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ELECTRIC POWER PLANT WASTE HEAT UTILIZATION

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ABSTRACT

An inevitable consequence of the second law of thermodynamics is that any electric power plant that operating on the closed Rankine cycle must reject approximately 60% to 70% of the heat that is added to the cycle through the condenser to the ambient environment in order to complete the cycle. The temperature of the waste heat exiting power plants, while too low for electric power generation, is often suitable for other purposes such as heating greenhouses and aquaculture facilities, particularly those that reject this waste heat directly to the atmosphere via cooling towers.

Few facilities currently exist that utilize waste heat from power plants on a relatively large scale. The challenges are institutional and economic, not technical. Most electric utilities see little benefit to themselves in waste heat utilization. The cost of delivering hot water to the waste heat user can be significant compared to the benefit to the end user. However, this paper presents a new concept for utilizing waste heat that significantly reduces the cost of delivering waste heat by an amalgamation of users and provides a significant benefit to the power plant by reducing the heat sink temperature, thus increasing the efficiency of the turbine cycle and increasing the electrical output.

A dedicated piping system was provided in the original design of the Tennessee Valley Authority's (TVA) Watts Bar Nuclear Plant (WBNP) to utilize the turbine cycle waste heat and a portion of the nuclear plant reservation was dedicated for that purpose. However, when Unit 2 of the plant was not completed as scheduled, plans for the waste heat energy park (WHEP) were shelved in the early 1980's. As this author supervised the engineering of that project, it will be used in the proposed paper to illustrate how the new concept may be applied.

INTRODUCTION

Using funds appropriated by the United States Congress, the TVA conducted extensive research into the uses of waste heat from electric power plants in the 1970's and 1980's. TVA operated research greenhouses at their Muscle Shoals facility and at the Browns Ferry Nuclear Plant and conducted experiments at aquaculture facilities at their Gallatin Fossil Plant and at the Browns Ferry Nuclear Plant. In 1978, the TVA spent \$300,000 to investigate the feasibility of utilizing the waste heat from their WBNP then under construction midway between Knoxville and Chattanooga Tennessee. As a result of that investigation that was supervised by the author in 1979 and 1980, the TVA spent \$5,700,000 of appropriated funds to install waste heat piping from the cooling towers to a point outside of the security fence that is in existence today[1]. Since the cooling towers are located to the east of the WBNP and the 400 acre area identified for the proposed Watts Bar Waste Heat Energy Park (WBWHEP) is located on the west side of the plant, the distance between the cooling towers and the existing termination point of the waste heat piping as routed is approximately 3,500' (1,067 M), accounting for the high cost of the piping. The piping system was designed to deliver 100,000 GPM (378,500 LPM) to the proposed WBWHEP. In 1980, the TVA issued a final environmental impact statement that concluded that the successful demonstration of commercial waste heat utilization will benefit the Tennessee Valley region and the Nation and that granting an easement to a park management organization for the development of a WBWHEP is an environmentally sound action with fewer adverse impacts than would be expected from similar development elsewhere utilizing conventional heat sources. TVA proceeded to implement an aggressive marketing campaign for the WBWHEP, receiving letters of interest from nine greenhouse companies and five manufacturing companies that engage in ethanol production, leather tanning, and wood preserving. In March of 1982 in a letter from the TVA Manager of Power to the Rhea County Executive, TVA promised Rhea County "If

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your consultants are able to obtain commitments of sufficient infrastructure funding from grants or other sources and a substantial user of hot water makes a firm commitment to locate in the park, TVA would install the waste heat piping required to serve his needs.[2] " However, TVA subsequently deferred and then cancelled the second unit at the WBNP, due to the high cost of nuclear construction and declining electric power demand. A WHEP that relies on the availability of a single electric generating unit is not considered feasible. The corporate memory of the once proposed WBWHEP no longer exists at TVA. However, in recent years, TVA has decided to complete Watts Bar Unit 2 which is scheduled to come on line in the near future.

Owing to his familiarity with the WBNP and the proposed WBWHEP, the author has chosen to base the analysis in this paper on that specific application for waste heat utilization. However, as the assumptions are clearly stated, the results of this analysis could be extrapolated to other potential applications.

THE PROBLEMS WITH WASTE HEAT UTILIZATION

One might easily agree that rejecting 60% to 70% of the heat that is added to the turbine cycle of a typical power plant is wasteful. However, the problems associated with utilizing at least some of the heat are institutional and economic, not technical. In the case of electric power plants that operate in an open cycle without cooling towers, the temperature of the waste heat exiting the plant can be as low as 50-60 ^oF (10.0-15.6 ^oC). Yet, TVA and others have clearly demonstrated that even this heat may be used to heat greenhouses, etc. A few such facilities where waste heat is utilized in greenhouses and aquaculture facilities actually exist, but these are relatively small demonstration projects, because the economics make little sense. Much more practical from an economic perspective are waste heat facilities that are associated with electric power plants that utilize cooling towers to reject the waste heat directly to the atmosphere. In those cases, the condenser circulating water (CCW) is returned to the plant at temperatures on the order of 50 - 60 ^oF (10.0-15.6 ^oC) and leaves the plant at minimum temperatures ranging from 80 - 95 ^oF (26.7-35.0 ^oC), depending on the plant condenser and CCW system design. In those cases, waste heat utilization, though still economically challenging, exhibits more promise.

The institutional problems associated with waste heat utilization are, perhaps, even more challenging than the economic issues. Unless the electric utility and the waste heat user see some significant economic benefit in cooperating in a WHEP that offsets the potential inconvenience, the project is not likely to mature. In the past, some electric utilities such as Northern States Power, Pennsylvania Power and Light, and TVA perceived some public relations benefit in cooperating with such projects, but with widespread deregulation of the electric utility industry, greater attention is paid to the bottom line. Indeed, TVA, although a corporation that is wholly owned by the United States Government no longer receives appropriated funds and must continue to be competitive with its neighbor utilities. Therefore, the future of waste heat utilization hinges more than ever on its economic viability as should be the case.

WATTS BAR NUCLEAR PLANT HEAT REJECTION SYSTEM

The WBNP consists of four CCW pumps per unit that pump approximately 410,000 GPM (1,552,000 LPM) of CCW through a multi-pressure condenser where the temperature of the CCW is increased by approximately 38 ^oF (21.1 ^oC). The CCW continues to one counter-flow natural draft cooling tower (NDCT) per unit where approximately 7.8 x 10^9 BTU/Hr (2.29 x 10^6 KW) of heat is rejected to the atmosphere. Reference 3 provides information that characterizes the temperature of the waste heat that is available from the plant. The temperature entering the NDCT varies from approximately 93 ^oF (33.9 ^oC) in the winter to approximately 130 ^oF (54.4 ^oC) in the summer. The temperature of the water varies by as much as 5 ^oF (2.78 ^oC) to 10 ^oF (5.56 ^oC) in a single day as the ambient conditions vary. After the initial completion of construction of the WBNP, TVA implemented a modification in which the CCW from the abandoned Watts Bar Fossil Plant was redirected to the WBNP to supplement the heat rejection capability of the NDCT. This supplemental CCW which enters the Unit 2 NDCT basin is routed to the Unit 1 CCW pump suction to reduce the CCW temperature entering the main condenser. The existing 72" (183 CM) WHEP supply piping ties into the CCW conduit just before it enters the cooling tower for each unit, and 42" (107 CM) and 60" (152 CM) lines are provided to return the CCW to the NDCT supply pipe and basin, respectively. Presently, the 60" (152 CM) line at the NDCT basins have been blanked off and a physical modification to the WBNP would be required to run the line over the basin wall and through a diffuser in the NDCT basin.

Table I and Figure 1 show the monthly average ambient conditions and the temperatures of the CCW entering and leaving the WBNP main condensers.

Table I
Monthly Average Ambient and Cooling Tower Temperatures

`	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WBT	35	38	43	52	60	67	70	69	64	53	43	37
DBT	38	41	46	56	65	73	75	75	69	57	46	39
CWT	57	58	61	68	73	78	81	82	79	72	65	60
HWT	94	94	98	104	111	116	119	119	116	109	102	96

WBT – Wet-bulb temperature, ^oF
DBT – Dry-bulb temperature, ^oF
CWT – Cold water temperature, ^oF
HWT – Hot water temperature, ^oF

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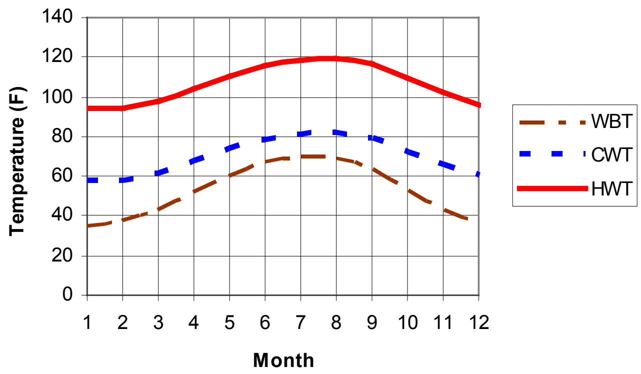
Figure 1
Watts Bar Nuclear Plant
Ambient and Natural Draft Cooling Tower
Temperatures with Two Unit Operation



Due to the nature of the supplemental CCW system, the values for CWT and HWT for the two units are somewhat different. The values presented above are estimated average values with both NDCT operating at 100% of design capability.

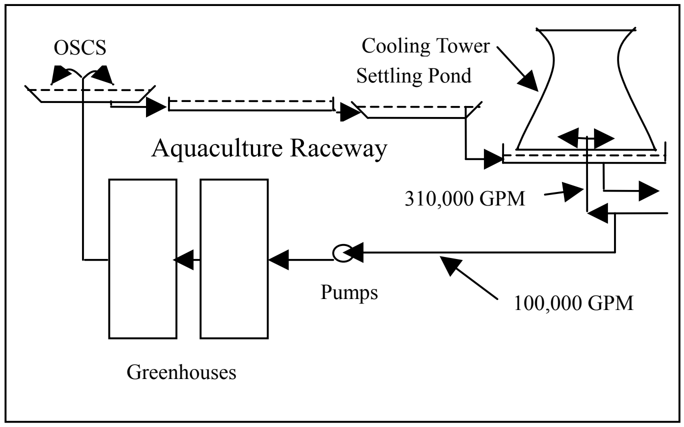
PROPOSED WASTE HEAT ENERGY PARK CONCEPT

A successful commercial WHEP must address the economic concerns of both the electric utility and the potential waste heat energy user such that both benefit financially. The author proposes that an amalgamation of users could provide a significant benefit to the waste heat user by reducing the cost of the waste heat delivery system and to the power plant by reducing the heat sink temperature, thus increasing the efficiency of the turbine cycle and increasing the electrical output.

The two most common uses of waste heat and the only applications for which demonstration projects have been conducted in the United States are greenhouse heating and aquaculture. Both benefit from waste heat but in very different ways. Greenhouses are consumers of waste heat to some degree, whereas, high density raceway aquaculture (HDRA), although requiring a significant flow at an optimum temperature, does not consume waste heat, since the temperature of the water entering and leaving the raceway is essentially unchanged. With an optimum growing temperature, HDRA is limited by the amount of dissolved oxygen and the buildup of ammonia from fish excrement.

Figure 2 shows schematically the proposed WHEP. Approximately 100,000 GPM (378,500 LPM) of CCW would be withdrawn from the CCW piping entering the cooling tower(s) and would be delivered through the existing waste heat piping to a point outside the security fence and on to a pumping station. From there it would be pumped through approximately 200 acres of greenhouses through the waste heat piping system and on to an Oriented Spray Cooling System (OSCS) where it would be further cooled before entering the HDRA facility. From the HDRA facility, the CCW would drain by gravity through a settling pond and back to the cooling tower basin.

Figure 2
Waste Heat Energy Park



The existing waste heat piping is connected to both of the existing NDCT, so the CCW could be extracted from either or both cooling towers. Since the water loading on the cooling tower(s) would be reduced, the cold water temperature coming from the cooling tower(s) would be lower than would otherwise be the case. The CCW going to the WHEP would be cooled through each of a series of two greenhouses and cooled further through the OSCS such that the CCW temperature entering the plant would be lower than would otherwise be the case. The fully aerated CCW leaving the OSCS would be at a temperature very close to the optimum temperature for feed conversion in HDRA facility.

The proposed WHEP provides the following significant technical and economic advantages:

- The temperature of the CCW leaving the plant is suitable for providing base load heating for greenhouses
- The temperature of the CCW leaving the OSCS is nearly optimum for feed conversion in HDRA facility
- The CCW leaving the OSCS would be full aerated
- The small amount of ammonia contributed by the fish in the HDRA would be dissipated in the plant
- The weighted average temperature of the CCW coming from the NDCT and the OSCS and entering the plant's main condenser would be less

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than would otherwise be the case, increasing the WBNP efficiency and electrical output

- The cost of the WHEP would be reduced by utilizing the same CCW in both the greenhouses and the HDRA facility
- In addition to the employment realized by the construction of the WHEP, approximately 1,000 full-time permanent jobs could be provided.

WASTE HEAT DELIVERY SYSTEM

The most significant cost factor in waste heat utilization is that of delivering the heated water to the waste heat user and back to the power plant. Fortunately, in the case of the WBWHEP, the most difficult hurdle, that of getting the CCW out of the plant and back again, has been crossed with a few minor exceptions. An outdoor pumping station consisting of several horizontal, centrifugal, pumps would be located outside the existing security fence to increase the pressure of the CCW in the waste heat piping by approximately 40 PSI. The CCW would discharge into high density poly-ethylene pipe to be distributed to the greenhouses and on to the OSCS and back to the existing waste heat piping.

WASTE HEAT GREENHOUSES

In a conventional greenhouse, common practice is to employ unit heaters that deliver forced hot air or perimeter and overhead heating pipes using steam or hot water as a heating source. TVA, Rutgers University, and others have conducted a considerable amount of research on waste heat greenhouses. One of the significant developments that is attractive for waste heat applications is to utilize floor heating using hot water heating tubing embedded in the floor. The floor heating system may include either a 3" – 4" (7.6-10.2 CM) slab of porous concrete poured over a bed of flooded stone aggregate containing the tubing or simply a 3" – 4" (7.6-10.2 CM) slab of porous concrete containing the tubing. This research has shown that the heat transfer coefficient is greater for a wet floor system compared to a dry floor system.[4] Additional overhead heating may be required during periods of colder weather.

For floor-heated greenhouses,

$$Q = U_F A(T_{wh\text{-}ave} - T_{GH}) = U_C A(T_{GH} - T_{amb})$$

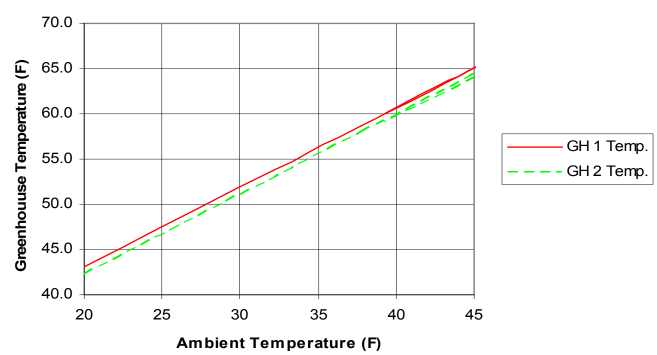
where

Q = Heat transfer rate, BTU/Hr
U_F = Floor heat transfer coefficient, BTU/Hr/FT ^{2} ^oF
A = Greenhouse floor area (neglecting side wall area)
$T_{wh\text{-}ave}$ = Average waste heat temperature, ^oF
T_{GH} = Greenhouse temperature, ^oF
U_C = Covering heat transfer coefficient, BTU/Hr/FT ^{2} ^oF
T_{amb} = Ambient temperature, ^oF

Published values for U_F from the heating pipes to the greenhouse interior vary from 0.73 to 1.23 BTU/Hr/FT ^{2} / ^oF (4.13 to 7.0 J/M^2/Sec/^oC), depending on the floor design and the configuration of the plants on the floor and/or on benches in the greenhouse.[5,6] The exact details of the greenhouse design, including the supplemental heating system, is beyond the scope if this investigation. In this analysis, a conservative value for U_F of 0.71 BTU/Hr/FT ^{2}/ ^oF (4.03 to J/M^2/Sec/^oC) is assumed. A wide variety of greenhouse designs are available. In this analysis, a single glazed glass design with a U_G of 1.2 BTU/Hr/FT ^{2}/ ^oF (6.81 J/M^2/Sec/^oC) is assumed.

The recommended limit in the length of heating tubes in the floor is approximately 150' to maintain a uniform temperature in the greenhouse. Therefore, as shown in Figure 3, the 200 acres of greenhouses would be arranged such that the CCW would cascade from the first greenhouse to the second with the operating temperatures and, perhaps, the crops being different in each. The temperatures shown in Figure 3 are without supplemental heat which would be provided as required for the particular crop being grown.

Figure 3
Greenhouse Temperature
without
Supplemental Heat



Since two greenhouses would share the same CCW flow, each acre of greenhouses would receive 1,000 GPM (3,785 LPM) flowing through 0.75" (1.9 CM) I.D. pipes embedded in the floor spaced 10" (25.4 CM) apart, each carrying a maximum flow of approximately 2.9 GPM (11.0 LPM) with a velocity of 2.1 FPS (0.64 MPS). A bypass would be provided around each greenhouse, so that the flow could be reduced as required to avoid overheating. Table II shows the greenhouse energy consumption.

Of course, during the warmer months, greenhouses require cooling, not heating, and the analysis assumes that all heating would be terminated when the ambient temperature exceeds approximately 65 ^oF (18.3 ^oC) . Each grower could tap into the pressurized waste heat piping to provide water for evaporative

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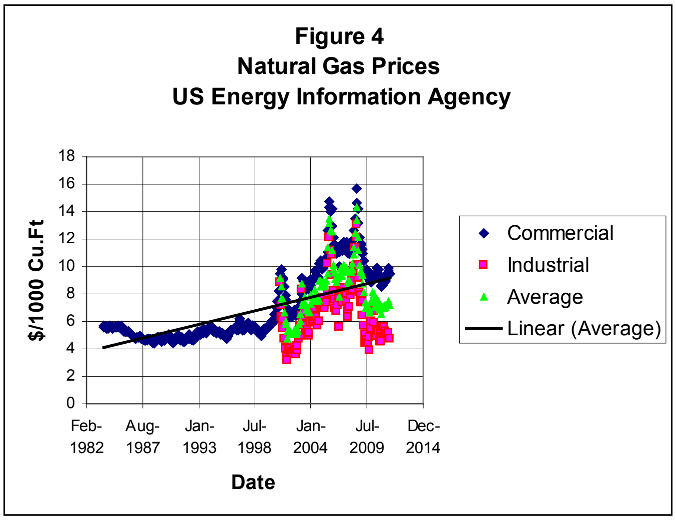
cooling pads as long as the remaining CCW is returned to the waste heat piping under pressure.

Table II
Greenhouse Heat Consumption

Amb Temp	Hours per yr	Deg. Hrs.	GH-1 Temp	GH-1 Heat Loss (BTU)	GH-1 Temp	GH-2 Heat Loss (BTU)
65	106	6,884	82.4	9.7E+07	81.7	9.3E+07
60	147	8,832	78.3	1.4E+08	77.6	1.3E+08
55	372	20,475	74.0	3.7E+08	73.3	3.6E+08
50	240	12,000	69.8	2.5E+08	69.1	2.4E+08
45	320	14,387	65.6	3.4E+08	64.8	3.3E+08
40	405	16,168	61.3	4.5E+08	60.5	4.4E+08
35	529	18,547	57.2	6.1E+08	56.4	5.9E+08
30	428	12,849	53.0	5.1E+08	52.1	4.9E+08
25	272	6,795	48.8	3.4E+08	47.8	3.3E+08
20	18	359	44.5	2.3E+07	43.6	2.2E+07
15	11	166	40.4	1.5E+07	39.5	1.4E+07
10	86	863	36.2	1.2E+08	35.2	1.1E+08
5	37	185	31.9	5.2E+07	30.9	5.0E+07
0	10	0	27.7	1.4E+07	26.7	1.4E+07
-5	2	-10	23.5	3.0E+06	22.4	2.9E+06
				3.3E+09		3.2E+09

Based on the stated assumptions, the amount of heat that would be transferred from the CCW to each acre of greenhouse would be approximately 3.3 x 10^9 BTU/year (3.5 x 10^{12} Joules/year). The value of this energy is based on the cost of natural gas. Figure 4 shows the historic cost of commercial and industrial natural gas as published by the US Energy Information Agency up to the end of 2011. Although the price of natural gas has declined in recent years, the general trend is certainly up. On this basis, the economic analysis is based on a value of energy of $9/MBTU.



ORIENTED SPRAY COOLING SYSTEM

Figure 5 shows an OSCS. References 7 - 10 document the development and verification of the OSCS. The idea was conceived of by the Thermosciences Research Group of

Figure 5
Oriented Spray Cooling System

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Ingersoll-Rand Research, Inc. in 1968 and the technology was further developed by Ecolaire Condenser, Inc. A full scale, two-dimensional OSCS was constructed at South Carolina Electric and Gas Company's Canadys Power Station. The first full-scale OSCS shown in Figure 5 was constructed and tested at the Ingersoll-Rand pump and turbine factory located at Phillipsburg, NJ. Two OSCS are the ultimate heat sink for the Columbia Generating Station in Richland, WA. The thermal performance of these OSCS was thoroughly tested to Nuclear Regulatory Commission requirements.

The OSCS has comparable performance to cooling towers without the typical spray pond dependence on ambient wind conditions. The OSCS offers significant advantages over mechanical draft cooling towers including superior simplicity and operability, lower preferred power requirements, and lower capital and maintenance costs. Unlike a conventional spray pond in which spray nozzles are arranged in a flat bed and spray upward, the OSCS nozzles are mounted on spray trees arranged in a circle and are tilted at an angle oriented towards the center of the circle. As a result, the water droplets drag air into the spray region while the warm air that is concentrated in the center of the circle rises. Both of these effects work together to increase air flow through the spray region. Increased air flow reduces the local WBT of the air in the spray pattern, promoting heat transfer and more efficient cooling.

During the late 1970's while working for the TVA, the author managed the development of a purely analytical model to predict the thermal performance of the OSCS which was successfully compared with the OSCS at the Columbia Generating Station in the mid 1980's. Having an analytical model allows the engineer to design the OSCS with the appropriate size, number and spacing of nozzles operating at the appropriate pressure to achieve the desired cooling objective.

Figure 6 shows the thermal performance for the OSCS that is assumed in this analysis where efficiency, η, is calculated from the following standard formula:

$$\eta = \frac{t_1 - t_2}{t_1 - t_{WB}}$$

Where

- t_1 - Spray nozzle inlet (hot) water temperature
- t_2 - Cold water temperature after spraying
- t_{WB} - Ambient wet-bulb temperature.

Therefore, one may see that the cold water temperature after spraying is a function of the OSCS efficiency, the spray nozzle inlet temperature (i.e. the second greenhouse exit temperature) and the ambient wet-bulb temperature. Noticeably absent is the ambient wind speed, since the OSCS creates its own wind. One may also note that the OSCS efficiency increases with WBT as is the case with cooling towers.

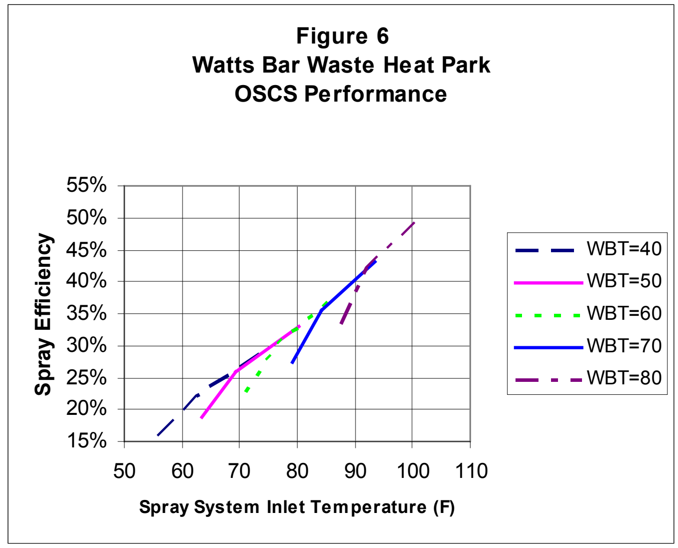
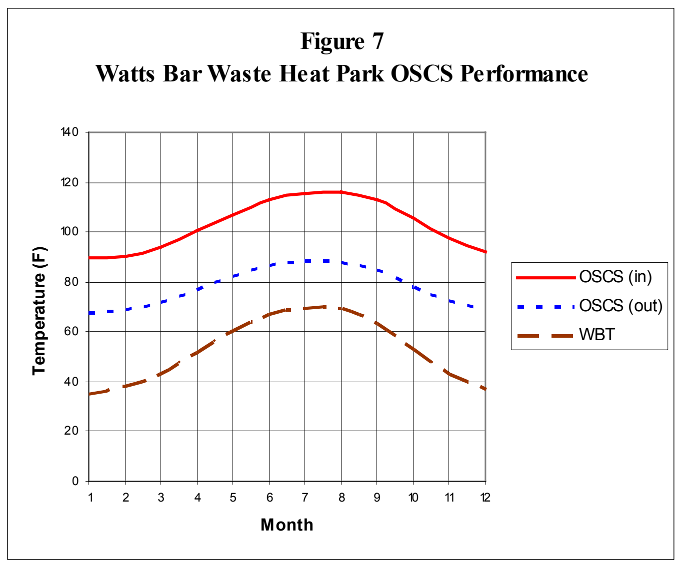


Figure 7 shows the monthly average temperature of the CCW entering and leaving the OSCS.



Five OSCS each 80' (24.4 M) in diameter and designed to cool 20,000 GPM (75,700 LPM) would be located in a single pond. The water elevation of the approximately 840' x 180' (256 x 55 M) pond would be approximately 15' (4.6 M) above the NDCT basin water level so that the CCW returning from the waste heat piping would flow through the HDRA facility and the settling pond and back to the cooling tower basin by gravity. The monthly average temperature of the CCW leaving the OSCS would vary between 67 °F and 88 °F (19.4-31.1 °C) .

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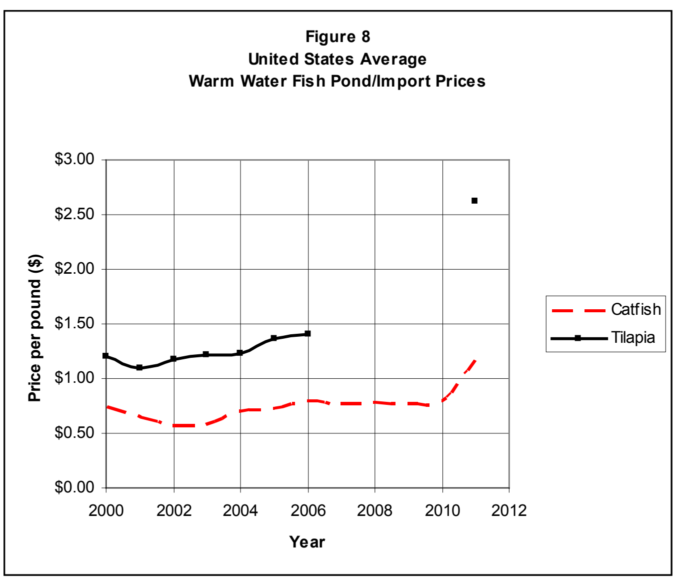
HIGH DENSITY RACEWAY AQUACULTURE FACILITY

TVA and several universities have conducted a considerable amount of research on high density raceway aquaculture. Both catfish and tilapia are species that benefit from warm water. The vast majority of all of the catfish that is produced in the United States comes from farm ponds in the southern states. Since 2003, domestic catfish production has declined dramatically as higher feed prices have forced producers to convert ponds used to grow catfish into row crops. From 2002 to 2010, the pond acreage has declined by 49%. As a result, the quantity of imported catfish has soared from 2002 to 2010 but still only constitutes less than half of the frozen fillets sold domestically.[11]

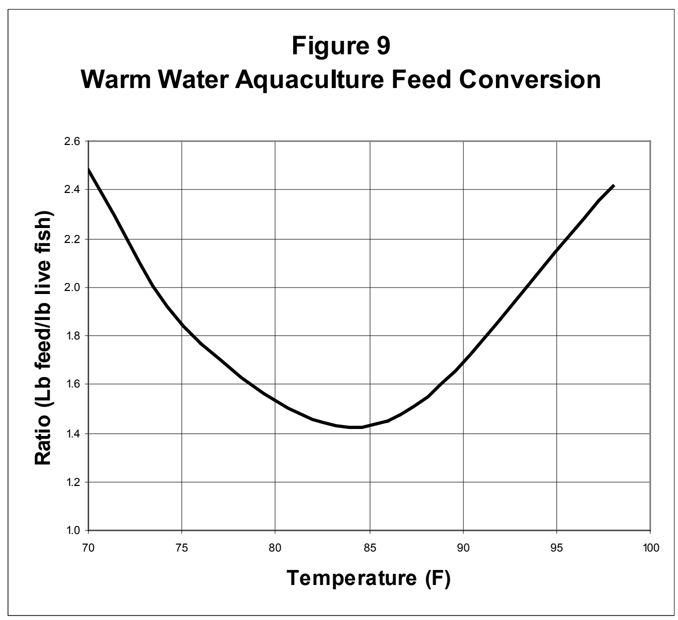
Domestic consumption of tilapia has increased dramatically as it has been transformed from a mostly ethnic cuisine to a staple on the menu of virtually every family restaurant chain in the United States. In 2009 Americans consumed only tuna, salmon, and pollock fish more than tilapia, and they are consuming more fish and shellfish virtually every year.[11] The vast majority of all tilapia that is consumed in the United States is imported from countries such as Taiwan, Costa Rica, and Ecuador.[12] Tilapia is the third largest aquaculture import, exceeded only by shrimp and Atlantic salmon.[13] Of the relatively small amount of domestically-produced tilapia, 70% is produced in indoor water re-circulating aquaculture systems, perhaps because tilapia production in outside ponds is strictly regulated in the southern United States for fear that some fish may escape and encroach on the native sport fishing population.[13, 14]

Figure 8 shows the average pond and import price paid for catfish and tilapia, respectively, as published by the United States Department of Agriculture (USDA).



The USDA stopped publishing the price of imported tilapia when it discontinued its *Aquaculture Outlook* in 2006. However, the price for U.S. farmed tilapia was approximately \$2.50 - \$2.75 at the end of 2011.[15] The sharp spike in catfish and tilapia prices in 2011 due to the shortage of product due to high feed prices and the resulting loss of production capacity is expected to continue as producers continue to struggle to achieve profitability[11]. The decision as to whether the HDRA facility would produce catfish or tilapia is beyond the scope of this investigation. However, for purposes of economic analysis, the author has assumed a farm price of \$1.90/lb of live fish.

Fish feed costs averaged \$353/ton in 2010 and was slightly higher in 2011.[11] For purposes of this investigation, the author assumed a feed price of \$400/ton. For both catfish and tilapia, the feed constitutes approximately 50% of the total cost of production[11,12]. Therefore, any feeding regimen that optimizes the ratio of feed to fish weight is to be desired. The preferred water temperature range for optimum growth is 82 ^{o}F - 86 ^{o}F (27.8-30.0 ^{o}C).[16] Figure 9 shows an estimated curve of feed conversion vs. water temperature. As one may see from Figure 7, the OSCS outlet temperature is very close to optimum for a HDRA facility for much of the year. Factors other than water temperature also affect the feed conversion ratio. This study assumes that the annual average feed/live weight ratio would be approximately 1.8:1 if the HDRA facility were to operate year-round as assumed in this analysis.[17,18]



Unlike the greenhouse waste heat user, this analysis includes an estimate of the cost and projected income of the proposed HDRA facility, since the design and operation of the facility would be essentially the same, whether catfish or tilapia.

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Properly designed raceways have a length to width to depth ratio of 30:3:1 with a flow rate of 6 – 12 GPM (23-45 LPM) per 100 pounds of fish, a water velocity of at least 6.5 FPS (2.0 MPS) and 4 – 10 water changes per hour to support the oxygen requirements. [15,19] Table III shows the design parameters employed for the purposes of this investigation.

Table III
High Density Raceway Design Parameters

Length, Ft	90
Width, Ft	9
Depth, Ft.	3
Water depth, Ft.	2.5
Number of raceways	54
Flow per raceway, GPM	1,852

Each raceway would be divided into eight sections. The first section at the CCW inlet end would contain fingerlings. As these grow to approximately 0.25 pounds in weight, they would be moved to the next two sections where they would grow from 0.25 to 0.5 pound and finally to the next four sections where they would grow to approximately 1.0 pound before being harvested. The last section would be reserved for flushing out the waste. Any residual waste would be collected in a settling pond before the CCW is returned to the WBNP by gravity.

The entire growing process requires approximately 105 days.[17] Assuming a final stocking rate of approximately 9.0 lb/Ft^3, each raceway would produce approximately 31,400 lbs/year for a total production of 1,700,000 lbs/year. Table IV shows the projected HDRA economic analysis for the assumed parameters. [14, 17, 18]

Table IV
High Density Raceway Economics

Live fish value, $/lb	$1.90
Production Costs per Lb	
Total feed, $/lb	$0.36
Labor, $/lb	$0.16
Fingerlings, $/lb	$0.10
Utilities & Fuel, $/lb	$0.03
Misc. fixed costs, $/lb	$0.14
Total production cost per pound, $/lb	$0.79
Net income, $/lb	$1.11
Net income per year	$1,900,000

In addition to the potential economic advantage of employing a HDRA facility in the WBWHEP, the following additional advantages should be considered:

- No supplemental aeration required
- Ammonia buildup not a problem
- Year round operation
- Shared infrastructure
- Central location for live delivery of the fish within a day to most major cities in the eastern United States.

ECONOMIC BENEFIT OF WASTE HEAT ENERGY PARK TO WATTS BAR NUCLEAR PLANT

As may be seen in Figures 1 and 7, the temperature of the CCW as it would be returned to the WBNP would be slightly higher than that coming from the NDCT if the WBWHEP did not exist. However, reducing the CCW flow to each of the existing NDCT by 50,000 GPM (189,000 LPM) would reduce the CWT from both NDCT by an average of approximately 1.9 ^oF (1.06 ^oC) and after adding back the slightly higher CCW from the WBWHEP, the mixed temperature of the CCW entering the WBNP main condensers would be approximately 1.2 ^oF (0.67 ^oC) less than would otherwise be the case.[20] A reduction in the main condenser inlet temperature of 1.2 ^oF (0.67 ^oC) to both main condensers would result in a reduction of the turbine back-pressures and an increase in net plant electrical output of approximately 1.5 MWe from each WBNP generating unit. Depending on the value of the electrical output, the additional electrical power could be worth approximately $800,000 a year to TVA.

PROPOSED WASTE HEAT ENERGY PARK COST

Table V shows an order-of-magnitude estimate of the cost of the proposed WBWHEP.

Table V
Watts Bar Waste Heat Energy Park Capital cost

Pumping station	$3,400,000
Distribution system	$24,200,000
OSCS pond, header piping & spray trees	$2,000,000
High density aquaculture raceways	$7,800,000
Settling pond	$600,000
Total capital cost	$38,000,000

This cost estimate includes both direct and indirect costs associated with the WBWHEP excepting those costs such as roads and utilities that would be associated with any industrial park and the cost of the greenhouses, since different growers might select very different greenhouse designs.

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PROPOSED WATTS BAR WASTE HEAT ENERGY PARK ECONOMIC ANALYSIS

The economic analysis of the WBWHEP shown in Table VI is limited to the direct benefits associated with the utilization of waste heat and the incremental costs associated with providing this resource. For example, it does not include either the cost or the profit to be realized from a successful greenhouse operation but only the fuel savings to the greenhouse operator due to the use of the waste heat for the base heating load. This approach is taken because there are many different types of possible greenhouse operations, each yielding its on economic analysis that could and do exist in the region without the benefit of waste heat. Indeed, the consumptive use of waste heat as envisioned with greenhouses would be only one possible application. Others might include a pig farrowing or broiler house operation, lumber drying, tanning, and ethanol production. The cost and benefit of the HDRA facility is included, because it is quite straightforward and because it would not be at all feasible without the waste heat being available.

Table VI
Watts Bar Waste Heat Energy Park Economic Analysis
Net Annual Income

		Assumptions
Savings in greenhouse energy	$5,900,000	$9.00/MBTU, U_F of 0.71 BTU/Hr/FT ^{2} °F
Aquaculture net income	$1,900,000	Live fish @ $1.90/Lb, Feed @ $400/ton
Gross income	$7,800,000	
Pumping power cost	$900,000	Power @ $50/MWH
Debt service	$3,000,000	20 years @ 5%
Net annual income	$3,900,000	

The economic analysis does not include costs associated with any typical industrial park such as roads and utilities or the benefits to the community such as the additional jobs and the increase in the tax base. The projected net annual income does not include the projected $800,000/year benefit to the TVA WBNP. Nor does it include the income or expenses including debt service for the proposed 200 acres of floor-heated greenhouses. The author estimates that the cost of the 4” (10.2 CM) concrete slab and 52,500’ (16,000 M) of 0.75” (1.9 CM) I.D. tubing embedded in each acre of greenhouse would be approximately $140,000/acre which may be approximately 20% more expensive than a conventional concrete floor.

If the reader chooses to take issue with the stated assumptions, an alternate economic analysis may be readily constructed by adjusting the assumed parameters.

CONCLUSION

The WHEP as envisioned in Figure 2 in which there exists an amalgamation of waste heat users that provide a significant benefit to the WBNP enjoys a significant economic advantage over an arrangement as envisioned in Reference 3 in which each waste heat user consumes a portion of the available waste heat piping and pumping capacity, regardless of the nature of their need. In that case, the economic benefit would be significantly diminished. However, based on the assumed parameters, the technical and economic feasibility of the WBWHEP as proposed is clearly demonstrated.

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