased light utilization efficiency, and increased hydrogen molar yield. The advantages of biological hydrogen production are that high-purity water is not required and toxic or polluting by-products are not generated. Table 1 provides the commercialization status of each hydrogen production process.[3]

Table 1: Technology Status of Hydrogen Production

Hydrogen Production Process	Commercialization Status
Steam Methane Reforming	Commercial
Electrolysis	Commercial
Biomass Gasification	Pre-commercial
Biomass Pyrolysis	R&D
Thermochemical	R&D
Photoelectrochemical	R&D
Photobiological	R&D

Opportunities: Biomass-to-Hydrogen Pathway

The composition of biomass varies depending on the species and local growing and harvesting conditions. Nevertheless, on a dry mass basis, biomass typically contains about 48% carbon, 6% hydrogen, and 42% oxygen. Biomass typically contains ~ 80% volatile matter and 15% fixed carbon. The volatile matter is classified as the amount of fuel mass which is driven off as a gas when a sample is heated in an inert environment.

Figure G5 illustrates that multiple pathways exist between plant/crop options on the left of the diagram and bioenergy products on the right. A number of technology components may be required for any pathway. Agricultural producers in Hawaii have grown a variety of crops and the basics cultural practices of land preparation, seed production, planting, fertilization, and weed control are well understood and not viewed as primary technology challenges. Crop harvesting and the transportation of the material from field to conversion facility are two remaining unit operations. Many of the crops proposed for bioenergy development have not previously been grown commercially in the State and cost effective harvesting techniques will be important.

[3] Hydrogen production information was taken from "Nurturing a Clean Energy Future in Hawaii: Assessing the Feasibility of Large-Scale Utilization of Hydrogen and Fuel Cells in Hawaii" Final Report (Revised July 2004) prepared by HNEI and Sentech Inc.

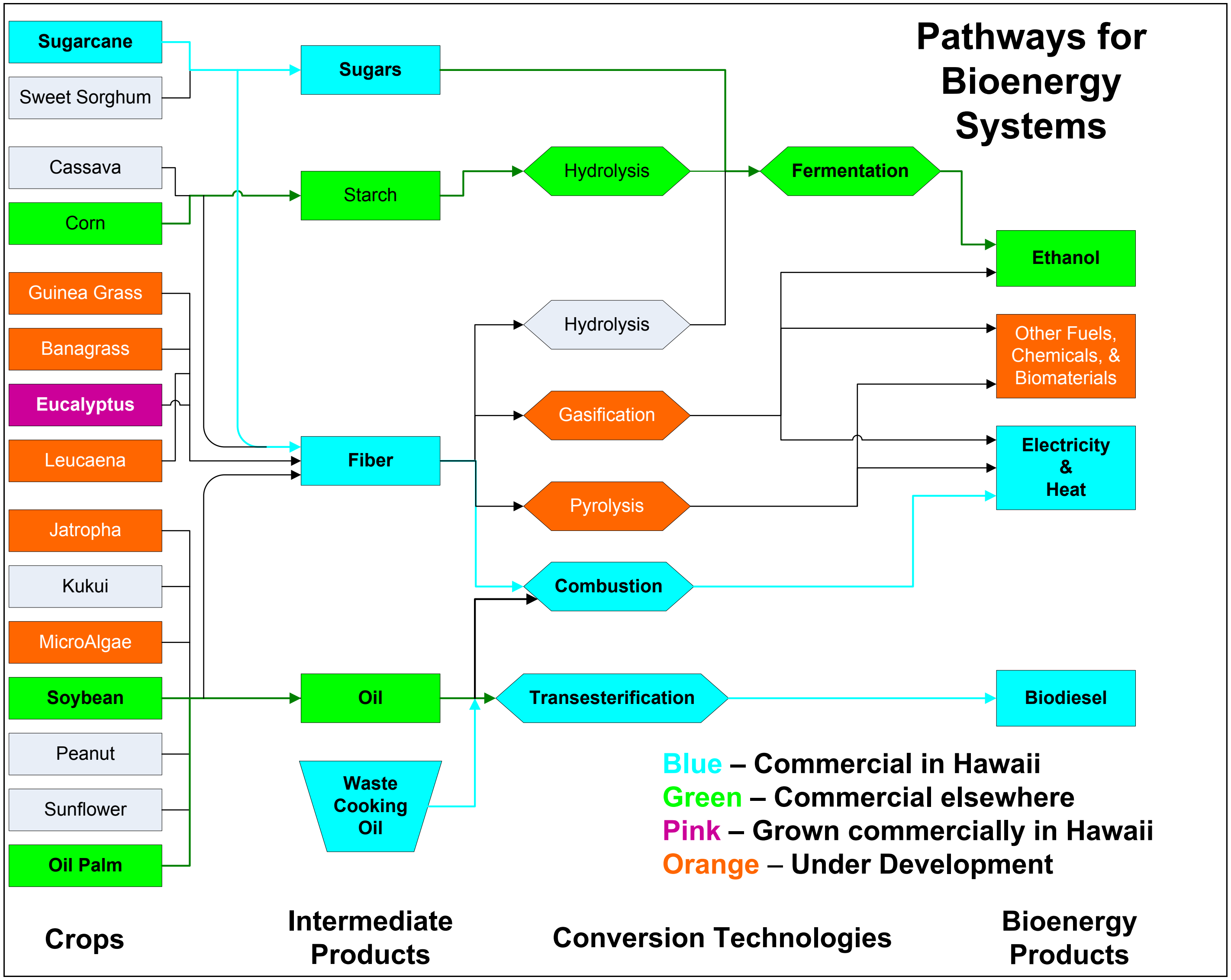


Figure G5: Pathways for Bioenergy Systems.

Pyrolysis

Pyrolysis is a process in which biomass is heated rapidly to ~600°C in the absence of oxygen. The biomass feedstock decomposes and when the products are brought to ambient conditions, the result is a mixture of solid char, permanent gases, and liquid phase bio-oil. Pyrolysis processes are designed to maximize the production of the liquid called bio-oil or pyrolysis oil. With additional processing bio-oil can be used in combustion turbines. In boilers, bio-oil does not provide energy advantages over firing biomass directly as any gain in efficiency is more than offset by the energy expended to produce the bio-oil.

Gasification

Gasification is the partial oxidation of a solid fuel to form a combustible gas. Generally the goal of a gasification process is to simultaneously maximize the solid fuel carbon conversion and the heating value of the product gas. Air and steam are commonly used oxidizers when electricity is the desired end product. A number of fuels and chemicals can be synthesized from gas rich in hydrogen and carbon monoxide commonly called syngas. Syngas containing a prescribed ratio of these two building block molecules is passed over a catalyst at specified conditions of temperature and pressure to synthesize target compounds. A recent report by the National Renewable Energy Laboratory reviewed possible fuel and chemical products that might be produced from biomass via gasification and included hydrogen. Hydrogen is also produced from the purification of syngas.

Biodiesel Production

Biodiesel can be produced from vegetable oils, animal fats, or recycled restaurant grease. Converting cooking oil and restaurant grease to biodiesel eliminates the need to dispose of these wastes, and creates a commercial product that reduces air emissions and decreases the nation's dependence on imported fossil fuels. Biodiesel has properties similar to those of petroleum-based fuel with several notable exceptions. Biodiesel is virtually free of sulfur, ring molecules, and aromatics often associated with its fossil counterpart. Biodiesel also has slightly lower energy density that petroleum diesel. Biodiesel is composed of fatty acid methyl esters derived from medium length fatty acid chains. Biodiesel is produced by esterfication of these fatty acids. Oil reacts with ethanol or methanol and a lye catalyst in a process called trans-esterfication to produce biodiesel. The major byproduct of the process is glycerin, which is separated.

Opportunities: Excess Renewable Electricity-to-Hydrogen Pathway

Excess Renewable Electricity-to-Hydrogen Pathway

The major renewable electricity generation resources in Hawaii are generated by geothermal, wind, and solar. Geothermal is base load (constant) power, and wind and solar resources are intermittent.

Electrolyzer Systems

There are two types of industrial electrolysis systems:

Alkaline Electrolyzer: uses an aqueous solution of 30% potassium hydroxide (KOH) as the electrolyte.

Solid Polymer Electrolyte (SPE) Electrolyzer: This type is also referred to as a PEM or Proton Exchange Membrane electrolyzer. The electrolyte is a solid ion-conducting membrane as opposed to the aqueous solution in the alkaline electrolyzers.

Electrolyzer Capital Cost: Electrolyzer capital costs are usually quoted on the basis of cost per kilowatt input power. These quotes are multiplied by the input power to obtain electrolyzer capital cost. The input power is calculated as the maximum electricity necessary to operate the electrolyzer at full capacity.

Electrolyzer System Efficiency

The system efficiency is defined as the higher heating value (HHV) of hydrogen divided by the energy consumed by the electrolysis system per kilogram of hydrogen produced. It includes the balance of system energy requirements and ranges from 56 to 73%. The PEM electrolyzer is the lowest at 56%. Alkaline bipolar electrolyzers are the highest at 73%. These efficiencies would decrease if additional compression were included due to compressor energy consumption.

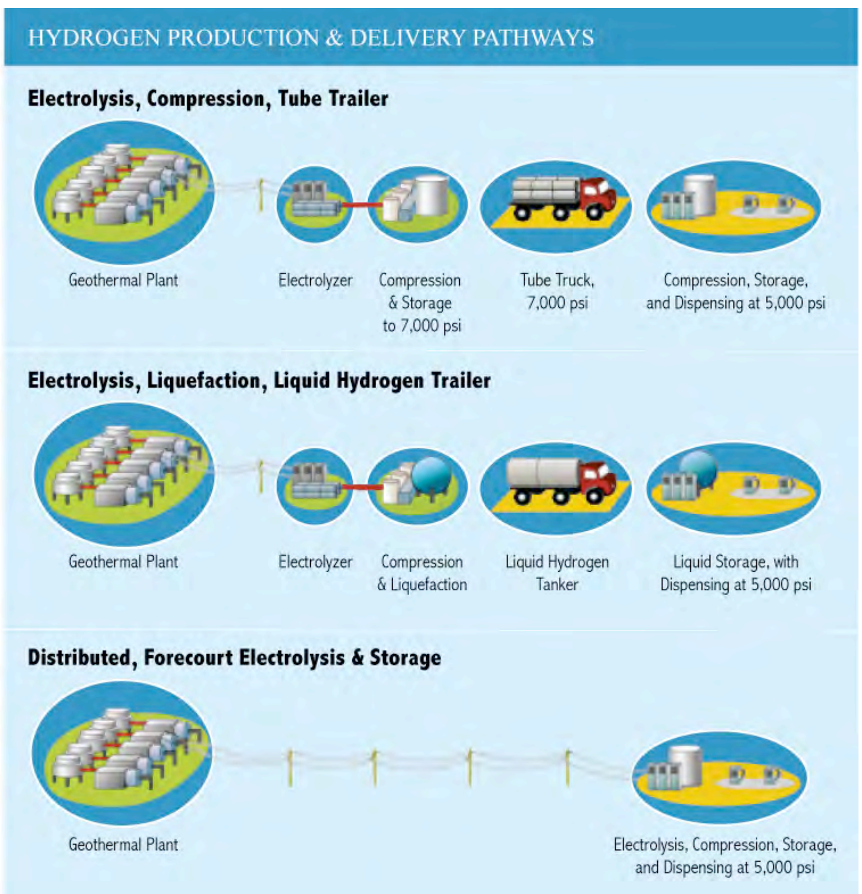


Figure G6: Hydrogen electrolyzer production and delivery pathways.[4]

[4] "Analysis of Geothermally Produced Hydrogen on the Big Island of Hawaii: A Roadmap for the Way Forward" prepared by Sentech, September 30, 2008.

Due to the electrolysis round-trip efficiency, storing the hydrogen, and then utilizing the hydrogen to provide energy services, it is always preferable to use renewable electricity generation resources as it is generated to meet a load demand. However wind and solar generators are intermittent and may produce electricity when there is no load to accept it. In the case of geothermal, it serves as a base load but may exceed the utilities requirements particularly at night when the grid load demand is significantly reduced. The geothermal plant prefers to maintain a steady state output to reduce thermal management issues. In these cases, instead of curtailing or dumping the electricity, it is preferable to use this electricity to produce hydrogen by powering an electrolyzer.

Compressors

Some electrolyzers produce hydrogen at 360 psi, so depending on the application, for example a stationary power system, a compressor may not be necessary. For the majority of transportation applications, onboard hydrogen storage is currently (2010) at 5,000 psi. This has recently increased to 10,000 psi for the GM Equinox. It is expected that other manufacturers will follow GM's lead. High pressure compression increases the cost of the hydrogen.

Electricity Cost

Electrolysis requires electricity and water to produce hydrogen. Figure G7 illustrates the impact of electricity cost on the cost of hydrogen**.**

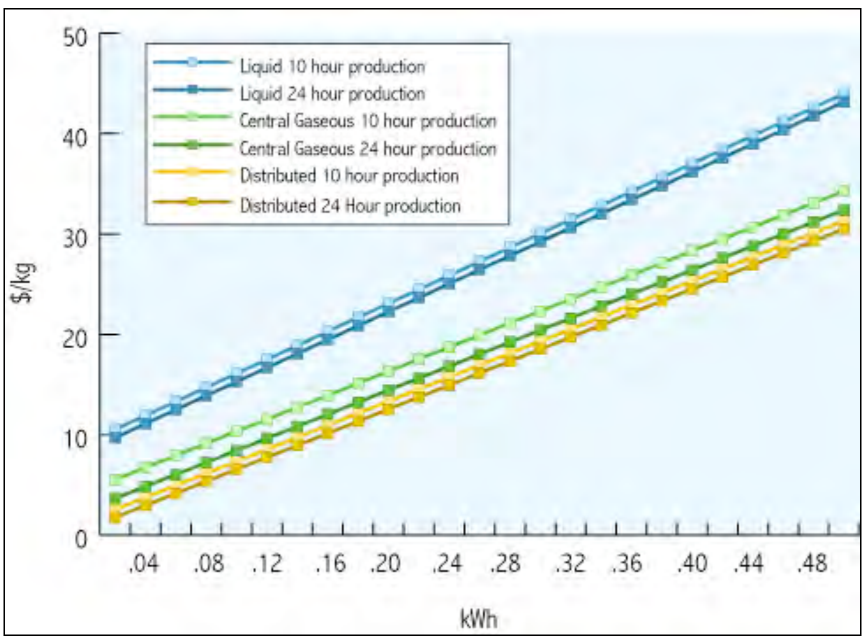


Figure G7: Cost per kilogram of hydrogen per kWh.[5]

As illustrated in Figure G7, electricity cost is the main cost driver to the cost of producing electrolytic hydrogen. Therefore for the renewable electricity to hydrogen pathway, the hydrogen fund should be focused on projects that drive down the cost of producing

[5] "Analysis of Geothermally Produced Hydrogen on the Big Island of Hawaii: A Roadmap for the Way Forward" prepared by Sentech, September 30, 2008.

renewable electricity. It can be argued that for curtailed renewable electricity that the cost of the electricity has a zero value and drives the cost of hydrogen to ~$1.50 per kg. This makes it very competitive with fossil fuels.

Investment Focus

Investment should be focused on projects that drive down the cost of electrical power and on distributed production installations. For example a renewable electrical generating system collocated with hydrogen production system at the point of dispensing.

Appendix H

Investment Summary:

Investments Made

The following investments have been made as of the 1st of January 2011.

ClearFuels Technology, Inc. **Venture Investment: $1,000,000**
ClearFuels and its partners are developing advanced sustainable bio-refineries that convert multiple mixed cellulosic biomass feedstocks into sustainable, high-value energy products including renewable Fischer-Tropsch ("FT") diesel, jet fuel, ethanol, hydrogen and power at industry-leading yields.

Big Island Biodiesel **Venture Investment: $800,000**
Big Island Biodiesel, LLC (BIB) is a spin-out of Pacific Biodiesel, Inc (PBI) formed to construct a new biodiesel facility on the Big Island. The new facility will incorporate the latest technology developed through PBI's subsidiary Pacific Biodiesel Technologies and will co-produce a high quality glycerin which can be transformed into hydrogen fuel.

Kuehnle Agrosystems, Inc. **Seed Investment: $200,000**
Cost-Share Investment: $375,000
Kuehnle Agrosystems, Inc. (KAS) is focusing on the market verticals of biofuels, carbon dioxide, and aquaculture, with KAS's live algae being the product to be sold or licensed. KAS, as a research organization, is in a position to discover and hold patents on algae strains optimized for hydrogen production by two possible means: gasification or fermentation of leftover algal components after oil extraction (indirect, byproduct hydrogen production), and direct methods of hydrogen creation from oil-rich algae in its entirety.

Real Green Power **Seed Investment: $200,000**
Cost-Share Investment: $150,000
RealGreen Power, Inc. ("RGP") is a wastewater technology company and renewable energy project developer. With proprietary technology, the Company transforms wastewater into agricultural grade or drinking water and generates renewable energy that can be sold at a premium to private businesses and utilities. RGP specializes in integrated wastewater treatment solutions that in addition to water rehabilitation generate substantial amounts of methane that in turn can be used for multiple applications. Methane is useful for power generation, hydrogen production, transportation fuels, and as combustion fuel for water heating.

Phycal **Cost-Share Investment: $200,000**
Phycal LLC is an algal biofuel company with plans to develop a pilot farm in Hawaii. Phycal's technical team has developed an integrated production system for growing algae and extracting products, primarily algal oil to be converted into drop-in "green" replacements for diesel, jet fuel and other energy products. Phycal's business team has identified a 34-acre pilot farm in Hawaii and has been selected by the Department of Energy to fund a major portion of the pilot. Phycal is focusing initially on Hawaii because of its climate, significant public support, and favorable market for algal biofuel.

Active Investments Under Consideration

The following investments are under consideration as of the 1st of January 2011. Due to the status of negotiations, the individual companies and amounts are confidential.

- Cost-Share Committed but not yet deployed: $2,675,000
- Investment Commitments under final due diligence review: $1,200,000