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Light Water Reactor Sustainability Program

Technical Evaluation of Electrochemical Metal Redox Cycle for Hydrogen Production, Heat Augmentation, and Energy Arbitrage

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Technical Evaluation of Electrochemical Metal Redox Cycle for Hydrogen Production, Heat Augmentation, and Energy Arbitrage

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EXECUTIVE SUMMARY

Under the U.S. Department of Energy's (DOE's) Light Water Reactor Sustainability (LWRS) Program's Flexible Plant Operation and Generation (FPOG) Pathway, research is performed to show how existing light-water reactors (LWRs) can flexibly provide heat and power to industrial processes to improve process cost and efficiency while diversifying their revenue sources. Researchers from Sandia National Laboratories (SNL) have proposed a process for splitting water into gaseous hydrogen and oxygen through a two-step liquid-metal-mediated process. First, steam oxidizes a reactive metal, producing hydrogen. The resulting metal oxide is then electrochemically reduced to regenerate the metal by off-gassing oxygen. This process is completed at high temperature and low pressure. Each step has been experimentally demonstrated at the bench-top scale at SNL. A block flow diagram (BFD) of the process is drawn in Figure ES1. An LWR could provide heat and power to this process to enable scaling and more-efficient operation.

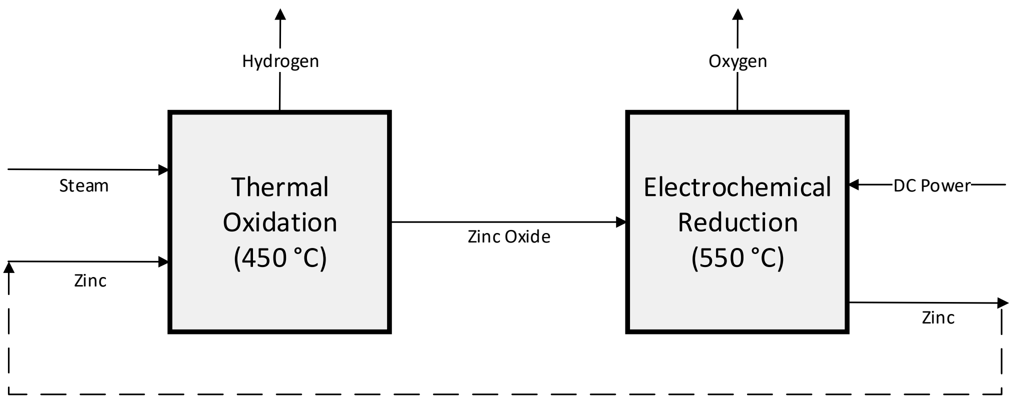

Figure ES1. BFD of the proposed electrochemical metal-redox cycle [1].

The purpose of this present work is to model a scaled-up design of this process focused on the exploration of this electrochemical metal-redox cycle using energy inputs from an LWR nuclear power plant (NPP). The scale chosen was 500 MWe alternating current (AC) input to the process. Three use cases have been envisioned for this novel process, including:

1. Hydrogen production
2. Heat augmentation
3. Energy Arbitrage.

The cycle's ability to perform in these three key areas is analyzed in this study.

Hydrogen Production

The novel process is first and foremost a water-splitting operation, with hydrogen as its primary product. Designing an efficient at-scale system requires robust heat integration, which is primarily derived from the performance of the electrochemical step. Zinc oxide has a per-cell thermodynamic potential that is very similar to the thermal neutral point of water, implying the possibility of a very efficient overall system. With the assumption of 95% rectification efficiency, 90% Faradaic efficiency, and an 8% nominal overpotential, an electricity requirement of 49.8kWh-e AC/kg-H_2 can be obtained. The latter two inefficiencies also define the temperature change across the reactor, which is based on the heat of reaction, Joule heating, and the proportion of redox-inert metal in the oxide alloy.

A process model was built in Aspen HYSYS using a custom thermochemical method based on thermodynamic data from the FactSage database [2]. The feedwater is vaporized and superheated by recuperating heat from the hydrogen product, oxygen-rich exhaust gas, and some low-grade heat from an LWR NPP. The model was scaled to 500 MWe-AC input to the electrolysis process, producing 241 MT/day of hydrogen product. Using the electrochemical assumptions above, along with an alloy composition of 87.5% tin (redox-inert carrier metal) and 12.5% zinc that is totally oxidized by an equimolar steam flow, key stream enthalpies could be obtained that define the heat integration and process-heat cogeneration capabilities of the system. Figure ES2 is a process-flow diagram (PFD) with embedded heat-transfer/temperature diagram which demonstrates that 10.2 kWh-th/kg-H_2 of process heat linearly attenuated between 845 and 550°C is recoverable from the thermal oxidation outlet, as 2.4 kWh-th/kg-H_2 of low-pressure steam is extracted from the NPP to vaporize a portion of the feedwater.

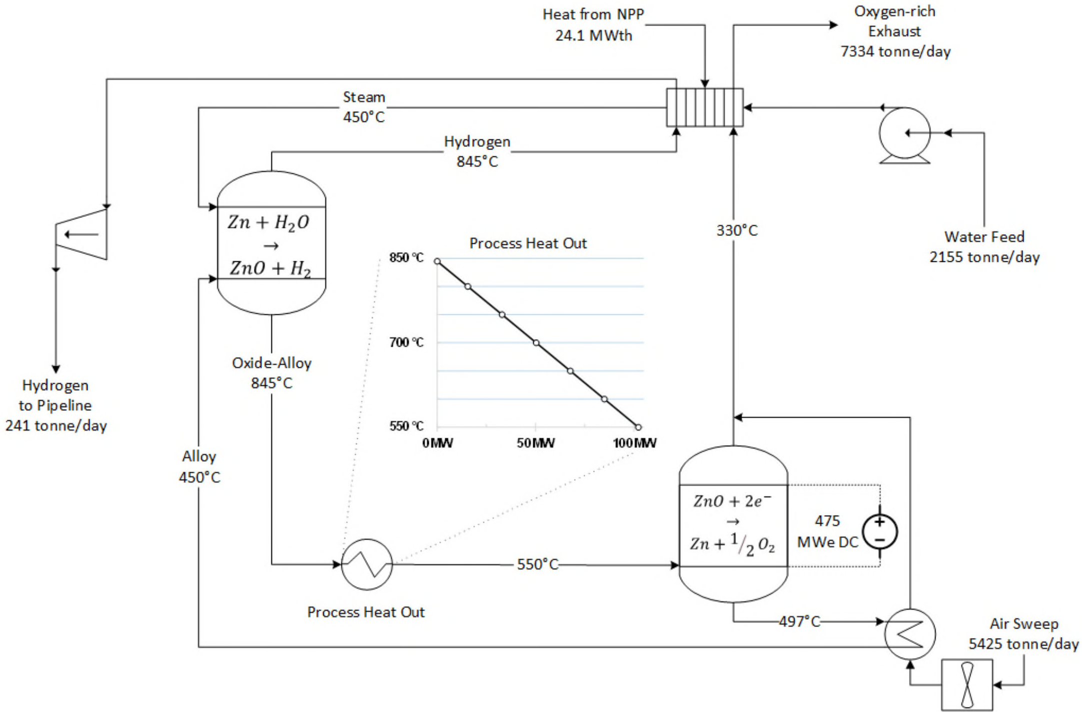

Figure ES2. PFD of the LWR-scale electrochemical metal-redox cycle, including an embedded heat transfer vs. temperature diagram of the process heat co-product.

The high-grade process heat that can be delivered by this system is exclusively sensible heat, so it cannot all be delivered at the oxidation outlet temperature (845°C), but some of it could be delivered above the reduction inlet temperature (550°C). The embedded diagram is a useful tool for determining how much heat could be delivered at a certain temperature. The oxide alloy enters the process heater at 845°C, corresponding to the top left of the diagram. The temperature drops as heat is transferred to the secondary system until it reaches 550°C in the bottom right. The heat-transfer/temperature diagram shows that the first 50.4 MW of process heat could be delivered to a process at 700°C while the remaining 52.0 MW could be delivered to another process at 550°C.

It is important to note that the process heat co-product recovers the electrical losses in the electrochemical step as it is recovered from the chemical potential of the electrochemically reduced zinc. This is a necessary result of practical cell thermodynamics—e.g., overpotentials present to support high current density and side reactions within the molten salt electrolyte that dissipate electricity as heat.

The H2Analysis tool was used to estimate a levelized cost of hydrogen (LCOH) of \$2.00/kg-H_2, with a detailed list of the engineering and economic assumptions included in Section 2.4. If high-temperature process heat is recovered and sold at a competitive price, the LCOH would be reduced to \$1.84b/kg-H_2. The sensitivity analysis shows that electricity cost is the dominant driver of the LCOH. These assumptions represent a reasonably achievable mature technology, and the LCOH sensitivity to the other parameters is only minor.

Heat Augmentation

The redox cycle can be reconfigured to appear similar to an Ericsson cycle, with work going toward manipulating the chemical potential, rather than the pressure, of the working fluid. In this case, the exotherm of the metal-oxidation reaction would be captured electrochemically and used to partially drive the metal-reduction reaction. This would allow a low-temperature heat duty to theoretically be supplied to the metal-reduction reactor and, by using robust recuperation, allow a high-temperature heat rejection from the oxidation step. This process would not produce a hydrogen product because the hydrogen evolved in the oxidation reactor would be looped to assist in reducing the oxide, regenerating steam instead of off-gassing oxygen at the anode. Figure ES3 is a BFD of this configuration.

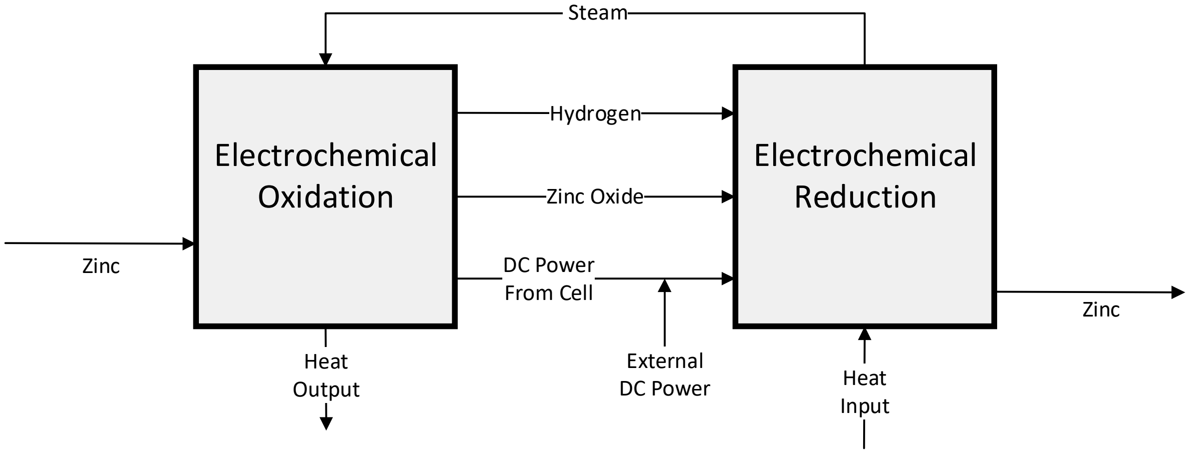

Figure ES3. BFD of the heat-augmentation configuration.

By analyzing the thermodynamic data from the FactSage database, the ideal coefficient of performance (CoP) for a redox-cycle configuration that takes in heat at 450°C and outputs it at 800°C was determined to be about 3. When considering the overpotentials required to drive the reactions, the practical CoP drops to about 1 for the expected performance. This is a relatively poor-performing heat pump. The same thermodynamic effects that make this effective for hydrogen production are the reasons the system is not ideal for operating as a heat pump. These issues are addressable with a second electrochemical step that is operated at low overpotential; however, currently no appropriate low -temperature electrolyte exists in a temperature range suitable for LWRs. Future high-temperature reactors or other heat sources could potentially employ this effect, but that is outside the scope of this analysis.

The redox-cycle heat pump would theoretically replace natural-gas burners and electric furnaces for high-grade heat delivery. For this system to be competitive, the capital cost of the heat-pump equipment must be less than 1.6 times that of conventional equipment if the heat is delivered at 600°C, diminishing to equivalent costs at 1200°C due to the decreasing CoP.

Energy Arbitrage

The metal-redox cycle discussed has its own intrinsic storage capability. Using this feature provides potential for value-added storage operation. The system operating in the configuration for the storage and production of electricity is designed to produce hydrogen and then use the hydrogen to fuel a simple combustion turbine. The turbine is modeled with a thermal efficiency of 56% on a lower-heating-value basis. The simple gas-turbine case is not the most well integrated or efficient possible energy-storage system (ESS); however, it represents a technical baseline using commercially available equipment. The charge and discharge cycles of this ESS are depicted by Figure ES4.

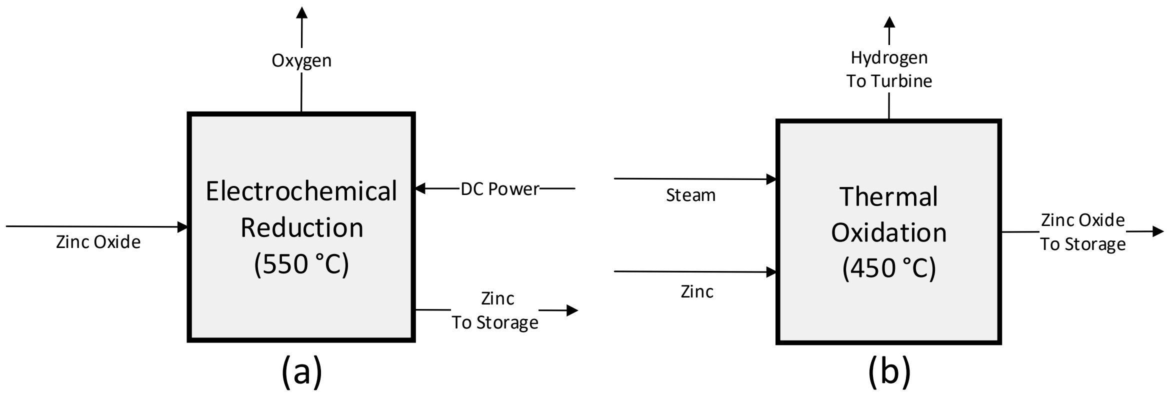

Figure ES4. ESS BFD for (a) a charging and (b) discharging cycle.

This represents a system with the same parameters for hydrogen production as the LCOH case. The hydrogen storage medium is the redox-active zinc metal, which is reduced electrochemically during periods of low demand from the electrical grid; the hydrogen-production reactor sizing is a major component of overall system cost. Oversizing the hydrogen-production reactor allows for fast on-demand hydrogen production from stored zinc during periods of high grid demand. In addition to using hydrogen to produce electricity, the hydrogen can be used to supply batch-type operations where large amounts of hydrogen are used or burned intermittently. This case, in which the expensive electrochemical reactor can be undersized and operated on a more-continuous basis, is also discussed in the body of the report (Sections 4.2 and 4.3).

Capital-cost estimates and economic assumptions are listed in Section 4.1. This case requires the use of a pure zinc melt with controlled partial oxidation. The use of tin drastically increases the storage cost to the point where the economics surrounding the ESS would be untenable. With a round-trip efficiency of around 40% AC-to-AC, the 500 MWe charging cycle will take more than twice as long as the 500 MWe discharge cycle, implying that the minimum levelized cost of storage (LCOS) should be calculated between 6 and 8 hours, stored.

A key assumption is that the system will be sized to cycle as often as it can be physically charged and discharged. This assumption may not be realistic to market conditions, and further detailed synthetic market histories would be necessary to predict the LCOS with higher fidelity. While there are other mitigating market factors, this represents a near best-case scenario for electricity storage and arbitrage using the proposed storage configuration.

A simplified LCOS of $163/MWh was obtained for the 8-hour arrangement, based on assumptions listed in Section 4.1. This was the minimum observed LCOS that corresponds roughly to the change in baseload demand and renewable generation throughout a day. A range of storage durations from 4 to 24 hours were also studied and plotted with the contribution of capital expenditure and operational expenditure broken down in the body of the report.

CONTENTS

FIGURES

TABLES

ACRONYMS

AC	Alternating current
BFD	Block-flow diagram
CAPEX	Capital expenditure
CoP	Coefficient of performance
CSTR	Continuous stirred-tank reactor
DC	Direct current
DOE	Department of Energy
ES	Executive summary
ESS	Energy-storage system
FPOG	Flexible plant operation and generation
HHV	Higher heating value
HTSE	High-temperature steam electrolysis
INL	Idaho National Laboratory
IRR	Internal rate of return
LCOH	Levelized cost of hydrogen
LCOS	Levelized cost of storage
LHV	Lower heating value
LTE	Low-temperature electrolysis
LWR	Light-water reactor
LWRS	Light Water Reactor Sustainability (Program)
NPP	Nuclear power plant
OPEX	Operational expenditure
PFD	Process-flow diagram
RTE	Round-trip efficiency
SNL	Sandia National Laboratories
SOEC	Solid-oxide electrolysis cell

Technical Evaluation of Electrochemical Metal Redox Cycle for Hydrogen Production, Heat Augmentation, and Energy Arbitrage

1. INTRODUCTION

Flexible plant operation and generation (FPOG) is one of the research pathways of the Light Water Reactor Sustainability (LWRS) Program. The U.S. Department of Energy (DOE) supports existing light-water reactor (LWR) nuclear power plants (NPPs) by researching potential ways of increasing and diversifying their revenue, often by investigating energy-storage systems (ESS) and chemical processes that use nuclear heat and electricity, especially in a way that accommodates versatility. In this study, a novel hybrid thermal/electrochemical engine, invented at Sandia National Laboratories (SNL), is analyzed at the engineering scale. The process has the potential to use nuclear power to split water, yielding hydrogen and recoverable high-grade process heat [**Error! Reference source not found.**].

Error! Reference source not found. depicts a simplified block-flow diagram (BFD) of the system, where a redox-active metal such as liquid zinc reacts exothermically with steam to produce hydrogen, according to the reaction:

$$Zn + H_2O \rightarrow ZnO + H_2$$

The oxide would then be conveyed to an electrochemical reactor by a redox-inert metal such as tin, where it would be reduced and recycled, evolving oxygen gas:

$$ZnO + 2e^- \rightarrow Zn + {}^1/_2\, O_2$$

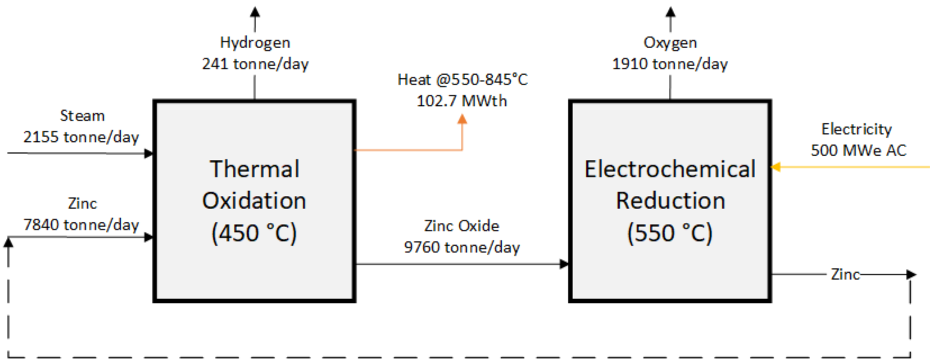

Figure 1. BFD of the electrochemical metal-redox cycle.

This report details the examination of such a system at the scale of 500 MWe-alternating current (AC) in three different modes of operation:

1. Continuous operation for hydrogen production, in which steam is split into hydrogen and oxygen gas, and low-grade waste heat is recovered to boil the feedwater
2. Continuous operation for heat augmentation, in which chemical potential from the metal-oxidation reaction is recovered in an electrochemical step, and the resulting current and hydrogen are looped to the reduction reactor
3. Variable operation in which the reduced zinc is used as a means of storing hydrogen, which can then be burned in a recuperated combustion turbine.

System configurations and first-principal physics are explored to define the expected performance metrics. Using these preliminary results as inputs, the chemical reactions and heat-transfer-unit operations were modeled to identify the requirements of the NPP in each of the cases.

2. HYDROGEN PRODUCTION

Employing the technology developed by SNL for hydrogen production via an electrochemical metal-redox cycle is attractive for the at-scale production of hydrogen from LWR temperatures. The arrangements of the system are explored, and theoretical efficiency is established. An estimated practical efficiency and framework for further levelized cost of hydrogen (LCOH) calculation is also examined. The thermochemical model was developed using thermodynamic data from the FactSage database [**Error! Reference source not found.**], which examines the possibilities for heat integration, utility requirements from a co-located NPP, and the potential to produce a high-grade process-heat coproduct in addition to the main hydrogen product.

2.1 System Design and Background

The system must have a high degree of thermal integration. The oxygen-evolution step is endothermic, and the hydrogen-production step is exothermic. Heat integration of these two steps is vital for an efficient hydrogen-production system from the metal-oxide system, which is depicted as a process-flow diagram (PFD) in Figure 2. Detailed discussion of heat integration, particularly as it pertains to generating the superheated steam that oxidizes the zinc, is included in Section 2.3.

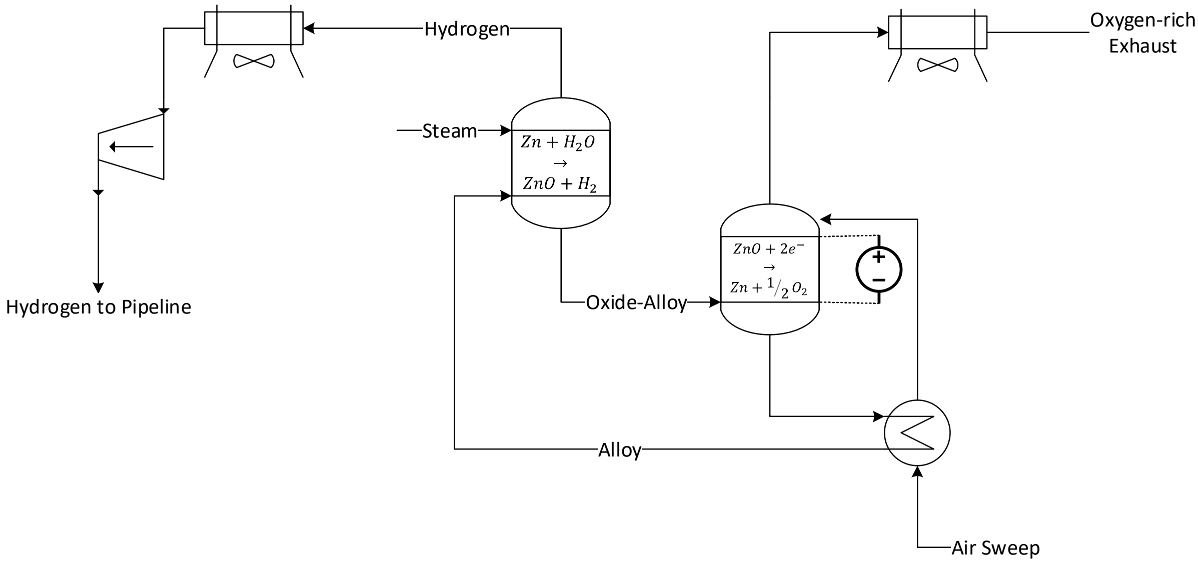

Figure 2. Simplified hydrogen-production PFD.

The transient exothermic steps in the reactor can be performed in batch or continuous-stirred tank reactor (CSTR) process. The heat produced in the exothermic reaction can bypass a heat-exchanger step and simply deliver a higher-temperature fluid to the endothermic oxygen-evolution reaction. The ideal thermal case can be accomplished via a number of equivalent alternative arrangements that will not be described in detail at this stage. It is sufficient for the case to know that alternative arrangements are possible.

2.2 Thermodynamic Analysis

The thermodynamics of the system are analyzed in an ideal case. This is done using a limited toolset and provides an order-of-magnitude estimate for the effect. The analysis also provides a framework for the analysis for further theory.

2.2.1 Ideal Thermodynamics

Using FactSage calculations to derive optimal thermodynamic data, a theoretical efficiency is shown in Figure 3, where V_{tn} is the thermal-neutral voltage of the reduction reaction, which corresponds to the ΔH of reaction. V_{eq} is the equilibrium voltage required to drive the reaction towards occurring spontaneously, which corresponds to the ΔG of reaction.

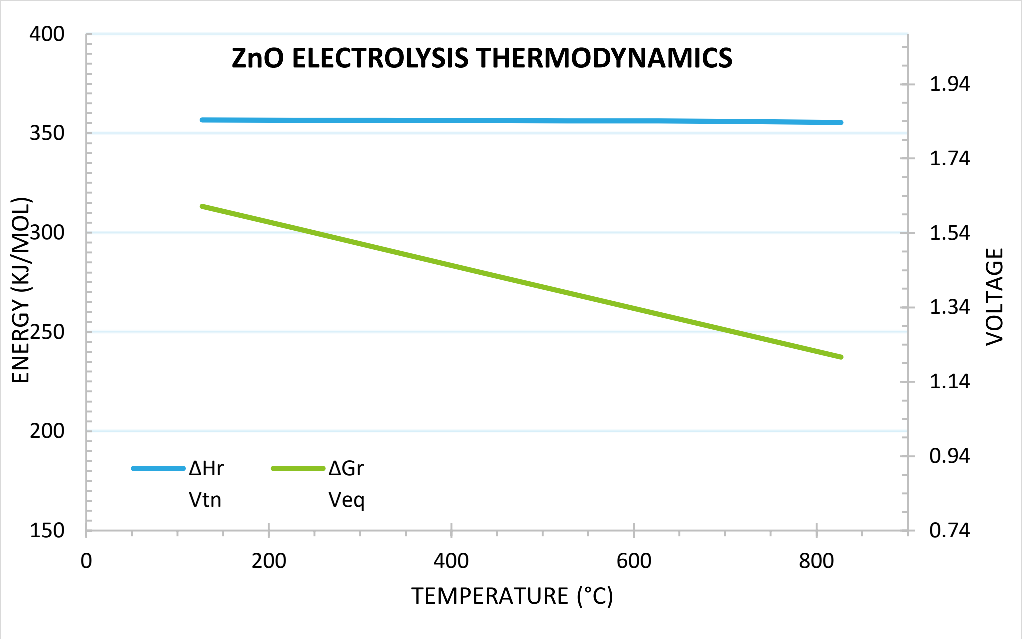

Figure 3. Thermodynamic-equilibrium data from FactSage calculations.

The thermodynamic potential for zinc oxide electrolysis is 1.38V/cell. The thermal-neutral voltage for the higher heating value (HHV) of hydrogen is 1.48 V/cell. Because the equilibrium voltage is lower than the equivalent to the HHV, the applied potential can operate at a point where, in the case of heat utilization, 100% total energy efficiency can be achieved. However, overpotentials will be required to drive the system at effective current densities. The potential of 1.38 V/cell also indicates that steam production from an external heat source will only provide a small overall system efficiency. The thermal neutral voltage is 1.90 V/cell; thus, in order to ensure the system operates efficiently, heat from the hydrogen-production step must be used in the endothermic zinc-reduction step.

Thermal integration of the two reaction steps is critical for overall efficiency. Thermal integration with other process heat can still provide benefits by delivering low-quality steam and using the process to export higher-quality heat. In this scenario, coupling to an LWR could be beneficial by coupling the steam system from the LWR and allowing a more-beneficial use of the high-quality process heat. Due to the temperature exiting the system, by coupling a low-temperature heat source, the exergetic efficiency can remain high if high-temperature heat is desired; i.e., the low-temperature heat source reduces the recuperation required of the system, freeing up high-temperature heat, which has a greater capacity to do work for another purpose.

The work input and output can be calculated by differences in ΔG, and the heat output by difference in Zn ΔG to ΔH. These values are all shown as positive for simplicity in calculation reference for voltages to follow. Conversion from thermodynamic energy to voltage is through the equation:

$$\frac{E}{zF} = \Delta G$$

Where E is the thermodynamic voltage, and *z* is the electrons transferred per reaction, and F is Faraday's constant. *z* in this case is 4, as the basis of the reactions in the Ellingham diagram are for a mole of O_2.

2.2.2 Practical Thermodynamics

With an ideal electrode, the system has an approximately ideal performance. With a real electrode, overpotentials will be present. In any configuration, the overpotentials will still exist at each cell. A nominal 0.2 V/cell electrode overpotential is a good first estimate for the expected practical level of system effectiveness. A simple diagram showing efficiency vs. applied voltage is shown as Figure 4. Any Faradaic efficiency would be multiplied by voltaic efficiency to give the overall efficiency of the electrochemical steps.

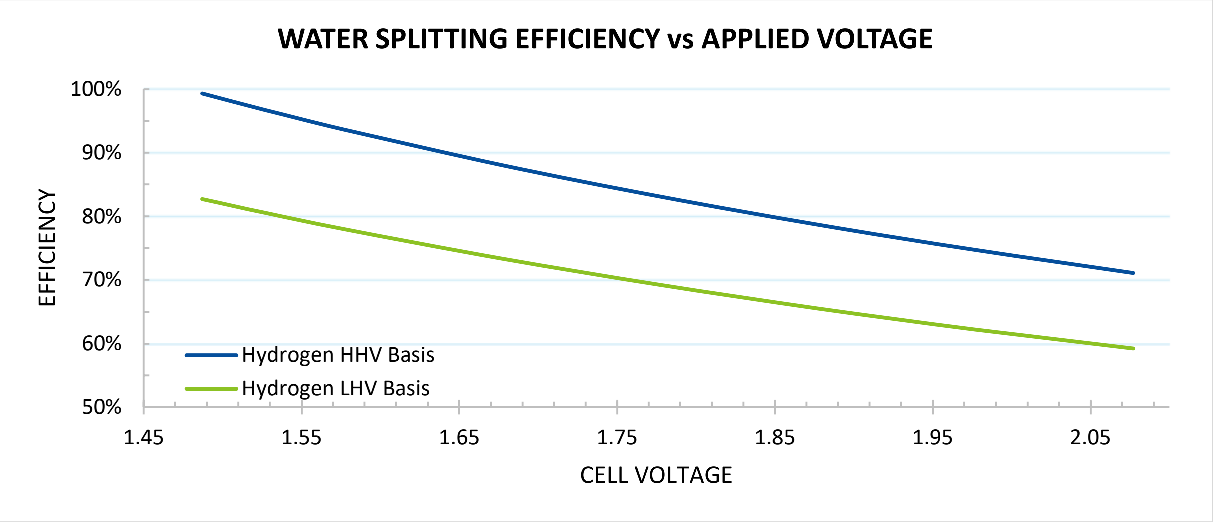

Figure 4. Water-splitting thermodynamics as a function of applied voltage.

2.3 Process Modeling

Due to the favorable thermodynamics discussed above, a process model of an LWR-scale system was developed to further investigate the thermal-integration capabilities of the system. The model was built using Aspen HYSYS. Gaseous streams (hydrogen, oxygen, and air) were modeled using the Peng-Robinson equation of state, water/steam was modeled using the NBS steam tables while the metal-metal oxide stream and the reactions of the system were modeled using custom methods that relied on thermochemical properties from the FactSage database [**Error! Reference source not found.**].

The stream tables from the model, described in detail below and depicted in Figure 5, are included in Appendix A. The model shows that hydrogen production via the redox cycle requires 49.8 kWh-e AC/kg-H_2, with 10.2 kWh-th/kg-H_2 of high-grade heat that is recoverable for chemical process integration during continuous operation.

2.3.1 Reaction Modeling

A fluid package that accurately and reliably describes the thermochemical and electrochemical interactions between zinc, hydrogen, oxygen, and steam was not identified within the Aspen databanks.

Upon consultation with the inventor and lead experimentalist of the electrochemical metal-redox cycle, the FactSage database was recommended as a property package that aligned well with experimental results [**Error! Reference source not found.**]. The built-in unit operations were bypassed for the thermal-oxidation and electrochemical-reduction reactions. HYSYS was only used to keep track of stream flows, and spreadsheets were designed to perform conversion chemistry calculations using the FactSage data.

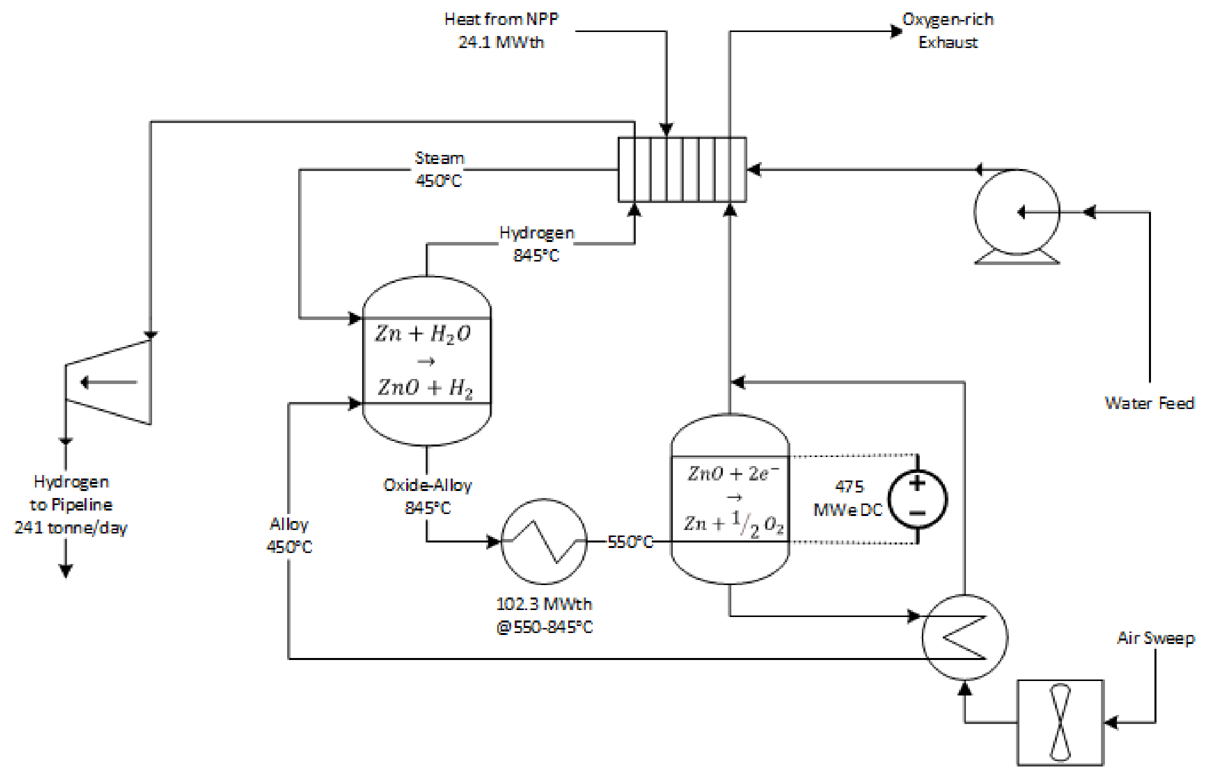

Figure 5. PFD of the hydrogen production model.

2.3.1.1 Thermal Oxidation

The thermal oxidation reaction, displayed below, was modeled using three steps. The results of the reactor are listed in Table 1, assuming equimolar steam and zinc flow and a 7:1 tin-zinc ratio in the feed alloy.

$$Zn + H_2O \rightarrow ZnO + H_2$$

Table 1. Thermal oxidation reactor results.

Stream	Molar Composition					Temperature
	Tin	Zinc	Zinc Oxide	Hydrogen	Water	-
Alloy	0.8750	0.1250	0.0000	0.0000	0.0000	450°C
Steam	0.0000	0.0000	0.0000	0.0000	1.0000	450°C
Reactants	0.7778	0.1111	0.0000	0.0000	0.1111	450°C
Products	0.7778	0.0000	0.1111	0.1111	0.0000	845°C
Overheads	0.0000	0.0000	0.0000	1.0000	0.0000	845°C

Stream	Molar Composition					Temperature
	Tin	Zinc	Zinc Oxide	Hydrogen	Water	-
Oxide-Alloy	0.8749	0.0000	0.1250	0.0001	0.0000	550°C

1. *Conversion chemistry*. Stoichiometry and the limiting reagent are used to determine the composition of the outlet given the inlet molar flows of the reactants and inerts, according to equation:

$$\dot{n}_i^{out} = \dot{n}_i^{in} + A_i \xi$$

where $\dot{n}_i$ is the molar flow of a species i, A_i is the stoichiometric coefficient where a negative coefficient represents consumption of the component and 0 represents the component being inert. ξ is the extent of reaction which is assumed to be defined by complete conversion of the limiting reagent.

2. *Reaction thermochemistry*. The molar flows of each component at the inlet and outlet of the reactor are multiplied by the molar intrinsic stream enthalpy (h_i), obtained from FactSage, which contains sensible and latent heat as well as the heat of formation of each component to find the enthalpy flow of the reactants at the inlet temperature (T_{in}), and of the products at an arbitrary outlet temperature (T_{out}):

$$\sum_i h_i(T_{in})\, \dot{n}_i^{in} = \sum_i h_i(T_{out})\, \dot{n}_i^{out}$$

Because the thermal-oxidation reactor is meant to be adiabatic, an adjust block was used to vary the arbitrary outlet temperature until the products and reactants had the same enthalpy flow. The results were checked with a first-law balance to ensure that the heat of reaction and sensible-heat rise of the products equated:

$$\Delta \mathrm{h_r}(T_{in})\xi = (T_{out} - T_{in}) \sum_i \dot{n}_i^{out} c_i$$

Where $\Delta h_r(T_{in})$ is the heat of reaction at the reactor-inlet temperature, obtained from FactSage, and c_i is the molar heat capacity of component i. This first-law balance confirms that the results of the conversion reactor are self-consistent by demonstrating a relative error of -2.4×10^{-4}.

3. *Oxide-alloy cooling*. A similar method to Step 2 was employed to model the cooling of the oxide-alloy to 550°C, which is the required inlet temperature for the electrochemical-reduction reactor. Because this step is not adiabatic, the heat rejection rate $\dot{Q}_{cool}$ was added to the energy balance:

$$\dot{Q}_{cool} = \sum_i h_i(T_{bottoms})\, \dot{n}_i^{bottoms} - \sum_i h_i(550°C)\, \dot{n}_i^{bottoms}$$

It was found that 102.3 MWth of high-grade heat can be recovered by cooling the oxide-alloy to the electrochemical-reduction feed temperature on the scale of a 500 MWe AC system. The scale of the system is determined in Section 2.3.1.2. Because this is a sensible-heat-transfer operation, some of the heat is available at temperatures higher than 550°C; Figure 6 is a heat-transfer vs. temperature diagram that shows the ability for the oxide alloy to deliver process heat at different temperatures.

The oxide alloy enters the process heater at 845°C, corresponding to the top left of the diagram. The temperature drops as heat is transferred to the secondary system until it reaches 550°C in the bottom right. The heat-transfer/temperature diagram shows that the first 50.4 MW of process heat could be delivered to a process at 700°C while the remaining 52.0 MW could be delivered to another process at 550°C.

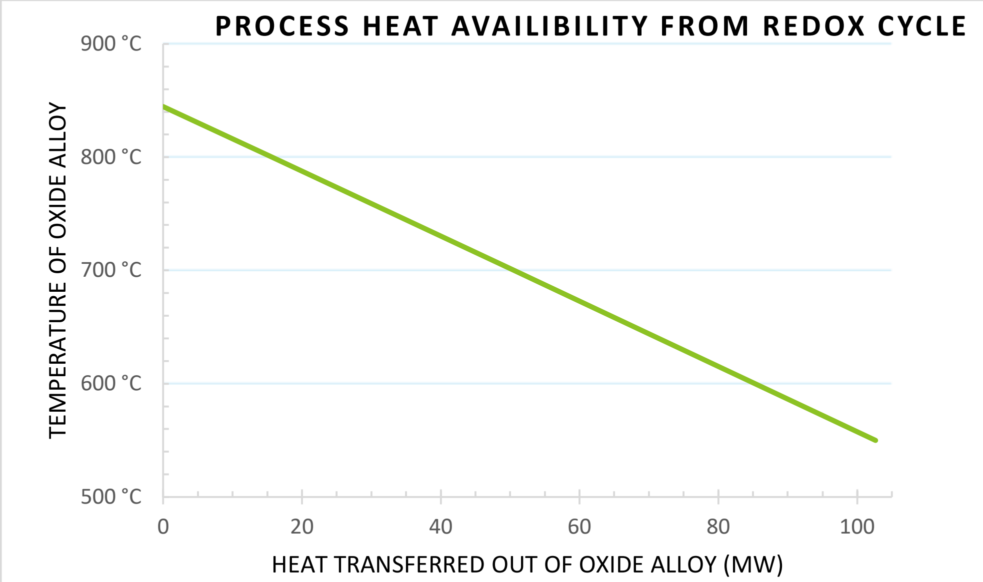

Figure 6. Heat-transfer vs. temperature diagram for oxide-alloy cooling.

2.3.1.2 Electrochemical Reduction

The electrochemical-reduction rection was modeled in much the same way as the thermal-oxidation reaction, with a few key exceptions discussed below. Table 2 lists the results from the reactor model.

$$ZnO + 2e^- \rightarrow Zn + {}^1/_2\, O_2$$

Table 2. Electrochemical reduction reactor results.

Stream	Molar Composition					Temperature
	Tin	Zinc	Zinc Oxide	Hydrogen	Oxygen	-
Oxide Alloy	0.8749	0.0000	0.1250	0.0001	0.0000	550°C
Products	0.8235	0.1116	0.0000	0.0001	0.0588	497°C
Anode Off-Gas	0.0000	0.0002	0.0000	0.0011	0.9987	497°C
Regenerated Alloy	0.8748	0.1250	0.0000	0.0001	0.0002	450°C

1. *Reaction electrochemistry*. The outlet composition was found using the same extent of reaction method as in Section 2.3.1.1, assuming complete conversion of the zinc oxide. The molar flow of zinc oxide was used along with an assumed Faradaic efficiency ($\eta_f = 90\%$), and an assumed cell voltage ($V = 1.6V$) to calculate the direct-current (DC) power ($\dot{W}_{elec}$) required to drive the reaction.

$$\dot{W}_{elec} = V \frac{2F(\dot{n}_{ZnO}^{in})}{\eta_f}$$

   where F is Faraday's constant, the product of Avogadro's number and the unit charge. An adjust block was used along with a rectification efficiency of 95% to find the system flow rate at which the electrochemical-reduction reactor consumes 500 MWe AC. As the electrochemical model is further developed, a more-refined cell overpotential and efficiency will improve the fidelity of this model. With the current assumptions, a flow rate of around 5000 kgmole/hr is required.

2. *Reaction thermochemistry*. A method similar to the thermal-oxidation section was used to find the electrochemical-reduction outlet temperature. This reaction is endothermic, but is not operated adiabatically, so the electrolyzer DC power must be added into the energy balance:

$$\sum_i h_i(T_{in})\,\dot{n}_i^{in} + \dot{W}_{elec} = \sum_i h_i(T_{out})\,\dot{n}_i^{out}$$

3. *Regenerated-alloy cooling*. The same sensible-heat-transfer method as above was employed to cool the regenerated alloy to 450°C so it can be recycled to the thermal-oxidation reactor. This heat is used to preheat a sweep-air stream. The sweep-air flow rate is selected to dilute the overhead product to 40 mol% oxygen. The sweep air leaving the preheater is warmed to 273°C, and the overhead product is 330°C. The heat in this oxygen-rich air is used to boil feedwater and exhausted. This system does not readily allow for a steam sweep to be used to later isolate the oxygen product; however, if it is desirable to use the oxygen for oxy-firing, a CO_2 sweep could instead be used to form a carboxy-air that is 60 mol% CO_2 and 40 mol% O_2. A smaller sweep flow rate would then be required, resulting in an overhead temperature of 409°C and a slight increase to the amount of feedwater that the exhaust stream could vaporize, leading to a slightly higher system efficiency by reducing the LWR steam duty. The feedwater heat integration is discussed in more detail in the next section.

2.3.2 Heat-Integration Modeling

As with high-temperature steam electrolysis (HTSE), this system relies on recuperation to produce superheated steam that is fed to the splitting stage. The hot hydrogen product, which is equimolar to the steam feed, is advantaged by the exotherm of the thermal-oxidation reaction. Cooling the hydrogen product, which comes out of the reactor at 845°C, to 420°C can superheat an equimolar atmospheric-pressure saturated steam to the desired 450°C, with a duty of 17.6 MW on this 500 MWe AC scale. The heat of vaporization for the required steam flow rate at near-ambient pressure is 56.5 MW. Boiling heat transfer is generally of high performance, so it is assumed that the 420°C hydrogen and 330°C oxygen-rich exhaust can boil the feedwater with a 5°C minimum approach, cooling each overhead stream to 106°C with duties of 12.7 and 19.4 MW, respectively. As Figure 7 depicts, the remaining 24.1 MW is supplied by LWR steam. Saturated steam at 140.5°C and 3.366 bar is assumed to be extracted from the low-pressure turbine of the associated NPP with a flow rate of 11.1 kg/s and condensed with 4°C of subcooling along 2% nominal pressure drop.

If the redox cycle is to produce hydrogen offsite—i.e., it is not co-located with the NPP—and an external steam source is not available, a different configuration is possible. The hydrogen would not be used to superheat the feed steam and would, instead, be exclusively used to boil feedwater. Between the full cooling duty of the hydrogen product and oxygen exhaust, the feed steam would have quality of 88.5%. Next, the bottom 24.1 MW of oxide-alloy cooling would have to be used to finish vaporizing and superheating the feed steam. This would reduce the availability of high-grade heat from the redox cycle to 78.3 MW of linearly attenuated sensible heat from 845 to 620°C.

The final piece of the model is the compression of the hydrogen product. The reaction model predicts no contamination of the product hydrogen, so the compression does not use cleanup. If excess steam were fed to the thermal-oxidation reactor to ensure the total oxidation of the tin, knockout drums would need to be added to the compression schematic. Each compression stage has a pressure ratio of 2.7, provided the assumption of 75% isentropic efficiency, 40°C inlet, 175°C outlet, and 2% nominal pressure drop across interstage and aftercoolers. The 241 MT/day of hydrogen product then consumes 21.9 MWe AC to reach 44.4 bar, which would be a modest pressure for a pipeline. With this level of compression, the feedwater could easily be preheated to 101°C (saturated at near-atmospheric pressure), absorbing 8.4 MW from the hot compressed hydrogen; 16 MW of additional cooling water or air cooling would be needed to reject the remaining heat of compression. A chiller would likely be needed to further increase the density of the hydrogen being fed into the pipeline, but the chiller is not modeled.

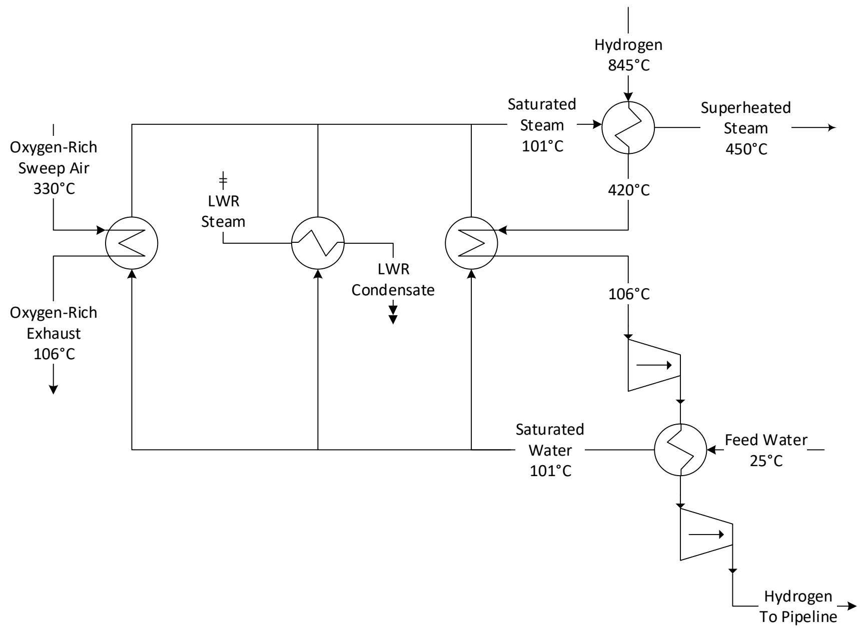

Figure 7. Heat-exchanger network for the hydrogen-production configuration.

2.4 Levelized Cost of Hydrogen

2.4.1 Technoeconomic Analysis

The process model provides the technical baseline to produce an LCOH estimate. The overall capital components have common parts with a solid-oxide electrolysis cell (SOEC) system as a basis of comparison. Using costs on power supplies, blowers, and industrial vessels, an initial cost estimate can be developed. The most substantial portion of the final cost of hydrogen is the electricity-feedstock price.

The H2Analysis tool was used to estimate an LCOH of \$1.98/kg-H_2, based on the following assumptions:

- 25-year capital lifetime
- Installed capital cost of \$435/kW
- Electricity cost of \$30/MWh-e
- Heat cost of \$10/MWh-th
- Electricity consumption of 50 kWh/kg-H_2
- Heat consumption of 2.4 kWh/kg-H_2
- 90% plant capacity factor
- 12% internal rate of return (IRR) [3].

It is expected that the system, as designed, will have potential for cost increases as certain aspects of the system may not have been captured. The main costs for the vessels, heat exchangers, and power electronics are multiplied by a 1.3 installation factor to provide an estimate of \$435 of direct capital costs.

Sensitivity analysis shows that electricity cost is the dominant driver of the LCOH. These assumptions represent a reasonably achievable mature technology and the LCOH sensitivity to the other parameters is only minor.

2.4.2 Sensitivity Analysis

This shows the preliminary viability of the technique for hydrogen production using analogous costs and kinetics of aluminum smelters and SOEC. By offsetting the hydrogen-production cost with the equivalent value of the recoverable high-temperature process heat, a cost reduction from \$1.98/kg H_2 to \$1.82/kg H_2 is achievable. The sensitivity results shown in the tornado chart (Figure 8) are based on using the higher-grade heat recovery available from the system. The process has the greatest sensitivity to feedstock (e.g., DC power) consumption, implying that any improvements that can be made to the efficiency of the electrochemical reduction step will have a significant impact on the LCOH.

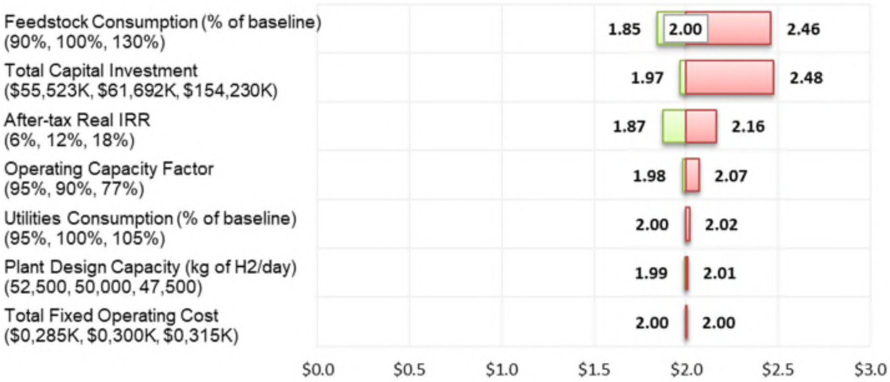

Figure 8. Tornado chart depicting the sensitivity of the LCOH to changes in certain parameters.

A waterfall chart (Figure 9) shows a best-case scenario version of the tornado chart where, if the costs associated with all of the cost drivers are skewed towards the lower end of the spectrum, the LCOH may be reduced to \$1.62/kg.

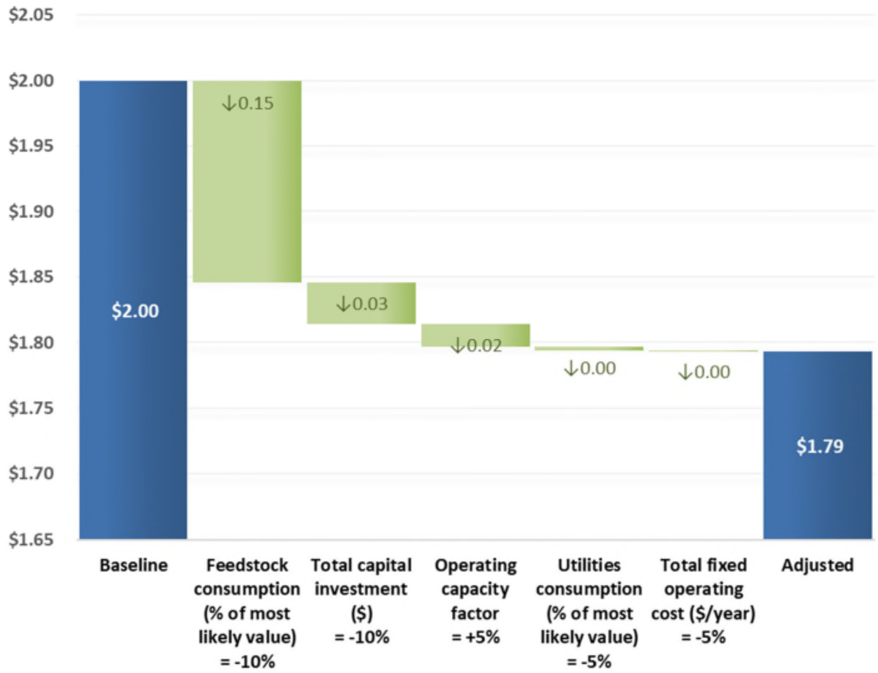

Figure 9. Waterfall chart of cost reductions through technology improvements and optimizations.

The proposed system, when used in conditions that meet the target needs, shows satisfactory preliminary results for producing economic hydrogen. This leads towards the 2026 target of $2/kg of hydrogen set by the DOE. Reduced electricity costs would result in further improvements. Additional economic benefits can be gained if the value of high-temperature heat is captured. Changing electricity costs from $30/MWh to $20/MWh reduced the baseline cost from $2.00 to $1.50/kg, and the sale of heat will reduce the cost by 8 cents. This leaves a current technology case at as low as $1.42/kg H_2 with lower-cost electricity.

2.4.3 Technical Targets

The technoeconomic case for hydrogen production shows potential for economic competitiveness with other green-hydrogen pathways. The electrochemical performance and further details of plant design are necessary to further validate the assumptions in the design. The technical targets for economic competitiveness suggest that a cell overpotential of less than 0.3 V would be necessary to have the hydrogen-production case be viable over the baseline low-temperature electrolysis (LTE) or HTSE production cases. Faradaic efficiency would also need to be greater than 90%. The experience in the SOEC-technology family is that the area specific resistance is less than 0.5 ohm-cm^2 [4]. The equivalent capital ($/Amp) would have to be near equivalent for the capital cost estimates used in this work to be valid.

To have similar current densities to aluminum smelters (>0.5 A/cm^2) [5] the cell resistance would need to meet a target of 0.6 Ohm cm^2 for an efficiency of 70% on a lower-heating-value (LHV) basis (83% HHV). Given the design similarities between the system and an aluminum smelter, this represents a good basis for the initial design. By evaluating in context of an aluminum smelter, full cell overpotentials are approximately 0.4–0.6 V for the full cell. These overpotentials would indicate the 0.2 V for half-reactions as the initial overpotential is a valid starting point. Possible adjustments that can be implemented to reduce the overpotential compared to the aluminum-smelter baseline would be the existence of better electrodes in place of the sacrificial carbon electrodes used in aluminum smelting and a thinner electrolyte layer.

The specific advantages of this system over SOEC are similar to the situational advantages of redox-flow batteries compared to lithium-ion batteries. There is a tradeoff for system lifetime and scalability vs efficiency. The metal-oxide system has the potential to have a similar or lower capital expenditure (CAPEX) for the upfront costs. The expectation is that the electrolyte life and electrode and vessel life of the system would need to maintain a lifetime greater than 10 years to be able to compete with a future SOEC system.

3. HEAT AUGMENTATION

Employing the redox-cycle technology developed by SNL for heat-augmentation via a metal-metal/oxide heat pump is an attractive possibility to produce high-temperature heat from LWR temperatures. The potential arrangements of the system are explored, and a theoretical coefficient of performance (CoP) is established. An estimated CoP for a practical system is also presented.

3.1 System Design and Background

The system required to yield a high CoP requires two electrochemical steps. The first step is endothermic and is the heat-absorption step; the second electrochemical step is a high-temperature exothermic step with heat recovery. The process can be approximated as an Ericsson cycle with electrochemical compression and expansion occurring near isothermally. A simple PFD of this configuration is included in Figure 10.

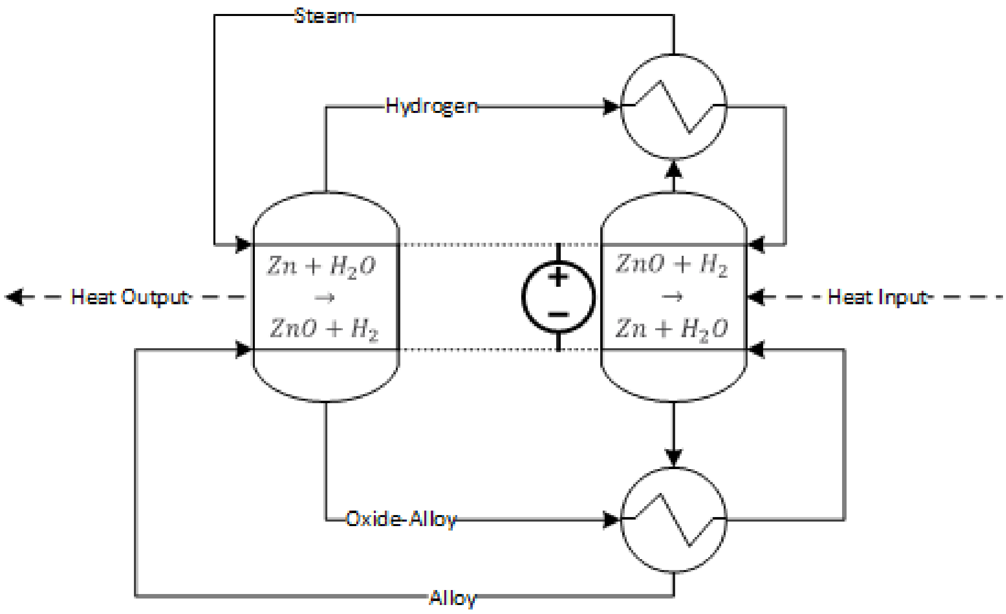

Figure 10. Basic PFD of redox cycle configured for heat augmentation.

These isothermal electrochemical steps then interact with a recuperating heat exchanger between the two stages. This ideal case can be accomplished via a number of alternative arrangements which will not be described in detail at this stage. It is sufficient for the case to know that other arrangements are possible.

3.2 Thermodynamic Analysis

The thermodynamics of the system are analyzed in an ideal case. This is done using a limited toolset and provides an order-of-magnitude estimate for the effect. The analysis also provides a framework for the analysis for further theory.

3.2.1 Ideal Thermodynamics

Using FactSage to derive thermodynamic data, a theoretical coefficient of performance of approximately 3 is identified for the cycle. Using a hydrogen depolarized electrode, the cycle can use steam/hydrogen instead of pure oxygen as the gas-phase working fluid. This is necessary for system safety as pure oxygen at the relevant temperatures represents a significant hazard. As the system is expected to operate at low pressure, hydrogen embrittlement is not a substantial concern for the types of alloys expected to be used in the vessel. Molten-zinc and tin-alloy material compatibility is a topic of future exploration after the initial technology prescreening assessment.

Table 3. Hybrid electrochemical heat-pump cycle reactions.

Reaction	Temperature (°C)	ΔH of reaction (kJ/mol)	ΔG of reaction (kJ/mol)
Forward: $Zn + H_2O \rightarrow ZnO + H_2$	800	-107.2	-51.6
Reverse: $ZnO + H_2 \rightarrow Zn + H_2O$	450	110.6	70.4

The CoP presented in Table 4 is derived using the thermodynamic data from **Error! Reference source not found.**, and the definition of Gibbs free energy:

$$\Delta G + T\Delta S = \Delta H$$

which is also the first law of thermodynamics for a steady-state steady flow system, neglecting changes to potential and kinetic energies, where W is work and Q is heat transfer:

$$W + Q = \Delta H$$

For the forward reaction:

$$W_{forward} = \Delta G_{forward}$$

$$Q_{forward} = \Delta H_{forward} - \Delta G_{forward}$$

For the reverse reaction:

$$W_{reverse} = \Delta G_{reverse}$$

$$Q_{reverse} = \Delta H_{reverse} - \Delta G_{reverse}$$

The net work is:

$$W_{net} = \Delta G_{forward} + \Delta G_{reverse}$$

The heat delivered is:

$$Q_{delivered} = Q_{forward}$$

The coefficient of performance is:

$$COP = \frac{Q_{delivered}}{W_{net}}$$

The work input and output can be calculated by the previous equations for the tabulated differences in ΔG, and the heat output by the difference in Zn ΔG to ΔH. For the net work to be equal to the difference between the ΔG of reaction for the forward and reverse reactions, there must be ideal extraction of work and recovery of work. The difference between this ideal case and the practical case will be discussed in Section 3.2.2. The values are all shown as positive for simplicity in the CoP reference shown in Table 4.

Table 4. CoP for the ideal redox-cycle heat pump.

Net Work (kJ/mol)	Heat Delivered (kJ/mol)	Heat Absorbed	CoP	CoP Carnot
18.8	55.6	40.2	2.96	3.07

These values are superimposed on the thermodynamic diagram in Figure 11 to provide a visual representation of calculating the CoP. The heat input is the space between the ΔH_r and ΔG_r lines at 450°C, and the heat output is the space between the lines at 800°C. The net work input is the difference between the ΔG_r line at the two temperatures. The CoP of 3 is represented graphically by the heat output line being three times as long as the net work line. The slope of the ΔG_r is steeper than the ΔH_r, which intuitively shows why a larger temperature differential leads to a smaller CoP; the net work that must be provided to drive the low temperature reaction grows more quickly than the heat output.

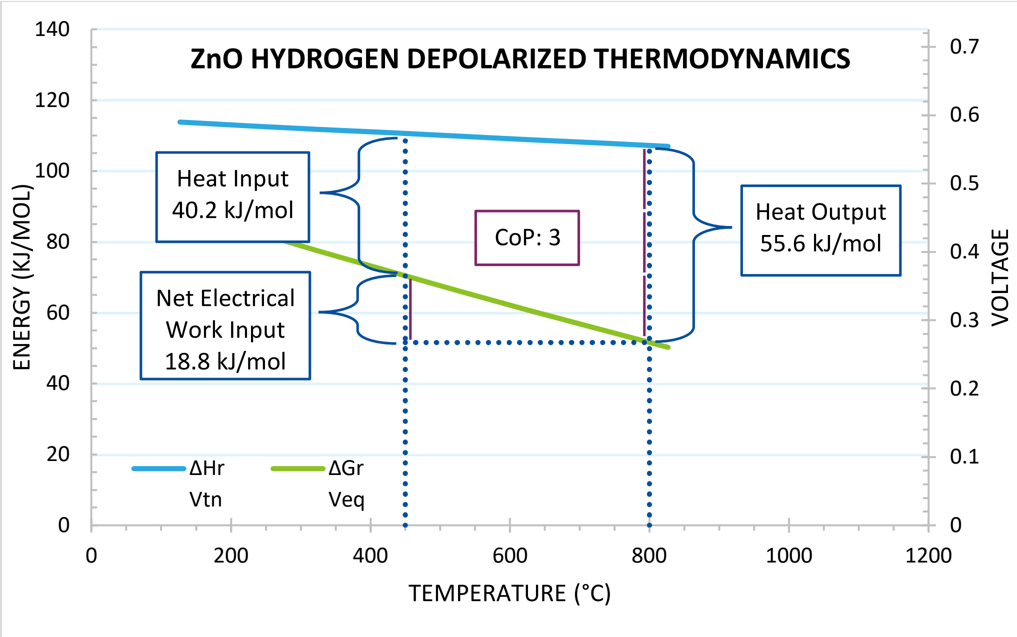

Figure 11. Heat-augmentation ideal thermodynamic cycle.

3.2.2 Practical Thermodynamics

With an ideal electrode, the system has an approximately ideal performance. With a real electrode overpotentials will be present. In any configuration, the overpotentials will still exist at each cell. A nominal 0.2 V/cell electrode overpotential is expected. Conversion from thermodynamic energy to voltage is through the equation:

$$E = \frac{\Delta G}{zF}$$

where E is the thermodynamic voltage. z is the electrons transferred per reaction, and F is Faraday's constant. Z in this case is 2, as the basis of the reactions are for a mole of Zn. This changes the ratio of electrical to heat input and output at each step. Overpotentials lead to a reduction of the work extracted and work recovered, with each step requiring 38.6 kJ/mol of non-ideal work. The polarization losses at the high-temperature step are dissipated as heat. The extra heat results in an increase in the total delivery of high-temperature heat at the cost of an increase in work and a reduction in CoP.

Using the new work input of 96 kJ/mol and the heat delivered of 94 kJ/mol calculated by adding the overpotential work from both electrodes to the net work, and one of them to the heat delivered, as displayed in Table 5, yields a CoP change from 2.9 to 0.98.

Table 5. CoP of 0.2 V/cell overpotential.

Net Work (kJ/mol)	Heat Delivered (kJ/mol)	Heat Absorbed (kJ/mol)	CoP
96.0	94.0	1.7	0.98

Figure 12 is a graphical representation of the effect overpotentials have on the practical thermodynamics of the heat augmentation cycle. At the high temperature, less electrical work can be recovered than in the ideal case. The orange bar represents an 0.2 V overpotential, which is dissipated as heat instead of driving the low-temperature reverse reaction. Not only is less work recovered from the forward reaction, but additional work corresponding to 0.2 V/cell is also needed to drive the low temperature reverse reaction. When adding the two half-cell overpotentials to the ideal net work (depicted by the purple bar), it can be shown that the CoP is reduced to approximately 1.

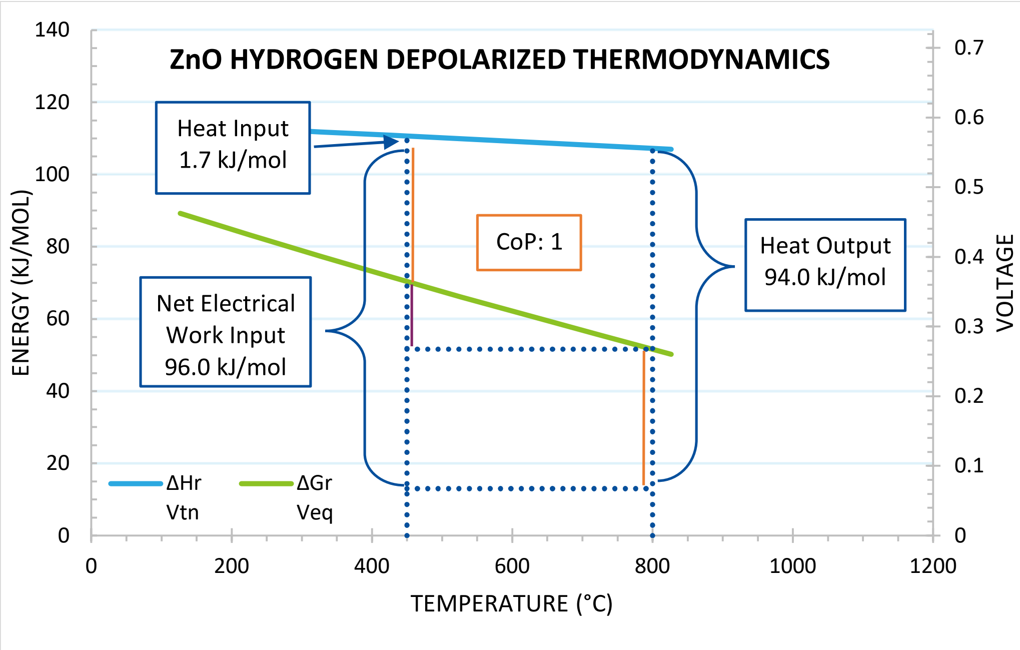

Figure 12: Heat-augmentation practical thermodynamic cycle including 0.2 V/cell overpotential.

The ideal case, while promising, changes quickly when including the consideration for the overpotential needed to drive the system, as shown by the curve plotted in Figure 13 quickly approaching a CoP of 1 for even modest overpotentials.

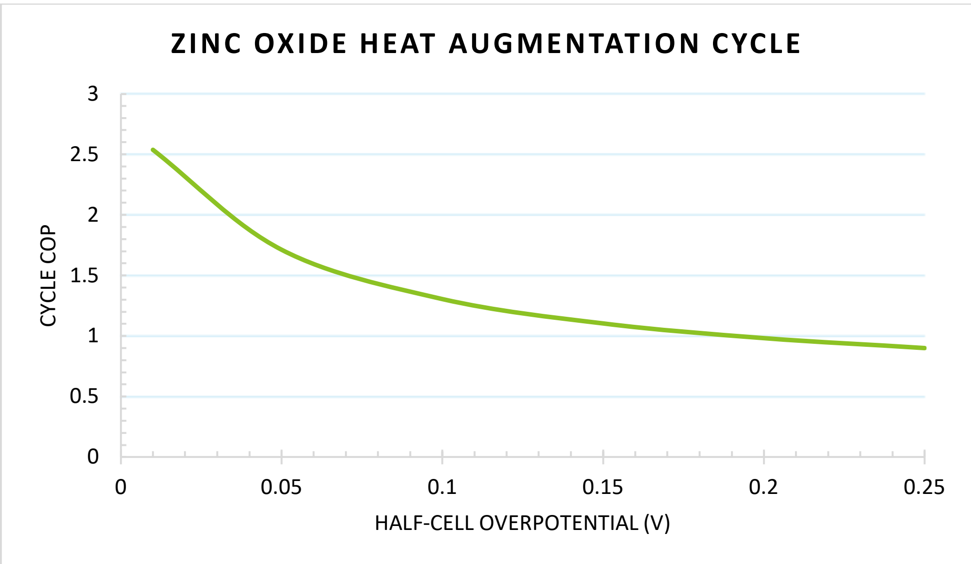

Figure 13. Redox cycle heat-pump CoP vs half-cell overpotential.

3.3 Technoeconomic Analysis

A simplified estimate for LWRs using an electricity price of $30/MWh-e and heat price of $10/MWh-th provides a case for the relative capital cost (compared to electric furnaces) for breakeven with a simple payback period. A practical and ideal CoP are shown in Figure 14 for comparison.

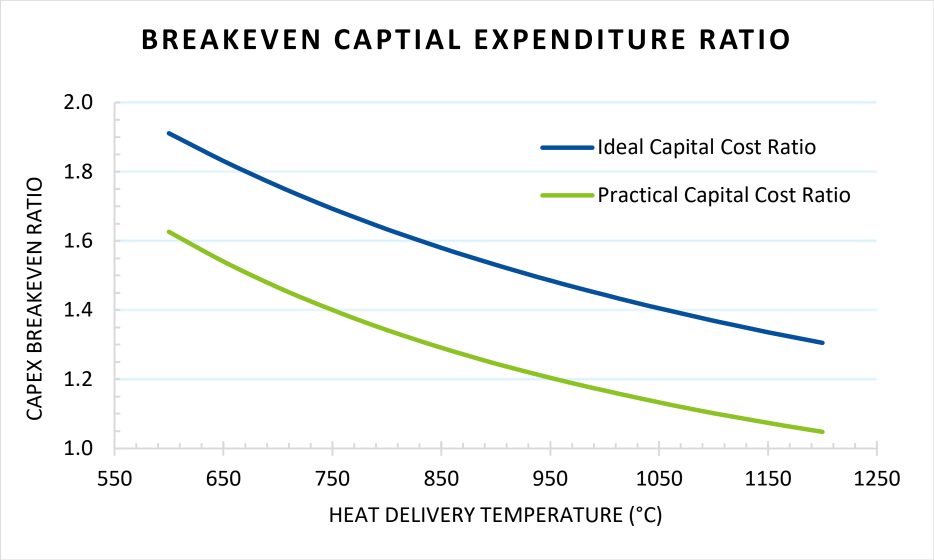

Figure 14. Capital-cost ratio for the heat-delivery temperature.

These numbers suggest that a maximum capital-cost ratio of 1.6 for the ideal CoP and 1.3 for the practical CoP with a heat delivery temperature of 800 °C are acceptable targets for system-breakeven costs with the reference-technology estimates. The higher the inlet temperature of the system, the less value is obtained in any heat-pump functionality.

The technoeconomic case for heat augmentation depends on there being key differences in system kinetics for the heat-augmentation case compared to a design reference of an aluminum smelter. The differences in system design make these differences feasible, but potentially challenging. Data suggesting that a per-cell overpotential of less than 0.1 V would be necessary to have the heat-augmentation case be viable over the baseline direct thermal-heating case via electric-resistive heating. These considerations do not consider the present lack of electrolyte suitable for heat input from the LWR fleet. Overpotentials at the lower electrode can displace heat supply needed for the heat augmentation. At present, these factors suggest that simple electrochemical-cell investigations would determine the viability of the cycle.

Based on the evaluation, and experience in related industries, we can estimate the needed cell performance. The experience in the SOEC-technology family is that the area-specific resistance in a cell is less than 0.5 ohm-cm^2 [4].The equivalent capital ($/Amp) would also need to be similar to or cheaper than the capital cost of SOEC for economic viability. To have current densities similar to aluminum smelters (0.5 A/cm^2) [5], the cell resistance would need to meet a target of 0.1 Ohm cm^2 for a CoP of 1.8. Given the design similarities between the system and an aluminum smelter, this represents a good basis for design. Evaluation of the system in the context of an aluminum smelter describes overpotentials that are expected to be approximately 0.4–0.6 V for the full cell. These overpotentials would indicate the 0.2 V initial overpotential is a valid starting point. Possible adjustments that can be implemented to reduce the overpotential compared to the aluminum-smelter baseline would be the existence of better electrodes—in place of the sacrificial carbon electrodes used in aluminum smelting—and a thinner electrolyte layer.

4. ENERGY ARBITRAGE

The case for energy arbitrage is a flexible operation that is a hybrid between a pure heat-augmentation case and a hydrogen-production case. While the technical targets for the heat-augmentation case still show key barriers, the hydrogen-production case still has a route to producing high-quality heat without substantially impacting hydrogen-production efficiency. Moreover, the molten-metal alloy represents intrinsic hydrogen storage to the system. The alloy can be reduced as low-cost electricity is available, and the decoupled hydrogen-production step can produce hot gas or hydrogen, as needed, to support other operations. The levelized cost of storage (LCOS) is low for this case if using thermal energy and storing hydrogen to produce electrical energy are acceptable. While this system is not better than specialized systems at either task, its flexibility can produce greater economic value than two separate, dedicated systems.

4.1 Levelized Cost of Electricity Storage

The redox cycle is attractive as an electrical-storage system. The electrochemical-reduction step can be operated nearly continuously, regenerating redox-active liquid metal. When it is advantageous to ramp up power production, the zinc can be oxidized rapidly, producing hydrogen that can be immediately burned in a combustion turbine, as illustrated by Figure 15. This approach is attractive because it allows the more expensive capital equipment—i.e., the electrochemical reactor—to be undersized relative to the hydrogen-evolution reactor.

The redox cycle, as modeled in Section 2.3 requires 49.8 kWh-e AC/kg-H_2, with 10.2 kWh-th/kg-H_2 of high-grade heat that is recoverable during continuous operation, but may be more difficult to find a use for in this case, and is not factored into the round-trip efficiency (RTE). The combustion turbine, which was modeled in previous work [3] and described in Appendix B, has a fuel efficiency of 18.6 kWh-e/kg-H_2, which corresponds to 56% thermal efficiency on a LHV basis. This gives a total AC-AC RTE of 37.4%, which could be improved by lowering the overpotential and increasing the Faradaic efficiency.

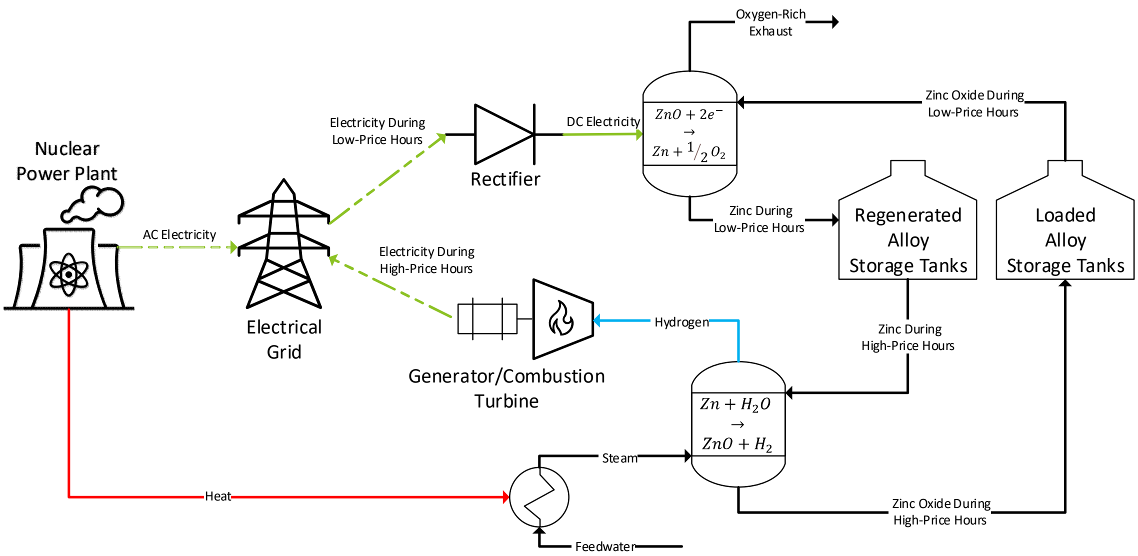

Figure 15. Schematic drawing of a metal-redox cycle used with a hydrogen-combustion turbine for electricity storage.

These numbers and an economic model based on the following assumptions allow the calculation of a relatively simple LCOS, which can be compared to previous work [3]:

- 25-year project lifetime
    - Full investment in Year 0
    - 30% availability in Year 1, 100% availability in Years 2–24
    - Decommissioning in Year 25
- The combustion turbine is operated for 40% the duration of the electrochemical reduction charging cycle, up to once per day
- Fixed operational expenditure (OPEX) of $9.4/kW annually [3, 6]
- $30/MWh-e electricity price for charging cycle and 40% RTE yield a discharge cost of $75/MWh-e
- Redox-cycle equipment cost of $250/kW
- Zinc cost of $2500/ton, corresponding to an ESS capital cost of $8.9/kWh [7]
- Turbine cost of $1060/kWe [3, 6]
- $25k per combustion turbine black-start [3, 6]
- IRR of 12% [3].

The electricity storage costs of the system are plotted in Figure 16 at different duration of storage and expected cycles per year. The capital contribution is very high for short storage durations, but this comes down to a lower level quickly as it approaches full utilization (between 6 and 8 hours stored), where the simplified LCOS is $163/MWh. The variable OPEX is relatively constant because it is primarily composed of the electricity price, which is always assumed to be $30/MWh. It does decrease slightly, corresponding to the decrease in annual startups for the longer-duration storage.

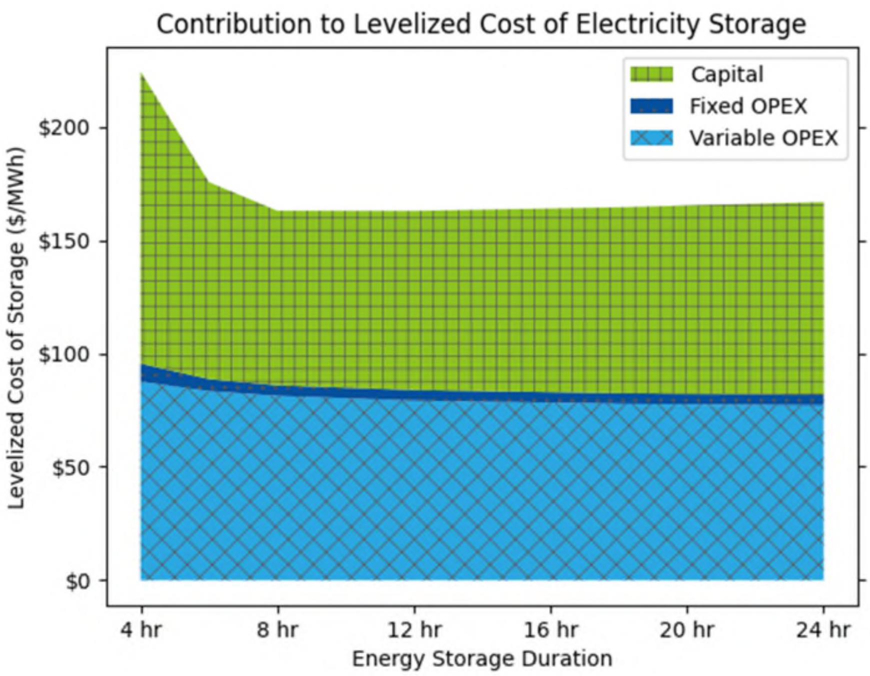

Figure 16. LCOS breakdown for a range of energy-storage durations.

4.2 Levelized Cost of Hydrogen Storage

The system has the potential to store energy for on-demand production of hydrogen in the reduced metal alloy and to regenerate the alloy at a later time. The relative scale of the hydrogen-production reactor and the redox reactor make the system able to store a large amount of hydrogen at a low-to-moderate cost. This arbitrage schematic (see Figure 17) is nearly identical to the electricity-storage case, except the combustion turbine is removed, and a generic batch process takes its place. This batch process may be an intermittent chemical process, or something as simple as filling tube trailers for shipping.

The zinc steam-oxidation reaction allows for fast production. Given the current and historical costs of zinc, the cost per unit capacity of zinc to hydrogen is \$5/kWh HHV or \$195/kg H_2. This provides an economical surge capacity compared to the alternative of storing hydrogen in pressure vessels, by liquefaction, or by other storage methods. With a simple daily cycle of hydrogen storage to ensure near-constant hydrogen availability and attempting to use cheap electrons (either overnight or during solar-peak overproduction), the system is expected to cycle about once a day. With an economic lifetime of 20 years and an IRR of 12%, this gives a hydrogen cost adder of 7¢/kg.

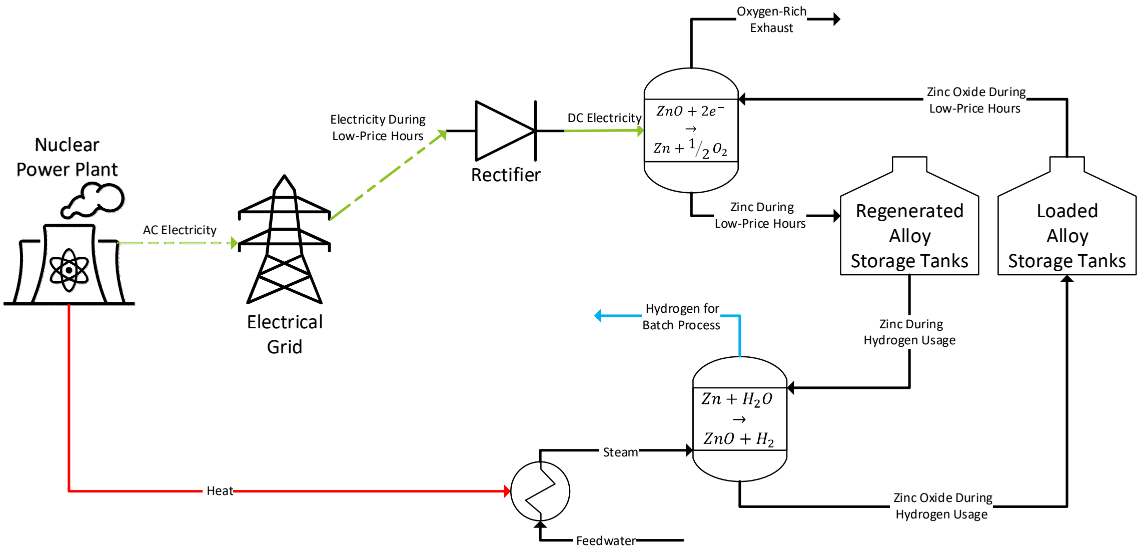

Figure 17. Schematic drawing of metal-redox cycle used for hydrogen storage.

4.3 Levelized Cost of Thermal-Energy Storage

Thermal-energy storage using the redox cycle is a subset of the hydrogen-storage case, as depicted by Figure 18. Heat can be stored in chemical media and accessed in bulk by burning hydrogen when there is a demand for combustion heat, for a capital cost of thermal-energy storage of \$8/kWh. The cost of this heat is electricity because the system largely does not store heat from a thermal source. It uses electricity, which is a higher-cost feedstock, but the heat is available at temperatures comparable to natural-gas-fired heaters, which is an upgrade over the thermal energy available from an LWR.

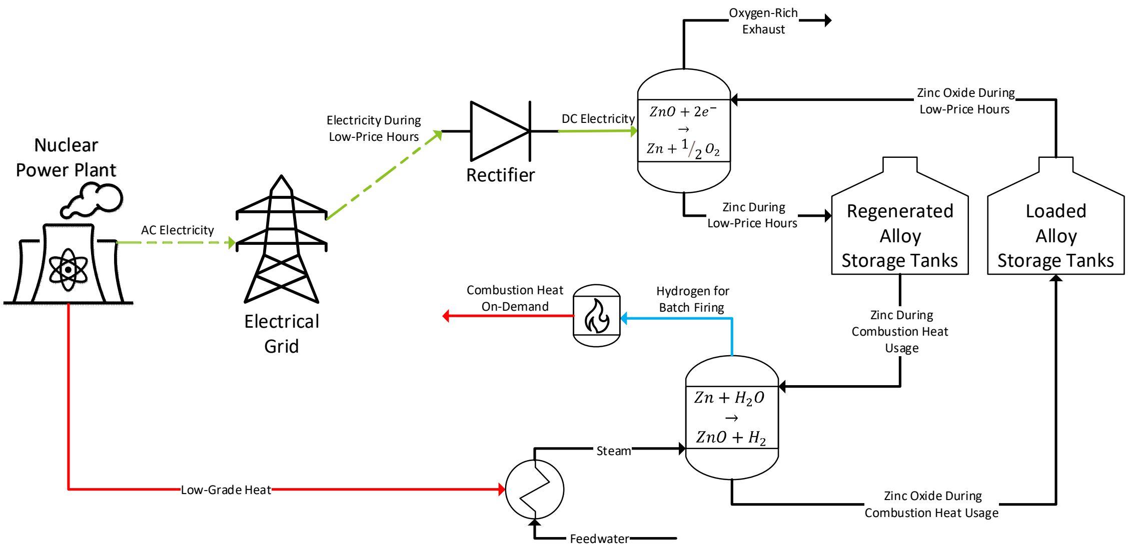

Figure 18. Schematic drawing of metal-redox cycle used for combustion-heat storage.

This ESS is charged by electricity and outputs combustion-grade heat. Given the specific electricity consumption of 49.8 kWh-e AC/kg-H_2 and assuming a 95% stack efficiency on an LHV basis with the recoverable process heat (10.2 kWh-th/kg-H_2) used for combustion air preheating, an 83% AC-to-thermal RTE can be calculated. This, along with the following assumptions, was used to calculate a non-electric LCOS.

- 25-year project lifetime
  - Full investment in Year 0
  - 30% availability in Year 1, 100% availability in Years 2–24
  - Decommissioning in Year 25
- The stored hydrogen is generated and combusted for 83% the duration of the electrochemical-reduction charging cycle, up to once per day
- Fixed OPEX of $3/kW annually
- $30/MWh-e electricity price for charging cycle and 83% RTE yields a discharge cost of $36/MWh-e
- Redox cycle equipment cost of $250/kW
- Zinc cost of $2500/ton corresponding to an ESS capital cost of $8.9/kWh [7]
- IRR of 12% [3].

The thermal-energy storage costs of the system are plotted in Figure 19 at different durations of storage and expected cycles per year. The capital contribution is very high for short durations, but this decreases quickly as the system approaches full utilization (between 10 and 12 hours stored), where the simplified LCOS is $49.61/MWh. The variable OPEX is constant at $36/MWh because it consists entirely of the electricity price.

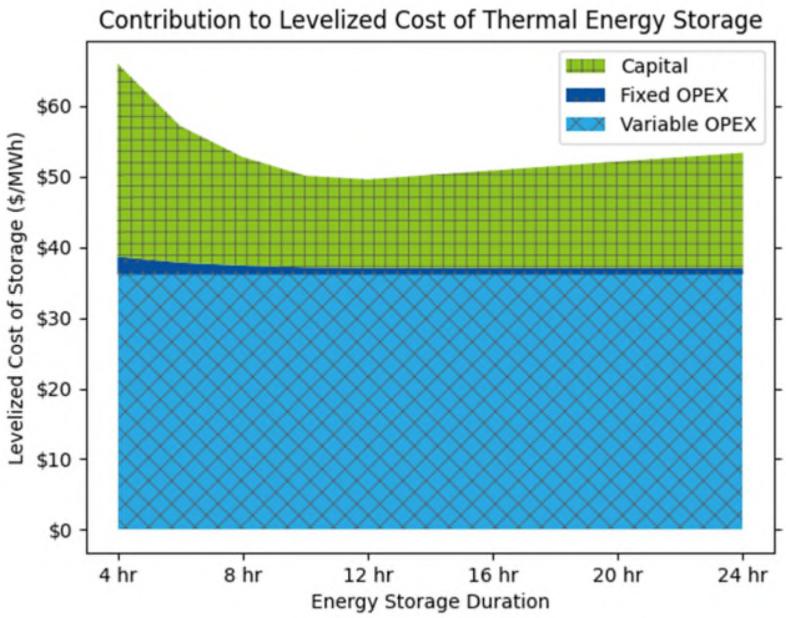

Figure 19. LCOS breakdown for a range of energy-storage durations.

5. FINAL REMARKS

5.1 Future Work

This report details the methodology and results from a study scoping the feasibility of integrating a novel electrochemical metal-redox cycle into an LWR NPP for hydrogen production, heat augmentation, and energy arbitrage. Several considerations would need to undergo further study, including:

- Liquid-metal pumping—it may be feasible to transport the metal/metal-oxide alloys between the two reactors using steam pressure. The thermal-oxidation reactor would be operated at slightly elevated pressure while the electrochemical-reduction reactor would be operated at a higher elevation. With backflow prevention and control-system design, the system could be driven primarily by a low-temperature feedwater pump. This would come at the expense of additional LWR steam because the increased feedwater-boiling point would reduce the recoverable thermal energy from the overhead products.
- Alloy compositions—tin has a very wide liquidus range, which makes it a good candidate carrier metal for the redox cycle. It is also very expensive and may require exotic alloys or coatings; thus, less performant but cheaper metals should be investigated, as should different proportions of zinc and tin.
- Exergy analysis—the redox cycle is a complicated system involving tradeoffs between different types of energy, including low- and high-grade heat, electricity, chemical potential, and combustion heat. An exergy analysis will be conducted to contextualize the system through the ability for each energy stream to do work.
- Improvements to the electrochemical and technoeconomic models—including:
  - Vessel coating and material
  - Physical arrangement of electrochemical step
  - Electrochemical performance details.

5.2 Conclusions

A novel hybrid electrochemical hydrogen production and energy storage system has been developed by SNL. INL has evaluated the basic process arrangements and produced an initial technology screening and techno-economic analysis. The system shows significant potential for hydrogen production. It also has potential to use the intrinsic hydrogen storage capabilities of the liquid metal intermediate. The use of the system as an electrochemical heat pump is likely to be impeded by practical thermodynamics. Exact physical embodiments of the new equipment will be necessary to provide a more accurate assessment of the LCOH. There is potential for improvement over the baseline case presented in this work; however, the sensitivity analysis shows more potential for decreased viability than increased viability. The current level of knowledge could be missing major factors that make the system uneconomical, but the level of practical experience has not identified all of these possible effects. Cross-comparison with other technologies is used to mitigate the risk of these unknown effects, but the risk of major unknown factors is still present.

Based upon the screening effort, an LCOH of $2/kg is predicted. The levelized cost of storage for the technology is dominated by low-to-moderate round trip efficiency. The capital cost contributions to the cost of storage are small relative to the variable operating costs of energy inputs. A flexible system utilizing zinc as an intermediate for hydrogen production as well as hydrogen, thermal, and electrical energy storage may be able to leverage technology in any of the required configurations. The flexibility of the system represents an attractive option for evaluating against conventional dedicated production and storage options.

With respect to hydrogen production, the following conclusions may be made:

- Hydrogen production via the redox cycle requires 49.8 kWh-e AC/kg-H_2
- 10.2 kWh-th/kg-H_2 high-grade heat is recoverable for chemical process integration during continuous operation at temperatures between 550°C and 845°C
- The LCOH is $1.82/kg H_2 and at best may be as low as $1.62/kg.
- The process has the greatest sensitivity to feedstock (e.g., DC power) consumption

Reconfiguring the process for heat augmentation, the following conclusions may be made

- For an ideal heat pump, the process achieves a coefficient of performance of 2.96
- Adding the overpotential work from both electrodes however reduces the COP to 0.98
- A maximum capital-cost ratio of 1.6 for the ideal CoP and 1.3 for the practical CoP are acceptable targets for system-breakeven costs

Using the process for energy arbitrage:

- Hydrogen may be stored as zinc during periods of low cost electricity
- Hydrogen may be generated with the thermal oxidation process and either burned to produce electricity in turbines during periods of high-cost electricity or used by process heat applications
- The LCOS for electricity storage is $163/MWh-e at full utilization (between 6 and 8 hours stored)
- The LCOS for thermal storage is $49.61/MWh-th at full utilization (between 10 and 12 hours stored).
- The contribution to the LCOH of storing hydrogen in the form of reduced zinc is 7¢/kg-H_2.

6. References

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Appendix A

Electrochemical Metal Redox Cycle Process Modeling

The main flowsheet of the process model is included as Figure A1, with stream tables following.

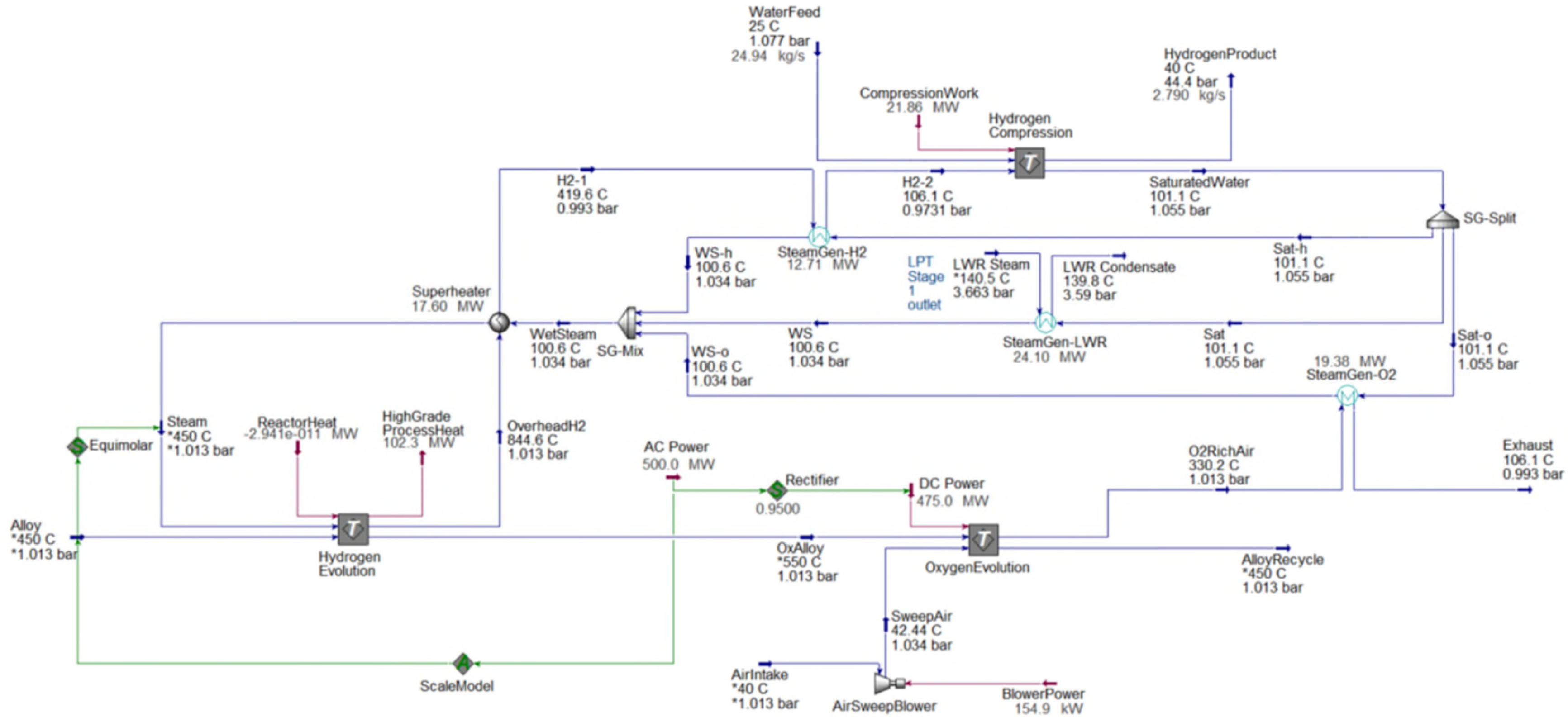

Figure A1. Redox-cycle process model main flowsheet.

Material Stream: Steam

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

	Overall	Vapour Phase			
Vapour / Phase Fraction	1.0000	1.0000			
Temperature: (C)	450.0 *	450.0			
Pressure: (bar)	1.013 *	1.013			
Molar Flow (kgmole/h)	4985	4985			
Mass Flow (kg/s)	24.94	24.94			
Std Ideal Liq Vol Flow (m3/h)	89.98	89.98			
Molar Enthalpy (kJ/kgmole)	-2.259e+005	-2.259e+005			
Molar Entropy (kJ/kgmole-C)	156.5	156.5			
Heat Flow (MW)	-312.8	-312.8			
Liq Vol Flow @Std Cond (m3/h)	89.88 *	89.88			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660 *	1.0000 *	89797.4575 *	1.0000 *	89.9787 *	1.0000 *
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Material Stream: Alloy

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

	Overall	Liquid Phase			
Vapour / Phase Fraction	0.0000	1.0000			
Temperature: (C)	450.0 *	450.0			
Pressure: (bar)	1.013 *	1.013			
Molar Flow (kgmole/h)	3.988e+004 *	3.988e+004			
Mass Flow (kg/s)	1241	1241			
Std Ideal Liq Vol Flow (m3/h)	6826	6826			
Molar Enthalpy (kJ/kgmole)	1.850e+004	1.850e+004			
Molar Entropy (kJ/kgmole-C)	40.85	40.85			
Heat Flow (MW)	205.0	205.0			
Liq Vol Flow @Std Cond (m3/h)	3.489e+109 *	3.489e+109			

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.5660 *	0.1250 *	325940.7714 *	0.0730 *	46.9437 *	0.0069 *
Zinc-Oxide	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Nitrogen	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Oxygen	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Water	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *

* Specified by user.

Material Stream: Alloy (continued)

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

COMPOSITION

Overall Phase (continued)

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Tin-White	34891.9621 *	0.8750 *	4.142024817e+06 *	0.9270 *	6778.9151 *	0.9931 *
Hydrogen	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Total	39876.5281	1.0000	4.467965589e+06	1.0000	6825.8588	1.0000

Liquid Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.5660	0.1250	325940.7714	0.0730	46.9437	0.0069
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8750	4.142024817e+06	0.9270	6778.9151	0.9931
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	39876.5281	1.0000	4.467965589e+06	1.0000	6825.8588	1.0000

Material Stream: OxAlloy

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Liquid Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	550.0 *	550.0			
Pressure:	(bar)	1.013	1.013			
Molar Flow	(kgmole/h)	3.988e+004	3.988e+004			
Mass Flow	(kg/s)	1263	1263			
Std Ideal Liq Vol Flow	(m3/h)	7747	7747			
Molar Enthalpy	(kJ/kgmole)	-1.305e+004	-1.305e+004			
Molar Entropy	(kJ/kgmole-C)	62.26	62.26			
Heat Flow	(MW)	-144.6	-144.6			
Liq Vol Flow @Std Cond	(m3/h)	3.489e+109 *	3.489e+109			

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000

* Specified by user.

Material Stream: OxAlloy (continued)

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

COMPOSITION

Liquid Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000

Material Stream: AlloyRecycle

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Liquid Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	450.0 *	450.0			
Pressure:	(bar)	1.013	1.013			
Molar Flow	(kgmole/h)	3.988e+004	3.988e+004			
Mass Flow	(kg/s)	1241	1241			
Std Ideal Liq Vol Flow	(m3/h)	6826	6826			
Molar Enthalpy	(kJ/kgmole)	1.854e+004	1.854e+004			
Molar Entropy	(kJ/kgmole-C)	40.90	40.90			
Heat Flow	(MW)	205.4	205.4			
Liq Vol Flow @Std Cond	(m3/h)	3.489e+109 *	3.489e+109			

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388	0.0069
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457	0.0001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151	0.9931
Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002	0.0000
Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998	1.0000

Liquid Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388	0.0069
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457	0.0001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151	0.9931

* Specified by user.

Material Stream: AlloyRecycle (continued)

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

COMPOSITION

Liquid Phase (continued)

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002	0.0000
Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998	1.0000

Material Stream: H2-2

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	106.1	106.1	106.1		
Pressure:	(bar)	0.9731	0.9731	0.9731		
Molar Flow	(kgmole/h)	4982	4982	5.285e-005		
Mass Flow	(kg/s)	2.790	2.790	1.195e-006		
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8	1.027e-005		
Molar Enthalpy	(kJ/kgmole)	2353	2353	-2.205e+005		
Molar Entropy	(kJ/kgmole-C)	7.310	7.310	4.743		
Heat Flow	(MW)	3.256	3.256	-3.237e-006		
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.222e+063	2.650e+063		

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0005	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6425	1.0000	266.8124	1.0000

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name:	Production.hsc
		Unit Set:	AmeyS2e
		Date/Time:	Fri Mar 29 15:06:27 2024

Material Stream: H2-2 (continued)

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

COMPOSITION

Liquid Phase — Phase Fraction 1.061e-008

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.9998	0.0043	1.0000	0.0000	1.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Total	0.0001	1.0000	0.0043	1.0000	0.0000	1.0000

Material Stream: Exhaust

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	106.1	106.1	106.1		
Pressure:	(bar)	0.9930	0.9930	0.9930		
Molar Flow	(kgmole/h)	1.032e+004	1.032e+004	0.5160		
Mass Flow	(kg/s)	84.88	84.87	9.372e-003		
Std Ideal Liq Vol Flow	(m3/h)	552.8	552.8	4.860e-003		
Molar Enthalpy	(kJ/kgmole)	2373	2375	-4.719e+004		
Molar Entropy	(kJ/kgmole-C)	12.83	12.83	-25.51		
Heat Flow	(MW)	6.803	6.810	-6.764e-003		
Liq Vol Flow @Std Cond	(m3/h)	858.4 *	858.4	4.930e-003		

COMPOSITION

Overall Phase — Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.5160	0.0000	33.7408	0.0001	0.0049	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	6189.5823	0.5996	173391.7402	0.5674	331.5004	0.5997
Oxygen	4129.2924	0.4000	132132.4006	0.4324	221.1558	0.4001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	2.7980	0.0003	5.6405	0.0000	0.1499	0.0003
Total	10322.1887	1.0000	305563.5221	1.0000	552.8109	1.0000

Vapour Phase — Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	6189.5823	0.5997	173391.7402	0.5675	331.5004	0.5997
Oxygen	4129.2924	0.4001	132132.4006	0.4325	221.1558	0.4001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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* Specified by user.

Material Stream: Exhaust (continued)

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

COMPOSITION

Vapour Phase (continued)

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Hydrogen	2.7980	0.0003	5.6405	0.0000	0.1499	0.0003
Total	10321.6727	1.0000	305529.7813	1.0000	552.8061	1.0000

Liquid Phase

Phase Fraction 4.999e-005

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.5160	1.0000	33.7408	1.0000	0.0049	1.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.5160	1.0000	33.7408	1.0000	0.0049	1.0000

Material Stream: HydrogenProduct

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	40.00	40.00	40.00		
Pressure:	(bar)	44.40	44.40	44.40		
Molar Flow	(kgmole/h)	4982	4982	6.027e-005		
Mass Flow	(kg/s)	2.790	2.790	1.359e-006		
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8	1.166e-005		
Molar Enthalpy	(kJ/kgmole)	462.8	462.8	-2.189e+005		
Molar Entropy	(kJ/kgmole-C)	-30.09	-30.09	-6.628		
Heat Flow	(MW)	0.6404	0.6404	-3.665e-006		
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	5.849e+063	1.875e+070		

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name:	Production.hsc
		Unit Set:	AmeyS2e
		Date/Time:	Fri Mar 29 15:06:27 2024

Material Stream: HydrogenProduct (continuec

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

COMPOSITION

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7648	1.0000	10042.6419	1.0000	266.8124	1.0000

Liquid Phase

Phase Fraction 1.210e-008

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.9874	0.0048	0.9897	0.0000	0.9915
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0069	0.0000	0.0101	0.0000	0.0070
Hydrogen	0.0000	0.0057	0.0000	0.0001	0.0000	0.0016
Total	0.0001	1.0000	0.0049	1.0000	0.0000	1.0000

Material Stream: O2RichAir

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	330.2	330.2	330.2		
Pressure:	(bar)	1.013	1.013	1.013		
Molar Flow	(kgmole/h)	1.032e+004	1.032e+004	0.5159		
Mass Flow	(kg/s)	84.88	84.87	9.370e-003		
Std Ideal Liq Vol Flow	(m3/h)	552.8	552.8	4.858e-003		
Molar Enthalpy	(kJ/kgmole)	9132	9134	-3.636e+004		
Molar Entropy	(kJ/kgmole-C)	26.64	26.64	-2.978		
Heat Flow	(MW)	26.18	26.19	-5.210e-003		
Liq Vol Flow @Std Cond	(m3/h)	858.4 *	858.4	4.929e-003		

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.5160	0.0000	33.7408	0.0001	0.0049	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	6189.5823	0.5996	173391.7402	0.5674	331.5004	0.5997
Oxygen	4129.2924	0.4000	132132.4006	0.4324	221.1558	0.4001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

* Specified by user.

Material Stream: O2RichAir (continued)

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

COMPOSITION

Overall Phase (continued)

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Hydrogen	2.7980	0.0003	5.6405	0.0000	0.1499	0.0003
Total	10322.1887	1.0000	305563.5221	1.0000	552.8109	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0001	0.0000	0.0092	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	6189.5823	0.5997	173391.7402	0.5675	331.5004	0.5997
Oxygen	4129.2924	0.4001	132132.4006	0.4325	221.1558	0.4001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	2.7980	0.0003	5.6405	0.0000	0.1499	0.0003
Total	10321.6728	1.0000	305529.7905	1.0000	552.8061	1.0000

Liquid Phase

Phase Fraction 4.998e-005

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.5159	1.0000	33.7316	1.0000	0.0049	1.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.5159	1.0000	33.7316	1.0000	0.0049	1.0000

Material Stream: SweepAir

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase
Vapour / Phase Fraction		1.0000	1.0000
Temperature:	(C)	42.44	42.44
Pressure:	(bar)	1.034	1.034
Molar Flow	(kgmole/h)	7835	7835
Mass Flow	(kg/s)	62.79	62.79
Std Ideal Liq Vol Flow	(m3/h)	419.6	419.6
Molar Enthalpy	(kJ/kgmole)	501.6	501.6
Molar Entropy	(kJ/kgmole-C)	5.744	5.744
Heat Flow	(MW)	1.092	1.092
Liq Vol Flow @Std Cond	(m3/h)	675.1 *	675.1

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name:	Production.hsc
		Unit Set:	AmeyS2e
		Date/Time:	Fri Mar 29 15:06:27 2024

Material Stream: SweepAir (continued)

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004	0.7900
Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204	0.2100
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004	0.7900
Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204	0.2100
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000

Material Stream: AirIntake

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase
Vapour / Phase Fraction		1.0000	1.0000
Temperature:	(C)	40.00 *	40.00
Pressure:	(bar)	1.013 *	1.013
Molar Flow	(kgmole/h)	7835	7835
Mass Flow	(kg/s)	62.79	62.79
Std Ideal Liq Vol Flow	(m3/h)	419.6	419.6
Molar Enthalpy	(kJ/kgmole)	430.4	430.4
Molar Entropy	(kJ/kgmole-C)	5.688	5.688
Heat Flow	(MW)	0.9367	0.9367
Liq Vol Flow @Std Cond	(m3/h)	675.1 *	675.1

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004	0.7900
Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204	0.2100
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name: Production.hsc Unit Set: AmeyS2e Date/Time: Fri Mar 29 15:06:27 2024

Material Stream: AirIntake (continued)

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

COMPOSITION

Overall Phase (continued)

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004	0.7900
Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204	0.2100
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000

Material Stream: Sat-o

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Aqueous Phase	Vapour Phase		
Vapour / Phase Fraction		0.0000 *	1.0000	0.0000		
Temperature:	(C)	101.1	101.1	101.1		
Pressure:	(bar)	1.055	1.055	1.055		
Molar Flow	(kgmole/h)	1719	1719	0.0000		
Mass Flow	(kg/s)	8.603	8.603	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	31.03	31.03	0.0000		
Molar Enthalpy	(kJ/kgmole)	-2.792e+005	-2.792e+005	-2.386e+005		
Molar Entropy	(kJ/kgmole-C)	23.77	23.77	132.2		
Heat Flow	(MW)	-133.4	-133.4	0.0000		
Liq Vol Flow @Std Cond	(m3/h)	31.00 *	31.00	0.0000		

COMPOSITION

Overall Phase

Vapour Fraction 0.0000 *

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	1719.2431 *	1.0000 *	30972.3369 *	1.0000 *	31.0348 *	1.0000 *
Total	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000

Aqueous Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000
Total	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000

* Specified by user.

Material Stream: Sat-o (continued)

Fluid Package: Steam
Property Package: NBS Steam

COMPOSITION

Vapour Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Material Stream: WS-o

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction		1.0000 *	1.0000	0.0000		
Temperature:	(C)	100.6	100.6	100.6		
Pressure:	(bar)	1.034	1.034	1.034		
Molar Flow	(kgmole/h)	1719	1719	0.0000		
Mass Flow	(kg/s)	8.603	8.603	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	31.03	31.03	0.0000		
Molar Enthalpy	(kJ/kgmole)	-2.387e+005	-2.387e+005	-2.793e+005		
Molar Entropy	(kJ/kgmole-C)	132.4	132.4	23.66		
Heat Flow	(MW)	-114.0	-114.0	0.0000		
Liq Vol Flow @Std Cond	(m3/h)	31.00 *	31.00	0.0000		

COMPOSITION

Overall Phase

Vapour Fraction 1.0000 *

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000
Total	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000
Total	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000

Aqueous Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Material Stream: H2-1

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	419.6	419.6			
Pressure:	(bar)	0.9930	0.9930			
Molar Flow	(kgmole/h)	4982	4982			

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name: Production.hsc Unit Set: AmeyS2e Date/Time: Fri Mar 29 15:06:27 2024

Material Stream: H2-1 (continued)

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase			
Mass Flow	(kg/s)	2.790	2.790			
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8			
Molar Enthalpy	(kJ/kgmole)	1.154e+004	1.154e+004			
Molar Entropy	(kJ/kgmole-C)	24.79	24.79			
Heat Flow	(MW)	15.97	15.97			
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.222e+063			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Material Stream: WetSteam

Fluid Package: Steam

Property Package: NBS Steam

CONDITIONS

		Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction		1.0000 *	1.0000	0.0000		
Temperature:	(C)	100.6	100.6	100.6		
Pressure:	(bar)	1.034	1.034	1.034		
Molar Flow	(kgmole/h)	4985	4985	0.0000		
Mass Flow	(kg/s)	24.94	24.94	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	89.98	89.98	0.0000		
Molar Enthalpy	(kJ/kgmole)	-2.387e+005	-2.387e+005	-2.793e+005		
Molar Entropy	(kJ/kgmole-C)	132.4	132.4	23.66		
Heat Flow	(MW)	-330.4	-330.4	0.0000		
Liq Vol Flow @Std Cond	(m3/h)	89.88 *	89.88	0.0000		

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name: Production.hsc Unit Set: AmeyS2e Date/Time: Fri Mar 29 15:06:27 2024

Material Stream: WetSteam (continued)

Fluid Package: Steam
Property Package: NBS Steam

COMPOSITION

Overall Phase

Vapour Fraction 1.0000 *

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Aqueous Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Material Stream: WS-h

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction		1.0000 *	1.0000	0.0000		
Temperature:	(C)	100.6	100.6	100.6		
Pressure:	(bar)	1.034	1.034	1.034		
Molar Flow	(kgmole/h)	1128	1128	0.0000		
Mass Flow	(kg/s)	5.643	5.643	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	20.36	20.36	0.0000		
Molar Enthalpy	(kJ/kgmole)	-2.387e+005	-2.387e+005	-2.793e+005		
Molar Entropy	(kJ/kgmole-C)	132.4	132.4	23.66		
Heat Flow	(MW)	-74.75	-74.75	0.0000		
Liq Vol Flow @Std Cond	(m3/h)	20.33 *	20.33	0.0000		

COMPOSITION

Overall Phase

Vapour Fraction 1.0000 *

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	1127.6444 *	1.0000 *	20314.6270 *	1.0000 *	20.3556 *	1.0000 *
Total	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000
Total	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000

* Specified by user.

Material Stream: WS-h (continued)

Fluid Package: Steam
Property Package: NBS Steam

COMPOSITION

Aqueous Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Material Stream: WS

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	100.6	100.6			
Pressure:	(bar)	1.034	1.034			
Molar Flow	(kgmole/h)	2138	2138			
Mass Flow	(kg/s)	10.70	10.70			
Std Ideal Liq Vol Flow	(m3/h)	38.59	38.59			
Molar Enthalpy	(kJ/kgmole)	-2.387e+005	-2.387e+005			
Molar Entropy	(kJ/kgmole-C)	132.4	132.4			
Heat Flow	(MW)	-141.7	-141.7			
Liq Vol Flow @Std Cond	(m3/h)	38.54 *	38.54			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2137.6785 *	1.0000 *	38510.4936 *	1.0000 *	38.5882 *	1.0000 *
Total	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000
Total	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000

Material Stream: Sat-h

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Aqueous Phase	Vapour Phase		
Vapour / Phase Fraction		0.0000 *	1.0000	0.0000		
Temperature:	(C)	101.1	101.1	101.1		
Pressure:	(bar)	1.055	1.055	1.055		
Molar Flow	(kgmole/h)	1128	1128	0.0000		
Mass Flow	(kg/s)	5.643	5.643	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	20.36	20.36	0.0000		
Molar Enthalpy	(kJ/kgmole)	-2.792e+005	-2.792e+005	-2.386e+005		
Molar Entropy	(kJ/kgmole-C)	23.77	23.77	132.2		
Heat Flow	(MW)	-87.47	-87.47	0.0000		
Liq Vol Flow @Std Cond	(m3/h)	20.33 *	20.33	0.0000		

* Specified by user.

Material Stream: Sat-h (continued)

Fluid Package: Steam

Property Package: NBS Steam

COMPOSITION

Overall Phase

Vapour Fraction 0.0000 *

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000
Total	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000

Aqueous Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000
Total	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000

Vapour Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Material Stream: Sat

Fluid Package: Steam

Property Package: NBS Steam

CONDITIONS

		Overall	Aqueous Phase	Vapour Phase		
Vapour / Phase Fraction		0.0000 *	1.0000	0.0000		
Temperature:	(C)	101.1	101.1	101.1		
Pressure:	(bar)	1.055	1.055	1.055		
Molar Flow	(kgmole/h)	2138	2138	0.0000		
Mass Flow	(kg/s)	10.70	10.70	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	38.59	38.59	0.0000		
Molar Enthalpy	(kJ/kgmole)	-2.792e+005	-2.792e+005	-2.386e+005		
Molar Entropy	(kJ/kgmole-C)	23.77	23.77	132.2		
Heat Flow	(MW)	-165.8	-165.8	0.0000		
Liq Vol Flow @Std Cond	(m3/h)	38.54 *	38.54	0.0000		

COMPOSITION

Overall Phase

Vapour Fraction 0.0000 *

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000
Total	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000

Aqueous Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000
Total	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000

* Specified by user.

Material Stream: Sat (continued)

Fluid Package: Steam
Property Package: NBS Steam

COMPOSITION

Vapour Phase Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Material Stream: SaturatedWater

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Aqueous Phase	Vapour Phase		
Vapour / Phase Fraction		0.0000	1.0000	0.0000		
Temperature:	(C)	101.1	101.1	101.1		
Pressure:	(bar)	1.055	1.055	1.055		
Molar Flow	(kgmole/h)	4985	4985	0.0000		
Mass Flow	(kg/s)	24.94	24.94	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	89.98	89.98	0.0000		
Molar Enthalpy	(kJ/kgmole)	-2.792e+005	-2.792e+005	-2.386e+005		
Molar Entropy	(kJ/kgmole-C)	23.77	23.77	132.2		
Heat Flow	(MW)	-386.6	-386.6	0.0000		
Liq Vol Flow @Std Cond	(m3/h)	89.88 *	89.88	0.0000		

COMPOSITION

Overall Phase Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Aqueous Phase Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Vapour Phase Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Material Stream: WaterFeed

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	25.00	25.00			
Pressure:	(bar)	1.077	1.077			
Molar Flow	(kgmole/h)	4985	4985			

* Specified by user.

Material Stream: WaterFeed (continued)

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Aqueous Phase			
Mass Flow	(kg/s)	24.94	24.94			
Std Ideal Liq Vol Flow	(m3/h)	89.98	89.98			
Molar Enthalpy	(kJ/kgmole)	-2.850e+005	-2.850e+005			
Molar Entropy	(kJ/kgmole-C)	6.610	6.610			
Heat Flow	(MW)	-394.6	-394.6			
Liq Vol Flow @Std Cond	(m3/h)	89.88 *	89.88			

COMPOSITION

Overall Phase Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Aqueous Phase Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Material Stream: OverheadH2

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	844.6	844.6			
Pressure:	(bar)	1.013	1.013			
Molar Flow	(kgmole/h)	4982	4982			
Mass Flow	(kg/s)	2.790	2.790			
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8			
Molar Enthalpy	(kJ/kgmole)	2.426e+004	2.426e+004			
Molar Entropy	(kJ/kgmole-C)	38.92	38.92			
Heat Flow	(MW)	33.57	33.57			
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.222e+063			

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

* Specified by user.

Material Stream: OverheadH2 (continued)

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

COMPOSITION

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Material Stream: LWR Condensate

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Aqueous Phase	Vapour Phase		
Vapour / Phase Fraction		0.0000 *	1.0000	0.0000		
Temperature:	(C)	139.8	139.8	139.8		
Pressure:	(bar)	3.590	3.590	3.590		
Molar Flow	(kgmole/h)	2244	2244	0.0000		
Mass Flow	(kg/s)	11.23	11.23	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	40.50	40.50	0.0000		
Molar Enthalpy	(kJ/kgmole)	-2.763e+005	-2.763e+005	-2.376e+005		
Molar Entropy	(kJ/kgmole-C)	31.29	31.29	124.9		
Heat Flow	(MW)	-172.2	-172.2	0.0000		
Liq Vol Flow @Std Cond	(m3/h)	40.46 *	40.46	0.0000		

COMPOSITION

Overall Phase

Vapour Fraction 0.0000 *

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000
Total	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000

Aqueous Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000
Total	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000

Vapour Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name:	Production.hsc
		Unit Set:	AmeyS2e
		Date/Time:	Fri Mar 29 15:06:27 2024

Material Stream: LWR Steam

Fluid Package: Steam

Property Package: NBS Steam

CONDITIONS

		Overall	Vapour Phase	Aqueous Phase		
Vapour / Phase Fraction		1.0000 *	1.0000	0.0000		
Temperature:	(C)	140.5 *	140.5	140.5		
Pressure:	(bar)	3.663	3.663	3.663		
Molar Flow	(kgmole/h)	2244	2244	0.0000		
Mass Flow	(kg/s)	11.23	11.23	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	40.50	40.50	0.0000		
Molar Enthalpy	(kJ/kgmole)	-2.376e+005	-2.376e+005	-2.762e+005		
Molar Entropy	(kJ/kgmole-C)	124.8	124.8	31.43		
Heat Flow	(MW)	-148.1	-148.1	0.0000		
Liq Vol Flow @Std Cond	(m3/h)	40.46 *	40.46	0.0000		

COMPOSITION

Overall Phase

Vapour Fraction 1.0000 *

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2243.8604 *	1.0000 *	40423.3697 *	1.0000 *	40.5049 *	1.0000 *
Total	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000
Total	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000

Aqueous Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Energy Stream: ReactorHeat

Fluid Package: Reaction

Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	SolveTemp @HER		
Duty SP:	-2.941e-011 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Energy Stream: DC Power

Fluid Package: Reaction

Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	SolveTemp @OER		
Duty SP:	475.0 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Energy Stream: AC Power

Fluid Package: Reaction

Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Rectifier		
Duty SP:	500.0 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name:	Production.hsc
		Unit Set:	AmeyS2e
		Date/Time:	Fri Mar 29 15:06:27 2024

Energy Stream: CompressionWork

Fluid Package: Reaction

Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:			
Duty SP:	21.86 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Energy Stream: BlowerPower

Fluid Package: Reaction

Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	AirSweepBlower		
Duty SP:	0.1549 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Energy Stream: HighGrade ProcessHeat

Fluid Package: Reaction

Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:			
Duty SP:	102.3 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

* Specified by user.

The hydrogen-evolution reactor sub-flowsheet of the process model is included as Figure A2, with stream tables following.

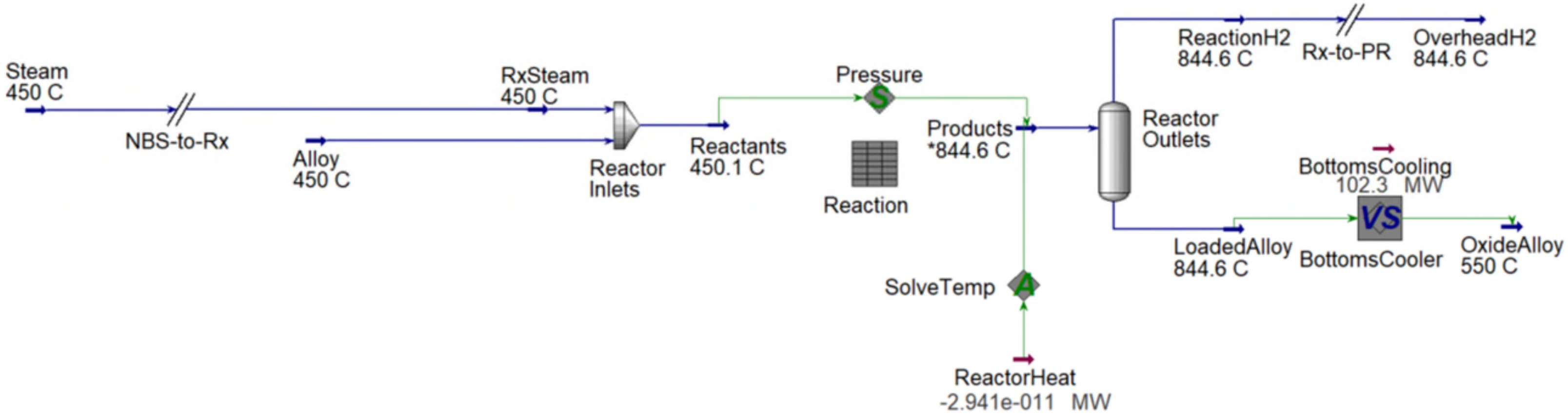

Figure A2. Redox-cycle process model hydrogen-evolution sub-flowsheet.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name:	Production.hsc
		Unit Set:	AmeyS2e
		Date/Time:	Fri Mar 29 15:31:10 2024

Material Stream: Steam

Fluid Package: Steam

Property Package: NBS Steam

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	450.0	450.0			
Pressure:	(bar)	1.013	1.013			
Molar Flow	(kgmole/h)	4985	4985			
Mass Flow	(kg/s)	24.94	24.94			
Std Ideal Liq Vol Flow	(m3/h)	89.98	89.98			
Molar Enthalpy	(kJ/kgmole)	-2.259e+005	-2.259e+005			
Molar Entropy	(kJ/kgmole-C)	156.5	156.5			
Heat Flow	(MW)	-312.8	-312.8			
Liq Vol Flow @Std Cond	(m3/h)	89.88 *	89.88			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Material Stream: Alloy

Fluid Package: Reaction

Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Liquid Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	450.0	450.0			
Pressure:	(bar)	1.013	1.013			
Molar Flow	(kgmole/h)	3.988e+004	3.988e+004			
Mass Flow	(kg/s)	1241	1241			
Std Ideal Liq Vol Flow	(m3/h)	6826	6826			
Molar Enthalpy	(kJ/kgmole)	1.850e+004	1.850e+004			
Molar Entropy	(kJ/kgmole-C)	40.85	40.85			
Heat Flow	(MW)	205.0	205.0			
Liq Vol Flow @Std Cond	(m3/h)	3.489e+109 *	3.489e+109			

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.5660	0.1250	325940.7714	0.0730	46.9437	0.0069
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

* Specified by user.

Material Stream: Alloy (continued)

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

COMPOSITION

Overall Phase (continued)

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Tin-White	34891.9621	0.8750	4.142024817e+06	0.9270	6778.9151	0.9931
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	39876.5281	1.0000	4.467965589e+06	1.0000	6825.8588	1.0000

Liquid Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.5660	0.1250	325940.7714	0.0730	46.9437	0.0069
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8750	4.142024817e+06	0.9270	6778.9151	0.9931
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	39876.5281	1.0000	4.467965589e+06	1.0000	6825.8588	1.0000

Material Stream: Reactants

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		0.1110	0.1110	0.8890		
Temperature:	(C)	450.1	450.1	450.1		
Pressure:	(bar)	1.013	1.013	1.013		
Molar Flow	(kgmole/h)	4.486e+004	4978	3.988e+004		
Mass Flow	(kg/s)	1266	24.91	1241		
Std Ideal Liq Vol Flow	(m3/h)	6916	89.85	6826		
Molar Enthalpy	(kJ/kgmole)	-8748	-2.267e+005	1.846e+004		
Molar Entropy	(kJ/kgmole-C)	34.84	-13.28	40.85		
Heat Flow	(MW)	-109.0	-313.5	204.5		
Liq Vol Flow @Std Cond	(m3/h)	3.489e+109 *	89.84	3.489e+109		

COMPOSITION

Overall Phase

Vapour Fraction 0.1110

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.5660	0.1111	325940.7714	0.0715	46.9437	0.0068
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	4984.5660	0.1111	89798.3523	0.0197	89.9714	0.0130
Tin-White	34891.9621	0.7778	4.142024817e+06	0.9088	6778.9151	0.9802
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	44861.0941	1.0000	4.557763941e+06	1.0000	6915.8302	1.0000

* Specified by user.

Material Stream: Reactants (continued)

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

COMPOSITION

Vapour Phase

Phase Fraction 0.1110

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.3083	0.0001	20.1580	0.0002	0.0029	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	4977.6530	0.9999	89673.8131	0.9998	89.8466	1.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	4977.9613	1.0000	89693.9710	1.0000	89.8495	1.0000

Liquid Phase

Phase Fraction 0.8890

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.2577	0.1250	325920.6134	0.0729	46.9408	0.0069
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	6.9130	0.0002	124.5393	0.0000	0.1248	0.0000
Tin-White	34891.9621	0.8749	4.142024817e+06	0.9270	6778.9151	0.9931
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	39883.1328	1.0000	4.468069970e+06	1.0000	6825.9806	1.0000

Material Stream: Products

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		0.1110	0.1110	0.8890		
Temperature:	(C)	844.6 *	844.6	844.6		
Pressure:	(bar)	1.013	1.013	1.013		
Molar Flow	(kgmole/h)	4.486e+004 *	4982	3.988e+004		
Mass Flow	(kg/s)	1266	2.790	1263		
Std Ideal Liq Vol Flow	(m3/h)	8014	266.8	7747		
Molar Enthalpy	(kJ/kgmole)	1389	2.426e+004	-1468		
Molar Entropy	(kJ/kgmole-C)	64.87	38.91	68.11		
Heat Flow	(MW)	17.30	33.57	-16.26		
Liq Vol Flow @Std Cond	(m3/h)	3.489e+109 *	1.555e+100	3.489e+109		

COMPOSITION

Overall Phase

Vapour Fraction 0.1110

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	4984.5660	0.1111	405690.8368	0.0890	968.4164	0.1208
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.7778	4.142024817e+06	0.9088	6778.9151	0.8459

* Specified by user.

Material Stream: Products (continued)

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

COMPOSITION

Overall Phase (continued)

Vapour Fraction 0.1110

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Hydrogen	4984.5660	0.1111	10048.2869	0.0022	266.9624	0.0333
Total	44861.0941	1.0000	4.557763941e+06	1.0000	8014.2939	1.0000

Vapour Phase

Phase Fraction 0.1110

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Liquid Phase

Phase Fraction 0.8890

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000

Material Stream: ReactionH2

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	844.6	844.6	844.6		
Pressure:	(bar)	1.013	1.013	1.013		
Molar Flow	(kgmole/h)	4982	4982	0.0000		
Mass Flow	(kg/s)	2.790	2.790	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8	0.0000		
Molar Enthalpy	(kJ/kgmole)	2.426e+004	2.426e+004	-1468		
Molar Entropy	(kJ/kgmole-C)	38.91	38.91	68.11		
Heat Flow	(MW)	33.57	33.57	0.0000		
Liq Vol Flow @Std Cond	(m3/h)	1.555e+100 *	1.555e+100	0.0000		

* Specified by user.

Material Stream: ReactionH2 (continued)

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Liquid Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.1250	0.0000	0.0892	0.0000	0.1250
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.8749	0.0000	0.9108	0.0000	0.8750
Hydrogen	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Material Stream: LoadedAlloy

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		0.0000	0.0000	1.0000		
Temperature:	(C)	844.6	844.6	844.6		
Pressure:	(bar)	1.013	1.013	1.013		
Molar Flow	(kgmole/h)	3.988e+004	0.0000	3.988e+004		
Mass Flow	(kg/s)	1263	0.0000	1263		
Std Ideal Liq Vol Flow	(m3/h)	7747	0.0000	7747		
Molar Enthalpy	(kJ/kgmole)	-1468	2.426e+004	-1468		
Molar Entropy	(kJ/kgmole-C)	68.11	38.91	68.11		
Heat Flow	(MW)	-16.26	0.0000	-16.26		
Liq Vol Flow @Std Cond	(m3/h)	3.489e+109 *	0.0000	3.489e+109		

* Specified by user.

Material Stream: LoadedAlloy (continued)

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000

Vapour Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Liquid Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000

Material Stream: OxideAlloy

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Liquid Phase
Vapour / Phase Fraction		0.0000	1.0000
Temperature:	(C)	550.0	550.0
Pressure:	(bar)	1.013	1.013
Molar Flow	(kgmole/h)	3.988e+004	3.988e+004
Mass Flow	(kg/s)	1263	1263
Std Ideal Liq Vol Flow	(m3/h)	7747	7747
Molar Enthalpy	(kJ/kgmole)	-1.305e+004	-1.305e+004
Molar Entropy	(kJ/kgmole-C)	62.26	62.26
Heat Flow	(MW)	-144.6	-144.6
Liq Vol Flow @Std Cond	(m3/h)	3.489e+109 *	3.489e+109

* Specified by user.

Material Stream: OxideAlloy (continued)

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000

Liquid Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000

Material Stream: OverheadH2

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase
Vapour / Phase Fraction		1.0000	1.0000
Temperature:	(C)	844.6	844.6
Pressure:	(bar)	1.013	1.013
Molar Flow	(kgmole/h)	4982	4982
Mass Flow	(kg/s)	2.790	2.790
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8
Molar Enthalpy	(kJ/kgmole)	2.426e+004	2.426e+004
Molar Entropy	(kJ/kgmole-C)	38.92	38.92
Heat Flow	(MW)	33.57	33.57
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.222e+063

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000

* Specified by user.

Material Stream: OverheadH2 (continued)

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

COMPOSITION

Overall Phase (continued)

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Material Stream: RxSteam

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	450.0	450.0			
Pressure:	(bar)	1.013	1.013			
Molar Flow	(kgmole/h)	4985	4985			
Mass Flow	(kg/s)	24.94	24.94			
Std Ideal Liq Vol Flow	(m3/h)	89.97	89.97			
Molar Enthalpy	(kJ/kgmole)	-2.268e+005	-2.268e+005			
Molar Entropy	(kJ/kgmole-C)	-13.30	-13.30			
Heat Flow	(MW)	-314.0	-314.0			
Liq Vol Flow @Std Cond	(m3/h)	89.96 *	89.96			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	4984.5660	1.0000	89798.3523	1.0000	89.9714	1.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	4984.5660	1.0000	89798.3523	1.0000	89.9714	1.0000

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name: Production.hsc Unit Set: AmeyS2e Date/Time: Fri Mar 29 15:31:10 2024

Material Stream: RxSteam (continued)

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

COMPOSITION

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	4984.5660	1.0000	89798.3523	1.0000	89.9714	1.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	4984.5660	1.0000	89798.3523	1.0000	89.9714	1.0000

Energy Stream: ReactorHeat

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	SolveTemp		
Duty SP:	-2.941e-011 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Energy Stream: BottomsCooling

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:			
Duty SP:	102.3 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

* Specified by user.

The oxygen-evolution reactor sub-flowsheet of the process model is included as Figure A3, with stream tables following.

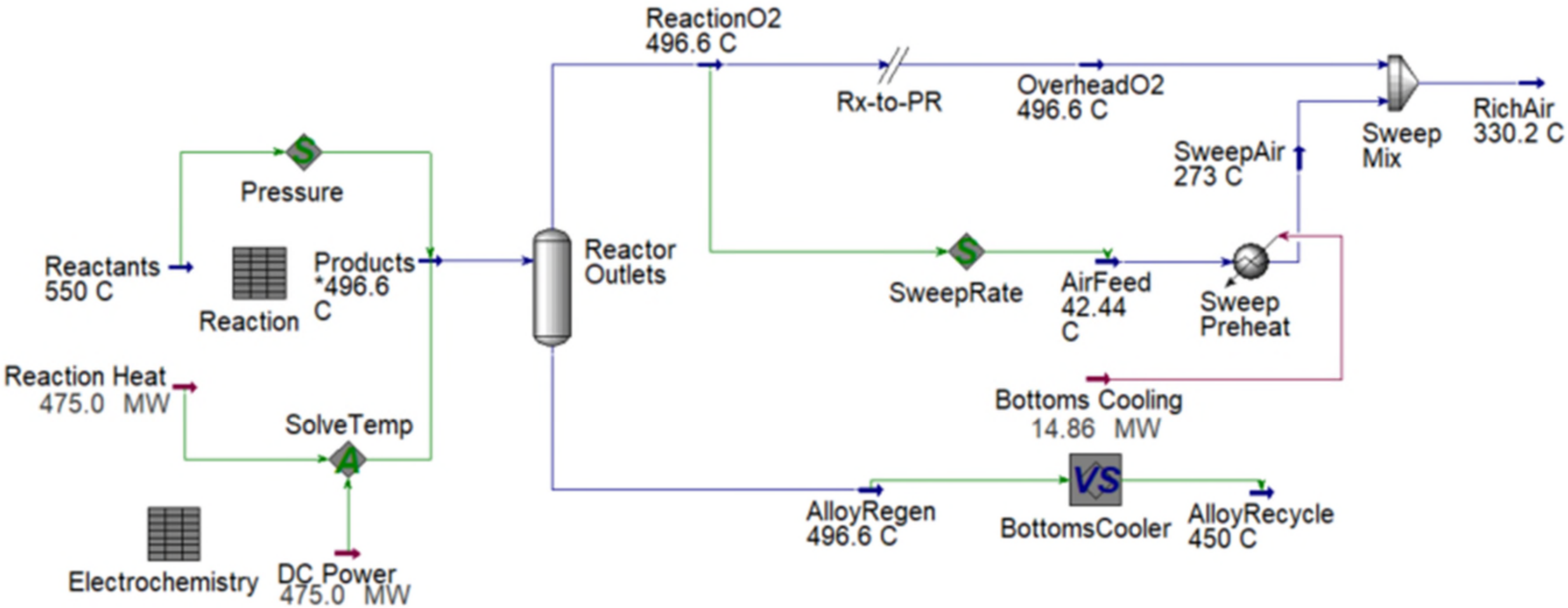

Figure A3. Redox-cycle process model oxygen-evolution sub-flowsheet.

aspentech — BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name: Production.hsc Unit Set: AmeyS2e Date/Time: Fri Mar 29 15:40:28 2024

Material Stream: Reactants

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Liquid Phase
Vapour / Phase Fraction		0.0000	1.0000
Temperature:	(C)	550.0	550.0
Pressure:	(bar)	1.013	1.013
Molar Flow	(kgmole/h)	3.988e+004	3.988e+004
Mass Flow	(kg/s)	1263	1263
Std Ideal Liq Vol Flow	(m3/h)	7747	7747
Molar Enthalpy	(kJ/kgmole)	-1.305e+004	-1.305e+004
Molar Entropy	(kJ/kgmole-C)	62.26	62.26
Heat Flow	(MW)	-144.6	-144.6
Liq Vol Flow @Std Cond	(m3/h)	3.489e+109 *	3.489e+109

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000

Liquid Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000

Material Stream: Products

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Vapour Phase	Liquid Phase
Vapour / Phase Fraction		0.0587	0.0587	0.9413
Temperature:	(C)	496.6 *	496.6	496.6
Pressure:	(bar)	1.013	1.013	1.013
Molar Flow	(kgmole/h)	4.237e+004 *	2487	3.988e+004
Mass Flow	(kg/s)	1263	22.09	1241
Std Ideal Liq Vol Flow	(m3/h)	6959	133.2	6826
Molar Enthalpy	(kJ/kgmole)	1.960e+004	1.484e+004	1.990e+004
Molar Entropy	(kJ/kgmole-C)	42.01	29.57	42.79
Heat Flow	(MW)	230.7	10.25	220.5

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* Specified by user.

Material Stream: Products (continued)

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Liq Vol Flow @Std Cond	(m3/h)	3.489e+109 *	4.854e+093	3.489e+109		

COMPOSITION

Overall Phase

Vapour Fraction 0.0587

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.5660	0.1176	325940.7675	0.0717	46.9437	0.0067
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	2492.2830	0.0588	79750.0645	0.0175	133.4812	0.0192
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8235	4.142024815e+06	0.9108	6778.9151	0.9741
Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
Total	42371.6122	1.0000	4.547721294e+06	1.0000	6959.4900	1.0000

Vapour Phase

Phase Fraction 5.870e-002

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.5160	0.0002	33.7408	0.0004	0.0049	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	2483.9604	0.9987	79483.7509	0.9995	133.0355	0.9988
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	2.7980	0.0011	5.6405	0.0001	0.1499	0.0011
Total	2487.2744	1.0000	79523.1322	1.0000	133.1902	1.0000

Liquid Phase

Phase Fraction 0.9413

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388	0.0069
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457	0.0001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151	0.9931
Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002	0.0000
Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998	1.0000

Material Stream: ReactionO2

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	496.6	496.6	496.6		
Pressure:	(bar)	1.013	1.013	1.013		
Molar Flow	(kgmole/h)	2487	2487	0.0000		
Mass Flow	(kg/s)	22.09	22.09	0.0000		
Std Ideal Liq Vol Flow	(m3/h)	133.2	133.2	0.0000		

* Specified by user.

@aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name:	Production.hsc
		Unit Set:	AmeyS2e
		Date/Time:	Fri Mar 29 15:40:28 2024

Material Stream: ReactionO2 (continued)

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Molar Enthalpy	(kJ/kgmole)	1.484e+004	1.484e+004	1.990e+004		
Molar Entropy	(kJ/kgmole-C)	29.57	29.57	42.79		
Heat Flow	(MW)	10.25	10.25	0.0000		
Liq Vol Flow @Std Cond	(m3/h)	4.854e+093 *	4.854e+093	0.0000		

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.5160	0.0002	33.7408	0.0004	0.0049	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	2483.9604	0.9987	79483.7509	0.9995	133.0355	0.9988
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	2.7980	0.0011	5.6405	0.0001	0.1499	0.0011
Total	2487.2744	1.0000	79523.1322	1.0000	133.1902	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.5160	0.0002	33.7408	0.0004	0.0049	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	2483.9604	0.9987	79483.7509	0.9995	133.0355	0.9988
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	2.7980	0.0011	5.6405	0.0001	0.1499	0.0011
Total	2487.2744	1.0000	79523.1322	1.0000	133.1902	1.0000

Liquid Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.1250	0.0000	0.0729	0.0000	0.0069
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0002	0.0000	0.0001	0.0000	0.0001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.8748	0.0000	0.9270	0.0000	0.9931
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Material Stream: AlloyRegen

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		0.0000	0.0000	1.0000		
Temperature:	(C)	496.6	496.6	496.6		
Pressure:	(bar)	1.013	1.013	1.013		

Material Stream: AlloyRegen (continued)

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Molar Flow	(kgmole/h)	3.988e+004	0.0000	3.988e+004		
Mass Flow	(kg/s)	1241	0.0000	1241		
Std Ideal Liq Vol Flow	(m3/h)	6826	0.0000	6826		
Molar Enthalpy	(kJ/kgmole)	1.990e+004	1.484e+004	1.990e+004		
Molar Entropy	(kJ/kgmole-C)	42.79	29.57	42.79		
Heat Flow	(MW)	220.5	0.0000	220.5		
Liq Vol Flow @Std Cond	(m3/h)	3.489e+109 *	0.0000	3.489e+109		

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388	0.0069
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457	0.0001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151	0.9931
Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002	0.0000
Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998	1.0000

Vapour Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0002	0.0000	0.0004	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.9987	0.0000	0.9995	0.0000	0.9988
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0011	0.0000	0.0001	0.0000	0.0011
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Liquid Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388	0.0069
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457	0.0001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151	0.9931
Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002	0.0000
Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998	1.0000

* Specified by user.

Material Stream: AlloyRecycle

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

		Overall	Liquid Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	450.0	450.0			
Pressure:	(bar)	1.013	1.013			
Molar Flow	(kgmole/h)	3.988e+004	3.988e+004			
Mass Flow	(kg/s)	1241	1241			
Std Ideal Liq Vol Flow	(m3/h)	6826	6826			
Molar Enthalpy	(kJ/kgmole)	1.854e+004	1.854e+004			
Molar Entropy	(kJ/kgmole-C)	40.90	40.90			
Heat Flow	(MW)	205.4	205.4			
Liq Vol Flow @Std Cond	(m3/h)	3.489e+109 *	3.489e+109			

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388	0.0069
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457	0.0001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151	0.9931
Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002	0.0000
Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998	1.0000

Liquid Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388	0.0069
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457	0.0001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151	0.9931
Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002	0.0000
Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998	1.0000

Material Stream: AirFeed

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	42.44	42.44			
Pressure:	(bar)	1.034	1.034			
Molar Flow	(kgmole/h)	7835	7835			
Mass Flow	(kg/s)	62.79	62.79			
Std Ideal Liq Vol Flow	(m3/h)	419.6	419.6			
Molar Enthalpy	(kJ/kgmole)	501.6	501.6			
Molar Entropy	(kJ/kgmole-C)	5.744	5.744			
Heat Flow	(MW)	1.092	1.092			

* Specified by user.

Material Stream: AirFeed (continued)

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase			
Liq Vol Flow @Std Cond	(m3/h)	675.1 *	675.1			

COMPOSITION

Overall Phase — Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Zinc-Oxide	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Nitrogen	6189.5823 *	0.7900 *	173391.7402 *	0.7671 *	331.5004 *	0.7900 *
Oxygen	1645.3320 *	0.2100 *	52648.6498 *	0.2329 *	88.1204 *	0.2100 *
Water	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Tin-White	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Hydrogen	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000

Vapour Phase — Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004	0.7900
Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204	0.2100
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000

Material Stream: SweepAir

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	273.0	273.0			
Pressure:	(bar)	1.013	1.013			
Molar Flow	(kgmole/h)	7835	7835			
Mass Flow	(kg/s)	62.79	62.79			
Std Ideal Liq Vol Flow	(m3/h)	419.6	419.6			
Molar Enthalpy	(kJ/kgmole)	7331	7331			
Molar Entropy	(kJ/kgmole-C)	22.14	22.14			
Heat Flow	(MW)	15.96	15.96			
Liq Vol Flow @Std Cond	(m3/h)	675.1 *	675.1			

COMPOSITION

Overall Phase — Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

* Specified by user.

Material Stream: SweepAir (continued)

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

COMPOSITION

Overall Phase (continued)

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004	0.7900
Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204	0.2100
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004	0.7900
Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204	0.2100
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000

Material Stream: RichAir

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	330.2	330.2	330.2		
Pressure:	(bar)	1.013	1.013	1.013		
Molar Flow	(kgmole/h)	1.032e+004	1.032e+004	0.5159		
Mass Flow	(kg/s)	84.88	84.87	9.370e-003		
Std Ideal Liq Vol Flow	(m3/h)	552.8	552.8	4.858e-003		
Molar Enthalpy	(kJ/kgmole)	9132	9134	-3.636e+004		
Molar Entropy	(kJ/kgmole-C)	26.64	26.64	-2.978		
Heat Flow	(MW)	26.18	26.19	-5.210e-003		
Liq Vol Flow @Std Cond	(m3/h)	858.4 *	858.4	4.929e-003		

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.5160	0.0000	33.7408	0.0001	0.0049	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	6189.5823	0.5996	173391.7402	0.5674	331.5004	0.5997
Oxygen	4129.2924	0.4000	132132.4006	0.4324	221.1558	0.4001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	2.7980	0.0003	5.6405	0.0000	0.1499	0.0003
Total	10322.1887	1.0000	305563.5221	1.0000	552.8109	1.0000

* Specified by user.

Material Stream: RichAir (continued)

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

COMPOSITION

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0001	0.0000	0.0092	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	6189.5823	0.5997	173391.7402	0.5675	331.5004	0.5997
Oxygen	4129.2924	0.4001	132132.4006	0.4325	221.1558	0.4001
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	2.7980	0.0003	5.6405	0.0000	0.1499	0.0003
Total	10321.6728	1.0000	305529.7905	1.0000	552.8061	1.0000

Liquid Phase

Phase Fraction 4.998e-005

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.5159	1.0000	33.7316	1.0000	0.0049	1.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.5159	1.0000	33.7316	1.0000	0.0049	1.0000

Material Stream: OverheadO2

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		0.9998	0.9998	0.0002		
Temperature:	(C)	496.6	496.6	496.6		
Pressure:	(bar)	1.013	1.013	1.013		
Molar Flow	(kgmole/h)	2487	2487	0.4610		
Mass Flow	(kg/s)	22.09	22.08	8.373e-003		
Std Ideal Liq Vol Flow	(m3/h)	133.2	133.2	4.341e-003		
Molar Enthalpy	(kJ/kgmole)	1.481e+004	1.481e+004	-2.883e+004		
Molar Entropy	(kJ/kgmole-C)	29.53	29.53	8.053		
Heat Flow	(MW)	10.23	10.23	-3.691e-003		
Liq Vol Flow @Std Cond	(m3/h)	2.629e+049 *	2.630e+049	4.404e-003		

COMPOSITION

Overall Phase

Vapour Fraction 0.9998

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.5160	0.0002	33.7408	0.0004	0.0049	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	2483.9604	0.9987	79483.7509	0.9995	133.0355	0.9988
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

* Specified by user.

Material Stream: OverheadO2 (continued)

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

COMPOSITION

Overall Phase (continued)

Vapour Fraction 0.9998

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Hydrogen	2.7980	0.0011	5.6405	0.0001	0.1499	0.0011
Total	2487.2744	1.0000	79523.1322	1.0000	133.1902	1.0000

Vapour Phase

Phase Fraction 0.9998

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0550	0.0000	3.5976	0.0000	0.0005	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	2483.9604	0.9989	79483.7509	0.9999	133.0355	0.9989
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	2.7980	0.0011	5.6405	0.0001	0.1499	0.0011
Total	2486.8134	1.0000	79492.9890	1.0000	133.1858	1.0000

Liquid Phase

Phase Fraction 1.853e-004

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.4610	1.0000	30.1432	1.0000	0.0043	1.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.4610	1.0000	30.1432	1.0000	0.0043	1.0000

Energy Stream: Reaction Heat

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	SolveTemp		
Duty SP:	475.0 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Energy Stream: DC Power

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	SolveTemp		
Duty SP:	475.0 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Energy Stream: Bottoms Cooling

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Sweep Preheat		
Duty SP:	14.86 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

* Specified by user.

The hydrogen-compression sub-flowsheet of the process model is included as Figure A3, with stream tables following.

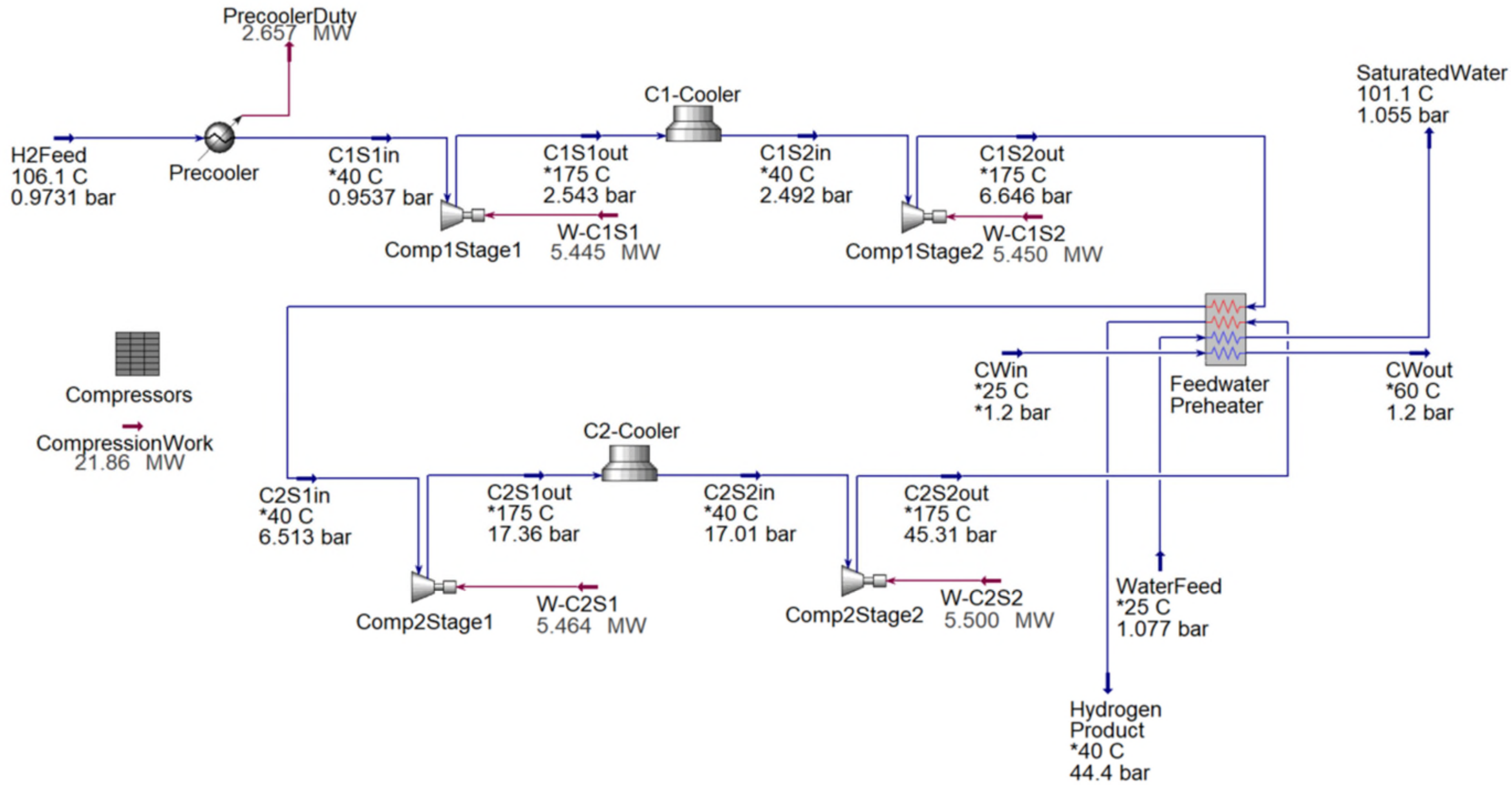

Figure A4. Redox-cycle process model hydrogen-compression sub-flowsheet.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name:	Production.hsc
		Unit Set:	AmeyS2e
		Date/Time:	Fri Mar 29 15:46:33 2024

Material Stream: H2Feed

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	106.1	106.1	106.1		
Pressure:	(bar)	0.9731	0.9731	0.9731		
Molar Flow	(kgmole/h)	4982	4982	5.285e-005		
Mass Flow	(kg/s)	2.790	2.790	1.195e-006		
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8	1.027e-005		
Molar Enthalpy	(kJ/kgmole)	2353	2353	-2.205e+005		
Molar Entropy	(kJ/kgmole-C)	7.310	7.310	4.743		
Heat Flow	(MW)	3.256	3.256	-3.237e-006		
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.222e+063	2.650e+063		

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0005	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6425	1.0000	266.8124	1.0000

Liquid Phase

Phase Fraction 1.061e-008

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.9998	0.0043	1.0000	0.0000	1.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Total	0.0001	1.0000	0.0043	1.0000	0.0000	1.0000

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* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name: Production.hsc Unit Set: AmeyS2e Date/Time: Fri Mar 29 15:46:33 2024

Material Stream: C1S1out

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	175.0 *	175.0			
Pressure:	(bar)	2.543	2.543			
Molar Flow	(kgmole/h)	4982	4982			
Mass Flow	(kg/s)	2.790	2.790			
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8			
Molar Enthalpy	(kJ/kgmole)	4368	4368			
Molar Entropy	(kJ/kgmole-C)	4.198	4.198			
Heat Flow	(MW)	6.044	6.044			
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.222e+063			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Material Stream: C1S1in

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	40.00 *	40.00	40.00		
Pressure:	(bar)	0.9537	0.9537	0.9537		
Molar Flow	(kgmole/h)	4982	4982	5.952e-005		
Mass Flow	(kg/s)	2.790	2.790	1.345e-006		
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8	1.156e-005		
Molar Enthalpy	(kJ/kgmole)	432.9	432.9	-2.245e+005		
Molar Entropy	(kJ/kgmole-C)	1.917	1.917	-7.126		
Heat Flow	(MW)	0.5991	0.5991	-3.711e-006		

* Specified by user.

Material Stream: C1S1in (continued)

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.212e+063	5.643e+066		

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7648	1.0000	10042.6419	1.0000	266.8124	1.0000

Liquid Phase

Phase Fraction 1.195e-008

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.9997	0.0048	0.9997	0.0000	0.9998
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0002	0.0000	0.0003	0.0000	0.0002
Hydrogen	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Total	0.0001	1.0000	0.0048	1.0000	0.0000	1.0000

Material Stream: C1S2in

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	40.00 *	40.00	40.00		
Pressure:	(bar)	2.492	2.492	2.492		
Molar Flow	(kgmole/h)	4982	4982	5.955e-005		
Mass Flow	(kg/s)	2.790	2.790	1.346e-006		
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8	1.157e-005		

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name:	Production.hsc
		Unit Set:	AmeyS2e
		Date/Time:	Fri Mar 29 15:46:33 2024

Material Stream: C1S2in (continued)

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Molar Enthalpy	(kJ/kgmole)	433.9	433.9	-2.243e+005		
Molar Entropy	(kJ/kgmole-C)	-6.074	-6.074	-7.092		
Heat Flow	(MW)	0.6005	0.6005	-3.710e-006		
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.195e+063	4.876e+067		

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7648	1.0000	10042.6419	1.0000	266.8124	1.0000

Liquid Phase

Phase Fraction 1.195e-008

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.9992	0.0048	0.9993	0.0000	0.9994
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0005	0.0000	0.0007	0.0000	0.0005
Hydrogen	0.0000	0.0003	0.0000	0.0000	0.0000	0.0001
Total	0.0001	1.0000	0.0048	1.0000	0.0000	1.0000

Material Stream: C1S2out

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	175.0 *	175.0			
Pressure:	(bar)	6.646	6.646			

* Specified by user.

Material Stream: C1S2out (continued)

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase			
Molar Flow	(kgmole/h)	4982	4982			
Mass Flow	(kg/s)	2.790	2.790			
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8			
Molar Enthalpy	(kJ/kgmole)	4372	4372			
Molar Entropy	(kJ/kgmole-C)	-3.790	-3.790			
Heat Flow	(MW)	6.051	6.051			
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.222e+063			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Material Stream: C2S1in

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	40.00 *	40.00	40.00		
Pressure:	(bar)	6.513	6.513	6.513		
Molar Flow	(kgmole/h)	4982	4982	5.963e-005		
Mass Flow	(kg/s)	2.790	2.790	1.348e-006		
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8	1.158e-005		
Molar Enthalpy	(kJ/kgmole)	436.6	436.6	-2.237e+005		
Molar Entropy	(kJ/kgmole-C)	-14.07	-14.07	-7.015		
Heat Flow	(MW)	0.6042	0.6042	-3.705e-006		
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.153e+063	4.063e+068		

* Specified by user.

Material Stream: C2S1in (continued)

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7648	1.0000	10042.6419	1.0000	266.8124	1.0000

Liquid Phase

Phase Fraction 1.197e-008

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.9979	0.0048	0.9981	0.0000	0.9985
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0013	0.0000	0.0019	0.0000	0.0013
Hydrogen	0.0000	0.0009	0.0000	0.0000	0.0000	0.0002
Total	0.0001	1.0000	0.0049	1.0000	0.0000	1.0000

Material Stream: C2S1out

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	175.0 *	175.0	175.0		
Pressure:	(bar)	17.36	17.36	17.36		
Molar Flow	(kgmole/h)	4982	4982	8.186e-006		
Mass Flow	(kg/s)	2.790	2.790	1.846e-007		
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8	1.587e-006		
Molar Enthalpy	(kJ/kgmole)	4385	4385	-2.153e+005		
Molar Entropy	(kJ/kgmole-C)	-11.78	-11.78	14.79		
Heat Flow	(MW)	6.068	6.068	-4.895e-007		
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.222e+063	1.079e+063		

* Specified by user.

Material Stream: C2S1out (continued)

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0042	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6461	1.0000	266.8124	1.0000

Liquid Phase

Phase Fraction 1.643e-009

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.9971	0.0007	0.9999	0.0000	0.9992
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0029	0.0000	0.0001	0.0000	0.0008
Total	0.0000	1.0000	0.0007	1.0000	0.0000	1.0000

Material Stream: C2S2in

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	40.00 *	40.00	40.00		
Pressure:	(bar)	17.01	17.01	17.01		
Molar Flow	(kgmole/h)	4982	4982	5.982e-005		
Mass Flow	(kg/s)	2.790	2.790	1.352e-006		
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8	1.160e-005		
Molar Enthalpy	(kJ/kgmole)	443.6	443.6	-2.222e+005		
Molar Entropy	(kJ/kgmole-C)	-22.07	-22.07	-6.862		
Heat Flow	(MW)	0.6139	0.6139	-3.693e-006		
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.053e+063	3.086e+069		

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name: Production.hsc Unit Set: AmeyS2e Date/Time: Fri Mar 29 15:46:33 2024

Material Stream: C2S2in (continued)

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7648	1.0000	10042.6419	1.0000	266.8124	1.0000

Liquid Phase

Phase Fraction 1.201e-008

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.9946	0.0048	0.9954	0.0000	0.9962
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0031	0.0000	0.0046	0.0000	0.0031
Hydrogen	0.0000	0.0022	0.0000	0.0001	0.0000	0.0006
Total	0.0001	1.0000	0.0049	1.0000	0.0000	1.0000

Material Stream: C2S2out

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	175.0 *	175.0	175.0		
Pressure:	(bar)	45.31	45.31	45.31		
Molar Flow	(kgmole/h)	4982	4982	3.857e-005		
Mass Flow	(kg/s)	2.790	2.790	8.658e-007		
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8	7.454e-006		
Molar Enthalpy	(kJ/kgmole)	4418	4418	-2.135e+005		
Molar Entropy	(kJ/kgmole-C)	-19.76	-19.76	14.56		
Heat Flow	(MW)	6.113	6.113	-2.288e-006		
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.221e+063	4.042e+064		

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA
Case Name:	Production.hsc
Unit Set:	AmeyS2e
Date/Time:	Fri Mar 29 15:46:33 2024

Material Stream: C2S2out (continued)

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0017	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6437	1.0000	266.8124	1.0000

Liquid Phase

Phase Fraction 7.743e-009

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.9926	0.0031	0.9998	0.0000	0.9979
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	0.0000	0.0074	0.0000	0.0002	0.0000	0.0020
Total	0.0000	1.0000	0.0031	1.0000	0.0000	1.0000

Material Stream: Hydrogen Product

Fluid Package: Overheads

Property Package: Aspen Properties (Peng-R

CONDITIONS

		Overall	Vapour Phase	Liquid Phase		
Vapour / Phase Fraction		1.0000	1.0000	0.0000		
Temperature:	(C)	40.00 *	40.00	40.00		
Pressure:	(bar)	44.40	44.40	44.40		
Molar Flow	(kgmole/h)	4982	4982	6.027e-005		
Mass Flow	(kg/s)	2.790	2.790	1.359e-006		
Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8	1.166e-005		
Molar Enthalpy	(kJ/kgmole)	462.8	462.8	-2.189e+005		
Molar Entropy	(kJ/kgmole-C)	-30.09	-30.09	-6.628		
Heat Flow	(MW)	0.6404	0.6404	-3.665e-006		
Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	5.849e+063	1.875e+070		

* Specified by user.

Material Stream: Hydrogen Product (continue

Fluid Package: Overheads
Property Package: Aspen Properties (Peng-R

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
Total	4981.7648	1.0000	10042.6419	1.0000	266.8124	1.0000

Liquid Phase

Phase Fraction 1.210e-008

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Zinc-Oxide	0.0001	0.9874	0.0048	0.9897	0.0000	0.9915
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Tin-White	0.0000	0.0069	0.0000	0.0101	0.0000	0.0070
Hydrogen	0.0000	0.0057	0.0000	0.0001	0.0000	0.0016
Total	0.0001	1.0000	0.0049	1.0000	0.0000	1.0000

Material Stream: SaturatedWater

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Aqueous Phase
Vapour / Phase Fraction		0.0000	1.0000
Temperature:	(C)	101.1	101.1
Pressure:	(bar)	1.055	1.055
Molar Flow	(kgmole/h)	4985	4985
Mass Flow	(kg/s)	24.94	24.94
Std Ideal Liq Vol Flow	(m3/h)	89.98	89.98
Molar Enthalpy	(kJ/kgmole)	-2.792e+005	-2.792e+005
Molar Entropy	(kJ/kgmole-C)	23.77	23.77
Heat Flow	(MW)	-386.6	-386.6
Liq Vol Flow @Std Cond	(m3/h)	89.88 *	89.88

* Specified by user.

Material Stream: SaturatedWater (continued)

Fluid Package: Steam
Property Package: NBS Steam

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Aqueous Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Material Stream: WaterFeed

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	25.00 *	25.00			
Pressure:	(bar)	1.077	1.077			
Molar Flow	(kgmole/h)	4985	4985			
Mass Flow	(kg/s)	24.94	24.94			
Std Ideal Liq Vol Flow	(m3/h)	89.98	89.98			
Molar Enthalpy	(kJ/kgmole)	-2.850e+005	-2.850e+005			
Molar Entropy	(kJ/kgmole-C)	6.610	6.610			
Heat Flow	(MW)	-394.6	-394.6			
Liq Vol Flow @Std Cond	(m3/h)	89.88 *	89.88			

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660 *	1.0000 *	89797.4575 *	1.0000 *	89.9787 *	1.0000 *
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Aqueous Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000

Material Stream: CWin

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	25.00 *	25.00			
Pressure:	(bar)	1.200 *	1.200			
Molar Flow	(kgmole/h)	4044	4044			

Material Stream: CWin (continued)

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Aqueous Phase			
Mass Flow	(kg/s)	20.24	20.24			
Std Ideal Liq Vol Flow	(m3/h)	73.00	73.00			
Molar Enthalpy	(kJ/kgmole)	-2.850e+005	-2.850e+005			
Molar Entropy	(kJ/kgmole-C)	6.610	6.610			
Heat Flow	(MW)	-320.1	-320.1			
Liq Vol Flow @Std Cond	(m3/h)	72.91 *	72.91			

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4043.9117 *	1.0000 *	72851.4751 *	1.0000 *	72.9985 *	1.0000 *
Total	4043.9117	1.0000	72851.4751	1.0000	72.9985	1.0000

Aqueous Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4043.9117	1.0000	72851.4751	1.0000	72.9985	1.0000
Total	4043.9117	1.0000	72851.4751	1.0000	72.9985	1.0000

Material Stream: CWout

Fluid Package: Steam
Property Package: NBS Steam

CONDITIONS

		Overall	Aqueous Phase			
Vapour / Phase Fraction		0.0000	1.0000			
Temperature:	(C)	60.00 *	60.00			
Pressure:	(bar)	1.200	1.200			
Molar Flow	(kgmole/h)	4044	4044			
Mass Flow	(kg/s)	20.24	20.24			
Std Ideal Liq Vol Flow	(m3/h)	73.00	73.00			
Molar Enthalpy	(kJ/kgmole)	-2.823e+005	-2.823e+005			
Molar Entropy	(kJ/kgmole-C)	14.97	14.97			
Heat Flow	(MW)	-317.2	-317.2			
Liq Vol Flow @Std Cond	(m3/h)	72.91 *	72.91			

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4043.9117	1.0000	72851.4751	1.0000	72.9985	1.0000
Total	4043.9117	1.0000	72851.4751	1.0000	72.9985	1.0000

Aqueous Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	4043.9117	1.0000	72851.4751	1.0000	72.9985	1.0000
Total	4043.9117	1.0000	72851.4751	1.0000	72.9985	1.0000

* Specified by user.

Energy Stream: W-C1S1

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Comp1Stage1		
Duty SP:	5.445 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Energy Stream: PrecoolerDuty

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Precooler		
Duty SP:	2.657 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Energy Stream: W-C1S2

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Comp1Stage2		
Duty SP:	5.450 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Energy Stream: W-C2S1

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Comp2Stage1		
Duty SP:	5.464 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Energy Stream: W-C2S2

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Comp2Stage2		
Duty SP:	5.500 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Energy Stream: CompressionWork

Fluid Package: Reaction
Property Package: Aspen Properties (Solids)

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:			
Duty SP:	21.86 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Appendix B

Hydrogen Combustion Turbine Process Modeling

A process model (**Error! Reference source not found.**) for a hydrogen combustion turbine was developed in Aspen HYSYS with the Peng-Robinson equation of state to study fuel efficiency and assist with cost estimates. It is common to operate combustion turbines at a high pressure ratio (10–15:1), and to use the bottoming heat to drive a Rankine cycle to improve the overall thermal efficiency of the power plant. The bottoming cycle, which operates in the two-phase regime, provides significant inertia to the power controller; therefore, combined-cycle power plants are preferred for baseload power. For energy arbitrage, a more-dynamic plant, with quicker black-start capability, is desired to allow the system to respond more rapidly to a call for power.

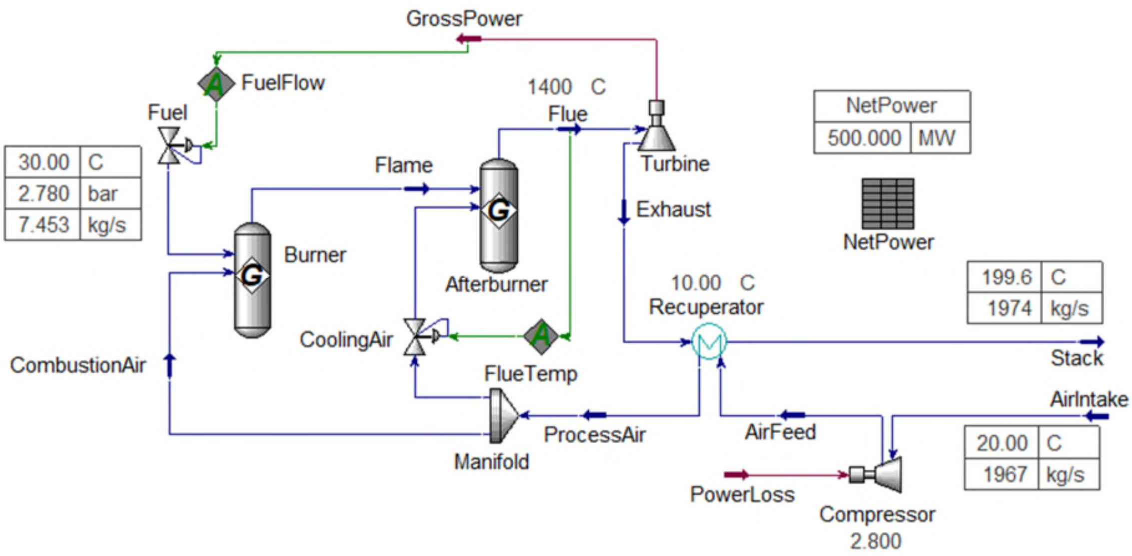

Figure B1. Combustion-turbine model.

With this in mind, a recuperated simple cycle with a lower pressure ratio was designed using parameters listed in Table B1. The model results in a fuel efficiency of 18.6 kWh-e/kg-H_2 (56% thermal efficiency on an LHV basis). A report containing stream conditions and compositions was generated by Aspen HYSYS and included in this appendix.

Table B1. Combustion-turbine model parameters.

Equipment	Parameter	Value	Unit
Compressor	Compression Ratio	2.8	–
	Isentropic Efficiency	75	%
Turbine	Net Power	500	MW
	Isentropic Efficiency	90	%
Recuperator	Allowable Pressure Drop (shell/tube)	2	%
	Minimum Approach	10	°C
	Effectiveness	98.9	%
Combustion Chamber	Excess Air (burner)	20	%
	Adiabatic Flame Temperature (afterburner)	1400	°C
Inlet Air	Temperature	20	°C
	Relative Humidity	50	%

The combustion chamber is broken down into two separate Gibbs reactors (reactors within the AspenTech suite that are preprogrammed to determine products from reactants based on the theoretical provision of the minimization of Gibbs free energy) with identical combustion reaction packages attached. The purpose of this setup is to preserve the peak flame temperature to give a more-accurate estimate of minor equilibrium reactions (nitrogen oxides, hydrogen peroxide, and ammonia). The reaction package is listed below:

$$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)}$$

$$N_2 + 3H_2 \leftrightarrow 2NH_3$$

$$N_2 + O_2 \leftrightarrow 2NO$$

$$2N_2 + O_2 \leftrightarrow 2N_2O$$

$$N_2 + 2O_2 \leftrightarrow 2NO_2$$

$$H_2 + O_2 \leftrightarrow H_2O_2$$

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name:	500MWe_HydrogenTurbine_recuperated.hsc
		Unit Set:	AmeyS2e
		Date/Time:	Wed Sep 27 09:15:46 2023

Material Stream: Fuel

Fluid Package: CombustionTurbineProce

Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	30.00 *	30.00			
Pressure:	(bar)	2.780	2.780			
Molar Flow	(kgmole/h)	1.331e+004	1.331e+004			
Mass Flow	(kg/s)	7.453 *	7.453			
Std Ideal Liq Vol Flow	(m3/h)	384.1	384.1			
Molar Enthalpy	(kJ/kgmole)	142.0	142.0			
Molar Entropy	(kJ/kgmole-C)	115.1	115.1			
Heat Flow	(MW)	0.5248	0.5248			
Liq Vol Flow @Std Cond	(m3/h)	3.148e+005 *	3.148e+005			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	13308.4696	1.0000	26829.8751	1.0000	384.0570	1.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	13308.4696	1.0000	26829.8751	1.0000	384.0570	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Hydrogen	13308.4696	1.0000	26829.8751	1.0000	384.0570	1.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	13308.4696	1.0000	26829.8751	1.0000	384.0570	1.0000

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name:	500MWe_HydrogenTurbine_recuperated.hsc
		Unit Set:	AmeyS2e
		Date/Time:	Wed Sep 27 09:15:46 2023

Material Stream: AirIntake

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	20.00 *	20.00			
Pressure:	(bar)	1.013 *	1.013			
Molar Flow	(kgmole/h)	2.465e+005	2.465e+005			
Mass Flow	(kg/s)	1967	1967			
Std Ideal Liq Vol Flow	(m3/h)	8178	8178			
Molar Enthalpy	(kJ/kgmole)	-2958	-2958			
Molar Entropy	(kJ/kgmole-C)	152.0	152.0			
Heat Flow	(MW)	-202.5	-202.5			
Liq Vol Flow @Std Cond	(m3/h)	5.824e+006 *	5.824e+006			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2857.0521 *	0.0116 *	51470.0804 *	0.0073 *	51.5739 *	0.0063 *
Hydrogen	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Nitrogen	192493.4427 *	0.7808 *	5.392318905e+06 *	0.7615 *	6687.1188 *	0.8177 *
Oxygen	51169.1430 *	0.2076 *	1.637412576e+06 *	0.2312 *	1439.2558 *	0.1760 *
Methane	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Ethane	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
CO2	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
N2O	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
NO2	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
NO	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
SO2	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
H2S	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
CO	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
H2O2	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Ammonia	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
Total	246519.6378	1.0000	7.081201561e+06	1.0000	8177.9485	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2857.0521	0.0116	51470.0804	0.0073	51.5739	0.0063
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	192493.4427	0.7808	5.392318905e+06	0.7615	6687.1188	0.8177
Oxygen	51169.1430	0.2076	1.637412576e+06	0.2312	1439.2558	0.1760
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	246519.6378	1.0000	7.081201561e+06	1.0000	8177.9485	1.0000

* Specified by user.

Material Stream: BurnerCondensate

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase	Liquid Phase	Aqueous Phase
Vapour / Phase Fraction		0.0000	0.0000	0.5000	0.5000
Temperature:	(C)	2387	2387	2387	2387
Pressure:	(bar)	2.730	2.730	2.730	2.730
Molar Flow	(kgmole/h)	0.0000	0.0000	0.0000	0.0000
Mass Flow	(kg/s)	0.0000	0.0000	0.0000	0.0000
Std Ideal Liq Vol Flow	(m3/h)	0.0000	0.0000	0.0000	0.0000
Molar Enthalpy	(kJ/kgmole)	2.651e+004	2.651e+004	2.651e+004	2.651e+004
Molar Entropy	(kJ/kgmole-C)	233.6	233.6	233.6	233.6
Heat Flow	(MW)	0.0000	0.0000	0.0000	0.0000
Liq Vol Flow @Std Cond	(m3/h)	0.0000 *	0.0000	0.0000	0.0000

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.2861	0.0000	0.2072	0.0000	0.1519
Hydrogen	0.0000	0.0162	0.0000	0.0013	0.0000	0.0138
Nitrogen	0.0000	0.6547	0.0000	0.7371	0.0000	0.6691
Oxygen	0.0000	0.0318	0.0000	0.0408	0.0000	0.0263
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0112	0.0000	0.0135	0.0000	0.1389
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Vapour Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.2861	0.0000	0.2072	0.0000	0.1519
Hydrogen	0.0000	0.0162	0.0000	0.0013	0.0000	0.0138
Nitrogen	0.0000	0.6547	0.0000	0.7371	0.0000	0.6691
Oxygen	0.0000	0.0318	0.0000	0.0408	0.0000	0.0263
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0112	0.0000	0.0135	0.0000	0.1389
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

* Specified by user.

Material Stream: BurnerCondensate (continue

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

COMPOSITION

Liquid Phase

Phase Fraction 0.5000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.2861	0.0000	0.2072	0.0000	0.1519
Hydrogen	0.0000	0.0162	0.0000	0.0013	0.0000	0.0138
Nitrogen	0.0000	0.6547	0.0000	0.7371	0.0000	0.6691
Oxygen	0.0000	0.0318	0.0000	0.0408	0.0000	0.0263
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0112	0.0000	0.0135	0.0000	0.1389
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Aqueous Phase

Phase Fraction 0.5000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.2861	0.0000	0.2072	0.0000	0.1519
Hydrogen	0.0000	0.0162	0.0000	0.0013	0.0000	0.0138
Nitrogen	0.0000	0.6547	0.0000	0.7371	0.0000	0.6691
Oxygen	0.0000	0.0318	0.0000	0.0408	0.0000	0.0263
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0112	0.0000	0.0135	0.0000	0.1389
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Material Stream: Flue

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase	Liquid Phase	Aqueous Phase	
Vapour / Phase Fraction		1.0000	1.0000	0.0000	0.0000	
Temperature:	(C)	1400	1400	1400	1400	
Pressure:	(bar)	2.730	2.730	2.730	2.730	
Molar Flow	(kgmole/h)	2.532e+005	2.532e+005	0.0000	0.0000	
Mass Flow	(kg/s)	1974	1974	0.0000	0.0000	
Std Ideal Liq Vol Flow	(m3/h)	8478	8478	0.0000	0.0000	
Molar Enthalpy	(kJ/kgmole)	3.049e+004	3.049e+004	3.049e+004	3.049e+004	
Molar Entropy	(kJ/kgmole-C)	202.5	202.5	202.5	202.5	

* Specified by user.

BATTELLE ENERGY ALLIANCE
Bedford, MA
USA

Case Name:	500MWe_HydrogenTurbine_recuperated.hsc
Unit Set:	AmeyS2e
Date/Time:	Wed Sep 27 09:15:46 2023

Material Stream: Flue (continued)

Fluid Package: CombustionTurbineProce

Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase	Liquid Phase	Aqueous Phase	
Heat Flow	(MW)	2144	2144	0.0000	0.0000	
Liq Vol Flow @Std Cond	(m3/h)	5.977e+006 *	5.977e+006	0.0000	0.0000	

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	16165.1670	0.0639	291217.1082	0.0410	291.8048	0.0344
Hydrogen	0.3486	0.0000	0.7027	0.0000	0.0101	0.0000
Nitrogen	192174.0963	0.7591	5.383373054e+06	0.7574	6676.0249	0.7874
Oxygen	44194.2520	0.1746	1.414216065e+06	0.1990	1243.0701	0.1466
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0486	0.0000	2.1409	0.0000	0.0026	0.0000
NO2	3.0108	0.0000	138.5141	0.0000	0.0942	0.0000
NO	635.5847	0.0025	19071.3557	0.0027	267.3953	0.0315
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0060	0.0000	0.2053	0.0000	0.0001	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	253172.5141	1.0000	7.108019145e+06	1.0000	8478.4022	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	16165.1670	0.0639	291217.1082	0.0410	291.8048	0.0344
Hydrogen	0.3486	0.0000	0.7027	0.0000	0.0101	0.0000
Nitrogen	192174.0963	0.7591	5.383373054e+06	0.7574	6676.0249	0.7874
Oxygen	44194.2520	0.1746	1.414216065e+06	0.1990	1243.0701	0.1466
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0486	0.0000	2.1409	0.0000	0.0026	0.0000
NO2	3.0108	0.0000	138.5141	0.0000	0.0942	0.0000
NO	635.5847	0.0025	19071.3557	0.0027	267.3953	0.0315
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0060	0.0000	0.2053	0.0000	0.0001	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	253172.5141	1.0000	7.108019145e+06	1.0000	8478.4022	1.0000

Liquid Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.0639	0.0000	0.0410	0.0000	0.0344
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.7591	0.0000	0.7574	0.0000	0.7874
Oxygen	0.0000	0.1746	0.0000	0.1990	0.0000	0.1466
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

* Specified by user.

Material Stream: Flue (continued)

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

COMPOSITION

Liquid Phase (continued)

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0025	0.0000	0.0027	0.0000	0.0315
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Aqueous Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.0639	0.0000	0.0410	0.0000	0.0344
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.7591	0.0000	0.7574	0.0000	0.7874
Oxygen	0.0000	0.1746	0.0000	0.1990	0.0000	0.1466
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0025	0.0000	0.0027	0.0000	0.0315
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Material Stream: Exhaust

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	1095	1095			
Pressure:	(bar)	1.033	1.033			
Molar Flow	(kgmole/h)	2.532e+005	2.532e+005			
Mass Flow	(kg/s)	1974	1974			
Std Ideal Liq Vol Flow	(m3/h)	8478	8478			
Molar Enthalpy	(kJ/kgmole)	1.960e+004	1.960e+004			
Molar Entropy	(kJ/kgmole-C)	203.4	203.4			
Heat Flow	(MW)	1378	1378			
Liq Vol Flow @Std Cond	(m3/h)	5.977e+006 *	5.977e+006			

* Specified by user.

Material Stream: Exhaust (continued)

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	16165.1670	0.0639	291217.1082	0.0410	291.8048	0.0344
Hydrogen	0.3486	0.0000	0.7027	0.0000	0.0101	0.0000
Nitrogen	192174.0963	0.7591	5.383373054e+06	0.7574	6676.0249	0.7874
Oxygen	44194.2520	0.1746	1.414216065e+06	0.1990	1243.0701	0.1466
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0486	0.0000	2.1409	0.0000	0.0026	0.0000
NO2	3.0108	0.0000	138.5141	0.0000	0.0942	0.0000
NO	635.5847	0.0025	19071.3557	0.0027	267.3953	0.0315
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0060	0.0000	0.2053	0.0000	0.0001	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	253172.5141	1.0000	7.108019145e+06	1.0000	8478.4022	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	16165.1670	0.0639	291217.1082	0.0410	291.8048	0.0344
Hydrogen	0.3486	0.0000	0.7027	0.0000	0.0101	0.0000
Nitrogen	192174.0963	0.7591	5.383373054e+06	0.7574	6676.0249	0.7874
Oxygen	44194.2520	0.1746	1.414216065e+06	0.1990	1243.0701	0.1466
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0486	0.0000	2.1409	0.0000	0.0026	0.0000
NO2	3.0108	0.0000	138.5141	0.0000	0.0942	0.0000
NO	635.5847	0.0025	19071.3557	0.0027	267.3953	0.0315
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0060	0.0000	0.2053	0.0000	0.0001	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	253172.5141	1.0000	7.108019145e+06	1.0000	8478.4022	1.0000

Material Stream: AirFeed

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	151.4	151.4			
Pressure:	(bar)	2.836	2.836			
Molar Flow	(kgmole/h)	2.465e+005	2.465e+005			
Mass Flow	(kg/s)	1967	1967			
Std Ideal Liq Vol Flow	(m3/h)	8178	8178			
Molar Enthalpy	(kJ/kgmole)	926.1	926.1			
Molar Entropy	(kJ/kgmole-C)	154.4	154.4			

* Specified by user.

Material Stream: AirFeed (continued)

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase			
Heat Flow	(MW)	63.42	63.42			
Liq Vol Flow @Std Cond	(m3/h)	5.824e+006 *	5.824e+006			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2857.0521	0.0116	51470.0804	0.0073	51.5739	0.0063
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	192493.4427	0.7808	5.392318905e+06	0.7615	6687.1188	0.8177
Oxygen	51169.1430	0.2076	1.637412576e+06	0.2312	1439.2558	0.1760
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	246519.6378	1.0000	7.081201561e+06	1.0000	8177.9485	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2857.0521	0.0116	51470.0804	0.0073	51.5739	0.0063
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	192493.4427	0.7808	5.392318905e+06	0.7615	6687.1188	0.8177
Oxygen	51169.1430	0.2076	1.637412576e+06	0.2312	1439.2558	0.1760
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	246519.6378	1.0000	7.081201561e+06	1.0000	8177.9485	1.0000

Material Stream: CombustionAir

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	1085	1085			
Pressure:	(bar)	2.780	2.780			

* Specified by user.

Material Stream: CombustionAir (continued)

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase			
Molar Flow	(kgmole/h)	3.847e+004	3.847e+004			
Mass Flow	(kg/s)	307.0	307.0			
Std Ideal Liq Vol Flow	(m3/h)	1276	1276			
Molar Enthalpy	(kJ/kgmole)	3.130e+004	3.130e+004			
Molar Entropy	(kJ/kgmole-C)	191.8	191.8			
Heat Flow	(MW)	334.5	334.5			
Liq Vol Flow @Std Cond	(m3/h)	9.088e+005 *	9.088e+005			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	445.8506	0.0116	8032.0438	0.0073	8.0483	0.0063
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	30039.1170	0.7808	841485.7992	0.7615	1043.5428	0.8177
Oxygen	7985.0817	0.2076	255522.6155	0.2312	224.5997	0.1760
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	38470.0494	1.0000	1.105040459e+06	1.0000	1276.1908	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	445.8506	0.0116	8032.0438	0.0073	8.0483	0.0063
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	30039.1170	0.7808	841485.7992	0.7615	1043.5428	0.8177
Oxygen	7985.0817	0.2076	255522.6155	0.2312	224.5997	0.1760
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	38470.0494	1.0000	1.105040459e+06	1.0000	1276.1908	1.0000

* Specified by user.

BATTELLE ENERGY ALLIANCE
Bedford, MA
USA

Case Name:	500MWe_HydrogenTurbine_recuperated.hsc
Unit Set:	AmeyS2e
Date/Time:	Wed Sep 27 09:15:46 2023

Material Stream: CoolingAir

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	1085	1085			
Pressure:	(bar)	2.780	2.780			
Molar Flow	(kgmole/h)	2.080e+005	2.080e+005			
Mass Flow	(kg/s)	1660 *	1660			
Std Ideal Liq Vol Flow	(m3/h)	6902	6902			
Molar Enthalpy	(kJ/kgmole)	3.130e+004	3.130e+004			
Molar Entropy	(kJ/kgmole-C)	191.8	191.8			
Heat Flow	(MW)	1809	1809			
Liq Vol Flow @Std Cond	(m3/h)	4.915e+006 *	4.915e+006			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2411.2015	0.0116	43438.0365	0.0073	43.5257	0.0063
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	162454.3257	0.7808	4.550833105e+06	0.7615	5643.5760	0.8177
Oxygen	43184.0613	0.2076	1.381889960e+06	0.2312	1214.6561	0.1760
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	208049.5884	1.0000	5.976161102e+06	1.0000	6901.7578	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2411.2015	0.0116	43438.0365	0.0073	43.5257	0.0063
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	162454.3257	0.7808	4.550833105e+06	0.7615	5643.5760	0.8177
Oxygen	43184.0613	0.2076	1.381889960e+06	0.2312	1214.6561	0.1760
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	208049.5884	1.0000	5.976161102e+06	1.0000	6901.7578	1.0000

* Specified by user.

aspentech

BATTELLE ENERGY ALLIANCE
Bedford, MA
USA

Case Name:	500MWe_HydrogenTurbine_recuperated.hsc
Unit Set:	AmeyS2e
Date/Time:	Wed Sep 27 09:15:46 2023

Material Stream: Flame

Fluid Package: CombustionTurbineProce

Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase	Liquid Phase	Aqueous Phase
Vapour / Phase Fraction		1.0000	1.0000	0.0000	0.0000
Temperature:	(C)	2387	2387	2387	2387
Pressure:	(bar)	2.730	2.730	2.730	2.730
Molar Flow	(kgmole/h)	4.549e+004	4.549e+004	0.0000	0.0000
Mass Flow	(kg/s)	314.4	314.4	0.0000	0.0000
Std Ideal Liq Vol Flow	(m3/h)	1546	1546	0.0000	0.0000
Molar Enthalpy	(kJ/kgmole)	2.651e+004	2.651e+004	2.651e+004	2.651e+004
Molar Entropy	(kJ/kgmole-C)	233.6	233.6	233.6	233.6
Heat Flow	(MW)	335.0	335.0	0.0000	0.0000
Liq Vol Flow @Std Cond	(m3/h)	1.071e+006 *	1.071e+006	0.0000	0.0000

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	13015.3926	0.2861	234473.6060	0.2072	234.9468	0.1519
Hydrogen	738.8685	0.0162	1489.5590	0.0013	21.3223	0.0138
Nitrogen	29783.6983	0.6547	834330.7540	0.7371	1034.6697	0.6691
Oxygen	1444.7455	0.0318	46231.8545	0.0408	40.6370	0.0263
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0287	0.0000	1.2632	0.0000	0.0015	0.0000
NO2	0.2089	0.0000	9.6125	0.0000	0.0065	0.0000
NO	510.5698	0.0112	15320.1586	0.0135	214.8006	0.1389
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0571	0.0000	1.9413	0.0000	0.0013	0.0000
Ammonia	0.0013	0.0000	0.0221	0.0000	0.0000	0.0000
Total	45493.5707	1.0000	1.131858771e+06	1.0000	1546.3858	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	13015.3926	0.2861	234473.6060	0.2072	234.9468	0.1519
Hydrogen	738.8685	0.0162	1489.5590	0.0013	21.3223	0.0138
Nitrogen	29783.6983	0.6547	834330.7540	0.7371	1034.6697	0.6691
Oxygen	1444.7455	0.0318	46231.8545	0.0408	40.6370	0.0263
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0287	0.0000	1.2632	0.0000	0.0015	0.0000
NO2	0.2089	0.0000	9.6125	0.0000	0.0065	0.0000
NO	510.5698	0.0112	15320.1586	0.0135	214.8006	0.1389
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0571	0.0000	1.9413	0.0000	0.0013	0.0000
Ammonia	0.0013	0.0000	0.0221	0.0000	0.0000	0.0000
Total	45493.5707	1.0000	1.131858771e+06	1.0000	1546.3858	1.0000

* Specified by user.

Material Stream: Flame (continued)

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

COMPOSITION

Liquid Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.2861	0.0000	0.2072	0.0000	0.1519
Hydrogen	0.0000	0.0162	0.0000	0.0013	0.0000	0.0138
Nitrogen	0.0000	0.6547	0.0000	0.7371	0.0000	0.6691
Oxygen	0.0000	0.0318	0.0000	0.0408	0.0000	0.0263
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0112	0.0000	0.0135	0.0000	0.1389
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Aqueous Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.2861	0.0000	0.2072	0.0000	0.1519
Hydrogen	0.0000	0.0162	0.0000	0.0013	0.0000	0.0138
Nitrogen	0.0000	0.6547	0.0000	0.7371	0.0000	0.6691
Oxygen	0.0000	0.0318	0.0000	0.0408	0.0000	0.0263
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0112	0.0000	0.0135	0.0000	0.1389
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Material Stream: ProcessAir

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	1085 *	1085			
Pressure:	(bar)	2.780	2.780			
Molar Flow	(kgmole/h)	2.465e+005	2.465e+005			
Mass Flow	(kg/s)	1967	1967			
Std Ideal Liq Vol Flow	(m3/h)	8178	8178			
Molar Enthalpy	(kJ/kgmole)	3.130e+004	3.130e+004			
Molar Entropy	(kJ/kgmole-C)	191.8	191.8			

* Specified by user.

Material Stream: ProcessAir (continued)

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase			
Heat Flow	(MW)	2143	2143			
Liq Vol Flow @Std Cond	(m3/h)	5.824e+006 *	5.824e+006			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2857.0521	0.0116	51470.0804	0.0073	51.5739	0.0063
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	192493.4427	0.7808	5.392318905e+06	0.7615	6687.1188	0.8177
Oxygen	51169.1430	0.2076	1.637412576e+06	0.2312	1439.2558	0.1760
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	246519.6378	1.0000	7.081201561e+06	1.0000	8177.9485	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	2857.0521	0.0116	51470.0804	0.0073	51.5739	0.0063
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	192493.4427	0.7808	5.392318905e+06	0.7615	6687.1188	0.8177
Oxygen	51169.1430	0.2076	1.637412576e+06	0.2312	1439.2558	0.1760
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	246519.6378	1.0000	7.081201561e+06	1.0000	8177.9485	1.0000

Material Stream: Stack

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase			
Vapour / Phase Fraction		1.0000	1.0000			
Temperature:	(C)	199.6	199.6			
Pressure:	(bar)	1.013 *	1.013			

* Specified by user.

aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA	Case Name:	500MWe_HydrogenTurbine_recuperated.hsc
		Unit Set:	AmeyS2e
		Date/Time:	Wed Sep 27 09:15:46 2023

Material Stream: Stack (continued)

Fluid Package: CombustionTurbineProce

Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase			
Molar Flow	(kgmole/h)	2.532e+005	2.532e+005			
Mass Flow	(kg/s)	1974	1974			
Std Ideal Liq Vol Flow	(m3/h)	8478	8478			
Molar Enthalpy	(kJ/kgmole)	-9982	-9982			
Molar Entropy	(kJ/kgmole-C)	168.9	168.9			
Heat Flow	(MW)	-702.0	-702.0			
Liq Vol Flow @Std Cond	(m3/h)	5.977e+006 *	5.977e+006			

COMPOSITION

Overall Phase

Vapour Fraction 1.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	16165.1670	0.0639	291217.1082	0.0410	291.8048	0.0344
Hydrogen	0.3486	0.0000	0.7027	0.0000	0.0101	0.0000
Nitrogen	192174.0963	0.7591	5.383373054e+06	0.7574	6676.0249	0.7874
Oxygen	44194.2520	0.1746	1.414216065e+06	0.1990	1243.0701	0.1466
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0486	0.0000	2.1409	0.0000	0.0026	0.0000
NO2	3.0108	0.0000	138.5141	0.0000	0.0942	0.0000
NO	635.5847	0.0025	19071.3557	0.0027	267.3953	0.0315
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0060	0.0000	0.2053	0.0000	0.0001	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	253172.5141	1.0000	7.108019145e+06	1.0000	8478.4022	1.0000

Vapour Phase

Phase Fraction 1.000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	16165.1670	0.0639	291217.1082	0.0410	291.8048	0.0344
Hydrogen	0.3486	0.0000	0.7027	0.0000	0.0101	0.0000
Nitrogen	192174.0963	0.7591	5.383373054e+06	0.7574	6676.0249	0.7874
Oxygen	44194.2520	0.1746	1.414216065e+06	0.1990	1243.0701	0.1466
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0486	0.0000	2.1409	0.0000	0.0026	0.0000
NO2	3.0108	0.0000	138.5141	0.0000	0.0942	0.0000
NO	635.5847	0.0025	19071.3557	0.0027	267.3953	0.0315
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0060	0.0000	0.2053	0.0000	0.0001	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	253172.5141	1.0000	7.108019145e+06	1.0000	8478.4022	1.0000

* Specified by user.

Material Stream: AfterburnerCondensate

Fluid Package: CombustionTurbineProce

Property Package: Peng-Robinson

CONDITIONS

		Overall	Vapour Phase	Liquid Phase	Aqueous Phase	
Vapour / Phase Fraction		0.0000	0.0000	0.5000	0.5000	
Temperature:	(C)	1400	1400	1400	1400	
Pressure:	(bar)	2.730	2.730	2.730	2.730	
Molar Flow	(kgmole/h)	0.0000	0.0000	0.0000	0.0000	
Mass Flow	(kg/s)	0.0000	0.0000	0.0000	0.0000	
Std Ideal Liq Vol Flow	(m3/h)	0.0000	0.0000	0.0000	0.0000	
Molar Enthalpy	(kJ/kgmole)	3.049e+004	3.049e+004	3.049e+004	3.049e+004	
Molar Entropy	(kJ/kgmole-C)	202.5	202.5	202.5	202.5	
Heat Flow	(MW)	0.0000	0.0000	0.0000	0.0000	
Liq Vol Flow @Std Cond	(m3/h)	0.0000 *	0.0000	0.0000	0.0000	

COMPOSITION

Overall Phase

Vapour Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.0639	0.0000	0.0410	0.0000	0.0344
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.7591	0.0000	0.7574	0.0000	0.7874
Oxygen	0.0000	0.1746	0.0000	0.1990	0.0000	0.1466
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0025	0.0000	0.0027	0.0000	0.0315
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Vapour Phase

Phase Fraction 0.0000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.0639	0.0000	0.0410	0.0000	0.0344
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.7591	0.0000	0.7574	0.0000	0.7874
Oxygen	0.0000	0.1746	0.0000	0.1990	0.0000	0.1466
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0025	0.0000	0.0027	0.0000	0.0315
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

* Specified by user.

Material Stream: AfterburnerCondensate (con

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

COMPOSITION

Liquid Phase

Phase Fraction 0.5000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.0639	0.0000	0.0410	0.0000	0.0344
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.7591	0.0000	0.7574	0.0000	0.7874
Oxygen	0.0000	0.1746	0.0000	0.1990	0.0000	0.1466
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0025	0.0000	0.0027	0.0000	0.0315
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Aqueous Phase

Phase Fraction 0.5000

COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
H2O	0.0000	0.0639	0.0000	0.0410	0.0000	0.0344
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.7591	0.0000	0.7574	0.0000	0.7874
Oxygen	0.0000	0.1746	0.0000	0.1990	0.0000	0.1466
Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NO	0.0000	0.0025	0.0000	0.0027	0.0000	0.0315
SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Energy Stream: GrossPower

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Turbine		
Duty SP:	766.0 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

Energy Stream: PowerLoss

Fluid Package: CombustionTurbineProce
Property Package: Peng-Robinson

CONDITIONS

Duty Type:	Direct Q	Duty Calculation Operation:	Compressor		
Duty SP:	266.0 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---

* Specified by user.