Summary Report of the Innovative Energy Systems Workshop[1]

Honolulu, HI – March 19-21, 2003

Workshop Overview

This two-day workshop presented the final results of the "Sea Water Air Conditioning Feasibility Analysis" project. Preliminary results from two other projects were also presented and discussed ("Integration of Energy Storage with Seawater Air Conditioning [SWAC] Systems" and "Application of the Kalina Cycle® to Waste Heat Recovery in Hawaii.")

The workshop covered district cooling systems, SWAC, thermal energy storage systems, applications of the Kalina Cycle®, and waste heat recovery. Selected invited speakers presented information on each of these topics. This workshop attempted to bring together mainland and international experts in energy storage systems, district cooling systems, and waste heat recovery with local experts in seawater air conditioning (SWAC) systems, in order to help commercialize such systems in Hawaii.

District Cooling provides chilled water from a cooling plant through a network of pipes to multiple residential, industrial and commercial buildings for air conditioning use. SWAC uses an abundant renewable energy resource, cold, deep seawater from depths of more than 1,600 feet, and a heat exchanger, to cool the chilled water used in a district cooling system. Thermal Energy Storage technology can be used to significantly reduce energy costs by allowing energy-intensive, electrically-driven cooling equipment to be predominantly operated during off-peak hours when electricity rates are lower.

The best system for Hawaii (and possibly other areas where the technology might be marketed) might be a hybrid SWAC/Thermal Energy Storage system. This would allow the SWAC system to supply a much larger base load cooling demand (for a given pipe

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[1] This summary was prepared from: (1) the Innovative Energy Systems Workshop Program; (2) the final report of the "Integration of Energy Storage with Seawater Air Conditioning (SWAC) Systems project prepared by John S. Andrepont of The Cool Solutions Company, Lisle, IL; and (3) the final report of the "Application of the Kalina Cycle® to Waste Heat Recovery in Hawaii" project prepared by Stephen Oney and Hans Krock of Ocean Engineering & Energy Systems (OCEES), Honolulu, HI.

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size and cost), and for the energy storage system to supply the peak demand. A smaller energy storage system would also be able to provide peaking capabilities for a much larger district cooling system. Utility demand during peak demand periods would be reduced significantly. Energy savings in excess of 80% are possible. Cost savings of 18 to 58% are also possible.
The Kalina Cycle® is a thermal-to-mechanical energy conversion process that is able to convert relatively low temperature waste heat into useful mechanical energy at better efficiencies than other types of heat engines. The Kalina Cycle® engine is at least 10 percent more efficient than the other heat engines, is simple in design, and can use readily-available, off-the-shelf components. Applications of the Kalina Cycle® include ocean thermal energy conversion (OTEC) and as a bottoming cycle for fossil fueled and geothermal power plans and combined heat and power (CHP) generation systems.

Applications of these innovative energy systems have the potential to supply more than half of the State of Hawaii's renewable energy goals and to allow a much more efficient use of current energy supplies.

Workshop Results

The two-day workshop and optional third-day technical tour, addressed the status of evaluations and developments in the areas of Seawater Air-Conditioning (SWAC) and Kalina Cycle® applications for Hawaii and elsewhere.

The first day of the workshop, Wednesday March 19, 2003, focused on the potential for commercial SWAC implementation in Hawaii as a follow-up to recommendations outlined in the DBEDT report "Seawater District Cooling Feasibility Analysis for the State of Hawaii," October 2002.

The second day of the workshop, Thursday March 20, 2003, entailed two varying topics. The morning session focused on the Kalina Cycle® technology and its potential applications with particular emphasis for Hawaii. The afternoon sessions provided a forum for workshop participants to provide feedback and suggestions towards implementing and actualizing the proposed energy systems into commercial applications in Hawaii.

Over 70 attendees participated in the workshop, representing a cross-section of researchers, industry experts, representatives of interested private, military and other government facilities, engineers and equipment suppliers.

The workshop was both an exposition of detailed useful information and an interactive forum for discussion and exchange (indeed expansion) of knowledge.

One point of consensus was that the workshop was very successful for the attendees, providing new information and insights to all participants. Many of the participants of the workshop expressed their recognition of Hawaii's unique opportunity, and therefore, responsibility, to embrace renewable technologies such as SWAC and the Kalina

Cycle® effectively leveraging Hawaii's most abundant natural resource, the tropical ocean.

Overall success of the workshop will be determined by the level of commercialization of the discussed technologies in Hawaii over the next few years.
Major consensus was apparent in several key areas, as highlighted by certain observations:

Seawater Air Conditioning (SWAC)/Thermal Energy Storage (TES)

- Technology developments are quite mature at this point. Demonstrations, and in many cases successful commercial installations, underscore the readiness for more widespread application.
- The cold water (deep ocean) resource is a unique advantage and opportunity throughout Hawaii.
- Hawaii offers numerous potentially beneficial uses of that resource.
- Benefits will accrue to users, developers, the community, the State, the environment, and others.
- Economic feasibility has now been demonstrated for many potential applications in Hawaii.
- Immediate effort should be focused on moving the technologies into commercial realization.
- A key element of successful commercial development could be the identification and formation of an appropriate Public-Private Partnership, along the models employed in other successful developments.

The Kalina Cycle®

- Kalina Cycle® technology is a very cost competitive technology to conventional systems when life cycle cost analysis is applied.
- The Kalina Cycle® has a very quick payoff period and a good return on investment (ROI) for many waste heat applications.
- The Kalina Cycle® has very low operational and maintenance costs with little or no deleterious environmental effects.
- Hawaii offers numerous potentially beneficial uses of this technology.
- The waste heat resources available for potential exploitation are significant.
- Three principal applications for Kalina Cycle® waste heat recovery stand out:
  - Ocean Thermal Energy Conversion (OTEC) – both land-based and shelf-mounted facilities.
  - Waste heat recovery from geothermal brine from Puna Geothermal power facility on the Big Island.
  - Bottoming cycle applications to existing fossil and bio-fuel based power plants across the state.

Day 1 – March 19, 2003

District Cooling, SWAC, and SWAC-TES Hybrids for Hawaii

Welcome and Opening Comments

Dr. David Rezachek, Alternate Energy Specialist – State of Hawaii DBEDT, ERTD

Dr. Rezachek provided a brief welcome to the attendees and an overview of the workshop.

District Cooling Systems – An Overview

Jack Kattner, CEO – FVB Energy, Inc.

Mr. Kattner, acting as a Director and past President of IDEA (International District Energy Association), provided a detailed overview of District Energy (DE) and the current trends in the DE industry.

- The concept of DE was presented, in which multiple buildings or facilities are heated and/or cooled, using thermal energy (steam, hot water, and/or chilled water) delivered to the customer facilities via piping networks.
- DE was stressed as a means of risk management for DE customers.
- DE is experiencing a lot of recent growth, on top of an already significant and technically mature industry.
- District Cooling (DC) serves to flatten customers' electric demand profiles.
- DC growth has been dramatic during the 1990s and since 2000.
- DE drivers include energy issues and costs and environmental issues. DE often serves as a key platform for the economic deployment of other technologies that benefit customer economics, energy efficiency and environmental emissions. Such technologies include Thermal Energy Storage (TES), cogeneration or Combined Heat & Power (CHP), thermal-driven chilling, hybrid chiller plants, alternate fuels, etc. Such technologies are often more readily and more economically employed in DE systems compared to individual building scenarios. In this way, DC may be key to deployment of SWAC.
- IDEA's "DE Space" collects IDEA members' reported data of new customers using DE services. This partial reporting of such data has totaled 225 million square feet of space from 1990 through 2001, or approximately 20 million square feet per year. Customer end-use types include: commercial offices, hotels, retail facilities, entertainment/cultural/sports facilities, convention centers, residential facilities, educational (school and university) facilities, healthcare (hospital and medical) facilities, government and institutional facilities, industrial & manufacturing facilities, and others.

- President Bush's Energy Policy was announced in the Spring of 2001 in St. Paul, Minnesota. The President cited District Energy St. Paul (DESP) and its DE/CHP system as a model of energy efficiency, energy diversity, and economy.
- Among the list of recent winners of IDEA's DE "System of the Year" award are DESP and Cornell University (noteworthy for its Deep Lake Source Cooling system).
- IDEA's nearly 1000 members represent a broad base of private and institutional DE system owners-operators, as well as suppliers and consultants to the industry. Members are primarily from North America, but also from dozens of countries around the world. IDEA produces a magazine, a newsletter and conferences and workshops. Additional information can be found on the IDEA website: http://www.districtenergy.org.

Project Financing for District Energy Systems

Scott Blumeyer, President – Norventus Group LLC

Mr. Blumeyer discussed the issues related to financing DE systems in general and Hawaii SWAC DE systems in particular.

- The SWAC feasibility analysis (Oct 2002) was referenced.
- Previously and recently, DC market analysis has been conducted for the Honolulu area.
- The technical precedent exists for both DC systems and for Deep Water Source DC systems.
- Government (State and Federal) mandates and support exist to encourage SWAC DC development.
- However, financial investment markets are generally "skittish" at present.
- Major barriers (per a recent IDEA/US DOE poll of universities) include:
  - Access to capital – a function of investor sentiment
  - Technical complexity – which impacts on the pro forma analysis
  - Market acceptance – dependent on the strategic sales cycle
- DE is an intersection of different things to different people. Relevant issues (and stakeholders) include: the energy play and real estate issues (users), economic development (local government), load management (local utility), and financial risk/reward (investors).
- A successful Finance Plan must: (1) be credible to DE investors, (2) strike a balance between cost of capital and covenants, (3) ensure a long-term funding commitment, and (4) result in a "close".
- The Capital Markets Equity Pool includes utilities, institutional, and investment funds.
- The Capital Markets Debt Pool includes institutional, commercial, and municipal.

- A potential resource would be a Public-Private Partnership (PPP). This would potentially offer: (1) improved access to land and rights-of-way, (2) a local component to complement mainland DC experience, and (3) an accelerated schedule for logistical issues. Examples of PPP include BOT (build-operate-transfer), BTO (build-transfer-operate), and perhaps most appropriately, BOO (build-own-operate). There are many precedents for the PPP approach, including water and wastewater treatment systems, infrastructure development (e.g. transportation), and indeed, DE systems.
- It is important to manage investor expectations and risk:
  - DE is not high-risk venture capital with high potential gains. Realistic and attractive returns are in the low teens.
  - Competitive debt rates are necessary.
  - The PPP approach helps with guarantors.
  - Coverage ratios should be attainable (by phasing development and investments, to the extent practical).
- Lessons Learned include the following necessities for successful financing: pre-sold long-term customer contracts, solid contract terms, credit worthiness of customers, and market sustainability.
- Also needed are DE management experience, DE marketing horsepower, and proven success stories.
- Recommended next steps for the Finance Plan for Hawaii SWAC systems include: (1) Developing a “qualifying prospectus”, (2) creating a PPP, (3) confirming the financial market feasibility, and (4) if warranted, producing an offering memorandum.
- A precursor to the pro forma includes defining: (1) what the market will bear, (2) price point analysis to reflect customer perspectives, (3) differentiation of customer load profiles, (4) chilled water rate structure, and a real-estate comparison ($ per sq ft basis).
- A Case Study of a Downtown Honolulu SWAC DC development (Phase 1) was completed, with the following assumptions:
  - 8,465 Tons of customers (40% market penetration) over 3 years
  - $42 million in capital costs
  - A composite debt rate of 6.25%
  - Equity equal to 30% of CapEx
  - Minimum Return on Equity (ROE) of 13%
  - Minimum Debt Coverage Ratio (free cash flow over debt service or EBITDA/P&I) of 1.5

- Preliminary pro forma results through 3 phases were developed and are promising.

	Phase 1	Phase 2	Phase 3
Percent market share*	40%	60%**	80%
Customer Load (Tons)	8,465	12,700	16,930
CapEx (cumulative total)	$42 million	$48 million	$50 million
ROE	16.0%	19.0%	24.5%
Debt Coverage Ratio	1.5	2.0	3.0

(* Based only on the large potential customers in Honolulu.)
(** Anders Rydaker noted that DESP's DC system achieved 60 to 65% market share after 10 years.)

- The West Waikiki development can be expected to produce comparable results.
- Other issues (not yet factored into the pro forma above), could generate significant further enhancements, such as: (1) investment tax credits, (2) Act 221 tax credits, (3) TES tax credits, (4) bonus depreciation schedules (IRS willing), (5) utility rebates (potentially up to $650 per avoided peak kW), and (6) federal energy production incentives (potentially $0.015 or even $0.045 per kWh of avoided energy use).

Seawater Air Conditioning (SWAC), Cold Water Pipe Design, and a Brief Overview of Toronto Lake Source Cooling Project

Dr. Joe Van Ryzin, President – Makai Ocean Engineering

Dr. Van Ryzin reviewed key aspects of SWAC system design and implementation, and provided a brief summary of the Lake Source Cooling project in Toronto, Ontario.

- SWAC systems employ a heat exchanger (HX) to segregate the seawater piping system from the fresh water cooling network. The SWAC HXs are routinely plate-and-frame type HXs using Titanium plates for corrosion resistance to the seawater. The seawater piping is HDPE (High Density Polyethylene), also providing corrosion resistance.
- Experience with SWAC (and related Deep Lake Source Cooling) systems is already substantial: 5 pipelines installed in Hawaii since 1979, plus recently or soon to be completed systems at Cornell University, Toronto, and French Polynesia.
- Piping system deployment is a sophisticated, well-planned, rapid, and proven process.
- The recent installation at NELHA on the Big Island is a 3,000 foot deep, 55 inch diameter pipe with 39 ºF (4 ºC) seawater and 17,000 ton potential cooling capacity.

- Reasons to consider and employ SWAC include:
  - the right thing to do both economically and environmentally
  - simple and abundant (essentially unlimited)
  - 75 to 90% energy savings (and similar emissions reduction)
  - reduction or elimination of CFC and other refrigerants
  - addresses global warming concerns
  - economical today at some locations
- SWAC and Deep Lake Source Cooling applications include:
  - Cornell University, Ithaca, NY – 20,000 tons
  - Toronto, Ontario – 58,000 tons (under construction)
  - Halifax, Nova Scotia – 1,000 tons (very early system)
  - Sweden – urban systems using harbor water
  - NELHA, Big Island – 30 to 50 tons (plus numerous aquaculture and agriculture applications)
  - Tahiti – underway
  - Curacao – underway
  - Korea – underway
- Toronto Lake Source Cooling
  - Combination system for District Cooling (DC) and municipal water supply
  - 58,000 ton ultimate cooling capacity
  - 3 x 63 inch diameter pipes, 4 miles long, ~80m deep
  - Lake water flows: from lake – to filtration system – to DC HX – to municipal water system.
  - DC system water flows in a closed loop: from DC HX – to chilled water plant (for additional cooling) – to DC users – back to DC HX.
  - 75% projected energy savings (30 million kWh/yr)
  - Similar savings in refrigerants, CO_2, NO_x, and SO_2.
- Relative to conventional AC systems, SWAC has a major increase in capital investment, but a dramatic reduction in energy costs. Total life cycle costs are significantly reduced with SWAC.
- Ideal conditions for SWAC:
  - coastline near deep water
  - cooling customers near to shore
  - high annual cooling usage
  - high local electric costs
  - large systems (benefiting from economy-of-scale)
  - new construction
- Required DC system operating temp impacts system design and cost:
  - Lower temps require deeper, longer, costlier pipes
  - High pipe cost dictates “preservation” of the minimum available temp
  - If necessary, conventional chillers can used in series with SWAC (as in Toronto)
- SWAC system Delta T can be increased, improving economics, through secondary uses of the warmed (but still cool) seawater.

- Attractive SWAC sites have been identified, especially on Oahu, where 50,000 tons are realistic:
    - West Coast – very near to deep cold water
    - Honolulu – requires longer cooling pipes, but a dense collection of large cooling demand
    - Kakaako – new development, large demand, few key decision-makers (however, 4+ miles to 500 m deep water, but can be supplemented with chillers and Thermal Energy Storage.
- SWAC can be developed within Hawaii now and can be an export technology for Hawaii.

Cornell Lake Source Cooling Project

W. S. (Lanny) Joyce, Manager of Engineering, Planning and Energy Management – Cornell University

Mr. Joyce provided an overview of the Cornell University's Lake Source Cooling (LSC) project, including the project's history, installation, challenges, and success. (Additional detail can be found at the website: http://www.utilities.cornell.edu.)

- Reasons to employ LSC at Cornell
    - 40,000 lbs of CFC eliminated or recycled
    - energy efficiency (over 80% energy savings)
    - decreased reliance on fossil fuels (reduce pollution, acid rain, global warming)
    - cost-effective over the long-term ($58 million in capital for a 20,000 ton LSC system, 10 to 13 year payback)
    - community benefits
- Existing campus cooling infrastructure prior to the LSC project included:
    - an 18,000 ton DC system
    - 3 chilled water plants with 8 large electric centrifugal chillers
    - a 4.5 million gallon chilled water TES tank
    - chilled water supply and return (CHWS/R) tempos of 45/60 ºF
- LSC system facts and figures:
    - Relatively nearby access to the deep cold water of Cayuga Lake (one of the Finger Lakes of upstate New York)
    - Offshore pipe – HDPE, 63 inch diameter, 10,400 long, 250 ft deep (39 to 40 ºF water temp)
    - HX station – producing 45 ºF CHWS for campus (in architecturally attractive building at the lake shore)
    - Onshore CHWS/R transmission piping – 12,000 ft long (3,000 ft in a city street), rising to 450 ft elevation above the lake
    - New CHWS/R headers on campus – 42, 36 and 24 inch diameters, direct-buried, un-insulated, carbon steel with HDPE outer coating (for corrosion protection), connecting at 5 points to the existing 11-mile campus DC piping network

- The university review & approval process included, and went beyond, normal steps for large projects:
    - Master planning
    - Scientific and engineering oversight
    - Faculty involvement
    - Advisory group of university officers and trustees
    - Peer consultant review (over $100,000)
- Community benefits played a major role in community acceptance, e.g.:
    - Ithaca High School saves $750,000 from LSC (in exchange for a right-of-way)
    - New sidewalks
    - Local employment for the construction ($20 million)
    - New lake shore park for the town
    - Bonding fees
    - Early groundwork within the community was critical to project acceptance
- The permitting and review process was extensive:
    - 17 or 18 required, specific to the locale
    - Federal – including wetlands, endangered species
    - State – including water discharge (toughest of all), historical preservation, department of transportation
    - Local – including various town, city, and county permits and reviews
    - Approximately $3 million in total cost
- Cornell's seasonal climate results in only a 20% annual cooling load factor. Hawaii's much higher annual cooling load factors (60 to 70%) will improve system economics further.
- Cornell LSC saves 87% in cooling energy use (~25 million kWh/yr).
- Cornell LSC system design life is 100 years.

Panel Discussion No. 1 – Identifying Barriers to Implementation

Kattner, Blumeyer, Van Ryzin, Joyce, and Anders Rydaker, President – District Energy St. Paul (DESP); moderator: Andrepont

The morning's speakers, accompanied by Mr. Anders Rydaker, President of DESP (the District Heating & Cooling system serving St. Paul, MN), answered questions from the attendees and identified important barriers to successful SWAC system development.

- Barriers very common to conventional DC developments:
    - High capital needs (chiller plants and DC piping network)
    - Introducing a new "outsourced" cooling concept to potential customers
    - Apprehension of reliance on a locally "new" technology
    - Achieving a "critical mass" of customers
    - Need for long-term customer commitments
    - Costly construction of a DC network in a congested urban environment
    - Need for support from local government and community for logistics of project
    - Note that these barriers, though significant, have frequently been successfully overcome.

- Barriers unique to Hawaii SWAC DC developments:
  - Even higher capital needs (seawater piping)
  - Apprehension of reliance on an additional perceived “new” technology
  - Need to combine local champions with very distant (mainland) experience and expertise
  - Note that these barriers are not different in kind, but merely different in degree, from the common barriers to DC noted above that are frequently overcome

Lunch Videos – Cornell Lake Source Cooling Project (Cornell University)

Two videos were presented:
- a promotional video summary of the project and its benefits
- video footage of project construction activities

Basics of Plate Heat Exchangers

Elizabeth Wheeler, Senior Application Engineer – Invensys APV

Ms. Wheeler briefly reviewed the concepts and details of plate-and-frame type HXs, a common element of SWAC systems.

- Plate HXs provide key benefits (versus shell-and-tube type HXs):
  - Compact, lightweight
  - Thermal efficiency, low cost
  - Potential for very low approach temperatures (critical for SWAC economics)
  - Expandability
  - Ease of maintenance
- Plate HXs are ASME Section VIII Division 1 pressure vessels, with standard operating pressures to 150 psig (and high pressure units available to 450 psig) and operating temperatures to 350 ºF.
- The narrow clearance between plates mandates the use of relatively clean fluids.
- Any leaks from one flow stream past plate-to-plate gaskets flow to atmosphere, rather than into the other flow stream.
- For SWAC applications, plate HXs employ Titanium plates and standard Nitrile (NBR) gaskets.
- Plate HXs are commonly used in conventional DC applications.

<u>Downtown Honolulu Ice Storage-District Cooling Project</u>

Jack Kattner, CEO – FVB Energy, Inc.

Mr. Kattner presented a detailed review of the issues associated with DC development in general and a Honolulu DC development in particular.

- Any potential DC market is continually evolving (new buildings, CFC chiller replacements, etc.).
- There are unique individual customer situations.
- DC opportunities include: old chillers, CFC chillers, additional regulations, capital needed for core business.
- Possible solutions: stockpile CFCs, rebuild/replace chillers, or outsource to DC.
- DC eliminates: capital drain, O&M concerns, environmental risk, focus on non-core business.
- DC provides availability of cooling service 24 hrs/day, 365 days/yr.
- DC is environmentally sound: energy, emissions, CFCs, noise, vibration, cooling tower plumes, CO_2/global warming, etc.
- DC-served buildings are easy to own, to operate, and to sell.
- DC creates predictability in capital budgeting.
- DC provides extremely high reliability. (Rydaker noted that DESP's DH system has experienced only 20 minutes of downtime in 20 years, i.e. 99.9998% reliability, much superior to the typical reliability of local electric utilities.)
- In N. America, there are now over 40 urban DC utility systems and ~2,000 institutional DC systems (universities, hospitals, airports, military facilities, etc.), plus other DC systems in Europe and Asia.
- The growth rate of DC systems is over 15%/yr. Activity has been especially high since 1990.
- DC is a catalyst for economic development in urban locales and central business districts.
- DC developments can be led by: electric or gas utilities, municipalities, independent private developers, customer co-operatives, or hybrids. Hawaii SWAC DC probably will require a strong public signal to investors; therefore, a PPP may be an appropriate approach.
- Typically necessary elements for success (from experiences with over 40 DC utility developments):
  - Educate and energize community leadership (public <u>and</u> private) – A must!
  - Meet customer needs through the DC service – More than just air-conditioning; capital avoidance, reliability, no surprises, ease to own & operate, 24/7 operation, cooling for special events and after-hours, data center cooling, etc., and risk management.
  - Allow 14 to 18 months from commitment to begin operations – Need to develop "anchor" customers or a "critical mass". The process includes: a "business appreciation" study, technical and financial feasibility analyses, service agreement (contract) terms, customer discussions (repeated again and again and again), and an investor/developer who can hold a steady course throughout.

  - Focus initially on downtown / CBD – For Hawaii, focus on downtown Honolulu CBD. Other high load density areas can also be attractive: campus areas (education, medical, government, industrial), convention/hotels, sports/entertainment.
- DC project elements include:
  - Targeting the market area (as defined above)
  - Selection of the source(s) of cooling - central chiller plants, TES, deep lakes or ocean, select existing customer chillers, and <u>creative</u> hybrid combinations, including phasing over time
  - Selection of distribution network details – piping material (carbon steel, ductile iron, HDPE), monitoring of water quality and quantity
  - Connections to customers – direct vs. indirect, HXs, metering, controls
- Phased development – important generally, and also for Honolulu.
- DC development example – Entergy DC – New Orleans, LA
  - Serves anchor customer: NORMC (New Orleans Regional Medical Center)
  - 32,000 ton peak capacity – from 20,000 tons of chillers and 62,000 ton-hours of ice TES
  - Expandable into the New Orleans CBD in future
- Deep water DC system examples include:
  - Cornell University and Toronto
  - Stockholm, Uppsala, and Norrengi in Sweden, and 2 others in Scandinavia
- Typical DC system operating temps are CHWS of 34 to 40 ºF and CHWR of 50 to 54 ºF.
- Summary of benefits from Honolulu DC:
  - Customers' capital and capital risk (predictability)
  - O&M risk – maintenance/repairs, chemicals, water, security, noise, insurance, space
  - Quick response, 24/7, low-load cooling, after-hours cooling, comfort (if lower CHWS temp), meter/monitor/assist customer (reduce in-building energy use)
  - Reliability, industrial grade equipment, TES, redundant capacity/distribution
  - Environmental – refrigerants, water treatment, noise, vibration, etc.
  - Supports municipal economic development
  - Helps relieve stress on HECO's electrical distribution system
  - In short, DC will be good for its customers, for Honolulu, and for Hawaii.

Results of the Hawaii SWAC Feasibility Analysis

Dr, David Rezachek, Alternate Energy Specialist – State of Hawaii DBEDT, ERTD

Dr. Rezachek summarized the findings of the SWAC Feasibility Analysis, which were published in the October 2002 Final Report. The full text of the report can be found at the website: http://www.hawaii.gov/dbedt/ert/swac.html.

- Objectives of the Study
    - Identify potential areas for SWAC applications
    - Update previous feasibility studies
    - Conduct preliminary technical and economic feasibility analyses for other locations
    - Prioritize the locations for further analysis
    - Develop a Marketing Plan to allow private sector development
    - Identify types of assistance that can be provided by the State of other government sources
- Areas Evaluated – 6 on Oahu and 4 on neighbor islands
    - Primary cooling demand areas on Oahu are not within practical reach of 1,000 m (3,300 ft) 4 ºC (39 ºF) water depth, but are within reach of 500 m (1,600 ft) 7 ºC (45 ºF) water depth.
    - Downtown Honolulu Waterfront, Kakaako, Waikiki are primary areas.
    - Other areas include UH-Manoa (with Waikiki), Pearl Harbor Naval Shipyard (PHNS), and Kaneohe Marine Corps Base Hawaii (KMCBH), as well as areas on Kauai.
- Economic Analyses
    - Employed the EPRI Technical Assessment Guide (TAG) method of analysis
    - All SWAC assumptions were purposely chosen to be reasonable worst case conservative
    - Even so, Honolulu Waterfront, Kakaako, and Waikiki cases showed lower life cycle costs for SWAC (10 to 20% below costs for conventional cooling).
    - UHM-Waikiki, PHNS and KMCBH had somewhat higher life cycle costs for SWAC versus conventional cooling.
    - Sensitivity analyses were conducted to explore the impact on economic results.
    - Numerous alternate assumptions have the potential to individually reduce life cycle SWAC costs by approximately an additional 10%. Such factors include: capital cost contingency, interest rates, real escalation rates of electricity costs, income tax rates, Federal investment tax credits, depreciation rates, utility DSM incentives, Hawaii Energy Conservation Income Tax Credit, energy production incentives, and property taxes.
    - Potentially realistic combinations of these alternate assumptions could result in reductions in life cycle SWAC costs by more than 50%. Thus, even many non-primary sites may be economically practical for SWAC.

- Other Benefits of SWAC
  - SWAC systems save 90% of cooling energy use
  - SWAC systems save 4,500 kWh/ton-yr (and 8.4 Bbl of imported oil per ton-yr)
  - These savings were extrapolated for each of the areas studied.
  - A 50,000 ton SWAC DC development (very practical for the Downtown-Kakaako-Waikiki area) yields energy and oil savings equivalent to 70,000 residential solar water heaters.
  - Significant reductions in greenhouse gas emissions and other air and water pollutants
  - Avoids use of harmful chemicals (refrigerants) in conventional cooling systems
  - Reduces water use and toxic chemicals associated with cooling towers
- Secondary Uses of SWAC Effluent
  - Economical and environmental uses of effluent (still relatively cool at 55 to 57 ºF)
  - Marine biotech industrial parks/facilities (cold water aquaculture)
  - Auxiliary cooling water for cooling systems, power plants, industrial facilities, etc.
  - Cooling of grounds, e.g. parks, golf courses (creating condensation and eliminating watering)
  - Discharge into brackish bodies of water, estuaries, canals, harbors, to improve water quality
- Conclusions
  - SWAC is simple, technically and economically feasible today, inexhaustible, renewable, and has minimal environmental impacts (indeed a major net benefit versus the alternative).
  - SWAC systems have great potential in Hawaii, statewide.
  - Hawaii has an estimated SWAC potential of over 100,000 tons, more than 50,000 tons in the Waikiki-Kakaako-downtown Honolulu area.
  - Those primary areas are economically attractive, even under conservative base case assumptions, with levelized life cycle cooling costs 18% below conventional cooling costs.
  - Sensitivity analyses show cases with even better economics, in some cases with over 50% cost savings. Thus many of the non-priority SWAC areas in Hawaii may also be economical.
  - Thus, SWAC customers and developers/investors can reap economic benefits.
  - Other benefits include reductions to greenhouse gas emissions, air and water pollution, harmful refrigerants, and cooling tower chemicals & water use.
  - Secondary uses of the 55 to 57 ºF effluent are numerous, economically and environmentally beneficial, and can aid overall system economics.
  - The best system for Hawaii (and elsewhere) may be a hybrid SWAC-TES DC system, which would increase capacity factor of the piping, increase peak load served, and lower capital cost per ton served.
  - SWAC will significantly reduce peak utility demand and reduce cooling energy use by 80 to 90%.

- Recommendations – to move the potential projects into commercial realization
  - Conduct a follow-up study to analyze integrated SWAC-TES DC systems. (This study is underway. See the summary of the presentation immediately below.)
  - Conduct more detailed site-specific evaluations for each of the positive and marginal (base case) sites identified in this study.

Preliminary Results of the SWAC-TES Project

John Andrepont, President – The Cool Solutions Company

Mr. Andrepont presented a brief overview of Thermal Energy Storage (TES) and its applications in DC systems, and a summary of the results to-date from the study of integrated SWAC TES DC systems for Hawaii.

- Overview of TES
  - Latent heat, i.e. ice TES, versus sensible heat, i.e. chilled water (CHW) or low temp fluid (LTF) TES – each has inherent characteristics and thus inherent advantages and limitations.
  - TES already widely used in DC applications – private industry DC, universities and colleges, hospital and medical facilities, other government facilities, DC utility systems, and Combustion Turbine Inlet Cooling (CTIC).
  - TES reduces operating costs (by shifting energy use to low-cost off-peak periods) and often reduces capital costs (by meeting peak cooling loads with a combination of TES and a smaller than conventional chiller plants).
- SWAC-TES project concept and objectives
  - Study builds on previous results
  - Ultimate objective – to commercialize SWAC systems for Hawaii, and as an export
  - Hybrid SWAC-TES DC systems allow
    - larger peak cooling loads to be served by a given SWAC pipe
    - smaller SWAC piping to be used to meet a given peak cooling load
    - improved system economics, and thus improved chance to realize and capture SWAC benefits
- SWAC-TES project tasks and results to-date
  - Task 1 – Review and analysis of earlier SWAC report
    - Assumptions generally valid and appropriate, if conservative
    - Most SWAC systems would benefit from integration of TES
    - Should reconsider contingency levels, incorporate operating personnel savings, and pursue SWAC DC with TES.
  - Task 2 – Literature search of TES applicable to SWAC
    - Reviewed, analyzed and summarized 6 design guides/handbooks, 30 case studies/analyses, and info from 8 TES equipment suppliers.
    - Identified numerous DC applications of TES in industry, institutions (educational, medical, and government), DC utilities and CTIC. Analyzed and evaluated types and sizes of TES technology employed.

        - All TES types (ice, CHW, and LTF) are used in DC.
        - CHW TES most often used in large DC - economy-of-scale, ease of retrofit with existing systems, and can be sited remotely from chillers.
        - Also, SWAC temps are too warm for directly recharging ice or LTF TES.
        - CHW TES best suited to SWAC DC, though all types of TES can be used.
    - Task 3 – Economic Analysis
        - Prelim results for a combined Honolulu Waterfront-Kakaako-Waikiki SWAC DC system – 24,000 ton peak met with 17,000 tons of SWAC plus 51,000 ton-hrs of CHW TES, resulting in 10 to 15% savings versus the non-TES SWAC base case.
        - Prelim results for an East Waikiki-UHM SWAC DC system – 7,800 ton peak met with 6,900 tons of SWAC plus 6,000 ton-hrs of CHW TES at UHM, resulting in smaller piping and ~12% savings versus the non-TES SWAC base case.
        - Promising candidates also include Kakaako (new developments), and West Oahu (deeper colder water and new development, industry and future CTIC potential)
    - Task 4 – Preliminary Design – to be completed
    - Task 5 – Marketing Plan – to be completed
        - Must address key anchor customers, plus all stakeholders, and benefits to all.
        - Stakeholders include – customers, engineers, affected community, general public, government, local permit authorities, local electric utility, auxiliary service users, equipment suppliers and contractors, and investors.
    - Task 6 – Financing Mechanisms – to be completed
        - Consider development via private, public, and PPP means
    - Task 7 – Innovative Energy Systems Workshop
        - Assistance in workshop planning, execution, and reporting
    - Task 8 – Final Report – to be completed, June 2003.
- Moving SWAC to commercial reality
    - Major barriers do exist – new concepts, a new business, capital investment, long-term outlook, creating “critical mass”, and finding a committed developer.
    - But there is much reason for optimism – numerous recent DC successes, unique resources and opportunities in Hawaii, proven local technologies and talent, energy and environmental mandates, avoided oil risks, positive economics further improved with TES, private and public interest in the development.

- Summary and Conclusions
  - Enormous benefits from SWAC
  - SWAC long used with harbor water (in Halifax, Nova Scotia and in Sweden)
  - Deep Lake Source DC, using Hawaiian technology (at Cornell U. and Toronto)
  - Unique potential in Hawaii – deep water access, over 100,000 ton potential, and mitigation of imported oil risks
  - TES a natural complement to SWAC, especially using CHW TES
  - Prelim results show 10 to15% improved economics with TES, and thus improved chances to realize commercialization
- Recommendations
  - Identify and address all significant barriers – to DC in general, to SWAC specifically, to Hawaii in particular, and specific to individual developments and customers.
  - Incorporate TES in SWAC designs to improve economics
  - Market the benefits of SWAC to all stakeholders

The benefits are much too great – not to persevere and turn the vision into a reality.

Overview of a Successful Public-Private Partnership District Energy Development

Anders Rydaker, President – District Energy St. Paul

Mr. Rydaker presented a brief overview of the District Energy development serving St. Paul, MN. (Additional detail can be found at the DESP website: http://www.districtenergy.com.)

- The DESP system was started with strong support from the then mayor.
- DESP was initially started as a DH system, using hot water distribution (on the European model).
- Later, DC service was added. The DC system has grown steadily from its start over the last 10 years, now serving 60 to 65 DC customers (~20,000 tons). Customers are both public and private facilities representing a 60 to 65% market share in the St. Paul CBD and government (State Capitol) district.
- The central plant has HW boilers (firing coal, oil, gas, and wood waste) and chillers (electric centrifugals and some absorption), plus a 2.5 million gallon chilled water TES tank.
- A new satellite chiller plant is on-line this spring with an additional 6,000 tons of electric centrifugal chillers and a 4 million gallon chilled water TES tank.
- Existing chillers at a few select customer buildings are contractually controlled by DESP for use as peaking and back-up chiller capacity (though rarely if ever operated).
- The most distant customers are 25 city blocks of piping distance from the main chilled water plant.
- The DESP system is a not-for-profit co-operative owned by its customers. Customers elect 3 of the 7 members of the Board of Directors.

Panel Discussion No. 2 – Overcoming Barriers to Implementation

Wheeler, Kattner, Rezachek, Andrepont, and Rydaker; moderator: Van Ryzin

The panelists answered questions from the attendees and discussed approaches to overcome barriers to implementing SWAC DC in Hawaii.

- There was clear consensus that, although there are significant barriers to the implementation of SWAC DC systems in Hawaii, the barriers are no different in kind, and only somewhat different in degree, to the barriers that are routinely overcome in other successful DC developments.
- Technical feasibility is not an issue, neither for the offshore SWAC subsystem nor for the onshore DC system. Past successes demonstrate the feasibility and will be a special aid the marketing effort.
- A broad-based determined marketing effort, and attention to unique individual customer needs, will be crucial in securing a critical mass of customers.
- Those anchor customers and their long-term commitment will be necessary to securing project financing/investment.
- A Public-Private Partnership (PPP) is a likely attractive mechanism for a successful development.
- Positive local government decisions will be key in moving the development into reality, e.g. one or more of the following:
    - Commitment to actively participate in the system ownership/development team
    - Assistance in educating the community regarding the numerous benefits to customers, the community, the environment, imported oil risk, etc.
    - Commitment to employ DC service in local government buildings.
    - Assistance with permitting and rights-of-way approvals
    - Consideration of and commitment to appropriate investment tax credits
    - Consideration of and commitment to appropriate DSM utility incentives
    - Consideration of and commitment to appropriate energy production incentives
    - Consideration of and commitment to appropriate property tax assessments
    - Consideration of and commitment to appropriate depreciation schedules

Day 2 – March 20, 2003

Waste Heat, the Kalina Cycle®, and Kalina Cycle® Applications in Hawaii

Welcome and Opening Comments

Dr. David Rezachek, Alternate Energy Specialist – State of Hawaii DBEDT, ERTD

Dr. Rezachek provided a brief overview of the day's activities.

The Kalina Cycle® – Description and Applications

Yakov Lerner, VP of Engineering and Projects – Recurrent Resources LLC

Mr. Lerner provided a brief introduction to the Kalina Cycle® technology and introduced the basic engineering concepts from which the cycle derives its efficiency improvements over the traditional Rankine cycle. He also provides a brief case study history of the Husavik, Iceland geothermal Kalina Cycle® facility constructed and operating since July '00.

- Recurrent Resources, LLC is the world-wide licensee of the Kalina Cycle®
    - The Kalina Cycle® is breakthrough technology providing higher levels of performance than have been impossible to attain with traditional steam plants. It reduces the cost of power and decreases pollutant emissions by making power plants more efficient.
    - This technology makes geothermal power competitive with all other new base-load generation technologies.
    - Exergy holds over 250 world-wide patents on the Kalina Cycle®
- Advantages of Kalina Cycle® power plants
    - Higher plant efficiency
    - Lower generation costs (less fuel, lower O&M costs)
    - Reduced emissions
    - Less energy to heat working fluid
    - Less fuel consumption in process
    - More energy recuperation
    - Lower cost of electricity per kilowatt-hour
- Kalina Cycle® provides significant power efficiency improvements over Rankine cycles for low temperature (100° – 1000° F) waste heat sources
    - Greatest performance enhancement at lower temperatures (~100°F)

- Waste heat can be most efficiently recovered to produce electrical energy using the Kalina Cycle®
  - Areas of application
    - Waste heat recovery in industry
      - Gas compressor stations
      - Iron & Steel industry
      - Cement industry
      - Chemical industry
      - Incineration plants
      - Diesel plants
    - Hot brine heat recuperation
      - Geothermal plants
- Kalina Cycle® is better than the Rankine cycle because:
  - Ammonia/water working fluid
  - Vary the mixture of working fluid throughout the cycle
  - Captures more thermal energy for generating electricity
  - Higher level of recuperation
  - Result: More kilowatt hours of output per unit of fuel input or cycle heat input
- Key advantages of the Kalina Cycle®
  - Structural process – no technical or component improvements required
    - Improved heat transfer
    - Improved recuperation
    - Reliance on proven plant components
  - Exploitation of an additional degree of freedom
    - Composition changes within the power cycle similar to refrigeration plants
  - Capital cost is less than Rankine cycle
- Kalina Cycle®: Inherent advantages
  - Improved heat transfer from hot to cold streams
- Key: Mixture boils at a variable temperature
- Closer temperature profile between heat transfer streams means improved efficiency
- Kalina Cycle® comparison
  - Geothermal heat acquisition comparison
    - Kalina Cycle® vs. ORC (Organic Rankine Cycle)
    - The water/ammonia working fluid more closely replicates the thermal resource in a counter flow heat exchanger over isopentane and other organic working fluids
- Kalina vs. ORC efficiency comparison
  - Kalina is 30-80% more efficient (higher efficiency at lower resource temperatures)
- Thermodynamic relationships of the Kalina Cycle® are well-known and documented
- The Kalina Cycle® components are well-known and off-the-shelf

- Commercial examples of Kalina Cycle® applications:
  - Sumitomo Metals, Tokyo, Japan
    - Configuration: Waste heat
    - Customer: Sumitomo Steel
    - Construction site: Tokyo, Japan
    - Electrical output: 3.1 MW
    - Commissioned: July '99
  - Husavik Power Plant, Husavik, Iceland
    - Configuration: Geothermal
    - Customer: Municipality – Husavik
    - Construction site: Husavik, Iceland
    - Electrical output: 2.0 MW
    - Commissioned: July '00
- Innovative cascaded use
  - Electrical power
  - Spent brine used for heating
  - Cooling water reused as well
- Commercial history of the Husavik-Kalina Cycle® plant
  - Bids from a number of binary cycle suppliers were submitted in 1999
  - Bid awarded to Exergy in 1999: 2 MW for $1,874,000 or $905/kW
  - Plant officially started up and entered service July 22, 2000
  - Plant performance tests in November 2001, after 15 months of operation
- The first year of operation for Husavik plant
  - Proven, stable operation
  - Output was lower than design output due to lower resource temperature
  - The separator caused problems; after the 2000-2001 peak winter season, this was fixed
  - Some equipment received mechanical erosion and pluggage resulting from poor chemical cleaning during commissioning
    - Separator screen
    - Turbine flow path
    - Feed pump
  - Plant demonstrated high reliability
  - It happily operates largely unattended
  - It proved to be quiet, sturdy and not smelly at all
  - Performance testing completed November 28 & 29, 2001, corrected net power output of 1959 kW to 2060 kW
- Kalina Cycle® configuration and components diagram shown
- Kalina Cycle® "waste heat" potential in the U.S. & Canada
  - U.S. ~ 3602 MW
  - Canada ~ 1349 MW

- Canoga Park Demonstration project
  - Configuration: Combined cycle
  - Operator: Boeing
  - Construction site: California
  - Electrical output: 6.5 MW
  - Commissioned: June ‘92
  - Operational: 1992 – 1997
- What are the advantages of the Kalina Cycle® over ORC
  - Proven reference
  - Thermodynamics are known and practiced
  - Higher output for a given heat source
  - Lower specific capital cost ($/kW)
  - High degree of plant safety
  - Kalina Cycle® is BACT
  - Strong OEM partnerships
- Ammonia safety concerns
  - Needs to be used carefully
  - Less hazardously flammable than more conventional working fluids
  - Comparatively environmentally benign
  - Ammonia vents easily, and is self-alarming
  - Ammonia is the 6th largest chemical product in the U.S.
  - Proven safety record in ammonia synthesis, power plants and refrigeration plants
- Kalina Cycle® technology conclusions:
  - Commercially available
  - Underlying principals are simple
  - Effective and safe
  - Utilized in refrigeration for over 100 years
  - Breakthrough in:
    - Understanding ammonia/water properties
    - Applying to power plant operations
    - Developing proprietary super-efficient cycle designs

<u>Preliminary Results of Hawaii Kalina Cycle® Feasibility Analysis</u>

Dr. Stephen K. Oney, Vice President – OCEES International, Inc.

Dr. Oney introduced the concepts of the Kalina Cycle® and its benefits over more traditional Rankine cycle systems. He also emphasized the unique advantages of the multiple working fluid concepts, particularly to low temperature, in waste heat recovery systems. Dr. Oney then addressed the potential waste heat sources initially identified in the *Hawaii Kalina Cycle® Feasibility Analysis* that OCEES is preparing for DBEDT. He provided some specific examples of promising potential applications and scenarios for Kalina Cycle® waste heat recovery in Hawaii.

- The Kalina Cycle®
    - Binary energy conversion cycle which uses ammonia/water mixture as the working fluid
    - Variable mixture (concentration changes throughout the cycle) which allows the working fluid to efficiently match the characteristics of the resource
        - Ideal for low temperature/bottoming cycle applications
- Ammonia/water safety concerns
    - Needs to be handled carefully
        - <u>Not</u> classified as hazardous
    - Less hazardously flammable than more conventional working fluids
    - Comparatively environmentally benign
    - Ammonia vents easily, is self-alarming
- Single working fluid thermodynamic limitation
    - Requires significant heat input to overcome change of state (i.e., liquid to vapor)
    - Binary working fluid allows for incremental increase in temperature for incremental addition of heat
- Simplified comparison of Rankine cycle to Kalina Cycle®
    - Similar components, but the Kalina Cycle® has a distillation/condensation sub-system (D/CSS) which the Rankine cycle does not
- There are several operational Kalina Cycle® plants with commercial experience
    - Canoga Park, California – 6.5 MW
    - Husavik, Iceland – 2.0 MW (geothermal)
    - Sumitomo Steel Factory – 3.5 MW (industrial waste heat)
- Husavik Geothermal Plant – "First two years"
    - Demonstrated high reliability (availability rate in the high 90%)
    - Operates successfully largely unattended
    - Proved quiet, sturdy with no odor
- Energy generation by source in Hawaii (1999)
    - Petroleum – 78%
    - Coal – 12%
    - Gas – 0.5%
    - Hydroelectric – 1.5%
    - Other (i.e., geothermal, wind, biomass, etc.) – 8%

- Ten largest power plants in Hawaii by generating capacity – 1999
  - Kahe – Petroleum – 582 MW - Oahu
  - Waiau – Petroleum – 457 MW - Oahu
  - Kalaeola Co-gen – Petroleum – 261 MW - Oahu
  - AES Hawaii – Coal – 189 MW - Oahu
  - Maalaea – Petroleum – 168 MW - Maui
  - Honolulu – Petroleum – 100 MW - Oahu
  - Port Allen – Petroleum – 97 MW - Kauai
  - H-Power – Waste – 61 MW - Oahu
  - Hawaiian Com & Sugar – Coal/biomass – 58 MW - Maui
  - W H Hill – Petroleum – 35 MW – Hawaii
- All forms of energy used for primary energy production in Hawaii have some form of waste heat – usually significant quantities
- How much waste heat in Hawaii?
  - ~ 9 billion kW-hr/year electricity from fossil fuels
  - Conservative estimate:
    - From stack gases: ~ 356 million kW-hr/year
    - From cooling water: ~ 534 million kW-hr/year
    - Total: ~ 890 million kW-hr/year (~10% of total energy production in Hawaii!)
  - Waste heat potential in Hawaii is quite significant
- Petroleum/Diesel Power Plants
  - Kahe Power Plant – Oahu
  - Maalea Power Plant – Maui
- Showed a simplified conceptual flow diagram for a diesel combined cycle
  - Heat recovery vapor generator for flue/hot gas
  - Distillation/condensation sub-system
  - Heat recovery vessel utilizing jacket water from engine cooling system
- Peak design capacity for diesel combined-cycle/bottoming cycle depends upon:
  - Diesel exhaust gas temperature and flow
  - Fuel sulfur content (limits the minimum stack temperature)
  - Type of cooling available (water or air cooled)
  - Capacity of diesel generating station
  - Site ambient conditions
  - Diesel back pressure requirements
  - Bottoming cycle design
- Design capacity comparison
  - First case study
    - Kohinoor Energy Ltd. – Pakistan
    - 8x Wartsila 18V46 diesel units
      - Existing Rankine bottoming cycle = ~ 8 MW_{net}
      - Initial Kalina Cycle® design = ~ 13.3 MW_{net} (+66%)
      - Optimized Kalina Cycle® design = ~ 16.0 MW_{net} (+100%)

  - Second case study
    - Kohinoor Energy Ltd. – India
    - 4x Wartsila 12V46 diesel units
      - Design Rankine bottoming cycle = ~ 1.87 MW_{net}
      - Kalina Cycle® design = ~ 3.24 MW_{net} (+66%)
- Case study example – Turkey - Basic assumptions
  - 100 MW capacity (PPA ~ 876 million kWh/yr)
  - Man B&W 18-V-48/60 diesel unit (18.39 MW each)
  - Three competing scenarios:
    - Scenario 1: 7 diesel generating units, no bottoming cycle, one diesel generating unit in standby
    - Scenario 2: 6 diesel generating units, no bottoming cycle, no diesel generating unit in standby
    - Scenario 3: 6 diesel generating units, Kalina bottoming cycle (11 MW), no diesel generating unit in standby
  - Capital costs
    - Diesel generation station ($650/kW)
    - Kalina Cycle® ($1200/kW)
  - O&M Costs
    - Diesel generation station ($0.01/kWh)
    - Kalina Cycle® ($0.005/kWh)
  - Fuel Costs ($0.20/kg)
- Case study summary
  - Total operating cost ($/yr)
    - Scenario 1: $41.22 million
    - Scenario 2: $39.25 million
    - Scenario 3: $37.78 million
  - Gross operating profit
    - Scenario 1: $15.72 million
    - Scenario 2: $15.05 million
    - Scenario 3: $19.16 million
  - Kalina Cycle® payback period
    - Scenario 1: 0.4 years
    - Scenario 2: 3.2 years
    - Scenario 3: --
  - Simple return on investment
    - Scenario 1: 18.8%
    - Scenario 2: 21.0%
    - Scenario 3: 22.5%

- Economics of bottoming cycles for large diesel generation stations
  - Capital costs:
    - Kalina Cycle® less than Rankine bottoming cycle ($/kW)
    - Kalina Cycle® more than diesel generation power plant
  - Savings in fuel cost more than makes up for additional capital
    - Savings on fuel is dependent upon fuel type
  - Include impact of standby diesel generation capacity for frequent diesel unit maintenance
- Economic viability of adding Kalina bottoming cycle to existing diesel generation station:
  - Size of the diesel station
  - Number and capacity of each diesel unit
  - Diesel unit annual average capacity factor
  - Diesel unit exhaust heat rejection
  - Capital cost of the Kalina bottoming cycle power plant
  - Avoided cost of energy (purchased energy tariff or cost of fuel and O&M)
  - Kalina Cycle® power plant O&M
  - Escalation assumptions
  - Discount rate or cost of capital
  - Debt assumptions
  - Tax assumptions
- Other potential plants in Hawaii
  - Coal burning facilities
    - AES Hawaii, Inc. - Oahu
  - Biomass/waste power plants
    - Hawaiian Com & Sugar (Coal/biomass) – Maui
    - H-Power (waste) - Oahu
  - Large industrial facilities
    - Tesoro refinery - Oahu
  - Geothermal power plants
    - Puna Geothermal Venture – Hawaii
      - Showed schematic of existing Puna geothermal facility
      - Showed schematic of potential addition of Kalina Cycle® system capturing waste heat from unused brine and condensate
- Husavik/Puna Resource Comparison
  - Husavik, Iceland Plant
    - Brine flow: 90 liters/sec @ 120° C
    - CW flow: 180 liters/sec @ 4° C
    - Power generated: 1.7 MW_{net}
    - Total cost: $1,875,000 ($905/kW)
  - Puna Geothermal Venture Plant
    - Brine flow: 189 liters/sec @ 149° C
    - CW flow: 85 liters/sec @ 40.6° C
  - Should the Puna Kalina Cycle® be air cooled or ocean water – design question!

- Other potential Kalina Cycle® applications for Hawaii
  - Could be used in conjunction with local power plants and future SWAC facilities to provide necessary pumping power for SWAC
  - Providing the power cycle for Ocean Thermal Energy Conversion applications
    - OTEC represents the greatest potential in Hawaii for Kalina Cycle® applications
- Predicted heat rate/efficiency gains by power plant technology
  - Geothermal plants
    - ~ 30 – 50% efficiency improvements
  - Coal/biomass/waste plants
    - ~ 20%
  - Diesel/Petroleum plants
    - ~ 10 – 15%
  - OTEC plants
    - ~ 50+%
- Conclusions:
  - The Kalina Cycle® is superior technology to traditional Rankine cycle of low temperature/bottoming cycle applications
  - Hawaii has significant waste heat resources for potential Kalina Cycle® integration
  - Integration of the Kalina Cycle® makes good environmental and economic sense under amenable conditions
  - Further analysis for specific identified applications is warranted

On-Going Kalina Cycle® Developments

Dr. Hans Jurgen Krock, President – OCEES International, Inc.

Dr. Krock focused on the implementation of the Kalina Cycle® and its adaptation as the preferred power system technology for integrated OTEC systems. He introduced the Workshop participants to the integrated, multi-product approach of OTEC systems currently being utilized by OCEES International, Inc. to commercialize OTEC globally in niche tropical island markets. He also outlined the potential for Kalina Cycle® based OTEC to function as the primary production mechanism for hydrogen in an impending hydrogen economy. The potential impact this could have on a future energy-exporting Hawaii economy was also presented.

- Bottoming cycle installations of the Kalina Cycle® exist in several locations under differing low temperature waste heat scenarios
  - Operational Kalina Cycle® plants
    - 6.5 MW Kalina Cycle® plant in Canoga Park, Ca.
    - 2 MW Kalina Cycle® plant in Husavik, Iceland
    - 3.5 MW Kalina Cycle® plant in Tokyo, Japan (Sumitomo Steel factory)
  - Each plant has excellent operational and performance records!

- Ocean Thermal Energy Conversion (OTEC) systems:
    - Economics work best in a niche market approach providing multi-product, optimized systems
    - Most efficient power cycle available for OTEC temperatures is the Kalina Cycle®
- OTEC utilizes the solar radiation incident upon and absorbed by the tropical ocean
    - Total human energy usage is equivalent to 0.005% of the total energy incident upon the earth's surface
    - Nearly 25% of the total solar energy incident upon the earth is absorbed by the tropical ocean
        - This represents the world's largest and most efficient solar energy collector on the planet
        - Utilizing this energy for total human consumption would still only represent 0.1% of the available energy which is within the noise of the natural system – humans could not begin to impact the system!
- Tropical ocean temperature profile
    - OTEC takes advantage of the same energy which drives the world's weather systems
        - Weather is driven by the temperature difference occurring between the tropical ocean and arctic oceans over thousands of miles
    - The same energy is available, vertically, over only 1 kilometer in the tropical ocean
        - The tropical ocean has a mixed surface layer (~ 100 meters) of "warm" water (~ 24 – 30° C)
        - The deep cold water is ~ 4 – 5° C at 1000+meter depths
- Hawaiian based research advances in OTEC over the past two decades
    - Cold water pipe design and installation
    - Open-Cycle OTEC net power production
    - Closed-Cycle OTEC demonstration facility
    - Bio-fouling control in warm water systems
    - Closed-Cycle aluminum heat exchanger dynamics
    - Non-condensable gas exchange dynamics
    - Aquaculture development
    - Open-Cycle OTEC fresh water production
- OTEC economics work best with an integrated multi-product approach in niche markets
    - OTEC power
        - Kalina Cycle® power system
        - Can be utilized through electrolysis to produce hydrogen
    - Desalinated water
        - Potable drinking water
        - Water for agriculture/industrial applications (irrigation)

    - Aquaculture
        - Finfish/shellfish
        - Micro-organisms/algae
        - Kelp, etc.
    - Cold water agriculture
        - Temporal crops available in tropical regions
        - Enhanced growing conditions/seasons
        - Additional irrigation potential utilizing natural humidity of air
    - Air conditioning
        - Building air conditioning (SWAC)
        - Process cooling for industrial facilities from plant effluent water
- Parameters required for a Kalina Cycle® OTEC design
    - Suitable temperature differential between warm water resource and cold water resource (~ 20° C)
    - Flow rates of resource water and temperatures
    - The chemical environment the Kalina Cycle® is expected to operate in (seawater, fresh water, etc.)
    - Elevation of plant above seawater
- Relevant technical developments over the last decade for OTEC commercialization
    - Operating Kalina Cycle® plants from which operational experience can be derived
    - Open-Cycle OTEC pilot plant experience
    - Non-condensable gas problems solved
    - Commercial-scale cold water AC systems installed
    - Open-Cycle OTEC turbine designs by reputable turbine manufacturers
    - Fresh water production with Open-Cycle OTEC systems
    - Multi-product systems engineering
    - Existing oil drilling platforms in depths greater than 3000 feet
- Economic conditions are presently favorable for OTEC development
    - Interest rates at 40 year lows
    - Oil prices at or near all-time highs
        - This is especially true in niche markets
- OTEC's future
    - Large scale floating systems for power production and hydrogen production via electrolysis and liquefaction
    - Deep water offshore platforms have already been developed by the oil industry and are adaptable for OTEC applications
- Natural synergies for liquid hydrogen production via OTEC
    - Constant production rates
        - OTEC operates 24/7 without interruption or fluctuation
            - Provides maximum return on investment
    - Pure water resources
        - Pure distilled water required for electrolysis process
            - Fresh water easily produced in OTEC systems

    - Heat sink for liquefaction readily available
        - Efficient hydrogen liquefaction requires significant heat sink resource
            - Cold water provides this resource
    - Convenient transport to world-wide demand centers
        - OTEC in the tropical ocean already exists on the preferred transport medium for large-scale energy distribution – tanker transport across the oceans
            - Hydrogen can be produced much closer than current oil transport distances reducing distribution costs
            - Can be stored and transported utilizing existing technology
- Economics for hydrogen production via OTEC are favorable if coordinated with the oil industry
- For fair comparison between hydrogen and current transportation fuels, an economic analysis should include evaluation criteria comparing miles traveled rather than purely equivalent energy of fuel types as hydrogen fuel-cells provide significantly better efficiency in power-to-work conversions over conventional internal combustion engines
- The Kalina Cycle® is proven technology with a bright future in the development of the largest renewable resource in the world – the tropical ocean!

Panel Discussion No. 3 – Kalina Cycle® Developments

Lerner, Oney, and Krock; moderator: Rezachek

This panel discussion was not performed as the presentations went longer than expected and an additional speaker was added. Several questions were posed the presenters at the conclusion of their talks and are addressed here in place of the Panel Discussion notes.

- Question: Can you explain the Uehara Cycle® vs. Kalina Cycle®?
    - Uehara Cycle® is a modified Kalina Cycle® developed by Saga University in Japan after analyzing the Kalina Cycle® facility built in Tokyo for Sumitomo Steel
    - The Uehara Cycle® utilizes an ammonia/water working fluid and essentially duplicates process equipment to avoid patent infringement concerns with the Kalina Cycle®
- Question: Of the scenarios outlined for Kalina Cycle® application in Hawaii, what are the most promising technologies?
    - For immediate implementation and benefit, probably the Puna Geothermal plant – Kalina Cycle® has excellent record in successful operation in conjunction with geothermal plants
    - Certainly, retrofitting some of the larger petroleum power plants for HECO as the Kalina Cycle® can be developed vertically in a plant to accommodate limited space availability
    - The most promising of all possible applications is the development of OTEC utilizing the Kalina Cycle® for the power cycle

- Question: How can Hawaii benefit from the development of OTEC?
    - If Hawaii were to develop the OTEC/SWAC industry, beyond merely exporting the technology as it now does, Hawaii could become a major energy exporter (hydrogen) thereby expanding its economic base beyond tourism, providing high quality jobs, export revenues, and taxes

Deep Ocean Water Applications Facility

Dr. Manfred J. Zapka, Senior Project Director – Marc M. Siah & Associates

Dr. Zapka provided a brief overview of the Deep Ocean Water Applications facility (DOWA) project commissioned by the Honolulu Board of Water Supply in January 2003. The project, as described by Zapka, will entail an investigation of several scenarios for fresh water production utilizing various sea water desalination technologies. Included in the analysis is Open-Cycle OTEC with single stage fresh water production, Cosed-Cycle OTEC utilizing the Kalina Cycle® power system with parallel fresh water production, multi-stage flash evaporation (MSF), and MED technologies. The study will also investigate the integration of other co-products and services associated with the deep ocean water such as SWAC, process cooling, and aquaculture support. Seven sites across the Southern and Southwestern shores of Oahu have been initially identified as possible candidate locations for the project development. The project is currently at the very initial stages and is expected to last through the remainder of 2003.

Financing, Ownership, Marketing, and Development of Innovative Energy Systems in Hawaii

Lunch Video – District Energy is the Link (International District Energy Association)

The IDEA's informational and promotional video was presented, illustrating:

- District Energy concepts
- Benefits to DE customers
- Benefits to energy efficiency and emissions
- Extent of the DE industry, in the U.S. and worldwide

Panel Discussion No. 4 – Facility Owner-Operator Feedback

Workshop attendees representing Hawaiian facilities (Mr. Kevin Saito – Utilities Manager and "landlord", US Navy PHNSY Energy Services Division, Mr. Gary Shimabukuro – Acting Energy Manager, US Navy PHNSY & IMF, and representative of the State of Hawaii DAGS, managing a $3 million/yr energy budget for Honolulu area State buildings); moderator: Andrepont

- DAGS representative stated that SWAC/TES was a possibility. However, he's concerned with low (6 ºF) delta T in his facilities. (Anders Rydaker: DE utilities work with building owners to improve controls and economics within customer buildings. John Andrepont: To achieve a better Delta T, there is often an incentive (carrot & stick) built into the DE rate structure. Addressing the low Delta T issue is most important during hot weather, high load conditions.)
- Navy hasn't moved much beyond basic energy efficiency – but they have been interested in SWAC.
    - PHNSY use of SWAC/TES – distance to deep cold sea water too great – but SWAC may be feasible with complementary chillers.
    - Military utility services – many offices that don't talk to each other and don't even know what each other does.
    - It is expected that the Navy will eventually have some sort of District Cooling.
    - Earlier explorations of SWAC identified challenges – This workshop answered some of their questions. (There should be follow-up to understand and explore any remaining questions.)
- Top SWAC DC candidates will be the most receptive customers. For example, even though PHNSY was not in the Top 3 (of potential sites), their desire to potentially use DE it is a major advantage. (Anders Rydaker: Once DE has initial customers, they help to sell it to others, enhancing marketing and market penetration.)

- Other potential benefits of DE are of interest to the facility managers, e.g.:
  - Most of the Pearl Harbor infrastructure is pre-WWII and needs replacement or upgrading.
  - Military is also consolidating facilities for greater efficiency.
  - However, DAGS has already changed-out many chillers, and installed T8 fluorescent lights with electronic ballasts.
  - Currently facilities managers have no peak demand control.
  - There are many "ancient" motors and pumps (and also high heat generation). They plan to add cooling. However, trenching to these loads is a concern.
  - Need to air-condition ships while in dry dock.
  - Real-time monitoring of cooling use is currently lacking. How best to actually measure a building's energy use? Need feedback on energy use. Could use a real time energy metering/monitoring system, as would be provided by DE. Drive behavior by measuring use and letting people know this information.
- Note: any technical or commercial solutions cannot affect the mission of military facilities. They must support that mission.
- Anders Rydaker: DESP maintains on-line communication with each and every customer – every seven minutes, they get a data point. Customers have access to the data. This real-time monitoring helps to keep DE system and customer costs down.
- The Navy of course does have some particularly critical cooling loads. An 1,800 ton chiller plant serves a part of the PHNSY loads. They have a computer center with 24/7 operation and cooling needs.
- Anders Rydaker: DE systems don't want to sell the customer too much contracted load, or too little. Customers who have are penalized (for too much cooling demand or for too little Delta T), aren't happy customers; accordingly, DE systems work closely with their customers to get it right.
- Public-Private Partnership (This can include the DE consumers themselves, as it does in St. Paul.) – DE consumer has some buy-in to the system. There is a mutually beneficial relationship. Do need to put in some contract clauses (as in all DE contracts).
- Anders Rydaker: DESP has a seven member Board of Directors, three of whom are elected by customers; thus, the customers have a strong voice on the board.
- Potential "deal-breaker" issues or items that need to be addressed:
  - Need money (rebuilding an infrastructure as large as Pearl Harbor is <u>very</u> expensive)
  - Operating costs may not decrease, because operating budgets don't include capital allocation. Closing a DE deal usually requires getting the capital guys (and their budgets) together with the operating guys (and their budgets).
  - Need to do due diligence.
  - Need to properly present (identify, estimate, and quantify) the benefits

Panel Discussion No. 5 – Recommended Next Steps for Realization

All workshop participants; moderator: Andrepont

The following suggestions were offered by all the attendees, in answer to the question: What should/must be done or addressed in order to move these technologies forward into commercial implementation quickly and effectively?

- Team building – a Public-Private Partnership.
- Public-Private Partnership.
- Reb Bellinger – give a presentation to PAC/DIV.
- Don't take all of this knowledge and put it on a shelf.
- Federal government should provide funding (DAGS representative).
- Finances is a focal point – Navy/Barbers Point redevelopment – looking for private sector funding.
- Government to provide land, etc. with financing from financial partners / other participants.
- Communication to others (beyond end users), e.g TES will be highly visible (we must address siting and aesthetics).
- Huge capital required – difficult to find locally – wants federal government to fund – doesn't think that it can be funded locally.
- Public education.
- Educate people so that they know they are part of the PUBLIC-PRIVATE PARTNERSHIP.
- Complete the model. This allows one to sit down and show what it would look like, how stakeholders will benefit – benefits/challenges. Need a good focal point. Time line. Dollar costs. Cost shares. Sources of funds. Need to create a "sense of urgency". Otherwise in 10 years will just be repeating everything.
- Concentrate on key players, e.g. State, military, and large land owners. Keep pecking away at them. Need to go around and convince these people. Web site can be a huge source of data regarding SWAC/TES – everything there for information. Similar to Cornell's web site.
- Huge value. All data goes on to web site. Link to Cornell. E-mail, phone number, fax number – now full blown.
- Distance learning. Asynchronous vs. just web site.
- Community building – networking.
- Web site needs to be very interactive and motivating. Needs to have certain learning ingredients.
- Employ "Educommerce" – offer learning on a commercial web site.
- Workshop – have more of these. Workshop with main players – develop strategic business plan – overarching goals and tie into public policy. DBEDT web site a good starting point. Help with networking/marketing.
- Work on an implementation plan from the overarching goals.

- Lots of work and information. Reports. Studies. What are the compelling set of questions/concerns that cause someone to take action. Does it work? Yes. What other motivators are there? Difficult but necessary to get people to make a change in their behavior. Define a set of compelling issues that will make the PUBLIC-PRIVATE PARTNERSHIP go forward.
- Get correct individuals – education (key), but it needs to be substantive, consistent, cohesive. Consumers as well as local political forces. Time line is very important. SWAC has many benefits. Greatest motivator is a deadline. Act 77 perspective. We have to develop some realistic timelines as a motivating tool.
- Issue that needs to be addressed: Avoided cost needs to be re-evaluated. Intermittent technologies and their value. Baseload renewables are offered only avoided energy costs.
- All for education. General education from a web site is really central. When people search for an answer, they use the web.
- People from all over the world have gone to the web site. Web site is critical and effective. It’s believable. Other than that, what do we do? What to do next? Find niche market that is commercially-viable without federal funding. We don’t need another demonstration.
- Diego Garcia is a good first start for OTEC. There are several islands with severe water (and electricity) problems and costs. Focus on places with significant costs for air-conditioning. Other markets (beyond Hawaii) may be best first.
- Complete systems approach. Will proceed when someone goes first.
- Puna Geothermal will be a good initial Hawaii Kalina Cycle® project.
- Need a champion.
- Put together a selection process and choose a business model. Choose one and go with it.
- Talk with important environmental stakeholders. Talk to them and get them to be supporters.
- The distribution system.
- Public education important. Politicians will follow the public.
- Where will we put the pumping station? How do we get these landowners on board?
- Technologies are available. SWAC and TES have been proven elsewhere. Convinced that the load is there and that this can be a commercially-viable proposition. Therefore, we next need a PUBLIC-PRIVATE PARTNERSHIP – What kind? How do we do it?
- How were they developed? In the same position as us 20 years ago. Need to get key players to understand the benefits. Need to get a champion to promote them.
- No doubt that this could be a success economically. But decision-makers don’t have all of the information available.
- Seed money is necessary. Some U.S. Department of Energy money may be available.

- Where are we now in the process (how far back are we from Cornell's project success)? Lanny Joyce:
    - We are very early in the process.
    - In the first year, Cornell spent $250,000.
    - Used a two-day intensive charrette. Team fresh off the Lake Source Cooling design.
    - 30-year master plan.
    - Immediately launched into environmental permitting and approval process.
    - Started out very early talking with community. Survey, three years into the project, showed only 13% were aware of this concept.
    - Quite a process. Community outreach and environmental impact assessment process was real cost. (Anders Rydaker: As another example, for the new Combined Heat and Power (CHP) project using biomass, DESP conducted 32 community meetings involving hundreds of people.) Mental filtering. Remember, a very small number of individuals in the community can make your life miserable.
- Get focused. Put packages and targets in front of people. But as part of that, note that there are very significant impacts the on bottom line made by various parameters (e.g. investment tax credits, utility DSM incentives, energy production incentives, property tax rates, and depreciation), each with ~10% improvement in bottom lines. Such treatments are realistic and have precedents, e.g. why a $650/kW utility rebate is justifiable. We need to explore deeper into and pin-down these issues. Confirming even one or two can move the developments into slam dunk financial winners.
- Need additional participation from the State and city/county and federal governments. They need to understand the great benefits of SWAC. News to all of us, before we were educated. Kudos to BOW and Dave Rezachek for their efforts to-date.
- Marketing plan should address all stakeholders. It needs to be consistent in its main message, but with a different focus and approach for different stakeholders.
- Canada has greatly increased its District Energy systems. Action was needed to be committed and was committed by Canadian municipal governments. DE infrastructure is seen as a similar responsibility for cities in Sweden.
- Let's go find out what's going on.
- Sense of action that needed to be taken. People's behavior needs to be changed. Need to get to the point where people ask: why <u>aren't</u> we doing this? Not – why should we do this?
- Stop studying this to death. Do something now. For example, set a goal of installing 100,000 tons on Oahu in 10 to 15 years. Identify the most likely initial system (e.g., downtown Honolulu). Then add systems to this (e.g., Kakaako). These systems can then be interconnected to provide for redundancy and reliability. Prepare a master plan for full development over the given time period. Let's get started NOW!

Day 3 – March 21, 2003

Optional Tour of NELHA (Natural Energy Laboratory of Hawaii Authority) – Keahole, Hawaii

The tour was attended by Dr. Rezachek of DBEDT, Lanny Joyce of Cornell University, and John and Karen Andrepont of The Cool Solutions Company.

Tour and Discussion of NELHA

Jan C. War, Operations Manager – NELHA

Mr. War provided an in-depth overview of the history and activities of the NELHA facility. Slides, poster-presentations, and a walking tour of some of the facilities helped to illustrate the varied activities.

- The newest and largest seawater pipeline at NELHA is a 55 inch diameter HDPE pipeline 9,000 ft long and 3,000 ft deep. It has the capability to deliver 4 ºC (39 ºF) seawater at a rate of up to 27,000 gpm. However, the initially installed pumping systems will only provide up to 7,000 gpm.
- NELHA also operates warm (surface) seawater intake pipes at 24 to 28 ºC (75 to 82 ºF). Most tenant users at NELHA employ blended water at temps of 16 to 18 ºC (60 to 65 ºF).
- NELHA charges tenants for their land, plus $0.08/kgal for cold seawater and $0.06/kgal for surface seawater. These current water tariffs cover incremental operating costs (but not the large initial capital costs). The tariffs may be increased somewhat in the future, especially as NELHA is under pressure to become self-funding.
- Andrepont noted that, if used at full capacity for cooling, and assuming a 15 ºF Delta T, the 55 inch pipeline could provide ~17,000 tons of cooling. The effluent temp would still be only 12 ºC (54 ºF),i.e. colder than temperature used by most NELHA tenants.
- Andrepont noted that, at least hypothetically, and based on the current NELHA cooling water tariffs, a cooling user could purchase deep cooling water at a rate of only $0.008/ton-hr. And, if the effluent were returned and credited at the current warm water tariff (even though the effluent is still much colder), the net cost would be reduced to only $0.002/ton-hr. (For perspective, “typical” DC tariffs in the mainland U.S. have a “consumption charge” (to cover marginal production cost) and a “capacity charge” (to cover capital and other fixed costs). The marginal consumption charges will generally be in the $0.07 to 0.10/ton-hr range, or higher, with total costs to customers varying from $0.20 to $0.35/ton-hr, or more, depending on annual cooling load factors.)
- NELHA tenants all operate in parallel with each other. No one returns seawater into the cold water or surface water supply headers.

Tour and Discussion of Common Heritage (an NELHA tenant)

Prof. John Craven, Founder and Anne M.-O. Bailey, CEO – Common Heritage Corporation (CHC)

Professor Craven and Ms. Bailey reviewed the history of the development of NELHA and provided a hands-on tour of the on-going activities that Common Heritage is researching and demonstrating at their facility within NELHA.

- Among the many fascinating highlights of the discussion and the demonstrations was the hospitality of an unexpected and delightful luncheon comprised of items produced on the property using deep ocean water agriculture and aquaculture (salad, bread, and Maine lobster), plus deep ocean water-refrigerated beverages.
- Many of CHC's demonstrations are part of an integrated serial process of using the cold resource. (e.g. fresh water production, refrigeration and agriculture sequentially utilize cold resource sequentially.
- Ms. Bailey described CHC's vision and efforts to expand NELHA operations into an integrated (series-configuration) ocean cooling process. The concept would employ piping the cold seawater from the new 55 inch pipeline inland to the "top" of the NELHA property (an elevation of ~250 ft above sealevel), adjacent to the highway. The cold resource could then flow back through the NELHA property by gravity, meeting the needs of numerous diverse processes and users, in series where appropriate.
- Andrepont noted to Bailey that any significant air-conditioning loads at or near the Kona Airport or across the highway, now or in the future, could be very economically served by such a system. A large SWAC HX could be the first step in CHC's series configured integrated process.