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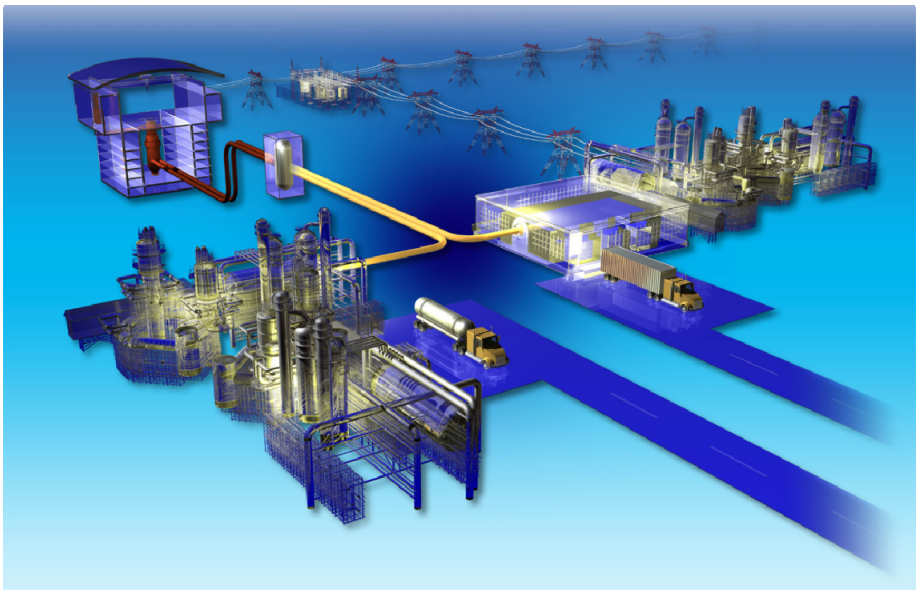
Technical Evaluation Study

Project No. 23843

Hydrogen Production via HTSE, Sensitivity to HTGR Reactor Outlet Temperature, Economic Analysis



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HYDROGEN PRODUCTION VIA HTSE, SENSITIVITY TO HTGR REACTOR OUTLET TEMPERATURE, ECONOMIC ANALYSIS	Identifier: TEV-994 Revision: 0 Effective Date: 09/17/10	Page: ~~1~~ 13 of ~~37~~ 91

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Signatures

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REVISION LOG

Rev.	Date	Affected Pages	Revision Description
0	09/17/10	All	Newly issued document.

EXECUTIVE SUMMARY

This technical evaluation (TEV) has been prepared as part of a study for the Next Generation Nuclear Plant (NGNP) Project to evaluate the economics of integrating a high-temperature gas-cooled reactor (HTGR) with conventional chemical processes. This TEV addresses the economics of hydrogen produced using an HTGR with high-temperature steam electrolysis (HTSE), as well as the effect of increasing the reactor outlet temperature (ROT), in terms of hydrogen production efficiency, on the economic results. These results are preliminary, as the HTGR cost estimate currently is not a function of the ROT. This TEV will be updated when the HTGR cost estimate update is complete.

The production of hydrogen using HTSE, as well as the effect of increasing the ROT on process results, has previously been addressed in detail in TEV-981 (Idaho National Laboratory [INL] 2010). The development of detailed process models for hydrogen production using an HTGR with HTSE, with a range of reactor outlet temperatures from 650 to 950°C, in 50°C increments, were discussed in this previous technical evaluation. This report is a follow-up to TEV-981 and evaluates the economics of the hydrogen cases modeled. However, as the HTGR cost estimate is not a function of the ROT at this point, only qualitative conclusions can be made regarding the economic impact of an increase in the ROT on hydrogen production.

As a result, before comprehensive conclusions can be made, a refined estimate of the HTGR capital cost, annual fuel costs, and annual operation and maintenance costs should be developed, including sensitivity to ROT.

CONTENTS

ACRONYMS AND NOMENCLATURE

AACE	Association for the Advancement of Cost Engineering
ATCF	after tax cash flow
BTCF	before tax cash flow
CEPCI	chemical engineering plant cost index
DOE	Department of Energy
EIA	Energy Information Administration
HTGR	high temperature gas-cooled reactor
HTSE	high temperature steam electrolysis
INL	Idaho National Laboratory
IRR	internal rate of return
MACRS	modified accelerated cost recovery system
MARR	minimum annual rate of return
NETL	National Energy Technology Laboratory
NGNP	Next Generation Nuclear Plant
NIBT	net income before taxes
O&M	operations and maintenance
PW	present worth
ROT	reactor outlet temperature
TCI	total capital investment
TEV	technical evaluation

C_1	cost of equipment with capacity q_1
C_2	cost of equipment with capacity q_2
C_k	capital expenditures
d_k	depreciation
E_k	cash outflows
i'	IRR
k	year
n	exponential factor
q_1	equipment capacity

q_2	equipment capacity
R_k	revenues
t	tax rate
T_k	income taxes

1. INTRODUCTION

This technical evaluation (TEV) has been prepared as part of a study for the Next Generation Nuclear Plant (NGNP) Project to evaluate the economics of integrating a high-temperature gas-cooled reactor (HTGR) with conventional chemical processes. The NGNP Project is being conducted under U.S. Department of Energy (DOE) direction to meet a national strategic need identified in the *Energy Policy Act of 2005* to promote reliance on safe, clean, economic nuclear energy and to establish a greenhouse-gas-free technology for the production of hydrogen. The NGNP represents an integration of high-temperature reactor technology with advanced hydrogen, electricity, and process heat production capabilities, thereby meeting the mission need identified by DOE. The strategic goal of the NGNP Project is to broaden the environmental and economic benefits of nuclear energy in the U.S. economy by demonstrating its applicability to market sectors not being served by light water reactors.

The HTGR produces steam, high-temperature helium that can be used for process heat, and/or electricity. Previous studies conducted by Idaho National Laboratory (INL) over the past year have assumed an HTGR outlet temperature of 750°C; this reflects the initial HTGR design and assumes a more conservative outlet temperature. Additionally, a 50°C temperature approach was assumed between the primary and secondary helium loops when helium was the delivered working fluid. As a result, the maximum helium temperature available for heat exchange in those studies was 700°C.[a]

Although initial HTGR implementations will likely target an HTGR outlet temperature of 750°C, temperatures of 950°C are anticipated for later designs. Unlike previous INL studies performed during the last year, this study removes the 750°C minimum/maximum HTGR outlet temperature assumption. Instead, various reactor outlet temperatures (ROTs) are assessed. For this study, a 25°C temperature approach is assumed between the primary and secondary helium loops, as opposed to the 50°C assumption used in previous studies. This study investigates the impact of varying ROTs from 650 to 950°C, in 50°C increments. Hence, using the 25°C temperature approach assumption between the primary and secondary loops, high-temperature helium can be delivered at temperatures between 625 and 925°C. HTGR product conditions assumed for this analysis are shown in Table 1.

Table 1. Projected outputs of the NGNP.

HTGR Product	Product Description
Steam	540°C and 17 MPa
High-Temperature Helium	Delivered at 625 to 925°C and 9.1 MPa
Electricity	Generated by Rankine cycle, with efficiency dependent upon ROT

a. See TEV-666, TEV-667, TEV-671, TEV-672, TEV-674, TEV-693, TEV-704, TEV-953, TEV-954, and INL/EXT-09-16942.

The production of hydrogen using high-temperature steam electrolysis (HTSE), as well as the effect of increasing the ROT on process results, has previously been addressed in detail in TEV-981 (INL 2010). The development of detailed process models for hydrogen production using an HTGR with HTSE, with a range of reactor outlet temperatures from 650 to 950°C, in 50°C increments, were discussed in this previous technical evaluation. The models documented in TEV-981 are used as the basis for the economic analysis conducted in this report. This TEV assumes familiarity with TEV-981; hence, detailed descriptions of the process models documented in TEV-981 are not presented here.

The economic models used for this analysis have been developed in Microsoft Excel (Excel 2007). This study makes extensive use of these models; this TEV assumes familiarity with Excel. A detailed explanation of the software capabilities is beyond the scope of this study.

This TEV first presents the general process configuration on which the economic models are based. Next, the details of the economic model are discussed. Finally, results of the economic analysis are presented and discussed. The results presented in the following TEV are preliminary, as the HTGR cost estimate currently is not a function of the ROT. This TEV will be updated when the HTGR cost estimate update is complete.

2. CASES CONSIDERED

Two sets of seven cases were identified for economic modeling for hydrogen generation using HTSE, one set for HTSE with a steam sweep configuration and another set with an air sweep configuration, based on the process models presented in TEV-981. The two sets of cases increase the HTGR ROT by 50°C from 650°C until a maximum ROT of 950°C is achieved. Hence, a total of 14 cases are compared and evaluated in this study:

- Steam sweep HTSE
  - Case 1 – ROT of 650°C
  - Case 2 – ROT of 700°C
  - Case 3 – ROT of 750°C
  - Case 4 – ROT of 800°C
  - Case 5 – ROT of 850°C
  - Case 6 – ROT of 900°C
  - Case 7 – ROT of 950°C
- Air sweep HTSE
  - Case 8 – ROT of 650°C
  - Case 9 – ROT of 700°C

- Case 10 – ROT of 750°C
- Case 11 – ROT of 800°C
- Case 12 – ROT of 850°C
- Case 13 – ROT of 900°C
- Case 14 – ROT of 950°C.

Figure 1 presents block flow diagrams of the HTSE processes with steam sweep. The reactor supplies heat to generate power and to raise the temperature of the water used for electrolysis and for the sweep gas. At lower ROTs (less than 850°C), additional heat is required to obtain an electrolysis temperature of 800°C. This heat is obtained from the combustion of natural gas. The steam sweep requires a small amount of make-up water due to water exiting with the oxygen byproduct. A steam sweep configuration would be used when both pure hydrogen and oxygen are required products.

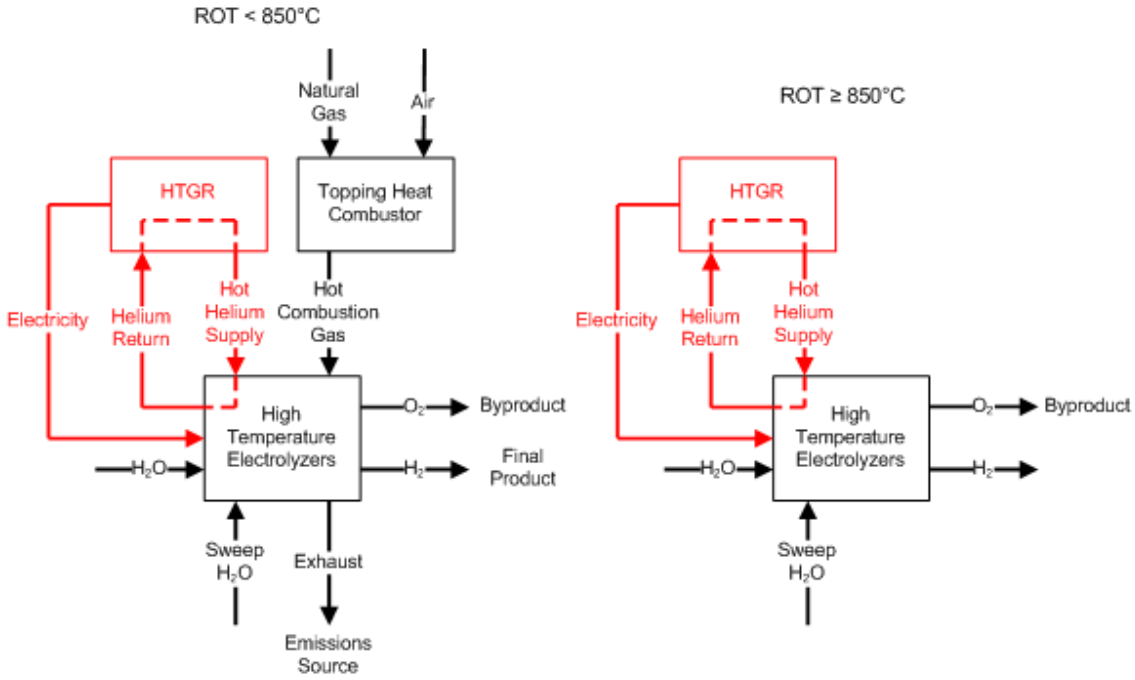

Figure 1. Block flow diagrams for the HTSE with steam sweep.

Figure 2 presents block flow diagrams of the HTSE processes with air sweep. The process is very similar to the steam sweep model except air is used as the sweep gas. Again, the reactor supplies heat to generate power and to raise the temperature of the water used for electrolysis and for the sweep air. At lower ROTs (less than 850°C), additional heat is required to obtain an electrolysis temperature of 800°C. This heat is obtained from the combustion of natural gas. Since air is used as the sweep medium the O_2 is no longer pure enough to offer as a byproduct.

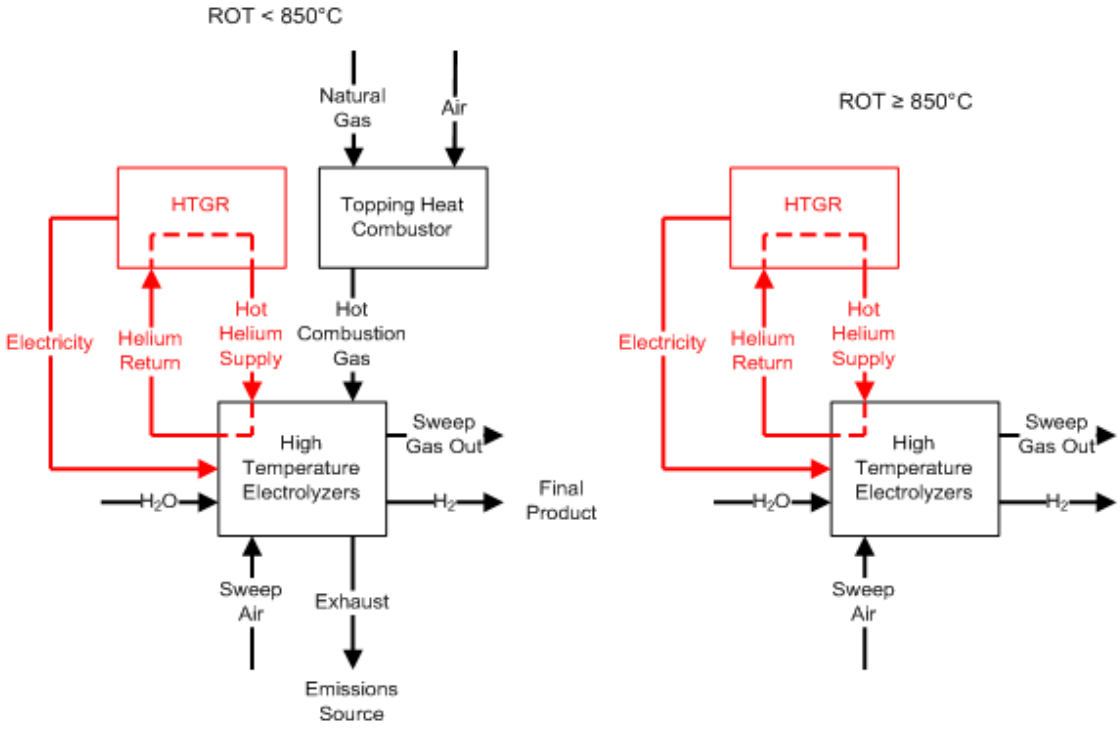

Figure 2. Block flow diagrams for the HTSE with air sweep.

For detailed descriptions of the process models that provide the basis for the configurations considered for the economic analysis, see TEV-981.

3. ECONOMIC MODELING OVERVIEW

The economic viability of the HTGR processes for hydrogen production was assessed using standard economic evaluation methods, specifically the internal rate of return (IRR). The economics were evaluated for the cases described in the previous section. The total capital investment (TCI), based on the total equipment costs, annual revenues, and annual manufacturing costs were first calculated for the cases. The present worth of the annual cash flows (after taxes) was then calculated for the TCI at both the nominal and target HTGR cost. Additionally, the economics were analyzed for multiple owner-operator scenarios, with the HTGR and HTSE facilities operated by independent organizations or a single owner-operator. The following sections describe the methods used to calculate the capital costs, annual revenues, annual manufacturing costs, and the resulting economic results. Again, the results presented below are preliminary, as the HTGR cost estimate currently is not a function of the ROT. This TEV will be updated when the HTGR cost estimate update is complete.

3.1 Capital Cost Estimation

Equipment items for this study were not individually priced. Rather, cost estimates were based on scaled costs for major plant processes from published literature or program information. Cost estimates were generated for the HTSE system, topping heat combustor, power generation equipment, and the HTGR. In some instances, several costs were averaged. The estimate presented is a Class 5 estimate and has a probable error of +50% and -30% (Association for the Advancement of Cost Engineering [AACE] 2005).

The installed capital costs presented for the HTSE, topping heat combustor, and power generation equipment are for inside the battery limits and exclude costs for administrative offices, storage areas, utilities, and other essential and nonessential auxiliary facilities. Fixed capital costs were estimated from literature estimates and scaled estimates (capacity, year, and material) from previous quotes. Capacity adjustments were based on the six-tenths factor rule:

$$C_2 = C_1 \left(\frac{q_2}{q_1}\right)^n \quad (1)$$

where C_1 is the cost of the equipment item at capacity q_1, C_2 is the cost of the equipment at capacity q_2, and n is the exponential factor, which typically has a value of 0.6 (Peters 2002). It was assumed that the number of trains did not have an impact on cost scaling. Cost indices were used to adjust equipment prices from previous years to 2009 using the Chemical Engineering Plant Cost Index (CEPCI) as depicted in Table 2. Costs for the HTGR and HTSE were scaled directly based on capacity; the six-tenths factor rule was not used.

Table 2. CEPCI data.

Year	CEPCI	Year	CEPCI
1990	357.6	2000	394.1
1991	361.3	2001	394.3
1992	358.2	2002	395.6
1993	359.2	2003	402.0
1994	368.1	2004	444.2
1995	381.1	2005	468.2
1996	381.7	2006	499.6
1997	386.5	2007	525.4
1998	389.5	2008	575.4
1999	390.6	2009	521.9

For the HTGR, the estimates of capital costs and operating and maintenance costs assumed the nuclear plant was an “nth of a kind.” In other words, the estimates were based on the costs expected after the HTGR technology is integrated into an industrial application more than ten times. The economic modeling calculations

were based on two capital cost scenarios for the HTGR unit, which does not include the power cycle: a nominal estimate of $1,708/kWt (Demick 2009)[b] and a target of $1,196/kWt (Demick 2009) where kWt is the thermal rating of the plant. In comparison, light water nuclear reactor costs are approximately $1,333/kWt (Nuclear Energy Institute [NEI] 2008). Based on the two capital cost scenarios for HTGR technology, the nominal capital cost for a 600-MWt HTGR would be $1.025 billion; the target capital cost would be $718 million.

After cost estimates were obtained for each of the process areas, the costs for water systems, piping, instrumentation and control, electrical systems, and buildings and structures were added based on scaling factors for the total installed equipment costs, based on information provided in studies performed by the National Energy Technology Laboratory (NETL) (2000). These factors were not added to the cost of the HTGR, as the cost basis for the HTGR was assumed to represent a complete and operable system. Table 3 presents the factors utilized in this study.

Table 3. Capital cost adjustment factors.

Year	Factor
Water Systems	7.1%
Piping	7.1%
Instrumentation and Control	2.6%
Electrical Systems	8.0%
Buildings and Structures	9.2%

Finally, an engineering fee of 10% and a project contingency of 18% were assumed to determine the TCI. The capital cost provided for the HTGR represents a complete and operable system; the total value represents all inside battery limits and outside battery limits elements as well as contingency and owner's costs; therefore, engineering fees and contingencies were not applied to this cost.

The AACE International recognizes five classes of estimates. The level of project definition for this study was determined to be an AACE International Class 5 estimate. Although the HTSE and steam turbines are actually more in line with the AACE International Class 4 estimate, which is associated with equipment factoring, parametric modeling, historical relationship factors, and broad unit cost data, the HTGR project definition falls under an AACE International Class 5 estimate, associated with less than two percent project definition, and based on

[b] The estimate provided by Demick was $2,000/$kW_t$ for the nominal case and included the cost of the power generation equipment. $292/$kW_t$ was subtracted for the power generation equipment to arrive at the listed cost of $1,708/$kW_t$. The cost for the target case was obtained by assuming 70% of the nominal case cost: $1,708/$kW_t$ x 0.70 = $1,196/$kW_t$.

preliminary design methodology (AACE 2005). Since the HTGR is a larger portion of the TCI, an overall Class 5 estimate was assumed.

Based on the AACE International contingency guidelines as presented in DOE/FETC-99/1100, the overall project contingency for the non-nuclear portion of the capital (power generation equipment and HTSE) should be in the range of 30 to 50%, 30 to 40% for Class 4, and 50% for Class 5 (Parsons 1999). However, because the cost estimates were scaled based on estimated, quoted, and actual project costs, the overall non-nuclear project contingency should be more in the range of 15 to 20%. Eighteen percent was selected based on similar studies conducted by NETL (2007). Again, contingency was not applied to the HTGR as project contingency was accounted for in the basis for the capital cost estimate.

Table 4 and Figure 3 present the capital cost estimate breakdown for the HTSE cases with steam sweep. Table 5 and Figure 4 present the capital cost estimate breakdown for the HTSE cases with air sweep. Varying only the cost of the nuclear facility was an adequate assumption, as the cost of the HTGR accounts for approximately 75% of the capital cost. In addition, there is a greater level of uncertainty in the nuclear plant price given the nascency of HTGR development. Again, the results presented are preliminary, as the HTGR cost estimate currently is not a function of the ROT. This TEV will be updated when the HTGR cost estimate update is complete.

Presently, with no variation in the HTGR ROT the TCI for the HTSE cases are all within two percent, as the capital cost of the system is dominated by the HTGR costs.

Appendix A presents the detailed methodology utilized for calculating the capital cost, less engineering fees and contingencies, for the HTSE system as well as the capital cost results. It should be noted that there is a slight difference in the numbers presented in the appendix and the numbers presented below, as values in the appendix were updated in order to maintain consistency for the various chemical processes analyzed. This can be attributed to slight differences in the calculation for the balance of plant items including water systems, piping, instrumentation and control, electrical systems, and buildings and structures. Additionally, the CEPCI was updated from what is presented in the appendix to represent the most current value available. In the future Appendix A will be updated to reflect the assumptions outlined in the previous sections.

Table 4. Total capital investment, HTSE with steam sweep ($).

	Case 1 (650°C ROT)	**Case 2 (700°C ROT)**	**Case 3 (750°C ROT)**	**Case 4 (800°C ROT)**	**Case 5 (850°C ROT)**	**Case 6 (900°C ROT)**	**Case 7 (950°C ROT)**
HTGR – Nominal Cost	1,025,000,000	1,025,000,000	1,025,000,000	1,025,000,000	1,025,000,000	1,025,000,000	1,025,000,000
HTGR – Target Cost	717,500,000	717,500,000	717,500,000	717,500,000	717,500,000	717,500,000	717,500,000
HTGR Power Cycle	190,190,611	192,465,257	194,484,752	196,280,265	197,974,070	199,560,005	201,006,245
HTSE	89,496,503	91,326,102	90,989,777	89,906,366	85,235,163	82,333,540	81,415,856
Topping Heat Equipment	7,500,075	6,970,816	6,373,719	5,702,673	N/A	N/A	N/A
Cooling Towers	151,204	149,537	148,023	146,632	36,022	36,156	36,279
Water Systems	6,897,493	6,989,698	6,923,318	6,798,653	6,054,254	5,848,248	5,783,102
Piping	6,897,493	6,989,698	6,923,318	6,798,653	6,054,254	5,848,248	5,783,102
Instrumentation and Control	2,525,842	2,559,608	2,535,299	2,489,647	2,217,051	2,141,612	2,117,756
Electrical Systems	7,771,823	7,875,716	7,800,921	7,660,454	6,821,695	6,589,576	6,516,171
Buildings and Structures	8,937,596	9,057,074	8,971,060	8,809,522	7,844,949	7,578,012	7,493,596
TCI – Nominal HTGR Cost	**1,345,368,639**	**1,349,383,507**	**1,350,150,186**	**1,349,592,864**	**1,337,237,457**	**1,334,935,399**	**1,335,152,106**
HTSE Plant	*130,178,028*	*131,918,250*	*130,665,435*	*128,312,599*	*114,263,387*	*110,375,393*	*109,145,861*
HTGR	*1,215,190,611*	*1,217,465,257*	*1,219,484,752*	*1,221,280,265*	*1,222,974,070*	*1,224,560,005*	*1,226,006,245*
TCI – Target HTGR Cost	**1,037,868,639**	**1,041,883,507**	**1,042,650,186**	**1,042,092,864**	**1,029,737,457**	**1,027,435,399**	**1,027,652,106**
HTSE Plant	*130,178,028*	*131,918,250*	*130,665,435*	*128,312,599*	*114,263,387*	*110,375,393*	*109,145,861*
HTGR	*907,690,611*	*909,965,257*	*911,984,752*	*913,780,265*	*915,474,070*	*917,060,005*	*918,506,245*

Table 5. Total capital investment, HTSE with air sweep ($).

	Case 8 (650°C ROT)	**Case 9 (700°C ROT)**	**Case 10 (750°C ROT)**	**Case 11 (800°C ROT)**	**Case 12 (850°C ROT)**	**Case 13 (900°C ROT)**	**Case 14 (950°C ROT)**
HTGR – Nominal Cost	1,025,000,000	1,025,000,000	1,025,000,000	1,025,000,000	1,025,000,000	1,025,000,000	1,025,000,000
HTGR – Target Cost	717,500,000	717,500,000	717,500,000	717,500,000	717,500,000	717,500,000	717,500,000
HTGR Power Cycle	191,381,191	193,695,691	195,743,180	197,623,970	198,812,682	200,265,386	201,663,940
HTSE	145,566,383	146,050,645	146,177,247	145,531,223	141,592,887	141,280,366	141,426,351
Topping Heat Equipment	7,787,928	7,258,669	6,662,795	5,990,526	N/A	N/A	N/A
Cooling Towers	22,437	22,581	22,674	22,705	21,724	21,915	22,082
Water Systems	10,889,749	10,886,565	10,853,253	10,759,656	10,054,637	10,032,462	10,042,839
Piping	10,889,749	10,886,565	10,853,253	10,759,656	10,054,637	10,032,462	10,042,839
Instrumentation and Control	3,987,795	3,986,629	3,974,431	3,940,156	3,681,980	3,673,859	3,677,659
Electrical Systems	12,270,140	12,266,552	12,229,017	12,123,556	11,329,169	11,304,183	11,315,875
Buildings and Structures	14,110,661	14,106,534	14,063,370	13,942,090	13,028,544	12,999,810	13,013,256
TCI – Nominal HTGR Cost	**1,421,906,034**	**1,424,160,431**	**1,425,579,219**	**1,425,693,538**	**1,413,576,261**	**1,414,610,443**	**1,416,204,840**
HTSE Plant	*205,524,842*	*205,464,741*	*204,836,039*	*203,069,567*	*189,763,579*	*189,345,057*	*189,540,900*
HTGR	*1,216,381,191*	*1,218,695,691*	*1,220,743,180*	*1,222,623,970*	*1,223,812,682*	*1,225,265,386*	*1,226,663,940*
TCI – Target HTGR Cost	**1,114,406,034**	**1,116,660,431**	**1,118,079,219**	**1,118,193,538**	**1,106,076,261**	**1,107,110,443**	**1,108,704,840**
HTSE Plant	*205,524,842*	*205,464,741*	*204,836,039*	*203,069,567*	*189,763,579*	*189,345,057*	*189,540,900*
HTGR	*908,881,191*	*911,195,691*	*913,243,180*	*915,123,970*	*916,312,682*	*917,765,386*	*919,163,940*

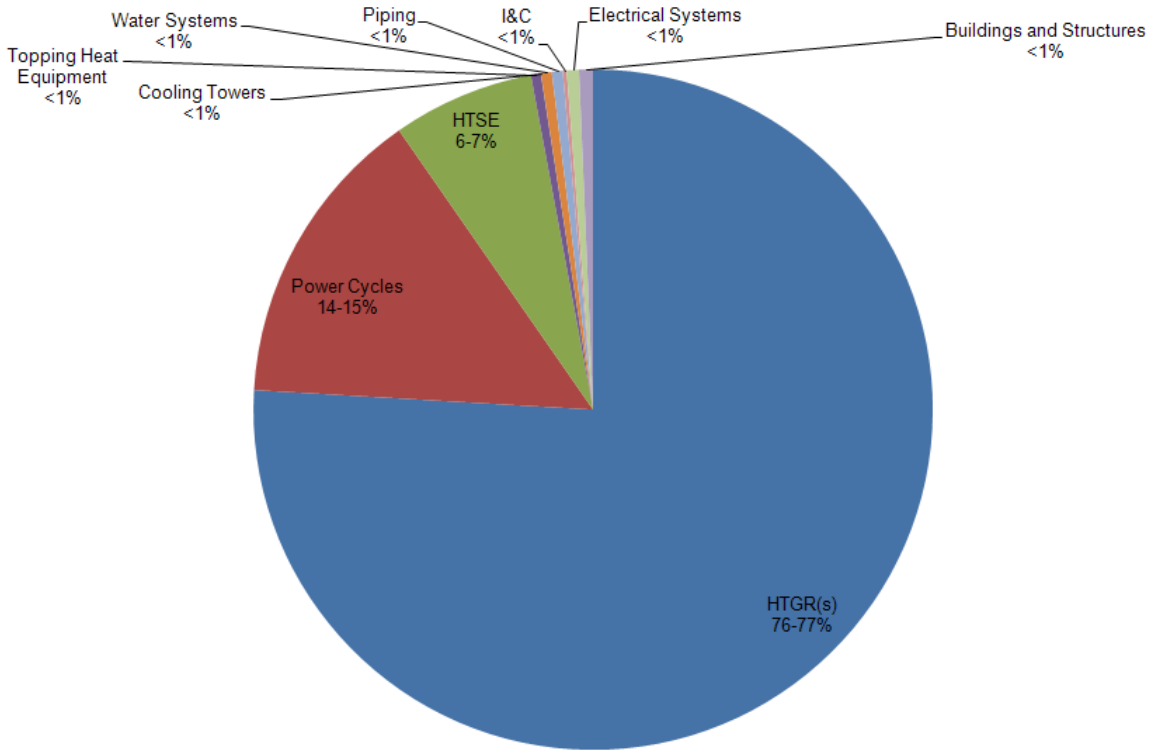

Figure 3. Total capital investment breakdown, HTSE with steam sweep, all ROTs.

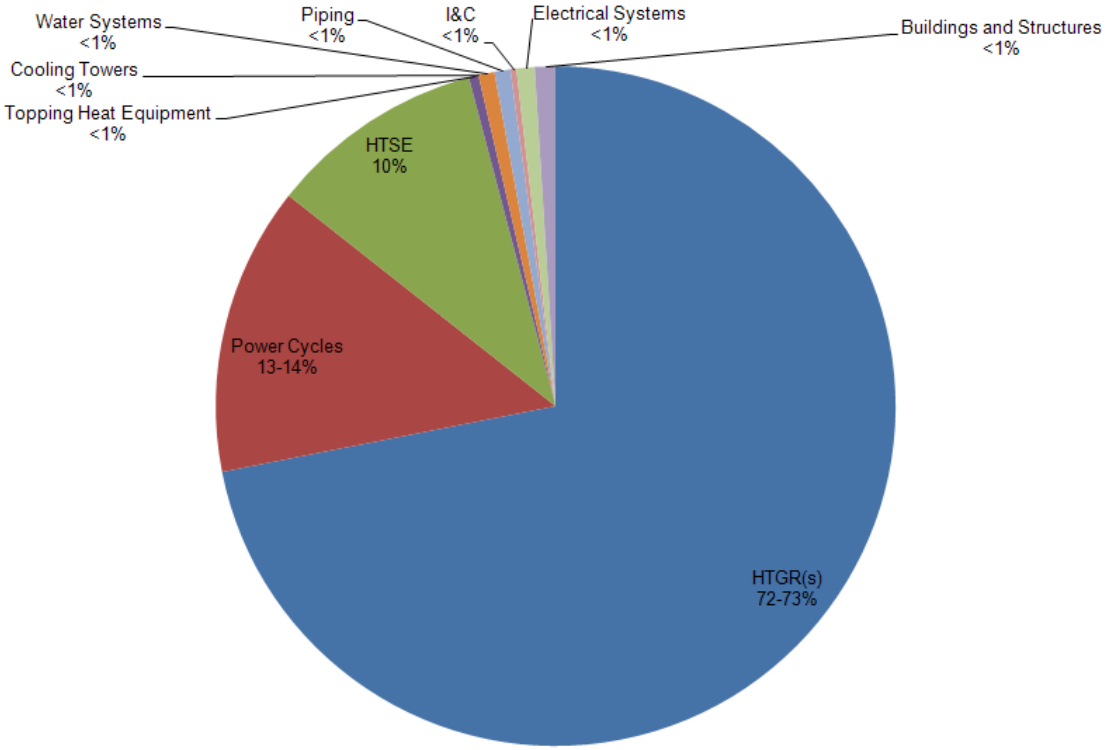

Figure 4. Total capital investment breakdown, HTSE with air sweep, all ROTs.

3.2 Estimation of Revenue

Yearly revenues were estimated for all cases based on recent price data for the various products generated, including hydrogen, heat, and electricity. When a separate owner-operator configuration is assumed, the HTGR collects revenues from the heat and electricity supplied to the HTSE process. When heat is exported from the HTGR, the selling price is assumed to be related to electricity price and the HTGR power generation efficiency based on the following equation:

$$Heat\ Price = Electricity\ Price * Power\ Generation\ Efficiency \quad (2)$$

This relationship provides that when either all heat or all electricity is generated with the HTGR the annual revenue remains the same for either product.

Revenues were also calculated to determine the necessary selling prices of hydrogen from the HTSE along with heat and electricity for the HTGR to achieve a specific rate of return.

The revenues presented for the HTSE portion are for selling hydrogen to achieve a 15% rate of return at the nominal HTGR price and average natural gas price for the independent owner-operator scenarios. Revenues were also calculated at the market price for hydrogen, $1.13/lb ($2.50/kg), which lies within the range specified in the NGNP Pre-Conceptual Design Report (INL 2007). However, the revenues for the market price scenarios are not presented. When intermediate revenues for the HTGR are presented for the independent owner-operator scenario, the heat and electricity price is presented to achieve the rate of return specified for the project, 15%, at the nominal HTGR price. A stream factor of 92% is assumed for both the HTSE and nuclear plants. Table 6 presents the revenues for the HTSE cases with steam sweep and Table 7 presents the revenues for the HTSE cases with air sweep.

Table 6. Annual revenues, HTSE with steam sweep, HTGR at nominal reactor price, 15% IRR.

Case	Product	Price	Generated	Annual Revenue
Case 1 650°C	Hydrogen	1.84 $/lb H_2	15,054 lb/hr	$223,240,702
	Annual Revenue – HTSE			**$223,240,702**
	Electricity	8.54 ¢/kW_e-hr	235 MW_e	$161,819,449
	Heat (Helium)	3.77 ¢/kW_t-hr	67 MW_t	$20,360,656
	Annual Revenue – HTGR (separate owner-operator)			**$182,180,105**
Case 2 700°C	Hydrogen	1.80 $/lb H_2	15,371 lb/hr	$222,977,166
	Annual Revenue – HTSE			**$222,977,166**
	Electricity	8.50 ¢/kW_e-hr	240 MW_e	$164,252,684
	Heat (Helium)	3.79 ¢/kW_t-hr	62 MW_t	$18,949,947
	Annual Revenue – HTGR (separate owner-operator)			**$183,202,631**
Case 3 750°C	Hydrogen	1.77 $/lb H_2	15,650 lb/hr	$223,238,079
	Annual Revenue – HTSE			**$223,238,079**
	Electricity	8.42 ¢/kW_e-hr	244 MW_e	$165,496,583
	Heat (Helium)	3.79 ¢/kW_t-hr	59 MW_t	$17,930,941
	Annual Revenue – HTGR (separate owner-operator)			**$183,427,525**
Case 4 800°C	Hydrogen	1.74 $/lb H_2	15,897 lb/hr	$222,927,606
	Annual Revenue – HTSE			**$222,927,606**
	Electricity	8.33 ¢/kW_e-hr	248 MW_e	$166,387,025
	Heat (Helium)	3.80 ¢/kW_t-hr	56 MW_t	$17,134,207
	Annual Revenue – HTGR (separate owner-operator)			**$183,521,232**
Case 5 850°C	Hydrogen	1.68 $/lb H_2	16,195 lb/hr	$219,273,378
	Annual Revenue – HTSE			**$219,273,378**
	Electricity	8.29 ¢/kW_e-hr	251 MW_e	$167,943,035
	Heat (Helium)	3.80 ¢/kW_t-hr	52 MW_t	$15,992,497
	Annual Revenue – HTGR (separate owner-operator)			**$183,935,532**
Case 6 900°C	Hydrogen	1.65 $/lb H_2	16,422 lb/hr	$218,376,568
	Annual Revenue – HTSE			**$218,376,568**
	Electricity	8.21 ¢/kW_e-hr	255 MW_e	$168,480,822
	Heat (Helium)	3.79 ¢/kW_t-hr	49 MW_t	$14,961,204
	Annual Revenue – HTGR (separate owner-operator)			**$183,442,026**
Case 7 950°C	Hydrogen	1.63 $/lb H_2	16,629 lb/hr	$218,449,687
	Annual Revenue – HTSE			**$218,449,687**
	Electricity	8.17 ¢/kW_e-hr	258 MW_e	$169,655,154
	Heat (Helium)	3.80 ¢/kW_t-hr	46 MW_t	$14,208,200
	Annual Revenue – HTGR (separate owner-operator)			**$183,863,353**

Table 7. Annual revenues, HTSE with air sweep, HTGR at nominal reactor price, 15% IRR.

Case	Product	Price	Generated	Annual Revenue
Case 8 650°C	Hydrogen	1.94 $/lb H_2	15,411 lb/hr	$240,951,643
	Annual Revenue – HTSE			**$240,951,643**
	Electricity	8.58 ¢/kW_e-hr	238 MW_e	$164,308,884
	Heat (Helium)	3.78 ¢/kW_t-hr	61 MW_t	$18,568,093
	Annual Revenue – HTGR (separate owner-operator)			**$182,876,976**
Case 9 700°C	Hydrogen	1.90 $/lb H_2	15,735 lb/hr	$240,944,650
	Annual Revenue – HTSE			**$240,944,650**
	Electricity	8.50 ¢/kW_e-hr	242 MW_e	$166,006,528
	Heat (Helium)	3.79 ¢/kW_t-hr	56 MW_t	$17,066,108
	Annual Revenue – HTGR (separate owner-operator)			**$183,072,637**
Case 10 750°C	Hydrogen	1.87 $/lb H_2	16,022 lb/hr	$241,457,721
	Annual Revenue – HTSE			**$241,457,721**
	Electricity	8.42 ¢/kW_e-hr	247 MW_e	$167,285,193
	Heat (Helium)	3.79 ¢/kW_t-hr	52 MW_t	$15,898,410
	Annual Revenue – HTGR (separate owner-operator)			**$183,183,604**
Case 11 800°C	Hydrogen	1.84 $/lb H_2	16,269 lb/hr	$241,250,895
	Annual Revenue – HTSE			**$241,250,895**
	Electricity	8.29 ¢/kW_e-hr	251 MW_e	$167,448,339
	Heat (Helium)	3.80 ¢/kW_t-hr	53 MW_t	$16,330,672
	Annual Revenue – HTGR (separate owner-operator)			**$183,779,012**
Case 12 850°C	Hydrogen	1.79 $/lb H_2	16,405 lb/hr	$236,655,026
	Annual Revenue – HTSE			**$236,655,025**
	Electricity	8.13 ¢/kW_e-hr	253 MW_e	$165,730,773
	Heat (Helium)	3.79 ¢/kW_t-hr	57 MW_t	$17,544,649
	Annual Revenue – HTGR (separate owner-operator)			**$183,275,422**
Case 13 900°C	Hydrogen	1.77 $/lb H_2	16,647 lb/hr	$237,468,395
	Annual Revenue – HTSE			**$237,468,395**
	Electricity	8.21 ¢/kW_e-hr	256 MW_e	$169,474,534
	Heat (Helium)	3.81 ¢/kW_t-hr	48 MW_t	$14,615,006
	Annual Revenue – HTGR (separate owner-operator)			**$184,089,540**
Case 14 950°C	Hydrogen	1.75 $/lb H_2	16,859 lb/hr	$237,778,324
	Annual Revenue – HTSE			**$237,778,324**
	Electricity	8.17 ¢/kW_e-hr	259 MW_e	$170,581,353
	Heat (Helium)	3.81 ¢/kW_t-hr	44 MW_t	$13,560,286
	Annual Revenue – HTGR (separate owner-operator)			**$184,141,638**

3.3 Estimation of Manufacturing Costs

Manufacturing cost is the sum of direct and indirect manufacturing costs. Direct manufacturing costs for this project include the cost of raw materials, utilities, and O&M. Indirect manufacturing costs include estimates for the cost of overhead and insurance and taxes (Perry 2008).

Labor costs for the HTSE plant are assumed to be 1.15% of the HTSE TCI. This percentage is based on staffing requirements for a conventional 50,000 bbl/day coal to liquids plant, that percentage is assumed to adequately represent the labor for the HTSE plant. Maintenance costs were assumed to be 3% of the TCI of the HTSE system, per the *Handbook of Petroleum Processing*, less the TCI of the electrolysis cells as HTSE cell replacement costs were calculated assuming cell replacement every six years based on vendor input. Taxes and insurance was assumed to be 1.5% of the TCI, excluding the HTGR, an overhead of 65% of the labor and maintenance costs was assumed, and royalties were assumed to be 1% of the yearly electrolysis cell replacement costs, this value was assumed based on information presented in the *Handbook of Petroleum Processing* (Jones 2006).

Manufacturing costs for the nuclear plant were based on data from General Atomics for the gas-turbine modular high-temperature reactor published in 2002; these costs were inflated to 2009 dollars (GA 2002). HTGR manufacturing costs include O&M and fuel costs. The manufacturing costs presented are preliminary, as the HTGR manufacturing costs are not a function of the ROT. This TEV will be updated when the HTGR cost estimate update is complete.

Availability of both the HTSE and nuclear plants was assumed to be 92%. Natural gas prices were varied to account for the large fluctuations seen in the market. Costs were calculated for a low ($4.50/MSCF), average ($6.50/MSCF), and high ($12.00/MSCF) industrial natural gas price. High prices correspond to prices from June 2008, low prices are from September 2009, and the average price was chosen to reflect current natural gas price (EIA 2010). Only average natural gas prices are presented in the tables below. The cases are presented for the single owner-operator scenario only. When the HTGR is operated independently, the HTSE process would purchase electricity and heat as specified in the revenue tables presented previously (Table 6 and Table 7) and the manufacturing costs would be comprised of the nuclear fuel and O&M costs presented below (Table 8 and Table 9).

Table 8 presents the annual manufacturing costs for the HTSE with steam sweep for the single owner-operator scenario and Table 9 presents the annual manufacturing costs for the HTSE with air sweep for the single owner-operator scenario. The manufacturing costs are valid for both the target and nominal HTGR cost.

Table 8. Annual manufacturing costs, HTSE with steam sweep, single owner-operator, average natural gas price.

	Section	Price		Consumed		Annual Cost
All Cases/ ROTs	Nuclear Costs					
	Fuel	4.34	$/MW$_t$-h	600	MW$_t$/day	$20,977,332
	O&M	1.76	$/MW$_t$-h	600	MW$_t$/day	$8,504,324
Case 1 650°C	Direct Costs					
	Materials					
	Average Natural Gas	6.50	$/MSCF	557	MSCFD	$1,216,291
	Makeup H_2O Clarifying	0.02	$/k-gal	385	k-gal/day	$3,210
	HTSE Cell Replacement	0.05	$/lb-$H_2$	361	k-lb/day	$6,363,881
	Utilities					
	Water	0.05	$/k-gal	385	k-gal/day	$5,950
	Royalties					$63,639
	Labor and Maintenance					$3,786,081
	Indirect Costs					
	Overhead					$2,460,953
	Insurance and Taxes					$1,952,670
	Manufacturing Costs, Including HTGR Costs					**$45,334,333**
Case 2 700°C	Direct Costs					
	Materials					
	Average Natural Gas	6.50	$/MSCF	502	MSCFD	$1,095,990
	Makeup H_2O Clarifying	0.02	$/k-gal	393	k-gal/day	$3,275
	HTSE Cell Replacement	0.05	$/lb-$H_2$	369	k-lb/day	$6,497,637
	Utilities					
	Water	0.05	$/k-gal	393	k-gal/day	$6,071
	Royalties					$64,976
	Labor and Maintenance					$3,825,258
	Indirect Costs					
	Overhead					$2,486,418
	Insurance and Taxes					$1,978,774
	Manufacturing Costs, Including HTGR Costs					**$45,440,056**
Case 3 750°C	Direct Costs					
	Materials					
	Average Natural Gas	6.50	$/MSCF	442	MSCFD	$964,629
	Makeup H_2O Clarifying	0.02	$/k-gal	400	k-gal/day	$3,335
	HTSE Cell Replacement	0.05	$/lb-$H_2$	376	k-lb/day	$6,615,524
	Utilities					
	Water	0.05	$/k-gal	400	k-gal/day	$6,181
	Royalties					$66,155
	Labor and Maintenance					$3,743,854
	Indirect Costs					
	Overhead					$2,433,505
	Insurance and Taxes					$1,959,982
	Manufacturing Costs, Including HTGR Costs					**$45,274,821**

Table 8. Annual manufacturing costs, HTSE with steam sweep, single owner-operator, average natural gas price.

Case 4 800°C	Direct Costs					
	Materials					
	Average Natural Gas	6.50	$/MSCF	377	MSCFD	$822,936
	Makeup H_2O Clarifying	0.02	$/k-gal	407	k-gal/day	$3,389
	HTSE Cell Replacement	0.05	$/lb-$H_2$	382	k-lb/day	$6,720,182
	Utilities					
	Water	0.05	$/k-gal	407	k-gal/day	$6,282
	Royalties					$67,202
	Labor and Maintenance					$3,617,651
	Indirect Costs					
	Overhead					$2,351,473
	Insurance and Taxes					$1,924,689
	Manufacturing Costs, Including HTGR Costs					**$44,995,460**
Case 5 850°C	Direct Costs					
	Materials					
	Makeup H_2O Clarifying	0.02	$/k-gal	414	k-gal/day	$3,454
	HTSE Cell Replacement	0.05	$/lb-$H_2$	389	k-lb/day	$6,846,913
	Utilities					
	Water	0.05	$/k-gal	414	k-gal/day	$6,402
	Royalties					$68,469
	Labor and Maintenance					$3,003,133
	Indirect Costs					
	Overhead					$1,952,037
	Insurance and Taxes					$1,713,951
	Manufacturing Costs, Including HTGR Costs					**$43,076,016**
Case 6 900°C	Direct Costs					
	Materials					
	Makeup H_2O Clarifying	0.02	$/k-gal	419	k-gal/day	$3,495
	HTSE Cell Replacement	0.05	$/lb-$H_2$	394	k-lb/day	$6,942,877
	Utilities					
	Water	0.05	$/k-gal	419	k-gal/day	$6,479
	Royalties					$69,429
	Labor and Maintenance					$2,816,994
	Indirect Costs					
	Overhead					$1,831,046
	Insurance and Taxes					$1,655,631
	Manufacturing Costs, Including HTGR Costs					**$42,807,608**

Table 8. Annual manufacturing costs, HTSE with steam sweep, single owner-operator, average natural gas price.

Case 7 950°C	Direct Costs					
	Materials					
	Makeup H_2O Clarifying	0.02	$/k-gal	427	k-gal/day	$3,562
	HTSE Cell Replacement	0.05	$/lb-$H_2$	399	k-lb/day	$7,030,410
	Utilities					
	Water	0.05	$/k-gal	427	k-gal/day	$6,601
	Royalties					$70,304
	Labor and Maintenance					$2,744,104
	Indirect Costs					
	Overhead					$1,783,667
	Insurance and Taxes					$1,637,188
	Manufacturing Costs, Including HTGR Costs					**$42,757,492**

Table 9. Annual manufacturing costs, HTSE with air sweep, single owner-operator, average natural gas price.

		Price		**Consumed**		**Annual Cost**
All Cases/ ROTs	Nuclear Costs					
	Fuel	4.34	$/$MW_t$-h	600	MW_t/day	$20,977,332
	O&M	1.76	$/$MW_t$-h	600	MW_t/day	$8,504,324
Case 8 650°C	Direct Costs					
	Materials					
	Average Natural Gas	6.50	$/MSCF	588	MSCFD	$1,283,477
	Makeup H_2O Clarifying	0.02	$/k-gal	396	k-gal/day	$3,300
	HTSE Cell Replacement	0.05	$/lb-$H_2$	370	k-lb/day	$6,512,418
	Utilities					
	Water	0.05	$/k-gal	396	k-gal/day	$6,116
	Royalties					$65,124
	Labor and Maintenance					$6,874,191
	Indirect Costs					
	Overhead					$4,468,224
	Insurance and Taxes					$3,082,873
	Manufacturing Costs, Including HTGR Costs					**$51,777,378**

Table 9. Annual manufacturing costs, HTSE with air sweep, single owner-operator, average natural gas price.

Case 9 700°C	Direct Costs					
	Materials					
	Average Natural Gas	6.50	$/MSCF	532	MSCFD	$1,161,081
	Makeup H_2O Clarifying	0.02	$/k-gal	402	k-gal/day	$3,354
	HTSE Cell Replacement	0.05	$/lb-$H_2$	378	k-lb/day	$6,649,328
	Utilities					
	Water	0.05	$/k-gal	402	k-gal/day	$6,217
	Royalties					$66,493
	Labor and Maintenance					$6,866,191
	Indirect Costs					
	Overhead					$4,463,024
	Insurance and Taxes					$3,081,971
	Manufacturing Costs, Including HTGR Costs					**$51,779,316**
Case 10 750°C	Direct Costs					
	Materials					
	Average Natural Gas	6.50	$/MSCF	471	MSCFD	$1,027,422
	Makeup H_2O Clarifying	0.02	$/k-gal	410	k-gal/day	$3,419
	HTSE Cell Replacement	0.05	$/lb-$H_2$	385	k-lb/day	$6,770,352
	Utilities					
	Water	0.05	$/k-gal	410	k-gal/day	$6,338
	Royalties					$67,704
	Labor and Maintenance					$6,781,651
	Indirect Costs					
	Overhead					$4,408,073
	Insurance and Taxes					$3,072,541
	Manufacturing Costs, Including HTGR Costs					**$51,619,157**
Case 11 800°C	Direct Costs					
	Materials					
	Average Natural Gas	6.50	$/MSCF	404	MSCFD	$882,615
	Makeup H_2O Clarifying	0.02	$/k-gal	416	k-gal/day	$3,467
	HTSE Cell Replacement	0.05	$/lb-$H_2$	390	k-lb/day	$6,874,888
	Utilities					
	Water	0.05	$/k-gal	416	k-gal/day	$6,426
	Royalties					$68,749
	Labor and Maintenance					$6,681,012
	Indirect Costs					
	Overhead					$4,342,658
	Insurance and Taxes					$3,046,044
	Manufacturing Costs, Including HTGR Costs					**$51,387,514**

Table 9. Annual manufacturing costs, HTSE with air sweep, single owner-operator, average natural gas price.

Case 12 850°C	Direct Costs					
	Materials					
	Makeup H_2O Clarifying	0.02	$/k-gal	421	k-gal/day	$3,511
	HTSE Cell Replacement	0.05	$/lb-$H_2$	394	k-lb/day	$6,933,124
	Utilities					
	Water	0.05	$/k-gal	421	k-gal/day	$6,507
	Royalties					$69,331
	Labor and Maintenance					$6,112,357
	Indirect Costs					
	Overhead					$3,973,032
	Insurance and Taxes					$2,846,454
	Manufacturing Costs, Including HTGR Costs					**$49,425,973**
Case 13 900°C	Direct Costs					
	Materials					
	Makeup H_2O Clarifying	0.02	$/k-gal	426	k-gal/day	$3,551
	HTSE Cell Replacement	0.05	$/lb-$H_2$	400	k-lb/day	$7,035,600
	Utilities					
	Water	0.05	$/k-gal	426	k-gal/day	$6,581
	Royalties					$70,356
	Labor and Maintenance					$6,069,210
	Indirect Costs					
	Overhead					$3,944,987
	Insurance and Taxes					$2,840,176
	Manufacturing Costs, Including HTGR Costs					**$49,452,117**
Case 14 950°C	Direct Costs					
	Materials					
	Makeup H_2O Clarifying	0.02	$/k-gal	431	k-gal/day	$3,596
	HTSE Cell Replacement	0.05	$/lb-$H_2$	405	k-lb/day	$7,125,269
	Utilities					
	Water	0.05	$/k-gal	431	k-gal/day	$6,665
	Royalties					$71,253
	Labor and Maintenance					$6,058,519
	Indirect Costs					
	Overhead					$3,938,037
	Insurance and Taxes					$2,843,114
	Manufacturing Costs, Including HTGR Costs					**$49,528,108**

3.4 Economic Comparison

Several economic indicators were calculated for each case to assess the economic desirability of HTSE hydrogen production. For all cases the IRR was calculated for HTSE cases at low, average, and high natural gas prices, as well as for multiple owner-operator scenarios. In addition, the hydrogen price necessary for a return of 15% was calculated for all cases at the target and nominal HTGR cost. Table 10 lists the economic assumptions made for the analyses.

Table 10. Economic assumptions.

	HTSE	**HTGR**
Plant Startup Year	2016	2016
Construction Information		
Construction Period	3 years	5 years
Year Construction Begins	2013	2011
Percent Capital Invested Each Year	33%	20%
Plant Startup Information		
Startup Time	1 year	1 year
Percent Operating Costs During Startup	85%	85%
Percent Revenues During Startup	60%	60%
Economic Analysis Period	30 years	30 years
Availability	92%	92%
Inflation Rate	3%	3%
Debt to Equity Ratio	55%/45%	70%/30%
Loan Information		
Interest Rate on Debt	4.5%	4.5%
Interest on Debt During Construction	4.5%	4.5%
Loan Repayment Term	15 years	15 years
Tax Information		
Effective Tax Rate	38.9%	38.9%
State Tax Rate	6%	6%
Federal Tax Rate	35%	35%
MACRS Depreciation Term	15 year life	15 year life
IRR	15%	15%

Initially, a carbon tax on carbon dioxide emissions was included in the analysis for the cases that utilized natural gas. However, the impact on taxing CO_2 emissions at values up to $200/ton had no appreciable impact on the selling price of hydrogen required (i.e., less than a $0.02 increase for a $200/ton tax on the CO_2 emissions).

3.4.1 Cash Flow

To assess the IRR and present worth (PW) of each scenario, it is necessary to calculate the after tax cash flow (ATCF). To calculate the ATCF, it is necessary to first calculate the revenues (R_k); cash outflows (E_k); sum of all noncash, or book, costs such as depreciation (d_k); net income before taxes (NIBT); the effective income tax rate (t); and the income taxes (T_k), for each year (k). The taxable income is revenue minus the sum of all cash outflows and noncash costs. Therefore the income taxes per year are defined as follows (Sullivan 2003):

$$T_k = t(R_k - E_k - d_k) \tag{3}$$

Depreciation for the economic calculations was calculated using a standard Modified Accelerated Cost Recovery System (MACRS) depreciation method with a property class of 15 years. Depreciation was assumed for the TCI with the first charge occurring the year the plant comes online. Table 11 presents the recovery rates for a 15-year property class (Perry 2008).

Table 11. MACRS depreciation.

Year	Recovery Rate	Year	Recovery Rate
1	0.05	9	0.0591
2	0.095	10	0.059
3	0.0855	11	0.0591
4	0.077	12	0.059
5	0.0693	13	0.0591
6	0.0623	14	0.059
7	0.059	15	0.0591
8	0.059	16	0.0295

The ATCF is then the sum of the before tax cash flow (BTCF) minus the income taxes owed. Note that the expenditures for capital are not taxed but are included in the BTCF each year there is a capital expenditure (C_k); this includes the equity capital and the debt principle. The BTCF is defined as follows (Sullivan 2003):

$$BTCF_k = R_k - E_k - C_k \tag{4}$$

The ATCF can then be defined as:

$$ATCF_k = BTCF_k - T_k \tag{5}$$

3.4.2 Internal Rate of Return

The IRR method is the most widely used rate of return method for performing engineering economic analyses. This method solves for the interest rate that equates the equivalent worth of an alternative's cash inflows to the equivalent worth of cash outflows (after tax cash flow), i.e., the interest rate at which the PW is zero. The resulting interest is the IRR (i'). For the project to be economically viable, the calculated IRR must be greater than the desired minimum annual rate of return (MARR) (Sullivan 2003).

$$PW(i') = \sum_{k=0}^{N} ATCF_k(1 + i')^{-k} = 0 \quad (6)$$

IRR calculations were performed selling hydrogen at its market price for the low, average, and high natural gas purchase prices for the HTSE cases at the target and nominal HTGR price. In addition, the price of hydrogen necessary for an IRR of 15% and a PW of zero was calculated for all cases. When an independent owner-operator scenario was modeled, the price of electricity and heat necessary was calculated to achieve a 15% IRR. The necessary electricity and heat selling price was then used for any electricity and heat purchased by the HTSE plant. The IRR and hydrogen price required (for an IRR of 15%) was solved for using the Goal Seek function in Excel (Excel 2007).

4. ECONOMIC MODELING RESULTS AND OBSERVATIONS

The results presented below are preliminary, as the HTGR cost estimate currently is not a function of the ROT. This TEV will be updated when the HTGR cost estimate update is complete.

Table 12 presents the results for the HTSE with steam sweep for the single owner-operator scenario as a function of natural gas price, ROT, and the HTGR price, listing the hydrogen selling price required for a 15% IRR as well as the IRR for selling hydrogen at the market price. From these results, it is apparent that given the small amount of natural gas required for the HTSE operation, for ROTs less than 850°C, the hydrogen selling price and IRR are not significantly impacted by increases in natural gas price. Consequently, low, average, and high natural gas prices are only presented for this case. Table 13 presents the results for the HTSE with steam sweep for the independent owner-operator scenario at the average natural gas price as a function of ROT and the HTGR price, listing the hydrogen selling price required for a 15% IRR as well as the IRR for selling hydrogen at the market price. In addition to the hydrogen prices required for a 15% IRR, the required selling price for electricity and heat for the HTGR is presented for a 15% IRR. A value of N/A for the IRR indicates that manufacturing costs exceeded revenues. Figure 5 presents the steam sweep results at the average natural gas price as a

function of ROT at the target and nominal HTGR price, comparing the single and independent owner-operator scenarios for a 15% IRR.

Table 12. HTSE steam sweep results, single owner-operator scenario.

ROT	Natural Gas Price	*TCI – Target HTGR*		*TCI – Nominal HTGR*	
		IRR	**Product Price**	**IRR**	**Product Price**
Case 1 650°C		$1,037,868,639		$1,345,368,639	
	Low NG $4.50/MSCF	10.51%	$1.13/lb H_2	7.85%	$1.13/lb H_2
		15.0%	$1.47/lb H_2	15.0%	$1.79/lb H_2
	Average NG $6.50/MSCF	10.46%	$1.13/lb H_2	7.81%	$1.13/lb H_2
		15.0%	$1.48/lb H_2	15.0%	$1.79/lb H_2
	High NG $12.00/MSCF	10.34%	$1.13/lb H_2	7.69%	$1.13/lb H_2
		15.0%	$1.49/lb H_2	15.0%	$1.80/lb H_2
Case 2 700°C		$1,041,883,507		$1,349,383,507	
	Low NG $4.50/MSCF	10.79%	$1.13/lb H_2	8.11%	$1.13/lb H_2
		15.0%	$1.45/lb H_2	15.0%	$1.76/lb H_2
	Average NG $6.50/MSCF	10.75%	$1.13/lb H_2	8.07%	$1.13/lb H_2
		15.0%	$1.45/lb H_2	15.0%	$1.76/lb H_2
	High NG $12.00/MSCF	10.64%	$1.13/lb H_2	7.97%	$1.13/lb H_2
		15.0%	$1.46/lb H_2	15.0%	$1.77/lb H_2
Case 3 750°C		$1,042,650,186		$1,350,150,186	
	Low NG $4.50/MSCF	11.10%	$1.13/lb H_2	8.38%	$1.13/lb H_2
		15.0%	$1.42/lb H_2	15.0%	$1.73/lb H_2
	Average NG $6.50/MSCF	11.06%	$1.13/lb H_2	8.35%	$1.13/lb H_2
		15.0%	$1.43/lb H_2	15.0%	$1.73/lb H_2
	High NG $12.00/MSCF	10.97%	$1.13/lb H_2	8.27%	$1.13/lb H_2
		15.0%	$1.43/lb H_2	15.0%	$1.74/lb H_2
Case 4 800°C		$1,042,092,864		$1,349,592,864	
	Low NG $4.50/MSCF	11.40%	$1.13/lb H_2	8.65%	$1.13/lb H_2
		15.0%	$1.40/lb H_2	15.0%	$1.70/lb H_2
	Average NG $6.50/MSCF	11.37%	$1.13/lb H_2	8.62%	$1.13/lb H_2
		15.0%	$1.40/lb H_2	15.0%	$/1.70 lb H_2
	High NG $12.00/MSCF	11.29%	$1.13/lb H_2	8.55%	$1.13/lb H_2
		15.0%	$1.41/lb H_2	15.0%	$1.71/lb H_2
Case 5 850°C	**N/A**	$1,029,737,457		$1,337,237,457	
		12.07%	$1.13/lb H_2	9.21%	$1.13/lb H_2
		15.0%	$1.34/lb H_2	15.0%	$1.64/lb H_2
Case 6 900°C	**N/A**	$1,027,435,399		$1,334,935,399	
		12.36%	$1.13/lb H_2	9.47%	$1.13/lb H_2
		15.0%	$1.32/lb H_2	15.0%	$1.61/lb H_2
Case 7 950°C	**N/A**	$1,027,652,106		$1,335,152,106	
		12.58%	$1.13/lb H_2	9.66%	$1.13/lb H_2
		15.0%	$1.30/lb H_2	15.0%	$1.59/lb H_2

Table 13. HTSE steam sweep results for average natural gas price, independent owner-operator scenario.

ROT	Plant Section	*TCI – Target HTGR*		*TCI – Nominal HTGR*	
		IRR	**Product Price**	**IRR**	**Product Price**
Case 1 650°C	**HTGR** Power & Heat Production	$907,690,611		$1,215,190,611	
		15.00%	¢6.75/kW_e-hr	15.00%	¢8.54/kW_e-hr
		15.00%	¢2.98/kW_t-hr	15.00%	¢3.77/kW_t-hr
	HTSE Average NG $6.50/MSCF	$130,178,028		$130,178,028	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.51/lb H_2	15.0%	$1.84/lb H_2
Case 2 700°C	**HTGR** Power & Heat Production	$909,965,256.87		$1,217,465,257	
		15.00%	¢6.71/kW_e-hr	15.00%	¢8.50/kW_e-hr
		15.00%	¢2.99/kW_t-hr	15.00%	¢3.79/kW_t-hr
	HTSE Average NG $6.50/MSCF	$131,918,250		$131,918,250	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.48/lb H_2	15.0%	$1.80/lb H_2
Case 3 750°C	**HTGR** Power & Heat Production	$911,984,752		$1,219,484,752	
		15.00%	¢6.63/kW_e-hr	15.00%	¢8.42/kW_e-hr
		15.00%	¢2.99/kW_t-hr	15.00%	¢3.79/kW_t-hr
	HTSE Average NG $6.50/MSCF	$130,665,435		$130,665,435	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.46/lb H_2	15.0%	$1.77/lb H_2
Case 4 800°C	**HTGR** Power & Heat Production	$913,780,265		$1,221,280,265	
		15.00%	¢6.58/kW_e-hr	15.00%	¢8.33/kW_e-hr
		15.00%	¢3.00/kW_t-hr	15.00%	¢3.80/kW_t-hr
	HTSE Average NG $6.50/MSCF	$128,312,599		$128,312,599	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.43/lb H_2	15.0%	$1.74/lb H_2
Case 5 850°C	**HTGR** Power & Heat Production	$915,474,070		$1,222,974,070	
		15.00%	¢6.54/kW_e-hr	15.00%	¢8.29/kW_e-hr
		15.00%	¢3.00/kW_t-hr	15.00%	¢3.80/kW_t-hr
	HTSE	$114,263,387		$114,263,387	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.38/lb H_2	15.0%	$1.68/lb H_2
Case 6 900°C	**HTGR** Power & Heat Production	$917,060,005		$1,224,560,005	
		15.00%	¢6.50/kW_e-hr	15.00%	¢8.21/kW_e-hr
		15.00%	¢3.00/kW_t-hr	15.00%	¢3.79/kW_t-hr
	HTSE	$110,375,393		$110,375,393	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.35/lb H_2	15.0%	$1.65/lb H_2
Case 7 950°C	**HTGR** Power & Heat Production	$918,506,245		$1,226,006,245	
		15.00%	¢6.46/kW_e-hr	15.00%	¢8.17/kW_e-hr
		15.00%	¢3.01/kW_t-hr	15.00%	¢3.80/kW_t-hr
	HTSE	$109,145,861		$109,145,861	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.34/lb H_2	15.0%	$1.63/lb H_2

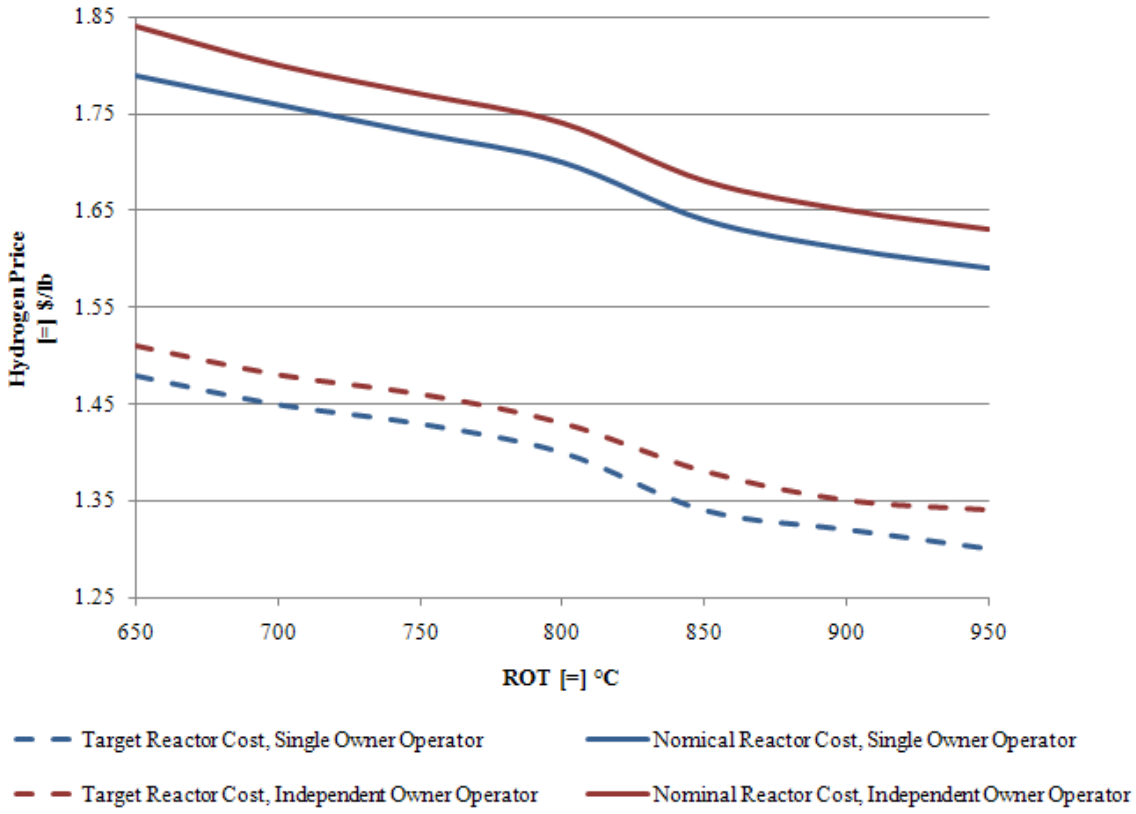

Figure 5. HTSE steam sweep results, average natural gas price, 15% IRR.

Table 14 presents the results for the HTSE with air sweep for the single owner-operator scenario at the average natural gas price as a function of ROT and the HTGR price, listing the hydrogen selling price required for a 15% IRR as well as the IRR for selling hydrogen at the market price. Table 15 presents the results for the HTSE with air sweep for the independent owner-operator scenario at the average natural gas price as a function of ROT and the HTGR price, listing the hydrogen selling price required for a 15% IRR as well as the IRR for selling hydrogen at the market price. In addition to the hydrogen prices required for a 15% IRR, the required selling price for electricity and heat for the HTGR is presented for a 15% IRR. Figure 6 presents the steam sweep results at the average natural gas price as a function of ROT at the target and nominal HTGR price, comparing the single and independent owner-operator scenarios for a 15% IRR. Figure 7 graphically compares the steam sweep and air sweep HTSE cases at the nominal HTGR cost.

Table 14. HTSE air sweep results for average natural gas price, single owner-operator scenario.

ROT	Natural Gas Price	*TCI – Target HTGR*		*TCI – Nominal HTGR*	
		IRR	**Product Price**	**IRR**	**Product Price**
Case 8 650°C	**Average NG** $6.50/MSCF	$1,114,406,034		$1,421,906,034	
		9.20%	$1.13/lb H_2	6.85%	$1.13/lb H_2
		15.0%	$1.59/lb H_2	15.0%	$1.90/lb H_2
Case 9 700°C	**Average NG** $6.50/MSCF	$1,116,660,431		$1,424,160,431	
		9.53%	$1.13/lb H_2	7.15%	$1.13/lb H_2
		15.0%	$1.55/lb H_2	15.0%	$1.86/lb H_2
Case 10 750°C	**Average NG** $6.50/MSCF	$1,118,079,219		$1,425,579,219	
		9.84%	$1.13/lb H_2	7.43%	$1.13/lb H_2
		15.0%	$1.53/lb H_2	15.0%	$1.83/lb H_2
Case 11 800°C	**Average NG** $6.50/MSCF	$1,118,193,538		$1,425,693,538	
		10.12%	$1.13/lb H_2	7.68%	$1.13/lb H_2
		15.0%	$1.50/lb H_2	15.0%	$/1.80 lb H_2
Case 12 850°C	**N/A**	$1,106,076,261		$1,413,576,261	
		10.62%	$1.13/lb H_2	8.11%	$1.13/lb H_2
		15.0%	$1.46/lb H_2	15.0%	$1.75/lb H_2
Case 13 900°C	**N/A**	$1,107,110,443		$1,414,610,443	
		10.86%	$1.13/lb H_2	8.32%	$1.13/lb H_2
		15.0%	$1.44/lb H_2	15.0%	$1.73/lb H_2
Case 14 950°C	**N/A**	$1,108,704,840		$1,416,204,840	
		11.05%	$1.13/lb H_2	8.49%	$1.13/lb H_2
		15.0%	$1.42/lb H_2	15.0%	$1.71/lb H_2

Table 15. HTSE air sweep results for average natural gas price, independent owner-operator scenario.

ROT	Plant Section	*TCI – Target HTGR* IRR	*TCI – Target HTGR* Product Price	*TCI – Nominal HTGR* IRR	*TCI – Nominal HTGR* Product Price
Case 8 650°C	**HTGR** Power & Heat Production	$908,881,191		$1,216,381,191	
		15.00%	¢6.71/kW_e-hr	15.00%	¢8.58/kW_e-hr
		15.00%	¢2.99/kW_t-hr	15.00%	¢3.78/kW_t-hr
	HTSE Average NG $6.50/MSCF	$205,524,842		$205,524,842	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.62/lb H_2	15.0%	$1.94/lb H_2
Case 9 700°C	**HTGR** Power & Heat Production	$911,195,691		$1,218,695,691	
		15.00%	¢6.71/kW_e-hr	15.00%	¢8.50/kW_e-hr
		15.00%	¢2.99/kW_t-hr	15.00%	¢3.79/kW_t-hr
	HTSE Average NG $6.50/MSCF	$205,464,741		$205,464,741	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.59/lb H_2	15.0%	$1.90/lb H_2
Case 10 750°C	**HTGR** Power & Heat Production	$913,243,180		$1,220,743,180	
		15.00%	¢6.67/kW_e-hr	15.00%	¢8.42/kW_e-hr
		15.00%	¢3.00/kW_t-hr	15.00%	¢3.79/kW_t-hr
	HTSE Average NG $6.50/MSCF	$204,836,039		$204,836,039	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.56/lb H_2	15.0%	$1.87/lb H_2
Case 11 800°C	**HTGR** Power & Heat Production	$915,123,970		$1,222,623,970	
		15.00%	¢6.54/kW_e-hr	15.00%	¢8.29/kW_e-hr
		15.00%	¢3.00/kW_t-hr	15.00%	¢3.80/kW_t-hr
	HTSE Average NG $6.50/MSCF	$203,069,567		$203,069,567	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.53/lb H_2	15.0%	$1.84/lb H_2
Case 12 850°C	**HTGR** Power & Heat Production	$916,312,682		$1,223,812,682	
		15.00%	¢6.42/kW_e-hr	15.00%	¢8.13/kW_e-hr
		15.00%	¢2.99/kW_t-hr	15.00%	¢3.79/kW_t-hr
	HTSE	$189,763,579		$189,763,579	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.49/lb H_2	15.0%	$1.79/lb H_2
Case 13 900°C	**HTGR** Power & Heat Production	$917,765,386		$1,225,265,386	
		15.00%	¢6.50/kW_e-hr	15.00%	¢8.21/kW_e-hr
		15.00%	¢3.01/kW_t-hr	15.00%	¢3.81/kW_t-hr
	HTSE	$189,345,057		$189,345,057	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.47/lb H_2	15.0%	$1.77/lb H_2
Case 14 950°C	**HTGR** Power & Heat Production	$919,163,940		$1,226,663,940	
		15.00%	¢6.46/kW_e-hr	15.00%	¢8.17/kW_e-hr
		15.00%	¢3.01/kW_t-hr	15.00%	¢3.81/kW_t-hr
	HTSE	$189,540,900		$189,540,900	
		N/A	$1.13/lb H_2	N/A	$1.13/lb H_2
		15.0%	$1.45/lb H_2	15.0%	$1.75/lb H_2

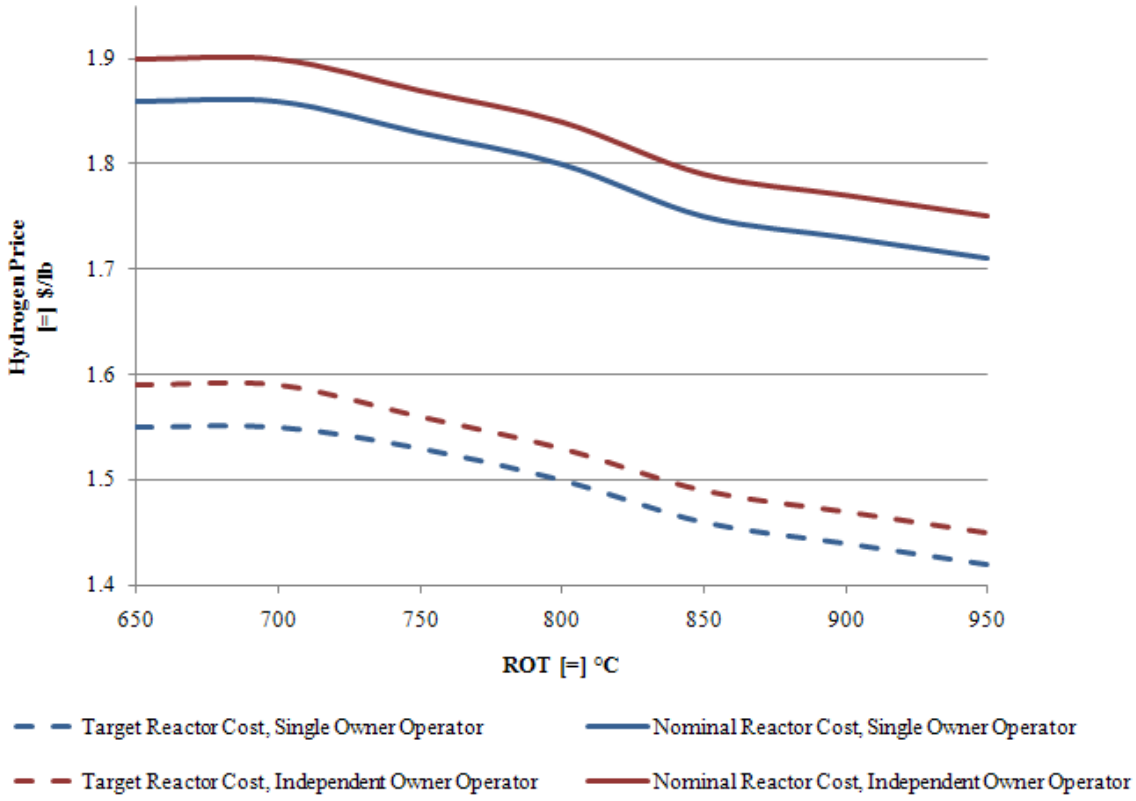

Figure 6. HTSE air sweep results, average natural gas price, 15% IRR.

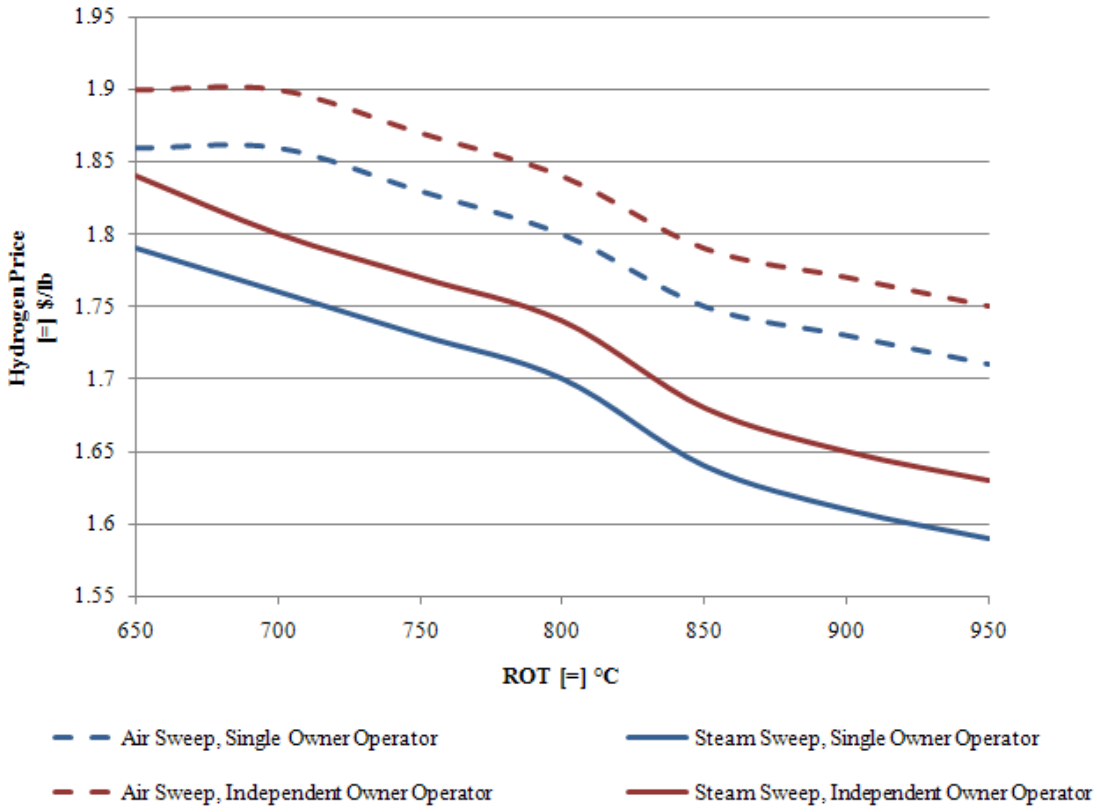

Figure 7. HTSE steam sweep versus air sweep results, average natural gas price, nominal reactor cost, 15% IRR.

The above results show that as the ROT is increased, the required selling price of hydrogen decreases for the air and steam sweep cases. However, as these results do not take into account the change in HTGR price for an increase in ROT, this trend could be negated. In addition, when an independent owner-operator scenario is selected in place of a single owner-operator scenario, the required selling price of hydrogen required for a 15% IRR increases. Thus, the hydrogen price is slightly higher for a multiple owner-operator to maintain an IRR of 15%. Finally, the steam sweep configuration produces hydrogen for a slightly lower selling price; though the air and steam sweep cases are very similar, economically.

The economic results presented in this TEV are qualitative, as the HTGR cost estimate currently is not a function of the ROT. It is recommended that the hydrogen product price be re-calculated when the HTGR cost estimate update is complete.

5. FUTURE WORK AND RECOMMENDATIONS

Based on the results of this study, the following activity is recommended before comprehensive conclusions can be made:

- Refined estimates of the HTGR capital cost, annual fuel costs, and annual operation and maintenance costs should be developed, including sensitivity to reactor outlet temperature.

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Appendix A

Capital Cost Assessment of the High Temperature Steam Electrolysis Process

A-1. INTRODUCTION

As part of the Next Generation Nuclear Plant (NGNP) project, a capital cost assessment of the Idaho National Laboratory (INL) High Temperature Steam Electrolysis (HTSE) process was performed using plant conditions and component operating parameters obtained from the HYSYS process analysis software. HYSYS models were developed for the HTSE process using both a steam sweep and an air sweep system. The HTSE process was integrated with a model of the NGNP reactor operating at 600 MW_t that provided both process heat and electricity to drive the HTSE process. Approximately 10% of the reactor power was used for process heat with the remaining reactor power used to produce electricity.

The HTSE process was evaluated for a range of reactor operating outlet temperatures ranging from 650 to 950°C. Since the electrolysis process itself operates at 800°C, lower reactor outlet temperatures required gas-fired heaters to raise the process steam and sweep-gas streams feeding the electrolysis process to the process operating temperature of the electrolysis stack.

The capital cost assessments were performed for just the electrolysis portion of the total integrated system so that differences in capital cost for the hydrogen plants using a steam-sweep or air-sweep system could be evaluated at different reactor outlet temperatures. Therefore, the capital costs presented in the following sections do not include the reactor power plant, power conversion system, or intermediate helium loop components. However, the steam generator(s) that transfer process heat from the intermediate helium loop to the hydrogen production process were considered to be part of the hydrogen production facility and were therefore included in the capital cost assessments.

This assessment was performed to provide information for HTSE capital cost to the work outlined in the main body of this TEV. When numbers or approaches differ between this appendix and the main body of the TEV, the main body of the TEV takes precedence.

A-2. CAPITAL COST ASSESSMENT METHODOLOGY

The capital cost assessment was performed using a modified Lang Methodology. Equipment purchase prices were primarily obtained from the website matche.com (2010), which appeared to give reasonably consistent equipment costs when compared with other sources. In cases where equipment costs were not available from this source, other sources were used, as discussed later. A Lang Factor of 4.74 was used to calculate the installed cost of equipment. However, rather than sum the total equipment purchase prices and multiply by the Lang Factor to arrive at a total installed system cost, individual component costs (based on sizing information from HYSYS) were multiplied by the

Lang Factor before summing, because the HYSYS models include individual fluid system components but do not include major supporting systems like the water supply and electrical and piping systems. Therefore, these major systems were addressed separately with cost information for these systems obtained from previous analyses (Harvego 2008). In addition, since the solid oxide electrolysis modules represent a unique design without historical bases for developing cost information, the purchase and installed cost of these modules was also handled separately, as discussed later.

The overall configurations of the air-sweep and steam-sweep HTSE processes are similar but involve different components (i.e., air compressors, etc., for the air-sweep system; and water pumps, etc., for the steam-sweep system). Therefore, separate HYSYS models were used to perform the capital cost assessment of these two basic systems. The following sections describe the process used for costing major components in each of these two systems beginning with the air-sweep configuration and following with the steam-sweep configuration. Although a range of reactor outlet temperatures was considered, only the installed costs for a reactor outlet temperature of 750°C are presented. The installed costs for the other reactor outlet temperatures are presented in spreadsheets at the end of this document.

A-2.1 Air-Sweep Equipment Cost Estimates

Equipment cost estimates were generally grouped into categories that included heat exchanger equipment, pumps, compressors/circulators, and coolers. The gas-fired heater and steam turbine were addressed separately, and as discussed earlier, the solid oxide electrolyzer, water supply, piping, electrical, and miscellaneous equipment were also considered separately.

For sizing of the heat exchanger equipment, the product of the overall heat transfer coefficient and the heat transfer surface area, UA, was obtained from HYSYS, and based on fluid conditions on either side of the heat exchanger, an overall heat transfer coefficient (U) was estimated (Kreith 1958). Dividing UA by the estimated U provided the total required area (A) of the heat exchanger, which is then used to obtain equipment costs from matche.com based on the selected heat exchanger, design, materials, and operating pressure (2010).

Table A-16 below summarizes the heat exchanger design parameters and uninstalled and installed equipment costs for each of the heat exchangers in the air-sweep HTSE system. Equipment costs in Reference 1 are in 2007 dollars, so the costs in 2009 dollars were obtained by multiplying by the ratio of Chemical Engineering Plant Cost Indexes (CEPCIs) for the two years (CEPCI(2009/2007) = 512/525). Installed costs were then obtained by multiplying by the Lang Factor (4.74). The CEPCI has been updated in the main TEV to reflect the most recent CEPCI; the Appendix will be updated for the next revision to reflect this update.

Table A-16. Air-sweep heat exchanger design and cost estimates.

Component Name (HYSYS)	Description	UA, Btu/hr-°F (from HYSYS)	U (estimated), Btu/hr-ft^2-°F	Heat Exchanger Area (A), ft^2	Uninstalled cost, 2007 (Matche 2010)	Uninstalled cost, 2009	Installed cost, 2009
Sweep Hi Temp Recup	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	31,184	30	1039	$182,200	$177,553	$841,602
Hi Temp Steam/H2 Recup	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	457,112	50	9142	$1,060,300	$1,033,258	$4,897,642
Sweep Low Temp Recup	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	319,188	30	10640	$1,198,900	$1,168,323	$5,537,850
Low Temp Steam/H2 Recup	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	925,002	400	2313	$348,200	$339,319	$1,608,374
E-100 (Sweep Gas)	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	3,667	30	122	$32,200	$31,379	$148,735
E-101 (Steam/H2)	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	19,210	50	384	$81,400	$79,324	$375,995
SG1	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	22,407	30	747	$139,400	$135,845	$643,904
Steam Gen: SG2	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	1,124,366	120	9370	$1,081,600	$1,054,014	$4,996,029

Table A-17 below summarizes the pump design parameters and uninstalled and installed equipment costs for each of the three water pumps used in the HTSE process with air-sweep. The primary design requirements are the volumetric flow, which determines the pump size (discharge pipe diameter), and the pump head and operating temperature, which were used to select the pump material, seal, and type. The discharge pipe diameter was calculated assuming a water discharge velocity of 5 feet per second. Based on the selected pump designs, the cost of the pumps (in 2007 dollars) were again obtained from matche.com and multiplied by the CEPCI ratio and Lang Factor to obtain the 2009 uninstalled and installed costs shown in Table A-17.

The next category of equipment consisted of gas compressors/circulators. This category of equipment included the hydrogen recirculator (H_2 recirculator) and the four air compressors for the air-sweep system. These components were sized based on required flow capacity, discharge pressure, and power. However, information from matche.com was only available for air compressors at a defined power level up to 125 psi discharge pressure, so that information was used for the initial cost estimates shown in Table A-18 below. However, as discussed later, additional sources of information were also identified to confirm that the costs shown in Table A-18 were reasonable. The hydrogen circulator was the smallest of the gas circulators and for this analysis was assumed to be comparable in cost to an air compressor of similar size. The four air compressors in the HYSYS analysis had similar power requirements, and therefore a 5000 hp design was selected for all four of these compressors. The 2007 equipment costs obtained from matche.com for the compressors shown in Table A-18 were again correct to provide uninstalled and installed costs in 2009 dollars.

Design and cost estimates for the air coolers and the water separation tank shown in Table A-19 were obtained by assuming that these components were tube and fin heat exchangers with an integral blower assembly. Therefore, the sizing of these units was obtained by using fluid temperatures from HYSYS to estimate a log mean temperature difference (LMTD), for each of the heat exchangers, and then using the heat flows from HYSYS to calculate the UAs for each heat exchanger. Then, using estimated overall heat transfer coefficients allowed the calculation of a total surface area for the heat exchangers, which, when divided by 15.5 (fin surface area ratio), provided an estimate of the bare tube surface area for the heat exchangers (Kreith 1958). With this information, matche.com provided cost estimates in 2007 dollars which were converted to 2009 dollars for the uninstalled and installed equipment summarized in Table A-19. As will be discussed later, because of the complexity in arriving at this particular set of cost estimates, additional sources were evaluated to confirm the estimated costs of these air coolers.

Table A-17. Air-sweep pump design and cost estimates.

Component	Description	Volumetric flow, m^3/hr (HYSYS)	Pump discharge pipe dia., in.	Uninstalled cost, 2007 (Matche 2010)	Uninstalled cost, 2009	Installed cost, 2009
Water Pump	Centrifugal, horizontal, 4-stage, split case; 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal	64.7	4.83	$83,700	$81,565	$386,619
Water Recycle Pump	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal	32.2	3.41	$29,200	$28,455	$134,878
Condenser Pump	Centrifugal, horizontal, 4-Stage, Horz. Split Case 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal	1.9	0.83	$34,800	$33,912	$160,745

Table A-18. Air-sweep gas compressor/circulator design and cost estimates.

Component	Description	Pressure rise, psi (from HYSYS)	Calculated compressor power, hp (HYSYS)	Uninstalled cost, 2007 (Matche 2010)	Uninstalled cost, 2009	Installed cost, 2009
H2 Recirculator	Air, Roltary Screw, 125 psi; 65 hp	58	61	$27,900	$27,188	$128,873
Air Compressor: K-100	Air, Centifugal, 125 psi; 5000 hp	31	5100	$1,177,900	$1,147,858	$5,440,849
Air Compressor: K-101	Air, Centifugal, 125 psi; 5000 hp	74	4545	$1,177,900	$1,147,858	$5,440,849
Air Compressor: K-102	Air, Centifugal, 125 psi; 5000 hp	193	4544	$1,177,900	$1,147,858	$5,440,849
Air Compressor: K-103	Air, Centifugal, 125 psi; 5000 hp	465	4288	$1,177,900	$1,147,858	$5,440,849

Table A-19. Air-sweep air cooler design and cost estimates.

Component name (HYSYS)	Description	Heat Flow, kJ/hr	Est. LMTD, F	UA, Btu/hr/F	U (est.), Btu/hr-ft^2-°F	A=UA/U, ft^2	Uninstalled cost, 2007 (Matche 2010)	Un-installed cost, 2009	Installed cost, 2009
Air Cooler: E-102	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)	12,241,188	97	119,496	25	4,780	$56,400	$54,962	$260,518
Air Cooler: E-103	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)	12,304,526	97	120,114	25	4,805	$56,600	$55,156	$261,442
Air Cooler: E-104	Air Cooled, Bare Tube Area = A/15.5, ss 304, 450 psi rating (air/air)	12,466,517	97	121,695	25	4,868	$71,200	$69,384	$328,881
Water Separation Tank (air cooled condensing heat exchanger)	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam	47,203,968	35	1,270,127	150	8,468	$133,300	$129,900	$615,727

Design and cost information for the gas fired heater used to heat the steam and sweep gas to the 800°C operating temperature of the electrolysis stack, and the steam turbine used to recover energy from the combustion gases after heating of the steam and sweep gas delivered the electrolysis stack, and the gas turbine used to recover energy from the oxygen product gas are summarized in Table A-20.The gas-fired heater uses natural gas as the fuel for the combustion process. The natural gas mass flow rate calculated by HYSYS was multiplied by the higher heating value of the gas to determine the required duty of the heater which, along with the assumed design, materials of construction, and design pressure, provided the information needed to estimate 2007 costs (Matche 2010). These results are shown in the first two rows of Table A-20, along with 2009 uninstalled and installed cost as calculated previously.

Cost information for the steam turbine was not available from matche.com, and therefore its cost was obtained from an alternative source based on the HYSYS-calculated power and the assumed design pressure and speed (Loh 2002). The cost estimate from this reference also includes the condenser and accessories for the turbine; therefore, the cost of the condenser is included in the steam turbine cost estimates shown in rows three and four of Table A-20, although shown as a separate component in the HYSYS model. Cost information for the gas (air-oxygen) turbine was also not available from matche.com, and therefore its cost was also obtained from an alternative source based on the HYSYS-calculated power (Loh 2002). Design and cost information for the gas turbine are given in Rows 5 and 6 of Table A-20.

The solid oxide electrolyzer (SOE) consisting of electrolysis cells arranged in parallel and/or series stacks within enclosed modules that are designed to control the feed and product gases, as well as the electrolysis stack temperatures and pressures, represent the largest single-cost item in the HTSE process. Since there is no historical cost data available, costs for the SOE cells are based on a production cost goal of $100/kW (2010 dollars), established by the Solid State Energy Conversion Alliance (SECA). In addition, installation cost factors are highly uncertain, but INL performed previous analyses that assumed an installed cost factor of 1.8, assuming relatively simple SOE module designs that are easy to install and change out. Using the above values, Table A-21 shows the projected SECA target uninstalled and installed cost goals for the SOE in 2009 dollars.

Additional support systems that included the water supply system, HTSE system piping, electrical system, and miscellaneous support equipment were not explicitly modeled with HYSYS, and therefore were not included as part of the above-described capital cost estimate. However, for completeness, cost estimates for these systems were obtained from previous analyses and are included in Table A-22. This table shows the estimated uninstalled costs for these systems in 2005 and 2009 dollars, the assumed installed cost factor, and the resulting installed system costs in 2009 dollars (Harvego 2008).

Table A-20. Air-sweep combustor and steam/gas turbine design and cost estimates.

Component	Description	Gas flow rate, kgmole/hr	Duty, MBTU/hr	Uninstalled cost, 2007 (Matche 2010)	Uninstalled cost, 2009	Installed cost, 2009
Gas-fired Heater: Combustion	Fired Heater, Box; SS 304; 150 psi	25.2	21.1	$976,600	$951,692	$4,511,022
Component	**Description**		**Power output, hp**	**Uninstalled cost from Ref. 4, 1998$**	**Uninstalled cost, 2009$**	**Installed cost, 2009$**
Steam Turbine	Steam Turbine, 400 psig, 3600 rpm, 1000 HP		765	$39,000	$50,108	$237,511
Gas turbine (air-oxygen)	Gas Turbine, multistage, Carbon Steel		20,336	$4,000,000	$5,139,272	$24,360,151

Table A-21. SOE power and cost estimates.

Component	2010 SECA cost goal, $/kW	Electrolysis power, kW	2010 uninstalled cost	2009 uninstalled cost	Assumed installed cost factor	2009 installed cost
SOE	100	246,666	$24,666,568	$24,064,944	1.8	$43,316,900

Table A-22. Support system cost estimates.

System	Uninstalled cost, 2005 (Harvego 2008)	Uninstalled cost, 2009	Assumed installed cost factor (Harvego 2008)	Reference 2 installed cost, 2009
Water Supply System	$1,000,000.00	$1,093,549.77	1.20	$1,312,259.72
HTSE Piping	$1,250,000.00	$1,366,937.21	1.20	$1,640,324.65
Electrical	$2,000,000.00	$2,187,099.53	1.20	$2,624,519.44
Misc. Equipment	$2,500,000.00	$2,733,874.41	1.20	$3,280,649.30

A summary of the total costs for the HTSE process with air sweep is provided in Table A-23. Total uninstalled and installed costs for the HTSE production process with air sweep are $46,700,000 and $124,000,000, respectively. The installed cost of the solid oxide electrolysis system represents the largest portion of the HTSE system cost at 35%. The heat exchangers, the gas (air-oxygen) turbine, and air compressors are the next most expensive items, each representing between 15% and 20% of the total system cost. The gas-fired heater, producing 21 MBTU, accounts for approximately 3.6% of the total system cost.

Table A-23. Summary of air-sweep HTSE system costs.

Major Components/Systems	Uninstalled cost, 2009	Installed cost, 2009	Percent of total system cost
Heat Exchangers	$4,019,015	$19,050,130	15.32%
Pumps	$143,933	$682,242	0.55%
Compressors and Circulators	$4,618,622	$21,892,268	17.60%
Air Coolers and Condenser	$309,402	$1,466,567	1.18%
Gas-fired Heater	$951,692	$4,511,022	3.63%
Steam Turbine	$50,108	$237,511	0.19%
Gas Turbine (air-oxygen)	$5,139,272	$24,360,151	19.59%
Solid Oxide Electrolyzer	$24,064,944	$43,316,900	34.83%
Water Supply System	$1,093,550	$1,312,260	1.06%
HTSE Piping	$1,366,937	$1,640,325	1.32%
Electrical	$2,187,100	$2,624,519	2.11%
Misc. Equipment	$2,733,874	$3,280,649	2.64%
Total System	**$46,678,450**	**$124,374,545**	**100.00%**

To confirm the above-estimated equipment costs, uninstalled equipment costs were also obtained from Guthrie (1969), which were provided in the form of logarithmic plots of cost versus equipment capacity or size. Multipliers were then applied to the resulting plot data to account for differences in design, materials of construction, and/or operating conditions (temperature, pressure, etc.). The Guthrie data is from 1968, so the costs were multiplied by the CEPCI to convert the costs to 2009 dollars (i.e., CEPCI (2009/2010) = 512/113.6). Since Guthrie does not have cost estimates for steam or gas turbines, these costs were estimated to be $200/kW and $411.65/kW, respectively, based on a review of the literature. In addition, the steam turbine cost also includes the cost of the associated condenser (Matche 2010) since the condenser and associated equipment is included in the NGNP cost estimate (Loh 2002). Table A-24 summarizes the results of these comparisons for the major systems and components. The total uninstalled heat exchanger cost comparisons are very close with the Guthrie estimate—approximately 10% higher than the estimate

used for NGNP. The Guthrie estimates for the pumps and air compressors/helium circulator are lower than those obtained using the NGNP method (approximately 35% respectively). The Guthrie estimates for the steam and gas turbines are higher than those obtained using the NGNP method (25.6% and 42%, respectively), but the Guthrie estimate for the gas-fired heater is lower. For the most part, the differences between the two estimates for the individual components and systems appear to fall within the expected uncertainty for a design at this stage of development. When the differences in cost for the individual components and systems are totaled, the uninstalled differences in cost are only 3.72%. However, the comparisons shown in Table A-24 do not include the SOE (since no historical cost information is available) or support systems (water, electrical, etc.), which have not been fully defined. Since the SOE represents a significant portion of the expected total systems costs, uncertainties in this cost item could have a significant impact on economics of the system.

Table A-24. Comparison of air-sweep uninstalled cost estimates.

Major Components/ Systems	Uninstalled cost (Guthrie 1969), 2009	Uninstalled cost (NGNP), 2009	Uninstalled Delta, $	Percent difference
Heat Exchangers	$4,431,988	$4,019,015	$412,973	10.28%
Pumps	$94,641	$143,933	$(49,292)	-34.25%
Compressors and Circulator	$2,920,020	$4,618,622	$(1,698,602)	-36.78%
Air coolers and Condenser	$324,913	$309,402	$15,511	5.01%
Gas-fired Heater	$552,113	$951,692	$(399,579)	-41.99%
Steam Turbine	$178,441[a]	$50,108	$128,333	256.11%
Gas (air-oxygen) Turbine	$7,297,266[b]	$5,139,272	$2,157,994	41.99%
Totals	$15,799,381	$15,232,044	$567,337	3.72%

a. Assume uninstalled steam turbine cost is $200/kW + condenser cost.
b. Assume gas turbine cost is $417.65/kW.

A-2.2 Steam-Sweep Equipment Cost Estimates

Steam-sweep equipment cost estimates were again grouped into categories that included heat exchanger equipment, pumps, compressors/circulators, and coolers. The gas-fired heater and steam turbine were addressed separately, and as discussed earlier, the SOE, water supply, piping, electrical, and miscellaneous equipment were also considered separately. Table A-25 through Table A-29 show equipment cost estimates for the above categories, which can be compared with the cost estimates in equivalent categories for the air-sweep HTSE process shown in Table A-16 through Table A-20. Since the cost of the SOE and support systems (water supply, HTSE, electrical and miscellaneous

equipment) does not change for the two concepts, costs in Table A-21 and Table A-22 also apply to the HTSE process with steam sweep.

Much of the equipment for the air-sweep and steam-sweep designs is the same, but costs may have changed due to differences in operating conditions that resulted in changes in component design and/or size. However, the change from an air-sweep to a steam-sweep system to remove oxygen from the anode side of the SOE resulted in the removal of some equipment associated with the air-sweep system and the addition of new equipment for the steam-sweep system. For example, an additional steam generator (SG1) was added to the heat exchanger equipment list in Table A-25 to provide process heat from the intermediate loop for heating of the steam sweep feeding the electrolysis stack. Two additional water pumps (the sweep water pump and sweep water recycle pump) were added to the equipment list in Table A-26, and an additional condensing heat exchanger (water separator) was added to Table A-28 to accommodate the requirements of the steam-sweep system. However, four air compressors and three ambient air coolers were also eliminated from Table A-27 and Table A-28, respectively, as a result of the removal of the air-sweep system. Since the oxygen product is recovered and stored at high pressure in the steam-sweep system, the gas (oxygen-air) turbine is no longer used to recover energy from that product stream, so the gas turbine has been eliminated from Table A-29.

Table A-25. Steam-sweep heat exchanger design and cost estimates.

Component (from HYSYS)	Description	UA, Btu/hr-°F (from HYSYS)	U (est.), Btu/hr-ft^2-°F	Heat Exchanger Area (A), ft^2	Uninstalled cost, 2007 (Matche 2010)	Uninstalled cost, 2009	Installed cost, 2009
Sweep Hi Temp Recup	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	91,052	50	1,821	$287,000	$279,680	$1,325,684
Hi Temp Steam/H2 Recup	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	446,492	50	8,930	$1,040,300	$1,013,768	$4,805,259
Sweep Low Temp Recup	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	519,957	50	10,399	$1,176,800	$1,146,786	$5,435,768
Low Temp Steam/H2 Recup	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	903,508	400	2,259	$341,700	$332,985	$1,578,350
E-100 (Sweep Gas)	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	2,728	50	55	$28,600	$27,871	$132,107
E-101 (Steam/H2)	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	18,764	50	375	$79,800	$77,765	$368,605
Stm Gen	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	21,044	30	701	$132,500	$129,121	$612,032
SG1	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	512,349	50	10247	$1,162,900	$1,133,241	$5,371,562
SG2	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating	1,098,647	120	9155	$1,061,500	$1,034,427	$4,903,184

Table A-26. Steam-sweep pump design and cost estimates.

Component	Description	Volumetric flow, m^3/s (from HYSYS)	Pump discharge pipe dia., in.	Uninstalled cost, 2007 (Matche 2010)	Uninstalled cost, 2009	Installed cost, 2009
Water Pump	Centrifugal, horizontal, 4-stage, split case; 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal	63.11	4.76	$83,700.00	$81,565	$386,619
Water Recycle Pump	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal	31.49	3.37	$29,200.00	$28,455	$134,878
Condenser Pump	Centrifugal, horizontal, 8-Stage, Horizonal Split Case 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal	1.79	0.80	$41,700.00	$40,636	$192,617
Sweep Water Pump	Centrifugal, horizontal, ANSI 1-Stage, 1.0-in. Discharge Pipe Dia; SS 304, Double Mech. Seal	0.06	0.14	$6,400.00	$6,237	$29,562
Sweep Water Recycle Pump	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal	31.53	3.37	$29,200.00	$28,455	$134,878

Table A-27. Steam-sweep hydrogen circulator design and cost estimates.

Component	Description	Pressure rise, psi (from HYSYS)	Calculated compressor power, hp (HYSYS)	Uninstalled cost, 2007 (Matche 2010)	Uninstalled cost, 2009	Installed cost, 2009
H2 Recirculator		58.02	59.58	$26,400	$25,727	$121,944

Table A-28. Steam-sweep condenser/separator design and cost estimates.

Component name (HYSYS)	Description	Heat Flow, kJ/hr	LMTD, F	UA, Btu/hr/F	U, Btu/hr-ft^2-°F	A=UA/U, ft2	Uninstalled cost, 2007 (Matche 2010)	Uninstalled cost, 2009	Installed Cost, 2009
Water Separation Tank (air cooled condensing heat exchanger)	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam	46,107,682	35.2	1,240,661	150	8271	$131,700	$128,341	$608,337
Water/O_2 Separation Tank (air-cooled condensing HX)	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam	72,714,475	62.5	1,103,552	150	7357	$123,800	$120,643	$571,846

Table A-29. Steam-sweep gas-fired heater and steam turbine estimates.

Component	Description	Gas flow rate, kgmole/hr	Duty, MBTU/hr	Uninstalled cost, 2007 (Matche 2010)	Uninstalled cost, 2009	Installed cost, 2009
Gas-fired Heater: Combustion	Fired Heater, Box; SS 304; 150 psi	23.64	19.83	$934,500	$910,666	$4,316,558
Component	**Description**		**Power output, hp**	**Uninstalled cost, 1998 (Loh 2002)**	**Uninstalled cost, 2009**	**Installed cost, 2009**
Steam Turbine	Steam Turbine, 400 psig, 3600 rpm, 1000 HP		716.27	$38,000	$48,823	$231,421

A summary of the total costs for the HTSE process with steam sweep is provided in Table A-30. Total uninstalled and installed costs for the HTSE production process with air sweep are $37,500,000 and $82,400,000, respectively. The installed cost of the solid oxide electrolysis system again represents the largest portion of the HTSE system cost at over 50%. With the elimination of a number of expensive components associated with the air-sweep system, heat exchangers now represent the second most expensive category of equipment at about 30% of the total system cost. The remaining categories of equipment shown in the left column of Table A-30 each represent less than 6% of the total installed system cost.

Table A-30. Summary of steam-sweep HTSE system costs.

Major Components/Systems	Uninstalled cost, 2009	Installed cost, 2009	Percent of total system cost
Heat Exchangers	$5,175,644	$24,532,551	29.76%
Pumps	$185,349	$878,555	1.07%
Circulator	$25,727	$121,944	0.15%
Air-cooled condensers	$248,984	$1,180,182	1.43%
Gas-fired heater	$910,666	$4,316,558	5.24%
Steam turbine	$48,823	$231,421	0.28%
Solid Oxide Electrolyzer	$23,514,612	$42,326,302	51.34%
Water Supply System	$1,093,550	$1,312,260	1.59%
HTSE Piping	$1,366,937	$1,640,325	1.99%
Electrical	$2,187,100	$2,624,519	3.18%
Misc. Equipment	$2,733,874	$3,280,649	3.98%
Total System	$37,491,266	$82,445,267	100.00%

A-2.3 Comparison of Installed System Costs for the HTSE Processes with Air- and Steam-sweep Systems

Table A-31 provides a comparison of the major components and systems for the HTSE processes with air- and steam-sweep systems. Heat exchanger costs for the HTSE process with steam-sweep are approximately 29% higher than for the HTSE process with air-sweep because of the need for a relatively expensive steam generator to provide process heat for the steam-sweep system. Pumping equipment costs are also higher for the steam-sweep system because of the addition of two water pumps, but because of the relatively low cost of the pumps, this difference is small compared to other equipment costs. The eliminations of the four relatively expensive air compressors results in a significant reduction in equipment costs for the HTSE process with steam-sweep since the only component remaining in this category of equipment is the hydrogen recirculator. Although three air-coolers are also eliminated with the steam-sweep system, the need for an additional water condenser/separator to remove moisture from the oxygen product stream results in a slight decrease in costs for the air coolers and condensers associated with the steam-sweep

process. The gas-fired heater cost for the steam-sweep system is about the same as the air-sweep system. The cost of the steam turbine for the HTSE process with steam sweep is about the same. As indicated in Table A-31 below, the cost of the remaining major components and systems, i.e., the SOE and support systems (water supply, HTSE piping, electrical and misc. equipment) did not change between the two HTSE processes with air sweep and steam sweep. As indicated in the last row of Table A-31, the overall relative difference in cost between the two HTSE processes was slightly more than 36%, with the installed HTSE process with steam-sweep costing $45,200,000 less than the HTSE process with air sweep.

Table A-31. Comparison of HTSE steam-sweep and air-sweep costs.

Major Components/ Systems	Installed cost of HTSE process with air-sweep, 2009	Installed cost of HTSE process with steam-sweep, 2009	Delta, 2009	Percent difference
Heat Exchangers	$19,050,130	$24,532,551	$5,482,421	28.78%
Pumps	$682,242	$878,555	$196,313	28.77%
Compressors and Circulators	$21,892,268	$121,944	($21,770,324)	-99.44%
Air coolers and Condensers	$1,466,567	$1,180,182	($286,385)	-19.53%
Gas-fired Heater	$4,511,022	$4,316,558	($194,464)	-4.31%
Steam Turbine	$237,511	$231,421	($6,090)	-2.56%
Gas (air-oxygen) Turbine	$24,360,151		($24,360,151)	-100.00%
Solid Oxide Electrolyzer	$43,316,900	$42,326,302	($990,598)	-2.29%
Water Supply System	$1,312,260	$1,312,260	($0)	0.00%
HTSE Piping	$1,640,325	$1,640,325	($0)	0.00%
Electrical	$2,624,519	$2,624,519	$0	0.00%
Misc. Equipment	$3,280,649	$3,280,649	$0	0.00%
Total System	$124,374,544	$79,164,618	($45,209,926)	-36.35%

A-3. REFERENCES

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A-4. CAPITAL COST SPREAD SHEETS

Air Sweep, Reactor Outlet Temperature 650°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Q	MBTU/hr	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
HX: Sweep HI Temp Recup	21% O2, N2/50% O2, N2	5.70E+04	3.00E+04	30	1000.04			$176,600.00	4.74	$837,084.00	$172,095.93	$815,794.69	Shell/Tube, Floating Head, Large SS 304; 900 psi rating
HX: HI Temp Steam/H2 Recup	30% Stm, H2/90% Stm, H2	1.18E+06	6.24E+05	50	12470.54			$1,363,400.00	4.74	$6,462,516.00	$1,328,627.33	$6,297,693.55	Shell/Tube, Floating Head, Large SS 304; 900 psi rating
HX: Sweep Low Temp Recup	21% O2, N2/50% O2, N2	5.83E+05	3.07E+05	30	10236.63			$1,161,900.00	4.74	$5,507,406.00	$1,132,266.46	$5,366,943.04	Shell/Tube, Floating Head, Large SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	1.64E+06	8.64E+05	400	2160.10			$329,500.00	4.74	$1,561,830.00	$321,096.31	$1,521,996.50	Shell/Tube, Floating Head, Large SS 304; 900 psi rating
Total Cost 4 Recuperators								**$3,031,400.00**	**4.74**	**$14,368,836.00**	**$2,954,086.03**	**$14,002,367.78**	
HX: E-100 (Sweep Gas)	Combustion Gas/21% O2m N2	6.70E+03	3.53E+03	30	117.64			$31,200.00	4.74	$147,888.00	$30,404.26	$144,116.21	Shell/Tube, Floating Head, Large SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/90% Stm, H2	4.82E+04	2.54E+04	50	507.46			$101,900.00	4.74	$483,006.00	$99,301.10	$470,687.23	Shell/Tube, Floating Head, Large SS 304; 900 psi rating
Total Cost 2 Combustion HXs								**$133,100.00**	**4.74**	**$630,894.00**	**$129,705.37**	**$614,803.44**	
Steam Gen: Stm Gen	Water, Stm/77%N2, O2, CO2	5.39E+04	2.84E+04	30	947.17			$169,000.00	4.74	$801,060.00	$164,689.76	$780,629.46	Shell/Tube, Floating Head, Large SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	2.13E+06	1.12E+06	120	9347.15			$1,079,500.00	4.74	$5,116,830.00	$1,051,968.02	$4,986,328.44	Shell/Tube, Floating Head, Large SS 304; 900 psi rating
Total Cost 2 Steam Generators								**$1,248,500.00**	**4.74**	**$5,917,890.00**	**$1,216,657.78**	**$5,766,957.90**	
Component		**Natural Gas Mass Heating Value, kJ/kgmole**	**Natural Gas flow rate, kgmole/hr**	**Q kJ/s**				**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Gas Fired Heater: Combustion	Natural Gas	894723	31.45095667	7729.275537			26.38001058	**$1,141,200.00**	**4.74**	**$5,409,288.00**	**$1,112,094.40**	**$5,271,327.48**	Fired Heater, Box; SS 304; 150 psi
	Vol. flow, m3/hr	**Velocity, ft/sec EngineeringToolBox.com**	**Discharge Pipe Area, ft2**	**Pump Discharge Dia., in**				**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Water Pump	62.44242949	5	0.122525357	4.739682982				$79,500.00	4.74	$376,830.00	$77,472.40	$367,219.19	Centrifugal, horizontal, 4-stage, split case; 4.77-in. Discharge Pipe Dia; SS 304, Double Mech. Seal

Water Separation Tank (air cooled condensing heat exchanger)	4.54E+07	35.23	1.22E+06	150	8137.71	$130,600.00	4.74	$619,044.00	$127,269.13	$603,255.67	Air Cooled, Bare Tube Area - A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam		
Total Cost 3 air coolers and ambient cooled water separation tank						$310,800.00	4.74	$1,473,192.00	$302,873.24	$1,435,619.15			
Component	**Pressure psig**	**Power, kW**	**Power, HP**	**1998 $**	**CEPCI INDEX 1998/2007**	**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**		
Steam turbine	2.13E+03	6.94E+02	930.95	$40,000.00	1.318444166	$52,737.77	4.74	$249,977.01	$51,392.72	$243,601.51	Steam Turbine, 400 psig, 3600 rpm, 5000 HP, ref. DOE/NETL-2002/1169		
Gas turbine (oxygen)		1.46E+04	19561.47	$4,000,000.00	1.318444166	$5,273,776.66	4.74	$24,997,701.38	$5,139,272.27	$24,360,150.56	Gas Turbine, multistage, Carbon Ss, ref. DOE/NETL-2002/1169 Pg. 38		
Component	**2005 cost**	**CEPCI INDEX 2007/2005**				**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**		
Water Supply System	$1,000,000.00	1.1222				$1,122,170.01	1.20	$1,346,604.02	$1,093,549.77	$1,312,259.72	No change from original estimate		
HTSE Piping	$1,250,000.00	1.1222				$1,402,712.52	1.20	$1,683,255.02	$1,366,937.21	$1,640,324.65	No change from original estimate		
Electrical	$2,000,000.00	1.1222				$2,244,340.03	1.20	$2,693,208.03	$2,187,099.53	$2,624,519.44	No change from original estimate		
Misc. Equipment	$2,500,000.00	1.1222				$2,805,425.03	1.20	$3,366,510.04	$2,733,874.41	$3,280,649.30	No change from original estimate		
Component	**Electrolysis Power, kW**	**$(2010)/kW**	**2010 $**			**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**			
Solid Oxide Electrolyzer	2.37E+05	100	$23,726,828.17			$23,753,954.88	1.80	$42,757,118.78	$23,148,125.04	$41,666,625.07	Assume $100/kW in 2010 $ with Installation Factor(F) = 1.8		
						Total Uninstalled Cost (2007 $)		**Total Installed Cost (2007 $)**	**Total Uninstalled Cost (2009 $)**	**Total Installed Cost (2009 $)**			
						$47,400,716.89		**$128,028,318.27**	**$46,151,791.11**	**$124,763,230.60**			
TOTAL COSTS													

Air Sweep, Reactor Outlet Temperature 700°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Q	MBTU/hr	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
HX: Sweep Hi Temp Recup	21% O2, N2/50% O2, N2	5.81E+04	3.06E+04	30	1020.89			$179,600.00	4.74	$851,304.00	$175,019.41	$829,592.02	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Hi Temp Steam/H2 Recup	30% Stm, H2/30% Stm, H2	1.05E+06	5.51E+05	50	11024.50			$1,233,900.00	4.74	$5,848,686.00	$1,202,430.15	$5,699,518.90	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Sweep Low Temp Recup	21% O2, N2/50% O2, N2	5.95E+05	3.14E+05	30	10452.05			$1,181,700.00	4.74	$5,601,258.00	$1,151,561.48	$5,458,401.40	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	1.70E+06	8.96E+05	400	2239.68			$339,300.00	4.74	$1,608,282.00	$330,646.36	$1,567,263.77	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 4 Recuperators								**$2,934,500.00**	**4.74**	**$13,909,530.00**	**$2,859,657.40**	**$13,554,776.09**	
HX: E-100 (Sweep Gas)	Combustion Gas/21% O2m N2	6.84E+03	3.60E+03	30	120.05			$31,700.00	4.74	$150,258.00	$30,891.51	$146,425.76	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/90% Stm, H2	4.25E+04	2.24E+04	50	447.92			$92,100.00	4.74	$436,554.00	$89,751.05	$425,419.96	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2 Combustion								**$123,800.00**	**4.74**	**$586,812.00**	**$120,642.56**	**$571,845.73**	
Steam Gen: Stm Gen	Water, Stm/77%N2, O2, CO2	4.84E+04	2.55E+04	30	850.21			$154,800.00	4.74	$733,752.00	$150,851.92	$715,038.11	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	2.12E+06	1.12E+06	120	9305.65			$1,075,600.00	4.74	$5,098,344.00	$1,048,167.49	$4,968,313.91	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2 Steam Generators								**$1,230,400.00**	**4.74**	**$5,832,096.00**	**$1,199,019.41**	**$5,683,352.02**	
Component		**Natural Gas Mass Heating Value, kJ/kgmole**	**Natural Gas flow rate, kgmole/hr**	**Q kJ/s**		**Q MBTU/hr**		**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Gas Fired Heater: Combustion	Natural Gas	890723	28.45171979	6992.191914	23.8643451			**$1,063,900.00**	**4.74**	**$5,042,886.00**	**$1,036,765.89**	**$4,914,270.33**	Fired Heater, Box; SS 304; 150 psi
	Vol. flow, m3/hr	**Velocity, ft/sec; EngineeringToolBox.com**	**Discharge Pipe Area, ft2**	**Pump Discharge Dia., in**				**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Water Pump	63.47782242	5	0.124557019	4.779817093				$79,500.00	4.74	$376,830.00	$77,472.40	$367,219.19	Centrifugal, horizontal, 4-stage, split case; 4.77-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Water Recycle Pump	31.66573939	5	0.062134932	3.375236575				$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Condenser Pump	2.13	5	0.004180384	0.875476283				$34,800.00	4.74	$164,952.00	$33,912.45	$160,745.00	Centrifugal, horizontal, 4-Stage, Horz, Split Case; 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Total Water Pump (3)								**$143,500.00**	**4.74**	**$680,190.00**	**$139,840.12**	**$662,842.18**	
	Pressure Rise, kPa	**Pressure Rise, psi**	**Power, kW**	**Power, HP**				**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**

H2 Recirculator	400	58.02	44.64935294	59.90		$26,400.00	4.74	$125,136.00	$25,726.68	$121,944.48	Assume Air, Rotary Screw, 125 psi; 60 hp
Air Compressor: K-100	212.9	30.88	3793.395846	5008.68		$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-101	511.5	74.19	3327.516354	4464.16		$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-102	1333	193.34	3326.661821	4463.01		$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-103	3204	464.70	3138.935912	4211.16		$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Total Compressor (1 He, 4 air) Costs						**$4,738,000.00**	**4.74**	**$22,458,120.00**	**$4,617,160.26**	**$21,885,389.63**	
Component	**Heat Flow, kJ/hr**	**Estimated LMTD, F**	**UA, Btu/hr/F**	**U (Kreith, Pg. 463) Btu/hr/ft2/F**	**A=UA/U, ft2**	**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Air Cooler: E-102	1.20E+07	97.12	1.17E+05	25	4694.44	$55,900.00	4.74	$264,966.00	$54,474.31	$258,208.21	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-103	1.21E+07	97.12	1.18E+05	25	4718.73	$56,000.00	4.74	$265,440.00	$54,571.75	$258,670.12	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-104	1.22E+07	97.12	1.20E+05	25	4780.85	$70,500.00	4.74	$334,170.00	$68,701.94	$325,647.20	Air Cooled, Bare Tube Area = A/15.5, ss 304, 450 psi rating (air/air)
Water Separation Tank (air cooled condensing heat exchanger)	4.64E+07	35.23	1.25E+06	150	8314.55	$132,100.00	4.74	$626,154.00	$128,730.87	$610,184.33	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Total Cost 3 air coolers and ambient cooled water separation tank						**$314,500.00**	**4.74**	**$1,490,730.00**	**$306,478.87**	**$1,452,703.86**	
Component	**Pressure psig**	**Power, kW**	**Power, HP**	**1998 $**	**CEPC INDEX 1998/2007**	**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Steam turbine	1.40E+03	6.36E+02	853.18	$40,000.00	1.318444166	**$52,737.77**	**4.74**	**$249,977.01**	**$51,392.72**	**$243,601.51**	Steam Turbine, 400 psig, 3600 rpm, 1000 HP, ref: DOE/NETL-2002/1169
Gas turbine (oxygen)		1.49E+04	19972.47	$4,000,000.00	1.318444166	**$5,273,776.66**	**4.74**	**$24,997,701.38**	**$5,139,272.27**	**$24,360,150.56**	Gas Turbine, multistage, Carbon St, ref. DOE/NETL-2002/1169,Pg. 38
Component	**2005 cost**	**CEPC INDEX 2007/2005**				**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Water Supply System	$1,000,000.00	1.1222				**$1,122,170.01**	**1.20**	**$1,346,604.02**	**$1,093,549.77**	**$1,312,259.72**	No change from original estimate
HTSE Piping	$1,250,000.00	1.1222				**$1,402,712.52**	**1.20**	**$1,683,255.02**	**$1,366,937.21**	**$1,640,324.65**	No change from original estimate
Electrical	$2,000,000.00	1.1222				**$2,244,340.03**	**1.20**	**$2,693,208.03**	**$2,187,099.53**	**$2,624,519.44**	No change from original estimate
Misc. Equipment	$2,500,000.00	1.1222				**$2,805,425.03**	**1.20**	**$3,366,510.04**	**$2,733,874.41**	**$3,280,649.30**	No change from original estimate

Component	Electrolysis Power, kW	$(2010)/kW	2010 $	Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2005 $)	
Solid Oxide Electrolyzer	2.42E+05	100	$24,225,636.58	$24,259,333.57	1.80	$43,656,000.42	$23,694,767.99	$42,542,981.30	Assume $100/kW in 2010 $ with Installation Factor(F) = 1.8

	Total Uninstalled Cost (2007 $)	Total Installed Cost (2007 $)	Total Uninstalled Cost (2009 $)	Total Installed Cost (2009 $)
TOTAL COSTS	$47,703,095.58	$127,988,619.92	$46,486,457.82	$124,729,222.31

Air Sweep, Reactor Outlet Temperature 750°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
HX: Sweep HI Temp Recup	21% O2, N2/50% O2, N2	5.92E+04	3.12E+04	30	1039.47	$182,200.00	4.74	$863,628.00	$177,593.10	$841,601.71	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: HI Temp Steam/H2 Recup	30% Stm, H2/90% Stm, H2	8.68E+05	4.57E+05	50	9142.24	$1,060,300.00	4.74	$5,025,822.00	$1,033,357.71	$4,897,641.54	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Sweep Low Temp Recup	21% O2, N2/50% O2, N2	6.06E+05	3.19E+05	30	10639.61	$1,198,900.00	4.74	$5,682,786.00	$1,168,322.80	$5,537,850.08	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	1.76E+06	9.25E+05	400	2312.50	$348,200.00	4.74	$1,650,468.00	$339,319.38	$1,608,373.84	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 4 Recuperators						**$2,789,600.00**	**4.74**	**$13,222,704.00**	**$2,718,452.99**	**$12,885,467.16**	
HX: E-100 (Sweep Gas)	Combustion Gas/21% O2m N2	6.96E+03	3.67E+03	30	122.24	$32,200.00	4.74	$152,628.00	$31,378.76	$148,735.32	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/90% Stm, H2	3.65E+04	1.92E+04	50	384.20	$81,400.00	4.74	$385,836.00	$79,323.94	$375,995.49	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2 Combustion HXs						**$113,600.00**	**4.74**	**$538,464.00**	**$110,702.70**	**$524,730.81**	
Steam Gen: Stm Gen	Water, Stm/77%N2, O2, CO2	4.25E+04	2.24E+04	30	746.91	$139,400.00	4.74	$660,756.00	$135,844.69	$643,903.83	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	2.13E+06	1.12E+06	120	9369.72	$1,081,600.00	4.74	$5,126,784.00	$1,054,014.47	$4,996,028.56	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2 Steam Generators						**$1,221,000.00**	**4.74**	**$5,787,540.00**	**$1,189,859.15**	**$5,639,932.39**	

Component		Natural Gas Mass Heating Value,	Natural Gas flow rate,	Q	kJ/s	Q	MBTU/hr	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Gas Fired Heater: Combustion	Natural Gas	984723	25.2	6187.278185		21.1		$976,600	4.74	$4,629,084.00	$951,692	$4,511,022	Fired Heater, Box; SS 304; 150 psi

	Vol. flow, m3/hr	Velocity, ft/sec; EngineeringToolBo	Discharge Pipe Area, ft2	Pump Discharge Dia., in	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Pump	64.71289333	5	0.126980491	4.825083209	$83,700.00	4.74	$396,738.00	$81,565.28	$386,619.44	Centrifugal, horizontal, 4-stage, split case; 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Water Recycle Pump	32.24208861	5	0.063265851	3.405814436	$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Condenser Pump	1.91	5	0.003746121	0.829756988	$34,800.00	4.74	$164,952.00	$33,912.45	$160,745.00	Centrifugal, horizontal, 4-Stage, Horz. Split Case 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Total Water Pump (3) Costs					**$147,700.00**	4.74	**$700,098.00**	**$143,933.00**	**$682,242.44**	

	Pressure Rise, kPa	Pressure Rise, psi	Power, kW	Power, HP			Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
H2 Recirculator	400	58.02	45.46244077	60.99			$27,900.00	4.74	$132,246.00	$27,188.43	$128,873.15	Assume Air, Rotary Screw, 125 psi; 65 hp
Air Compressor: K-100	212.9	30.88	3801.308217	5099.79			$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-101	511.5	74.19	3388.045571	4545.36			$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-102	1333	193.34	3387.175493	4544.19			$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-103	3204	464.70	3196.034754	4287.76			$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Total Compressor (1 He, 4 air) Costs:							**$4,789,500.00**	**4.74**	**$22,465,230.00**	**$4,618,622.00**	**$21,892,268.29**	
Component	**Heat Flow, kJ/hr**	**Estimated LMTD, F**	**UA, Btu/hr/F**		**U (Kreith, Pg. 463) Btu/hr/ft2/F**	**A=UA/U, ft2**	**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Air Cooler: E-102	1.22E+07	97.12	1.19E+05		25	4779.83	$566,400.00	4.74	$267,336.00	$54,961.55	$260,517.76	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-103	1.23E+07	97.12	1.20E+05		25	4804.56	$566,600.00	4.74	$268,284.00	$55,156.45	$261,441.58	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-104	1.25E+07	97.12	1.22E+05		25	4867.82	$71,200.00	4.74	$337,488.00	$69,384.09	$328,880.58	Air Cooled, Bare Tube Area = A/15.5, ss 304, 450 psi rating (air/air)
Water Separation Tank (air cooled condensing heat exchanger)	4.72E+07	35.23	1.27E+06		150	8467.52	$133,300.00	4.74	$631,842.00	$129,900.27	$615,727.26	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Total Cost 3 air coolers and ambient cooled water separation tank							**$317,500.00**	**4.74**	**$1,504,950.00**	**$309,402.36**	**$1,466,567.19**	
Component	**Pressure psig**	**Power, kW**	**Power, HP**	**1998 $**	**CEPC INDEX 1998/2007**	**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**	
Steam turbine	1.40E+03	5.70E+02	764.55	$39,000.00	1.318444	**$51,419.32**	**4.74**	**$243,727.59**	**$50,107.90**	**$237,511.47**	Steam Turbine, 400 psig, 3600 rpm, 1000 HP, ref: DOE/NETL-2002/1169	
Gas turbine (oxygen)		1.52E+04	20336.46	$4,000,000.00	1.318444	**$5,278,776.66**	**4.74**	**$24,997,701.38**	**$5,139,272.27**	**$24,360,150.56**	Gas Turbine, multistage, Carbon St, ref: DOE/NETL-2002/1169, Pg. 38	
Component	**2005 cost**	**CEPC INDEX 2007/2005**				**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**	
Water Supply System	$1,000,000.00	1.1222				**$1,122,170.01**	**1.20**	**$1,346,604.02**	**$1,099,549.77**	**$1,312,259.72**	No change from original	
HTSE Piping	$1,250,000.00	1.1222				**$1,402,712.52**	**1.20**	**$1,683,255.02**	**$1,374,437.21**	**$1,640,324.65**	No change from original	

Electrical	$2,000,000.00	1.1222		$2,244,340.03	1.20	$2,693,208.03	$2,187,099.53	$2,624,519.44	No change from original
Misc. Equipment	$2,500,000.00	1.1222		$2,805,425.03	1.20	$3,366,510.04	$2,733,874.41	$3,280,649.30	No change from original
Component	**Electroysis Power, kW**	**$(2010)/kW**	**2010 $**	**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	
Solid Oxide Electrolyzer	246,666	100	$24,666,568	$24,694,768.97	1.80	$44,450,584.15	$24,064,944	$43,316,900	Assume $100/kW in 2010 $
				Total Uninstalled Cost		**Total Installed Cost (2007**	**Total Uninstalled Cost**	**Total Installed Cost (2009**	
TOTAL COSTS				**$47,900,112.55**		**$127,629,660.23**	**$46,678,449.99**	**$124,374,545.18**	

Air Sweep, Reactor Outlet Temperature 800°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kraith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2005 $)	Installed Cost (2009 $)	Comments
HX: Sweep Hi Temp Recup	21% O2, N2/50% O2, N2	6.01E+04	3.17E+04	30	1055.54	$184,500.00	4.74	$874,530.00	$179,754.44	$852,225.66	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Hi Temp Steam/H2 Recup	30% Stm, H2/90% Stm, H2	6.34E+05	3.34E+05	50	6683.17	$822,600.00	4.74	$3,899,124.00	$801,620.10	$3,799,679.27	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Sweep Low Temp Recup	21% O2, N2/50% O2, N2	6.16E+05	3.24E+05	30	10806.54	$1,244,100.00	4.74	$5,754,894.00	$1,183,135.14	$5,608,060.54	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	1.81E+06	9.53E+05	400	2382.13	$356,700.00	4.74	$1,690,758.00	$347,602.59	$1,647,636.27	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 4 Recuperators						**$2,577,900.00**	**4.74**	**$12,219,246.00**	**$2,512,152.26**	**$11,907,601.74**	
HX: E-100 (Sweep Gas)	Combustion Gas/21% O2m N2	7.07E+03	3.72E+03	30	124.13	$32,600.00	4.74	$154,524.00	$31,768.56	$150,382.96	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/90% Stm, H2	3.00E+04	1.58E+04	50	316.42	$69,500.00	4.74	$329,430.00	$67,727.45	$321,028.09	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2 Combustion HXs						**$102,100.00**	**4.74**	**$483,954.00**	**$99,496.00**	**$471,411.05**	
Steam Gen: Stm Gen	Water, Stm/77%N2, O2, CO2	3.63E+04	1.91E+04	30	637.35	$122,600.00	4.74	$581,124.00	$119,473.16	$566,302.79	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	1.78E+06	9.39E+05	120	7828.90	$935,100.00	4.74	$4,432,374.00	$911,250.86	$4,319,329.06	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2 Steam Generators						**$1,057,700.00**	**4.74**	**$5,013,498.00**	**$1,030,724.02**	**$4,885,631.85**	

Component	Natural Gas Mass Heating Value, kJ/kgmole	Natural Gas flow rate, kgmole/hr	Q kJ/s	Q MBTU/hr	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2005 $)	Installed Cost (2009 $)	Comments
Gas Fired Heater: Combustion	884723	21.62803122	5315.226851	18.14086924	**$878,100.00**	**4.74**	**$4,162,194.00**	**$855,704.61**	**$4,056,039.83**	Fired Heater; Box; SS 304; 150 psi

	Vol. flow, m3/hr	Velocity, ft/sec EngineeringToolBox.com	Discharge Pipe Area, ft2	Pump Discharge Dia., in	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2005 $)	Installed Cost (2009 $)	Comments
Water Pump	65.60811327	5	0.128737104	4.858942999	$83,700.00	4.74	$396,738.00	$81,565.28	$386,619.44	Centrifugal, horizontal, 4-stage, split case; 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Water Recycle Pump	32.73991195	5	0.064242686	3.432006897	$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1 Stage 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Condenser Pump	1.66	5	0.003257574	0.772829104	$34,800.00	4.74	$164,952.00	$33,912.45	$160,745.00	Centrifugal, horizontal, 4-Stage, Horiz. Split Case 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal

Total Water Pump (3) Costs

						$147,700.00	4.74	$700,098.00	$148,933.00	$682,242.44		
	Pressure Rise, kPa	Pressure Rise, psi	Power, kW	Power, HP		Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)		Comments
H2 Recirculator	400	58.02	46.16397547	61.93		$27,900.00	4.74	$132,246.00	$27,188.43	$128,873.15		Assume Air, Rotary Screw, 125 psi; 65 hp
Air Compressor: K-100	212.9	30.88	3860.101937	5178.67		$1,299,800.00	4.74	$6,161,052.00	$1,266,649.41	$6,003,918.20		Air, Centifugal, 125 psi; 5500 hp
Air Compressor: K-101	511.5	74.19	3440.447479	4615.66		$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79		Air, Centifugal, 125 psi; 5000 hp
Air Compressor: K-102	1333	193.34	3439.563943	4614.48		$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79		Air, Centifugal, 125 psi; 5000 hp
Air Compressor: K-103	3204	464.70	3245.466887	4354.08		$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79		Air, Centifugal, 125 psi; 5000 hp
Total Compressor (1 He, 4 air) Costs						**$4,861,400.00**	**4.74**	**$23,043,036.00**	**$4,737,413.02**	**$22,455,387.71**		

						$320,100.00	4.74	$1,517,274.00	$311,936.05	$1,478,576.87		
Component	**Heat Flow, kJ/hr**	**Estimated LMTD, F**	**UA, Btu/hr/F**	**U (Kreith, Pg. 463) Btu/hr/ft2/F**	**A=UA/U, ft2**	**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**		**Comments**
Air Cooler: E-102	1.24E+07	97.12	1.21E+05	25	4853.76	$56,900.00	4.74	$269,706.00	$55,448.80	$262,827.32		Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-103	1.25E+07	97.12	1.22E+05	25	4878.87	$57,000.00	4.74	$270,180.00	$55,646.25	$263,289.23		Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-104	1.27E+07	97.12	1.24E+05	25	4943.10	$71,800.00	4.74	$340,332.00	$69,968.79	$331,652.04		Air Cooled, Bare Tube Area = A/15.5, ss 304, 450 psi rating (air/air)
Water Separation Tank (air cooled condensing heat exchanger)	4.79E+07	35.23	1.29E+06	150	8590.06	$134,400.00	4.74	$637,056.00	$130,972.21	$620,808.28		Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam

Total Cost 3 air coolers and ambient cooled water separation tank

Component	**Pressure psig**	**Power, kW**	**Power, HP**	**1998 $**	**CEPCI INDEX 1998/2007**	**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Steam turbine	1.40E+03	5.70E+02	764.55	$39,000.00	1.318444166	**$51,419.32**	**4.74**	**$243,727.59**	**$50,107.90**	**$237,511.47**	Steam Turbine, 400 psig, 3600 rpm, 1000 HP, ref. DOE/NETL-2002/1169
Gas turbine (oxygen)		1.54E+04	20650.19	$4,000,000.00	1.318444166	**$5,273,776.66**	**4.74**	**$24,997,701.38**	**$5,139,272.27**	**$24,360,150.56**	Gas Turbine, multistage, Carbon St, ref. DOE/NETL-2002/1169,Pg. 38

Component	**2005 cost**	**CEPCI INDEX 2007/2005**				**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**

Water Supply System	$1,000,000.00	1.1222			$1,122,170.01	1.20	$1,346,604.02	$1,093,549.77	$1,312,259.72	No change from original estimate
HTSE Piping	$1,250,000.00	1.1222			$1,402,712.52	1.20	$1,683,255.02	$1,366,937.21	$1,640,324.65	No change from original estimate
Electrical	$2,000,000.00	1.1222			$2,244,340.03	1.20	$2,693,208.03	$2,187,099.53	$2,624,519.44	No change from original estimate
Misc. Equipment	$2,500,000.00	1.1222			$2,805,425.03	1.20	$3,366,510.04	$2,733,874.41	$3,280,649.30	No change from original estimate
Component	**Electrolysis Power, kW**	**$(2010)/kW**	**2010 $**		**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2005 $)**	**Installed Cost (2009 $)**	
Solid Oxide Electrolyzer	2.50E+05	100	$25,047,423.83		$25,076,060.37	1.80	$45,136,908.66	$24,436,511.05	$43,985,719.90	Assume $100/kW in 2010 $ with Installation Factor(F) = 1.8
				Total Uninstalled Cost (2007 $)			**Total Installed Cost (2007 $)**	**Total Uninstalled Cost (2005 $)**	**Total Installed Cost (2009 $)**	
TOTAL COSTS				**$47,920,903.94**			**$125,607,214.73**	**$46,698,711.11**	**$123,378,176.52**	

Air Sweep, Reactor Outlet Temperature 850°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
HX: Sweep HI Temp Recup	21% O2, N2/50% O2, N2	0.00E+00	0.00E+00	30	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Larger; SS 304; 900 psi rating
HX: HI Temp Steam/H2 Recup	30% Stm, H2/90% Stm, H2	0.00E+00	0.00E+00	50	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Larger; SS 304; 900 psi rating
HX: Sweep Low Temp Recup	21% O2, N2/50% O2, N2	6.18E+05	3.26E+05	30	10850.56	$1,218,100.00	4.74	$5,773,794.00	$1,187,033.12	$5,626,536.98	Shell/Tube, Floating Head, Larger; SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	1.86E+06	9.82E+05	400	2453.94	$365,400.00	4.74	$1,731,996.00	$355,080.70	$1,687,822.52	Shell/Tube, Floating Head, Larger; SS 304; 900 psi rating
Total Cost 4						**$1,583,500.00**	**4.74**	**$7,505,790.00**	**$1,543,113.82**	**$7,314,359.50**	
HX: E-100 (Sweep Gas)	Combustion Gas/21% O2m N2	0.00E+00	0.00E+00	30	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Larger; SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/90% Stm, H2	0.00E+00	0.00E+00	50	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Larger; SS 304; 900 psi rating
Total Cost 2						**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	
Steam Gen: SG	Helium/water, Stm	2.42E+06	1.27E+06	120	10618.58	$1,196,900.00	4.74	$5,673,306.00	$1,166,373.81	$5,528,611.86	Shell/Tube, Floating Head, Larger; SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	1.04E+05	5.50E+04	120	458.58	$93,900.00	4.74	$445,086.00	$91,505.14	$433,734.36	Shell/Tube, Floating Head, Larger; SS 304; 900 psi rating
Total Cost 2 Steam						**$1,290,800.00**	**4.74**	**$6,118,392.00**	**$1,257,878.95**	**$5,962,346.22**	

Component	Fluids	Natural Gas Mass Heating Value, kJ/kgmole	Natural Gas flow rate, kgmole/hr	Q	MBTU/hr	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2008 $)	Installed Cost (2008 $)	Comments
Gas Fired Heater: Combustion	Natural Gas	884723	0	0	0	**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	Fired Heater, Base; SS 304; 150 psi

Component	Vol. flow, m3/hr	Velocity, ft/sec; EngineeringToolBox	Discharge Pipe Area, ft2	Pump Discharge Dia., in	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2008 $)	Installed Cost (2008 $)	Comments
Water Pump	66.44175347	5	0.130372962	4.889112964	$83,700.00	4.74	$396,738.00	$81,565.28	$386,619.44	Centrifugal, horizontal, 4-stage, split case; 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Water Recycle Pump	33.01837374	5	0.064789088	3.446571067	$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Condenser Pump	0.00	5	0	0	$0.00	4.74	$0.00	$0.00	$0.00	Centrifugal, horizontal, 4-Stage, Horz. Split Case 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Total Water Pump (3) Costs					**$112,900.00**	4.74	**$535,146.00**	**$110,020.56**	**$521,497.43**	

	Pressure Rise, kPa	Pressure Rise, psi	Power, kW	Power, HP	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
H2 Recirculator	400	58.02	23.1316086	31.03	$18,400.00	4.74	$87,216.00	$17,930.72	$84,991.61	Assume Air, Rotary Screw, 125 psi; 35 hp
Air Compressor: K-100	212.9	30.88	3860.101937	5178.67	$1,299,800.00	4.74	$6,161,052.00	$1,266,649.41	$6,003,918.20	Air, Centrifugal, 125 psi; 5500 hp
Air Compressor: K-101	511.5	74.19	3440.447479	4615.66	$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-102	1333	193.34	3439.563943	4614.48	$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-103	3204	464.70	3169.242575	4251.82	$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Total Compressor (1 He, 4 air) Costs					**$4,851,900.00**	**4.74**	**$22,998,006.00**	**$4,728,155.31**	**$22,411,456.17**	

Component	Heat Flow, kJ/hr	Estimated LMTD, F	UA, Btu/hr/F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Air Cooler: E-102	1.24E+07	97.12	1.21E+05	25	4853.76	$56,900.00	4.74	$269,706.00	$55,448.80	$262,827.32	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-103	1.25E+07	97.12	1.22E+05	25	4878.87	$57,000.00	4.74	$270,180.00	$55,546.25	$263,289.23	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-104	1.27E+07	97.12	1.24E+05	25	4943.10	$71,800.00	4.74	$340,332.00	$69,968.79	$331,652.04	Air Cooled, Bare Tube Area = A/15.5, ss 304, 450 psi rating (air/air)
Water Separation Tank (air cooled condensing heat exchanger)	4.80E+07	35.23	1.29E+06	150	8609.01	$134,500.00	4.74	$637,530.00	$131,069.66	$621,270.19	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Total Cost 3 air coolers and ambient cooled water separation tank						**$320,200.00**	**4.74**	**$1,517,748.00**	**$312,038.50**	**$1,479,038.78**	

Component	Pressure psig	Power, kW	Power, HP	1998 $	CEPC INDEX 1998/2007	Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Steam turbine	1.40E+03	0.00E+00	0.00	$0.00	1.318444166	**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	Steam Turbine, 400 psig, 3600 rpm, 1000 HP, ref. DOE/NETL-2002/1169
Gas turbine (oxygen)		1.56E+04	20864.26	$4,100,000.00	1.318444166	**$5,405,621.08**	**4.74**	**$25,622,643.51**	**$5,267,754.08**	**$24,969,154.33**	Gas Turbine, multistage, Carbon St, ref. DOE/NETL-2002/1169,Pg. 38

Component	2005 cost	CEPCI INDEX 2007/2005			Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Supply System	$1,000,000.00	1.1222			$1,122,170.01	1.20	$1,346,604.02	$1,098,548.77	$1,312,259.72	No change from original estimate
HTSE Piping	$1,250,000.00	1.1222			$1,402,712.52	1.20	$1,683,255.02	$1,366,937.21	$1,640,324.65	No change from original estimate
Electrical	$2,000,000.00	1.1222			$2,244,340.03	1.20	$2,693,208.03	$2,187,099.53	$2,624,519.44	No change from original estimate
Misc. Equipment	$2,500,000.00	1.1222			$2,805,425.03	1.20	$3,366,510.04	$2,733,874.41	$3,280,649.30	No change from original estimate
Component	**Electrolysis Power, kW**	**$(2010)/kW**	**2010 $**		**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	
Solid Oxide Electrolyzer	2.53E+05	100	$25,259,598.08		$25,288,477.19	1.80	$45,519,256.95	$24,643,510.32	$44,358,318.58	Assume $100/kW in 2010 $ with Installation Factor(F) = 1.8
					Total Uninstalled Cost (2007 $)		**Total Installed Cost (2007 $)**	**Total Uninstalled Cost (2009 $)**	**Total Installed Cost (2009 $)**	
TOTAL COSTS					**$46,428,045.86**		**$118,906,561.97**	**$45,243,927.45**	**$115,879,934.11**	

Air Sweep, Reactor Outlet Temperature 900°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Q	MBTU/hr	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
HX: Sweep Hi Temp Recup	21% O2, N2/50% O2, N2	0.00E+00	0.00E+00	30	0.00			$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Hi Temp Steam/H2 Recup	30% Stm, H2/30% Stm, H2	0.00E+00	0.00E+00	50	0.00			$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Sweep Low Temp Recup	21% O2, N2/50% O2, N2	6.15E+05	3.24E+05	30	10791.32			$1,212,700.00	4.74	$5,748,198.00	$1,181,770.84	$5,601,593.79	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	1.85E+06	9.96E+05	400	2490.15			$369,700.00	4.74	$1,752,378.00	$360,271.03	$1,707,684.69	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 4 Recuperators								**$1,582,400.00**	**4.74**	**$7,500,576.00**	**$1,542,041.87**	**$7,309,278.48**	
HX: E-100 (Sweep Gas)	Combustion Gas/21% O2in N2	0.00E+00	0.00E+00	30	0.00			$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/90% Stm, H2	0.00E+00	0.00E+00	50	0.00			$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2 Combustion HXs								**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	
Steam Gen: SG	Helium/water, Stm	1.88E+06	9.88E+05	120	8233.75			$974,100.00	4.74	$4,617,234.00	$949,256.19	$4,499,474.32	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	5.74E+04	3.02E+04	120	252.00			$57,800.00	4.74	$279,972.00	$56,325.85	$266,984.51	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2 Steam								**$1,031,900.00**	**4.74**	**$4,891,206.00**	**$1,005,582.03**	**$4,766,458.84**	

Component	Natural Gas Mass Heating Value, kJ/kgmole	Natural Gas flow rate, kgmole/hr	Q	kJ/s	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Gas Fired Heater: Combustion	884723	0	0	0	**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	Fired Heater, Box; SS 304; 150 psi

Component	Vol. flow, m3/hr	Velocity, ft/sec; EngineeringToolBox.com	Discharge Pipe Area, ft2	Pump Discharge Dia., in	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Pump	67.1955022	5	0.131851899	4.916765555	$83,700.00	4.74	$396,738.00	$81,565.28	$386,619.44	Centrifugal, horizontal, 4-stage, split case; 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Water Recycle Pump	33.50640616	5	0.065746711	3.471948885	$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1-Stage; 4-in, Discharge Pipe Dia; SS 304, Double Mech. Seal

Condenser Pump	0.00	5	0	0		$0.00	4.74	$0.00	$0.00	$0.00	Centrifugal, horizontal, 4-Stage, Horz. Split Case 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Total Water Pump (3) Costs						**$112,900.00**	4.74	**$535,146.00**	**$110,020.56**	**$521,497.43**	

	Pressure Rise, kPa	Pressure Rise, psi	Power, kW	Power, HP		Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
H2 Recirculator	400	58.02	23.47354513	31.43		$18,400.00	4.74	$87,216.00	$17,930.72	$84,991.61	Assume Air, Rotary Screw, 125 psi; 35 hp
Air Compressor: K-100	212.9	30.88	3860.101937	5178.57		$1,299,800.00	4.74	$6,161,052.00	$1,266,649.41	$6,003,918.20	Air, Centrifugal, 125 psi; 5500 hp
Air Compressor: K-101	511.5	74.19	3440.447479	4615.36		$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-102	1333	193.34	3439.563943	4614.18		$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-103	3204	464.70	3169.242575	4251.32		$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centrifugal, 125 psi; 5000 hp
Total Compressor (1 H2, 4 air) Costs						**$4,851,900.00**	**4.74**	**$22,998,006.00**	**$4,728,155.31**	**$22,411,456.17**	

Component	Heat Flow, kJ/hr	Estimated LMTD, F	UA, Btu/hr/F	U (Kraith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Air Cooler: E-102	1.24E+07	97.12	1.21E+05	25	4853.76	$56,900.00	4.74	$269,706.00	$55,448.80	$262,827.32	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-103	1.25E+07	97.12	1.22E+05	25	4878.87	$57,000.00	4.74	$270,180.00	$55,546.25	$263,289.23	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-104	1.27E+07	97.12	1.24E+05	25	4943.10	$71,800.00	4.74	$340,332.00	$69,968.79	$331,652.04	Air Cooled, Bare Tube Area = A/15.5, ss 304, 450 psi rating (air/air)
Water Separation Tank (air cooled condensing heat exchanger)	4.87E+07	35.23	1.31E+06	150	8735.57	$135,500.00	4.74	$642,270.00	$132,044.16	$625,889.30	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Total Cost 3 air coolers and ambient cooled water separation tank						**$321,200.00**	**4.74**	**$1,522,488.00**	**$313,007.99**	**$1,483,657.89**	

Component	Pressure psig	Power, kW	Power, HP	1998 $	CEPCI INDEX 1998/2007	Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments

Steam turbine	1.40E+03	0.00E+00	0.00	$0.00	1.319444166	$0.00	4.74	$0.00	$0.00	$0.00	Steam Turbine, 400 psig, 3600 rpm, 1000 HP, ref. DOE/NETL-2002/1169
Gas turbine (oxygen)		1.57E+04	21046.50	$4,150,000.00	1.319444166	$5,471,543.29	4.74	$25,935,115.18	$5,331,994.98	$25,279,656.21	Gas Turbine, multistage, Carbon St, ref. DOE/NETL-2002/1169,Pg. 38

Component	2005 cost	CEPC INDEX 2007/2005			Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Supply System	$1,000,000.00	1.1222			$1,122,170.01	1.20	$1,346,604.02	$1,093,549.77	$1,312,259.72	No change from original estimate
HTSE Piping	$1,250,000.00	1.1222			$1,402,712.52	1.20	$1,683,255.02	$1,366,937.21	$1,640,324.65	No change from original estimate
Electrical	$2,000,000.00	1.1222			$2,244,340.03	1.20	$2,693,208.03	$2,187,099.53	$2,624,519.44	No change from original estimate
Misc. Equipment	$2,500,000.00	1.1222			$2,805,425.03	1.20	$3,366,510.04	$2,733,874.41	$3,280,649.30	No change from original estimate

Component	Electrolysis Power, kW	$(2010)/kW	2010 $		Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	
Solid Oxide Electrolyzer	2.56E+05	100	$25,632,950.73		$25,662,256.69	1.80	$46,192,062.05	$25,007,756.81	$45,013,962.25	Assume $100/kW in 2010 $ with Installation Factor(F) = 1.8

	Total Uninstalled Cost (2007 $)	Total Installed Cost (2007 $)	Total Uninstalled Cost (2009 $)	Total Installed Cost (2009 $)
TOTAL COSTS	$46,608,747.57	$118,664,176.33	$45,420,020.47	$115,637,720.37

Air Sweep, Reactor Outlet Temperature 950°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2			Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
HX: Sweep Hi Temp Recup	21% O2, N2/50% O2, N2	0.00E+00	0.00E+00	30	0.00			$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Hi Temp Steam/H2 Recup	30% Stm, H2/90% Stm, H2	0.00E+00	0.00E+00	50	0.00			$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Sweep Low Temp Recup	21% O2, N2/50% O2, N2	6.12E+05	3.22E+05	30	10741.14			$1,208,100.00	4.74	$5,726,394.00	$1,177,288.16	$5,580,345.89	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	1.92E+06	1.01E+06	400	2521.89			$373,600.00	4.74	$1,770,864.00	$364,071.56	$1,725,699.22	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 4 Recuperators								**$1,581,700.00**	**4.74**	**$7,497,258.00**	**$1,541,359.73**	**$7,305,045.10**	
HX: E-100 (Sweep Gas)	Combustion Gas/21% O2m N2	0.00E+00	0.00E+00	30	0.00			$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/90% Stm, H2	0.00E+00	0.00E+00	50	0.00			$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2								**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	
Steam Gen: SG	Helium/water, Stm	1.64E+06	8.63E+05	120	7194.58			$873,200.00	4.74	$4,138,968.00	$850,929.58	$4,033,406.20	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	4.21E+04	2.21E+04	120	184.58			$44,900.00	4.74	$212,826.00	$43,754.85	$207,398.01	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2 Steam Generators								**$918,100.00**	**4.74**	**$4,351,794.00**	**$894,684.43**	**$4,240,804.20**	

Component	Natural Gas Mass Heating Value, kJ/kgmole	Natural Gas flow rate, kgmole/hr	Q	MBTU/hr	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Gas Fired Heater: Combustion	884723	0	0	0	**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	Fired Heater, Box SS 304; 150 psi

	Vol. Flow, m3/hr	Velocity, ft/sec; EngineeringToolBox.com	Discharge Pipe Area, ft2	Pump Discharge Dia., in			Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
				Q	kJ/s							
Water Pump	68.05195692	5	0.133533446	4.948000 19			$83,700.00	4.74	$396,738.00	$81,565.28	$386,619.44	Centrifugal, horizontal, 4-stage, split case; 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Water Recycle Pump	33.93344627	5	0.066584655	3.494003878			$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1 Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Condenser Pump	0.00	5	0	0			$0.00	4.74	$0.00	$0.00	$0.00	Centrifugal, horizontal, 4-Stage, Horz. Split Case 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Total Water Pump (3) Costs							**$112,900.00**	4.74	**$535,146.00**	**$110,020.56**	**$521,497.43**	

	Pressure Rise, kPa	Pressure Rise, psi	Power, kW	Power, HP	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
H2 Recirculator	400	58.02	23.77252034	31.89	$18,400.00	4.74	$87,216.00	$17,930.72	$84,991.61	Assume Air, Rotary Screw, 125 psi; 35 hp
Air Compressor: K-100	212.9	30.88	3880.101937	5178.67	$1,299,800.00	4.74	$6,161,052.00	$1,266,649.41	$6,003,918.20	Air, Centifugal, 125 psi; 5500 hp
Air Compressor: K-101	511.5	74.19	3440.447479	4615.66	$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centifugal, 125 psi; 5000 hp
Air Compressor: K-102	1333	193.34	3439.563943	4614.48	$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centifugal, 125 psi; 5000 hp
Air Compressor: K-103	3204	464.70	3169.243575	4251.82	$1,177,900.00	4.74	$5,583,246.00	$1,147,858.39	$5,440,848.79	Air, Centifugal, 125 psi; 5000 hp
Total Compressor (1 He, 4 air) Costs					**$4,851,900.00**	**4.74**	**$22,998,006.00**	**$4,729,155.31**	**$22,411,456.17**	

Component	Heat Flow, kJ/hr	Estimated LMTD, F	UA, Btu/hr/F	U (Kraith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Air Cooler: E-102	1.24E+07	97.12	1.21E+05	25	4853.76	$56,900.00	4.74	$269,706.00	$55,448.80	$262,827.32	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-103	1.25E+07	97.12	1.22E+05	25	4878.87	$57,000.00	4.74	$270,180.00	$55,546.25	$263,289.23	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-104	1.27E+07	97.12	1.24E+05	25	4943.10	$71,800.00	4.74	$340,332.00	$69,968.79	$331,652.04	Air Cooled, Bare Tube Area = A/15.5, ss 304, 450 psi rating (air/air)
Water Separation Tank (air cooled condensing heat exchanger)	4.93E+07	35.23	1.33E+06	150	8846.90	$136,500.00	4.74	$647,010.00	$133,018.65	$630,508.41	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Total Cost 3 air coolers and ambient cooled water separation tank					**$322,200.00**	**4.74**	**$1,527,228.00**	**$313,982.49**	**$1,488,277.00**	

Component	Pressure psig	Power, kW	Power, HP	1998 $	CEPC INDEX 1998/2007	Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Steam turbine	1.40E+03	0.00E+00	0.00	$0.00	1.318444166	$0.00	4.74	$0.00	$0.00	$0.00	Steam Turbine, 400 psig, 3600 rpm, 1000 HP, ref. DOE/NETL-2002/1169
Gas turbine (oxygen)		1.58E+04	21205.85	$4,160,000.00	1.318444166	$5,484,727.73	4.74	$25,997,609.44	$5,344,843.16	$25,334,556.59	Gas Turbine, multistage, Carbon St, ref. DOE/NETL-2002/1169,Pg. 38

Component	2005 cost	CEPCI INDEX 2007/2005			Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Supply System	$1,000,000.00	1.1222			$1,122,170.01	1.20	$1,346,604.02	$1,093,549.77	$1,312,259.72	No change from original estimate
HTSE Piping	$1,250,000.00	1.1222			$1,402,712.52	1.20	$1,683,255.02	$1,366,937.21	$1,640,324.65	No change from original estimate
Electrical	$2,000,000.00	1.1222			$2,244,340.03	1.20	$2,693,208.03	$2,187,099.53	$2,624,519.44	No change from original estimate
Misc. Equipment	$2,500,000.00	1.1222			$2,805,425.03	1.20	$3,366,510.04	$2,733,874.41	$3,280,649.30	No change from original estimate
Component	**Electrolysis Power, kW**	**$(2010)/kW**	**2010 $**		**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	
Solid Oxide Electrolyzer	2.60E+05	100	$25,959,643.27		$25,959,322.74	1.80	$46,780,780.93	$25,326,481.24	$45,587,666.23	Assume $100/kW in 2010 $ with Installation Factor(F) = 1.8
					Total Uninstalled Cost (2007 $)		**Total Installed Cost (2007 $)**	**Total Uninstalled Cost (2009 $)**	**Total Installed Cost (2009 $)**	
TOTAL COSTS					**$46,835,498.06**		**$118,777,399.47**	**$45,640,987.83**	**$115,748,055.82**	

Steam Sweep, Reactor Outlet Temperature 650°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kraith, Fig. 463) Btu/hr/ft2/F	A=UA/U, ft2	Q MBTU/hr	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
HX: Sweep HI Temp Recup	100% steam/50% steam,O2	2.59E+05	2.37E+05	50	2730.84		$398,400.00	4.74	$1,888,416.00	$388,239.06	$1,840,253.13	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: HI Temp Steam/H2 Recup	30% Stm, H2/90% Stm, H2	1.16E+06	6.09E+05	50	12181.85		$1,337,800.00	4.74	$6,341,172.00	$1,303,680.24	$6,179,444.35	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Sweep Low Temp Recup	100% steam/50% O2, N2	9.29E+05	4.89E+05	50	9783.88		$1,120,100.00	4.74	$5,309,274.00	$1,091,532.55	$5,173,864.27	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	1.60E+06	8.44E+05	400	2110.11		$323,300.00	4.74	$1,532,442.00	$315,054.43	$1,493,358.02	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 4							**$3,179,600.00**	**4.74**	**$15,071,304.00**	**$3,098,506.28**	**$14,686,919.77**	
HX: E-100 (Sweep Gas)	Combustion Gas/100% steam	4.98E+03	2.62E+03	50	52.48		$28,100.00	4.74	$133,194.00	$27,383.33	$129,796.97	Shell/Tube, Floating Head, Small; SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/90% Stm, H2	4.71E+04	2.48E+04	50	495.70		$100,000.00	4.74	$474,000.00	$97,449.56	$461,910.93	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2 Combustion HXs							**$128,100.00**	**4.74**	**$607,194.00**	**$124,832.89**	**$591,707.89**	
Steam Gen: Stm Gen	Water, Stm/77%N2, O2, CO2	5.12E+04	2.69E+04	30	898.14		$161,900.00	4.74	$767,406.00	$157,770.84	$747,833.79	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Steam Gen: SG1	Helium/steam	7.18E+05	3.78E+05	50	7567.25		$909,700.00	4.74	$4,311,978.00	$886,498.67	$4,202,003.68	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	2.08E+06	1.10E+06	120	9133.78		$1,059,500.00	4.74	$5,022,030.00	$1,032,478.11	$4,893,946.25	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 3 Steam							**$2,131,100.00**	**4.74**	**$10,101,414.00**	**$2,076,747.62**	**$9,843,783.72**	
Component		**Natural Gas Mass Heating Value, kJ/kgmole**	**Natural Gas flow rate, kgmole/hr**	**Q kJ/s**			**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Gas Fired Heater: Combustion	Natural Gas	8841723	29.80	7324.671969	24.99910543		**$1,099,100.00**	**4.74**	**$5,219,734.00**	**$1,071,068.14**	**$5,076,862.98**	Fired Heater, Box, SS 304; 150 psi
	Vol. flow, m3/hr	**Velocity, ft/sec; EngineeringToolBox.com**	**Discharge Pipe Area, ft2**	**Pump Discharge Dia., in**			**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Water Pump	60.75536767	5	0.019214983	4.675216487			$83,700.00	4.74	$396,738.00	$81,565.28	$386,619.44	Centrifugal, horizontal, 4-stage, split case; 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Water Recycle Pump	30.29573434	5	0.059446889	3.301415153			$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Condenser Pump	2.20	5	0.004313331	0.889288496			$41,700.00	4.74	$197,658.00	$40,636.47	$192,616.86	Centrifugal, horizontal, 8-Stage, Horizontal Split Case 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Sweep Water Pump	0.03	5	6.63258E-05	0.110276153			$6,400.00	4.74	$30,336.00	$6,236.77	$29,562.30	Centrifugal, horizontal, ANSI 1-Stage, 1.0-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Sweep Water Recycle Pump	30.33	5	0.059512146	3.303323226			$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Total Water							**$190,200.00**	4.74	**$901,548.00**	**$185,349.07**	**$878,554.58**	

	Pressure Rise, kPa	Pressure Rise, psi	Power, kW	Power, HP		Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2005 $)	Installed Cost (2005 $)	Comments
H2 Recirculator	400	58.02	42.71769782	57.31		$26,400.00	4.74	$125,136.00	$25,726.68	$121,944.48	Assume Air, Rotary Screw, 125 psi; 60 hp
Air Compressor: K-101	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-102	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-103	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-104	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Total Compressor (1 He, 4 air) Costs						**$26,400.00**	**4.74**	**$125,136.00**	**$25,726.68**	**$121,944.48**	
Component	**Heat Flow, kJ/hr**	**Estimated LMTD, F**	**UA, Btu/hr/F**	**U (Krath, Pg. 463) Btu/hr/ft2/F**	**A=UA/U, ft2**	**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2005 $)**	**Installed Cost (2005 $)**	**Comments**
Air Cooler: E-102	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-103	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-104	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 450 psi rating (air/air)
Water Separation Tank (air cooled condensing heat exchanger)	4.43E+07	35.23	1.19E+06	150	7949.28	$129,000.00	4.74	$611,460.00	$125,709.94	$595,865.09	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Water/Oxygen Separation Tank (air-cooled condensing HX)	7.00E+07	62.47	1.06E+06	150	7080.69	$121,400.00	4.74	$575,436.00	$118,303.77	$560,759.86	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Total Cost 3 air						**$250,400.00**	**4.74**	**$1,186,896.00**	**$244,013.70**	**$1,156,624.96**	
Component	**Pressure psig**	**Power, kW**	**Power, HP**	**1998 $**	**CEPC INDEX 1998/2007**	**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2005 $)**	**Installed Cost (2005 $)**	**Comments**
Steam turbine	1.41E+03	6.55E+02	879.85	$39,000.00	1.318444166	**$51,419.32**	**4.74**	**$243,727.59**	**$50,107.90**	**$237,511.47**	Steam Turbine, 400 psig, 3600 rpm, 1000 HP, ref. DOE/NETL-2002/1169
Gas turbine (oxygen)		0.00E+00	0.00	$0.00	1.318444166	**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	Gas Turbine, multistage, Carbon St, ref. DOE/NETL-2002/1169,Pg. 38
Component	**2005 cost**	**CEPC INDEX 2007/2005**				**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2005 $)**	**Installed Cost (2005 $)**	**Comments**
Water Supply	$1,000,000.00	1.1222				**$1,122,170.01**	**1.20**	**$1,346,604.02**	**$1,093,549.77**	**$1,312,259.72**	No change from original estimate
HTSE Piping	$1,250,000.00	1.1222				**$1,402,712.52**	**1.20**	**$1,683,255.02**	**$1,366,937.21**	**$1,640,324.65**	No change from original estimate
Electrical	$2,000,000.00	1.1222				**$2,244,340.03**	**1.20**	**$2,693,208.03**	**$2,187,099.53**	**$2,624,519.44**	No change from original estimate
Misc. Equipment	$2,500,000.00	1.1222				**$2,805,425.03**	**1.20**	**$3,366,510.04**	**$2,733,874.41**	**$3,280,649.30**	No change from original estimate
Component	**Electrolysis Power, kW**	**$(2010)/kW**	**2010 $**			**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2005 $)**	**Installed Cost (2005 $)**	


Assume $100/kW in 2010 $ with Installation Factor(F) = 1.8
$40,716,286.96
$22,620,159.42
$41,781,908.53
1.80
$23,212,171.41
$23,185,663.41
100
2.32E+05
Solid Oxide Electrolyzer
Total Installed Cost (2009 $) $82,167,949.91
Total Uninstalled Cost (2009 $) $36,877,972.62
Total Installed Cost (2007 $) $84,318,439.22
Total Uninstalled Cost (2007 $) $37,843,188.31
TOTAL COSTS

Steam Sweep, Reactor Outlet Temperature 700°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
HX: Sweep HI Temp Recup	100% steam/50% steam,O2	2.24E+05	1.18E+05	50	2363.50	$354,400.00	4.74	$1,679,856.00	$345,361.25	$1,637,012.32	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: HI Temp Steam/H2 Recup	30% Stm, H2/90% Stm, H2	1.02E+06	5.38E+05	50	10769.16	$1,210,700.00	4.74	$5,738,718.00	$1,179,821.85	$5,592,355.57	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Sweep Low Temp Recup	100% steam/50% O2, N2	9.60E+05	5.05E+05	50	10109.54	$1,150,200.00	4.74	$5,451,948.00	$1,120,864.86	$5,312,899.46	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	1.66E+06	8.75E+05	400	2187.93	$333,000.00	4.74	$1,578,420.00	$324,507.04	$1,538,163.38	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 4 Recuperators						**$3,048,300.00**	**4.74**	**$14,448,942.00**	**$2,970,555.01**	**$14,080,430.73**	
HX: E-100 (Sweep Gas)	Combustion Gas/100% steam	5.09E+03	2.68E+03	50	53.58	$28,400.00	4.74	$134,616.00	$27,675.68	$131,182.70	Shell/Tube, Floating Head, Small; SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/90% Stm, H2	4.15E+04	2.19E+04	50	437.57	$90,400.00	4.74	$428,496.00	$88,094.40	$417,567.48	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2 Combustion HXs						**$118,800.00**	**4.74**	**$563,112.00**	**$115,770.08**	**$548,750.18**	
Steam Gen: Stm Gen	Water, Stm/77%N2, O2, CO2	4.57E+04	2.41E+04	30	802.91	$147,800.00	4.74	$700,572.00	$144,030.45	$682,704.35	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Steam Gen: SG1	Helium/steam	9.80E+05	5.16E+05	50	10327.47	$1,170,300.00	4.74	$5,547,222.00	$1,140,452.23	$5,405,743.56	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	2.07E+06	1.09E+06	120	9092.51	$1,055,600.00	4.74	$5,003,544.00	$1,028,677.58	$4,875,931.72	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 3 Steam Generators						**$2,373,700.00**	**4.74**	**$11,251,338.00**	**$2,313,160.26**	**$10,964,379.63**	

Component		Natural Gas Mass Heating Value, kJ/kgmole	Natural Gas flow rate, kgmole/hr	Q	kJ/s	Q	MBTU/hr	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Gas Fired Heater: Combustion	Natural Gas	889,723	26.85	6600.205127	22.5265001			**$1,021,800.00**	**4.74**	**$4,843,332.00**	**$995,739.63**	**$4,719,805.83**	Fired Heater, Box, SS 304; 150 psi

Component	Vol. flow, m3/hr	Velocity, ft/sec; EngineeringToolBox.com	Discharge Pipe Area, ft2	Pump Discharge Dia., in	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Pump	61.985215529	5	0.121628206	4.722298714	$83,700.00	4.74	$396,738.00	$81,565.28	$386,619.44	Centrifugal, horizontal, 4-stage, split case; 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Water Recycle Pump	30.93248933	5	0.060696138	3.335929273	$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.09	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Condenser Pump	2.01	5	0.003938373	0.84975699	$41,700.00	4.74	$197,658.00	$40,636.47	$192,616.86	Centrifugal, horizontal, 8-Stage, Horizonal Split Case 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Sweep Water Pump	0.03	5	6.67091E-05	0.110593307	$6,400.00	4.74	$30,336.00	$6,236.77	$29,562.30	Centrifugal, horizontal, ANSI 1-Stage, 1.0-in. Discharge Pipe Dia; SS 304, Double Mech. Seal

Sweep Water Recycle Pump	30.97	5	0.060765809	3.337943321			$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1-Stage: 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Total Water Pump [5]							**$190,200.00**	4.74	**$901,548.00**	**$185,349.07**	**$878,554.58**	
	Pressure Rise, kPa	**Pressure Rise, psi**	**Power, kW**	**Power, HP**			**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
H2 Recirculator	400	58.02	43.61533273	58.51			$26,400.00	4.74	$125,136.00	$25,726.68	$121,944.48	Assume Air, Roltary Screw, 125 psi; 60 hp
Air Compressor K-100	0	0.00	0	0.00				4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor K-101	0	0.00	0	0.00				4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor K-102	0	0.00	0	0.00				4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor K-103	0	0.00	0	0.00				4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Total Compressor (1 He, 4 air) Costs							**$26,400.00**	**4.74**	**$125,136.00**	**$25,726.68**	**$121,944.48**	
Component	**Heat Flow, kJ/hr**	**Estimated LMTD, F**	**UA, Btu/hr/F**	**U (Kreith, Pg. 463) Btu/hr/ft2/F**	**A=UA/U, ft2**	**CEPCI INDEX 1998/2007**	**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Air Cooler: E-102	0.00E+00	97.12	0.00E+00	25	0.00			4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-103	0.00E+00	97.12	0.00E+00	25	0.00			4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-104	0.00E+00	97.12	0.00E+00	25	0.00			4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 450 psi rating (air/air)
Water Separation Tank (air cooled condensing heat exchanger)	4.53E+07	35.23	1.22E+06	150	8121.98		$130,500.00	4.74	$618,570.00	$127,171.68	$602,793.76	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Water/Oxygen Separation Tank (air-cooled condensing HX)	7.14E+07	62.47	1.08E+06	150	7227.64		$122,700.00	4.74	$581,598.00	$119,570.61	$566,764.70	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Total Cost 3 air coolers and 2 ambient cooled water separation tank							**$253,200.00**	**4.74**	**$1,200,168.00**	**$246,742.29**	**$1,169,558.46**	
Component	**Pressure psig**	**Power, kW**	**Power, HP**	**1998 $**	**CEPC INDEX 1998/2007**		**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Steam turbine	1.41E+03	5.99E+02	803.36	$39,000.00	1.318444166		**$51,419.32**	**4.74**	**$243,727.59**	**$50,107.90**	**$237,511.47**	Steam Turbine, 400 psig, 3600 rpm, 1000 HP, ref: DOE/NETL-2002/1169
Gas turbine (oxygen)		0.00E+00	0.00	$0.00	1.318444166		**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	Gas Turbine, multistage, Carbon St, ref. DOE/NETL-2002/1169,Pg. 38

Component	2005 cost	CEPCI INDEX 2007/2005		Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Supply System	$1,000,000.00	1.1222		$1,122,170.01	1.20	$1,346,604.02	$1,093,549.77	$1,312,259.72	No change from original estimate
HTSE Piping	$1,250,000.00	1.1222		$1,402,712.52	1.20	$1,683,255.02	$1,366,937.21	$1,640,324.65	No change from original estimate
Electrical	$2,000,000.00	1.1222		$2,244,340.03	1.20	$2,693,208.03	$2,187,099.53	$2,624,519.44	No change from original estimate
Misc. Equipment	$2,500,000.00	1.1222		$2,805,425.03	1.20	$3,366,510.04	$2,733,874.41	$3,280,649.30	No change from original estimate
Component	**Electrolysis Power, kW**	**$/(2010)/kW**	**2010 $**	**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	
Solid Oxide Electrolyzer	2.37E+05	100	$23,672,979.28	$23,700,044.43	1.80	$42,660,079.97	$23,095,593.54	$41,572,061.18	Assume $100/kW in 2010 $ with Installation Factor(F) = 1.8
				Total Uninstalled Cost (2007 $)		Total Installed Cost (2007 $)	Total Uninstalled Cost (2009 $)	Total Installed Cost (2009 $)	
TOTAL COSTS				$38,358,511.34		$85,326,960.66	$37,380,201.38	$83,150,749.64	

Appendix A

Steam Sweep, Reactor Outlet Temperature 750°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2			Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
						Q	MBTU/hr						
HX: Sweep Hi Temp Recup	100% steam/50% steam,O2	1.73E+05	91,052	50	1,821			$287,000	4.74	$1,360,380.00	$279,680	$1,325,684	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Hi Temp Steam/H2 Recup	30% Stm, H2/90% Stm, H2	8.45E+05	446,492	50	8,930			$1,040,300	4.74	$4,931,022.00	$1,013,768	$4,805,259	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Sweep Low Temp Recup	100% steam/50% O2, N2	9.87E+05	519,957	50	10,399			$1,176,800	4.74	$5,578,032.00	$1,146,786	$5,435,768	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	1.72E+06	903,508	400	2,259			$341,700	4.74	$1,619,658.00	$332,985	$1,579,350	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 4 Recuperators								**$2,845,800.00**	**4.74**	**$13,489,092.00**	**$2,773,219.64**	**$13,145,061.10**	
HX: E-100 (Sweep Gas)	Combustion Gas/100% steam	5.18E+03	2,728	50	55			$28,600	4.74	$135,564.00	$27,871	$132,107	Shell/Tube, Floating Head, Small; SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/90% Stm, H2	3.56E+04	18,764	50	375			$79,800	4.74	$378,252.00	$77,765	$368,605	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2 Combustion HXs								**$108,400.00**	**4.74**	**$513,816.00**	**$105,635.33**	**$500,711.44**	
Steam Gen: Stm Gen	Water, Stm/77%N2, O2, CO2	4.00E+04	21,044	30	701			$132,500	4.74	$628,050.00	$129,121	$612,032	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Steam Gen: SG1	Helium/steam	9.73E+05	512,349	50	10247			$1,162,900	4.74	$5,512,146.00	$1,133,241	$5,371,562	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	2.09E+06	1,098,647	120	9155			$1,061,500	4.74	$5,031,510.00	$1,034,427	$4,903,184	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 3 Steam Generators								**$2,356,900.00**	**4.74**	**$11,171,706.00**	**$2,296,788.73**	**$10,886,778.59**	

Component	Natural Gas Mass Heating Value, kJ/kgmole	Natural Gas flow rate, kgmole/hr	Q	kJ/s	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Gas Fired Heater: Combustion	884723	23.64	5809.127745	19.82655299	**4.74**	**$4,429,530.00**	**$910,666.16**	**$4,316,557.59**	Fired Heater, Box, SS 304; 150 psi

	Vol. flow, m3/hr	Velocity, ft/sec; EngineeringToolBox.com	Discharge Pipe Area, ft2	Pump Discharge Dia., in	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Pump	63.11	5	0.123837773	4.76	4.74	$396,738.00	$81,565	$386,619	Centrifugal, horizontal, 4-stage, split case; 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Water Recycle Pump	31.49	5	0.061797347	3.37	4.74	$138,408.00	$28,455	$134,878	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Condenser Pump	1.79	5	0.003511332	0.80	4.74	$197,658.00	$40,636	$192,617	Centrifugal, horizontal, 8-Stage, Horizontal Split Case 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal

Sweep Water Pump	0.06	5	0.000113939	0.14			$6,400.00	4.74	$30,336.00	$6,237	$29,562	Centrifugal, horizontal, ANSI 1-Stage, 1.0-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Sweep Water Recycle Pump	31.53	5	0.061864389	3.37			$29,200.00	4.74	$138,408.00	$28,455	$134,878	Centrifugal, horizontal, API-610, 1-Stage 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Total Water Pump (5) Costs							**$190,200.00**	4.74	**$901,548.00**	**$185,349.07**	**$878,554.58**	

	Pressure Rise, kPa	Pressure Rise, psi	Power, kW	Power, HP	U (Kraith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
H2 Recirculator	400	58.02	44.41	59.58			$26,400	4.74	$125,136.00	$25,727	$121,944	Assume Air, Rotary Screw, 125 psi; 60 hp
Air Compressor: K-100	0	0.00	0	0.00				4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-101	0	0.00	0	0.00				4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-102	0	0.00	0	0.00				4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-103	0	0.00	0	0.00				4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Total Compressor (1 He, 4 air) Costs							**$26,400.00**	**4.74**	**$125,136.00**	**$25,726.68**	**$121,944.48**	

Component	Heat Flow, kJ/hr	Estimated LMTD, F	UA, Btu/hr/F	U (Kraith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Air Cooler: E-102	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-103	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-104	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 450 psi rating (air/air)
Water Separation Tank (air cooled condensing heat exchanger)	46,107,682	35.2	1,240,661	150	8271	$131,700	4.74	$624,258.00	$128,341	$608,337	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Water/Oxygen Separation Tank (air-cooled condensing HX)	72,714,475	62.5	1,103,552	150	7357	$123,800	4.74	$586,812.00	$120,643	$571,846	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Total Cost 3 air coolers and 2 ambient cooled water separation tank						**$255,500.00**	**4.74**	**$1,211,070.00**	**$248,983.63**	**$1,180,182.41**	

Component	Pressure psig	Power, kW	Power, HP	1998 $	CEPC INDEX 1998/2007	Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Steam turbine	1.41E+03	5.34E+02	716.25	$38,000.00	1.318444166	$50,100.88	4.74	$237,478.15	$48,823.09	$231,421.43	Steam Turbine, 400 psig, 3600 rpm, 1000 HP, ref. DOE/NETL-2002/1169
Gas turbine (oxygen)		0.00E+00	0.00	$0.00	1.318444166	$0.00	4.74	$0.00	$0.00	$0.00	Gas Turbine, multistage, Carbon St, ref. DOE/NETL-2002/1169,Pg. 38

Component	2005 cost	CEPC INDEX 2007/2005			Uninstalled Cost (2007 $)	Installed Cost	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Supply System	$1,000,000.00	1.1222			$1,122,170.01	1.20	$1,346,604.02	$1,093,549.77	$1,312,259.72	No change from original estimate
HTSE Piping	$1,250,000.00	1.1222			$1,402,712.52	1.20	$1,683,255.02	$1,366,937.21	$1,640,324.65	No change from original estimate
Electrical	$2,000,000.00	1.1222			$2,244,340.03	1.20	$2,693,208.03	$2,187,099.53	$2,624,519.44	No change from original estimate
Misc. Equipment	$2,500,000.00	1.1222			$2,805,425.03	1.20	$3,366,510.04	$2,733,874.41	$3,280,649.30	No change from original estimate

Component	Electrolysis Power, kW	$(2010)/kW	2010 $		Uninstalled Cost (2007 $)	Installed Cost	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	
Solid Oxide Electrolyzer	2.41E+05	100	$24,102,477.63		$24,130,033.81	1.80	$43,434,060.86	$23,514,612.32	$42,326,302.17	Assume $100/kW in 2010 $ with
					Total Uninstalled Cost (2007 $)		Total Installed Cost (2007 $)	Total Uninstalled Cost (2009 $)	Total Installed Cost (2009 $)	
TOTAL COSTS					$38,472,482.28		$84,603,014.13	$37,491,365.56	$82,445,266.91	

Steam Sweep, Reactor Outlet Temperature 800°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2			Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
HX: Sweep Hi Temp Recup	100% steam/50% steam, O2	8.85E+04	4.68E+04	50	936.20			$167,400.00	4.74	$793,476.00	$163,130.57	$773,298.89	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
HX: Hi Temp Steam/H2 Recup	30% Stm, H2/30% Stm, H2	6.20E+05	3.27E+05	50	6530.49			$807,400.00	4.74	$3,827,076.00	$786,807.77	$3,729,468.81	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
HX: Sweep Low Temp Recup	100% steam/50% O2, N2	1.01E+06	5.33E+05	50	10658.68			$1,200,600.00	4.74	$5,690,844.00	$1,169,979.44	$5,545,702.57	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	1.77E+06	9.31E+05	400	2327.70			$350,100.00	4.74	$1,659,474.00	$341,170.92	$1,617,150.15	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Total Cost 4 Recuperators								**$2,525,500.00**	**4.74**	**$11,970,870.00**	**$2,461,088.69**	**$11,665,560.41**	
HX: E-100 (Sweep Gas)	Combustion Gas/100% steam	5.26E+03	2.77E+03	50	55.42			$28,800.00	4.74	$136,512.00	$28,065.47	$133,030.35	Shell/Tube, Floating Head, Small: SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/50% Stm, H2	2.93E+04	1.54E+04	50	308.85			$68,200.00	4.74	$323,268.00	$66,460.60	$315,023.25	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Total Cost 2 Combustion HXs								**$97,000.00**	**4.74**	**$459,780.00**	**$94,526.08**	**$448,053.60**	
Steam Gen: Stm Gen	Water, Stm/77%N2, O2, CO2	3.36E+04	1.78E+04	30	594.22			$115,800.00	4.74	$548,892.00	$112,846.59	$534,892.85	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Steam Gen: SG1	Helium/steam	9.71E+05	5.11E+05	50	10229.88			$1,161,300.00	4.74	$5,504,562.00	$1,131,681.77	$5,364,171.57	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	2.12E+06	1.12E+06	120	9320.05			$1,076,900.00	4.74	$5,104,506.00	$1,049,434.34	$4,974,318.75	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Total Cost 3 Steam Generators								**$2,354,000.00**	**4.74**	**$11,157,960.00**	**$2,293,962.70**	**$10,873,383.17**	
Component		**Natural Gas Mass Heating Value, kJ/kgmole**	**Natural Gas flow rate, kgmole/hr**			**Q**	**MBTU/hr**	**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Gas Fired Heater: Combustion	Natural Gas	8841723	20.17			4955.833574	16.91425999	**$836,100.00**	**4.74**	**$3,963,114.00**	**$814,775.79**	**$3,862,037.24**	Fired Heater, Box, SS 304; 150 psi
	Vol. flow, m3/hr	**Velocity, ft/sec; EngineeringToolBox .com**	**Discharge Pipe Area, ft2**	**Pump Discharge Dia., in**				**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Water Pump	64.14306938	5	0.125862375	4.803792806				$83,700.00	4.74	$396,738.00	$81,565.28	$386,619.44	Centrifugal, horizontal, 4-stage, split case; 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Water Recycle Pump	31.99192847	5	0.062774983	3.392576618				$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Condenser Pump	1.55	5	0.003033925	0.745828115				$41,700.00	4.74	$197,658.00	$40,636.47	$192,616.86	Centrifugal, horizontal, 6-Stage, Horizontal Split Case 2-In. Discharge Pipe Dia; SS 304, Double Mech. Seal
Sweep Water Pump	0.06	5	0.000108243	0.140875515				$6,400.00	4.74	$30,336.00	$6,236.77	$29,562.30	Centrifugal, horizontal, ANSI 1-Stage, 1.0-In. Discharge Pipe Dia; SS 304, Double Mech. Seal
Sweep Water Recycle Pump	32.03	5	0.062984482	3.394462774				$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Total Water Pump (5) Costs								**$190,200.00**	**4.74**	**$901,548.00**	**$185,349.07**	**$878,554.58**	

	Pressure Rise, kPa	Pressure Rise, psi	Power, kW	Power, HP		Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
H2 Recirculator	400	58.02	45.10929633	60.52		$27,900.00	4.74	$132,246.00	$27,188.43	$128,873.15	Assume Air, Rotary Screw, 125 psi; 65 hp
Air Compressor: K-100	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-101	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-102	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-103	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Total Compressor (1 H2, 4 air) Costs						**$27,900.00**	**4.74**	**$132,246.00**	**$27,188.43**	**$128,873.15**	
Component	**Heat Flow, kJ/hr**	**Estimated LMTD, F**	**UA, Btu/hr/F**	**U (Kreith, Pg. 463) Btu/hr/ft2/F**	**A=UA/U, ft2**	**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Air Cooler: E-102	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-103	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-104	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 450 psi rating (air/air)
Water Separation Tank (air cooled condensing heat exchanger)	4.68E+07	35.23	1.26E+06	150	8394.06	$132,700.00	4.74	$628,998.00	$129,315.57	$612,955.80	Air Cooled, Bare Tube Area – A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Water/Oxygen Separation Tank (air-cooled condensing HX)	7.39E+07	62.47	1.12E+06	150	7473.19	$124,900.00	4.74	$592,026.00	$121,714.50	$576,926.75	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Total Cost 3 air coolers and 2 ambient cooled water separation tank						**$257,600.00**	**4.74**	**$1,221,024.00**	**$251,030.07**	**$1,189,882.54**	
Component	**Pressure psig**	**Power, kW**	**Power, HP**	**1998 $**	**CEPC INDEX 1998/2007**	**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Steam turbine	1.41E+03	4.61E+02	618.87	$36,000.00	1.318444166	**$47,463.99**	**4.74**	**$224,979.31**	**$46,259.45**	**$219,241.36**	Steam Turbine, 400 psig, 3600 rpm, 1000 HP, ref. DOE/NETL-2002/1169
Gas turbine (oxygen)		0.00E+00	0.00	$0.00	1.318444166	**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	Gas Turbine, multistage, Carbon St, ref. DOE/NETL-2002/1169, Pg. 38
Component	**2005 cost**	**CEPC INDEX 2007/2005**				**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**
Water Supply System	$1,000,000.00	1.1222				**$1,122,170.01**	**1.20**	**$1,346,604.02**	**$1,093,549.77**	**$1,312,258.72**	No change from original estimate
HTSE Piping	$1,250,000.00	1.1222				**$1,402,712.52**	**1.20**	**$1,683,255.02**	**$1,366,937.21**	**$1,640,324.65**	No change from original estimate
Electrical	$2,000,000.00	1.1222				**$2,244,340.03**	**1.20**	**$2,693,208.03**	**$2,187,099.53**	**$2,624,519.44**	No change from original estimate
Misc. Equipment	$2,500,000.00	1.1222				**$2,805,425.03**	**1.20**	**$3,366,510.04**	**$2,733,874.41**	**$3,280,649.30**	No change from original estimate
Component	**Electrolysis Power, kW**	**$/(2010)/kW**	**2010 $**			**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	
Solid Oxide Electrolyzer	2.45E+05	100	$24,483,779.75			**$24,511,771.87**	**1.80**	**$44,121,189.37**	**$23,886,614.39**	**$42,995,905.90**	Assume $100/kW in 2010 $ with installation Factor(F) = 1.8
						Total Uninstalled Cost (2007 $)		**Total Installed Cost (2007 $)**	**Total Uninstalled Cost (2009 $)**	**Total Installed Cost (2009 $)**	
TOTAL COSTS						**$38,422,183.45**		**$83,242,287.79**	**$37,442,249.58**	**$81,119,245.05**	

Steam Sweep, Reactor Outlet Temperature 850°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
HX: Sweep Hi Temp Recup	100% steam/50% steam,O2	0.00E+00	0.00E+00	50	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Hi Temp Steam/H2 Recup	30% Stm, H2/30% Stm, H2	0.00E+00	0.00E+00	50	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Sweep Low Temp Recup	100% steam/50% O2, N2	1.05E+06	5.52E+05	50	11044.45	$1,235,700.00	4.74	$5,857,218.00	$1,204,184.24	$5,707,833.30	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	2.54E+06	1.34E+06	400	3347.76	$469,500.00	4.74	$2,227,326.00	$457,915.49	$2,170,519.44	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 4 Recuperators						**$1,705,600.00**	**4.74**	**$8,084,544.00**	**$1,662,099.73**	**$7,878,352.74**	
HX: E-100 (Sweep Gas)	Combustion Gas/100% steam	0.00E+00	0.00E+00	50	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Small; SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/30% Stm, H2	0.00E+00	0.00E+00	50	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 2 Combustion HXs						**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	
Steam Gen: Stm Gen	Water, Stm/77%N2, O2,	0.00E+00	0.00E+00	30	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Steam Gen: SG1	Helium/steam	9.76E+05	5.14E+05	50	10280.41	$1,166,000.00	4.74	$5,526,840.00	$1,136,261.90	$5,385,881.39	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	2.38E+06	1.25E+06	120	10442.19	$1,180,800.00	4.74	$5,596,992.00	$1,150,684.43	$5,454,244.20	Shell/Tube, Floating Head, Large; SS 304; 900 psi rating
Total Cost 3 Steam Generators						**$2,346,800.00**	**4.74**	**$11,123,832.00**	**$2,286,946.33**	**$10,840,125.59**	

Component		Natural Gas Mass Heating Value, kJ/kgmole	Natural Gas flow rate, kgmole/hr	Q	kJ/s	Q	MBTU/hr	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Gas Fired Heater: Combustion	Natural Gas	884723	-	0		0		**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	Fired Heater, Box, SS 304; 150 psi

	Vol. flow, m3/hr	Velocity, ft/sec; EngineeringToolBox.com	Discharge Pipe Area, ft2	Pump Discharge Dia., in	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Pump	65.37060477	5	0.128271062	4.849541161	$83,700.00	4.74	$396,738.00	$81,565.28	$386,619.44	Centrifugal, horizontal, 4-stage, split case; 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Water Recycle Pump	32.59639062	5	0.063961067	3.424476223	$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API 610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Condenser Pump	0.00	5	0	0	$0.00	4.74	$0.00	$0.00	$0.00	Centrifugal, horizontal, 8-Stage, Horizontal Split Case 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Sweep Water Pump	0.04	5	6.96488E-05	0.113003786	$6,400.00	4.74	$30,336.00	$6,236.77	$29,562.30	Centrifugal, horizontal, ANSI 1-Stage, 1.0-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Sweep Water Recycle Pump	32.42	5	0.063622031	3.415388181	$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API 610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Total Water Pump [$] Costs					**$148,500.00**	4.74	**$703,890.00**	**$144,712.60**	**$685,597.72**	

	Pressure Rise, kPa	Pressure Rise, psi	Power, kW	Power, HP		Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
H2 Recirculator	400	58.02	22.83594063	30.64		$18,400.00	4.74	$87,216.00	$17,930.72	$84,991.61	Assume Air, Rotary Screw, 125 psi; 35 hp
Air Compressor: K-100	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-101	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-102	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-103	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Total Compressor (1 He, 4 air) Costs						**$18,400.00**	**4.74**	**$87,216.00**	**$17,930.72**	**$84,991.61**	

Component	Heat Flow, kJ/hr	Estimated LMTD, F	UA, Btu/hr/F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Air Cooler: E-102	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-103	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-104	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 450 psi rating (air/air)
Water Separation Tank (air cooled condensing heat exchanger)	3.80E+07	35.23	1.02E+06	150	6824.50	$119,000.00	4.74	$564,060.00	$115,964.98	$549,674.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Water/Oxygen Separation Tank (air-cooled condensing HX)	7.35E+07	62.47	1.11E+06	150	7433.33	$124,500.00	4.74	$590,130.00	$121,324.70	$575,079.10	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Total Cost 3 air coolers and 2 ambient cooled water separation tank						**$249,500.00**	**4.74**	**$1,154,190.00**	**$237,289.68**	**$1,124,753.10**	

Component	Pressure psig	Power, kW	Power, HP	1998 $	CEPCI INDEX 1998/2007	Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Steam turbine	1.41E+03	0.00E+00	0.00	$36,000.00	1.318444166	**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	Steam Turbine, 400 psig, 3600 rpm, 1000 HP, ref. DOE/NETL-2002/1169
Gas turbine (oxygen)		0.00E+00	0.00	$0.00	1.318444166	**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	Gas Turbine, multistage, Carbon St, ref. DOE/NETL-2002/1169,Pg. 38

Component	2005 cost	CEPCI INDEX 2007/2005				Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Supply System	$1,000,000.00	1.1222				**$1,122,170.01**	**1.20**	**$1,346,604.02**	**$1,093,549.77**	**$1,312,259.72**	No change from original estimate
HTSE Piping	$1,250,000.00	1.1222				**$1,402,712.52**	**1.20**	**$1,683,255.02**	**$1,366,937.21**	**$1,640,324.65**	No change from original estimate
Electrical	$2,000,000.00	1.1222				**$2,244,340.03**	**1.20**	**$2,693,208.03**	**$2,187,099.53**	**$2,624,519.44**	No change from original estimate
Misc. Equipment	$2,500,000.00	1.1222				**$2,805,425.03**	**1.20**	**$3,366,510.04**	**$2,733,874.41**	**$3,280,649.30**	No change from original estimate

Component	Electrolysis Power, kW	$(2010)/kW	2010 $			Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	
Solid Oxide Electrolyzer	2.49E+05	100	$24,945,502.55			**$24,974,022.56**	**1.80**	**$44,953,240.61**	**$24,537,075.66**	**$43,806,736.19**	Assume $100/kW in 2010 $ with Installation Factor(F) = 1.8

						Total Uninstalled Cost (2007 $)		Total Installed Cost (2007 $)	Total Uninstalled Cost (2009 $)	Total Installed Cost (2009 $)	
TOTAL COSTS						**$37,011,470.15**		**$75,196,489.72**	**$36,067,515.64**	**$73,278,650.05**	

Steam Sweep, Reactor Outlet Temperature 900°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
HX: Sweep HI Temp Recup	100% steam/50% steam,O2	0.00E+00	0.00E+00	50	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
HX: HI Temp Steam/H2 Recup	30% Stm, H2/90% Stm, H2	0.00E+00	0.00E+00	50	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
HX: Sweep Low Temp Recup	100% steam/50% O2, N2	1.06E+06	5.57E+05	50	11149.39	$1,245,200.00	4.74	$5,902,248.00	$1,213,441.95	$5,751,714.84	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	2.58E+06	1.36E+06	400	3394.32	$475,200.00	4.74	$2,252,448.00	$463,080.32	$2,195,000.72	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Total Cost 4 Recuperators						**$1,720,400.00**	**4.74**	**$8,154,696.00**	**$1,676,522.27**	**$7,946,715.55**	
HX: E-100 (Sweep Gas)	Combustion Gas/100% steam	0.00E+00	0.00E+00	50	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Small: SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/90% Stm, H2	0.00E+00	0.00E+00	50	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Total Cost 2 Combustion HXs						**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	
Steam Gen: Stm Gen	Water, Stm/77%N2, O2, CO2	0.00E+00	0.00E+00	30	0.00	$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Steam Gen: SG1	Helium/steam	5.88E+05	3.10E+05	50	6195.42	$773,600.00	4.74	$3,666,864.00	$753,869.81	$3,573,342.92	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	1.82E+06	9.58E+05	120	7979.21	$949,600.00	4.74	$4,501,104.00	$925,381.04	$4,386,306.14	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Total Cost 3 Steam Generators						**$1,723,200.00**	**4.74**	**$8,167,968.00**	**$1,679,250.86**	**$7,959,649.06**	

Component	Natural Gas Mass Heating Value, kJ/kgmole	Natural Gas flow rate, kgmole/hr	Q	kJ/s	Q	MBTU/hr	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Gas Fired Heater: Combustion	884723	-	0	0	0		**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	Fired Heater, Box, SS 304; 150 psi

	Vol. flow, m3/hr	Velocity, ft/sec; EngineeringToolBox.com	Discharge Pipe Area, ft2	Pump Discharge Dia., in	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Pump	66.14938201	5	0.129799188	4.878942566	$83,700.00	4.74	$396,738.00	$81,565.28	$386,619.44	Centrifugal, horizontal, 4-stage, split case; 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Water Recycle Pump	33.05333355	5	0.064857686	3.448395197	$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Condenser Pump	0.00	5	0	0	$0.00	4.74	$0.00	$0.00	$0.00	Centrifugal, horizontal, 8-Stage, Horizontal Split Case 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Sweep Water Pump	0.04	5	6.96488E-05	0.113003786	$6,400.00	4.74	$30,336.00	$6,236.77	$29,562.30	Centrifugal, horizontal, ANSI 1-Stage, 1.0-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Sweep Water Recycle Pump	32.42	5	0.063621051	3.415361862	$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1-Stage; 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal

Total Water Pump (*) Costs						$148,500.00	4.74	$703,890.00	$144,712.60	$685,587.72			
	Pressure Rise, kPa	**Pressure Rise, psi**	**Power, kW**	**Power, HP**		**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**		
H2 Recirculator	400	58.02	23.15591648	31.07		$18,400.00	4.74	$87,216.00	$17,930.72	$84,991.61	Assume Air, Rotary Screw, 125 psi: 35 hp		
Air Compressor: K-100	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centfugal, 125 psi: 5000 hp		
Air Compressor: K-101	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centfugal, 125 psi: 5000 hp		
Air Compressor: K-102	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centfugal, 125 psi: 5000 hp		
Air Compressor: K-103	0	0.00	0	0.00			4.74	$0.00	$0.00	$0.00	Air, Centfugal, 125 psi: 5000 hp		
Total Compressor (1 He, 4 air) Costs						**$18,400.00**	**4.74**	**$87,216.00**	**$17,930.72**	**$84,991.61**			
Component	**Heat Flow, kJ/hr**	**Estimated LMTD, F**	**UA, Btu/hr/F**	**U (Kreith, Pg. 463) Btu/hr/ft2/F**	**A=UA/U, ft2**	**Uninstalled Cost at matche.com (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**		
Air Cooler: E-102	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)		
Air Cooler: E-103	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 150 psi rating (air/air)		
Air Cooler: E-104	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area = A/15.5, ss 304, 450 psi rating (air/air)		
Water Separation Tank (air cooled condensing heat exchanger)	3.86E+07	35.23	1.04E+06	150	6920.37	$119,900.00	4.74	$568,326.00	$116,842.03	$553,831.20	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam		
Water/Oxygen Separation Tank (air-cooled condensing HX)	7.36E+07	62.47	1.12E+06	150	7449.78	$124,700.00	4.74	$591,078.00	$121,519.60	$576,002.92	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam		
Total Cost 3 air coolers and 2 ambient cooled water separation tank						**$244,600.00**	**4.74**	**$1,159,404.00**	**$238,361.63**	**$1,129,834.12**			
Component	**Pressure psig**	**Power, kW**	**Power, HP**	**1998 $**	**CEPC INDEX 1998/2007**	**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**		
Steam turbine	1.41E+03	0.00E+00	0.00	$36,000.00	1.319444166	$0.00	4.74	$0.00	$0.00	$0.00	Steam Turbine, 400 psig, 3600 rpm, 1000 HP, ref: DOE/NETL-2002/1169		
Gas turbine (oxygen)		0.00E+00	0.00	$0.00	1.319444166	$0.00	4.74	$0.00	$0.00	$0.00	Gas Turbine, multistage, Carbon Si, ref: DOE/NETL-2002/1169,Pg. 3E		
Component	**2005 cost**	**CEPC INDEX 2007/2005**				**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**	**Comments**		
Water Supply System	$1,000,000.00	1.1222				$1,122,170.01	1.20	$1,346,604.02	$1,093,549.77	$1,312,259.72	No change from original estimate		
HTSE Piping	$1,250,000.00	1.1222				$1,402,712.52	1.20	$1,683,255.02	$1,366,937.21	$1,640,324.65	No change from original estimate		
Electrical	$2,000,000.00	1.1222				$2,244,340.03	1.20	$2,693,208.03	$2,187,099.53	$2,624,519.44	No change from original estimate		
Misc. Equipment	$2,500,000.00	1.1222				$2,805,425.03	1.20	$3,366,510.04	$2,733,874.41	$3,280,649.30	No change from original estimate		
Component	**Electrolysis Power, kW**	**$/(2010)/kW**	**2010 $**			**Uninstalled Cost (2007 $)**	**Installed Cost Factor**	**Installed Cost (2007 $)**	**Uninstalled Cost (2009 $)**	**Installed Cost (2009 $)**			
Solid Oxide Electrolyzer	2.53E+05	100	$25,295,130.46			$25,324,050.20	1.80	$45,583,290.36	$24,678,176.06	$44,420,716.91	Assume $100/kW in 2010 $ with installation Factor(F) = 1.8		
						Total Uninstalled Cost (2007 $)		**Total Installed Cost (2007 $)**	**Total Uninstalled Cost (2009 $)**	**Total Installed Cost (2009 $)**			
TOTAL COSTS						**$36,753,797.79**		**$72,946,041.46**	**$35,816,415.05**	**$71,085,598.08**			

Steam Sweep, Reactor Outlet Temperature 950°C

Component	Fluids	UA, kJ/C-h	UA, Btu/hr-F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Q MBTU/hr	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
HX: Sweep HI Temp Recup	100% steam/50% steam,O2	0.00E+00	0.00E+00	50	0.00		$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
HX: HI Temp Steam/H2 Recup	30% Stm, H2/50% Stm, H2	0.00E+00	0.00E+00	50	0.00		$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
HX: Sweep Low Temp Recup	100% steam/50% O2, N2	1.07E+06	5.62E+05	50	11246.76		$1,254,000.00	4.74	$5,943,960.00	$1,222,017.51	$5,792,363.00	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
HX: Low Temp Steam/H2 Recup	30% Stm, H2/water	2.61E+06	1.37E+06	400	3437.47		$480,100.00	4.74	$2,275,674.00	$467,855.35	$2,217,634.35	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Total Cost 4 Recuperators							**$1,734,100.00**	**4.74**	**$8,219,634.00**	**$1,689,872.86**	**$8,009,997.35**	
HX: E-100 (Sweep Gas)	Combustion Gas/100% steam	0.00E+00	0.00E+00	50	0.00		$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Small: SS 304; 900 psi rating
HX: E-101 (Steam/H2)	Combustion Gas/90% Stm, H2	0.00E+00	0.00E+00	50	0.00		$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Total Cost 2 Combustion HXs							**$0.00**	**4.74**	**$0.00**	**$0.00**	**$0.00**	
Steam Gen: Stm Gen	Water, Stm/77%N2, O2,	0.00E+00	0.00E+00	30	0.00		$0.00	4.74	$0.00	$0.00	$0.00	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Steam Gen: SG1	Helium/steam	2.22E+05	2.22E+05	50	4431.94		$589,800.00	4.74	$2,795,652.00	$574,757.52	$2,724,350.64	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Steam Gen: SG2	Helium/water, Stm	1.58E+06	8.32E+05	120	6932.75		$847,400.00	4.74	$4,016,676.00	$825,787.59	$3,914,233.18	Shell/Tube, Floating Head, Large: SS 304; 900 psi rating
Total Cost 3 Steam Generators							**$1,437,200.00**	**4.74**	**$6,812,328.00**	**$1,400,545.11**	**$6,638,583.81**	

Component	Natural Gas Mass Heating Value, kJ/kgmole	Natural Gas flow rate, kgmole/hr	Q kJ/s	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Gas Fired Heater: Combustion	Natural Gas	884723	- 0	$0.00	4.74	$0.00	$0.00	$0.00	Fired Heater, Box, SS 304; 150 psi

	Vol. flow, m3/hr	Velocity, ft/sec; EngineeringToolBox.com	Discharge Pipe Area, ft2	Pump Discharge Dia., in	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Pump	67.40201717	5	0.132257126	4.924315218	$83,700.00	4.74	$396,738.00	$81,565.28	$386,619.44	Centrifugal, horizontal, 4-stage, split case: 5-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Water Recycle Pump	33.47013214	5	0.065675534	3.470069011	$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1-Stage: 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Condenser Pump	0.00	5	0	0	$0.00	4.74	$0.00	$0.00	$0.00	Centrifugal, horizontal, 8-Stage, Horizonal Split Case 2-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Sweep Water Pump	0.04	5	6.96488E-05	0.113003786	$6,400.00	4.74	$30,336.00	$6,236.77	$29,562.30	Centrifugal, horizontal, ANSI 1-Stage, 1.0-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Sweep Water Recycle Pump	32.42	5	0.063620156	3.415337856	$29,200.00	4.74	$138,408.00	$28,455.27	$134,877.99	Centrifugal, horizontal, API-610, 1-Stage: 4-in. Discharge Pipe Dia; SS 304, Double Mech. Seal
Total Water Pump (5) Costs					**$148,500.00**	4.74	**$703,890.00**	**$144,712.60**	**$685,937.72**	

	Pressure Rise, kPa	Pressure Rise, psi	Power, kW	Power, HP	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
H2 Recirculator	400	58.02	23,448.80	31.46	$18,400.00	4.74	$87,216.00	$17,930.72	$84,991.61	Assume Air, Rotary Screw, 125 psi; 35 hp
Air Compressor: K-100	0	0.00	0	0.00		4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-101	0	0.00	0	0.00		4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-102	0	0.00	0	0.00		4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Air Compressor: K-103	0	0.00	0	0.00		4.74	$0.00	$0.00	$0.00	Air, Centrifugal, 125 psi; 5000 hp
Total Compressor (1 He, 4 air) Costs					**$18,400.00**	**4.74**	**$87,216.00**	**$17,930.72**	**$84,991.61**	

Component	Heat Flow, kJ/hr	Estimated LMTD, F	UA, Btu/hr/F	U (Kreith, Pg. 463) Btu/hr/ft2/F	A=UA/U, ft2	Uninstalled Cost at matche.com (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Air Cooler: E-102	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area - A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-103	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area - A/15.5, ss 304, 150 psi rating (air/air)
Air Cooler: E-104	0.00E+00	97.12	0.00E+00	25	0.00		4.74	$0.00	$0.00	$0.00	Air Cooled, Bare Tube Area - A/15.5, ss 304, 450 psi rating (air/air)
Water Separation Tank (air cooled condensing heat exchanger)	3.91E+07	35.23	1.05E+06	150	7007.67	$120,700.00	4.74	$572,118.00	$117,621.62	$557,526.49	Air Cooled, Bare Tube Area = A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Water/Oxygen Separation Tank (air-cooled condensing HX)	7.38E+07	62.47	1.12E+06	150	7464.95	$124,800.00	4.74	$591,552.00	$121,617.05	$576,464.83	Air Cooled, Bare Tube Area - A/15.5, ss 304, 900 psi rating (condensing steam/air) assume high press steam is higher U compared to low press steam
Total Cost 3 air coolers and 2 ambient cooled water separation tank						**$245,500.00**	**4.74**	**$1,163,670.00**	**$239,238.68**	**$1,133,991.32**	

Component	Pressure psig	Power, kW	Power, HP	1998 $	CEPC INDEX 1998/2007	Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Steam turbine	1.41E+03	0.00E+00	0.00	$36,000.00	1.318444166	$0.00	4.74	$0.00	$0.00	$0.00	Steam Turbine, 400 psig, 3600 rpm, 1000 HP, ref. DOE/NETL-2002/1169
Gas turbine (oxygen)		0.00E+00	0.00	$0.00	1.318444166	$0.00	4.74	$0.00	$0.00	$0.00	Gas Turbine, multistage, Carbon St., ref. DOE/NETL-2002/1169,Pg. 38

Component	2005 cost	CEPC INDEX 2007/2005	Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	Comments
Water Supply System	$1,000,000.00	1.1222	$1,122,170.01	1.20	$1,346,604.02	$1,093,549.77	$1,312,259.72	No change from original estimate
HTSE Piping	$1,250,000.00	1.1222	$1,402,712.52	1.20	$1,683,255.02	$1,366,937.21	$1,640,324.65	No change from original estimate
Electrical	$2,000,000.00	1.1222	$2,244,340.03	1.20	$2,693,208.03	$2,187,099.53	$2,624,519.44	No change from original estimate
Misc. Equipment	$2,500,000.00	1.1222	$2,805,425.03	1.20	$3,366,510.04	$2,733,874.41	$3,280,649.30	No change from original estimate

Component	Electrolysis Power, kW	2010 $	Uninstalled Cost (2007 $)	Installed Cost Factor	Installed Cost (2007 $)	Uninstalled Cost (2009 $)	Installed Cost (2009 $)	
Solid Oxide Electrolyzer	2.56E+05	100	$25,643,325.73	1.80	$46,157,986.31	$24,983,308.66	$44,980,755.60	Assume $100/kW in 2010 $ with Installation Factor(F) = 1.8
			Total Uninstalled Cost (2007 $)		**Total Installed Cost (2007 $)**	**Total Uninstalled Cost (2009 $)**	**Total Installed Cost (2009 $)**	
TOTAL COSTS			**$36,801,673.31**		**$72,234,301.41**	**$35,863,069.54**	**$70,392,010.51**	