

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.

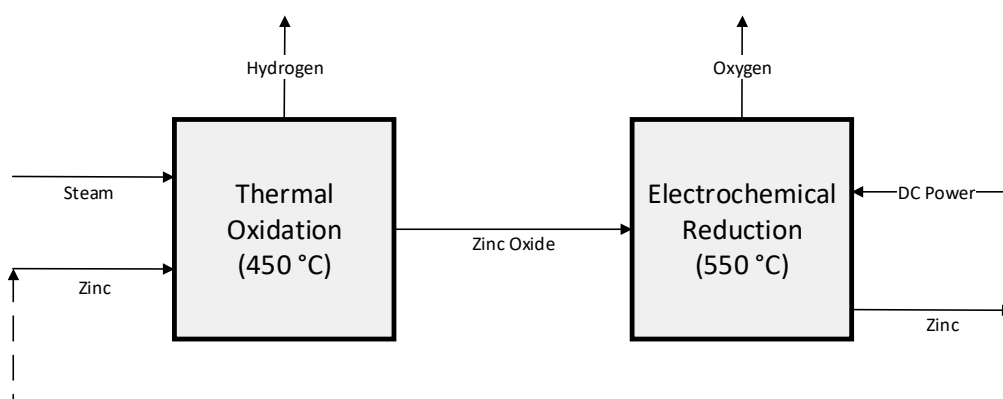


Figure ES1. BFD of the proposed electrochemical metal-redox cycle [1].

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-H₂ 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-H₂ of process heat linearly attenuated between 845 and 550°C is recoverable from the thermal oxidation outlet, as 2.4 kWh-th/kg-H₂ of low-pressure steam is extracted from the NPP to vaporize a portion of the feedwater.

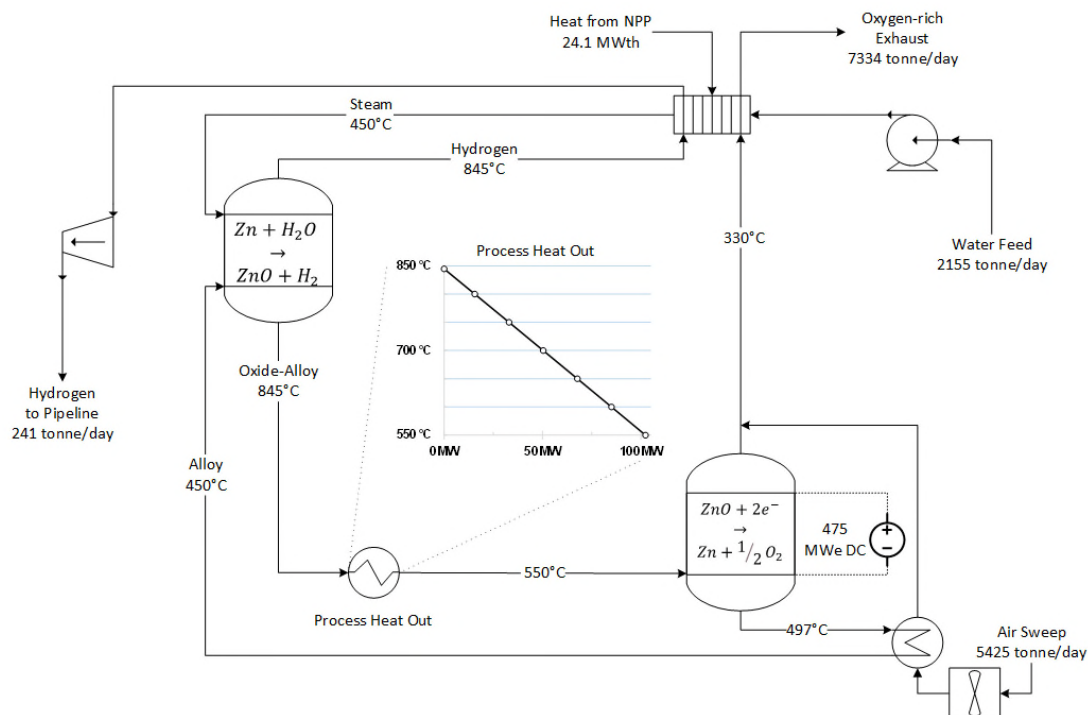


Figure ES2. PFD of the LWR-scale electrochemical metal-redox cycle, including an embedded heat transfer vs. temperature diagram of the process heat co-product.

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-H₂, 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-H₂. 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.

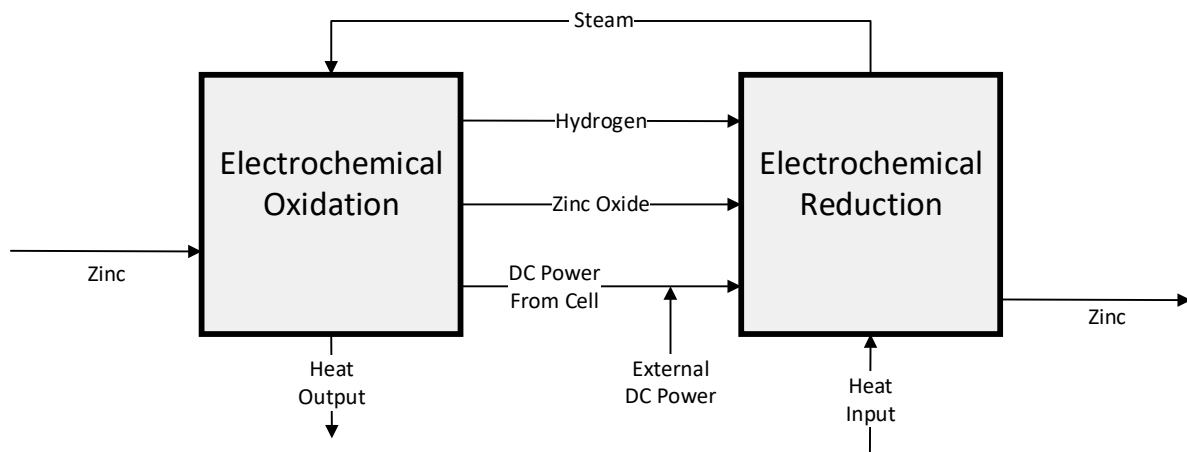


Figure ES3. BFD of the heat-augmentation configuration.

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.

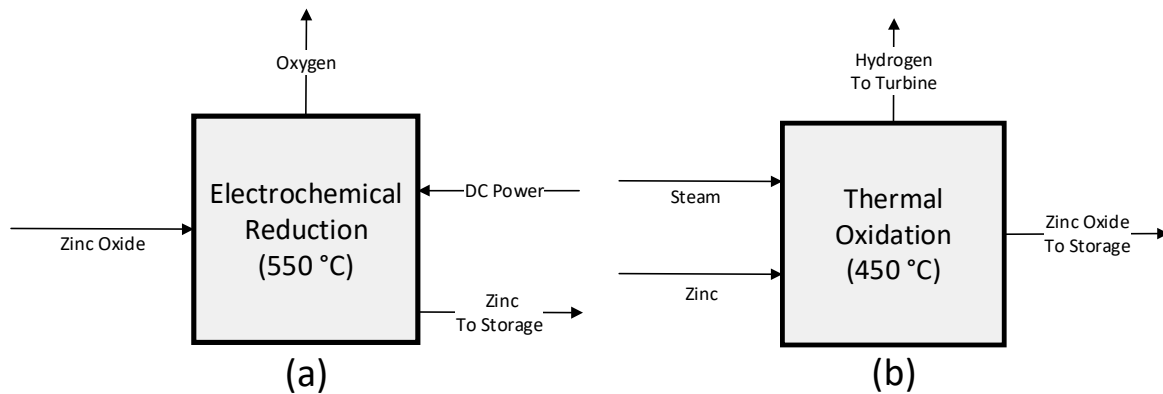


Figure ES4. ESS BFD for (a) a charging and (b) discharging cycle.

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.

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ACRONYMS

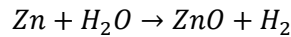
AC	Alternating current
BFD	Block-flow diagram
CAPEX	Capital expenditure
CoP	Coefficient of performance
CSTR	Continuous stirred-tank reactor
DC	Direct current
DOE	Department of Energy
ES	Executive summary
ESS	Energy-storage system
FPOG	Flexible plant operation and generation
HHV	Higher heating value
HTSE	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

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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:



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:

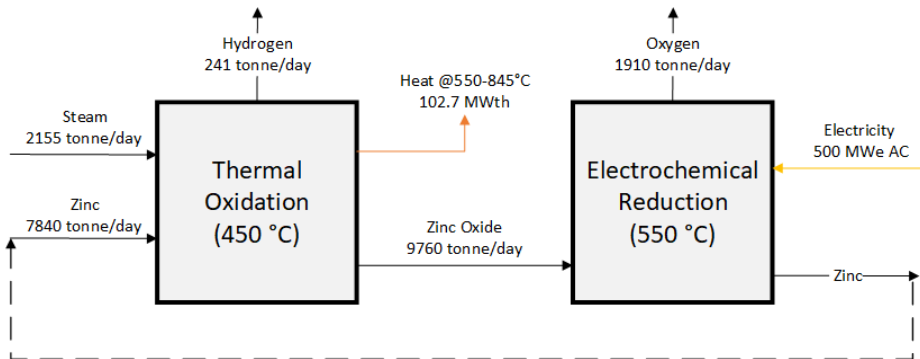
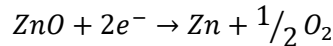


Figure 1. BFD of the electrochemical metal-redox cycle.

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.

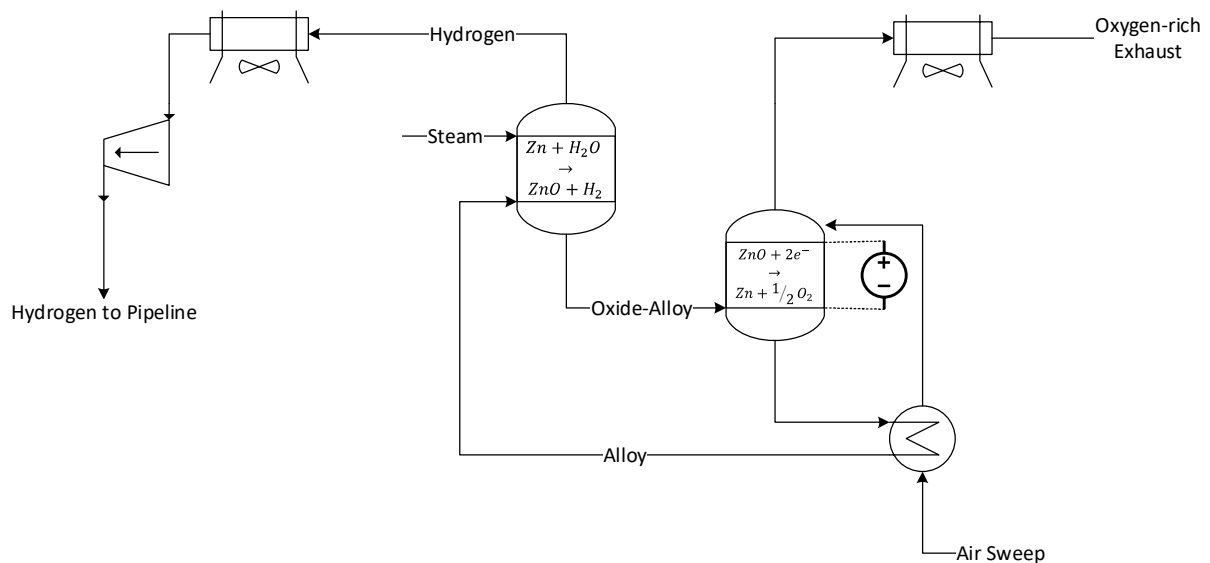


Figure 2. Simplified hydrogen-production PFD.

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.

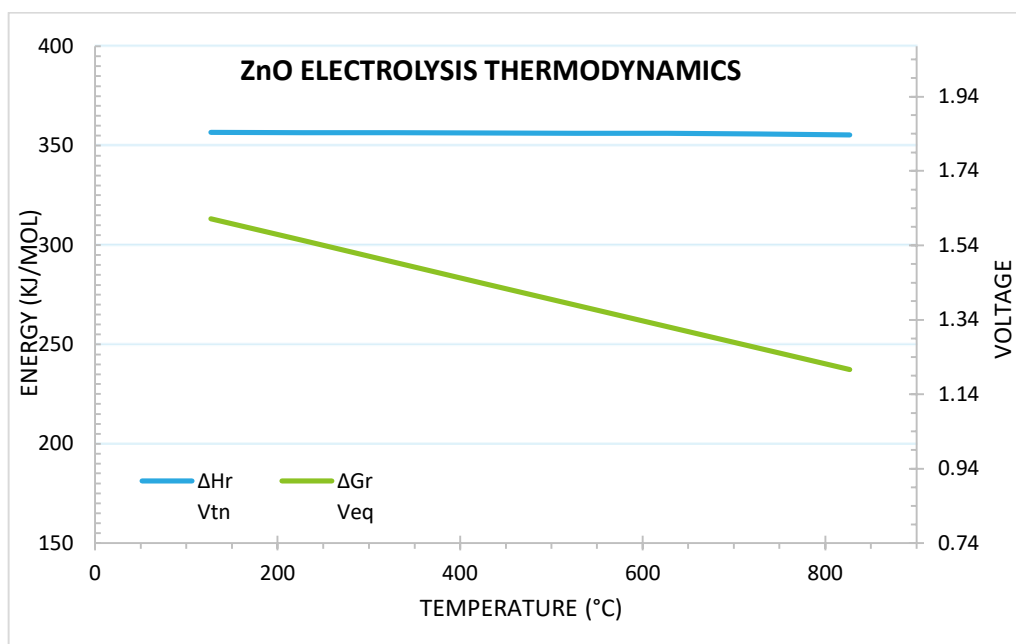


Figure 3. Thermodynamic-equilibrium data from FactSage calculations.

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 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.

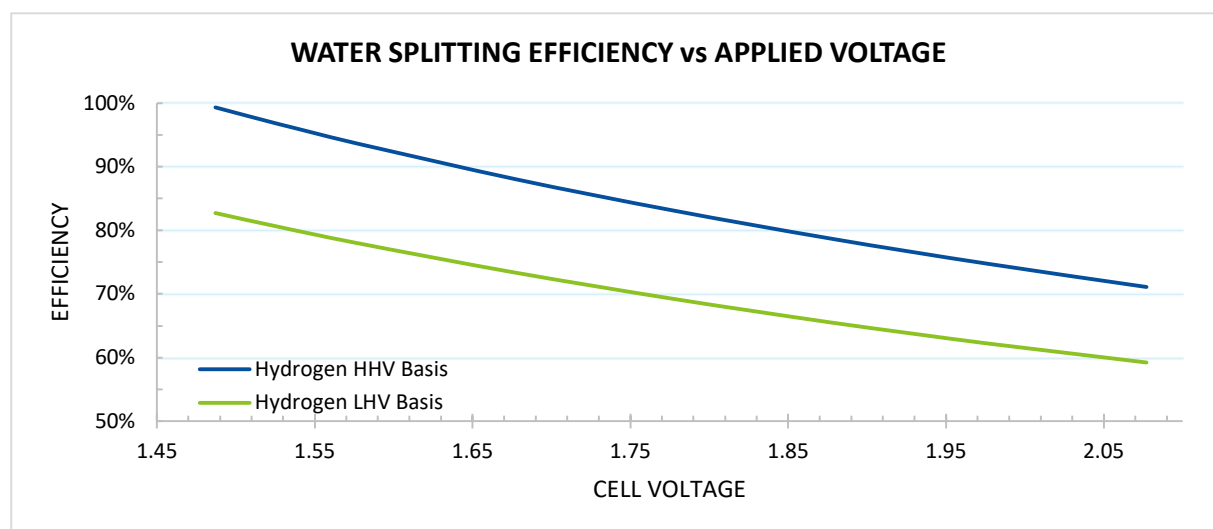


Figure 4. Water-splitting thermodynamics as a function of applied voltage.

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.

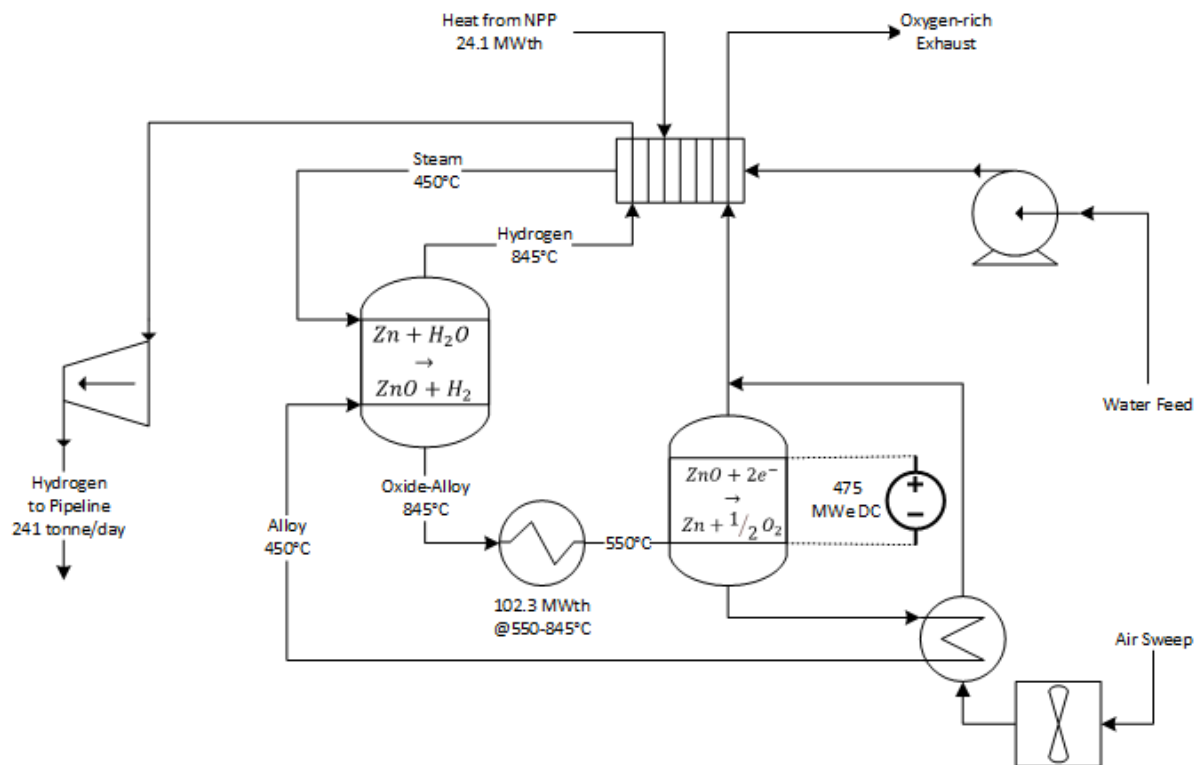


Figure 5. PFD of the hydrogen production model.

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.

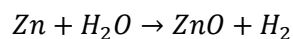


Table 1. Thermal oxidation reactor results.

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:

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

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:

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

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.

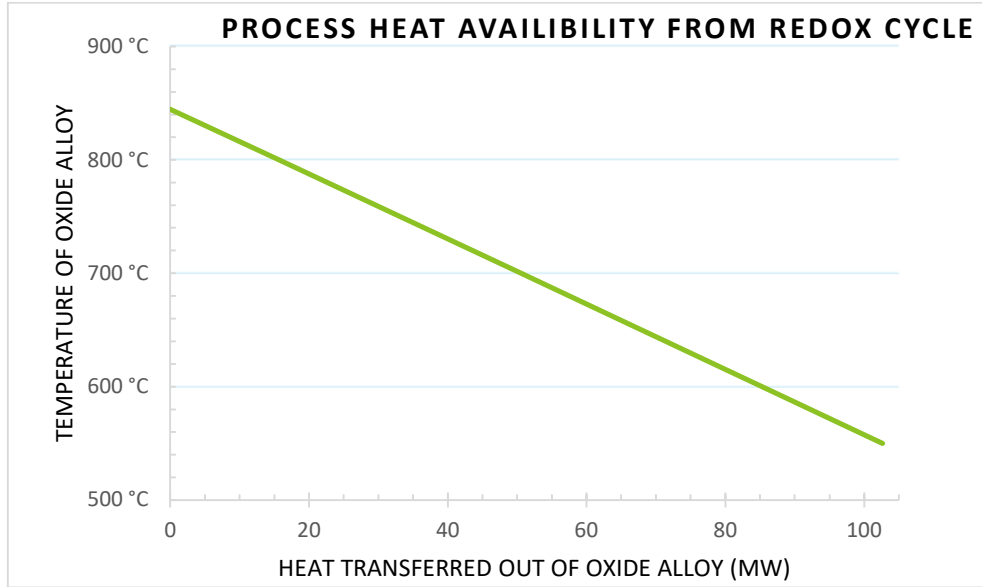


Figure 6. Heat-transfer vs. temperature diagram for oxide-alloy cooling.

2.3.1.2 Electrochemical Reduction

The electrochemical-reduction reaction 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.

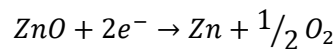


Table 2. Electrochemical reduction reactor results.

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:

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

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 CO₂ sweep could instead be used to form a carboxy-air that is 60 mol% CO₂ and 40 mol% O₂. 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.

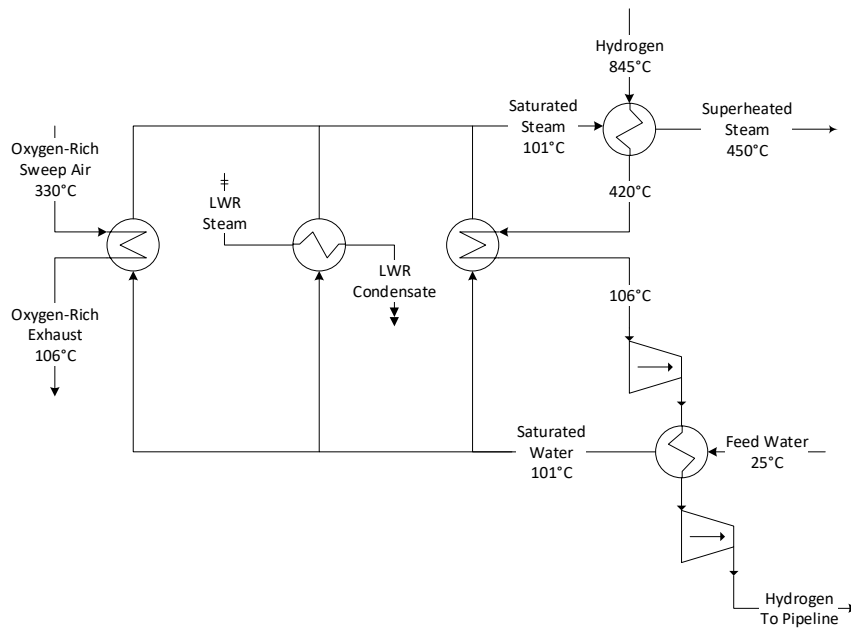


Figure 7. Heat-exchanger network for the hydrogen-production configuration.

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-H₂, 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-H₂
- Heat consumption of 2.4 kWh/kg-H₂
- 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 H₂ to \$1.82/kg H₂ 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.

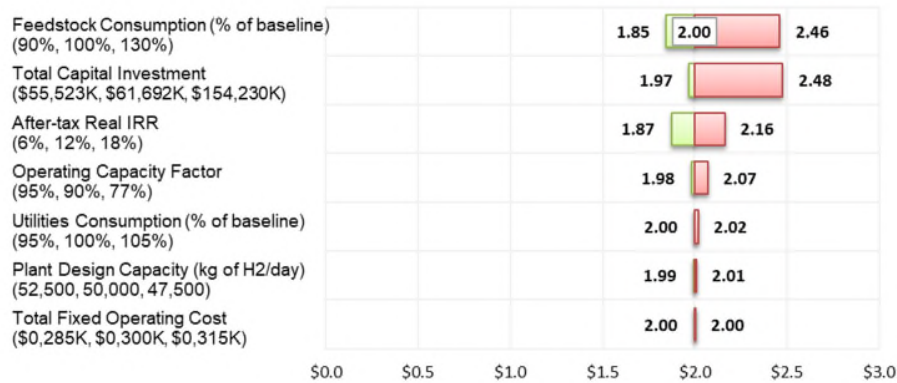


Figure 8. Tornado chart depicting the sensitivity of the LCOH to changes in certain parameters.

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.

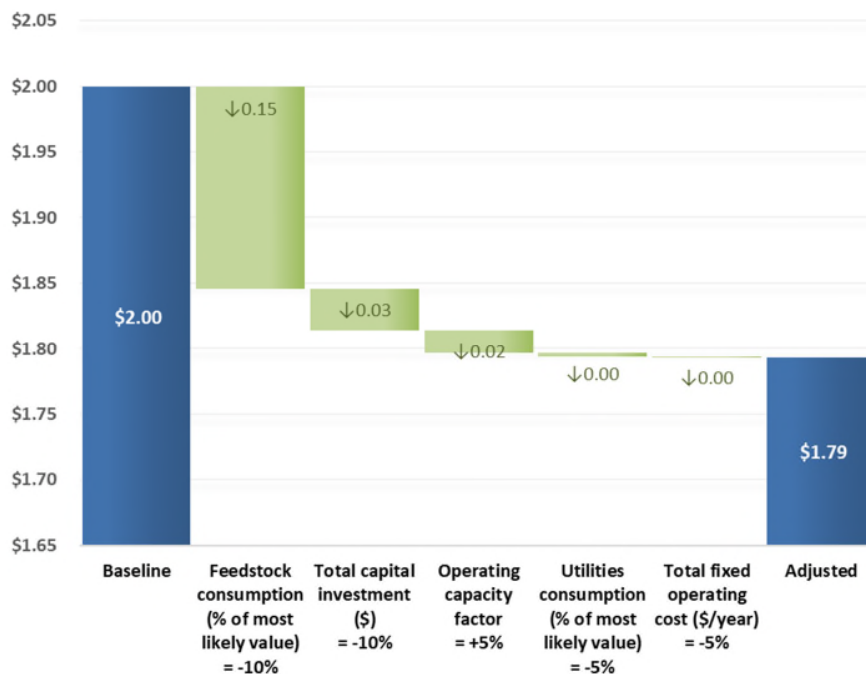


Figure 9. Waterfall chart of cost reductions through technology improvements and optimizations.

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 H₂ 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-cm² [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/cm²) [5] the cell resistance would need to meet a target of 0.6 Ohm cm² 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.

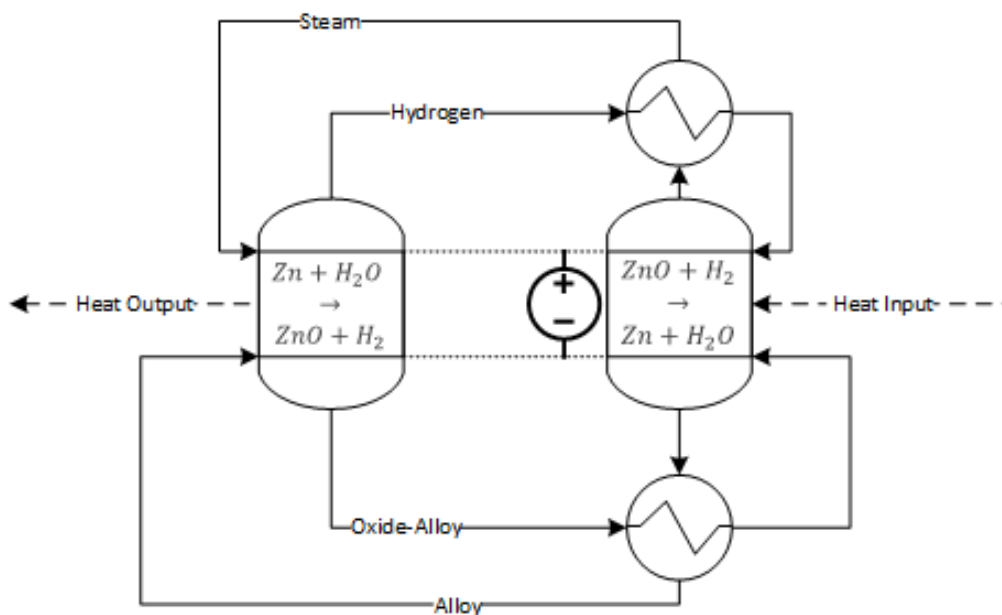


Figure 10. Basic PFD of redox cycle configured for heat augmentation.

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.

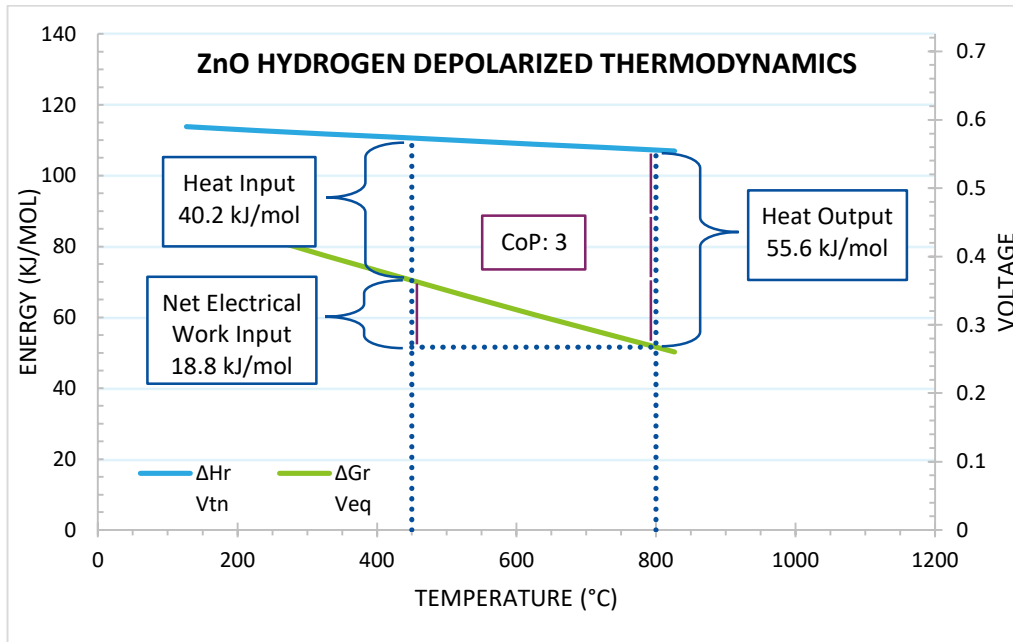


Figure 11. Heat-augmentation ideal thermodynamic cycle.

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.

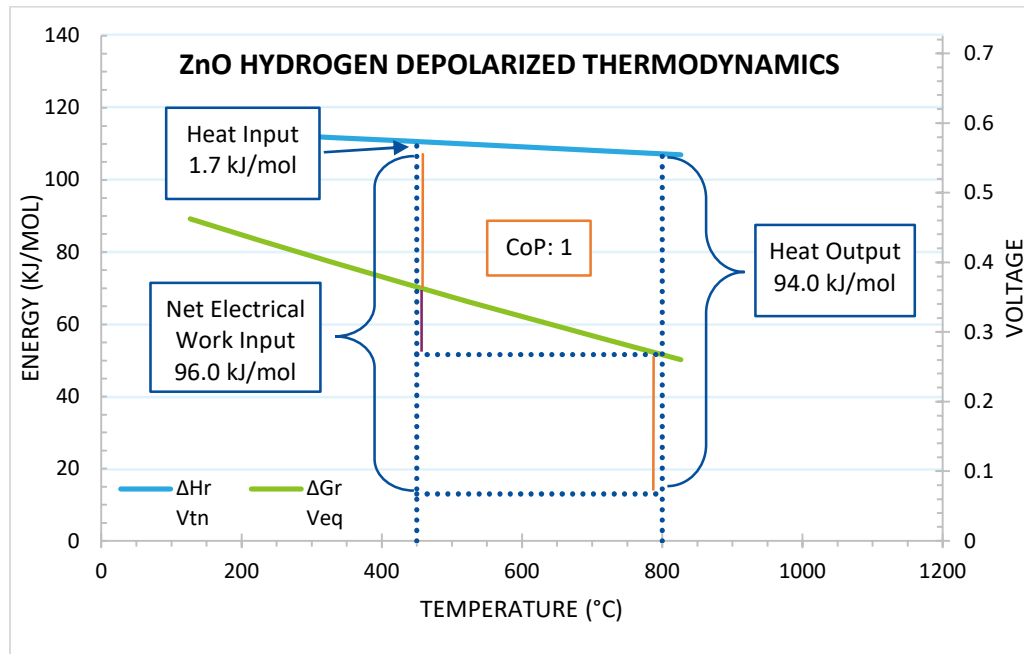


Figure 12: Heat-augmentation practical thermodynamic cycle including 0.2 V/cell overpotential.

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.

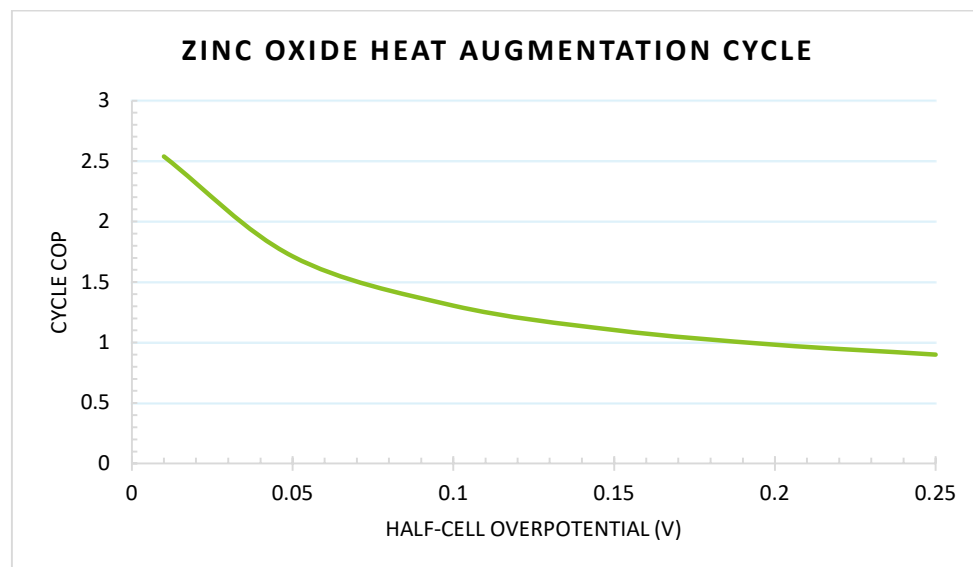


Figure 13. Redox cycle heat-pump CoP vs half-cell overpotential.

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.

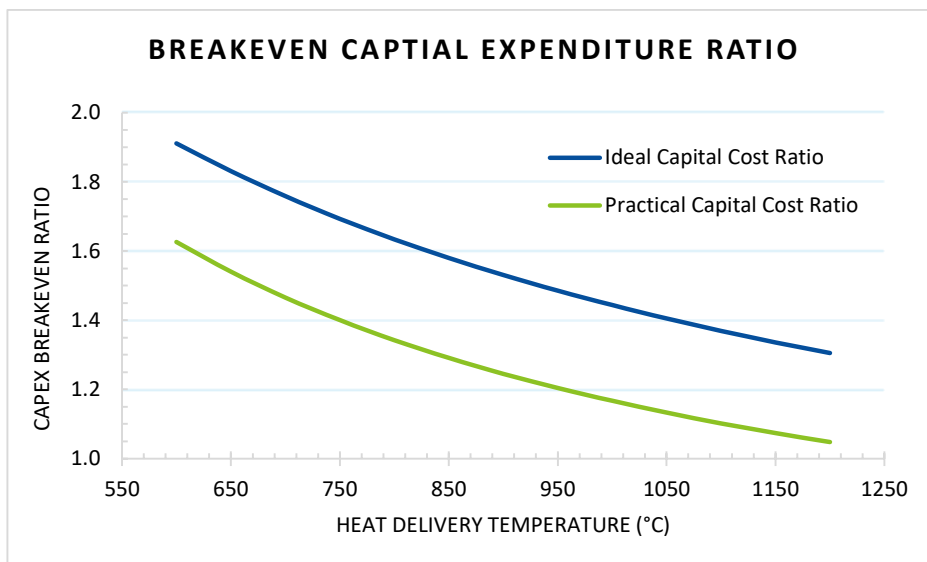


Figure 14. Capital-cost ratio for the heat-delivery temperature.

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-cm² [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/cm²) [5], the cell resistance would need to meet a target of 0.1 Ohm cm² 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-H₂, with 10.2 kWh-th/kg-H₂ 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-H₂, 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.

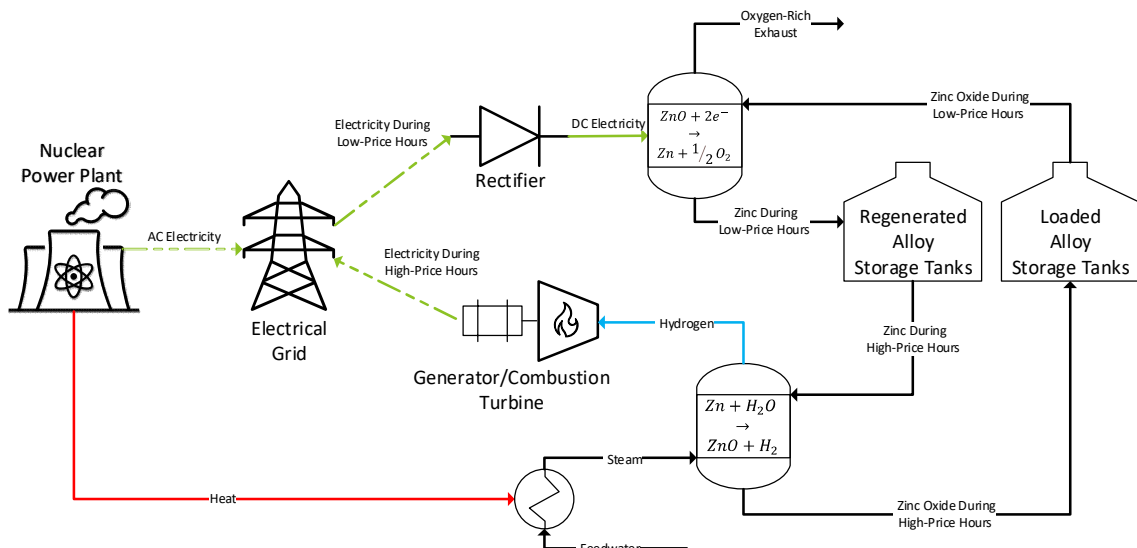


Figure 15. Schematic drawing of a metal-redox cycle used with a hydrogen-combustion turbine for electricity storage.

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.

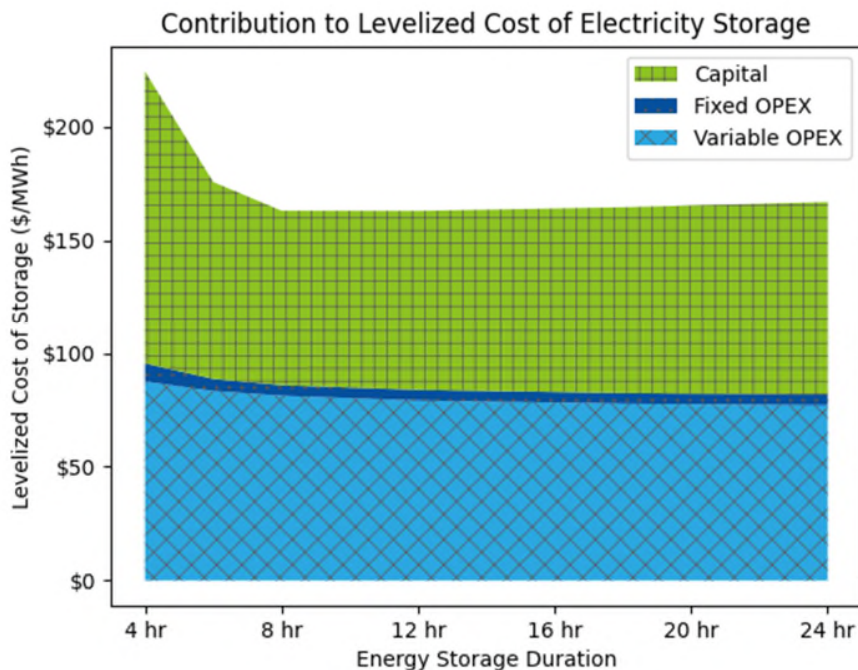


Figure 16. LCOS breakdown for a range of energy-storage durations.

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 H₂. 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.

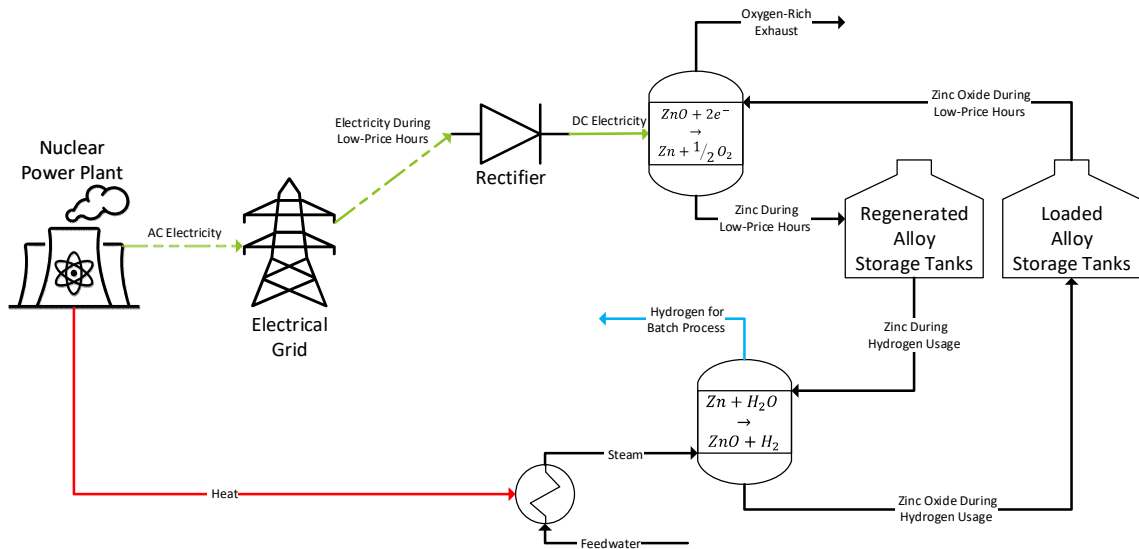


Figure 17. Schematic drawing of metal-redox cycle used for hydrogen storage.

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.

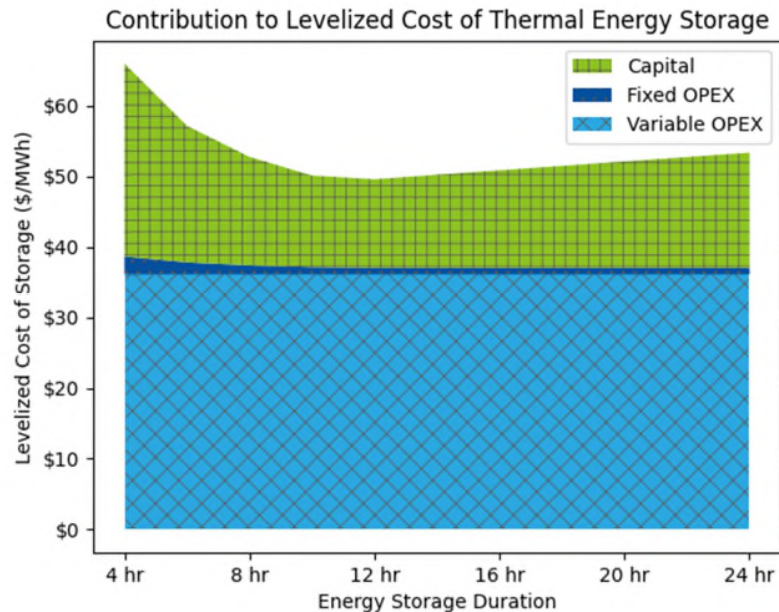


Figure 19. LCOS breakdown for a range of energy-storage durations.

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 techno-economic 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-H₂
- 10.2 kWh-th/kg-H₂ 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 H₂ 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-H₂.

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.

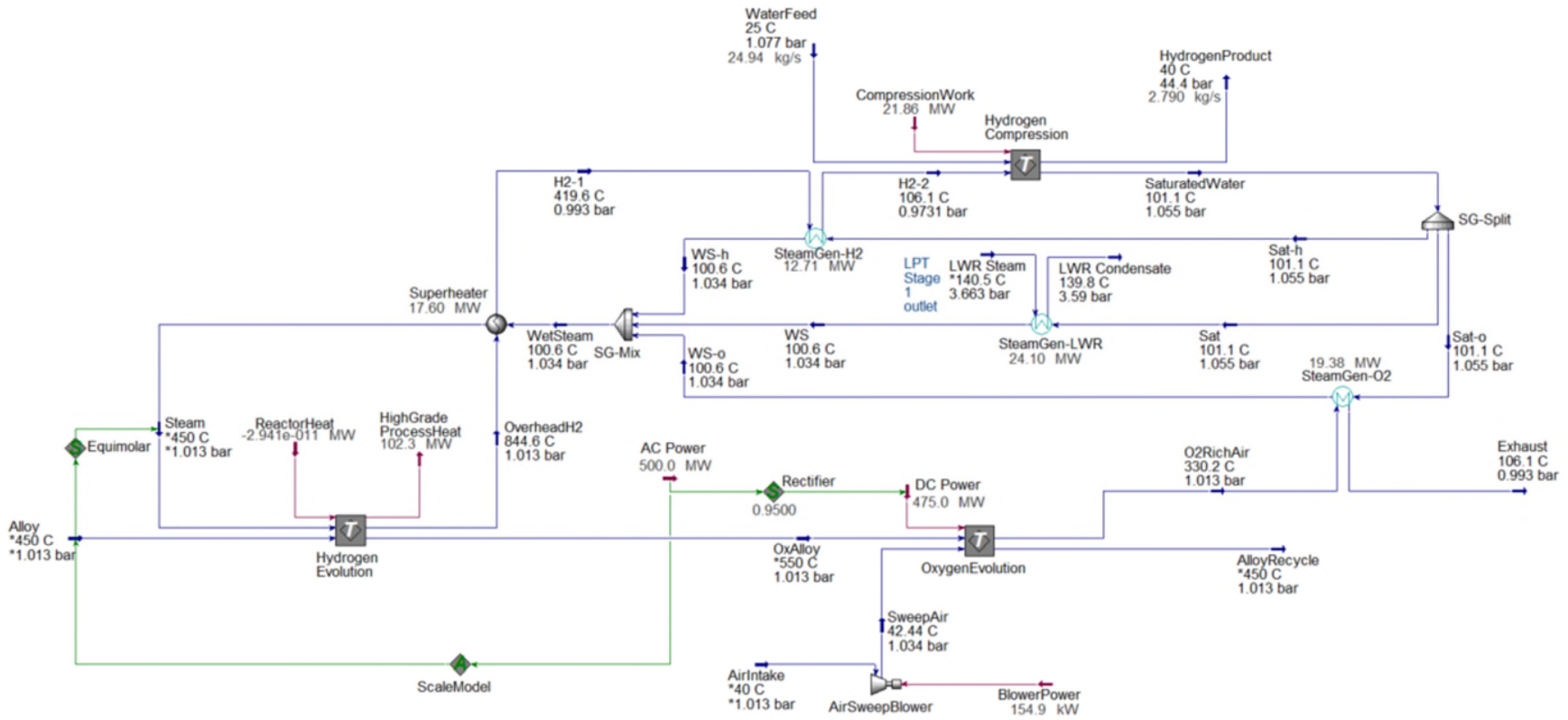





Figure A1. Redox-cycle process model main flowsheet.

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Fri Mar 29 15:06:27 2024				
4							
5	Material Stream: Steam		Fluid Package: Steam				
6			Property Package: NBS Steam				
7	CONDITIONS						
8		Overall	Vapour Phase				
9	Vapour / Phase Fraction	1.0000	1.0000				
10	Temperature: (C)	450.0 *	450.0				
11	Pressure: (bar)	1.013 *	1.013				
12	Molar Flow (kgmole/h)	4985	4985				
13	Mass Flow (kg/s)	24.94	24.94				
14	Std Ideal Liq Vol Flow (m3/h)	89.98	89.98				
15	Molar Enthalpy (kJ/kgmole)	-2.259e+005	-2.259e+005				
16	Molar Entropy (kJ/kgmole-C)	156.5	156.5				
17	Heat Flow (MW)	-312.8	-312.8				
18	Liq Vol Flow @Std Cond (m3/h)	89.88 *	89.88				
19	COMPOSITION						
20	Overall Phase			Vapour Fraction 1.0000			
21	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
22	H2O	4984.5660 *	1.0000 *	89797.4575 *	1.0000 *	89.9787 *	1.0000 *
23	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
24	Vapour Phase			Phase Fraction 1.000			
25	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
26	H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
27	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
28	Material Stream: Alloy		Fluid Package: Reaction				
29			Property Package: Aspen Properties (Solids)				
30	CONDITIONS						
31		Overall	Liquid Phase				
32	Vapour / Phase Fraction	0.0000	1.0000				
33	Temperature: (C)	450.0 *	450.0				
34	Pressure: (bar)	1.013 *	1.013				
35	Molar Flow (kgmole/h)	3.988e+004 *	3.988e+004				
36	Mass Flow (kg/s)	1241	1241				
37	Std Ideal Liq Vol Flow (m3/h)	6826	6826				
38	Molar Enthalpy (kJ/kgmole)	1.850e+004	1.850e+004				
39	Molar Entropy (kJ/kgmole-C)	40.85	40.85				
40	Heat Flow (MW)	205.0	205.0				
41	Liq Vol Flow @Std Cond (m3/h)	3.489e+109 *	3.489e+109				
42	COMPOSITION						
43	Overall Phase			Vapour Fraction 0.0000			
44	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
45	Zinc	4984.5660 *	0.1250 *	325940.7714 *	0.0730 *	46.9437 *	0.0069 *
46	Zinc-Oxide	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
47	Nitrogen	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
48	Oxygen	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
49	Water	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:06:27 2024		
4							
5				Fluid Package:	Reaction		
6	Material Stream: Alloy (continued)			Property Package:	Aspen Properties (Solids)		
7							
8				COMPOSITION			
9				Overall Phase (continued)			
10				Vapour Fraction	0.0000		
11				COMPOSITION			
12	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
13	Tin-White	34891.9621 *	0.8750 *	4.142024817e+06 *	0.9270 *	6778.9151 *	0.9931 *
14	Hydrogen	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
15	Total	39876.5281	1.0000	4.467965589e+06	1.0000	6825.8588	1.0000
16				Liquid Phase			
17				Phase Fraction	1.000		
18				COMPOSITION			
19	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
20	Zinc	4984.5660	0.1250	325940.7714	0.0730	46.9437	0.0069
21	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Tin-White	34891.9621	0.8750	4.142024817e+06	0.9270	6778.9151	0.9931
26	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	Total	39876.5281	1.0000	4.467965589e+06	1.0000	6825.8588	1.0000
28				COMPOSITION			
29				Overall Phase			
30				Vapour Fraction	0.0000		
31				COMPOSITION			
32				Overall Phase			
33				Vapour Fraction	0.0000		
34				CONDITIONS			
35				Overall	Liquid Phase		
36	Vapour / Phase Fraction			0.0000	1.0000		
37	Temperature:	(C)		550.0 *	550.0		
38	Pressure:	(bar)		1.013	1.013		
39	Molar Flow	(kgmole/h)		3.988e+004	3.988e+004		
40	Mass Flow	(kg/s)		1263	1263		
41	Std Ideal Liq Vol Flow	(m3/h)		7747	7747		
42	Molar Enthalpy	(kJ/kgmole)		-1.305e+004	-1.305e+004		
43	Molar Entropy	(kJ/kgmole-C)		62.26	62.26		
44	Heat Flow	(MW)		-144.6	-144.6		
45	Liq Vol Flow @Std Cond	(m3/h)		3.489e+109 *	3.489e+109		
46				COMPOSITION			
47				Overall Phase			
48				Vapour Fraction	0.0000		
49				COMPOSITION			
50	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
51	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
53	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
54	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
56	Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
57	Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
58	Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000
59				COMPOSITION			
60				Overall Phase			
61				Vapour Fraction	0.0000		
62				COMPOSITION			
63				Overall Phase			
64				Vapour Fraction	0.0000		

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: Production.hsc			
2				Unit Set: AmeyS2e			
3				Date/Time: Fri Mar 29 15:06:27 2024			
4							
5				Fluid Package: Reaction			
6	Material Stream: OxAlloy (continued)			Property Package: Aspen Properties (Solids)			
7							
8	COMPOSITION						
9	Liquid Phase						
10						Phase Fraction	1.000
11	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
12	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
14	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
18	Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
19	Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000
20				Fluid Package: Reaction			
21	Material Stream: AlloyRecycle			Property Package: Aspen Properties (Solids)			
22	CONDITIONS						
23		Overall	Liquid Phase				
24	Vapour / Phase Fraction	0.0000	1.0000				
25	Temperature: (C)	450.0 *	450.0				
26	Pressure: (bar)	1.013	1.013				
27	Molar Flow (kgmole/h)	3.988e+004	3.988e+004				
28	Mass Flow (kg/s)	1241	1241				
29	Std Ideal Liq Vol Flow (m3/h)	6826	6826				
30	Molar Enthalpy (kJ/kgmole)	1.854e+004	1.854e+004				
31	Molar Entropy (kJ/kgmole-C)	40.90	40.90				
32	Heat Flow (MW)	205.4	205.4				
33	Liq Vol Flow @Std Cond (m3/h)	3.489e+109 *	3.489e+109				
34	COMPOSITION						
35	Overall Phase						
36						Vapour Fraction	0.0000
37	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
38	Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388	0.0069
39	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
41	Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457	0.0001
42	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151	0.9931
44	Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002	0.0000
45	Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998	1.0000
46	Liquid Phase						
47						Phase Fraction	1.000
48	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
49	Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388	0.0069
50	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457	0.0001
53	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
54	Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151	0.9931


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* Specified by user.


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: Production.hsc			
2				Unit Set: AmeyS2e			
3				Date/Time: Fri Mar 29 15:06:27 2024			
4							
5	Material Stream: AlloyRecycle (continued)			Fluid Package: Reaction			
6				Property Package: Aspen Properties (Solids)			
7	COMPOSITION						
8	Liquid Phase (continued)						
9						Phase Fraction	1.000
10	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
11	Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002	0.0000
12	Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998	1.0000
13	Material Stream: H2-2			Fluid Package: Overheads			
14				Property Package: Aspen Properties (Peng-R			
15	CONDITIONS						
16		Overall	Vapour Phase	Liquid Phase			
17	Vapour / Phase Fraction	1.0000	1.0000	0.0000			
18	Temperature: (C)	106.1	106.1	106.1			
19	Pressure: (bar)	0.9731	0.9731	0.9731			
20	Molar Flow (kgmole/h)	4982	4982	5.285e-005			
21	Mass Flow (kg/s)	2.790	2.790	1.195e-006			
22	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8	1.027e-005			
23	Molar Enthalpy (kJ/kgmole)	2353	2353	-2.205e+005			
24	Molar Entropy (kJ/kgmole-C)	7.310	7.310	4.743			
25	Heat Flow (MW)	3.256	3.256	-3.237e-006			
26	Liq Vol Flow @Std Cond (m3/h)	6.222e+063 *	6.222e+063	2.650e+063			
27	COMPOSITION						
28	Overall Phase						
29						Vapour Fraction	1.0000
30	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
31	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
33	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
37	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
38	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000
39	Vapour Phase						
40						Phase Fraction	1.000
41	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
42	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	Zinc-Oxide	0.0000	0.0000	0.0005	0.0000	0.0000	0.0000
44	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
46	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
48	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
49	Total	4981.7649	1.0000	10042.6425	1.0000	266.8124	1.0000
50							
51							
52							
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60							
61							
62							
63	Aspen Technology Inc.		Aspen HYSYS Version 12.1			Page 4 of 20	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: Production.hsc			
2				Unit Set: AmeyS2e			
3				Date/Time: Fri Mar 29 15:06:27 2024			
4							
5	Material Stream: H2-2 (continued)			Fluid Package: Overheads			
6				Property Package: Aspen Properties (Peng-R)			
7	COMPOSITION						
8	Liquid Phase Phase Fraction 1.061e-008						
9	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
10	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	Zinc-Oxide	0.0001	0.9998	0.0043	1.0000	0.0000	1.0000
12	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	Hydrogen	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
17	Total	0.0001	1.0000	0.0043	1.0000	0.0000	1.0000
18	Material Stream: Exhaust			Fluid Package: Overheads			
19				Property Package: Aspen Properties (Peng-R)			
20	CONDITIONS						
21		Overall	Vapour Phase	Liquid Phase			
22	Vapour / Phase Fraction	1.0000	1.0000	0.0000			
23	Temperature: (C)	106.1	106.1	106.1			
24	Pressure: (bar)	0.9930	0.9930	0.9930			
25	Molar Flow (kgmole/h)	1.032e+004	1.032e+004	0.5160			
26	Mass Flow (kg/s)	84.88	84.87	9.372e-003			
27	Std Ideal Liq Vol Flow (m3/h)	552.8	552.8	4.860e-003			
28	Molar Enthalpy (kJ/kgmole)	2373	2375	-4.719e+004			
29	Molar Entropy (kJ/kgmole-C)	12.83	12.83	-25.51			
30	Heat Flow (MW)	6.803	6.810	-6.764e-003			
31	Liq Vol Flow @Std Cond (m3/h)	858.4	858.4	4.930e-003			
32	COMPOSITION						
33	Overall Phase Vapour Fraction 1.0000						
34	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
35	Zinc	0.5160	0.0000	33.7408	0.0001	0.0049	0.0000
36	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
37	Nitrogen	6189.5823	0.5996	173391.7402	0.5674	331.5004	0.5997
38	Oxygen	4129.2924	0.4000	132132.4006	0.4324	221.1558	0.4001
39	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
41	Hydrogen	2.7980	0.0003	5.6405	0.0000	0.1499	0.0003
42	Total	10322.1887	1.0000	305563.5221	1.0000	552.8109	1.0000
43	Vapour Phase Phase Fraction 1.000						
44	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
45	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
46	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	Nitrogen	6189.5823	0.5997	173391.7402	0.5675	331.5004	0.5997
48	Oxygen	4129.2924	0.4001	132132.4006	0.4325	221.1558	0.4001
49	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	Hydrogen	2.7980	0.0003	5.6405	0.0000	0.1499	0.0003
52	Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 5 of 20						


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:06:27 2024		
4							
5				Fluid Package:	Overheads		
6	Material Stream: Exhaust (continued)			Property Package:	Aspen Properties (Peng-R		
7							
8	COMPOSITION						
9							
10	Vapour Phase (continued)						
11						Phase Fraction	1.000
12	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
13	Hydrogen	2.7980	0.0003	5.6405	0.0000	0.1499	0.0003
14	Total	10321.6727	1.0000	305529.7813	1.0000	552.8061	1.0000
15	Liquid Phase						
16						Phase Fraction	4.999e-005
17	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
18	Zinc	0.5160	1.0000	33.7408	1.0000	0.0049	1.0000
19	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Total	0.5160	1.0000	33.7408	1.0000	0.0049	1.0000
26				Fluid Package:	Overheads		
27	Material Stream: HydrogenProduct			Property Package:	Aspen Properties (Peng-R		
28							
29	CONDITIONS						
30							
31		Overall	Vapour Phase	Liquid Phase			
32	Vapour / Phase Fraction	1.0000	1.0000	0.0000			
33	Temperature: (C)	40.00	40.00	40.00			
34	Pressure: (bar)	44.40	44.40	44.40			
35	Molar Flow (kgmole/h)	4982	4982	6.027e-005			
36	Mass Flow (kg/s)	2.790	2.790	1.359e-006			
37	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8	1.166e-005			
38	Molar Enthalpy (kJ/kgmole)	462.8	462.8	-2.189e+005			
39	Molar Entropy (kJ/kgmole-C)	-30.09	-30.09	-6.628			
40	Heat Flow (MW)	0.6404	0.6404	-3.665e-006			
41	Liq Vol Flow @Std Cond (m3/h)	6.222e+063 *	5.849e+063	1.875e+070			
42	COMPOSITION						
43							
44	Overall Phase						
45						Vapour Fraction	1.0000
46	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
47	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
48	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
49	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
53	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
54	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000
55							
56							
57							
58							
59							
60							
61							
62							
63	Aspen Technology Inc.			Aspen HYSYS Version 12.1		Page 6 of 20	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:06:27 2024		
4							Fluid Package:
5	Material Stream: HydrogenProduct (continuec			Property Package:	Aspen Properties (Peng-R		
6							
7	COMPOSITION						
8	Vapour Phase Phase Fraction 1.000						
9	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
10	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
16	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
17	Total	4981.7648	1.0000	10042.6419	1.0000	266.8124	1.0000
18	Liquid Phase Phase Fraction 1.210e-008						
19	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
20	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	Zinc-Oxide	0.0001	0.9874	0.0048	0.9897	0.0000	0.9915
22	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Tin-White	0.0000	0.0069	0.0000	0.0101	0.0000	0.0070
26	Hydrogen	0.0000	0.0057	0.0000	0.0001	0.0000	0.0016
27	Total	0.0001	1.0000	0.0049	1.0000	0.0000	1.0000
28	Material Stream: O2RichAir			Fluid Package:	Overheads		
29				Property Package:	Aspen Properties (Peng-R		
30	CONDITIONS						
31		Overall	Vapour Phase	Liquid Phase			
32	Vapour / Phase Fraction	1.0000	1.0000	0.0000			
33	Temperature: (C)	330.2	330.2	330.2			
34	Pressure: (bar)	1.013	1.013	1.013			
35	Molar Flow (kgmole/h)	1.032e+004	1.032e+004	0.5159			
36	Mass Flow (kg/s)	84.88	84.87	9.370e-003			
37	Std Ideal Liq Vol Flow (m3/h)	552.8	552.8	4.858e-003			
38	Molar Enthalpy (kJ/kgmole)	9132	9134	-3.636e+004			
39	Molar Entropy (kJ/kgmole-C)	26.64	26.64	-2.978			
40	Heat Flow (MW)	26.18	26.19	-5.210e-003			
41	Liq Vol Flow @Std Cond (m3/h)	858.4 *	858.4	4.929e-003			
42	COMPOSITION						
43	Overall Phase Vapour Fraction 1.0000						
44	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
45	Zinc	0.5160	0.0000	33.7408	0.0001	0.0049	0.0000
46	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	Nitrogen	6189.5823	0.5996	173391.7402	0.5674	331.5004	0.5997
48	Oxygen	4129.2924	0.4000	132132.4006	0.4324	221.1558	0.4001
49	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc			
2			Unit Set: AmeyS2e			
3			Date/Time: Fri Mar 29 15:06:27 2024			
4						
5						
6	Material Stream: O2RichAir (continued)		Fluid Package: Overheads			
7			Property Package: Aspen Properties (Peng-R			
8						
9	COMPOSITION					
10						
11	Overall Phase (continued)				Vapour Fraction	1.0000
12	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
13						LIQUID VOLUME FRACTION
14	Hydrogen	2.7980	0.0003	5.6405	0.0000	0.1499
15	Total	10322.1887	1.0000	305563.5221	1.0000	552.8109
16	Vapour Phase				Phase Fraction	1.000
17	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
18						LIQUID VOLUME FRACTION
19	Zinc	0.0001	0.0000	0.0092	0.0000	0.0000
20	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000
21	Nitrogen	6189.5823	0.5997	173391.7402	0.5675	331.5004
22	Oxygen	4129.2924	0.4001	132132.4006	0.4325	221.1558
23	Water	0.0000	0.0000	0.0000	0.0000	0.0000
24	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000
25	Hydrogen	2.7980	0.0003	5.6405	0.0000	0.1499
26	Total	10321.6728	1.0000	305529.7905	1.0000	552.8061
27	Liquid Phase				Phase Fraction	4.998e-005
28	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
29						LIQUID VOLUME FRACTION
30	Zinc	0.5159	1.0000	33.7316	1.0000	0.0049
31	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000
32	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000
33	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000
34	Water	0.0000	0.0000	0.0000	0.0000	0.0000
35	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000
36	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000
37	Total	0.5159	1.0000	33.7316	1.0000	0.0049
38	Material Stream: SweepAir		Fluid Package: Overheads			
39			Property Package: Aspen Properties (Peng-R			
40						
41	CONDITIONS					
42		Overall	Vapour Phase			
43	Vapour / Phase Fraction	1.0000	1.0000			
44	Temperature: (C)	42.44	42.44			
45	Pressure: (bar)	1.034	1.034			
46	Molar Flow (kgmole/h)	7835	7835			
47	Mass Flow (kg/s)	62.79	62.79			
48	Std Ideal Liq Vol Flow (m3/h)	419.6	419.6			
49	Molar Enthalpy (kJ/kgmole)	501.6	501.6			
50	Molar Entropy (kJ/kgmole-C)	5.744	5.744			
51	Heat Flow (MW)	1.092	1.092			
52	Liq Vol Flow @Std Cond (m3/h)	675.1 *	675.1			
53						
54						
55						
56						
57						
58						
59						
60						
61						
62						
63	Aspen Technology Inc.		Aspen HYSYS Version 12.1		Page 8 of 20	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc			
2				Unit Set:	AmeyS2e			
3				Date/Time:	Fri Mar 29 15:06:27 2024			
4								
5	Material Stream: SweepAir (continued)			Fluid Package:	Overheads			
6				Property Package:	Aspen Properties (Peng-R			
7								
8	COMPOSITION							
9	Overall Phase							
10							Vapour Fraction	1.0000
11	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
12	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
13	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
14	Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004	0.7900	
15	Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204	0.2100	
16	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
17	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
18	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
19	Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000	
20	Vapour Phase							
21							Phase Fraction	1.000
22	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
23	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
24	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
25	Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004	0.7900	
26	Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204	0.2100	
27	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
28	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
29	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
30	Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000	
31	Material Stream: AirIntake			Fluid Package:	Overheads			
32				Property Package:	Aspen Properties (Peng-R			
33								
34	CONDITIONS							
35			Overall	Vapour Phase				
36	Vapour / Phase Fraction	1.0000		1.0000				
37	Temperature:	(C)	40.00 *	40.00				
38	Pressure:	(bar)	1.013 *	1.013				
39	Molar Flow	(kgmole/h)	7835	7835				
40	Mass Flow	(kg/s)	62.79	62.79				
41	Std Ideal Liq Vol Flow	(m3/h)	419.6	419.6				
42	Molar Enthalpy	(kJ/kgmole)	430.4	430.4				
43	Molar Entropy	(kJ/kgmole-C)	5.688	5.688				
44	Heat Flow	(MW)	0.9367	0.9367				
45	Liq Vol Flow @Std Cond	(m3/h)	675.1 *	675.1				
46	COMPOSITION							
47	Overall Phase							
48							Vapour Fraction	1.0000
49	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
50	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
51	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
52	Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004	0.7900	
53	Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204	0.2100	
54	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
55	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: Production.hsc				
2				Unit Set: AmeyS2e				
3				Date/Time: Fri Mar 29 15:06:27 2024				
4								
5	Material Stream: AirIntake (continued)			Fluid Package: Overheads				
6				Property Package: Aspen Properties (Peng-R				
7	COMPOSITION							
8	Overall Phase (continued)							
9						Vapour Fraction	1.0000	
10	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
11	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
12	Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000	
13	Vapour Phase						Phase Fraction	1.000
14	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
15	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
16	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
17	Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004	0.7900	
18	Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204	0.2100	
19	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
20	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
21	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
22	Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000	
23	Material Stream: Sat-o			Fluid Package: Steam				
24				Property Package: NBS Steam				
25	CONDITIONS							
26		Overall	Aqueous Phase	Vapour Phase				
27	Vapour / Phase Fraction	0.0000 *	1.0000	0.0000				
28	Temperature: (C)	101.1	101.1	101.1				
29	Pressure: (bar)	1.055	1.055	1.055				
30	Molar Flow (kgmole/h)	1719	1719	0.0000				
31	Mass Flow (kg/s)	8.603	8.603	0.0000				
32	Std Ideal Liq Vol Flow (m3/h)	31.03	31.03	0.0000				
33	Molar Enthalpy (kJ/kgmole)	-2.792e+005	-2.792e+005	-2.386e+005				
34	Molar Entropy (kJ/kgmole-C)	23.77	23.77	132.2				
35	Heat Flow (MW)	-133.4	-133.4	0.0000				
36	Liq Vol Flow @Std Cond (m3/h)	31.00 *	31.00	0.0000				
37	COMPOSITION							
38	Overall Phase							
39						Vapour Fraction	0.0000 *	
40	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
41	H2O	1719.2431 *	1.0000 *	30972.3369 *	1.0000 *	31.0348 *	1.0000 *	
42	Total	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000	
43	Aqueous Phase						Phase Fraction	1.000
44	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
45	H2O	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000	
46	Total	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000	
47	Aspen Technology Inc.						Aspen HYSYS Version 12.1	
48	Licensed to: BATTELLE ENERGY ALLIANCE						Page 10 of 20	
49							* Specified by user.	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Fri Mar 29 15:06:27 2024				
4							
5							
6	Material Stream: Sat-o (continued)				Fluid Package: Steam		
7					Property Package: NBS Steam		
8	COMPOSITION						
9	Vapour Phase						
10						Phase Fraction	0.0000
11	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
12	H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
13	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
14	Material Stream: WS-o				Fluid Package: Steam		
15					Property Package: NBS Steam		
16	CONDITIONS						
17		Overall	Vapour Phase	Aqueous Phase			
18	Vapour / Phase Fraction	1.0000 *	1.0000	0.0000			
19	Temperature: (C)	100.6	100.6	100.6			
20	Pressure: (bar)	1.034	1.034	1.034			
21	Molar Flow (kgmole/h)	1719	1719	0.0000			
22	Mass Flow (kg/s)	8.603	8.603	0.0000			
23	Std Ideal Liq Vol Flow (m3/h)	31.03	31.03	0.0000			
24	Molar Enthalpy (kJ/kgmole)	-2.387e+005	-2.387e+005	-2.793e+005			
25	Molar Entropy (kJ/kgmole-C)	132.4	132.4	23.66			
26	Heat Flow (MW)	-114.0	-114.0	0.0000			
27	Liq Vol Flow @Std Cond (m3/h)	31.00 *	31.00	0.0000			
28	COMPOSITION						
29	Overall Phase					Vapour Fraction	1.0000 *
30	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
31	H2O	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000
32	Total	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000
33	Vapour Phase					Phase Fraction	1.000
34	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
35	H2O	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000
36	Total	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000
37	Aqueous Phase					Phase Fraction	0.0000
38	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
39	H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
40	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
41	Material Stream: H2-1				Fluid Package: Overheads		
42					Property Package: Aspen Properties (Peng-R)		
43	CONDITIONS						
44		Overall	Vapour Phase				
45	Vapour / Phase Fraction	1.0000	1.0000				
46	Temperature: (C)	419.6	419.6				
47	Pressure: (bar)	0.9930	0.9930				
48	Molar Flow (kgmole/h)	4982	4982				


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc			
2			Unit Set: AmeyS2e			
3			Date/Time: Fri Mar 29 15:06:27 2024			
4						
5	Material Stream: H2-1 (continued)				Fluid Package: Overheads	
6					Property Package: Aspen Properties (Peng-R	
7	CONDITIONS					
8						
9						
10						
11						
12	Mass Flow (kg/s)	Overall	Vapour Phase			
13	Std Ideal Liq Vol Flow (m3/h)	2.790	2.790			
14	Molar Enthalpy (kJ/kgmole)	266.8	266.8			
15	Molar Entropy (kJ/kgmole-C)	1.154e+004	1.154e+004			
16	Heat Flow (MW)	24.79	24.79			
17	Liq Vol Flow @Std Cond (m3/h)	15.97	15.97			
18		6.222e+063 *	6.222e+063			
19	COMPOSITION					
20	Overall Phase					
21						Vapour Fraction 1.0000
22	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
23						LIQUID VOLUME FRACTION
24	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000
25	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000
26	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000
27	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000
28	Water	0.0000	0.0000	0.0000	0.0000	0.0000
29	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000
30	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124
31	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124
32	Vapour Phase					
33						Phase Fraction 1.000
34	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
35						LIQUID VOLUME FRACTION
36	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000
37	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000
38	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000
39	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000
40	Water	0.0000	0.0000	0.0000	0.0000	0.0000
41	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000
42	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124
43	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124
44	Material Stream: WetSteam				Fluid Package: Steam	
45					Property Package: NBS Steam	
46	CONDITIONS					
47	Overall					
48						
49	Vapour / Phase Fraction	Overall	Vapour Phase	Aqueous Phase		
50	Temperature: (C)	1.0000 *	1.0000	0.0000		
51	Pressure: (bar)	100.6	100.6	100.6		
52	Molar Flow (kgmole/h)	1.034	1.034	1.034		
53	Mass Flow (kg/s)	4985	4985	0.0000		
54	Std Ideal Liq Vol Flow (m3/h)	24.94	24.94	0.0000		
55	Molar Enthalpy (kJ/kgmole)	89.98	89.98	0.0000		
56	Molar Entropy (kJ/kgmole-C)	-2.387e+005	-2.387e+005	-2.793e+005		
57	Heat Flow (MW)	132.4	132.4	23.66		
58	Liq Vol Flow @Std Cond (m3/h)	-330.4	-330.4	0.0000		
59		89.88 *	89.88	0.0000		
60						
61						
62						
63	Aspen Technology Inc.		Aspen HYSYS Version 12.1		Page 12 of 20	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc			
2				Unit Set:	AmeyS2e			
3				Date/Time:	Fri Mar 29 15:06:27 2024			
4								
5	Material Stream: WetSteam (continued)							
6				Fluid Package:	Steam			
7				Property Package:	NBS Steam			
8	COMPOSITION							
9	Overall Phase							
10							Vapour Fraction	1.0000 *
11	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
12	H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000	
13	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000	
14	Vapour Phase							
15							Phase Fraction	1.000
16	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
17	H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000	
18	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000	
19	Aqueous Phase							
20							Phase Fraction	0.0000
21	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
22	H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	
23	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	
24							Fluid Package:	Steam
25	Material Stream: WS-h						Property Package:	NBS Steam
26	CONDITIONS							
27		Overall	Vapour Phase	Aqueous Phase				
28	Vapour / Phase Fraction	1.0000 *	1.0000	0.0000				
29	Temperature: (C)	100.6	100.6	100.6				
30	Pressure: (bar)	1.034	1.034	1.034				
31	Molar Flow (kgmole/h)	1128	1128	0.0000				
32	Mass Flow (kg/s)	5.643	5.643	0.0000				
33	Std Ideal Liq Vol Flow (m3/h)	20.36	20.36	0.0000				
34	Molar Enthalpy (kJ/kgmole)	-2.387e+005	-2.387e+005	-2.793e+005				
35	Molar Entropy (kJ/kgmole-C)	132.4	132.4	23.66				
36	Heat Flow (MW)	-74.75	-74.75	0.0000				
37	Liq Vol Flow @Std Cond (m3/h)	20.33 *	20.33	0.0000				
38	COMPOSITION							
39	Overall Phase							
40							Vapour Fraction	1.0000 *
41	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
42	H2O	1127.6444 *	1.0000 *	20314.6270 *	1.0000 *	20.3556 *	1.0000 *	
43	Total	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000	
44	Vapour Phase							
45							Phase Fraction	1.000
46	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
47	H2O	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000	
48	Total	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000	
49								
50								
51								
52								
53								
54								
55								
56								
57								
58								
59								
60								
61								
62								
63	Aspen Technology Inc.		Aspen HYSYS Version 12.1			Page 13 of 20		


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc					
2			Unit Set: AmeyS2e					
3			Date/Time: Fri Mar 29 15:06:27 2024					
4								
5								
6	Material Stream: WS-h (continued)				Fluid Package: Steam			
7					Property Package: NBS Steam			
8								
9	COMPOSITION							
10	Aqueous Phase							
11						Phase Fraction	0.0000	
12	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
13	H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	
14	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	
15	Material Stream: WS				Fluid Package: Steam			
16					Property Package: NBS Steam			
17								
18	CONDITIONS							
19		Overall	Vapour Phase					
20	Vapour / Phase Fraction	1.0000	1.0000					
21	Temperature: (C)	100.6	100.6					
22	Pressure: (bar)	1.034	1.034					
23	Molar Flow (kgmole/h)	2138	2138					
24	Mass Flow (kg/s)	10.70	10.70					
25	Std Ideal Liq Vol Flow (m3/h)	38.59	38.59					
26	Molar Enthalpy (kJ/kgmole)	-2.387e+005	-2.387e+005					
27	Molar Entropy (kJ/kgmole-C)	132.4	132.4					
28	Heat Flow (MW)	-141.7	-141.7					
29	Liq Vol Flow @Std Cond (m3/h)	38.54 *	38.54					
30	COMPOSITION							
31	Overall Phase							
32						Vapour Fraction	1.0000	
33	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
34	H2O	2137.6785 *	1.0000 *	38510.4936 *	1.0000 *	38.5882 *	1.0000 *	
35	Total	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000	
36	Vapour Phase							
37						Phase Fraction	1.000	
38	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
39	H2O	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000	
40	Total	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000	
41	Material Stream: Sat-h				Fluid Package: Steam			
42					Property Package: NBS Steam			
43								
44	CONDITIONS							
45		Overall	Aqueous Phase	Vapour Phase				
46	Vapour / Phase Fraction	0.0000 *	1.0000	0.0000				
47	Temperature: (C)	101.1	101.1	101.1				
48	Pressure: (bar)	1.055	1.055	1.055				
49	Molar Flow (kgmole/h)	1128	1128	0.0000				
50	Mass Flow (kg/s)	5.643	5.643	0.0000				
51	Std Ideal Liq Vol Flow (m3/h)	20.36	20.36	0.0000				
52	Molar Enthalpy (kJ/kgmole)	-2.792e+005	-2.792e+005	-2.386e+005				
53	Molar Entropy (kJ/kgmole-C)	23.77	23.77	132.2				
54	Heat Flow (MW)	-87.47	-87.47	0.0000				
55	Liq Vol Flow @Std Cond (m3/h)	20.33 *	20.33	0.0000				
56	Aspen Technology Inc.		Aspen HYSYS Version 12.1		Page 14 of 20			


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:06:27 2024		
4							
5				Fluid Package:	Steam		
6	Material Stream: Sat-h (continued)			Property Package:	NBS Steam		
7							
8							
9	COMPOSITION						
10							
11	Overall Phase					Vapour Fraction	0.0000 *
12	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
13	H2O	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000
14	Total	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000
15	Aqueous Phase						
16						Phase Fraction	1.000
17	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
18	H2O	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000
19	Total	1127.6444	1.0000	20314.6270	1.0000	20.3556	1.0000
20	Vapour Phase						
21						Phase Fraction	0.0000
22	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
23	H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
24	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
25				Fluid Package:	Steam		
26	Material Stream: Sat			Property Package:	NBS Steam		
27							
28	CONDITIONS						
29							
30		Overall	Aqueous Phase	Vapour Phase			
31	Vapour / Phase Fraction	0.0000 *	1.0000	0.0000			
32	Temperature: (C)	101.1	101.1	101.1			
33	Pressure: (bar)	1.055	1.055	1.055			
34	Molar Flow (kgmole/h)	2138	2138	0.0000			
35	Mass Flow (kg/s)	10.70	10.70	0.0000			
36	Std Ideal Liq Vol Flow (m3/h)	38.59	38.59	0.0000			
37	Molar Enthalpy (kJ/kgmole)	-2.792e+005	-2.792e+005	-2.386e+005			
38	Molar Entropy (kJ/kgmole-C)	23.77	23.77	132.2			
39	Heat Flow (MW)	-165.8	-165.8	0.0000			
40	Liq Vol Flow @Std Cond (m3/h)	38.54 *	38.54	0.0000			
41	COMPOSITION						
42							
43	Overall Phase					Vapour Fraction	0.0000 *
44	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
45	H2O	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000
46	Total	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000
47	Aqueous Phase						
48						Phase Fraction	1.000
49	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
50	H2O	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000
51	Total	2137.6785	1.0000	38510.4936	1.0000	38.5882	1.0000
52							
53							
54							
55							
56							
57							
58							
59							
60							
61							
62							
63	Aspen Technology Inc.			Aspen HYSYS Version 12.1		Page 15 of 20	

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Fri Mar 29 15:06:27 2024				
4							
5							
6	Material Stream: Sat (continued)				Fluid Package: Steam		
7					Property Package: NBS Steam		
8	COMPOSITION						
9	Vapour Phase						
10						Phase Fraction	0.0000
11	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
12	H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
13	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
14	Material Stream: SaturatedWater				Fluid Package: Steam		
15					Property Package: NBS Steam		
16	CONDITIONS						
17		Overall	Aqueous Phase	Vapour Phase			
18	Vapour / Phase Fraction	0.0000	1.0000	0.0000			
19	Temperature: (C)	101.1	101.1	101.1			
20	Pressure: (bar)	1.055	1.055	1.055			
21	Molar Flow (kgmole/h)	4985	4985	0.0000			
22	Mass Flow (kg/s)	24.94	24.94	0.0000			
23	Std Ideal Liq Vol Flow (m3/h)	89.98	89.98	0.0000			
24	Molar Enthalpy (kJ/kgmole)	-2.792e+005	-2.792e+005	-2.386e+005			
25	Molar Entropy (kJ/kgmole-C)	23.77	23.77	132.2			
26	Heat Flow (MW)	-386.6	-386.6	0.0000			
27	Liq Vol Flow @Std Cond (m3/h)	89.88 *	89.88	0.0000			
28	COMPOSITION						
29	Overall Phase						
30						Vapour Fraction	0.0000
31	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
32	H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
33	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
34	Aqueous Phase						
35						Phase Fraction	1.000
36	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
37	H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
38	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
39	Vapour Phase						
40						Phase Fraction	0.0000
41	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
42	H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
43	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
44	Material Stream: WaterFeed				Fluid Package: Steam		
45					Property Package: NBS Steam		
46	CONDITIONS						
47		Overall	Aqueous Phase				
48	Vapour / Phase Fraction	0.0000	1.0000				
49	Temperature: (C)	25.00	25.00				
50	Pressure: (bar)	1.077	1.077				
51	Molar Flow (kgmole/h)	4985	4985				

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Fri Mar 29 15:06:27 2024				
4							
5							
6	Material Stream: WaterFeed (continued)		Fluid Package: Steam				
7			Property Package: NBS Steam				
8							
9	CONDITIONS						
10							
11		Overall	Aqueous Phase				
12	Mass Flow (kg/s)	24.94	24.94				
13	Std Ideal Liq Vol Flow (m3/h)	89.98	89.98				
14	Molar Enthalpy (kJ/kgmole)	-2.850e+005	-2.850e+005				
15	Molar Entropy (kJ/kgmole-C)	6.610	6.610				
16	Heat Flow (MW)	-394.6	-394.6				
17	Liq Vol Flow @Std Cond (m3/h)	89.88	89.88				
18	COMPOSITION						
19							
20	Overall Phase						
21						Vapour Fraction	0.0000
22	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
23							
24	H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
25	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
26	Aqueous Phase						
27						Phase Fraction	1.000
28	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
29							
30	H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
31	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787	1.0000
32	Material Stream: OverheadH2		Fluid Package: Overheads				
33			Property Package: Aspen Properties (Peng-R				
34							
35	CONDITIONS						
36							
37		Overall	Vapour Phase				
38	Vapour / Phase Fraction	1.0000	1.0000				
39	Temperature: (C)	844.6	844.6				
40	Pressure: (bar)	1.013	1.013				
41	Molar Flow (kgmole/h)	4982	4982				
42	Mass Flow (kg/s)	2.790	2.790				
43	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8				
44	Molar Enthalpy (kJ/kgmole)	2.426e+004	2.426e+004				
45	Molar Entropy (kJ/kgmole-C)	38.92	38.92				
46	Heat Flow (MW)	33.57	33.57				
47	Liq Vol Flow @Std Cond (m3/h)	6.222e+063	6.222e+063				
48	COMPOSITION						
49							
50	Overall Phase						
51						Vapour Fraction	1.0000
52	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
53							
54	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
56	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
57	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
58	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
59	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
60	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
61	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000
62							
63	Aspen Technology Inc.		Aspen HYSYS Version 12.1		Page 17 of 20		

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:06:27 2024		
4							
5							
6	Material Stream: OverheadH2 (continued)				Fluid Package:	Overheads	
7					Property Package:	Aspen Properties (Peng-R	
8							
9	COMPOSITION						
10							
11	Vapour Phase				Phase Fraction	1.000	
12							
13	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
14							
15	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
17	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
21	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
22	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000
23							
24	Material Stream: LWR Condensate				Fluid Package:	Steam	
25					Property Package:	NBS Steam	
26							
27	CONDITIONS						
28			Overall	Aqueous Phase	Vapour Phase		
29	Vapour / Phase Fraction		0.0000 *	1.0000	0.0000		
30	Temperature: (C)		139.8	139.8	139.8		
31	Pressure: (bar)		3.590	3.590	3.590		
32	Molar Flow (kgmole/h)		2244	2244	0.0000		
33	Mass Flow (kg/s)		11.23	11.23	0.0000		
34	Std Ideal Liq Vol Flow (m3/h)		40.50	40.50	0.0000		
35	Molar Enthalpy (kJ/kgmole)		-2.763e+005	-2.763e+005	-2.376e+005		
36	Molar Entropy (kJ/kgmole-C)		31.29	31.29	124.9		
37	Heat Flow (MW)		-172.2	-172.2	0.0000		
38	Liq Vol Flow @Std Cond (m3/h)		40.46 *	40.46	0.0000		
39							
40	COMPOSITION						
41							
42	Overall Phase				Vapour Fraction	0.0000 *	
43							
44	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
45	H2O	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000
46	Total	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000
47							
48	Aqueous Phase				Phase Fraction	1.000	
49							
50	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
51	H2O	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000
52	Total	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000
53							
54	Vapour Phase				Phase Fraction	0.0000	
55							
56	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
57	H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
58	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
59							
60							
61							
62							
63	Aspen Technology Inc.		Aspen HYSYS Version 12.1			Page 18 of 20	

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Fri Mar 29 15:06:27 2024				
4							
5	Material Stream: LWR Steam		Fluid Package: Steam				
6			Property Package: NBS Steam				
7	CONDITIONS						
8		Overall	Vapour Phase	Aqueous Phase			
9	Vapour / Phase Fraction	1.0000 *	1.0000	0.0000			
10	Temperature: (C)	140.5 *	140.5	140.5			
11	Pressure: (bar)	3.663	3.663	3.663			
12	Molar Flow (kgmole/h)	2244	2244	0.0000			
13	Mass Flow (kg/s)	11.23	11.23	0.0000			
14	Std Ideal Liq Vol Flow (m3/h)	40.50	40.50	0.0000			
15	Molar Enthalpy (kJ/kgmole)	-2.376e+005	-2.376e+005	-2.762e+005			
16	Molar Entropy (kJ/kgmole-C)	124.8	124.8	31.43			
17	Heat Flow (MW)	-148.1	-148.1	0.0000			
18	Liq Vol Flow @Std Cond (m3/h)	40.46 *	40.46	0.0000			
19	COMPOSITION						
20	Overall Phase				Vapour Fraction 1.0000 *		
21	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
22	H2O	2243.8604 *	1.0000 *	40423.3697 *	1.0000 *	40.5049 *	1.0000 *
23	Total	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000
24	Vapour Phase				Phase Fraction 1.000		
25	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
26	H2O	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000
27	Total	2243.8604	1.0000	40423.3697	1.0000	40.5049	1.0000
28	Aqueous Phase				Phase Fraction 0.0000		
29	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
30	H2O	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
31	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
32	Energy Stream: ReactorHeat		Fluid Package: Reaction				
33			Property Package: Aspen Properties (Solids)				
34	CONDITIONS						
35	Duty Type: Direct Q	Duty Calculation Operation: SolveTemp @HER					
36	Duty SP: -2.941e-011 MW	Minimum Available Duty: 0.0000 MW	Maximum Available Duty: ---				
37	Energy Stream: DC Power		Fluid Package: Reaction				
38			Property Package: Aspen Properties (Solids)				
39	CONDITIONS						
40	Duty Type: Direct Q	Duty Calculation Operation: SolveTemp @OER					
41	Duty SP: 475.0 MW	Minimum Available Duty: 0.0000 MW	Maximum Available Duty: ---				
42	Energy Stream: AC Power		Fluid Package: Reaction				
43			Property Package: Aspen Properties (Solids)				
44	CONDITIONS						
45	Duty Type: Direct Q	Duty Calculation Operation: Rectifier					
46	Duty SP: 500.0 MW	Minimum Available Duty: 0.0000 MW	Maximum Available Duty: ---				

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name:	Production.hsc	
2			Unit Set:	Ameys2e	
3			Date/Time:	Fri Mar 29 15:06:27 2024	
4					
5	Energy Stream: CompressionWork			Fluid Package:	Reaction
6				Property Package:	Aspen Properties (Solids)
7	CONDITIONS				
8	Duty Type:	Direct Q	Duty Calculation Operation:		
9	Duty SP:	21.86 MW	Minimum Available Duty:	0.0000 MW	
10				Maximum Available Duty:	---
11	Energy Stream: BlowerPower			Fluid Package:	Reaction
12				Property Package:	Aspen Properties (Solids)
13	CONDITIONS				
14	Duty Type:	Direct Q	Duty Calculation Operation:	AirSweepBlower	
15	Duty SP:	0.1549 MW	Minimum Available Duty:	0.0000 MW	
16				Maximum Available Duty:	---
17	Energy Stream: HighGrade ProcessHeat			Fluid Package:	Reaction
18				Property Package:	Aspen Properties (Solids)
19	CONDITIONS				
20	Duty Type:	Direct Q	Duty Calculation Operation:		
21	Duty SP:	102.3 MW	Minimum Available Duty:	0.0000 MW	
22				Maximum Available Duty:	---
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
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34					
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36					
37					
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63	Aspen Technology Inc.		Aspen HYSYS Version 12.1		Page 20 of 20

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

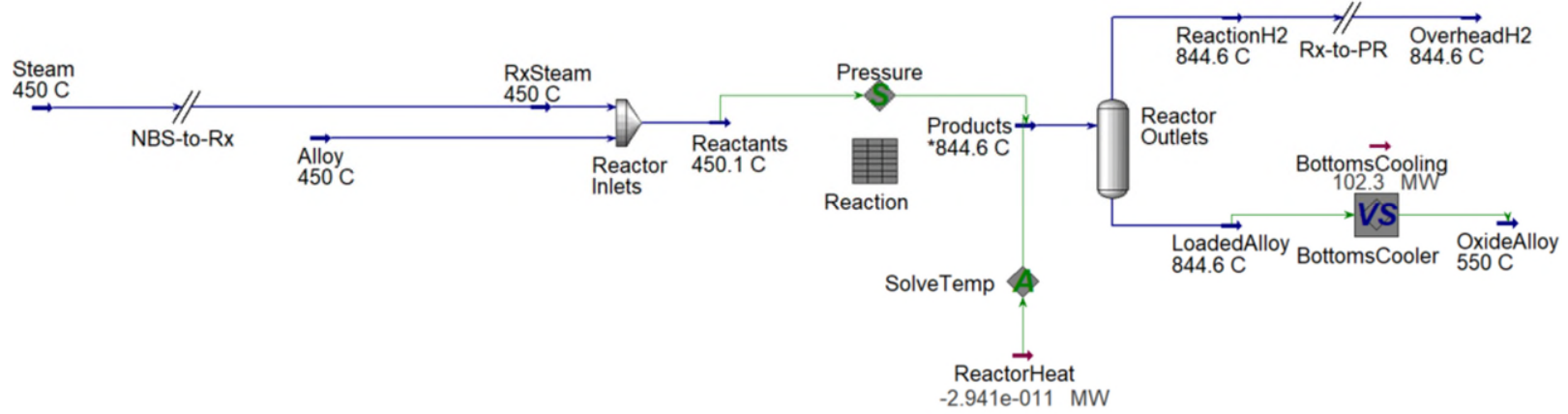







Figure A2. Redox-cycle process model hydrogen-evolution sub-flowsheet.


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc					
2			Unit Set: AmeyS2e					
3			Date/Time: Fri Mar 29 15:31:10 2024					
4								
5	Material Stream: Steam				Fluid Package: Steam			
6					Property Package: NBS Steam			
7								
8	CONDITIONS							
9		Overall	Vapour Phase					
10	Vapour / Phase Fraction	1.0000	1.0000					
11	Temperature: (C)	450.0	450.0					
12	Pressure: (bar)	1.013	1.013					
13	Molar Flow (kgmole/h)	4985	4985					
14	Mass Flow (kg/s)	24.94	24.94					
15	Std Ideal Liq Vol Flow (m3/h)	89.98	89.98					
16	Molar Enthalpy (kJ/kgmole)	-2.259e+005	-2.259e+005					
17	Molar Entropy (kJ/kgmole-C)	156.5	156.5					
18	Heat Flow (MW)	-312.8	-312.8					
19	Liq Vol Flow @Std Cond (m3/h)	89.88 *	89.88					
20	COMPOSITION							
21	Overall Phase				Vapour Fraction 1.0000			
22	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)		
23	H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787		
24	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787		
25	Vapour Phase				Phase Fraction 1.000			
26	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)		
27	H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787		
28	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787		
29	Material Stream: Alloy				Fluid Package: Reaction			
30					Property Package: Aspen Properties (Solids)			
31	CONDITIONS							
32		Overall	Liquid Phase					
33	Vapour / Phase Fraction	0.0000	1.0000					
34	Temperature: (C)	450.0	450.0					
35	Pressure: (bar)	1.013	1.013					
36	Molar Flow (kgmole/h)	3.988e+004	3.988e+004					
37	Mass Flow (kg/s)	1241	1241					
38	Std Ideal Liq Vol Flow (m3/h)	6826	6826					
39	Molar Enthalpy (kJ/kgmole)	1.850e+004	1.850e+004					
40	Molar Entropy (kJ/kgmole-C)	40.85	40.85					
41	Heat Flow (MW)	205.0	205.0					
42	Liq Vol Flow @Std Cond (m3/h)	3.489e+109 *	3.489e+109					
43	COMPOSITION							
44	Overall Phase				Vapour Fraction 0.0000			
45	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)		
46	Zinc	4984.5660	0.1250	325940.7714	0.0730	46.9437		
47	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000		
48	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000		
49	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000		
50	Water	0.0000	0.0000	0.0000	0.0000	0.0000		
51	Aspen Technology Inc.		Aspen HYSYS Version 12.1		Page 1 of 9			


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: Production.hsc			
2				Unit Set: AmeyS2e			
3				Date/Time: Fri Mar 29 15:31:10 2024			
4							
5	Material Stream: Alloy (continued)			Fluid Package: Reaction			
6				Property Package: Aspen Properties (Solids)			
7	COMPOSITION						
8	Overall Phase (continued)						
9							
10	Vapour Fraction 0.0000						
11	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
12	Tin-White	34891.9621	0.8750	4.142024817e+06	0.9270	6778.9151	0.9931
13	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	Total	39876.5281	1.0000	4.467965589e+06	1.0000	6825.8588	1.0000
15	Liquid Phase						
16	Phase Fraction 1.000						
17	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
18	Zinc	4984.5660	0.1250	325940.7714	0.0730	46.9437	0.0069
19	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	Tin-White	34891.9621	0.8750	4.142024817e+06	0.9270	6778.9151	0.9931
24	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Total	39876.5281	1.0000	4.467965589e+06	1.0000	6825.8588	1.0000
26	Material Stream: Reactants			Fluid Package: Reaction			
27				Property Package: Aspen Properties (Solids)			
28	CONDITIONS						
29		Overall	Vapour Phase	Liquid Phase			
30	Vapour / Phase Fraction	0.1110	0.1110	0.8890			
31	Temperature: (C)	450.1	450.1	450.1			
32	Pressure: (bar)	1.013	1.013	1.013			
33	Molar Flow (kgmole/h)	4.486e+004	4978	3.988e+004			
34	Mass Flow (kg/s)	1266	24.91	1241			
35	Std Ideal Liq Vol Flow (m3/h)	6916	89.85	6826			
36	Molar Enthalpy (kJ/kgmole)	-8748	-2.267e+005	1.846e+004			
37	Molar Entropy (kJ/kgmole-C)	34.84	-13.28	40.85			
38	Heat Flow (MW)	-109.0	-313.5	204.5			
39	Liq Vol Flow @Std Cond (m3/h)	3.489e+109 *	89.84	3.489e+109			
40	COMPOSITION						
41	Overall Phase						
42	Vapour Fraction 0.1110						
43	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
44	Zinc	4984.5660	0.1111	325940.7714	0.0715	46.9437	0.0068
45	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
46	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
48	Water	4984.5660	0.1111	89798.3523	0.0197	89.9714	0.0130
49	Tin-White	34891.9621	0.7778	4.142024817e+06	0.9088	6778.9151	0.9802
50	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	Total	44861.0941	1.0000	4.557763941e+06	1.0000	6915.8302	1.0000
52	Aspen Technology Inc.			Aspen HYSYS Version 12.1		Page 2 of 9	
53	Licensed to: BATTELLE ENERGY ALLIANCE					* Specified by user.	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: Production.hsc			
2				Unit Set: AmeyS2e			
3				Date/Time: Fri Mar 29 15:31:10 2024			
4							
5	Material Stream: Reactants (continued)			Fluid Package: Reaction			
6				Property Package: Aspen Properties (Solids)			
7							
8	COMPOSITION						
9	Vapour Phase Phase Fraction 0.1110						
10	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
11	Zinc	0.3083	0.0001	20.1580	0.0002	0.0029	0.0000
12	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Water	4977.6530	0.9999	89673.8131	0.9998	89.8466	1.0000
16	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	Total	4977.9613	1.0000	89693.9710	1.0000	89.8495	1.0000
19	Liquid Phase Phase Fraction 0.8890						
20	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
21	Zinc	4984.2577	0.1250	325920.6134	0.0729	46.9408	0.0069
22	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Water	6.9130	0.0002	124.5393	0.0000	0.1248	0.0000
26	Tin-White	34891.9621	0.8749	4.142024817e+06	0.9270	6778.9151	0.9931
27	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	Total	39883.1328	1.0000	4.468069970e+06	1.0000	6825.9806	1.0000
29	Material Stream: Products			Fluid Package: Reaction			
30				Property Package: Aspen Properties (Solids)			
31	CONDITIONS						
32		Overall	Vapour Phase	Liquid Phase			
33	Vapour / Phase Fraction	0.1110	0.1110	0.8890			
34	Temperature: (C)	844.6 *	844.6	844.6			
35	Pressure: (bar)	1.013	1.013	1.013			
36	Molar Flow (kgmole/h)	4.486e+004 *	4982	3.988e+004			
37	Mass Flow (kg/s)	1266	2.790	1263			
38	Std Ideal Liq Vol Flow (m3/h)	8014	266.8	7747			
39	Molar Enthalpy (kJ/kgmole)	1389	2.426e+004	-1468			
40	Molar Entropy (kJ/kgmole-C)	64.87	38.91	68.11			
41	Heat Flow (MW)	17.30	33.57	-16.26			
42	Liq Vol Flow @Std Cond (m3/h)	3.489e+109 *	1.555e+100	3.489e+109			
43	COMPOSITION						
44	Overall Phase Vapour Fraction 0.1110						
45	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
46	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	Zinc-Oxide	4984.5660	0.1111	405690.8368	0.0890	968.4164	0.1208
48	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
49	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	Tin-White	34891.9621	0.7778	4.142024817e+06	0.9088	6778.9151	0.8459
52	Aspen Technology Inc.			Aspen HYSYS Version 12.1		Page 3 of 9	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:31:10 2024		
4							
5							
6	Material Stream: Products (continued)				Fluid Package:	Reaction	
7					Property Package:	Aspen Properties (Solids)	
8							
9	COMPOSITION						
10							
11	Overall Phase (continued)				Vapour Fraction	0.1110	
12	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
13	Hydrogen	4984.5660	0.1111	10048.2869	0.0022	266.9624	0.0333
14	Total	44861.0941	1.0000	4.557763941e+06	1.0000	8014.2939	1.0000
15							
16	Vapour Phase				Phase Fraction	0.1110	
17	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
18	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
20	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
24	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
25	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000
26							
27	Liquid Phase				Phase Fraction	0.8890	
28	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
29	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
31	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
35	Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
36	Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000
37							
38	Material Stream: ReactionH2				Fluid Package:	Reaction	
39					Property Package:	Aspen Properties (Solids)	
40							
41	CONDITIONS						
42		Overall	Vapour Phase	Liquid Phase			
43	Vapour / Phase Fraction	1.0000	1.0000	0.0000			
44	Temperature: (C)	844.6	844.6	844.6			
45	Pressure: (bar)	1.013	1.013	1.013			
46	Molar Flow (kgmole/h)	4982	4982	0.0000			
47	Mass Flow (kg/s)	2.790	2.790	0.0000			
48	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8	0.0000			
49	Molar Enthalpy (kJ/kgmole)	2.426e+004	2.426e+004	-1468			
50	Molar Entropy (kJ/kgmole-C)	38.91	38.91	68.11			
51	Heat Flow (MW)	33.57	33.57	0.0000			
52	Liq Vol Flow @Std Cond (m3/h)	1.555e+100 *	1.555e+100	0.0000			
53							
54							
55							
56							
57							
58							
59							
60							
61							
62							
63	Aspen Technology Inc.	Aspen HYSYS Version 12.1			Page 4 of 9		

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc			
2				Unit Set:	AmeyS2e			
3				Date/Time:	Fri Mar 29 15:31:10 2024			
4								
5	Material Stream: ReactionH2 (continued)			Fluid Package:	Reaction			
6				Property Package:	Aspen Properties (Solids)			
7	COMPOSITION							
8	Overall Phase							
9							Vapour Fraction	1.0000
10	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
11	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
12	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000	
13	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
14	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
15	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
16	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000	
17	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000	
18	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000	
19	Vapour Phase							
20							Phase Fraction	1.000
21	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
22	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
23	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000	
24	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
25	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
26	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
27	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000	
28	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000	
29	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000	
30	Liquid Phase							
31							Phase Fraction	0.0000
32	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
33	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
34	Zinc-Oxide	0.0000	0.1250	0.0000	0.0892	0.0000	0.1250	
35	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
36	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
37	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
38	Tin-White	0.0000	0.8749	0.0000	0.9108	0.0000	0.8750	
39	Hydrogen	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	
40	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	
41	Material Stream: LoadedAlloy			Fluid Package:	Reaction			
42				Property Package:	Aspen Properties (Solids)			
43	CONDITIONS							
44		Overall	Vapour Phase	Liquid Phase				
45	Vapour / Phase Fraction	0.0000	0.0000	1.0000				
46	Temperature: (C)	844.6	844.6	844.6				
47	Pressure: (bar)	1.013	1.013	1.013				
48	Molar Flow (kgmole/h)	3.988e+004	0.0000	3.988e+004				
49	Mass Flow (kg/s)	1263	0.0000	1263				
50	Std Ideal Liq Vol Flow (m3/h)	7747	0.0000	7747				
51	Molar Enthalpy (kJ/kgmole)	-1468	2.426e+004	-1468				
52	Molar Entropy (kJ/kgmole-C)	68.11	38.91	68.11				
53	Heat Flow (MW)	-16.26	0.0000	-16.26				
54	Liq Vol Flow @Std Cond (m3/h)	3.489e+109 *	0.0000	3.489e+109				
55	Aspen Technology Inc.			Aspen HYSYS Version 12.1		Page 5 of 9		
56	Licensed to: BATTELLE ENERGY ALLIANCE					* Specified by user.		

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc			
2				Unit Set:	AmeyS2e			
3				Date/Time:	Fri Mar 29 15:31:10 2024			
4								
5				Fluid Package:	Reaction			
6	Material Stream: LoadedAlloy (continued)			Property Package:	Aspen Properties (Solids)			
7								
8								
9	COMPOSITION							
10	Overall Phase							
11							Vapour Fraction	0.0000
12	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
13	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
14	Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250	
15	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
16	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
17	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
18	Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750	
19	Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000	
20	Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000	
21	Vapour Phase							
22							Phase Fraction	0.0000
23	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
24	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
25	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
26	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
27	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
28	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
29	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
30	Hydrogen	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	
31	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	
32	Liquid Phase							
33							Phase Fraction	1.000
34	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
35	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
36	Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250	
37	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
38	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
39	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
40	Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750	
41	Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000	
42	Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000	
43				Fluid Package:	Reaction			
44	Material Stream: OxideAlloy			Property Package:	Aspen Properties (Solids)			
45								
46	CONDITIONS							
47		Overall	Liquid Phase					
48	Vapour / Phase Fraction	0.0000	1.0000					
49	Temperature: (C)	550.0	550.0					
50	Pressure: (bar)	1.013	1.013					
51	Molar Flow (kgmole/h)	3.988e+004	3.988e+004					
52	Mass Flow (kg/s)	1263	1263					
53	Std Ideal Liq Vol Flow (m3/h)	7747	7747					
54	Molar Enthalpy (kJ/kgmole)	-1.305e+004	-1.305e+004					
55	Molar Entropy (kJ/kgmole-C)	62.26	62.26					
56	Heat Flow (MW)	-144.6	-144.6					
57	Liq Vol Flow @Std Cond (m3/h)	3.489e+109 *	3.489e+109					
58	Aspen Technology Inc.			Aspen HYSYS Version 12.1		Page 6 of 9		

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:31:10 2024		
4							
5							
6	Material Stream: OxideAlloy (continued)				Fluid Package:	Reaction	
7					Property Package:	Aspen Properties (Solids)	
8							
9	COMPOSITION						
10							
11	Overall Phase				Vapour Fraction	0.0000	
12							
13	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
14	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
16	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
20	Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
21	Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000
22							
23	Liquid Phase				Phase Fraction	1.000	
24							
25	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
26	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
28	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
29	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
32	Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
33	Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000
34							
35	Material Stream: OverheadH2				Fluid Package:	Overheads	
36					Property Package:	Aspen Properties (Peng-R	
37							
38	CONDITIONS						
39							
40		Overall	Vapour Phase				
41	Vapour / Phase Fraction	1.0000	1.0000				
42	Temperature: (C)	844.6	844.6				
43	Pressure: (bar)	1.013	1.013				
44	Molar Flow (kgmole/h)	4982	4982				
45	Mass Flow (kg/s)	2.790	2.790				
46	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8				
47	Molar Enthalpy (kJ/kgmole)	2.426e+004	2.426e+004				
48	Molar Entropy (kJ/kgmole-C)	38.92	38.92				
49	Heat Flow (MW)	33.57	33.57				
50	Liq Vol Flow @Std Cond (m3/h)	6.222e+063 *	6.222e+063				
51							
52	COMPOSITION						
53							
54	Overall Phase				Vapour Fraction	1.0000	
55							
56	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
57	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
58	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
59	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
60	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
61	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
62	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
63							

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc			
2				Unit Set:	AmeyS2e			
3				Date/Time:	Fri Mar 29 15:31:10 2024			
4								
5	Material Stream: OverheadH2 (continued)			Fluid Package:	Overheads			
6				Property Package:	Aspen Properties (Peng-R			
7	COMPOSITION							
8	Overall Phase (continued)							
9							Vapour Fraction	1.0000
10	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
11	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000	
12	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000	
13	Vapour Phase							
14							Phase Fraction	1.000
15	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
16	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
17	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000	
18	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
19	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
20	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
21	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000	
22	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000	
23	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000	
24	Material Stream: RxSteam							
25				Fluid Package:	Reaction			
26				Property Package:	Aspen Properties (Solids)			
27	CONDITIONS							
28		Overall	Vapour Phase					
29	Vapour / Phase Fraction	1.0000	1.0000					
30	Temperature: (C)	450.0	450.0					
31	Pressure: (bar)	1.013	1.013					
32	Molar Flow (kgmole/h)	4985	4985					
33	Mass Flow (kg/s)	24.94	24.94					
34	Std Ideal Liq Vol Flow (m3/h)	89.97	89.97					
35	Molar Enthalpy (kJ/kgmole)	-2.268e+005	-2.268e+005					
36	Molar Entropy (kJ/kgmole-C)	-13.30	-13.30					
37	Heat Flow (MW)	-314.0	-314.0					
38	Liq Vol Flow @Std Cond (m3/h)	89.96 *	89.96					
39	COMPOSITION							
40	Overall Phase							
41							Vapour Fraction	1.0000
42	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
43	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
44	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
45	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
46	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
47	Water	4984.5660	1.0000	89798.3523	1.0000	89.9714	1.0000	
48	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
49	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
50	Total	4984.5660	1.0000	89798.3523	1.0000	89.9714	1.0000	
51								
52								
53								
54								
55								
56								
57								
58								
59								
60								
61								
62								
63	Aspen Technology Inc.			Aspen HYSYS Version 12.1		Page 8 of 9		

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA				Case Name: Production.hsc		
2					Unit Set: AmeyS2e		
3					Date/Time: Fri Mar 29 15:31:10 2024		
4							
5	Material Stream: RxSteam (continued)				Fluid Package: Reaction		
6					Property Package: Aspen Properties (Solids)		
7	COMPOSITION						
8	Vapour Phase						
9						Phase Fraction	1.000
10	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
11	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Water	4984.5660	1.0000	89798.3523	1.0000	89.9714	1.0000
16	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	Total	4984.5660	1.0000	89798.3523	1.0000	89.9714	1.0000
19	Energy Stream: ReactorHeat				Fluid Package: Reaction		
20					Property Package: Aspen Properties (Solids)		
21	CONDITIONS						
22	Duty Type:	Direct Q	Duty Calculation Operation:	SolveTemp			
23	Duty SP:	-2.941e-011 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---	
24	Energy Stream: BottomsCooling				Fluid Package: Reaction		
25					Property Package: Aspen Properties (Solids)		
26	CONDITIONS						
27	Duty Type:	Direct Q	Duty Calculation Operation:				
28	Duty SP:	102.3 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---	
29							
30							
31							
32							
33							
34							
35							
36							
37							
38							
39							
40							
41							
42							
43							
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62							
63	Aspen Technology Inc.		Aspen HYSYS Version 12.1		Page 9 of 9		

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

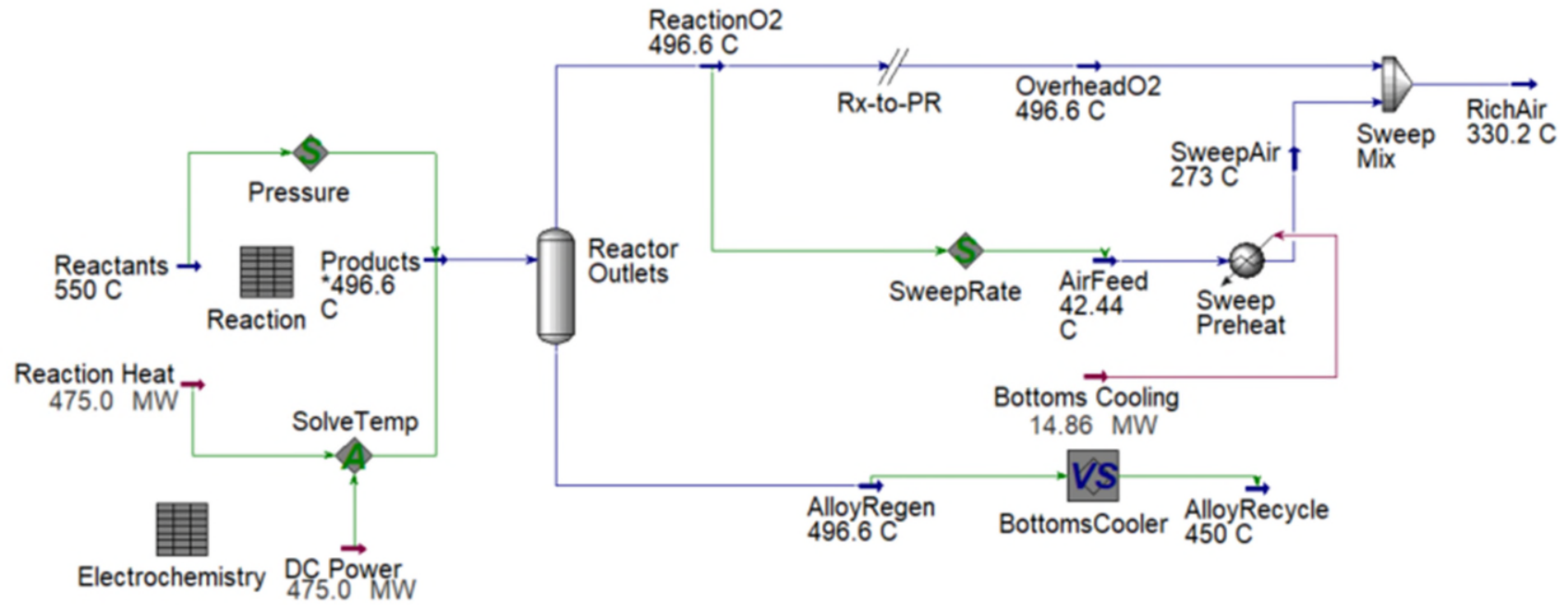







Figure A3. Redox-cycle process model oxygen-evolution sub-flowsheet.


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name:	Production.hsc			
2			Unit Set:	AmeyS2e			
3			Date/Time:	Fri Mar 29 15:40:28 2024			
4							
5			Fluid Package:	Reaction			
6	Material Stream: Reactants		Property Package:	Aspen Properties (Solids)			
7							
8							
9	CONDITIONS						
10		Overall	Liquid Phase				
11	Vapour / Phase Fraction	0.0000	1.0000				
12	Temperature: (C)	550.0	550.0				
13	Pressure: (bar)	1.013	1.013				
14	Molar Flow (kgmole/h)	3.988e+004	3.988e+004				
15	Mass Flow (kg/s)	1263	1263				
16	Std Ideal Liq Vol Flow (m3/h)	7747	7747				
17	Molar Enthalpy (kJ/kgmole)	-1.305e+004	-1.305e+004				
18	Molar Entropy (kJ/kgmole-C)	62.26	62.26				
19	Heat Flow (MW)	-144.6	-144.6				
20	Liq Vol Flow @Std Cond (m3/h)	3.489e+109 *	3.489e+109				
21							
22	COMPOSITION						
23							
24	Overall Phase				Vapour Fraction	0.0000	
25							
26	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
27	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
29	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
33	Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
34	Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000
35							
36	Liquid Phase				Phase Fraction	1.000	
37							
38	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
39	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	Zinc-Oxide	4984.5660	0.1250	405690.8320	0.0892	968.4164	0.1250
41	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
42	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
44	Tin-White	34891.9621	0.8749	4.142024815e+06	0.9108	6778.9151	0.8750
45	Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500	0.0000
46	Total	39879.3292	1.0000	4.547721294e+06	1.0000	7747.4815	1.0000
47							
48	Material Stream: Products		Fluid Package:	Reaction			
49			Property Package:	Aspen Properties (Solids)			
50							
51	CONDITIONS						
52		Overall	Vapour Phase	Liquid Phase			
53	Vapour / Phase Fraction	0.0587	0.0587	0.9413			
54	Temperature: (C)	496.6 *	496.6	496.6			
55	Pressure: (bar)	1.013	1.013	1.013			
56	Molar Flow (kgmole/h)	4.237e+004 *	2487	3.988e+004			
57	Mass Flow (kg/s)	1263	22.09	1241			
58	Std Ideal Liq Vol Flow (m3/h)	6959	133.2	6826			
59	Molar Enthalpy (kJ/kgmole)	1.960e+004	1.484e+004	1.990e+004			
60	Molar Entropy (kJ/kgmole-C)	42.01	29.57	42.79			
61	Heat Flow (MW)	230.7	10.25	220.5			
62							
63	Aspen Technology Inc.		Aspen HYSYS Version 12.1			Page 1 of 9	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc			
2			Unit Set: AmeyS2e			
3			Date/Time: Fri Mar 29 15:40:28 2024			
4						
5						
6	Material Stream: Products (continued)				Fluid Package: Reaction	
7					Property Package: Aspen Properties (Solids)	
8						
9	CONDITIONS					
10						
11		Overall	Vapour Phase	Liquid Phase		
12	Liq Vol Flow @Std Cond (m3/h)	3.489e+109 *	4.854e+093	3.489e+109		
13	COMPOSITION					
14	Overall Phase					
15						Vapour Fraction 0.0587
16	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
17						LIQUID VOLUME FRACTION
18	Zinc	4984.5660	0.1176	325940.7675	0.0717	46.9437
19	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000
20	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000
21	Oxygen	2492.2830	0.0588	79750.0645	0.0175	133.4812
22	Water	0.0000	0.0000	0.0000	0.0000	0.0000
23	Tin-White	34891.9621	0.8235	4.142024815e+06	0.9108	6778.9151
24	Hydrogen	2.8012	0.0001	5.6468	0.0000	0.1500
25	Total	42371.6122	1.0000	4.547721294e+06	1.0000	6959.4900
26	Vapour Phase					
27						Phase Fraction 5.870e-002
28	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
29						LIQUID VOLUME FRACTION
30	Zinc	0.5160	0.0002	33.7408	0.0004	0.0049
31	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000
32	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000
33	Oxygen	2483.9604	0.9987	79483.7509	0.9995	133.0355
34	Water	0.0000	0.0000	0.0000	0.0000	0.0000
35	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000
36	Hydrogen	2.7980	0.0011	5.6405	0.0001	0.1499
37	Total	2487.2744	1.0000	79523.1322	1.0000	133.1902
38	Liquid Phase					
39						Phase Fraction 0.9413
40	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
41						LIQUID VOLUME FRACTION
42	Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388
43	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000
44	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000
45	Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457
46	Water	0.0000	0.0000	0.0000	0.0000	0.0000
47	Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151
48	Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002
49	Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998
50						
51	Material Stream: ReactionO2				Fluid Package: Reaction	
52					Property Package: Aspen Properties (Solids)	
53	CONDITIONS					
54						
55		Overall	Vapour Phase	Liquid Phase		
56	Vapour / Phase Fraction	1.0000	1.0000	0.0000		
57	Temperature: (C)	496.6	496.6	496.6		
58	Pressure: (bar)	1.013	1.013	1.013		
59	Molar Flow (kgmole/h)	2487	2487	0.0000		
60	Mass Flow (kg/s)	22.09	22.09	0.0000		
61	Std Ideal Liq Vol Flow (m3/h)	133.2	133.2	0.0000		
62						
63	Aspen Technology Inc.		Aspen HYSYS Version 12.1		Page 2 of 9	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:40:28 2024		
4							Fluid Package:
5				Property Package:	Aspen Properties (Solids)		
6	Material Stream: ReactionO2 (continued)						
7							
8							
9	CONDITIONS						
10							
11		Overall	Vapour Phase	Liquid Phase			
12	Molar Enthalpy (kJ/kgmole)	1.484e+004	1.484e+004	1.990e+004			
13	Molar Entropy (kJ/kgmole-C)	29.57	29.57	42.79			
14	Heat Flow (MW)	10.25	10.25	0.0000			
15	Liq Vol Flow @Std Cond (m3/h)	4.854e+093 *	4.854e+093	0.0000			
16	COMPOSITION						
17							
18	Overall Phase						Vapour Fraction 1.0000
19							
20	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
21	Zinc	0.5160	0.0002	33.7408	0.0004	0.0049	0.0000
22	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	Oxygen	2483.9604	0.9987	79483.7509	0.9995	133.0355	0.9988
25	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	Hydrogen	2.7980	0.0011	5.6405	0.0001	0.1499	0.0011
28	Total	2487.2744	1.0000	79523.1322	1.0000	133.1902	1.0000
29							
30	Vapour Phase						Phase Fraction 1.000
31							
32	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
33	Zinc	0.5160	0.0002	33.7408	0.0004	0.0049	0.0000
34	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	Oxygen	2483.9604	0.9987	79483.7509	0.9995	133.0355	0.9988
37	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
38	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
39	Hydrogen	2.7980	0.0011	5.6405	0.0001	0.1499	0.0011
40	Total	2487.2744	1.0000	79523.1322	1.0000	133.1902	1.0000
41							
42	Liquid Phase						Phase Fraction 0.0000
43							
44	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
45	Zinc	0.0000	0.1250	0.0000	0.0729	0.0000	0.0069
46	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
48	Oxygen	0.0000	0.0002	0.0000	0.0001	0.0000	0.0001
49	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	Tin-White	0.0000	0.8748	0.0000	0.9270	0.0000	0.9931
51	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
53							
54	Material Stream: AlloyRegen						Fluid Package: Reaction
55							Property Package: Aspen Properties (Solids)
56							
57	CONDITIONS						
58							
59		Overall	Vapour Phase	Liquid Phase			
60	Vapour / Phase Fraction	0.0000	0.0000	1.0000			
61	Temperature: (C)	496.6	496.6	496.6			
62	Pressure: (bar)	1.013	1.013	1.013			
63	Aspen Technology Inc.						Page 3 of 9


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name:	Production.hsc							
2			Unit Set:	AmeyS2e							
3			Date/Time:	Fri Mar 29 15:40:28 2024							
4			Material Stream: AlloyRegen (continued)						Fluid Package:	Reaction	
5	Property Package:	Aspen Properties (Solids)									
6	CONDITIONS										
7		Overall	Vapour Phase	Liquid Phase							
8	Molar Flow (kgmole/h)	3.988e+004	0.0000	3.988e+004							
9	Mass Flow (kg/s)	1241	0.0000	1241							
10	Std Ideal Liq Vol Flow (m3/h)	6826	0.0000	6826							
11	Molar Enthalpy (kJ/kgmole)	1.990e+004	1.484e+004	1.990e+004							
12	Molar Entropy (kJ/kgmole-C)	42.79	29.57	42.79							
13	Heat Flow (MW)	220.5	0.0000	220.5							
14	Liq Vol Flow @Std Cond (m3/h)	3.489e+109 *	0.0000	3.489e+109							
15	COMPOSITION										
16	Overall Phase						Vapour Fraction	0.0000			
17	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION				
18	Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388	0.0069				
19	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
20	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
21	Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457	0.0001				
22	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
23	Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151	0.9931				
24	Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002	0.0000				
25	Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998	1.0000				
26	Vapour Phase						Phase Fraction	0.0000			
27	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION				
28	Zinc	0.0000	0.0002	0.0000	0.0004	0.0000	0.0000				
29	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
30	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
31	Oxygen	0.0000	0.9987	0.0000	0.9995	0.0000	0.9988				
32	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
33	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
34	Hydrogen	0.0000	0.0011	0.0000	0.0001	0.0000	0.0011				
35	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000				
36	Liquid Phase						Phase Fraction	1.000			
37	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION				
38	Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388	0.0069				
39	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
40	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
41	Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457	0.0001				
42	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
43	Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151	0.9931				
44	Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002	0.0000				
45	Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998	1.0000				

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Fri Mar 29 15:40:26 2024				
4							
5	Material Stream: AlloyRecycle		Fluid Package: Reaction				
6			Property Package: Aspen Properties (Solids)				
7							
8	CONDITIONS						
9		Overall	Liquid Phase				
10	Vapour / Phase Fraction	0.0000	1.0000				
11	Temperature: (C)	450.0	450.0				
12	Pressure: (bar)	1.013	1.013				
13	Molar Flow (kgmole/h)	3.988e+004	3.988e+004				
14	Mass Flow (kg/s)	1241	1241				
15	Std Ideal Liq Vol Flow (m3/h)	6826	6826				
16	Molar Enthalpy (kJ/kgmole)	1.854e+004	1.854e+004				
17	Molar Entropy (kJ/kgmole-C)	40.90	40.90				
18	Heat Flow (MW)	205.4	205.4				
19	Liq Vol Flow @Std Cond (m3/h)	3.489e+109 *	3.489e+109				
20	COMPOSITION						
21	Overall Phase				Vapour Fraction	0.0000	
22	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
23	Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388	0.0069
24	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457	0.0001
27	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151	0.9931
29	Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002	0.0000
30	Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998	1.0000
31	Liquid Phase				Phase Fraction	1.000	
32	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
33	Zinc	4984.0500	0.1250	325907.0267	0.0729	46.9388	0.0069
34	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	Oxygen	8.3226	0.0002	266.3136	0.0001	0.4457	0.0001
37	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
38	Tin-White	34891.9621	0.8748	4.142024815e+06	0.9270	6778.9151	0.9931
39	Hydrogen	0.0032	0.0000	0.0064	0.0000	0.0002	0.0000
40	Total	39884.3378	1.0000	4.468198162e+06	1.0000	6826.2998	1.0000
41	Material Stream: AirFeed		Fluid Package: Overheads				
42			Property Package: Aspen Properties (Peng-R)				
43							
44	CONDITIONS						
45		Overall	Vapour Phase				
46	Vapour / Phase Fraction	1.0000	1.0000				
47	Temperature: (C)	42.44	42.44				
48	Pressure: (bar)	1.034	1.034				
49	Molar Flow (kgmole/h)	7835	7835				
50	Mass Flow (kg/s)	62.79	62.79				
51	Std Ideal Liq Vol Flow (m3/h)	419.6	419.6				
52	Molar Enthalpy (kJ/kgmole)	501.6	501.6				
53	Molar Entropy (kJ/kgmole-C)	5.744	5.744				
54	Heat Flow (MW)	1.092	1.092				
55	Aspen Technology Inc.		Aspen HYSYS Version 12.1		Page 5 of 9		

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: Production.hsc		
2				Unit Set: AmeyS2e		
3				Date/Time: Fri Mar 29 15:40:28 2024		
4						
5	Material Stream: AirFeed (continued)			Fluid Package: Overheads		
6				Property Package: Aspen Properties (Peng-R		
7	CONDITIONS					
8			Overall	Vapour Phase		
9	Liq Vol Flow @Std Cond	(m3/h)	675.1 *	675.1		
10	COMPOSITION					
11	Overall Phase				Vapour Fraction 1.0000	
12	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
13	Zinc	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
14	Zinc-Oxide	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
15	Nitrogen	6189.5823 *	0.7900 *	173391.7402 *	0.7671 *	331.5004 *
16	Oxygen	1645.3320 *	0.2100 *	52648.6498 *	0.2329 *	88.1204 *
17	Water	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
18	Tin-White	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
19	Hydrogen	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
20	Total	7834.9143	1.0000	226040.3899	1.0000	419.6208
21	Vapour Phase				Phase Fraction 1.000	
22	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
23	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000
24	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000
25	Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004
26	Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204
27	Water	0.0000	0.0000	0.0000	0.0000	0.0000
28	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000
29	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000
30	Total	7834.9143	1.0000	226040.3899	1.0000	419.6208
31	Material Stream: SweepAir			Fluid Package: Overheads		
32				Property Package: Aspen Properties (Peng-R		
33	CONDITIONS					
34			Overall	Vapour Phase		
35	Vapour / Phase Fraction		1.0000	1.0000		
36	Temperature:	(C)	273.0	273.0		
37	Pressure:	(bar)	1.013	1.013		
38	Molar Flow	(kgmole/h)	7835	7835		
39	Mass Flow	(kg/s)	62.79	62.79		
40	Std Ideal Liq Vol Flow	(m3/h)	419.6	419.6		
41	Molar Enthalpy	(kJ/kgmole)	7331	7331		
42	Molar Entropy	(kJ/kgmole-C)	22.14	22.14		
43	Heat Flow	(MW)	15.96	15.96		
44	Liq Vol Flow @Std Cond	(m3/h)	675.1 *	675.1		
45	COMPOSITION					
46	Overall Phase				Vapour Fraction 1.0000	
47	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
48	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000
49	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:40:28 2024		
4							
5				Fluid Package:	Overheads		
6	Material Stream: SweepAir (continued)			Property Package:	Aspen Properties (Peng-R		
7							
8				COMPOSITION			
9				Overall Phase (continued)			
10				Vapour Fraction	1.0000		
11	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
12	Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004	0.7900
13	Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204	0.2100
14	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000
18				Vapour Phase			
19				Phase Fraction	1.000		
20	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
21	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	Nitrogen	6189.5823	0.7900	173391.7402	0.7671	331.5004	0.7900
24	Oxygen	1645.3320	0.2100	52648.6498	0.2329	88.1204	0.2100
25	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000
29				Material Stream: RichAir			
30				Fluid Package:	Overheads		
31				Property Package:	Aspen Properties (Peng-R		
32				CONDITIONS			
33		Overall	Vapour Phase	Liquid Phase			
34	Vapour / Phase Fraction	1.0000	1.0000	0.0000			
35	Temperature: (C)	330.2	330.2	330.2			
36	Pressure: (bar)	1.013	1.013	1.013			
37	Molar Flow (kgmole/h)	1.032e+004	1.032e+004	0.5159			
38	Mass Flow (kg/s)	84.88	84.87	9.370e-003			
39	Std Ideal Liq Vol Flow (m3/h)	552.8	552.8	4.858e-003			
40	Molar Enthalpy (kJ/kgmole)	9132	9134	-3.636e+004			
41	Molar Entropy (kJ/kgmole-C)	26.64	26.64	-2.978			
42	Heat Flow (MW)	26.18	26.19	-5.210e-003			
43	Liq Vol Flow @Std Cond (m3/h)	858.4 *	858.4	4.929e-003			
44				COMPOSITION			
45				Overall Phase			
46				Vapour Fraction	1.0000		
47	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
48	Zinc	0.5160	0.0000	33.7408	0.0001	0.0049	0.0000
49	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	Nitrogen	6189.5823	0.5996	173391.7402	0.5674	331.5004	0.5997
51	Oxygen	4129.2924	0.4000	132132.4006	0.4324	221.1558	0.4001
52	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
53	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
54	Hydrogen	2.7980	0.0003	5.6405	0.0000	0.1499	0.0003
55	Total	10322.1887	1.0000	305563.5221	1.0000	552.8109	1.0000
56	Aspen Technology Inc.			Aspen HYSYS Version 12.1			Page 7 of 9

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:40:28 2024		
4							
5				Fluid Package:	Overheads		
6	Material Stream: RichAir (continued)			Property Package:	Aspen Properties (Peng-R		
7							
8	COMPOSITION						
9							
10	Vapour Phase						
11							Phase Fraction 1.000
12	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
13	Zinc	0.0001	0.0000	0.0092	0.0000	0.0000	0.0000
14	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Nitrogen	6189.5823	0.5997	173391.7402	0.5675	331.5004	0.5997
16	Oxygen	4129.2924	0.4001	132132.4006	0.4325	221.1558	0.4001
17	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	Hydrogen	2.7980	0.0003	5.6405	0.0000	0.1499	0.0003
20	Total	10321.6728	1.0000	305529.7905	1.0000	552.8061	1.0000
21							
22	Liquid Phase						
23							Phase Fraction 4.998e-005
24	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
25	Zinc	0.5159	1.0000	33.7316	1.0000	0.0049	1.0000
26	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
29	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	Total	0.5159	1.0000	33.7316	1.0000	0.0049	1.0000
33							
34	Material Stream: OverheadO2			Fluid Package:	Overheads		
35				Property Package:	Aspen Properties (Peng-R		
36							
37	CONDITIONS						
38							
39							
40		Overall	Vapour Phase	Liquid Phase			
41	Vapour / Phase Fraction	0.9998	0.9998	0.0002			
42	Temperature: (C)	496.6	496.6	496.6			
43	Pressure: (bar)	1.013	1.013	1.013			
44	Molar Flow (kgmole/h)	2487	2487	0.4610			
45	Mass Flow (kg/s)	22.09	22.08	8.373e-003			
46	Std Ideal Liq Vol Flow (m3/h)	133.2	133.2	4.341e-003			
47	Molar Enthalpy (kJ/kgmole)	1.481e+004	1.481e+004	-2.883e+004			
48	Molar Entropy (kJ/kgmole-C)	29.53	29.53	8.053			
49	Heat Flow (MW)	10.23	10.23	-3.691e-003			
50	Liq Vol Flow @Std Cond (m3/h)	2.629e+049 *	2.630e+049	4.404e-003			
51							
52	COMPOSITION						
53							
54	Overall Phase						
55							Vapour Fraction 0.9998
56	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
57	Zinc	0.5160	0.0002	33.7408	0.0004	0.0049	0.0000
58	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
59	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
60	Oxygen	2483.9604	0.9987	79483.7509	0.9995	133.0355	0.9988
61	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
62	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
63	Aspen Technology Inc.			Aspen HYSYS Version 12.1		Page 8 of 9	

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:40:28 2024		
4							
5							
6	Material Stream: OverheadO2 (continued)			Fluid Package:	Overheads		
7				Property Package:	Aspen Properties (Peng-R)		
8							
9	COMPOSITION						
10							
11	Overall Phase (continued)			Vapour Fraction	0.9998		
12							
13	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
14	Hydrogen	2.7980	0.0011	5.6405	0.0001	0.1499	0.0011
15	Total	2487.2744	1.0000	79523.1322	1.0000	133.1902	1.0000
16							
17	Vapour Phase			Phase Fraction	0.9998		
18							
19	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
20	Zinc	0.0550	0.0000	3.5976	0.0000	0.0005	0.0000
21	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	Oxygen	2483.9604	0.9989	79483.7509	0.9999	133.0355	0.9989
24	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	Hydrogen	2.7980	0.0011	5.6405	0.0001	0.1499	0.0011
27	Total	2486.8134	1.0000	79492.9890	1.0000	133.1858	1.0000
28							
29	Liquid Phase			Phase Fraction	1.853e-004		
30							
31	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
32	Zinc	0.4610	1.0000	30.1432	1.0000	0.0043	1.0000
33	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
37	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
38	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
39	Total	0.4610	1.0000	30.1432	1.0000	0.0043	1.0000
40							
41	Energy Stream: Reaction Heat			Fluid Package:	Reaction		
42				Property Package:	Aspen Properties (Solids)		
43							
44	CONDITIONS						
45							
46	Duty Type:	Direct Q	Duty Calculation Operation:	SolveTemp			
47	Duty SP:	475.0 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---	
48							
49	Energy Stream: DC Power			Fluid Package:	Reaction		
50				Property Package:	Aspen Properties (Solids)		
51							
52	CONDITIONS						
53							
54	Duty Type:	Direct Q	Duty Calculation Operation:	SolveTemp			
55	Duty SP:	475.0 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---	
56							
57	Energy Stream: Bottoms Cooling			Fluid Package:	Reaction		
58				Property Package:	Aspen Properties (Solids)		
59							
60	CONDITIONS						
61							
62	Duty Type:	Direct Q	Duty Calculation Operation:	Sweep Preheat			
63	Duty SP:	14.86 MW	Minimum Available Duty:	0.0000 MW	Maximum Available Duty:	---	

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

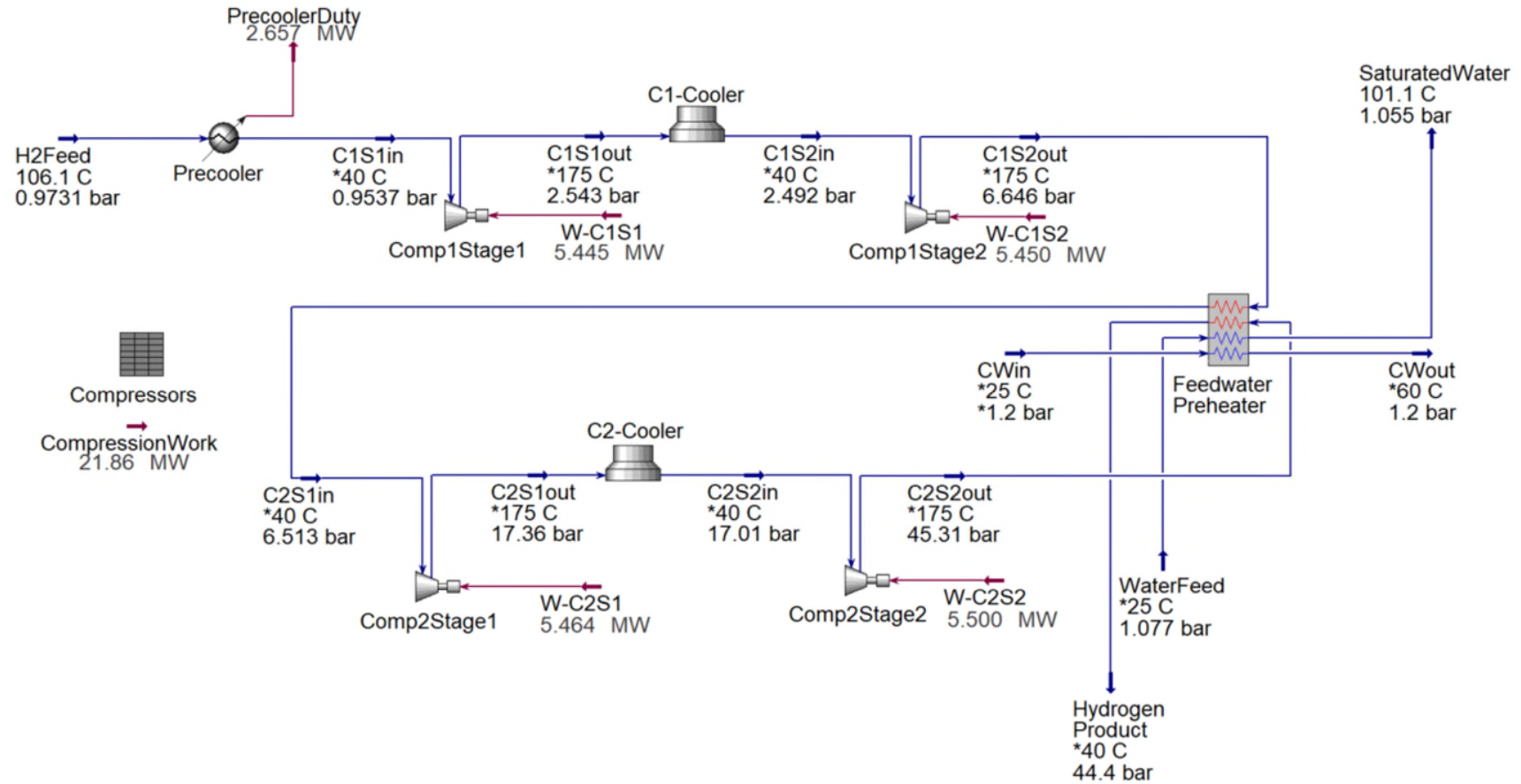







Figure A4. Redox-cycle process model hydrogen-compression sub-flowsheet.


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: Production.hsc		
2				Unit Set: AmeyS2e		
3				Date/Time: Fri Mar 29 15:46:33 2024		
4						
5	Material Stream: H2Feed			Fluid Package: Overheads		
6				Property Package: Aspen Properties (Peng-R		
7	CONDITIONS					
8		Overall	Vapour Phase	Liquid Phase		
9	Vapour / Phase Fraction	1.0000	1.0000	0.0000		
10	Temperature: (C)	106.1	106.1	106.1		
11	Pressure: (bar)	0.9731	0.9731	0.9731		
12	Molar Flow (kgmole/h)	4982	4982	5.285e-005		
13	Mass Flow (kg/s)	2.790	2.790	1.195e-006		
14	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8	1.027e-005		
15	Molar Enthalpy (kJ/kgmole)	2353	2353	-2.205e+005		
16	Molar Entropy (kJ/kgmole-C)	7.310	7.310	4.743		
17	Heat Flow (MW)	3.256	3.256	-3.237e-006		
18	Liq Vol Flow @Std Cond (m3/h)	6.222e+063 *	6.222e+063	2.650e+063		
19	COMPOSITION					
20	Overall Phase			Vapour Fraction	1.0000	
21	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
22	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000
23	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000
24	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000
25	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000
26	Water	0.0000	0.0000	0.0000	0.0000	0.0000
27	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000
28	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124
29	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124
30	Vapour Phase			Phase Fraction	1.000	
31	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
32	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000
33	Zinc-Oxide	0.0000	0.0000	0.0005	0.0000	0.0000
34	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000
35	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000
36	Water	0.0000	0.0000	0.0000	0.0000	0.0000
37	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000
38	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124
39	Total	4981.7649	1.0000	10042.6425	1.0000	266.8124
40	Liquid Phase			Phase Fraction	1.061e-008	
41	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
42	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000
43	Zinc-Oxide	0.0001	0.9998	0.0043	1.0000	0.0000
44	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000
45	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000
46	Water	0.0000	0.0000	0.0000	0.0000	0.0000
47	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000
48	Hydrogen	0.0000	0.0001	0.0000	0.0000	0.0000
49	Total	0.0001	1.0000	0.0043	1.0000	0.0000


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:46:33 2024		
4							Fluid Package:
5				Property Package:	Aspen Properties (Peng-R		
6	Material Stream: C1S1out						
7	CONDITIONS						
8		Overall	Vapour Phase				
9	Vapour / Phase Fraction	1.0000	1.0000				
10	Temperature: (C)	175.0 *	175.0				
11	Pressure: (bar)	2.543	2.543				
12	Molar Flow (kgmole/h)	4982	4982				
13	Mass Flow (kg/s)	2.790	2.790				
14	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8				
15	Molar Enthalpy (kJ/kgmole)	4368	4368				
16	Molar Entropy (kJ/kgmole-C)	4.198	4.198				
17	Heat Flow (MW)	6.044	6.044				
18	Liq Vol Flow @Std Cond (m3/h)	6.222e+063 *	6.222e+063				
19	COMPOSITION						
20	Overall Phase			Vapour Fraction	1.0000		
21	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
22	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
24	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
28	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
29	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000
30	Vapour Phase			Phase Fraction	1.000		
31	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
32	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
34	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
37	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
38	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
39	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000
40	Material Stream: C1S1in			Fluid Package:	Overheads		
41				Property Package:	Aspen Properties (Peng-R		
42	CONDITIONS						
43		Overall	Vapour Phase	Liquid Phase			
44	Vapour / Phase Fraction	1.0000	1.0000	0.0000			
45	Temperature: (C)	40.00 *	40.00	40.00			
46	Pressure: (bar)	0.9537	0.9537	0.9537			
47	Molar Flow (kgmole/h)	4982	4982	5.952e-005			
48	Mass Flow (kg/s)	2.790	2.790	1.345e-006			
49	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8	1.156e-005			
50	Molar Enthalpy (kJ/kgmole)	432.9	432.9	-2.245e+005			
51	Molar Entropy (kJ/kgmole-C)	1.917	1.917	-7.126			
52	Heat Flow (MW)	0.5991	0.5991	-3.711e-006			
53	Aspen Technology Inc.			Aspen HYSYS Version 12.1		Page 2 of 13	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc					
2			Unit Set: AmeyS2e					
3			Date/Time: Fri Mar 29 15:46:33 2024					
4								
5	Material Stream: C1S1in (continued)				Fluid Package: Overheads			
6					Property Package: Aspen Properties (Peng-R			
7								
8	CONDITIONS							
9								
10								
11								
12	Liq Vol Flow @Std Cond (m3/h)	Overall	Vapour Phase	Liquid Phase				
13		6.222e+063 *	6.212e+063	5.643e+066				
14	COMPOSITION							
15	Overall Phase							
16						Vapour Fraction	1.0000	
17	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
18	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
19	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000	
20	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
21	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
22	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
23	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000	
24	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000	
25	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000	
26	Vapour Phase							
27						Phase Fraction	1.000	
28	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
29	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
30	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
31	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
32	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
33	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
34	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000	
35	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000	
36	Total	4981.7648	1.0000	10042.6419	1.0000	266.8124	1.0000	
37	Liquid Phase							
38						Phase Fraction	1.195e-008	
39	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
40	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
41	Zinc-Oxide	0.0001	0.9997	0.0048	0.9997	0.0000	0.9998	
42	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
43	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
44	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
45	Tin-White	0.0000	0.0002	0.0000	0.0003	0.0000	0.0002	
46	Hydrogen	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	
47	Total	0.0001	1.0000	0.0048	1.0000	0.0000	1.0000	
48	Material Stream: C1S2in				Fluid Package: Overheads			
49					Property Package: Aspen Properties (Peng-R			
50								
51	CONDITIONS							
52								
53								
54								
55								
56								
57	Vapour / Phase Fraction	Overall	Vapour Phase	Liquid Phase				
58		1.0000	1.0000	0.0000				
59	Temperature: (C)	40.00 *	40.00	40.00				
60	Pressure: (bar)	2.492	2.492	2.492				
61	Molar Flow (kgmole/h)	4982	4982	5.955e-005				
62	Mass Flow (kg/s)	2.790	2.790	1.346e-006				
63	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8	1.157e-005				


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:46:33 2024		
4							
5				Fluid Package:	Overheads		
6	Material Stream: C1S2in (continued)			Property Package:	Aspen Properties (Peng-R		
7							
8	CONDITIONS						
9							
10		Overall	Vapour Phase	Liquid Phase			
11	Molar Enthalpy	(kJ/kgmole)	433.9	433.9	-2.243e+005		
12	Molar Entropy	(kJ/kgmole-C)	-6.074	-6.074	-7.092		
13	Heat Flow	(MW)	0.6005	0.6005	-3.710e-006		
14	Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.195e+063	4.876e+067		
15							
16	COMPOSITION						
17							
18	Overall Phase			Vapour Fraction 1.0000			
19							
20	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
21	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
23	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
27	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
28	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000
29							
30	Vapour Phase			Phase Fraction 1.000			
31							
32	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
33	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
37	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
38	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
39	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
40	Total	4981.7648	1.0000	10042.6419	1.0000	266.8124	1.0000
41							
42	Liquid Phase			Phase Fraction 1.195e-008			
43							
44	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
45	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
46	Zinc-Oxide	0.0001	0.9992	0.0048	0.9993	0.0000	0.9994
47	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
48	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
49	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	Tin-White	0.0000	0.0005	0.0000	0.0007	0.0000	0.0005
51	Hydrogen	0.0000	0.0003	0.0000	0.0000	0.0000	0.0001
52	Total	0.0001	1.0000	0.0048	1.0000	0.0000	1.0000
53							
54	Material Stream: C1S2out			Fluid Package:	Overheads		
55				Property Package:	Aspen Properties (Peng-R		
56							
57	CONDITIONS						
58							
59		Overall	Vapour Phase				
60	Vapour / Phase Fraction		1.0000	1.0000			
61	Temperature:	(C)	175.0 *	175.0			
62	Pressure:	(bar)	6.646	6.646			
63	Aspen Technology Inc.			Aspen HYSYS Version 12.1		Page 4 of 13	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc					
2			Unit Set: AmeyS2e					
3			Date/Time: Fri Mar 29 15:46:33 2024					
4								
5	Material Stream: C1S2out (continued)				Fluid Package: Overheads			
6					Property Package: Aspen Properties (Peng-R			
7	CONDITIONS							
8		Overall	Vapour Phase					
9	Molar Flow (kgmole/h)	4982	4982					
10	Mass Flow (kg/s)	2.790	2.790					
11	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8					
12	Molar Enthalpy (kJ/kgmole)	4372	4372					
13	Molar Entropy (kJ/kgmole-C)	-3.790	-3.790					
14	Heat Flow (MW)	6.051	6.051					
15	Liq Vol Flow @Std Cond (m3/h)	6.222e+063 *	6.222e+063					
16	COMPOSITION							
17	Overall Phase							
18						Vapour Fraction	1.0000	
19	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
20	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
21	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000	
22	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
23	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
24	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
25	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000	
26	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000	
27	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000	
28	Vapour Phase						Phase Fraction	1.000
29	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
30	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
31	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000	
32	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
33	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
34	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
35	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000	
36	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000	
37	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000	
38	Material Stream: C2S1in				Fluid Package: Overheads			
39					Property Package: Aspen Properties (Peng-R			
40	CONDITIONS							
41		Overall	Vapour Phase	Liquid Phase				
42	Vapour / Phase Fraction	1.0000	1.0000	0.0000				
43	Temperature: (C)	40.00 *	40.00	40.00				
44	Pressure: (bar)	6.513	6.513	6.513				
45	Molar Flow (kgmole/h)	4982	4982	5.963e-005				
46	Mass Flow (kg/s)	2.790	2.790	1.348e-006				
47	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8	1.158e-005				
48	Molar Enthalpy (kJ/kgmole)	436.6	436.6	-2.237e+005				
49	Molar Entropy (kJ/kgmole-C)	-14.07	-14.07	-7.015				
50	Heat Flow (MW)	0.6042	0.6042	-3.705e-006				
51	Liq Vol Flow @Std Cond (m3/h)	6.222e+063 *	6.153e+063	4.063e+068				
52	Aspen Technology Inc.							
53	Aspen HYSYS Version 12.1			Page 5 of 13				
54	Licensed to: BATTELLE ENERGY ALLIANCE							
55	* Specified by user.							


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: Production.hsc			
2				Unit Set: AmeyS2e			
3				Date/Time: Fri Mar 29 15:46:33 2024			
4							
5	Material Stream: C2S1in (continued)			Fluid Package: Overheads			
6				Property Package: Aspen Properties (Peng-R			
7	COMPOSITION						
8	Overall Phase Vapour Fraction 1.0000						
9	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
10	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
12	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
16	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
17	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000
18	Vapour Phase Phase Fraction 1.000						
19	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
20	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
26	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
27	Total	4981.7648	1.0000	10042.6419	1.0000	266.8124	1.0000
28	Liquid Phase Phase Fraction 1.197e-008						
29	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
30	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	Zinc-Oxide	0.0001	0.9979	0.0048	0.9981	0.0000	0.9985
32	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	Tin-White	0.0000	0.0013	0.0000	0.0019	0.0000	0.0013
36	Hydrogen	0.0000	0.0009	0.0000	0.0000	0.0000	0.0002
37	Total	0.0001	1.0000	0.0049	1.0000	0.0000	1.0000
38	Material Stream: C2S1out			Fluid Package: Overheads			
39				Property Package: Aspen Properties (Peng-R			
40	CONDITIONS						
41		Overall	Vapour Phase	Liquid Phase			
42	Vapour / Phase Fraction	1.0000	1.0000	0.0000			
43	Temperature: (C)	175.0 *	175.0	175.0			
44	Pressure: (bar)	17.36	17.36	17.36			
45	Molar Flow (kgmole/h)	4982	4982	8.186e-006			
46	Mass Flow (kg/s)	2.790	2.790	1.846e-007			
47	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8	1.587e-006			
48	Molar Enthalpy (kJ/kgmole)	4385	4385	-2.153e+005			
49	Molar Entropy (kJ/kgmole-C)	-11.78	-11.78	14.79			
50	Heat Flow (MW)	6.068	6.068	-4.895e-007			
51	Liq Vol Flow @Std Cond (m3/h)	6.222e+063 *	6.222e+063	1.079e+063			
52	Aspen Technology Inc.			Aspen HYSYS Version 12.1		Page 6 of 13	
53	Licensed to: BATTELLE ENERGY ALLIANCE					* Specified by user.	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: Production.hsc			
2				Unit Set: AmeyS2e			
3				Date/Time: Fri Mar 29 15:46:33 2024			
4							
5	Material Stream: C2S1out (continued)			Fluid Package: Overheads			
6				Property Package: Aspen Properties (Peng-R)			
7	COMPOSITION						
8	Overall Phase Vapour Fraction 1.0000						
9	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
10	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
12	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
16	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
17	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000
18	Vapour Phase Phase Fraction 1.000						
19	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
20	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	Zinc-Oxide	0.0001	0.0000	0.0042	0.0000	0.0000	0.0000
22	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
26	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
27	Total	4981.7649	1.0000	10042.6461	1.0000	266.8124	1.0000
28	Liquid Phase Phase Fraction 1.643e-009						
29	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
30	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	Zinc-Oxide	0.0000	0.9971	0.0007	0.9999	0.0000	0.9992
32	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	Hydrogen	0.0000	0.0029	0.0000	0.0001	0.0000	0.0008
37	Total	0.0000	1.0000	0.0007	1.0000	0.0000	1.0000
38	Material Stream: C2S2in			Fluid Package: Overheads			
39				Property Package: Aspen Properties (Peng-R)			
40	CONDITIONS						
41		Overall	Vapour Phase	Liquid Phase			
42	Vapour / Phase Fraction	1.0000	1.0000	0.0000			
43	Temperature: (C)	40.00 *	40.00	40.00			
44	Pressure: (bar)	17.01	17.01	17.01			
45	Molar Flow (kgmole/h)	4982	4982	5.982e-005			
46	Mass Flow (kg/s)	2.790	2.790	1.352e-006			
47	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8	1.160e-005			
48	Molar Enthalpy (kJ/kgmole)	443.6	443.6	-2.222e+005			
49	Molar Entropy (kJ/kgmole-C)	-22.07	-22.07	-6.862			
50	Heat Flow (MW)	0.6139	0.6139	-3.693e-006			
51	Liq Vol Flow @Std Cond (m3/h)	6.222e+063 *	6.053e+063	3.086e+069			
52	Aspen Technology Inc.			Aspen HYSYS Version 12.1		Page 7 of 13	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:46:33 2024		
4							
5							
6	Material Stream: C2S2in (continued)			Fluid Package:	Overheads		
7				Property Package:	Aspen Properties (Peng-R		
8							
9	COMPOSITION						
10							
11	Overall Phase				Vapour Fraction	1.0000	
12	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
13	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
15	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
19	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
20	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000
21							
22	Vapour Phase				Phase Fraction	1.000	
23	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
24	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
29	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
30	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
31	Total	4981.7648	1.0000	10042.6419	1.0000	266.8124	1.0000
32							
33	Liquid Phase				Phase Fraction	1.201e-008	
34	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
35	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	Zinc-Oxide	0.0001	0.9946	0.0048	0.9954	0.0000	0.9962
37	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
38	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
39	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	Tin-White	0.0000	0.0031	0.0000	0.0046	0.0000	0.0031
41	Hydrogen	0.0000	0.0022	0.0000	0.0001	0.0000	0.0006
42	Total	0.0001	1.0000	0.0049	1.0000	0.0000	1.0000
43							
44	Material Stream: C2S2out			Fluid Package:	Overheads		
45				Property Package:	Aspen Properties (Peng-R		
46							
47	CONDITIONS						
48							
49		Overall	Vapour Phase	Liquid Phase			
50	Vapour / Phase Fraction	1.0000	1.0000	0.0000			
51	Temperature: (C)	175.0 *	175.0	175.0			
52	Pressure: (bar)	45.31	45.31	45.31			
53	Molar Flow (kgmole/h)	4982	4982	3.857e-005			
54	Mass Flow (kg/s)	2.790	2.790	8.658e-007			
55	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8	7.454e-006			
56	Molar Enthalpy (kJ/kgmole)	4418	4418	-2.135e+005			
57	Molar Entropy (kJ/kgmole-C)	-19.76	-19.76	14.56			
58	Heat Flow (MW)	6.113	6.113	-2.288e-006			
59	Liq Vol Flow @Std Cond (m3/h)	6.222e+063 *	6.221e+063	4.042e+064			
60	Aspen Technology Inc.						
61	Aspen HYSYS Version 12.1			Page 8 of 13			

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:46:33 2024		
4							
5	Material Stream: C2S2out (continued)			Fluid Package:	Overheads		
6				Property Package:	Aspen Properties (Peng-R		
7	COMPOSITION						
8	Overall Phase Vapour Fraction 1.000						
9	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
10	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
12	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
16	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
17	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000
18	Vapour Phase Phase Fraction 1.000						
19	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
20	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	Zinc-Oxide	0.0000	0.0000	0.0017	0.0000	0.0000	0.0000
22	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
26	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
27	Total	4981.7649	1.0000	10042.6437	1.0000	266.8124	1.0000
28	Liquid Phase Phase Fraction 7.743e-009						
29	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
30	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	Zinc-Oxide	0.0000	0.9926	0.0031	0.9998	0.0000	0.9979
32	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	Tin-White	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	Hydrogen	0.0000	0.0074	0.0000	0.0002	0.0000	0.0020
37	Total	0.0000	1.0000	0.0031	1.0000	0.0000	1.0000
38	Material Stream: Hydrogen Product			Fluid Package:	Overheads		
39				Property Package:	Aspen Properties (Peng-R		
40	CONDITIONS						
41		Overall	Vapour Phase	Liquid Phase			
42	Vapour / Phase Fraction	1.0000	1.0000	0.0000			
43	Temperature: (C)	40.00 *	40.00	40.00			
44	Pressure: (bar)	44.40	44.40	44.40			
45	Molar Flow (kgmole/h)	4982	4982	6.027e-005			
46	Mass Flow (kg/s)	2.790	2.790	1.359e-006			
47	Std Ideal Liq Vol Flow (m3/h)	266.8	266.8	1.166e-005			
48	Molar Enthalpy (kJ/kgmole)	462.8	462.8	-2.189e+005			
49	Molar Entropy (kJ/kgmole-C)	-30.09	-30.09	-6.628			
50	Heat Flow (MW)	0.6404	0.6404	-3.665e-006			
51	Liq Vol Flow @Std Cond (m3/h)	6.222e+063 *	5.849e+063	1.875e+070			
52	Aspen Technology Inc.	Aspen HYSYS Version 12.1			Page 9 of 13		
53	Licensed to: BATTELLE ENERGY ALLIANCE			* Specified by user.			

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name:	Production.hsc		
2				Unit Set:	AmeyS2e		
3				Date/Time:	Fri Mar 29 15:46:33 2024		
4							
5				Fluid Package:	Overheads		
6	Material Stream: Hydrogen Product (continue)			Property Package:	Aspen Properties (Peng-R		
7							
8							
9	COMPOSITION						
10							
11	Overall Phase					Vapour Fraction	1.0000
12	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
13	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	Zinc-Oxide	0.0001	0.0000	0.0048	0.0000	0.0000	0.0000
15	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
19	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
20	Total	4981.7649	1.0000	10042.6468	1.0000	266.8124	1.0000
21							
22	Vapour Phase					Phase Fraction	1.000
23	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
24	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Zinc-Oxide	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
29	Tin-White	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000
30	Hydrogen	4981.7648	1.0000	10042.6401	1.0000	266.8124	1.0000
31	Total	4981.7648	1.0000	10042.6419	1.0000	266.8124	1.0000
32							
33	Liquid Phase					Phase Fraction	1.210e-008
34	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
35	Zinc	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	Zinc-Oxide	0.0001	0.9874	0.0048	0.9897	0.0000	0.9915
37	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
38	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
39	Water	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	Tin-White	0.0000	0.0069	0.0000	0.0101	0.0000	0.0070
41	Hydrogen	0.0000	0.0057	0.0000	0.0001	0.0000	0.0016
42	Total	0.0001	1.0000	0.0049	1.0000	0.0000	1.0000
43							
44	Material Stream: SaturatedWater			Fluid Package:	Steam		
45				Property Package:	NBS Steam		
46							
47	CONDITIONS						
48							
49		Overall	Aqueous Phase				
50	Vapour / Phase Fraction	0.0000	1.0000				
51	Temperature: (C)	101.1	101.1				
52	Pressure: (bar)	1.055	1.055				
53	Molar Flow (kgmole/h)	4985	4985				
54	Mass Flow (kg/s)	24.94	24.94				
55	Std Ideal Liq Vol Flow (m3/h)	89.98	89.98				
56	Molar Enthalpy (kJ/kgmole)	-2.792e+005	-2.792e+005				
57	Molar Entropy (kJ/kgmole-C)	23.77	23.77				
58	Heat Flow (MW)	-386.6	-386.6				
59	Liq Vol Flow @Std Cond (m3/h)	89.88 *	89.88				
60							
61	Aspen Technology Inc.			Aspen HYSYS Version 12.1		Page 10 of 13	
62	Licensed to: BATTELLE ENERGY ALLIANCE					* Specified by user.	

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc			
2			Unit Set: AmeyS2e			
3			Date/Time: Fri Mar 29 15:46:33 2024			
4						
5						
6	Material Stream: SaturatedWater (continued)				Fluid Package: Steam	
7					Property Package: NBS Steam	
8						
9	COMPOSITION					
10						
11	Overall Phase				Vapour Fraction 0.0000	
12						
13	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
14						LIQUID VOLUME FRACTION
15	H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787
16	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787
17	Aqueous Phase				Phase Fraction 1.000	
18						
19	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
20						LIQUID VOLUME FRACTION
21	H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787
22	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787
23	Material Stream: WaterFeed				Fluid Package: Steam	
24					Property Package: NBS Steam	
25						
26	CONDITIONS					
27						
28		Overall	Aqueous Phase			
29	Vapour / Phase Fraction	0.0000	1.0000			
30	Temperature: (C)	25.00 *	25.00			
31	Pressure: (bar)	1.077	1.077			
32	Molar Flow (kgmole/h)	4985	4985			
33	Mass Flow (kg/s)	24.94	24.94			
34	Std Ideal Liq Vol Flow (m3/h)	89.98	89.98			
35	Molar Enthalpy (kJ/kgmole)	-2.850e+005	-2.850e+005			
36	Molar Entropy (kJ/kgmole-C)	6.610	6.610			
37	Heat Flow (MW)	-394.6	-394.6			
38	Liq Vol Flow @Std Cond (m3/h)	89.88 *	89.88			
39						
40	COMPOSITION					
41						
42	Overall Phase				Vapour Fraction 0.0000	
43						
44	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
45						LIQUID VOLUME FRACTION
46	H2O	4984.5660 *	1.0000 *	89797.4575 *	1.0000 *	89.9787 *
47	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787
48	Aqueous Phase				Phase Fraction 1.000	
49						
50	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
51						LIQUID VOLUME FRACTION
52	H2O	4984.5660	1.0000	89797.4575	1.0000	89.9787
53	Total	4984.5660	1.0000	89797.4575	1.0000	89.9787
54	Material Stream: CWin				Fluid Package: Steam	
55					Property Package: NBS Steam	
56						
57	CONDITIONS					
58						
59		Overall	Aqueous Phase			
60	Vapour / Phase Fraction	0.0000	1.0000			
61	Temperature: (C)	25.00 *	25.00			
62	Pressure: (bar)	1.200 *	1.200			
63	Molar Flow (kgmole/h)	4044	4044			

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: Production.hsc			
2			Unit Set: AmeyS2e			
3			Date/Time: Fri Mar 29 15:46:33 2024			
4						
5						
6	Material Stream: CWin (continued)				Fluid Package: Steam	
7					Property Package: NBS Steam	
8	CONDITIONS					
9						
10						
11		Overall	Aqueous Phase			
12	Mass Flow (kg/s)	20.24	20.24			
13	Std Ideal Liq Vol Flow (m3/h)	73.00	73.00			
14	Molar Enthalpy (kJ/kgmole)	-2.850e+005	-2.850e+005			
15	Molar Entropy (kJ/kgmole-C)	6.610	6.610			
16	Heat Flow (MW)	-320.1	-320.1			
17	Liq Vol Flow @Std Cond (m3/h)	72.91 *	72.91			
18	COMPOSITION					
19						
20	Overall Phase					
21						Vapour Fraction 0.0000
22	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
23						LIQUID VOLUME FRACTION
24	H2O	4043.9117 *	1.0000 *	72851.4751 *	1.0000 *	72.9985 *
25	Total	4043.9117	1.0000	72851.4751	1.0000	72.9985
26	Aqueous Phase					
27						Phase Fraction 1.000
28	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
29						LIQUID VOLUME FRACTION
30	H2O	4043.9117	1.0000	72851.4751	1.0000	72.9985
31	Total	4043.9117	1.0000	72851.4751	1.0000	72.9985
32	Material Stream: CWout				Fluid Package: Steam	
33					Property Package: NBS Steam	
34	CONDITIONS					
35						
36						
37		Overall	Aqueous Phase			
38	Vapour / Phase Fraction	0.0000	1.0000			
39	Temperature: (C)	60.00 *	60.00			
40	Pressure: (bar)	1.200	1.200			
41	Molar Flow (kgmole/h)	4044	4044			
42	Mass Flow (kg/s)	20.24	20.24			
43	Std Ideal Liq Vol Flow (m3/h)	73.00	73.00			
44	Molar Enthalpy (kJ/kgmole)	-2.823e+005	-2.823e+005			
45	Molar Entropy (kJ/kgmole-C)	14.97	14.97			
46	Heat Flow (MW)	-317.2	-317.2			
47	Liq Vol Flow @Std Cond (m3/h)	72.91 *	72.91			
48	COMPOSITION					
49						
50	Overall Phase					
51						Vapour Fraction 0.0000
52	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
53						LIQUID VOLUME FRACTION
54	H2O	4043.9117	1.0000	72851.4751	1.0000	72.9985
55	Total	4043.9117	1.0000	72851.4751	1.0000	72.9985
56	Aqueous Phase					
57						Phase Fraction 1.000
58	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
59						LIQUID VOLUME FRACTION
60	H2O	4043.9117	1.0000	72851.4751	1.0000	72.9985
61	Total	4043.9117	1.0000	72851.4751	1.0000	72.9985
62						
63	Aspen Technology Inc.		Aspen HYSYS Version 12.1		Page 12 of 13	
	Licensed to: BATTELLE ENERGY ALLIANCE				* Specified by user.	

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name:	Production.hsc
2			Unit Set:	AmeyS2e
3			Date/Time:	Fri Mar 29 15:46:33 2024
4				
5	Energy Stream: W-C1S1			Fluid Package: Reaction
6				Property Package: Aspen Properties (Solids)
7	CONDITIONS			
8	Duty Type:	Direct Q	Duty Calculation Operation:	Comp1Stage1
9	Duty SP:	5.445 MW	Minimum Available Duty:	0.0000 MW
10				Maximum Available Duty: ---
11	Energy Stream: PrecoolerDuty			Fluid Package: Reaction
12				Property Package: Aspen Properties (Solids)
13	CONDITIONS			
14	Duty Type:	Direct Q	Duty Calculation Operation:	Precooler
15	Duty SP:	2.657 MW	Minimum Available Duty:	0.0000 MW
16				Maximum Available Duty: ---
17	Energy Stream: W-C1S2			Fluid Package: Reaction
18				Property Package: Aspen Properties (Solids)
19	CONDITIONS			
20	Duty Type:	Direct Q	Duty Calculation Operation:	Comp1Stage2
21	Duty SP:	5.450 MW	Minimum Available Duty:	0.0000 MW
22				Maximum Available Duty: ---
23	Energy Stream: W-C2S1			Fluid Package: Reaction
24				Property Package: Aspen Properties (Solids)
25	CONDITIONS			
26	Duty Type:	Direct Q	Duty Calculation Operation:	Comp2Stage1
27	Duty SP:	5.464 MW	Minimum Available Duty:	0.0000 MW
28				Maximum Available Duty: ---
29	Energy Stream: W-C2S2			Fluid Package: Reaction
30				Property Package: Aspen Properties (Solids)
31	CONDITIONS			
32	Duty Type:	Direct Q	Duty Calculation Operation:	Comp2Stage2
33	Duty SP:	5.500 MW	Minimum Available Duty:	0.0000 MW
34				Maximum Available Duty: ---
35	Energy Stream: CompressionWork			Fluid Package: Reaction
36				Property Package: Aspen Properties (Solids)
37	CONDITIONS			
38	Duty Type:	Direct Q	Duty Calculation Operation:	
39	Duty SP:	21.86 MW	Minimum Available Duty:	0.0000 MW
40				Maximum Available Duty: ---
41				
42				
43				
44				
45				
46				
47				
48				
49				
50				
51				
52				
53				
54				
55				
56				
57				
58				
59				
60				
61				
62				
63	Aspen Technology Inc.		Aspen HYSYS Version 12.1	

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.

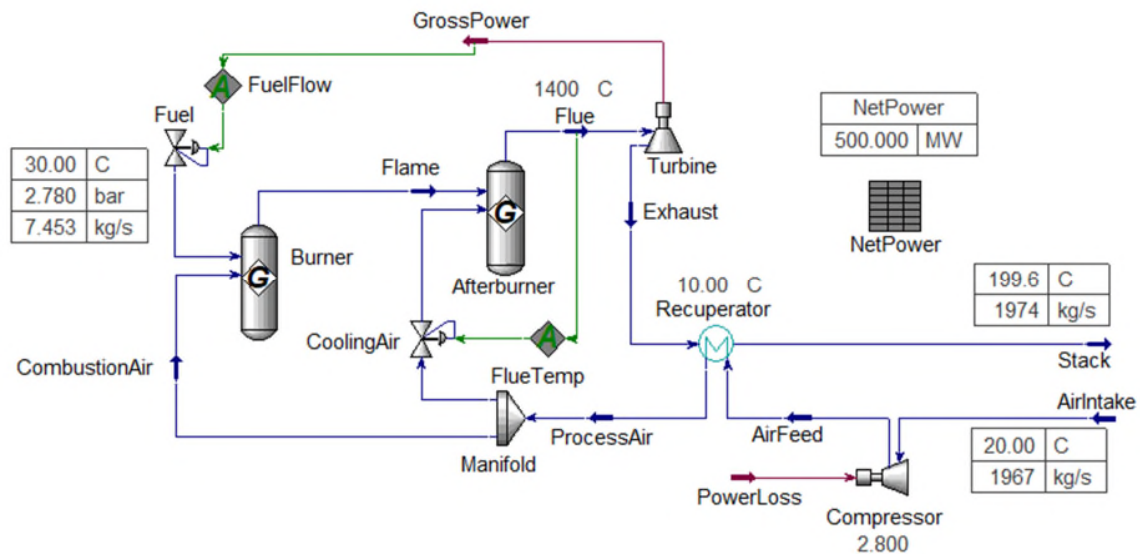


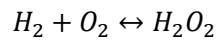
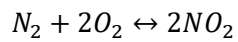
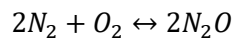
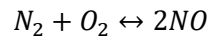
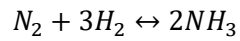
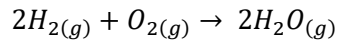
Figure B1. Combustion-turbine model.


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-H₂ (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:





1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: 500MWe_HydrogenTurbine_recuperated.hsc			
2			Unit Set: AmeyS2e			
3			Date/Time: Wed Sep 27 09:15:46 2023			
4						
5	Material Stream: Fuel		Fluid Package: CombustionTurbineProce			
6			Property Package: Peng-Robinson			
7						
8	CONDITIONS					
9						
10						
11		Overall	Vapour Phase			
12	Vapour / Phase Fraction	1.0000	1.0000			
13	Temperature: (C)	30.00 *	30.00			
14	Pressure: (bar)	2.780	2.780			
15	Molar Flow (kgmole/h)	1.331e+004	1.331e+004			
16	Mass Flow (kg/s)	7.453 *	7.453			
17	Std Ideal Liq Vol Flow (m3/h)	384.1	384.1			
18	Molar Enthalpy (kJ/kgmole)	142.0	142.0			
19	Molar Entropy (kJ/kgmole-C)	115.1	115.1			
20	Heat Flow (MW)	0.5248	0.5248			
21	Liq Vol Flow @Std Cond (m3/h)	3.148e+005 *	3.148e+005			
22	COMPOSITION					
23						
24	Overall Phase					
25						Vapour Fraction 1.0000
26	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
27						LIQUID VOLUME FRACTION
28	H2O	0.0000	0.0000	0.0000	0.0000	0.0000
29	Hydrogen	13308.4696	1.0000	26829.8751	1.0000	384.0570
30	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000
31	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000
32	Methane	0.0000	0.0000	0.0000	0.0000	0.0000
33	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000
34	CO2	0.0000	0.0000	0.0000	0.0000	0.0000
35	N2O	0.0000	0.0000	0.0000	0.0000	0.0000
36	NO2	0.0000	0.0000	0.0000	0.0000	0.0000
37	NO	0.0000	0.0000	0.0000	0.0000	0.0000
38	SO2	0.0000	0.0000	0.0000	0.0000	0.0000
39	H2S	0.0000	0.0000	0.0000	0.0000	0.0000
40	CO	0.0000	0.0000	0.0000	0.0000	0.0000
41	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000
42	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000
43	Total	13308.4696	1.0000	26829.8751	1.0000	384.0570
44	Vapour Phase					
45						Phase Fraction 1.000
46	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)
47						LIQUID VOLUME FRACTION
48	H2O	0.0000	0.0000	0.0000	0.0000	0.0000
49	Hydrogen	13308.4696	1.0000	26829.8751	1.0000	384.0570
50	Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000
51	Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000
52	Methane	0.0000	0.0000	0.0000	0.0000	0.0000
53	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000
54	CO2	0.0000	0.0000	0.0000	0.0000	0.0000
55	N2O	0.0000	0.0000	0.0000	0.0000	0.0000
56	NO2	0.0000	0.0000	0.0000	0.0000	0.0000
57	NO	0.0000	0.0000	0.0000	0.0000	0.0000
58	SO2	0.0000	0.0000	0.0000	0.0000	0.0000
59	H2S	0.0000	0.0000	0.0000	0.0000	0.0000
60	CO	0.0000	0.0000	0.0000	0.0000	0.0000
61	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000
62	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000
63	Total	13308.4696	1.0000	26829.8751	1.0000	384.0570
64						
65	Aspen Technology Inc.		Aspen HYSYS Version 11		Page 1 of 16	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: 500MWe_HydrogenTurbine_recuperated.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Wed Sep 27 09:15:46 2023				
4							
5	Material Stream: AirIntake				Fluid Package: CombustionTurbineProce		
6					Property Package: Peng-Robinson		
7	CONDITIONS						
8		Overall	Vapour Phase				
9	Vapour / Phase Fraction	1.0000	1.0000				
10	Temperature: (C)	20.00 *	20.00				
11	Pressure: (bar)	1.013 *	1.013				
12	Molar Flow (kgmole/h)	2.465e+005	2.465e+005				
13	Mass Flow (kg/s)	1967	1967				
14	Std Ideal Liq Vol Flow (m3/h)	8178	8178				
15	Molar Enthalpy (kJ/kgmole)	-2958	-2958				
16	Molar Entropy (kJ/kgmole-C)	152.0	152.0				
17	Heat Flow (MW)	-202.5	-202.5				
18	Liq Vol Flow @Std Cond (m3/h)	5.824e+006 *	5.824e+006				
19	COMPOSITION						
20	Overall Phase						
21				Vapour Fraction	1.0000		
22	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
23	H2O	2857.0521 *	0.0116 *	51470.0804 *	0.0073 *	51.5739 *	0.0063 *
24	Hydrogen	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
25	Nitrogen	192493.4427 *	0.7808 *	5.392318905e+06 *	0.7615 *	6687.1188 *	0.8177 *
26	Oxygen	51169.1430 *	0.2076 *	1.637412576e+06 *	0.2312 *	1439.2558 *	0.1760 *
27	Methane	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
28	Ethane	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
29	CO2	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
30	N2O	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
31	NO2	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
32	NO	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
33	SO2	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
34	H2S	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
35	CO	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
36	H2O2	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
37	Ammonia	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *	0.0000 *
38	Total	246519.6378	1.0000	7.081201561e+06	1.0000	8177.9485	1.0000
39	Vapour Phase						
40				Phase Fraction	1.000		
41	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
42	H2O	2857.0521	0.0116	51470.0804	0.0073	51.5739	0.0063
43	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
44	Nitrogen	192493.4427	0.7808	5.392318905e+06	0.7615	6687.1188	0.8177
45	Oxygen	51169.1430	0.2076	1.637412576e+06	0.2312	1439.2558	0.1760
46	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
48	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
49	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
53	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
54	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
56	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
57	Total	246519.6378	1.0000	7.081201561e+06	1.0000	8177.9485	1.0000


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: 500MWe_HydrogenTurbine_recuperated.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Wed Sep 27 09:15:46 2023				
4							
5	Material Stream: BurnerCondensate		Fluid Package: CombustionTurbineProc				
6			Property Package: Peng-Robinson				
7	CONDITIONS						
8		Overall	Vapour Phase	Liquid Phase	Aqueous Phase		
9	Vapour / Phase Fraction	0.0000	0.0000	0.5000	0.5000		
10	Temperature: (C)	2387	2387	2387	2387		
11	Pressure: (bar)	2.730	2.730	2.730	2.730		
12	Molar Flow (kgmole/h)	0.0000	0.0000	0.0000	0.0000		
13	Mass Flow (kg/s)	0.0000	0.0000	0.0000	0.0000		
14	Std Ideal Liq Vol Flow (m3/h)	0.0000	0.0000	0.0000	0.0000		
15	Molar Enthalpy (kJ/kgmole)	2.651e+004	2.651e+004	2.651e+004	2.651e+004		
16	Molar Entropy (kJ/kgmole-C)	233.6	233.6	233.6	233.6		
17	Heat Flow (MW)	0.0000	0.0000	0.0000	0.0000		
18	Liq Vol Flow @Std Cond (m3/h)	0.0000 *	0.0000	0.0000	0.0000		
19	COMPOSITION						
20	Overall Phase				Vapour Fraction	0.0000	
21	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
22	H2O	0.0000	0.2861	0.0000	0.2072	0.0000	0.1519
23	Hydrogen	0.0000	0.0162	0.0000	0.0013	0.0000	0.0138
24	Nitrogen	0.0000	0.6547	0.0000	0.7371	0.0000	0.6691
25	Oxygen	0.0000	0.0318	0.0000	0.0408	0.0000	0.0263
26	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
29	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	NO	0.0000	0.0112	0.0000	0.0135	0.0000	0.1389
32	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
37	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
38	Vapour Phase				Phase Fraction	0.0000	
39	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
40	H2O	0.0000	0.2861	0.0000	0.2072	0.0000	0.1519
41	Hydrogen	0.0000	0.0162	0.0000	0.0013	0.0000	0.0138
42	Nitrogen	0.0000	0.6547	0.0000	0.7371	0.0000	0.6691
43	Oxygen	0.0000	0.0318	0.0000	0.0408	0.0000	0.0263
44	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
46	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
48	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
49	NO	0.0000	0.0112	0.0000	0.0135	0.0000	0.1389
50	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
53	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
54	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
56	Aspen Technology Inc.		Aspen HYSYS Version 11		Page 3 of 16		


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: 500MWe_HydrogenTurbine_recuperated.hsc				
2				Unit Set: AmeyS2e				
3				Date/Time: Wed Sep 27 09:15:46 2023				
4								
5	Material Stream: BurnerCondensate (continue)			Fluid Package: CombustionTurbineProce				
6				Property Package: Peng-Robinson				
7	COMPOSITION							
8	Liquid Phase							
9						Phase Fraction	0.5000	
10	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
11	H2O	0.0000	0.2861	0.0000	0.2072	0.0000	0.1519	
12	Hydrogen	0.0000	0.0162	0.0000	0.0013	0.0000	0.0138	
13	Nitrogen	0.0000	0.6547	0.0000	0.7371	0.0000	0.6691	
14	Oxygen	0.0000	0.0318	0.0000	0.0408	0.0000	0.0263	
15	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
16	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
17	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
18	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
19	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
20	NO	0.0000	0.0112	0.0000	0.0135	0.0000	0.1389	
21	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
22	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
23	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
24	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
25	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
26	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	
27	Aqueous Phase						Phase Fraction	0.5000
28	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
29	H2O	0.0000	0.2861	0.0000	0.2072	0.0000	0.1519	
30	Hydrogen	0.0000	0.0162	0.0000	0.0013	0.0000	0.0138	
31	Nitrogen	0.0000	0.6547	0.0000	0.7371	0.0000	0.6691	
32	Oxygen	0.0000	0.0318	0.0000	0.0408	0.0000	0.0263	
33	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
34	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
35	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
36	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
37	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
38	NO	0.0000	0.0112	0.0000	0.0135	0.0000	0.1389	
39	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
40	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
41	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
42	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
43	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
44	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000	
45	Material Stream: Flue			Fluid Package: CombustionTurbineProce				
46				Property Package: Peng-Robinson				
47	CONDITIONS							
48		Overall	Vapour Phase	Liquid Phase	Aqueous Phase			
49	Vapour / Phase Fraction	1.0000	1.0000	0.0000	0.0000			
50	Temperature: (C)	1400	1400	1400	1400			
51	Pressure: (bar)	2.730	2.730	2.730	2.730			
52	Molar Flow (kgmole/h)	2.532e+005	2.532e+005	0.0000	0.0000			
53	Mass Flow (kg/s)	1974	1974	0.0000	0.0000			
54	Std Ideal Liq Vol Flow (m3/h)	8478	8478	0.0000	0.0000			
55	Molar Enthalpy (kJ/kgmole)	3.049e+004	3.049e+004	3.049e+004	3.049e+004			
56	Molar Entropy (kJ/kgmole-C)	202.5	202.5	202.5	202.5			


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: 500MWe_HydrogenTurbine_recuperated.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Wed Sep 27 09:15:46 2023				
4							
5	Material Stream: Flue (continued)				Fluid Package: CombustionTurbineProc		
6					Property Package: Peng-Robinson		
7	CONDITIONS						
8		Overall	Vapour Phase	Liquid Phase	Aqueous Phase		
9	Heat Flow (MW)	2144	2144	0.0000	0.0000		
10	Liq Vol Flow @Std Cond (m3/h)	5.977e+006 *	5.977e+006	0.0000	0.0000		
11	COMPOSITION						
12	Overall Phase				Vapour Fraction	1.0000	
13	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
14	H2O	16165.1670	0.0639	291217.1082	0.0410	291.8048	0.0344
15	Hydrogen	0.3486	0.0000	0.7027	0.0000	0.0101	0.0000
16	Nitrogen	192174.0963	0.7591	5.383373054e+06	0.7574	6676.0249	0.7874
17	Oxygen	44194.2520	0.1746	1.414216065e+06	0.1990	1243.0701	0.1466
18	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	N2O	0.0486	0.0000	2.1409	0.0000	0.0026	0.0000
22	NO2	3.0108	0.0000	138.5141	0.0000	0.0942	0.0000
23	NO	635.5847	0.0025	19071.3557	0.0027	267.3953	0.0315
24	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	H2O2	0.0060	0.0000	0.2053	0.0000	0.0001	0.0000
28	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
29	Total	253172.5141	1.0000	7.108019145e+06	1.0000	8478.4022	1.0000
30	Vapour Phase				Phase Fraction	1.000	
31	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
32	H2O	16165.1670	0.0639	291217.1082	0.0410	291.8048	0.0344
33	Hydrogen	0.3486	0.0000	0.7027	0.0000	0.0101	0.0000
34	Nitrogen	192174.0963	0.7591	5.383373054e+06	0.7574	6676.0249	0.7874
35	Oxygen	44194.2520	0.1746	1.414216065e+06	0.1990	1243.0701	0.1466
36	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
37	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
38	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
39	N2O	0.0486	0.0000	2.1409	0.0000	0.0026	0.0000
40	NO2	3.0108	0.0000	138.5141	0.0000	0.0942	0.0000
41	NO	635.5847	0.0025	19071.3557	0.0027	267.3953	0.0315
42	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
44	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	H2O2	0.0060	0.0000	0.2053	0.0000	0.0001	0.0000
46	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	Total	253172.5141	1.0000	7.108019145e+06	1.0000	8478.4022	1.0000
48	Liquid Phase				Phase Fraction	0.0000	
49	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
50	H2O	0.0000	0.0639	0.0000	0.0410	0.0000	0.0344
51	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	Nitrogen	0.0000	0.7591	0.0000	0.7574	0.0000	0.7874
53	Oxygen	0.0000	0.1746	0.0000	0.1990	0.0000	0.1466
54	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: 500MWe_HydrogenTurbine_recuperated.hsc			
2				Unit Set: AmeyS2e			
3				Date/Time: Wed Sep 27 09:15:46 2023			
4							
5	Material Stream: Flue (continued)			Fluid Package: CombustionTurbineProce			
6				Property Package: Peng-Robinson			
7	COMPOSITION						
8	Liquid Phase (continued)						
9						Phase Fraction	0.0000
10	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
11	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	NO	0.0000	0.0025	0.0000	0.0027	0.0000	0.0315
16	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
22	Aqueous Phase						
23						Phase Fraction	0.0000
24	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
25	H2O	0.0000	0.0639	0.0000	0.0410	0.0000	0.0344
26	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	Nitrogen	0.0000	0.7591	0.0000	0.7574	0.0000	0.7874
28	Oxygen	0.0000	0.1746	0.0000	0.1990	0.0000	0.1466
29	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	NO	0.0000	0.0025	0.0000	0.0027	0.0000	0.0315
35	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
37	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
38	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
39	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
41	Material Stream: Exhaust			Fluid Package: CombustionTurbineProce			
42				Property Package: Peng-Robinson			
43	CONDITIONS						
44		Overall	Vapour Phase				
45	Vapour / Phase Fraction	1.0000	1.0000				
46	Temperature: (C)	1095	1095				
47	Pressure: (bar)	1.033	1.033				
48	Molar Flow (kgmole/h)	2.532e+005	2.532e+005				
49	Mass Flow (kg/s)	1974	1974				
50	Std Ideal Liq Vol Flow (m3/h)	8478	8478				
51	Molar Enthalpy (kJ/kgmole)	1.960e+004	1.960e+004				
52	Molar Entropy (kJ/kgmole-C)	203.4	203.4				
53	Heat Flow (MW)	1378	1378				
54	Liq Vol Flow @Std Cond (m3/h)	5.977e+006 *	5.977e+006				
55							
56							
57							
58							
59							
60							
61							
62							
63							
64							
65	Aspen Technology Inc.	Aspen HYSYS Version 11			Page 6 of 16		


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: 500MWe_HydrogenTurbine_recuperated.hsc																																																																																																																									
2				Unit Set: AmeyS2e																																																																																																																									
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COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION																																																																																																																							
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Total	253172.5141	1.0000	7.108019145e+06	1.0000	8478.4022	1.0000																																																																																																																							
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16	Vapour / Phase Fraction		1.0000	1.0000																																																																																																																									
17	Temperature: (C)		151.4	151.4																																																																																																																									
18	Pressure: (bar)		2.836	2.836																																																																																																																									
19	Molar Flow (kgmole/h)		2.465e+005	2.465e+005																																																																																																																									
20	Mass Flow (kg/s)		1967	1967																																																																																																																									
21	Std Ideal Liq Vol Flow (m3/h)		8178	8178																																																																																																																									
22	Molar Enthalpy (kJ/kgmole)		926.1	926.1																																																																																																																									
23	Molar Entropy (kJ/kgmole-C)		154.4	154.4																																																																																																																									
24	Aspen Technology Inc.			Aspen HYSYS Version 11		Page 7 of 16																																																																																																																							


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: 500MWe_HydrogenTurbine_recuperated.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Wed Sep 27 09:15:46 2023				
4							
5	Material Stream: AirFeed (continued)					Fluid Package: CombustionTurbineProce	
6						Property Package: Peng-Robinson	
7	CONDITIONS						
8		Overall	Vapour Phase				
9	Heat Flow (MW)	63.42	63.42				
10	Liq Vol Flow @Std Cond (m3/h)	5.824e+006 *	5.824e+006				
11	COMPOSITION						
12	Overall Phase						
13						Vapour Fraction 1.0000	
14	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	
15						LIQUID VOLUME FRACTION	
16	H2O	2857.0521	0.0116	51470.0804	0.0073	51.5739	
17	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	
18	Nitrogen	192493.4427	0.7808	5.392318905e+06	0.7615	6687.1188	
19	Oxygen	51169.1430	0.2076	1.637412576e+06	0.2312	1439.2558	
20	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	
21	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	
22	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	
23	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	
24	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	
25	NO	0.0000	0.0000	0.0000	0.0000	0.0000	
26	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	
27	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	
28	CO	0.0000	0.0000	0.0000	0.0000	0.0000	
29	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	
30	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	
31	Total	246519.6378	1.0000	7.081201561e+06	1.0000	8177.9485	
32	Vapour Phase						
33						Phase Fraction 1.000	
34	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	
35						LIQUID VOLUME FRACTION	
36	H2O	2857.0521	0.0116	51470.0804	0.0073	51.5739	
37	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	
38	Nitrogen	192493.4427	0.7808	5.392318905e+06	0.7615	6687.1188	
39	Oxygen	51169.1430	0.2076	1.637412576e+06	0.2312	1439.2558	
40	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	
41	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	
42	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	
43	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	
44	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	
45	NO	0.0000	0.0000	0.0000	0.0000	0.0000	
46	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	
47	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	
48	CO	0.0000	0.0000	0.0000	0.0000	0.0000	
49	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	
50	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	
51	Total	246519.6378	1.0000	7.081201561e+06	1.0000	8177.9485	
52	Material Stream: CombustionAir					Fluid Package: CombustionTurbineProce	
53						Property Package: Peng-Robinson	
54	CONDITIONS						
55		Overall	Vapour Phase				
56	Vapour / Phase Fraction	1.0000	1.0000				
57	Temperature: (C)	1085	1085				
58	Pressure: (bar)	2.780	2.780				
59	Aspen Technology Inc.		Aspen HYSYS Version 11			Page 8 of 16	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: 500MWe_HydrogenTurbine_recuperated.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Wed Sep 27 09:15:46 2023				
4							
5	Material Stream: CombustionAir (continued)					Fluid Package: CombustionTurbineProce	
6						Property Package: Peng-Robinson	
7	CONDITIONS						
8							
9							
10							
11		Overall	Vapour Phase				
12	Molar Flow (kgmole/h)	3.847e+004	3.847e+004				
13	Mass Flow (kg/s)	307.0	307.0				
14	Std Ideal Liq Vol Flow (m3/h)	1276	1276				
15	Molar Enthalpy (kJ/kgmole)	3.130e+004	3.130e+004				
16	Molar Entropy (kJ/kgmole-C)	191.8	191.8				
17	Heat Flow (MW)	334.5	334.5				
18	Liq Vol Flow @Std Cond (m3/h)	9.088e+005 *	9.088e+005				
19	COMPOSITION						
20							
21	Overall Phase						
22						Vapour Fraction 1.0000	
23	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
24							
25	H2O	445.8506	0.0116	8032.0438	0.0073	8.0483	0.0063
26	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	Nitrogen	30039.1170	0.7808	841485.7992	0.7615	1043.5428	0.8177
28	Oxygen	7985.0817	0.2076	255522.6155	0.2312	224.5997	0.1760
29	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
37	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
38	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
39	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	Total	38470.0494	1.0000	1.105040459e+06	1.0000	1276.1908	1.0000
41	Vapour Phase						Phase Fraction 1.000
42							
43	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
44							
45	H2O	445.8506	0.0116	8032.0438	0.0073	8.0483	0.0063
46	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	Nitrogen	30039.1170	0.7808	841485.7992	0.7615	1043.5428	0.8177
48	Oxygen	7985.0817	0.2076	255522.6155	0.2312	224.5997	0.1760
49	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
53	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
54	NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
56	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
57	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
58	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
59	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
60	Total	38470.0494	1.0000	1.105040459e+06	1.0000	1276.1908	1.0000
61							
62							
63							
64							
65	Aspen Technology Inc.		Aspen HYSYS Version 11			Page 9 of 16	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: 500MWe_HydrogenTurbine_recuperated.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Wed Sep 27 09:15:46 2023				
4							
5	Material Stream: CoolingAir					Fluid Package: CombustionTurbineProce	
6						Property Package: Peng-Robinson	
7	CONDITIONS						
8		Overall	Vapour Phase				
9	Vapour / Phase Fraction	1.0000	1.0000				
10	Temperature: (C)	1085	1085				
11	Pressure: (bar)	2.780	2.780				
12	Molar Flow (kgmole/h)	2.080e+005	2.080e+005				
13	Mass Flow (kg/s)	1660 *	1660				
14	Std Ideal Liq Vol Flow (m3/h)	6902	6902				
15	Molar Enthalpy (kJ/kgmole)	3.130e+004	3.130e+004				
16	Molar Entropy (kJ/kgmole-C)	191.8	191.8				
17	Heat Flow (MW)	1809	1809				
18	Liq Vol Flow @Std Cond (m3/h)	4.915e+006 *	4.915e+006				
19	COMPOSITION						
20	Overall Phase					Vapour Fraction 1.0000	
21	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	
22						LIQUID VOLUME FRACTION	
23	H2O	2411.2015	0.0116	43438.0365	0.0073	43.5257	
24	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	
25	Nitrogen	162454.3257	0.7808	4.550833105e+06	0.7615	5643.5760	
26	Oxygen	43184.0613	0.2076	1.381889960e+06	0.2312	1214.6561	
27	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	
28	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	
29	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	
30	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	
31	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	
32	NO	0.0000	0.0000	0.0000	0.0000	0.0000	
33	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	
34	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	
35	CO	0.0000	0.0000	0.0000	0.0000	0.0000	
36	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	
37	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	
38	Total	208049.5884	1.0000	5.976161102e+06	1.0000	6901.7578	
39	Vapour Phase					Phase Fraction 1.000	
40	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	
41						LIQUID VOLUME FRACTION	
42	H2O	2411.2015	0.0116	43438.0365	0.0073	43.5257	
43	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	
44	Nitrogen	162454.3257	0.7808	4.550833105e+06	0.7615	5643.5760	
45	Oxygen	43184.0613	0.2076	1.381889960e+06	0.2312	1214.6561	
46	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	
47	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	
48	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	
49	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	
50	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	
51	NO	0.0000	0.0000	0.0000	0.0000	0.0000	
52	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	
53	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	
54	CO	0.0000	0.0000	0.0000	0.0000	0.0000	
55	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	
56	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	
57	Total	208049.5884	1.0000	5.976161102e+06	1.0000	6901.7578	


1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: 500MWe_HydrogenTurbine_recuperated.hsc			
2				Unit Set: AmeyS2e			
3				Date/Time: Wed Sep 27 09:15:46 2023			
4							
5	Material Stream: Flame			Fluid Package: CombustionTurbineProce			
6				Property Package: Peng-Robinson			
7	CONDITIONS						
8		Overall	Vapour Phase	Liquid Phase	Aqueous Phase		
9	Vapour / Phase Fraction	1.0000	1.0000	0.0000	0.0000		
10	Temperature: (C)	2387	2387	2387	2387		
11	Pressure: (bar)	2.730	2.730	2.730	2.730		
12	Molar Flow (kgmole/h)	4.549e+004	4.549e+004	0.0000	0.0000		
13	Mass Flow (kg/s)	314.4	314.4	0.0000	0.0000		
14	Std Ideal Liq Vol Flow (m3/h)	1546	1546	0.0000	0.0000		
15	Molar Enthalpy (kJ/kgmole)	2.651e+004	2.651e+004	2.651e+004	2.651e+004		
16	Molar Entropy (kJ/kgmole-C)	233.6	233.6	233.6	233.6		
17	Heat Flow (MW)	335.0	335.0	0.0000	0.0000		
18	Liq Vol Flow @Std Cond (m3/h)	1.071e+006 *	1.071e+006	0.0000	0.0000		
19	COMPOSITION						
20	Overall Phase			Vapour Fraction 1.0000			
21	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
22	H2O	13015.3926	0.2861	234473.6060	0.2072	234.9468	0.1519
23	Hydrogen	738.8685	0.0162	1489.5590	0.0013	21.3223	0.0138
24	Nitrogen	29783.6983	0.6547	834330.7540	0.7371	1034.6697	0.6691
25	Oxygen	1444.7455	0.0318	46231.8545	0.0408	40.6370	0.0263
26	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
29	N2O	0.0287	0.0000	1.2632	0.0000	0.0015	0.0000
30	NO2	0.2089	0.0000	9.6125	0.0000	0.0065	0.0000
31	NO	510.5698	0.0112	15320.1586	0.0135	214.8006	0.1389
32	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	H2O2	0.0571	0.0000	1.9413	0.0000	0.0013	0.0000
36	Ammonia	0.0013	0.0000	0.0221	0.0000	0.0000	0.0000
37	Total	45493.5707	1.0000	1.131858771e+06	1.0000	1546.3858	1.0000
38	Vapour Phase			Phase Fraction 1.000			
39	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
40	H2O	13015.3926	0.2861	234473.6060	0.2072	234.9468	0.1519
41	Hydrogen	738.8685	0.0162	1489.5590	0.0013	21.3223	0.0138
42	Nitrogen	29783.6983	0.6547	834330.7540	0.7371	1034.6697	0.6691
43	Oxygen	1444.7455	0.0318	46231.8545	0.0408	40.6370	0.0263
44	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
46	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	N2O	0.0287	0.0000	1.2632	0.0000	0.0015	0.0000
48	NO2	0.2089	0.0000	9.6125	0.0000	0.0065	0.0000
49	NO	510.5698	0.0112	15320.1586	0.0135	214.8006	0.1389
50	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
53	H2O2	0.0571	0.0000	1.9413	0.0000	0.0013	0.0000
54	Ammonia	0.0013	0.0000	0.0221	0.0000	0.0000	0.0000
55	Total	45493.5707	1.0000	1.131858771e+06	1.0000	1546.3858	1.0000

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: 500MWe_HydrogenTurbine_recuperated.hsc			
2				Unit Set: AmeyS2e			
3				Date/Time: Wed Sep 27 09:15:46 2023			
4							
5	Material Stream: Flame (continued)			Fluid Package: CombustionTurbineProce			
6				Property Package: Peng-Robinson			
7	COMPOSITION						
8	Liquid Phase Phase Fraction 0.0000						
9	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
10	H2O	0.0000	0.2861	0.0000	0.2072	0.0000	0.1519
11	Hydrogen	0.0000	0.0162	0.0000	0.0013	0.0000	0.0138
12	Nitrogen	0.0000	0.6547	0.0000	0.7371	0.0000	0.6691
13	Oxygen	0.0000	0.0318	0.0000	0.0408	0.0000	0.0263
14	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	NO	0.0000	0.0112	0.0000	0.0135	0.0000	0.1389
20	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
26	Aqueous Phase Phase Fraction 0.0000						
27	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
28	H2O	0.0000	0.2861	0.0000	0.2072	0.0000	0.1519
29	Hydrogen	0.0000	0.0162	0.0000	0.0013	0.0000	0.0138
30	Nitrogen	0.0000	0.6547	0.0000	0.7371	0.0000	0.6691
31	Oxygen	0.0000	0.0318	0.0000	0.0408	0.0000	0.0263
32	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
37	NO	0.0000	0.0112	0.0000	0.0135	0.0000	0.1389
38	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
39	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
41	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
42	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
44	Material Stream: ProcessAir			Fluid Package: CombustionTurbineProce			
45				Property Package: Peng-Robinson			
46	CONDITIONS						
47		Overall	Vapour Phase				
48	Vapour / Phase Fraction	1.0000	1.0000				
49	Temperature: (C)	1085 *	1085				
50	Pressure: (bar)	2.780	2.780				
51	Molar Flow (kgmole/h)	2.465e+005	2.465e+005				
52	Mass Flow (kg/s)	1967	1967				
53	Std Ideal Liq Vol Flow (m3/h)	8178	8178				
54	Molar Enthalpy (kJ/kgmole)	3.130e+004	3.130e+004				
55	Molar Entropy (kJ/kgmole-C)	191.8	191.8				
56	Aspen Technology Inc.			Aspen HYSYS Version 11		Page 12 of 16	

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: 500MWe_HydrogenTurbine_recuperated.hsc			
2				Unit Set: AmeyS2e			
3				Date/Time: Wed Sep 27 09:15:46 2023			
4							
5	Material Stream: ProcessAir (continued)						
6					Fluid Package: CombustionTurbineProce		
7					Property Package: Peng-Robinson		
8	CONDITIONS						
9							
10			Overall	Vapour Phase			
11	Heat Flow (MW)		2143	2143			
12	Liq Vol Flow @Std Cond (m3/h)		5.824e+006 *	5.824e+006			
13	COMPOSITION						
14							
15	Overall Phase						
16						Vapour Fraction 1.0000	
17							
18	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
19							
20	H2O	2857.0521	0.0116	51470.0804	0.0073	51.5739	0.0063
21	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	Nitrogen	192493.4427	0.7808	5.392318905e+06	0.7615	6687.1188	0.8177
23	Oxygen	51169.1430	0.2076	1.637412576e+06	0.2312	1439.2558	0.1760
24	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
29	NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
33	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	Total	246519.6378	1.0000	7.081201561e+06	1.0000	8177.9485	1.0000
36	Vapour Phase						
37						Phase Fraction 1.000	
38	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
39							
40	H2O	2857.0521	0.0116	51470.0804	0.0073	51.5739	0.0063
41	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
42	Nitrogen	192493.4427	0.7808	5.392318905e+06	0.7615	6687.1188	0.8177
43	Oxygen	51169.1430	0.2076	1.637412576e+06	0.2312	1439.2558	0.1760
44	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
46	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
48	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
49	NO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
53	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
54	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	Total	246519.6378	1.0000	7.081201561e+06	1.0000	8177.9485	1.0000
56	Material Stream: Stack						
57					Fluid Package: CombustionTurbineProce		
58					Property Package: Peng-Robinson		
59	CONDITIONS						
60							
61			Overall	Vapour Phase			
62	Vapour / Phase Fraction		1.0000	1.0000			
63	Temperature: (C)		199.6	199.6			
64	Pressure: (bar)		1.013 *	1.013			
65	Aspen Technology Inc.		Aspen HYSYS Version 11			Page 13 of 16	

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: 500MWe_HydrogenTurbine_recuperated.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Wed Sep 27 09:15:46 2023				
4							
5					Fluid Package: CombustionTurbineProce		
6	Material Stream: Stack (continued)				Property Package: Peng-Robinson		
7							
8							
9	CONDITIONS						
10							
11		Overall	Vapour Phase				
12	Molar Flow (kgmole/h)	2.532e+005	2.532e+005				
13	Mass Flow (kg/s)	1974	1974				
14	Std Ideal Liq Vol Flow (m3/h)	8478	8478				
15	Molar Enthalpy (kJ/kgmole)	-9982	-9982				
16	Molar Entropy (kJ/kgmole-C)	168.9	168.9				
17	Heat Flow (MW)	-702.0	-702.0				
18	Liq Vol Flow @Std Cond (m3/h)	5.977e+006 *	5.977e+006				
19	COMPOSITION						
20							
21	Overall Phase						
22						Vapour Fraction 1.0000	
23	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
24							
25	H2O	16165.1670	0.0639	291217.1082	0.0410	291.8048	0.0344
26	Hydrogen	0.3486	0.0000	0.7027	0.0000	0.0101	0.0000
27	Nitrogen	192174.0963	0.7591	5.383373054e+06	0.7574	6676.0249	0.7874
28	Oxygen	44194.2520	0.1746	1.414216065e+06	0.1990	1243.0701	0.1466
29	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	N2O	0.0486	0.0000	2.1409	0.0000	0.0026	0.0000
33	NO2	3.0108	0.0000	138.5141	0.0000	0.0942	0.0000
34	NO	635.5847	0.0025	19071.3557	0.0027	267.3953	0.0315
35	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
37	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
38	H2O2	0.0060	0.0000	0.2053	0.0000	0.0001	0.0000
39	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	Total	253172.5141	1.0000	7.108019145e+06	1.0000	8478.4022	1.0000
41	Vapour Phase						
42						Phase Fraction 1.000	
43	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
44							
45	H2O	16165.1670	0.0639	291217.1082	0.0410	291.8048	0.0344
46	Hydrogen	0.3486	0.0000	0.7027	0.0000	0.0101	0.0000
47	Nitrogen	192174.0963	0.7591	5.383373054e+06	0.7574	6676.0249	0.7874
48	Oxygen	44194.2520	0.1746	1.414216065e+06	0.1990	1243.0701	0.1466
49	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	N2O	0.0486	0.0000	2.1409	0.0000	0.0026	0.0000
53	NO2	3.0108	0.0000	138.5141	0.0000	0.0942	0.0000
54	NO	635.5847	0.0025	19071.3557	0.0027	267.3953	0.0315
55	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
56	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
57	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
58	H2O2	0.0060	0.0000	0.2053	0.0000	0.0001	0.0000
59	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
60	Total	253172.5141	1.0000	7.108019145e+06	1.0000	8478.4022	1.0000
61							
62							
63							
64							
65	Aspen Technology Inc.		Aspen HYSYS Version 11			Page 14 of 16	

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA		Case Name: 500MWe_HydrogenTurbine_recuperated.hsc				
2			Unit Set: AmeyS2e				
3			Date/Time: Wed Sep 27 09:15:46 2023				
4							
5	Material Stream: AfterburnerCondensate					Fluid Package: CombustionTurbineProce	
6						Property Package: Peng-Robinson	
7	CONDITIONS						
8		Overall	Vapour Phase	Liquid Phase	Aqueous Phase		
9	Vapour / Phase Fraction	0.0000	0.0000	0.5000	0.5000		
10	Temperature: (C)	1400	1400	1400	1400		
11	Pressure: (bar)	2.730	2.730	2.730	2.730		
12	Molar Flow (kgmole/h)	0.0000	0.0000	0.0000	0.0000		
13	Mass Flow (kg/s)	0.0000	0.0000	0.0000	0.0000		
14	Std Ideal Liq Vol Flow (m3/h)	0.0000	0.0000	0.0000	0.0000		
15	Molar Enthalpy (kJ/kgmole)	3.049e+004	3.049e+004	3.049e+004	3.049e+004		
16	Molar Entropy (kJ/kgmole-C)	202.5	202.5	202.5	202.5		
17	Heat Flow (MW)	0.0000	0.0000	0.0000	0.0000		
18	Liq Vol Flow @Std Cond (m3/h)	0.0000 *	0.0000	0.0000	0.0000		
19	COMPOSITION						
20	Overall Phase					Vapour Fraction 0.0000	
21	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	
22						LIQUID VOLUME FRACTION	
23	H2O	0.0000	0.0639	0.0000	0.0410	0.0000	0.0344
24	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	Nitrogen	0.0000	0.7591	0.0000	0.7574	0.0000	0.7874
26	Oxygen	0.0000	0.1746	0.0000	0.1990	0.0000	0.1466
27	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
29	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	NO	0.0000	0.0025	0.0000	0.0027	0.0000	0.0315
33	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
35	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
36	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
37	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
38	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
39	Vapour Phase					Phase Fraction 0.0000	
40	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
41	H2O	0.0000	0.0639	0.0000	0.0410	0.0000	0.0344
42	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	Nitrogen	0.0000	0.7591	0.0000	0.7574	0.0000	0.7874
44	Oxygen	0.0000	0.1746	0.0000	0.1990	0.0000	0.1466
45	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
46	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
48	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
49	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	NO	0.0000	0.0025	0.0000	0.0027	0.0000	0.0315
51	SO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
53	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
54	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
56	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
57	Aspen Technology Inc. Aspen HYSYS Version 11 Page 15 of 16						

1	 BATTELLE ENERGY ALLIANCE Bedford, MA USA			Case Name: 500MWe_HydrogenTurbine_recuperated.hsc																																																																																																																										
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COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION																																																																																																																								
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COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION																																																																																																																								
35	H2O	0.0000	0.0639	0.0000	0.0410	0.0000																																																																																																																								
36	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000																																																																																																																								
37	Nitrogen	0.0000	0.7591	0.0000	0.7574	0.0000																																																																																																																								
38	Oxygen	0.0000	0.1746	0.0000	0.1990	0.0000																																																																																																																								
39	Methane	0.0000	0.0000	0.0000	0.0000	0.0000																																																																																																																								
40	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000																																																																																																																								
41	CO2	0.0000	0.0000	0.0000	0.0000	0.0000																																																																																																																								
42	N2O	0.0000	0.0000	0.0000	0.0000	0.0000																																																																																																																								
43	NO2	0.0000	0.0000	0.0000	0.0000	0.0000																																																																																																																								
44	NO	0.0000	0.0025	0.0000	0.0027	0.0000																																																																																																																								
45	SO2	0.0000	0.0000	0.0000	0.0000	0.0000																																																																																																																								
46	H2S	0.0000	0.0000	0.0000	0.0000	0.0000																																																																																																																								
47	CO	0.0000	0.0000	0.0000	0.0000	0.0000																																																																																																																								
48	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000																																																																																																																								
49	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000																																																																																																																								
50	Total	0.0000	1.0000	0.0000	1.0000	0.0000																																																																																																																								
51	Energy Stream: GrossPower			Fluid Package: CombustionTurbineProce																																																																																																																										
52				Property Package: Peng-Robinson																																																																																																																										
53	CONDITIONS																																																																																																																													
54	Duty Type: Direct Q		Duty Calculation Operation: Turbine																																																																																																																											
55	Duty SP: 766.0 MW		Minimum Available Duty: 0.0000 MW		Maximum Available Duty: ---																																																																																																																									
56	Energy Stream: PowerLoss			Fluid Package: CombustionTurbineProce																																																																																																																										
57				Property Package: Peng-Robinson																																																																																																																										
58	CONDITIONS																																																																																																																													
59	Duty Type: Direct Q		Duty Calculation Operation: Compressor																																																																																																																											
60	Duty SP: 266.0 MW		Minimum Available Duty: 0.0000 MW		Maximum Available Duty: ---																																																																																																																									
61	Aspen Technology Inc. Aspen HYSYS Version 11 Page 16 of 16																																																																																																																													