Energy - Docket Optical System

From:	Campos, Alicia@Energy
Sent:	Thursday, January 03, 2013 9:35 AM
To:	Energy - Docket Optical System
Subject:	12-AFC-03 Redondo Beach Energy Project - Public Comment from Hank Leibowitz, dated December 31, 2012
Attachments:	Integrated Steam-ORC Bottoming Cycle R14 Final1.pdf

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From: Hank [mailto:hank@wasteheatsol.com]
Sent: Monday, December 31, 2012 11:56 AM
To: Kelly, Patricia@Energy
Subject: Redondo Beach Power Station

Ms. Kelly,
I would like to take this opportunity to make you aware that technology currently exists that could significantly reduce the water consumption and site impact of the proposed plant.

The proposed plant uses air cooled condensers (ACC) to replace water-cooled (presumably ocean water) condensers in a heavily populated area. Due to the very low pressure of steam at condensing conditions the volume of steam is very high, resulting in a very large and expansive array of ACC equipment. (I'm guessing the nearby residents haven't seen the plant's equipment layout and renderings yet) If the latter stages of the steam turbine were replaced with a turbine that uses a refrigerant the volume flow into the ACC would be reduced by a factor of about 100. This would significantly reduce the size and footprint of the ACC. Further, use of the refrigerant in the ACC would reduce water consumption in the steam turbine by millions of gallons per year.

I've attached a recent report that discusses this in detail.

Please call at your convenience if you have any questions and/or need of further information.

Sincerely,

Hank Leibowitz
President
Waste Heat Solutions LLC
2010 Crow Canyon Place Suite 300
San Ramon CA 94583
Office: 925-4982501
Mobile: 925-3243089

High Performance, Air-Cooled, Integrated Steam/ORC Power Plant

TAS Energy, Inc.
6110 Cullen Blvd
Houston, TX 77021
March 15, 2011 (revised May 04, 2011)

Contacts-

TAS Energy; Tom Pierson, Founder & CTO, tpierson@tas.com
Waste Heat Solutions; Hank Leibowitz, President, hank@wasteheatsol.com

Background/Experience-

1. **TAS Energy, Inc.**
   TAS designs and builds modular power systems, gas turbine inlet cooling systems (TIC) and industrial chilling plants. The power systems focus on use of refrigerant working fluids in organic Rankine cycle (ORC) designs, mainly for unfired thermal power applications such as geothermal, engine and gas turbine bottoming cycles, industrial waste heat, and solar thermal. Plant sizes in the 1-100MW range are offered. ***TAS was recently awarded the largest ever air-cooled ORC plant in the US (97 MW).*** TAS has been in business since 1999.

2. **Waste Heat Solutions**
   Waste Heat Solutions (WHS) provides engineering consulting services in the field of unfired thermal power systems, mostly ORC for geothermal and waste heat applications. The principal of WHS, Hank Leibowitz, has been active in this field since 1978 and been working with TAS for the past five years. Overall, Mr. Leibowitz has in excess of forty years experience in the field of thermal power systems and turbo-machinery development.

   Mr. Leibowitz will be the lead Project Manager on behalf of TAS.

Brief Description of Operations and Mission-

TAS is an energy systems solutions company that has successfully exploited its strong background in refrigeration & power generation with expertise in manufacturing and packaging to become the dominant supplier of Turbine Inlet Cooling (TIC) systems worldwide. The company's success is directly attributable to its ability to transform what had been a highly engineered, custom designed, field-erected product to one focused on standardization, supply chain optimization and factory-built modular plants.

TAS is well on its way to doing the same for ORC power systems. The combination of the company's in-depth knowledge of refrigeration engineering and modular solutions is expected to provide a pathway to success in ORC technology by meeting four major objectives:

1. Increase product performance using refrigeration process, power and equipment expertise
2. Increase the quality of delivered products by in-house fabrication
3. Shorten project lead time by significantly reducing field erection
4. Reduce custom engineering content

Principal Investigators-
Tom Pierson, TAS Chief Technology Officer, tpierson@tas.com; 713/877-8700
Ryan Elliott; TAS Senior Energy Systems Engineer, relliott@tas.com; 713/440-4268
Hank Leibowitz; President Waste Heat Solutions, hank@wasteheatsol.com; 925/324-3089
Tom Tillman; TAS Renewable Energy Systems, Business Development Manager; ttillman@tas.com; 713-877-8700

Bios of Principal Investigators-
See attached

Web Links-
TAS; www.tas.com
Waste Heat Solutions LLC; www.wasteheatsol.com

Objective-
TAS' objectives in responding to this RFI are to provide EPRI with:

- An alternative to standard "A-frame" sub-atmospheric air-cooled steam condensers with a high-density, positive-pressure design that reduces the CapEx and OpEx of air-cooled operations. This would be accomplished with an advanced cascaded bottoming cycle created through the addition of proven ORC technology to "bottom" the steam cycle.
- An advanced air-cooled condenser design that reduces CapEx and parasitic fan loss.
- A method to mitigate any potential steam output losses or cycle efficiency impact through efficiently shifting power (8) from off-peak to on-peak, significantly increasing peak power plant capacity.

Technology Description-
TAS proposes to modify utility size steam plants (including solar thermal) applications, with an integrated steam/ORC (Steam Turbine/ORC) design in which the traditional condensing portion of the steam cycle is replaced by a high performance ORC using an advanced air-cooled condenser.

State of the art-
The state of the art in utility size steam plants (direct-fired boiler or GT bottoming) is typically multi-pressure, superheated, fully condensing cycle having turbine inlet throttle temperature in excess of 1000F. Direct fired plants operate at pressures in excess of 2000 psi with reheat, while unfired steam cycles have lower pressures often without reheat. The steam bottoming cycle for the "F" Class of gas turbines has been chosen as the baseline state of the art with which to compare the TAS' steam/ORC (even though this technology is equally applicable to coal boilers, flash geothermal systems, and solar thermal and potentially even nuclear). See Figure 1.

The common GE 7241FA water-cooled bottoming cycle shown below contains a traditional two- or three-pressure HRSG consisting of two evaporators (IPE2 and HPE3), two drums (IPB and HPB1) and two super-heaters (IPS1 and HPS3). The GE technology is shown for introductory reference only.

In the proposed study, in addition to the GE 7FA, we will also explore the viability of modifying the Siemens-Westinghouse offering, which is actually already much closer to the technical vision of TAS' ST/ORC concept. Siemen's "fast-start" *Flex-Plant 10* design, several of which have already been built or ordered, is based on the SGT6-5000F gas turbine, already presumes a commercially proven single-pressure HRSG, a back-pressure steam turbine (SST-800) and a positive-pressure air-cooled condenser.

- *Condensing Steam Turbine with Air Cooled Condenser-*

In the water-cooled GE application (shown), the gross steam cycle yields 87.8 MW gross and 84.2 MW net. Replacing the wet cooling tower with an A-frame type air-cooled condenser, the steam plant output is reduced by approximately 3.1 MW (5" pressure drop in the AC condenser). That sets the new baseline net steam plant output to 81.1MW.

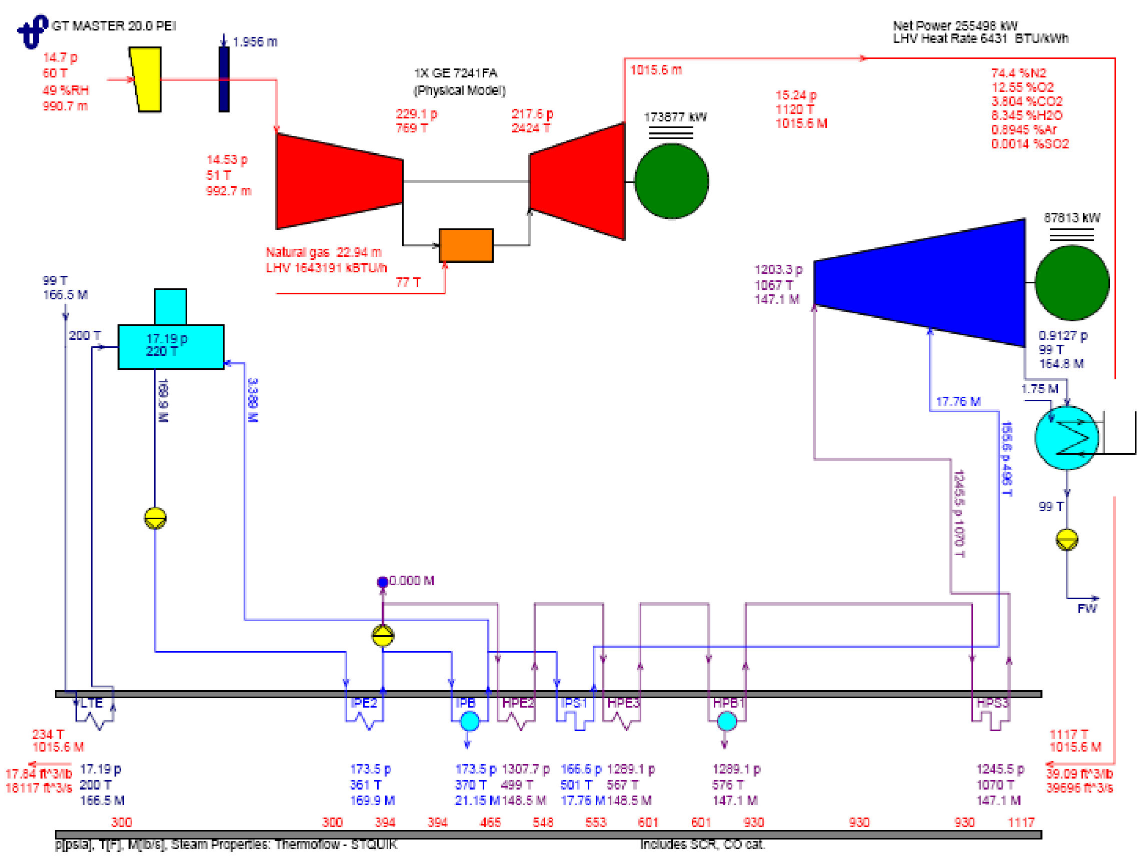

Fig 1 – 7FA w/Condensing Steam Bottoming Cycle

How the proposed technology works-

- *Replacing ST Condensing Stages with an ORC*

The proposed technology consists of an integrated steam and organic Rankine cycle (ORC) in which the "back end" portion of the steam cycle is removed and replaced with an ORC. Additionally, a newer, advanced (not an "A-Frame") air-cooled refrigerant condenser is installed and used instead of a wet cooling tower or traditional air-cooled steam condenser.

The proposed steam/ORC plant ("ST/ORC") contains a similar steam turbine as the original condensing version but with the "back end" stages removed following expansion to 24 psia. At this pressure, the saturation temperature is 240F though expansion from the original throttle condition results in approximately 20F of superheat remaining in the steam. In its place, an ORC is installed, containing an expander that operates at an inlet condition of 240F (including 20F superheat) and at elevated pressure (depending on fluid selected) and expands to approximately 97F at above atmospheric pressure. See Figure 2 below.

Using an air-cooled condenser at 59F ambient, the ORC produces **20.4MW, net** of all associated loads including refrigerant feed pump and condenser fan motors.

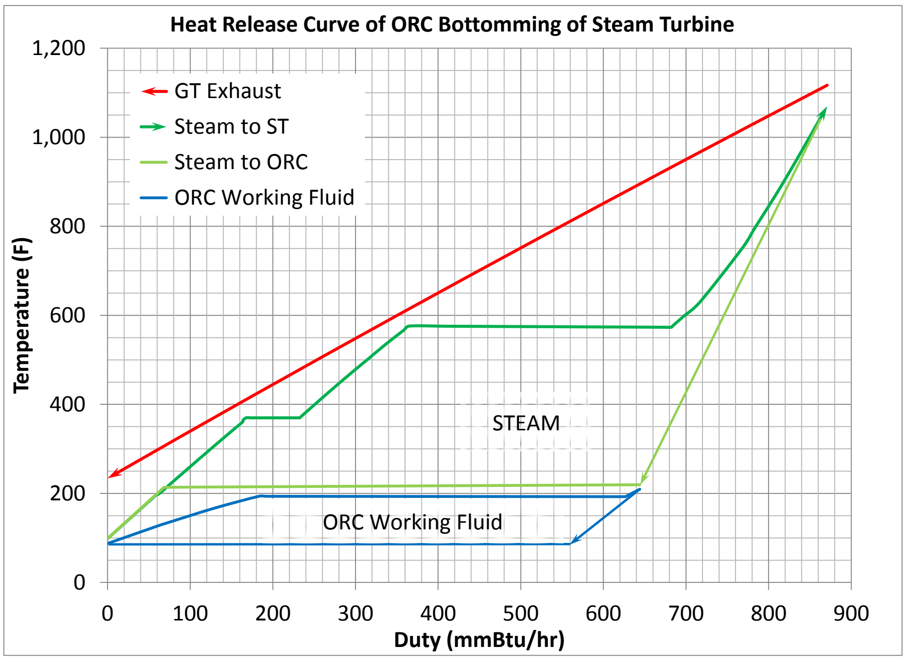

Figure 2- Steam Bottoming with ORC

The steam turbine expansion, revised to 24 psia backpressure, produces approximately 59 MWe gross at the generator terminal, with a **net "topping" steam cycle net output of 58.2MW** (no cooling tower pump and fan power losses or vacuum pump losses apply).

In fact, we believe that the output of the steam plant could be even greater with elimination of the live steam-fed D/A, by making this steam available for additional ORC power. Further, the IP pinch point that occurs at 173.5 psia will be eliminated, allowing the IP stage to operate at higher pressure, generating further additional output. We propose to compare shifting the IP stage to a more optimum pressure, or eliminating it all together in a single-pressure HRSG.

The net plant output of the ORC, using an *air cooled* condenser, is **20.4MW**. Thus the net output of the **ST/ORC is 58.2 + 20.4 = 78.6 MW.** This compares with **the air-cooled condensing steam cycle net output of 81.1 MW (*2.5 MW lower*).** The study will show how we can eradicate this 2.5 MW deficit by eliminating LP steam requirements for the D/A, and by optimizing the pinch point at this pressure/temperature. A LP steam generating section may be used to further lower the flue gas temperature and for direct heating of the ORC. Further, we will attempt to eliminate the power deficit *relative to the water-cooled plant*, so that the optimized ST/ORC plant would achieve 84.2 MW net.

- *Effects of Replacing the Air-Cooled Condenser of the ST with an ORC*

Substituting the ORC for the steam turbine stages from 24 psia through condensing will result in the following:

1. Volume of working fluid will be reduced by more than a factor of 100
2. Elimination of all vacuum during normal operation
3. Elimination of DA (12,000 lb/h of live steam) and vacuum removal system. Any air entry during shutdown will be removed via above-atmospheric non-condensable gas (NCG) removal (vent in steam condenser/vaporizer)
4. Reduction of blow down make-up from approx. 12,000 lb/h (assuming 2% of steam flow) to 8,000 lb/h, resulting in **annual water savings of 4.5 million gal.**

- *Turbine Inlet Chilling (TIC)*-

To the extent that the ST/ORC hybrid system generates less output than the baseline condensing steam cycle, a fully integrated GT inlet chiller can make up for this deficiency and more, particularly during summer operation. At high ambient temperature the gas turbine output falls off ("droops") and the ST/ORC cycle output also decreases due to the effects of increased condensing temperature with air cooling. TIC can restore the GT output back to ISO conditions. See Figure 3 below.

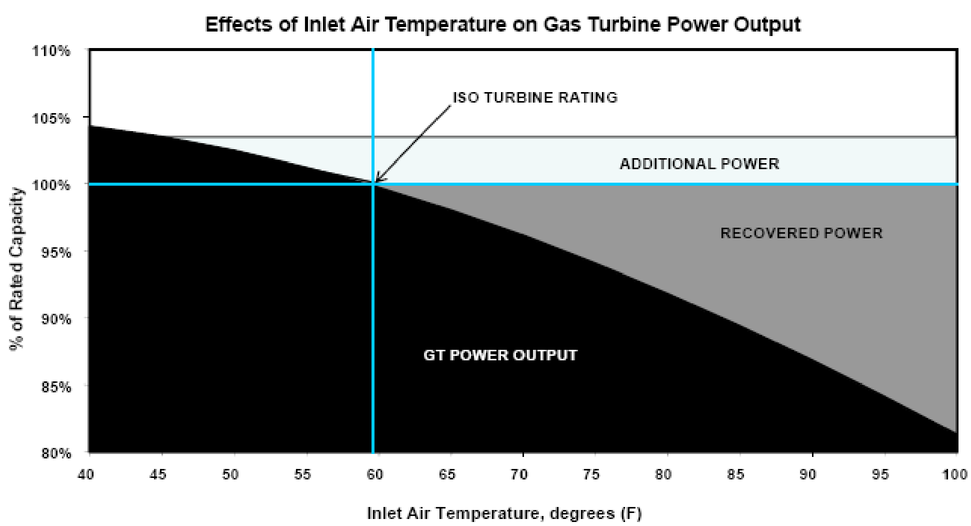

Figure 3 – Turbine Inlet Chiller Performance

Further, with thermal energy storage (TES), TAS can provide up to 5% greater output than the air-cooled baseline plant, and demonstrate capacity parity with the water-cooled plant.

- *Advanced Air-Cooled Condenser-*

  TAS has developed an air-cooled condenser with features that provide greater efficiency and lower O&M cost. The design is proprietary but it reduces the number of fan drives, compared to current ORC ACC units by a factor of 9:1. Additionally, the recirculation problem (hot air leaving the condenser deck circulates back to the underside of the condenser resulting in an increase of condensing temperature by as much as 5 F or more) is eliminated by the addition of an aerodynamic velocity recovery fairing installed on and extending above the deck.

- *Annualized Heat Rate Improvements*

  Although normally associated with hot weather, air-cooled plants are typically located where winter over-night temperatures can drop well below the freezing point of water. On an annual average basis, the ST/ORC system will have a lower ST back-pressure than for a typical air-cooled A-Frame plant. This is because the ORC cycle can operate at significantly lower condensing temperatures during cold weather without the risk of freezing. Accordingly, we expect that the annualized net cycle heat rate for this ST/ORC configuration will be as good, or better, than the referenced air-cooled plant.

  A table, such as Table 1 below, will be generated to demonstrate the relative performance of the proposed system across a wide range of ambient conditions. Annualized results will be generated either by factoring the 3 temperature points shown below, or with a bin model, or an actual 8,760 hour analysis.

		Winter 32F			ISO 59F			Summer 95F		
parameter	units	base	new	delta	base	new	delta	base	new	delta
Capacity	MW	TBD	-	-	-	-	-	-	-	-
Energy	MWHr	TBD	-	-	-	-	-	-	-	-
Revenue	$M	TBD	-	-	-	-	-	-	-	-
Heat Rate	Btu/kWHr	TBD	-	-	-	-	-	-	-	-
Fuel	mmBtu	TBD	-	-	-	-	-	-	-	-
Fuel	$M	TBD	-	-	-	-	-	-	-	-
Net	$M	TBD	-	-	-	-	-	-	-	-

Table 1 – New vs Baseline

With this annualized data, TAS expects that we can reasonably demonstrate that the concept proposed will not result in a loss of power, a degradation of heat rate, or a loss of net revenue, while still eliminating the use of cooling tower water for steam condensing.

Applications-

The ST/ORC hybrid cycle design described may be applied to all condensing steam cycle plants but mainly for direct-fired (coal) and gas turbine combined cycles that are the dominant plant designs of the US utility industry, most of which employ wet cooling towers

Advantages-

1. The ability to eliminate the use of wet cooling towers by incorporating an ORC, whose volume flow is ***1/100 of that of steam***, results in substantial reduction (estimated to be ~$27M [(1)] in the installed cost of the air-cooled condenser for the 7FA steam bottoming cycle).
2. Air cooling for this size plant saves up to ~1,175 gpm. On an annualized basis, this saves 935 acre-feet of water, or ***about 300 million gallon****s, or $600,000 per year.*
3. Cooling the GT exhaust further, (not beneficial in steam plant), removing the DA, and system optimization will likely allow the ST/ORC to generate the same output as an air-cooled condensing steam plant.
4. Integration of TIC and TES increases plant output back to water-cooled ISO base-line over the range of warm-weather operations, offsetting performance loss associated with air cooling and should get performance close to or better than the water-cooled CC plant.
5. TAS' high efficiency air-cooled condenser could reduce fan losses and O&M costs below that of current designs.
6. TAS-designed ST/ORC bottoming cycle reduces amount of live steam needed for deaerator, reduces vacuum pump power, and chemical treatment of feed water, all resulting from total elimination of vacuum stages of the steam turbine.
7. TAS-designed ST/ORC provides better match between GT exhaust gas cooling and ST/ORC heating curves, thus reducing Second Law losses. System output is improved.
8. With a single-pressure HRSG and a positive-pressure condensing system, plant start-up time would be reduced, allowing for more cycling capability.
9. The Capital Expense for a water treatment plant to prepare brackish water or waste water for cooling tower service is eliminated. This expense is estimated at a unit cost of $5M per MGD X 1.5 MGD per unit = $7.5M per unit. This cost is translated into a unit CapEx of $3 per thousand gallons of water, or $900,000 per year.
10. The ORC can operate at lower condensing temperatures in cold weather. Annualized heat rate is therefore maintained commensurate with the reference air-cooled plant. Further, because the ORC is passively freeze-protected, it can tolerate long periods of shut-down in cold weather.

Disadvantages-

The disadvantage of the ST/ORC is the added equipment in separating the bottoming cycle into two parts.

Technology Readiness-

The major elements of the ST/ORC system are commercially available except for the 25-50 MW-class expander. There are no ST/ORC plants in operation, and integration of the two, including control logic and design, needs to be developed. TAS is well qualified to do this.

Number of Years Required for Commercialization-

Commercialization will be paced by the time and willingness of the remaining OEM steam turbine suppliers to commercially support operating their systems as back pressure units (although already accepted and implemented by Siemens), and the time required for TAS to modify off-the-shelf expander designs in the 25 – 50 MW range for ORC duty.

It is estimated that these can be completed within a three year engineering/development project, with the TAS design portion being achievable within 12-18 months.

Anticipated Cost of the Commercialized Technology-

A summary of plant output and budget cost estimate is presented to show differences between condensing steam turbine (water and air cooled) vs. hybrid ST/ORC. See Table 2 below.

	Condensing ST Water-Cooled (7FA)	**Condensing ST <u>base-line</u> Air-Cooled**	Hybrid ST/ORC Air-Cooled	Hybrid ST/ORC Air-Cooled and Optimized	Hybrid ST/ORC Air-Cooled, Optimized, with TES
Net Output ~MW	84.2	**81.1**	78.6	81+/-*	84+/-*
	Installed Cost Relative to Baseline ~$:				
Air Cooled Condenser	-$42M (1)		-$42M	-$42M	-$42M
Steam Condenser	$2M (3)				
Cooling Tower	$6M (2)				
ORC			$30M (4)	$31M	$31M
DA and Vac Removal			-$1M	-$1M	-$1M
Water-treatment plant	$7.5M				
TIC					$10M
TES					$2M
Net Cost Difference	-$26.5M		-$13M	-$12M	$0

* Includes cooling stack by additional 50F, eliminating DA steam and system optimization

Table 2- Condensing ST vs. ST/ORC

From the information shown in Table 2, an optimized Hybrid ST/ORC generates about the same net output as the air-cooled ST but at lower capital cost (-$12M). The maximized ST/ORC plant with TES achieves the same output as the water-cooled plant, with no change in cost relative to the base-line air-cooled plant.

Efficiency-

As shown above the optimized *air-cooled* ST/ORC hybrid plant operates at greater than 95% of the output of the baseline 7FA *water-cooled* condensing steam plant, and at about the same output as an air-cooled condensing steam plant, not including any additional ST/ORC output achieved by integration of TIC with or without TES.

During winter operation the efficiency of the combined cycle employing the ST/ORC will likely reach or exceed that of the water-cooled baseline. During summer operation the TIC/TES will restore the combined cycle's output to ISO and in some cases exceed ISO rating.

Specifications-

Design details and specifications of the ST/ORC plant are proprietary and are not made available at this time. The overall design approach is shown in Figure 2.

Risks, Potential for Success and Possible Impediments-

The major risk associated with commercial implementation of this approach is the willingness of the OEM equipment suppliers, of mainly the steam turbines, to modify their turbines for back pressure operation, i.e., removal of the low pressure (including all condensing stages) portion of the turbine to make it compatible with the heat requirements of the ORC.

The integration of the steam cycle with the ORC in the manner described represents a process improvement, requiring additional controls engineering and the design of a 25MW-class expander or turbine.

Scope-

It is suggested that a design study be conducted, having the objective of comparing the performance (output and efficiency), installed cost, O&M cost and water consumption of an air-cooled ST/ORC plant with a 100MW-class steam-only utility bottoming cycle. The ST/ORC contains TIC and TES for combined cycle operation. A preliminary design of a 25MW expander is also essential and suggested. The steam bottoming cycle used in the F-Class combined cycle is suggested as the baseline design.

Project Tasks-

A comprehensive design study is suggested, consisting of:

- Layout (plan and elevation) and P&ID of 100MW-class ST/ORC plant using F-Class combined cycle steam bottoming cycle as baseline.
- Layout (plan and elevation) and P&ID of 250MW-class direct, coal-fired ST/ORC plant (double pressure with reheat).
- Develop process flow and heat/mass balance for combined cycle and direct fired including a performance estimate of the ST/ORC compared to baseline steam-only for average annual, winter and summer operation.
- Develop preliminary control logic and design for integration of steam cycle and ORC
- Preliminary design of 25MW-class expander; dimensions, performance and mechanical features including lubrication, seals, rotational speed, etc.
- Develop design specification for TIC and TES required for reference combined cycle baseline. TIC and TES not applicable to direct-fired steam.
- Estimate of water savings using ST/ORC design.

- Estimate of equipment cost and total installed cost of ST/ ORC compared to steam baseline.
- Estimate of value proposition of adopting ST/ORC.
- Estimate of O&M costs for each.

Modeling-

TAS has expertise and experience in the modeling of ORC plants, both subcritical and supercritical, using an array of possible working fluids including ammonia, R134a, R245fa, (iso)butane, (iso)pentane, etc. It also has the capability of using a variety of heat sources including steam, combustion gas, water and thermal oil. The model can be used for air cooled or water cooled condensing, and is able to estimate the internal loads within the ORC that must be deducted from the generator output to derive net plant output.

The model contains an important feature of calculating the heat acquisition process of the ORC's evaporator. In so doing the designer can estimate the temperature differences between the source and ORC fluid to insure there are no "crosses", and to reduce Second Law losses as a means to optimize plant output.

TAS also has the design tools to specify the parameters of the TIC based on GT conditions, ambient wet and dry bulb, etc. In addition, the model can be used to design the thermal energy storage system to augment the plant's output beyond that provided by the TIC alone.

Schedule-

The duration of the study is expected to take 18 months.

Funding-

A budget estimate for the tasks described above is $300K.

Deliverables-

TAS will provide a comprehensive report containing all the elements listed in the Project Tasks.

References-

1. Powers Engineering, *Correspondence to Black & Veatch*, p.3/4, March 31, 2008
2. SAIC, *Symposium on Cooling Water Intake Technologies to Protect Against Aquatic Organisms*, p. 15/21, May 2003
3. TP Sales Inc., budget price estimates
4. TAS, budget price estimate
5. Foster Cove Engineering, budget price estimate
6. Combustion Engineering, *Steam Tables, Properties of Saturated and Superheated Steam*, Third Edition, 1940
7. Keenan, J and Keyes, F., *Theoretical Steam Rate Tables*, ASME, 1938
8. AB 2514, State of California, Energy Storage legislation, 2010

CV/Resumes of principal investigators follow below

TOM L. PIERSON

Founder & Chief Technology Officer, TAS Energy

Tom Pierson is Founder and Chief Technology Officer of TAS, a leading green energy provider of high-efficiency modular energy solutions serving the global Power, Renewable Energy and Industrial Cooling industries.

A visionary & entrepreneur, Mr. Pierson has always been at the forefront of change and environmental consciousness through innovation in energy conversion processes. He founded TAS Energy (formerly known as Turbine Air Systems) to provide completely factory engineered and prefabricated modular utility plants for utility infrastructure which had previously always been field erected. The factory-built approach provided guaranteed performance, improved efficiency, reduced project risk and streamlined deliveries for a variety of different industries. TAS is the originator and global leader in producing additional peaking power from gas turbine power plants through Turbine Inlet Cooling (TIC) which Tom pioneered by completing the world's first TIC project in the 1980s. This concept was later expanded into highly efficient District Cooling when TAS completed the Palm Island project in Dubai (the worlds largest at the time). Tom and TAS have recently focused on expanding this modular concept to utilize heat from geothermal or from waste heat sources and converting this thermal energy directly into electrical power through patented Organic Rankine Cycle (ORC) modular power plants which are the most efficient in the industry. Tom has also been involved in expanding this modular concept to the Data Center & internet industry to improve efficiency and reduce the cost of converting electrical power into data.

Tom received his B.S. in Chemical Engineering from the University of Arkansas. He is a member of ASME, ASHRAE, U.S. Green Building Council, is a founder and past Chairman of the Turbine Inlet Cooling Association (TICA), and has been on the Boards of the International District Energy Association (IDEA), the U.S. Clean Heat and Power Assoc (USCHPA), and the Houston Green Building Task Force. Tom & TAS recently received the "E-Award" from US Commerce Secretary Gary Locke which is the highest award offered by the US government for Export Excellence. Mr. Pierson holds (8) U.S. Patents related to high efficiency Central Plant designs, Turbine Inlet Cooling, and Integrated Energy Systems and he remains active in the development of new technologies related to utility energy efficiency, Mission Critical utilities, Renewable Energy and modular power generation. Tom and his wife, Dana have three children and reside in Sugar Land, Texas.

Herman M. Leibowitz

2010 Crow Canyon Place • San Ramon, CA 94583 • (925) 498-2501 • hank@wasteheatsol.com

Professional Experience

Waste Heat Solutions LLC, San Ramon, CA 2004 – Present

President

Waste Heat Solutions LLC provides development and consulting services associated with the use of alternative thermal power systems, mainly for the conversion of low to moderate temperature heat sources (industrial waste heat, geothermal, engine exhaust, etc.) to electric power primarily using organic Rankine cycle (ORC) technology.

Clients served by WHS include the following:

- Alcoa Inc.
- Calnetix Power Systems
- Econotherm Canada Ltd.
- Electratherm Inc.
- Elementa Group, Inc.
- Energy Concepts
- Heliex Power Ltd.
- Infinity Turbine
- Lockheed Martin
- Mechanology Inc.
- Nooter Eriksen
- Ram Power Inc
- Redpoint Capital
- SDP Energy LLC
- Squires, Sanders and Dempsey
- Turbine Air Systems
- Turbogenix Inc.
- US Department of Energy
- US Geothermal Inc.
- UTC Power

UTC Power, South Windsor, CT 2003 – 2004

Manager, Commercial Development PureCycle™ ORC

Lead role in bringing PureCycle™ ORC from alpha testing to commercial market place. Working with engineering and sales was able to identify most promising markets and developed product specifications.

Submitted invention disclosure for integration of reciprocating engine jacket water and exhaust gas waste heat as ORC heat source.

Developed strategic alliances with three major industrial Fortune 100 companies as potential end users and/or OEM suppliers. Identified field trial sites and negotiated terms of field trials with host.

Ormat International, Sparks, NV 1999 - 2003

Manager, Heat Recovery Systems
Directed sales/marketing effort in North America using Ormat ORC technology for waste heat applications. Major focus was on midstream natural gas plants, pipeline compressor stations, reciprocating engine exhaust and energy intensive processes such as cement and glass manufacturing and food process plants.

Developed project and completed sale of 4 MW ORC for midstream gas plant in Louisiana. Commercial market breakthrough; first commercial gas pipeline heat recovery ORC plant installed in the US.

Wrote proposal and negotiated sale of 28 MW of ORC capacity (4 x 7MW) for pipeline compressor stations in Alberta, Canada.

Exergy, Inc., Hayward, CA 1985 - 1999

Vice President, Business Development
Vice President, Projects
Principal member of start-up company engaged in development and commercialization of novel power generation technology; the Kalina Cycle.

Developed and managed all aspects of first reduction to practice of KC technology; a 6MW combined cycle plant near Canoga Park, CA.

Following demo plant success I led effort to commercialize the technology for geothermal and waste heat applications. Conducted applications engineering and design studies with prospective licensees. Completed license agreement with Ansaldo Energia and Far West Capital for geothermal power.

Secured public sector (DOE, CEC) funds in excess of $10 million for demonstration/R&D plant testing.

Developed and sold first commercial geothermal plant using KC technology; 2 MW plant in Husavik, Iceland.

Mechanical Technology Inc., Latham, NY 1978-1985

Manager, Energy Systems Branch
Managed engineers involved in R&D of advanced power systems such as steam-injected gas turbines for cogeneration, organic Rankine cycles, and industrial heat pumps. Responsibility for meeting revenue budgets through R&D contracting with public and private sector sources.

Brought in $8 million in new projects over five year period.

Developed cogeneration projects for GM plant in Warren, MI and solar thermal plant in Shenandoah, GA.

General Electric Company (CR&D), Schenectady, NY 1973 - 1978

Senior Research Engineer

Developed project and test article for development of ultra-high temperature, water-cooled gas turbine. Testing was successfully completed at 2300F.

Designed and managed installation of a rotating heat transfer rig. Tests yielded empirical data for use on full scale, prototype hardware in product department.

Pratt&Whitney (division of United Technologies), East Harford, CT 1965 - 1973

Project Engineer

Supervised assembly and testing of axial compressors for military and commercial jet engine programs. Solved compressor stall problem on engine for F-111 aircraft.

Education

MBA - **Rensselaer Polytechnic Institute**, 1977
MS Mechanical Engineering - **University of Connecticut**, 1968
BS Mechanical Engineering - **City College of New York**, 1965

Awards and Publications

Author or Co-Author of more than twenty-five, peer-reviewed technical papers in the areas of advanced thermal power systems and high performance turbo-machinery.

Awarded four U.S. patents in the area of advanced power systems and turbomachinery design. Two additional patents in this field are pending.

RYAN ELLIOT

Professional Experience

TURBINE AIR SYSTEMS; RENEWABLE ENERGY SYSTEMS GROUP

APPLICATIONS LEAD ENGINEER

APRIL 2008 - PRESENT

- Member of core team that developed an Organic Rankine Cycle (ORC) power plant market offering. Heat to power product offering covered plant sizes from 500kW to 15MW in a standardized fashion. Responsible for proper technology selection of components and vendor vetting and coordination. Generation of P&IDs, sequence of operations and electrical distribution philosophy for the standard product.
- Developed thermal modeling tools and detailed performance calculation procedures.
- Developed costing models and integration of tools to generate technical proposals with minimal effort.
- Individual responsible for performance and costing of commercial offerings and proposals.
- Assisted in design and execution installation of 800kW ORC prototype/proof of concept unit.
- Process modeler and engineer for non-standard products, applications, and opportunities.
- Technical interface between sales team and customers. Frequently involved in technical and commercial issues of closing power plant sales.

PAGE SOUTHERLAND PAGE, LLP (CONSULTING ENGINEERING FIRM)

MECHANICAL DESIGN ENGINEER

AUGUST 2006 - APRIL 2008

- Design engineer responsible for numerous building and process systems designs. Responsible for system architecture, technology selection and specification, and installation supervision.
- Developed designs and oversaw installation of combined heating and power systems involving both absorption and steam driven technologies.
- Central utility plant design for campus facilities. Included large steam boiler and large tonnage chiller systems installed in new facilities.
- Primary engineer responsible for building energy consumption analyses and renewable energy implementation including photovoltaic and solar thermal installations.
- Managed contractors, permitting, and code requirements.

THE BOEING COMPANY, INTEGRATED DEFENSE SYSTEMS, 737 MMA PROGRAM

MECHANICAL DESIGN ENGINEER

JANUARY 2004 - AUGUST 2006

- Design engineer responsible for an onboard inert gas generating system (OBIGGS) that was used to protect the vehicle from ballistic threat. Responsible for system architecture, control and performance analysis.
- Computational Fluid Dynamics analyst for the system. Major efforts in this category focused on the fluid flow through the tanks and vent systems. Required detailed analysis of the thermal effects of mixing flows and distribution of flows of different species.
- Design and analysis of inlet air scoop to capture external flow for use in system heat exchanger. Required integration into overall flow model of the air vehicle for in-flight and on-ground performance.
- Managed prototype development and computer modeled integration into air vehicle.

Professional Experience Continued

APPLIED MATERIALS, NEW PRODUCTS GROUP, SYNEXIS

MECHANICAL DESIGN ENGINEER - COOP

JANUARY 2003 - AUGUST 2003

- Design engineer responsible for initial prototype builds with eye for manufacturability. Designed and managed modifications to prototype designs that allowed for more rapid assembly on the production line.

- Designed robot lift tools to assist in field repairs of wafer handling tools.
- Managed business process of driving engineering changes and configuration control.

Research Experience

TEXAS A&M UNIVERSITY, POLYMER TECHNOLOGY CENTER

JULY 2004 – NOVEMBER 2004

- Student project entitled "Creation of Optically Transparent Ballistic Material Samples" under the supervision of Dr. Roger Morgan.
    - Developed manufacturing techniques for sample generation. Included coatings for existing windows and new complete window assemblies. Examined multiple polymers for the suitability to the application. Tested and summarized results on performance against a ballistic threat.

APRIL 2002 – AUGUST 2003

- Student project entitled "Machine Augmented Composites" under the supervision of Dr. Roger Morgan and Dr. Terry Creasy.
    - The goal of this research was to use the simple shear concept to probe the lamellar scale morphology evolution of semicrystalline PET subjected to simple shear conditions. The equal channel angular extrusion (ECAE) process was chosen for this purpose. Owing to the nature of the ECAE, a high level of simple shear deformation was achieved in the billet. Compared with conventional polymer processing methods, such as drawing, hydrostatic extrusion and rolling, the ECAE technique offers several significant advantages. These advantages were studied.

APRIL 2002 – SEPTEMBER 2002

- Student project entitled "Multifunctional, Smart, Integrated Materials Development" under the supervision of Dr. Roger Morgan and Dr. Terry Creasy.
    - Developed smart, miniaturized, integrated, multi-performance structures driven by bi-component fiber development in which the fiber skin performed a different integrated function than the fiber core. Once these bicomponent fibers were created they were formed into 3-D arrays using a single fiber element winder that allowed controlled distribution of the chemical and physical multi-functional characteristics into 3-D space devices. Alternately the fibers were spun into multifilament yarns and then woven into fabrics. Funded by Air Force, DOD, and NASA.

Education

TEXAS A&M UNIVERSITY – COLLEGE STATION, TEXAS

Bachelor of Science, Mechanical Engineering

GPA: 3.59/4.0
Graduated with Honors, Cum Laude.

Skills Summary

- Aspen HYSYS
- Aspen TASC+
- Gambit Mesh Generator
- Fluent CFD
- Autodesk Building Systems
- CATIA
- SolidWorks
- Autodesk Inventor
- AutoCAD
- Trane Trace Load Analyzer
- eQuest Energy Modeler
- MatLab & Simulink
- Visual Basic for Applications

Thomas Tillman

3114 Williams Glen Dr.
Sugar Land (Houston), TX 77479
CO PE #27077

AREAS OF EXPERTISE

- High-Level International Sales; Proposal Generation, Negotiation, Risk Management
- Management of construction, engineering and operations teams
- Power, Refrigeration, Process, and Energy Engineering

EDUCATION

- Master of Business Administration (MBA/Finance)
  State University of New York, Albany, NY
- Bachelor Science Mechanical Engineering (BSME)
  Worcester Polytechnic Institute (WPI), Worcester, MA

EXPERIENCE

TAS ENERGY, Inc. (TAS)
Houston, TX 2000 – 2005; 2011 -
Renewable Energy Systems, Business Development Manager

TAS is a manufacturer of large pre-engineered process systems for the energy markets. Managed in diverse leadership positions through rapid expansion by creating, staffing, and coaching new departments in fabrication, process engineering, proposal engineering, and IT.

- As Business Development Manager for TAS' Renewable Energy Systems division, work with customers to provide optimized technical and commercial solution for the capture of waste heat from industrial sources.
- Developed and negotiated record-size mechanical contract in Dubai, UAE.
- Reduced proposal generation time from 2 weeks to 15 minutes through "expert system".
- Established the company's turbine inlet cooling (TIC) construction capabilities in the "F" class turbine market.
- Created 100-person bi-lingual heavy fabrication facility, bringing in out-sourced production.

PAST EXPERIENCE

TEXYN Hydrocarbon
Houston, TX 2005 – 2010

TEXYN is a developer of gasification technology for hydrogen production and for "EOR gas", that is, industrial-scale gas supplies for enhanced oil recovery (aka tertiary recovery).

- Developer of a patented CO_2-centric underground coal gasification technology to produce high-pressure hydrogen gas at low cost and at industrial scale. Designed for zero-emissions due to total collection of pollutants and CO_2.
- Patented and patent-pending syngas waste products capture (in addition to CO_2) built-in for enhanced oil recovery (EOR) operations. Identified and analyzed non-traditional EOR-capable oil fields for analysis and acquisition in South Texas, from King Ranch area north to Hastings.
- 2008 Rice Alliance Energy & Clean Technology "Most Promising" award.
- Project developer for $600M coal gasification plant in Corpus Christi, TX.
- Engineering support for unique ethanol project which was not just energy self-sufficient, but also a net exporter of electricity. System designed for full CO_2 capture.
- Proposal manager for Caldwell Energy mechanical turbine systems.

Millstone Development Corp
Saratoga Springs, NY 1995 - 2000

- Developer of low-temperature liquid-desiccant gas dehydration technology.
- Developed business plan and operations budget for 7FA Front Range Power JV O&M group.
- Successfully negotiated complicated "gray market" gas turbine warranty transfer from OEM.
- Project developer for 800 MW brown-field combined cycle plant.

EDM / Northridge Construction
Saratoga Springs, NY

- Engineering Manager for industrial design-build construction and maintenance contractor serving power plants and heavy industry.

Altresco Pittsfield
Pittsfield, MA; Denver, CO
Plant Engineer

- Managed natural gas supply, steam and electrical sales for 170 MW cogeneration plant. Coached third-party O&M Contractor for dramatic plant operations improvements (2% heat rate improvement, 7% capacity increase, and >99% reliability).

Colorado Springs Utilities
Colorado Springs, CO
Construction / Operations Engineer

- Performed as project/operations engineer for capital projects and performance improvements for diverse hydro, natural gas, and coal 600 MW portfolio.