INL/RPT-24-77659

Light Water Reactor Sustainability Program

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



April 2024

U.S. Department of Energy Office of Nuclear Energy

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INL/RPT-24-77659 Revision 0

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

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April 2024

Prepared for the U.S. Department of Energy Office of Nuclear Energy Light Water Reactor Sustainability Program

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.





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.





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 lightwater reactor (LWR) nuclear power plants (NPPs) by researching potential ways of increasing and diversifying their revenue, often by investigating energy-storage systems (ESS) and chemical processes that use nuclear heat and electricity, especially in a way that accommodates versatility. In this study, a novel hybrid thermal/electrochemical engine, invented at Sandia National Laboratories (SNL), is analyzed at the engineering scale. The process has the potential to use nuclear power to split water, yielding hydrogen and recoverable high-grade process heat [**Error! Reference source not found.**].

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

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

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



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 metalredox 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 processflow diagram (PFD) in Figure 2. Detailed discussion of heat integration, particularly as it pertains to generating the superheated steam that oxidizes the zinc, is included in Section 2.3.



Figure 2. Simplified hydrogen-production PFD.

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

2.2 Thermodynamic Analysis

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

2.2.1 Ideal Thermodynamics

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



Figure 3. Thermodynamic-equilibrium data from FactSage calculations.

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

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

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

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

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

2.2.2 Practical Thermodynamics

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



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

2.3 Process Modeling

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

The stream tables from the model, described in detail below and depicted in Figure 5, are included in Appendix A. The model shows that hydrogen production via the redox cycle requires 49.8 kWh-e AC/kg-H₂, with 10.2 kWh-th/kg-H₂ of high-grade heat that is recoverable for chemical process integration during continuous operation.

2.3.1 Reaction Modeling

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

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



Figure 5. PFD of the hydrogen production model.

2.3.1.1 Thermal Oxidation

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

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

Stream		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

Table 1. Thermal oxidation reactor results.

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 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:

$$\Delta \mathbf{h}_{\mathrm{r}}(T_{in})\xi = (T_{out} - T_{in})\sum_{i} \dot{n}_{i}^{out}c_{i}$$

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 oxidealloy 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:

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

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

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



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

2.3.1.2 Electrochemical Reduction

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

$$ZnO + 2e^- \rightarrow Zn + \frac{1}{2}O_2$$

Stream		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

Table 2. Electrochemical reduction reactor results.

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

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

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

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

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

3. *Regenerated-alloy cooling*. The same sensible-heat-transfer method as above was employed to cool the regenerated alloy to 450°C so it can be recycled to the thermal-oxidation reactor. This heat is used to preheat a sweep-air stream. The sweep-air flow rate is selected to dilute the overhead product to 40 mol% oxygen. The sweep air leaving the preheater is warmed to 273°C, and the overhead product is 330°C. The heat in this oxygen-rich air is used to boil feedwater and exhausted. This system does not readily allow for a steam sweep to be used to later isolate the oxygen product; however, if it is desirable to use the oxygen for oxy-firing, a 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 oxygenrich exhaust can boil the feedwater with a 5°C minimum approach, cooling each overhead stream to 106°C with duties of 12.7 and 19.4 MW, respectively. As Figure 7 depicts, the remaining 24.1 MW is supplied by LWR steam. Saturated steam at 140.5°C and 3.366 bar is assumed to be extracted from the low-pressure turbine of the associated NPP with a flow rate of 11.1 kg/s and condensed with 4°C of subcooling along 2% nominal pressure drop.

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

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



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

2.4 Levelized Cost of Hydrogen

2.4.1 Technoeconomic Analysis

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

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

- 25-year capital lifetime
- Installed capital cost of \$435/kW
- Electricity cost of \$30/MWh-e
- Heat cost of \$10/MWh-th
- Electricity consumption of 50 kWh/kg-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 halfreactions 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 redoxflow 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 metalmetal/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.

·	Temperature	ΔH of reaction	ΔG of reaction
Reaction	(°C)	(kJ/mol)	(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

Table 3. Hybrid electrochemical heat-pump cycle reactions.

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	Heat Delivered			
(kJ/mol)	(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.
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Net Work	Heat Delivered	Heat Absorbed		
(kJ/mol)	(kJ/mol)	(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.





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 $7\phi/kg$.



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

4.3 Levelized Cost of Thermal-Energy Storage

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



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

This ESS is charged by electricity and outputs combustion-grade heat. Given the specific electricity consumption of 49.8 kWh-e AC/kg-H₂ and assuming a 95% stack efficiency on an LHV basis with the recoverable process heat (10.2 kWh-th/kg-H₂) used for combustion air preheating, an 83% AC-to-thermal RTE can be calculated. This, along with the following assumptions, was used to calculate a non-electric LCOS.

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

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



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



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

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

5.2 Conclusions

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

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

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

- Hydrogen production via the redox cycle requires 49.8 kWh-e AC/kg-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 $1.82/kg H_2$ and at best may be as low as 1.62/kg.
- The process has the greatest sensitivity to feedstock (e.g., DC power) consumption

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

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

Using the process for energy arbitrage:

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

			-			Case Name:	Proc	duction.hsc		
3	(e)aspentech	Bedford, M	A	SY ALLIANCE		Unit Set:	Ame	eyS2e		
4		USA				Date/Time:	Fri M	Mar 29 15:06:27 2024		
6 7 8	Mater	ial Strea	am:	Steam				Fi	uid Package: St operty Package: NB	eam 3S Steam
9					c	CONDITIONS				
10				Quarall	1	annur Dhasa				
12	Vanour / Phase Fraction			1 0000	v	1 0000	-			
13	Temperature:	(C)		450.0 *		450.0	-			
14	Pressure:	(bar)		1.013 *		1.013				
15	Molar Flow	(kgmole/h)		4985		4985				
16	Mass Flow	(ka/s)		24.94		24,94				
17	Std Ideal Lig Vol Flow	(m3/h)		89.98		89.98				
18	Molar Enthalpy	(kJ/kgmole)		-2.259e+005		-2.259e+005				
19	Molar Entropy (kJ/kgmole-C)	156.5			156.5				
20	Heat Flow	(MW)	-312.8			-312.8				
21	Liq Vol Flow @Std Cond	(m3/h)		89.88 *		89.88				
22 23					С	OMPOSITION				
24 25			0	verall Phase			Vapour F	raction 1.0000		
26 27	COMPONENTS MOLAR FLOW MOLE FRACTI (kgmole/h)				ION	MASS FLOW (kg/b)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME
28	H20	4984	5660 *	1.0	• 000	89797 457	75 •	1.0000	89.9787	1,0000 *
29	H2O 4984 Total 4984		5660	1.0	000	89797.457	75 1.0000		89.9787	1,0000
30	30				V	apour Phase	-		Phase Fr	action 1.000
32	COMPONENTS MOLAR FLOW MOLE FRAC (kompole(h))			MOLE FRACTI	ION	MASS FLOW		MASS FRACTION	LIQUID VOLUME FLOW (m3/b)	LIQUID VOLUME FRACTION
34	H20	4984	5660	1.0	000	89797.457	75	1.0000	89.9787	1,0000
35	Total	4984	5660	1.0	000	89797.457	75	1.0000	89,9787	1,0000
38 37 38	Mater	ial Strea	am:	Alloy				Fli	uid Package: Re operty Package: As	eaction open Properties (Solids)
39 40					0	CONDITIONS				
41				Overall	1	liquid Phase				
42	Vapour / Phase Fraction			0.0000		1.0000	-			
43	Temperature:	(C)	_	450.0 *		450.0				
44	Pressure:	(bar)	_	1.013 *		1.013	-			
45	Molar Flow	(kgmole/n)	-	3.988e+004 *		3.988e+004				
48	Mass Flow	(kg/s)	_	1241		1241	_			
47	Std loeal Lig Vol Flow	(m3/n)	-	6826		6826	_			
48	Molar Entrary	(KJ/Kgmole)	-	1.0500+004		1.6508+004	-			
49	Heat Flow	(MAA)		40.85		40.85	_			
51	Lig Vol Flow @Std Cond	(IVIVV) (m2(h)	-	205.0		205.0	-			
52	Eld voi Flow @Sta Colid	(main)		3,4036+103	-	3.4056+105	_			
53					C	OMPOSITION				
54	3 4 (5)		0	verall Phase			Vapour F	raction 0.0000		
56	COMPONENTS	MOLAR FL	WC	MOLE FRACTI	ION	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME
58	Zinc	4984	5660 *	0.1	250 *	325940 771	14 .	0.0730	46 9437 *	. 6900 0
59	Zinc-Oxide	0	0000 *	0.0	000 *	0.000	00 *	0.0000	0.0000 *	0.0000 *
60	Nitrogen	0	0000 *	0.0	000 *	0.000	00 .	0.0000	0.0000 *	0.0000 *
61	Oxygen	0	0000 *	0.0	000 *	0.000	00 .	0.0000	0.0000 *	0.0000 *
62	Water	0.	0000 *	0.0	000 *	0.000	00 *	0.0000	0.0000 *	0.0000 *
63	Aspen Technology Inc.			Aspen HYSYS Version				1		Page 1 of 20
	internet and the		1.1							

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1						Case Name: Production.hsc						
3	(aspentech	BATTELLE Bedford, M	ENER(SY ALLIANCE		Unit Set:	Ame	eyS2e				
4		USA				Date/Time:	Fri M	Mar 29 15:06:27 2024				
6 7 8	Mater	ial Stre	am:	Alloy (d	con	tinued)		Fluid	d Package: Re perty Package: As	eaction pen Propertie	es (Solids)	
9					с	OMPOSITION						
11				Ov	erall	Phase (contin	ue	d)	Vapour F	raction	0.0000	
12	COMPONENTS	MOLAR EL	ow	MOLE ERACT	ION	MASSELOW		MASS FRACTION			OLUME	
14		(kgmole/	h)	more rivior		(kg/h)			FLOW (m3/h)	FRACT	ION	
15	Tin-White	34891	.9621 *	0.8	750 *	4.142024817e+0	6 '	0.9270 *	6778.9151 *		0.9931 *	
18	Hydrogen	0	* 0000	0.0	000 *	0.000	0.	• 0000.0	0.0000 *		0.0000 *	
17	lotal	39876	.5281	1.0	000	4_46/965589e+0	6	1.0000	6825.8588		1.0000	
19		<u></u>			L	Liquid Phase			Phase Fr	action	1.000	
20 21	COMPONENTS	MOLAR FL (kgmole/	OW h)	MOLE FRACTION		MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VO	OLUME	
22	Zinc	4984	.5660	0.1	250	325940.771	4	0.0730	46.9437		0.0069	
23	Zinc-Oxide	0	.0000	0.0	000	0.000	0	0.0000	0.0000		0.0000	
24	Nitrogen	0	.0000	0.0	000	0.000	0	0.0000	0.0000		0.0000	
25	Oxygen	0	.0000	0.0	000	0.000	0	0.0000	0.0000		0.0000	
20	Water Tio White	24904	.0000	0.0	750	0.000	0	0.0000	0.0000		0.0000	
28	Hydrogen	34091	0000	0.0	000	4.142024017640	0	0.0000	0.0000		0.0000	
29	Total 39876.5281		5281	1.0	000	4.467965589e+0	6	1.0000	6825.8588		1.0000	
32 33 34					(CONDITIONS		Ploy	City Fackage. A	pen Properae	5 (50ids)	
35				Overall		Liquid Phase						
38	Vapour / Phase Fraction			0.0000		1.0000						
37	Temperature:	(C)		550.0 *		550.0						
30	Molar Flow	(komole/h)		3.988e+004		1.013						
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						
48	Liq voi Flow @Sta Cond	(m3/n)		3.4898+109		3.469e+109						
47					С	OMPOSITION						
48 49					0	verall Phase			Vapour F	raction	0.0000	
50 51	COMPONENTS	MOLAR FL (kgmole/	OW h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VO	OLUME	
52	Zinc	0	.0000	0.0	000	0.000	0	0.0000	0.0000		0.0000	
53	Zinc-Oxide	4984	.5660	0.1	250	405690.832	0	0.0892	968.4164		0.1250	
54	Nitrogen	0	.0000	0.0	000	0.000	0	0.0000	0.0000		0.0000	
55	Oxygen	0	.0000	0.0	000	0.000	0	0.0000	0.0000		0.0000	
56	Water Tip White	24904	.0000	0.0	740	0.000	0	0.0000	0.0000		0.0000	
58	Hydrogen	34091	8012	0.8	001	4.142024015840	8	0.0000	0//0.9151		0.0000	
59	Total	39879	3292	1.0	000	4.547721294e+0	6	1.0000	7747.4815		1.0000	
eo e1 e2 e3 Aspen Technology Inc. Aspen Licensed to PATTELE ENERGY ALLIANCE					spen	HYSYS Version	12.	1		Page	2 of 20	

<u> </u>							_			
1			Case Name: Production.hsc							
3	(aspentech	Bedford, M	A	ST ALLIANCE		Unit Set:	Am	eyS2e		
4		USA				Date/Time:	Fri I	Mar 29 15:06:27 2024		
6 7 8	Mater	ial Stre	am:	OxAllo	y (d	continue	d)	Flui Pro	d Package: Re perty Package: As	action pen Properties (Solids)
9 10					С	OMPOSITION	í.			
11					L	iquid Phase			Phase Fra	action 1.000
13	COMPONENTS	MOLAR FL (kamole/	OW h)	MOLE FRACTI	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
15	Zinc	0	0000	0.0	000	0.00	00	0.0000	0.0000	0.0000
18	Zinc-Ovide	4984	5660	0.1250		405690.83	20	0.0892	968 4164	0.1250
17	Nitronen	4304	0000	0,1250		0.00	00	0.0002	0.0000	0.0000
10	Owner	0	0000	0,0	000	0.00	00	0.0000	0.0000	0.0000
10	Oxygen	0	0000	0.0	000	0.00	00	0.0000	0.0000	0.0000
19	water		.0000	0.0	000	0.00	00	0.0000	0.0000	0.0000
20	Tin-White	34891	.9621	0.8	749	4.142024815e+	06	0.9108	6778.9151	0.8750
21	Hydrogen	2	.8012	0.0	001	5.64	68	0.0000	0.1500	0.0000
22	Total 39879.3292		.3292	1.0	000	4.547721294e+	06	1.0000	7747.4815	1.0000
23 24 25	Material Stream			AlloyRe	ecy	cle		Flui Pro	d Package: Re perty Package: As	action pen Properties (Solids)
26 27				(CONDITIONS					
28				Overall		Liquid Phase				
29	Vapour / Phase Fraction			0.0000		1.0000				
30	Temperature:	(C)		450.0 *		450.0				
31	Pressure:	(bar)		1.013		1.013				
32	Molar Flow	(kgmole/h)		3.988e+004		3.988e+004				
33	Mass Flow	(kg/s)		1241		1241				
34	Std Ideal Lig Vol Flow	(m3/h)		6826		6826				
35	Molar Enthalov	(k.l/komole)		1.854e+004		1.854e+004				
36	Molar Entropy (k.l/komole-C)		40.90		40.90	-			
37	Heat Flow	(MW)		205.4		205.4				
38	Lig Vol Flow @Std Cond	(m3/b)		3.489e+109 *		3.489e+109				
20	Eld voi i low @Sta Colla	(((13(1))		3.40364103		3.4696+109				
40					С	OMPOSITION				
41					C	overall Phase	_		Vapour Fr	action 0.0000
43	COMPONENTS	MOLAR FL	WO	MOLE FRACT	ON	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME
44		(kgmole/	h)			(kg/h)			FLOW (m3/h)	FRACTION
45	Zinc	4984	.0500	0.1	250	325907.02	67	0.0729	46.9388	0.0069
46	Zinc-Oxide	0	.0000	0.0	000	0.00	00	0.0000	0.0000	0.0000
47	Nitrogen	0	.0000	0.0	000	0.00	00	0.0000	0.0000	0.0000
48	Oxygen	8	.3226	0.0	002	266.31	36	0.0001	0.4457	0.0001
49	Water	0	.0000	0.0	000	0.00	00	0.0000	0.0000	0.0000
50	Tin-White	34891	.9621	0.8	748	4.142024815e+	06	0.9270	6778.9151	0.9931
51	Hydrogen	0	.0032	0.0	000	0.00	64	0.0000	0.0002	0.0000
52	Total	39884	.3378	1.0	000	4.468198162e+	06	1.0000	6826.2998	1.0000
53 54					L	iquid Phase			Phase Fra	action 1.000
55 58	COMPONENTS	MOLAR FL (kamole/	OW h)	MOLE FRACTI	ON	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
57	Zinc	4984	0500	0.1	250	325907.02	67	0.0729	46.9388	0.0069
58	Zinc-Oxide	0	0000	0.0	000	0.00	00	0.0000	0.000	0,0000
59	Nitrogen	0	0000	0.0	000	0.00	00	0.0000	0.0000	0.0000
60	Oxygen	9	3226	0.0	002	266.24	36	0.0001	0.4457	0.0001
81	Water	0	0000	0.0	000	0.00	00	0.0001	0.0000	0.0001
82	Tin-White	24804	9621	0.0	748	4 1420248150	06	0.000	6778 0154	0.000
63	Aspen Technology Inc	04031		0.0	spen	HYSYS Version	112	1	0110.0131	Page 3 of 20
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1		-		Case Name: Production.hsc							
2	(aspentech	BATTELLE ENE Bedford, MA	RGY ALLIANCE	Unit	Set: An	neyS2e					
4	0.	USA		Date	/Time: Fri	Mar 29 15:06:27 20	24				
6 7 8	Mater	ial Stream	: AlloyRe	ecycle	e (contin	nued)	Fluid Package: Property Package:	Reaction Aspen Properties (Solids)			
9				COM	POSITION						
11			Lic	uid Pha	se (continue	d)	Phase	Fraction 1.000			
12	COMPONENTS	MOLAR FLOW	MOLE FRACT	ION I	MASS FLOW	MASS FRACTIO	N LIQUID VOLUM	E LIQUID VOLUME			
14	Distance	(kgmole/h)		000	(kg/h)	0.000	FLOW (m3/h)	FRACTION			
15	Total	39884 3378	10	000 44	0.0064 68198162e+06	1.000	0.000	0.0000			
17 18 19	Mater	ial Stream	: H2-2		001001020100	1 1.00	Fluid Package: Property Package:	Overheads Aspen Properties (Peng-F			
20				DITIONS							
22			Overall	Vapou	r Phase	Liquid Phase					
23	Vapour / Phase Fraction		1.0000		1.0000	0.0000					
24	Temperature:	(C)	106.1		106.1	106.1					
25	Pressure:	(bar)	0.9731	-	0.9731	0.9731					
20	Mass Flow	(kg/s)	2 790		2 790	1 195e-006					
28	Std Ideal Lig Vol Flow	(m3/h)	266.8		266.8	1.027e-005					
29	Molar Enthalpy	(kJ/kgmole)	2353		2353	-2.205e+005					
30	Molar Entropy (I	kJ/kgmole-C)	7.310		7.310	4.743					
31	Heat Flow	(MW)	3.256		3.256	-3.237e-006					
32	Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6	.222e+063	2.650e+063					
34				COM	POSITION						
35				Overa	all Phase		Vapou	r Fraction 1.0000			
37 38	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTI	ION I	MASS FLOW (kg/h)	MASS FRACTIO	N LIQUID VOLUM FLOW (m3/h)	E LIQUID VOLUME FRACTION			
39	Zinc	0.0000	0.0	000	0.0000	0.000	0.000	0000.0 00			
40	Zinc-Oxide	0.0001	0.0	000	0.0048	0.000	00.00	0000.0			
41	Nitrogen	0.0000	0.0	000	0.0000	0.000	00.000	0000.0			
42	Oxygen	0.0000	0.0	000	0.0000	0.000	0.000	0.0000			
43	Tin_White	0.0000	0.0	000	0.0000	0.000	0.000	0.0000			
45	Hydrogen	4981.7648	1.0	000	10042,6401	1.000	266.812	24 1.0000			
46	Total	4981.7649	1.0	000	10042.6468	1.000	266.812	1.0000			
47				Vapo	ur Phase		Phase	Fraction 1.000			
49 50	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTI	ION I	MASS FLOW (kg/h)	MASS FRACTIO	N LIQUID VOLUM FLOW (m3/h)	E LIQUID VOLUME FRACTION			
51	Zinc	0.0000	0.0	000	0.0000	0.000	00.00	0.0000 00			
52	Zinc-Oxide	0.0000	0.0	000	0.0005	0.000	00.00	0000.0000			
53	Nitrogen	0.0000	0.0	000	0.0000	0.000	00.000	0000.0			
55	Uxygen Water	0.0000	0.0	000	0.0000	0.000	0.000	0.0000			
58	Tin-White	0.0000	0.0	000	0.0000	0.000	0.000	0.0000			
57	Hydrogen	4981.7648	1.0	000	10042.6401	1.000	266.812	24 1.0000			
58	Total	4981.7649	1.0	000	10042.6425	1.000	266.812	1.0000			
59 60 61 62 63	Aspen Technology Inc.		A	spen HYS	YS Version 12	2.1		Page 4 of 20			
	Licensed to: BATTELLE ENERG	GY ALLIANCE						* Specified by user.			

1		Case Name: Production.hsc										
3	(e)aspentech	BATTELLE Bedford, M	ENERO IA	SY ALLIANCE		Unit Set:	Ame	eyS2e				
4		USA				Date/Time:	Fri I	Mar 29 15:06:27 2024				
6 7 8	Mater	ial Stre	am:	H2-2 (c	on	tinued)		Flui Pro	d Package: Ov perty Package: As	erheads pen Properties (Peng-R		
9					С	OMPOSITION						
11					L	iquid Phase			Phase Fraction 1.061e-008			
13	COMPONENTS	MOLAR FL	OW b)	MOLE FRACTI	ION	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME		
15	Zinc	0	.0000	0.0000		0.000	00	0.0000	0.0000	0.0000		
16	Zinc-Oxide	0	.0001	0.9998		0.004	43	1.0000	0.0000	1.0000		
17	Nitrogen	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
18	Oxygen	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
19	Water	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
20	Tin-White	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
21	Hydrogen	0	.0000	0.0	001	0.000	00	0.0000	0.0000	0.0000		
22	Total	0	.0001	1.0	000	0.004	43	1.0000	0.0000	1.0000		
23 24 25	Material Stream		am:	Exhaus	st			Flui Pro	d Package: Ov perty Package: As	erheads pen Properties (Peng-R		
28 27	5				0	CONDITIONS						
28				Overall	V	/apour Phase		Liquid Phase				
29	Vapour / Phase Fraction			1.0000	_	1.0000		0.0000				
30	Temperature:	(C)		106.1		106.1		106.1				
31	Pressure:	(bar)		0.9930		0.9930		0.9930				
32	Molar Flow	(kgmole/h)		1.032e+004		1.032e+004		0.5160				
33	Mass Flow	(kg/s)		84.88		84.87		9.372e-003				
34	Std Ideal Liq Vol Flow	(m3/h)		552.8		552.8		4.860e-003				
35	Molar Enthalpy	(kJ/kgmole)		2373	2375			-4.719e+004				
38	Molar Entropy (kJ/kgmole-C)		12.83		12.83		-25.51				
37	Heat Flow	(MW)		6.803		6.810		-6.764e-003				
38	Liq Vol Flow @Std Cond	(m3/h)		858.4 *		858.4		4.930e-003				
39 40				COMPOSITION								
41 42					0	verall Phase			Vapour Fr	action 1.0000		
43 44	COMPONENTS	MOLAR FL	OW h)	MOLE FRACTI	ION	MASS FLOW		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	ERACTION		
45	Zinc	0	5160	0.0	000	33.74	08	0.0001	0.0049	0.0000		
48	Zinc-Oxide	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
47	Nitrogen	6189	5823	0.5	996	173391.740	02	0.5674	331,5004	0.5997		
48	Oxygen	4129	2924	0.4	000	132132.400	06	0.4324	221,1558	0.4001		
49	Water	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
50	Tin-White	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
51	Hydrogen	2	7980	0.0	003	5.640	05	0.0000	0.1499	0.0003		
52	Total	10322	1887	1.0	000	305563.522	21	1.0000	552,8109	1.0000		
53					v	apour Phase			Phase Fra	action 1.000		
04 55	COMPONENTS	MOLAR FL	w	MOLE FRACTI	ION	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME		
58		(kgmole/	h)			(kg/h)	_		FLOW (m3/h)	FRACTION		
57	Zinc	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
58	Zinc-Oxide	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
59	Nitrogen	6189	.5823	0.5	997	173391.740	02	0.5675	331.5004	0.5997		
60	Oxygen	4129	.2924	0.4	001	132132.400	06	0.4325	221.1558	0.4001		
61	Water	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
62	Tin-White	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
63	Aspen Technology Inc			As	spen	HYSYS Version	112.	.1		Page 5 of 20		

1				Case Name: Production.hsc						
3	(aspentech	BATTELLE ENER Bedford, MA	GY ALLIANCE	Unit Set: An	neyS2e					
4		USA		Date/Time: Fri	Mar 29 15:06:27 2024					
6 7 8	Mater	rial Stream	Exhaust	(continued)	Flui Pro	d Package: Ov perty Package: As	erheads pen Properties (Peng-R			
9				COMPOSITION						
11			Vapo	our Phase (continue	ed)	Phase Fra	action 1.000			
12	COMPONENTS	MOLAR FLOW	MOLE FRACTIO	N MASS FLOW	MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME			
14		(kgmole/h)		(kg/h)		FLOW (m3/h)	FRACTION			
15	Hydrogen	2.7980	0.000	3 5.6405	0.0000	0.1499	0.0003			
16	Total	10321.6727	1.000	0 305529.7813	1.0000	552.8061	1.0000			
18				Liquid Phase		Phase Fra	action 4.999e-005			
19 20	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTIO	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION			
21	Zinc	0.5160	1.000	0 33.7408	1.0000	0.0049	1.0000			
22	Zinc-Oxide	0.0000	0.000	0 0.0000	0.0000	0.0000	0.0000			
23	Nitrogen	0.0000	0.000	0.0000	0.0000	0.0000	0.0000			
24	Oxygen	0.0000	0.000	0 0.0000	0.0000	0.0000	0.0000			
25	Water Tin White	0.0000	0.000	0 0.0000	0.0000	0.0000	0.0000			
27	Hydrogen	0.0000	0.000	0 0.0000	0.0000	0.0000	0.0000			
28	Total 0.5160		1.000	0 33.7408	1.0000	0.0049	1.0000			
31 32 33				CONDITIONS	Pro	perty Package: As	pen Properties (Peng-R			
34			Overall	Vapour Phase	Liquid Phase					
35	Vapour / Phase Fraction		1.0000	1.0000	0.0000					
36	Temperature:	(C)	40.00	40.00	40.00					
3/	Molar Flow	(bar)	44.40	44.40	6.027e-005					
39	Mass Flow	(kg/s)	2,790	2.790	1.359e-006					
40	Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8	1.166e-005					
41	Molar Enthalpy	(kJ/kgmole)	462.8	462.8	-2.189e+005					
42	Molar Entropy	(kJ/kgmole-C)	-30.09	-30.09	-6.628					
43	Heat Flow	(MW)	0.6404	0.6404	-3.665e-006					
44 45 48	Liq Vol Flow @Std Cond	(m3/n)	6.222e+063 *	COMPOSITION	1.875e+070					
47				Overall Phase		Vapour Fr	action 1.0000			
49 50	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTIO	N MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION			
51	Zinc	0.0000	0.000	0 0.0000	0.0000	0.0000	0.0000			
52	Zinc-Oxide	0.0001	0.000	0 0.0048	0.0000	0.0000	0.0000			
53	Nitrogen	0.0000	0.000	0 0.0000	0.0000	0.0000	0.0000			
54	Oxygen	0.0000	0.000	0 0.0000	0.0000	0.0000	0.0000			
50	Tip White	0.0000	0.000	0.0000	0.0000	0.0000	0.0000			
57	Hydrogen	4981,7648	1,000	0 10042.6401	1,0000	266.8124	1,0000			
58	Total	4981.7649	1.000	0 10042.6468	1.0000	266.8124	1.0000			
59 60 61 62 63	Aspen Technology Inc		Asp	en HYSYS Version 12	2.1		Page 6 of 20			
	Licensed to: BATTELLE ENER	GY ALLIANCE					* Specified by user.			

1					Case Name: Production.hsc						
3	(aspentech	BATTELLE Bedford, N		SY ALLIANCE		Unit Set:	Am	eyS2e			
4	<u> </u>	USA				Date/Time:	Fri I	Mar 29 15:06:27 2024			
6 7 8	Mater	rial Stre	am:	Hydrog	jen	Product	(c	ontinuec Pro	d Package: Ove	erheads pen Properties (Peng-R	
9					с	OMPOSITION					
11					v	apour Phase			Phase Fra	ction 1.000	
13 14	COMPONENTS	MOLAR FL (kgmole/	OW h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	FRACTION	
15	Zinc	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000	
18	Zinc-Oxide	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000	
17	Nitrogen	0	0000.	0.0	000	0.000	00	0.0000	0.0000	0.0000	
18	Oxygen 0.000		.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000	
19	Water	Water 0.000		0.0	000	0.000	00	0.0000	0.0000	0.0000	
20	Tin-White	0	.0000	0.0	000	0.001	18	0.0000	0.0000	0.0000	
21	Hydrogen 4981.		.7648	1.0	000	10042.640	01	1.0000	266.8124	1.0000	
22	Total 4981.764		.7648	1.0	000	10042.641	19	1.0000	266.8124	1.0000	
23 24			L	iquid Phase			Phase Fra	ction 1.210e-008			
25 28	COMPONENTS MOLAR FLOW (kgmole/h)		OW h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
27	Zinc	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000	
28	Zinc-Oxide	0	.0001	0.9	874	0.004	48	0.9897	0.0000	0.9915	
29	Nitrogen 0.0000		.0000	0.0000		0.000	00	0.0000	0.0000	0.0000	
30	Oxygen	0.0000		0.0000		000.0 000		0.0000	0.0000	0.0000	
31	Water	0.0000		0.0	000	0.000	00	0.0000	0.0000	0.0000	
32	Tin-White	0	.0000	0.0	069	0.000	00	0.0101	0.0000	0.0070	
33	Hydrogen	0	.0000	0.0	057	0.000	00	0.0001	0.0000	0.0016	
34	Total	0	.0001	1.0	000	0.004	49	1.0000	0.0000	1.0000	
35 38	Mater	rial Stre	am:	O2Rich	n Aiı	r		Flui	d Package: Ove	erheads	
37					(CONDITIONS			,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,		
39				Overall	V	apour Phase		Liquid Phase			
41	Vapour / Phase Fraction			1.0000		1.0000		0.0000			
42	Temperature:	(C)		330.2		330.2		330.2			
43	Pressure:	(bar)		1.013		1.013		1.013			
44	Molar Flow	(kgmole/h)		1.032e+004		1.032e+004		0.5159			
45	Mass Flow	(kg/s)		84.88		84.87		9.370e-003			
46	Std Ideal Liq Vol Flow	(m3/h)		552.8		552.8		4.858e-003			
47	Molar Enthalpy	(kJ/kgmole)		9132		9134		-3.636e+004			
48	Molar Entropy	(kJ/kgmole-C)		26.64		26.64		-2.978			
49	Heat Flow	(MW)		26.18		26.19		-5.210e-003			
50	Liq Vol Flow @Std Cond	(m3/h)		858.4 *		858.4		4.929e-003			
51 52					c	OMPOSITION					
53					0	verall Phase			Vapour Fra	action 1.0000	
55	COMPONENTS	MOLAR FL	ow	MOLE FRACT	ION	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME	
56		(kgmole/	h)			(kg/h)			FLOW (m3/h)	FRACTION	
57	Zinc	0	5160	0.0	000	33.740	80	0.0001	0.0049	0.0000	
58	Zinc-Oxide	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000	
59	Nitrogen	6189	.5823	0.5	996	173391.740	02	0.5674	331.5004	0.5997	
60	Oxygen	4129	.2924	0.4	000	132132.400	06	0.4324	221.1558	0.4001	
61	Water	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000	
62	Tin-White	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000	
63	Aspen Technology Inc.			A	spen HYSYS Version 12.1 Page 7 of 2						

1			Case Name: Production.hsc							
2	() aspentech	BATTELLE ENE Bedford MA	RGY ALLIANCE		Unit Sat	Ame	av 52a			
4	Gaspenteen	USA USA			Unit Set.	Ann	59326			
5					Date/Time:	Fn	Mar 29 15:06:27 2024			
6 7 8	Mate	rial Stream	: O2Rich	nAir	(continu	le	d) Flui Pro	id Package: Ov perty Package: As	verheads pen Properties (Peng-R	
9				C	OMPOSITION					
10										
12			Ov	erall	Phase (contin	nue	d)	Vapour Fr	raction 1.0000	
13 14	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
15	Hydrogen	2.7980	0.0	003	5.640	05	0.0000	0.1499	0.0003	
16	Total	10322.1887	1.0	000	305563.523	21	1.0000	552.8109	1.0000	
17				V	Vapour Phase			Phase Fra	action 1.000	
19	COMPONENTS	MOLAR FLOW	MOLE FRACT	ION	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME	
21	Zinc	0.0001	0.0	000	0.00	92	0.0000	0.0000	0.0000	
22	Zinc-Oxide	0.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000	
23	Nitrogen	6189.5823	0.5	997	173391.740	02	0.5675	331.5004	0.5997	
24	Oxygen	4129.2924	0.4	001	132132.400	06	0.4325	221.1558	0.4001	
25	Water	0.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000	
28	Tin-White	0.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000	
27	Hydrogen	2.7980	0.0	003	5.64	05	0.0000	0.1499	0.0003	
28	Total 1032		1.0	000	305529.790	05	1.0000	552.8061	1.0000	
29			L	iquid Phase			Phase Fra	action 4.998e-005		
31	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
33	Zinc	0.5159	1.0	000	33.73	16	1.0000	0.0049	1.0000	
34	Zinc-Oxide	0.0000	0,0	000	0.000	00	0.0000	0.0000	0.0000	
35	Nitrogen	0.0000	0.0000		0.00	00	0.0000	0.0000	0.0000	
36	Oxygen	0.0000	0.0	000	0.000		0.0000	0.0000	0.0000	
37	Water	0.0000	0.0	000	0.0000		0.0000	0.0000	0.0000	
38	Tin-White	0.0000	0.0	000	0.00	0.0000		0.0000	0.0000	
39	Hydrogen	0.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000	
40	Total	0.5159	1.0	000	33.73	16	1.0000	0.0049	1.0000	
41 42 43	Mater	rial Stream	: Sweep	Air			Flui	id Package: Ov perty Package: As	erheads pen Properties (Peng-R	
44				c	ONDITIONS					
48			Overall	V	apour Phase					
47	Vapour / Phase Fraction		1.0000		1.0000	-				
48	Temperature:	(C)	42.44		42.44					
49	Pressure:	(bar)	1.034		1.034					
50	Molar Flow	(kgmole/h)	7835		7835					
51	Mass Flow	(kg/s)	62.79		62.79					
52	Std Ideal Liq Vol Flow	(m3/h)	419.6		419.6					
53	Molar Enthalpy	(kJ/kgmole)	501.6		501.6					
54	Molar Entropy	(kJ/kgmole-C)	5.744		5.744					
55	Heat Flow	(MW)	1.092		1.092					
57	Liq Vol Flow @Std Cond	(m3/n)	675.1 *		675.1					
58 59										
60 61 62										
83	Aspen Technology In		٨	spen	HYSYS Version	12	1		Page 8 of 20	
03	Licensed to: BATTELLE ENER	GY ALLIANCE	A	spen	In 515 Version	12			' Specified by user.	

1					Case Name: Production.hsc						
3	(aspentech	BATTELLE Bedford, M	ENERG	SY ALLIANCE		Unit Set: Am	eyS2e				
4	<u> </u>	USA				Date/Time: Fri I	Mar 29 15:06:27 2024				
6 7 8	Mater	ial Stre	am:	SweepA	١r	(continued	Flui Pro	id Package: Ov perty Package: As	erheads pen Properties (Peng-R		
9					С	OMPOSITION					
11					0	verall Phase		Vapour Fr	action 1.0000		
13 14	COMPONENTS	MOLAR FL (kgmole/	OW h)	MOLE FRACTIO	N	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION		
15	Zinc	0.	0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
16	Zinc-Oxide	0.	0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
17	Nitrogen	6189	5823	0.790	00	173391.7402	0.7671	331.5004	0.7900		
18	Oxygen	1645.	3320	0.210	00	52648.6498	0.2329	88.1204	0.2100		
19	Water	0.	0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
20	Tin-White	0.	0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
21	Hydrogen	0.	0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
22	Total	7834.	9143	1.000	00	226040.3899	1.0000	419.6208	1.0000		
23 24					v	apour Phase		Phase Fra	action 1.000		
25 26	COMPONENTS MOLAR FLOW (kgmole/h)		OW h)	MOLE FRACTIO	N	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION		
27	Zinc 0.0		0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
28	Zinc-Oxide 0.0		0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
29	Nitrogen 6189.58		5823	0.7900		173391.7402	0.7671	331.5004	0.7900		
30	Oxygen 1645.3320		3320	0.210	00	52648.6498	0.2329	88.1204	0.2100		
31	Water 0.0000		0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
32	Tin-White	0.	0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
33	Hydrogen 0.0000		0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
34	Total	7834.	9143	1.000	00	226040.3899	1.0000	419.6208	1.0000		
35 36 37 38	Mater	ial Stre	am:	AirIntak	e		Flui Pro	id Package: Ov perty Package: As	erheads pen Properties (Peng-R		
39						CONDITIONS					
40				Overall	1	/apour Phase					
41	Vapour / Phase Fraction			1.0000		1.0000					
42	Temperature:	(C)		40.00		40.00					
43	Pressure:	(bar)		1.013		1.013					
44	Mora Flow	(kgmole/h)		/835		/835					
40	Mass Flow	(kg/s)		62.79		62.79					
40	Molar Enthalow	(mom)		419.0		419.0					
40	Molar Entropy	k //kamele ()		5 699		5 698					
40	Heat Flow	(MAA)		0.0267		0.0367					
50	Lig Vol Flow @Std Cond	(19199)		675.4.*		675.4					
51	Eld Vol Flow @Std Colld	(mon)		075.1	с	OMPOSITION					
52 53	1				-	Verall Phase		Vanaur Fr	action 1 0000		
54					-	verall Phase		vapour Fr	1.0000		
55 56	COMPONENTS	MOLAR FL (kgmole/	OW h)	MOLE FRACTIO	N	MASS FLOW (kg/h)	MASS FRACTION	FLOW (m3/h)	FRACTION		
57	Zinc	0.	0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
58	Zinc-Oxide	0.	0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
59	Nitrogen	6189	5823	0.790	00	173391.7402	0.7671	331.5004	0.7900		
60	Oxygen	1645.	3320	0.210	00	52648.6498	0.2329	88.1204	0.2100		
61	Water	0.	0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
62	Tin-White	0.	0000	0.000	00	0.0000	0.0000	0.0000	0.0000		
63	63 Aspen Technology Inc.			Asr	pen	HYSYS Version 12	.1		Page 9 of 20		

1				Case Name: Production.hsc							
3	(aspentech	BATTELLE ENE Bedford, MA	RGY ALLIANCE	Unit Set: Am	eyS2e						
4	C	USA		Date/Time: Fri	Mar 29 15:06:27 2024	24					
8 7	Mate	rial Stream	: AirIntake	(continued) Fluid	d Package: Ov	erheads				
8				COMPOSITION		ing i denage. Pie	pent reperies (r eng r				
10				COMPOSITION							
12			Overa	II Phase (continue	ed)	Vapour Fr	action 1.0000				
13 14	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION				
15	Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
18	Total	7834.9143	1.0000	226040.3899	1.0000	419.6208	1.0000				
17				Vapour Phase		Phase Fraction 1.00					
19	COMPONENTS	MOLAR FLOW	MOLE FRACTION	MASS FLOW	MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME				
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				
28	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				
30 31 32	Mate	rial Stream	: Sat-o	CONDITIONS	Prop	perty Package: NB	is Steam				
33				CONDITIONS							
34			Overall	Aqueous Phase	Vapour Phase						
35	Vapour / Phase Fraction	(0)	0.0000 *	1.0000	0.0000						
37	Pressure:	(bar)	1.055	1055	1.055						
38	Molar Flow	(kamole/h)	1719	1719	0.0000						
39	Mass Flow	(kg/s)	8 603	8 603	0.0000						
40	Std Ideal Lig Vol Flow	(m3/h)	31.03	31.03	0.0000						
41	Molar Enthalpy	(kJ/kgmole)	-2.792e+005	-2.792e+005	-2.386e+005						
42	Molar Entropy	(kJ/kgmole-C)	23.77	23.77	132.2						
43	Heat Flow	(MW)	-133.4	-133.4	0.0000						
44	Liq Vol Flow @Std Cond	(m3/h)	31.00 *	31.00	0.0000						
45 48				COMPOSITION							
47				Overall Phase		Vapour Fr	action 0.0000 *				
49	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION				
51	H2O	1719.2431	• 1.0000	* 30972.3369 *	1.0000 *	31.0348 *	1.0000 *				
52	Total	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000				
53				Disease Disease			-				
54				Aqueous Phase		Phase Fra	scuon 1.000				
55 58	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION				
57	H2O	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000				
58	Total	1719.2431	1.0000	30972.3369	1.0000	31.0348	1.0000				
59 60 61 62											
63	Aspen Technology Inc	c.	Aspe	n HYSYS Version 12	.1		Page 10 of 20				
-	Licensed to: BATTELLE ENER	RGY ALLIANCE					* Specified by user.				

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1				Case Name: Proc				oduction.hsc			
3	@aspen tech	BATTELLE Bedford, M	ENERG	SY ALLIANCE		Unit Set:	Ame	eyS2e			
4		USA			1	Date/Time:	Fri I	Mar 29 15:06:27 2024			
6 7 8	Mater	ial Strea	am:	Sat-o (o	con	tinued)		Flui Pro	d Package: Si perty Package: N	eam BS Steam	
9					C	OMPOSITION					
11					Va	apour Phase			Phase Fr	action	0.0000
12	COMPONENTS	MOLAR EL	w	MOLE ERACTI	ON	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID	VOLUME
14		(kgmole/l	1)			(kg/h)			FLOW (m3/h)	FRAG	CTION
15	H2O	0.	0000	1.00	000	0.000	00	1.0000	0.0000		1.0000
16	Total	0.	0000	1.00	000	0.000	00	1.0000	0.0000		1.0000
17 18 19	Mater	rial Strea	am:	WS-o				Flui Pro	d Package: Si perty Package: N	eam BS Steam	
20 21					C	ONDITIONS					
22				Overall	V	apour Phase		Aqueous Phase			
23	Vapour / Phase Fraction		-	1.0000 *		1.0000		0.0000			
24	Temperature:	(C)		100.6		100.6		100.6			
25	Pressure:	(bar)		1.034		1.034	_	1.034			
20	Molar Flow	(kgmole/h)		1/19		1/19	-	0.0000			
28	Std Ideal Lin Vol Flow	(ng/s) (m3/h)		31.03		31.03	_	0.0000			
29	Molar Enthalpy	(kJ/kgmole)		-2.387e+005		-2.387e+005		-2.793e+005			
30	Molar Entropy	(kJ/kgmole-C)		132.4		132.4		23.66			
31	Heat Flow	(MW)		-114.0		-114.0		0.0000			
32	Liq Vol Flow @Std Cond	(m3/h)		31.00 *		31.00		0.0000			
33					C	OMPOSITION					
34					-						
35					0	verall Phase			Vapour F	raction	1.0000 *
37	COMPONENTS	MOLAR FL	w	MOLE FRACTI	ON	MASS FLOW	-	MASS FRACTION	LIQUID VOLUME	LIQUID	VOLUME
38	oom onerro	(kgmole/l	1)			(kg/h)			FLOW (m3/h)	FRAG	CTION
39	H2O	1719.	2431	1.00	000	30972.336	69	1.0000	31.0348		1.0000
40	Total	1719.	2431	1.00	000	30972.336	9	1.0000	31.0348		1.0000
41					Va	apour Phase			Phase Fr	action	1.000
43	COMPONENTS	MOLAR FLO	wc	MOLE FRACTI	ON	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID	VOLUME
44		(kgmole/	1)			(kg/h)			FLOW (m3/h)	FRAG	CTION
45	H2O	1719.	2431	1.00	000	30972.336	9	1,0000	31.0348		1.0000
48	Total	1719.	2431	1.00	000	30972.336	9	1.0000	31.0348		1.0000
4/					Aq	ueous Phase	_		Phase Fr	action	0.0000
49 50	COMPONENTS	MOLAR FLO	DW 1)	MOLE FRACTI	ON	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID	VOLUME
51	H2O	0.	0000	1.00	000	0.000	00	1,0000	0.0000		1.0000
52	Total	0.	0000	1.00	000	0.000	00	1.0000	0.0000		1.0000
53								Flui	d Package: O	verheads	
54	Mater	rial Strea	am:	H2-1				Dee	ant Daskans A	Deser Deser	tion (Dama E
55								Pro	perty Package: A	spen Proper	ues (Peng-H
57					C	ONDITIONS					
58				Overall	V	apour Phase					
59	Vapour / Phase Fraction			1.0000		1.0000					
60	Temperature:	(C)		419.6		419.6					
61	Pressure:	(bar)		0.9930		0.9930					
62	Molar Flow	(kgmole/h)		4982	_	4982				_	
63	Aspen Technology Inc			As	spen	HYSYS Version	12	.1		Page	11 of 20
	Licensed to: BATTELLE ENER	GT ALLIANCE								 Specified 	by user.

1					Case Name: Production.hsc							
3	(aspentech	Bedford, MA	ENERG	YALLIANCE	Unit Set:	Am	neyS2e					
4		USA			Date/Time:	Fri	Mar 29 15:06:27 2024					
6 7 8	Mater	ial Strea	ım:	H2-1 (co	ontinued)		FI	uid Package:	Overheads Aspen Properties (Peng-F			
9 10					CONDITIONS							
11			(Overall	Vapour Phase							
12	Mass Flow	(kg/s)		2.790	2.790							
13	Std Ideal Liq Vol Flow	(m3/h)		266.8	266.8							
14	Molar Enthalpy	(kJ/kgmole)		1.154e+004	1.154e+004							
15	Molar Entropy (kJ/kgmole-C)		24.79	24.79							
16	Heat Flow	(MW)		15.97	15.97							
17	Liq Vol Flow @Std Cond	(m3/h)		6.222e+063 *	6.222e+063							
18					COMPOSITIO	N						
20 21 Overall Phase Vapour Fraction 1.0000												
22	COMPONENTS	MOLARELO	14/				MACC EDACTION		LIQUID VOLUME			
22	COMPONENTS	MOLAR FLO	WV	MOLE PRACTIO	N MASS FLOV	v	MASS PRACTION	ELOW (m3/h)	ERACTION			
20	Zine	(kginoleni)	0000	0.000	(ngn)	000	0.0000	0.0000	0.0000			
25	Zine Ovide	0.0	0001	0.000	0.0	049	0.0000	0.0000	0.0000			
28	Nitrogen	0.0	000	0.000	0.0	040	0.0000	0.0000	0.0000			
27	Owner	0.0	000	0.000	0.0	000	0.0000	0.0000	0.0000			
20	Water	0.0	0000	0.000	0.0	000	0.0000	0.0000	0.0000			
20	Tin White	0.0	000	0.000	0.0	010	0.0000	0.0000	0.0000			
20	Hudsenen	4081.7	649	1.000	0.0	404	1.0000	266.8424	1.0000			
30	Total	4901.7	640	1.000	10042.0	401	1.0000	200.0124	1.0000			
22	Total	4301.7	043	1.000	10042.0	400	1.0000	200.0124	1.0000			
33					Vapour Phase			Phase F	Fraction 1.000			
34 35	COMPONENTS	MOLAR FLO (kgmole/h)	W(MOLE FRACTIO	N MASS FLOV (kg/h)	v	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION			
38	Zinc	0.0	0000	0.000	0.0 0.0	000	0.0000	0.0000	0.0000			
37	Zinc-Oxide	0.0	001	0.000	0.0	048	0.0000	0.0000	0.0000			
38	Nitrogen	0.0	0000	0.000	0.0 0.0	000	0.0000	0.0000	0.0000			
39	Oxygen	0.0	0000	0.000	0.0 0.0	000	0.0000	0.0000	0.0000			
40	Water	0.0	0000	0.000	0.0	000	0.0000	0.0000	0.0000			
41	Tin-White	0.0	0000	0.000	0.0	018	0.0000	0.0000	0.0000			
42	Hydrogen	4981.7	648	1.000	10042.6	401	1.0000	266.8124	1.0000			
43	Total	4981.7	649	1.000	10042.6	468	1.0000	266.8124	1.0000			
44 45 48	Mater	ial Strea	ım:	WetStea	am		FI	uid Package:	Steam NBS Steam			
48					CONDITIONS							
49			(Overall	Vapour Phase		Aqueous Phase					
50	Vapour / Phase Fraction			1.0000 *	1.0000		0.0000					
51	Temperature:	(C)		100.6	100.6		100.6					
52	Pressure:	(bar)		1.034	1.034		1.034					
53	Molar Flow	(kgmole/h)		4985	4985		0.0000					
54	Mass Flow	(kg/s)		24.94	24.94		0.0000					
55	Std Ideal Liq Vol Flow	(m3/h)		89.98	89.98		0.0000					
58	Molar Enthalpy	(kJ/kgmole)		-2.387e+005	-2.387e+005		-2.793e+005		-			
57	Molar Entropy (kJ/kgmole-C)		132.4	132.4		23.66		-			
58	Heat Flow	(MW)		-330.4	-330.4		0.0000					
59	Liq Vol Flow @Std Cond	(m3/h)		89.88 *	89.88		0.0000					
Aspen Technology Inc. Aspen HYSYS Version 12.1								Page 12 of 20				
-	Licensed to: BATTELLE ENER	GY ALLIANCE							* Specified by user.			

1					Case Name:	Production.hsc			
2	(aspentech	BATTELLE Bedford, MA	ENERG	Y ALLIANCE	Unit Set:	AmeyS2e			
4	0. 1	USA			Date/Time: F	ri Mar 29 15:06:27 2	2024		
6 7 8	Mater	rial Strea	m:	WetSteam	n (continu	ed)	Fluid Package: Property Package:	Stea NBS	am S Steam
9				c	OMPOSITION				
11				c	overall Phase		V	apour Fra	action 1.0000 *
12	COMPONENTS	MOLAR FLO	w	MOLE FRACTION	MASS FLOW	MASS FRACTI		LUME	LIQUID VOLUME
14	100	(kgmole/h	000	1 0000	(kg/h)		FLOW (m	n3/h)	FRACTION
16	Total	4904.5	660	1.0000	89797.4575	5 1.0	000 89	9.9787	1.0000
17				v	apour Phase		P	hase Fra	tion 1.000
18 19	COMPONENTS	MOLAR FLO	w	MOLE FRACTION	MASS FLOW	MASS FRACTI	ON LIQUID VOI	LUME	LIQUID VOLUME
20	1120	(kgmole/h		4 0000	(kg/h)		FLOW (m	13/h)	FRACTION
21	H2O Total	4984.5	660	1.0000	89797.4575	5 1.0	000 85	9.9787	1.0000
23	- Crui	4004.4	000 1	1.0000	Dhase			have Free	
24 25	COMPONENTS	MOLAR FLO	w	MOLE FRACTION	MASS FLOW	MASS FRACTI		LUME	LIQUID VOLUME
26		(kgmole/h)	1		(kg/h)		FLOW (n	n3/h)	FRACTION
27	H2O	0.0	000	1.0000	0.0000	1.0	000 000	0.0000	1.0000
29 30 31 32	Mater	rial Strea	m:	WS-h	CONDITIONS		Fluid Package: Property Package:	Ster	am S Steam
33				Querall	Vanours Phase	Aguagua Phase			
35	Vapour / Phase Fraction			1.0000 *	1.0000	Aqueous Phase 0.0000)		
36	Temperature:	(C)		100.6	100.6	100.6	5		
37	Pressure:	(bar)		1.034	1.034	1.034	4		
39	Molar Flow Mass Flow	(kgmole/n) (kg/s)		5.643	5.643	0.0000		-	
40	Std Ideal Lig Vol Flow	(m3/h)		20.36	20.36	0.0000)		
41	Molar Enthalpy	(kJ/kgmole)		-2.387e+005	-2.387e+005	-2.793e+005	5		
42	Molar Entropy	(kJ/kgmole-C)		132.4	132.4	23.66	3	-	
44	Lig Vol Flow @Std Cond	(m3/h)		20.33 *	20.33	0.0000)	-	
45	-			c	OMPOSITION				
47				c	overall Phase		V	apour Fra	ction 1.0000 *
49	COMPONENTS	MOLAR FLO	w	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTI	ON LIQUID VOI FLOW (n	LUME 13/h)	LIQUID VOLUME FRACTION
51	H2O	1127.6	444 *	1.0000 *	20314.6270	1.0	000 * 20	0.3556 *	1.0000 *
52	Total	1127.6	444	1.0000	20314.6270	1.0	000 20	0.3556	1.0000
53 54				v	apour Phase		P	hase Fra	ction 1.000
55 58	COMPONENTS	MOLAR FLO (kgmole/h)	W	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTI	ON LIQUID VOI FLOW (m	LUME n3/h)	FRACTION
57	H2O	1127.6	444	1.0000	20314.6270	1.0	000 20	0.3556	1.0000
58 59 60	Total	1127.6	444	1.0000	20314.6270	0 1.0	000 20	0.3556	1.0000
61 62	_								_
63	Aspen Technology Inc Licensed to: BATTELLE ENER	GY ALLIANCE		Aspen	HYSYS Version	12.1			Page 13 of 20 * Specified by user.

1											
2	(December of	BATTELLE B	ENERGY ALLIA	NCE	Case Name.	Production.risc					
3	(easpentech	Bedford, MA		ļ	Unit Set:	AmeyS2e					
4		USA			Date/Time:	Fri Mar 29 15:06:27 20	24				
6 7 8	Mater	rial Strea	m: WS	-h (co	ntinued)		Fluid Package: St Property Package: NI	eam BS Steam			
9				(COMPOSITION						
11				•	queous Phase	ueous Phase Praction					
12	0011001151170				que ous r nuse	11100 551 0710					
14	COMPONENTS	(kgmole/h)	MOLE	RACTION	(kg/h)	MASSFRACTIO	FLOW (m3/h)	FRACTION			
15	H2O	0.0	000	1.0000	0.000	00 1.000	0.0000	1.0000			
16	Total	0.0	000	1.0000	0.000	1.000	0.0000	1.0000			
17 18 19	Mater	rial Strea	m: WS				Fluid Package: St Property Package: NI	eam BS Steam			
20 21					CONDITIONS						
22			Overall		Vapour Phase						
23	Vapour / Phase Fraction		1.	0000	1.0000						
24	Temperature:	(C)	1	00.6	100.6						
25	Pressure:	(bar)	1	.034	1.034						
20	Mass Flow	(kgmole/n)	1	0.70	10.70						
28	Std Ideal Lig Vol Flow	(m3/h)	3	8.59	38.59						
29	Molar Enthalpy	(kJ/kgmole)	-2.387e	+005	-2.387e+005						
30	Molar Entropy	(kJ/kgmole-C)	1	32.4	132.4						
31	Heat Flow	(MW)	-1	41.7	-141.7						
32	Liq Vol Flow @Std Cond	(m3/h)	3	8.54 *	38.54						
33				(COMPOSITION						
35					Overall Phase		Vapour F	raction 1.0000			
30	COMPONENTS	MOLAR FLO	W MOLE	FRACTION	MASS FLOW	MASS FRACTIO	N LIQUID VOLUME	LIQUID VOLUME			
38		(kgmole/h))		(kg/h)		FLOW (m3/h)	FRACTION			
39	H2O Total	2137.6	785 *	1.0000	38510.493	36 1.000	38.5882	1.0000 *			
41	Total	2157.0	105	1.0000	30510.45	1.000	50.5002	1.0000			
42					vapour Phase		Phase Fr	action 1.000			
43	COMPONENTS	MOLAR FLO	W MOLE	FRACTION	MASS FLOW	MASS FRACTIO	N LIQUID VOLUME	LIQUID VOLUME			
44	1120	(kgmole/h)	705	4 0000	(kg/h)		FLOW (m3/h)	FRACTION			
45	H2O Total	2137.6	785	1.0000	38510.49	36 1.000	38,5882	1.0000			
47	Total	2107.0	100	1.0000	56510.45	1.000	Elvid Daekaes:	1.0000			
48 49	Mater	rial Strea	m: Sat	-h			Property Package: N	BS Steam			
50					CONDITIONS						
52			Overall		Aqueous Phase	Vanour Phase					
53	Vapour / Phase Fraction		0.0	0000 *	1.0000	0.0000					
54	Temperature:	(C)	1	01.1	101.1	101.1					
55	Pressure:	(bar)	1	.055	1.055	1.055					
58	Molar Flow	(kgmole/h))	1128	1128	0.0000					
57	Mass Flow	(kg/s)	5	0.643	5.643	0.0000					
59	Molar Enthalov	(m3/h) (kJ/komole)	-2 7926	+005	-2.792e+005	-2.386e+005					
60	Molar Entropy	(kJ/kgmole-C)	2.1020	3.77	23.77	132.2					
61	Heat Flow	(MW)	-8	7.47	-87.47	0.0000					
62	Liq Vol Flow @Std Cond	(m3/h)	2	0.33 *	20.33	0.0000					
63	Aspen Technology Inc	2.		Asper	HYSYS Version	12.1		Page 14 of 20			
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1					Case Name: Production.hsc							
3	(aspentech	BATTELLE Bedford, MA	ENERG	SY ALLIANCE		Unit Set:	Am	eyS2e				
4		USA				Date/Time:	Fri I	Mar 29 15:06:27 2024				
6 7 8	Mater	ial Strea	am:	Sat-h (cor	ntinued)		Flui Pro	d Package: Ste perty Package: NB	eam IS Steam		
9 10					c	OMPOSITION						
11					c	verall Phase			Vapour Fr	action 0.0000 *		
13	COMPONENTS	MOLAR FLO	w	MOLE FRACT	ON	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME		
14	H20	(kgmole/h) 5444	10	000	(kg/h) 20314 621	70	1 0000	FLOW (m3/h) 20.3556	FRACTION 1 0000		
16	Total	1127.6	6444	1.0	000	20314.627	70	1.0000	20.3556	1.0000		
17					A	ueous Phase			Phase Fraction 1.000			
19	COMPONENTS	MOLAR FLC	W	MOLE FRACT	ON	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION		
21	H2O	1127.6	6444	1.0	000	20314.627	70	1.0000	20.3556	1.0000		
22	Total	1127.6	5444	1.0	000	20314.627	70	1.0000	20.3556	1.0000		
23 24					V	apour Phase			Phase Fra	action 0.0000		
25 26	COMPONENTS	MOLAR FLC (kgmole/h	ww	MOLE FRACT	ON	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION		
27	H2O	0.0	0000	1.0	000	0.000	00	1.0000	0.0000	1.0000		
28	Total	0.0	0000	1.0	000	0.000	00	1.0000	0.0000	1.0000		
29 30 31	Mater	ial Strea	am:	Sat				Flui Pro	d Package: Ste perty Package: NB	eam IS Steam		
33					(CONDITIONS						
34				Overall	A	queous Phase		Vapour Phase				
35	Vapour / Phase Fraction			0.0000 *	_	1.0000	_	0.0000				
36	Temperature:	(C)		101.1		101.1		101.1				
38	Molar Flow	(kgmole/h)		2138		2138		0.0000				
39	Mass Flow	(kg/s)		10.70		10.70		0.0000				
40	Std Ideal Liq Vol Flow	(m3/h)		38.59		38.59		0.0000				
41	Molar Enthalpy	(kJ/kgmole)		-2.792e+005		-2.792e+005	_	-2.386e+005				
42	Molar Entropy	kJ/kgmole-C)		23.77	_	23.77		132.2				
43	Heat Flow	(MW)		-165.8	_	-165.8	-	0.0000				
44	Liq Voi Flow @Sta Cond	(m3/n)		30.54	c	OMPOSITION		0.0000				
47					C	verall Phase			Vapour Fr	action 0.0000 *		
49	COMPONENTS	MOLAR FLO	W	MOLE FRACT	ON	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME		
51	H20	2137.6	6785	1.0	000	38510.493	36	1,0000	38,5882	1.0000		
52	Total	2137.6	6785	1.0	000	38510.493	36	1.0000	38.5882	1.0000		
53						Dhare Dhare			Dhave F	ation 4000		
54					AC	ueous Phase			Phase Fra	1.000		
55	COMPONENTS	MOLAR FLO	w	MOLE FRACT	ON	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME		
57	H2O	(kgmole/n 2137 6	3785	10	000	(Kg/n) 38510.493	36	1 0000	PLOW (m3/n)	1 0000		
58	Total	2137.6	6785	1.0	000	38510.493	36	1.0000	38.5882	1.0000		
59 60 61 62 63	Aspen Technology Inc	*		A	spen	HYSYS Version	12	.1		Page 15 of 20		
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							_				
1						Case Name:	Proc	luction.hsc			
3	(aspentech	BATTELLE Bedford, M	A	SY ALLIANCE		Unit Set:	Ame	eyS2e			
4	0. 1	USA				Date/Time:	Fri M	Mar 29 15:06:27 2024			
5											
7	Mater	ial Stre	am.	Sat (co	ntir	(heu		Flui	d Package: S	team	
8	mator			our (co		iucu)		Pro	perty Package: N	BS Steam	
9					c	OMPOSITION					
10											
12					Va	apour Phase			Phase Fr	action	0.0000
13	COMPONENTS	MOLAR FLO	WC	MOLE FRACTI	ON	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUI	VOLUME
14		(kgmole/t	1)			(kg/h)			FLOW (m3/h)	FRA	ACTION
15	H2O Total	0.	0000	1.00	000	0.000	0	1.0000	0.0000		1.0000
17	lotai	0.	0000 1	1.00	00 1	0.000		1.0000	0.0000		1.0000
18	Mater	ial Stre	am'	Saturat	ed)	Water		Flui	d Package: 5	team	
19	mater		ann.	Vaturat	cu	valei		Pro	perty Package: N	BS Steam	
20					c	ONDITIONS					
21						- Cite Incite					
22	Manager (Dhana Españan			Overall	Aq	ueous Phase		Vapour Phase			
23	Temperature:	(C)		101.1		101.1		101.1			
25	Pressure:	(bar)		1.055		1.055		1.055			
28	Molar Flow	(kgmole/h)		4985		4985		0.0000			
27	Mass Flow	(kg/s)		24.94		24.94		0.0000			
28	Std Ideal Liq Vol Flow	(m3/h)		89.98		89.98		0.0000			
29	Molar Enthalpy	(kJ/kgmole)		-2.792e+005		-2.792e+005		-2.386e+005			
30	Molar Entropy (kJ/kgmole-C)		23.77	_	23.77		132.2			
32	Lin Vol Flow @Std Cond	(m3/h)		-300.0		-300.0		0.0000			
33		(~						
34					C	OMPOSITION					
35					0	verall Phase			Vapour F	raction	0.0000
30	COMPONENTS	MOLAR EL	W			MASSELOW		MASS EPACTION	LIQUID VOLUME	LIOU	VOLUME
38	COMPONENTS	(kgmole/f	1)	MOLL ITONOT		(kg/h)		MASS TRACTION	FLOW (m3/h)	FRA	ACTION
39	H2O	4984.	5660	1.00	000	89797.457	5	1.0000	89.9787		1.0000
40	Total	4984.	5660	1.00	000	89797.457	5	1.0000	89.9787		1.0000
41					Aq	ueous Phase			Phase Fr	action	1.000
42	COMPONENTS	MOLADEL		MOLE ERACTI	-	MACCELOW		MASS EPACTION	HOURD VOLUME	1101	VOLUME
44	COMPONENTS	(kamole/	1)	MOLE FRACTI		(kg/h)		MASS FRACTION	FLOW (m3/h)	FRA	ACTION
45	H2O	4984.	5660	1.00	000	89797.457	5	1.0000	89.9787		1.0000
48	Total	4984.	5660	1.00	000	89797.457	5	1.0000	89.9787		1.0000
47					Va	apour Phase			Phase Fr	action	0.0000
48	COMPONENTS	MOLADIEL	DIAK	MOLE EDUCT		MACCELOW		MACC EPACTION	LIQUID VOLUME	11011	NOLUME
50	COMPONENTS	(kamole/	1)	MOLE FRACTI		(kg/h)		MASS FRACTION	FLOW (m3/h)	FRA	ACTION
51	H2O	0.	0000	1.00	000	0.000	0	1.0000	0.0000	-	1.0000
52	Total	0.	0000	1.00	000	0.000	0	1.0000	0.0000		1.0000
53								Flui	d Package: S	team	
54	Mater	ial Strea	am:	WaterF	eec	d l		Pro	nerty Package: N	RS Steam	
55							_	PIO	pony raonayo. N	oo olcain	
57					C	ONDITIONS					
58				Overall	Aq	ueous Phase					
59	Vapour / Phase Fraction			0.0000		1.0000					
60	Temperature:	(C)		25.00		25.00					
61	Pressure:	(bar)	_	1.077		1.077					
63	Aspen Technology Inc.	(kgmolé/h)		4985	nen l	4985 HYSYS Version	12	1		Page	e 16 of 20
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1				(Case Name:	Pro	duction.hsc		
3	(aspentech	Bedford, MA	RGY ALLIANCE	L	Unit Set:	Ame	eyS2e		
4		USA		(Date/Time:	Fri I	Mar 29 15:06:27 2024		
6 7 8	Mater	ial Stream	: WaterF	eec	d (contin	ue	ed) File Pro	id Package:	Steam NBS Steam
9				С	ONDITIONS				
11			Overall	Aq	ueous 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				
19				C	OMPOSITION				
20				0	verall Phase			Vapour	Fraction 0.0000
22	COMPONENTS	MOLAR FLOW	MOLE FRACT	ION	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME
23		(kgmole/h)			(kg/h)			FLOW (m3/h)	FRACTION
24	H2O	4984.5660	1.0	000	89797.45	75	1.0000	89.9787	1.0000
25	Total	4984.5660	1.0	000	89797.45	75	1.0000	89.9787	1.0000
28				Aq	ueous Phase			Phase F	raction 1.000
28 29	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
30	H2O	4984.5660	1.0	000	89797.45	75	1.0000	89.9787	1,0000
31	Total	4984.5660	1.0	000	89797.45	75	1.0000	89.9787	1.0000
34 35 36	Mater	iai otrean	. Overne	c	ONDITIONS		Pro	operty Package:	Aspen Properties (Peng-R
37			Overall	Va	apour 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/n)	266.8		266.8				
45	Molar Entropy ((KJ/Kgmole_C)	2.4208+004		2.4208+004				
48	Heat Flow	(MW)	33.57		33.57				
47	Lig Vol Flow @Std Cond	(m3/h)	6.222e+063 *		6.222e+063				
48				c	OMPOSITION				
50				0	verall Phase			Vapour	Fraction 1.0000
51	COMPONIENTS	MOLAR FLOW	MOLEEDACT		MASS FLOW		MASS EPACTION		
53	COMPONENTS	(kgmole/h)	MOLE FRACT		(kg/h)		MASSPRACTION	FLOW (m3/h)	FRACTION
54	Zinc	0.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
55	Zinc-Oxide	0.0001	0.0	000	0.004	48	0.0000	0.0000	0.0000
56	Nitrogen	0.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
50	Water	0.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
50	Tin-White	0.0000	0.0	000	0.000	18	0.0000	0.0000	0.0000
80	Hydrogen	4981 7649	0.0	000	10042 64	01	1,0000	266.8124	1,0000
61	Total	4981 7640	1.0	000	10042.040	68	1,0000	266,8124	1,0000
62		4001.7045	1.0		10042.040	~	1.0000	200.0124	1.0000
63	Aspen Technology Inc.		A	spen H	HYSYS Version	112	.1		Page 17 of 20
	Lineared to: BATTELLE ENER	SY ALLIANCE				-			* Specified by user

ERGY ALL

1					Cas	e Name:	Produ	uction.hsc		
3	(aspentech	BATTELLE Bedford, N	E ENERG	SY ALLIANCE	Unit	Set:	Amey	/S2e		
4	<u> </u>	USA			Date	e/Time:	Fri M	ar 29 15:06:27 2024		
6 7 8	Mate	rial Stre	am:	Overhe	adH2	2 (conti	inu	ed) Flu Pro	id Package: O perty Package: A	verheads spen Properties (Peng-R
9 10					COM	POSITION				
11					Vapo	our Phase			Phase Fr	raction 1.000
12	COMPONENTS	MOLAR FL	ow	MOLE FRACT	ION	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME
14		(kgmole/	h)			(kg/h)			FLOW (m3/h)	FRACTION
15	Zinc	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
10	Zinc-Oxide Nitrogen	0	0000	0.0	000	0.004	48	0.0000	0.0000	0.0000
18	Oween	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
19	Water	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
20	Tin-White	0	.0000	0.0	000	0.00	18	0.0000	0.0000	0.0000
21	Hydrogen	4981	7648	1.0	000	10042.640	01	1.0000	266.8124	1.0000
22	Total	4981	.7649	1.0	000	10042.646	68	1.0000	266.8124	1.0000
23 24 25	Mate	rial Stre	am:	LWR C	onde	nsate		Flu Pro	id Package: S perty Package: N	team BS Steam
28					CON	DITIONS				
28				Overall	Aqueo	us Phase	V	apour 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		
38	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					COM	POSITION				
41 42					Over	all Phase			Vapour F	raction 0.0000 *
43	COMPONENTS	MOLAR FL	ow	MOLE FRACT	ION	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME
44		(kgmole/	h)			(kg/h)			FLOW (m3/h)	FRACTION
45	H2O	2243	.8604	1.0	000	40423.369	97	1.0000	40.5049	1.0000
46	Total	2243	.8604	1.0	000	40423.369	97	1.0000	40.5049	1.0000
47 48					Aque	ous Phase	•		Phase Fr	raction 1.000
49 50	COMPONENTS	MOLAR FL (kamole/	OW h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
51	H2O	2243	8604	1.0	000	40423.369	97	1.0000	40,5049	1.0000
52	Total	2243	.8604	1.0	000	40423.369	97	1.0000	40.5049	1.0000
53					Van	Dhan			-	
54					Vapo	our Phase			Phase Fr	action 0.0000
55 56	COMPONENTS	MOLAR FL (kgmole/	OW h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	FRACTION
57	H2O	0	.0000	1.0	000	0.000	00	1.0000	0.0000	1.0000
58	Total	0	.0000	1.0	000	0.00	00	1.0000	0.0000	1.0000
59 60 61 62 63	Aspen Technology Inc	2.		A	spen HYS	SYS Version	12.1			Page 18 of 20
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1				Case Name:	Production.hsc			
3	(aspentech	Bedford, MA	GY ALLIANCE	Unit Set:	AmeyS2e			
4	0. 1	USA		Date/Time:	Eri Mar 29 15:00	8-27 2024		
5							d Davlara O	
7	Mater	ial Stream:	LWR St	eam		Fiu	d Package. Si	leam
8						Pro	perty Package: N	BS Steam
9				CONDITIONS	5			
11			Overall	Vapour Phase	Aqueous Ph	ase		
12	Vapour / Phase Fraction		1.0000 *	1.0000	0	.0000		
13	Temperature:	(C)	140.5 *	140.5		140.5		
14	Pressure:	(bar)	3.663	3.663	-	3.663		
15	Molar Flow	(kgmole/h)	2244	2244	0	0000		
10	Mass Flow Std Ideal Lin Vol Flow	(Kg/s)	11.23	11.23	0	0000		
18	Molar Enthainy	(k.l/kamole)	-2 376e+005	-2 376e+005	-2 7626	+005		
19	Molar Entropy (kJ/kamole-C)	124.8	124.8	-2.7020	31.43		
20	Heat Flow	(MW)	-148.1	-148.1	0	.0000		
21	Liq Vol Flow @Std Cond	(m3/h)	40.46 *	40.46	0	.0000		
22				COMPOSITIO	N			
23								
25				Overall Phase	•		Vapour F	raction 1.0000
26	COMPONENTS	MOLAR FLOW	MOLE FRACTIO	MASS FLOW	MASS FR	ACTION	LIQUID VOLUME	LIQUID VOLUME
27		(kgmole/h)		(kg/h)			FLOW (m3/h)	FRACTION
28	H2O	2243.8604 *	1.000	40423.3	697 ·	1.0000 *	40.5049	1.0000
29	Total	2243.8604	1.000	40423.3	697	1.0000	40.5049	1.0000
30				Vapour Phase			Phase Fr	action 1.000
32	COMPONENTS	MOLAD FLOW	MOLE ERACTIC	MACC ELON	MARCE ED	ACTION	LIQUID VOLUME	LIQUID VOLUME
33	COMPONENTS	(kgmole/h)	MULE PRACTIC	(kg/h)	MASSIFR	ACTION	FLOW (m3/h)	FRACTION
34	H2O	2243.8604	1.000	40423.3	697	1.0000	40.5049	1.0000
35	Total	2243.8604	1.000	00 40423.3	697	1.0000	40.5049	1.0000
36				Aqueous Phas	e		Phase Fr	action 0.0000
37								
38	COMPONENTS	MOLAR FLOW	MOLE FRACTIC	MASS FLOV	MASS FR	ACTION	ELOW (m3/b)	ERACTION
40	H2O	0.0000	1.000	0.0	000	1.0000	0.0000	1.0000
41	Total	0.0000	1.000	0.0	000	1.0000	0.0000	1.0000
42						Flui	d Package: R	eaction
43	Ener	gy Stream:	Reactor	Heat		Dro	nerty Dackage: A	span Dropartias (Solida
44						FIU	perty Package. A	speri Properties (Solids)
48				CONDITIONS	5			
47	Duty Type:	Direct (Duty Calcula	tion Operation: So	olveTemp @HER			
48	Duty SP:	-2.941e-011 MV	V Minimum Ava	ailable Duty:	0.0000 MW	Maximu	um Available Duty:	
49	Ener		DC Dave			Flui	d Package: R	eaction
50	Ener	gy Stream:	DC POW	er		Pro	perty Package: A	spen Properties (Solids
52								
53				CONDITIONS	5			
54	Duty Type:	Direct (Duty Calcula	tion Operation: So	olveTemp @OER			
55	Duty SP:	475.0 MV	V Minimum Ava	ailable Duty:	0.0000 MW	Maximu	um Available Duty:	
58	-					Flui	d Package: R	eaction
57	Ener	gy Stream:	AC POW	er		Pro	perty Package: A	spen Properties (Solids
59								
60				CONDITIONS				
61	Duty Type:	Direct	Duty Calcula	tion Operation:	Rectifier			
62	Duty SP:	500.0 MV	V Minimum Ava	ailable Duty:	0.0000 MW	Maximu	um Available Duty:	
63	Aspen Technology Inc	GY ALLIANCE	Asp	ben HYSYS Versio	on 12.1			Page 19 of 20
	NUMBER OF DATIELLE ENER							UNEWHER UV USEL

1			Case Name:	Production.hsc		
3	easpentech Bedford, MA	ALLIANCE	Unit Set:	AmeyS2e		
4	USA		Date/Time:	Fri Mar 29 15:06:	27 2024	
6	En annu Straamu G				Fluid Package:	Reaction
8	Energy Stream: C	ompres	sionwor	К	Property Package:	Aspen Properties (Solids)
9			CONDITIONS	3		
11	Duty Type: Direct Q	Duty Calculatio	on Operation:			
12	Duty SP: 21.86 MW	Minimum Availa	able Duty:	0.0000 MW	Maximum Available Duty:	
14	Energy Stream: E	BlowerP	ower		Fluid Package:	Reaction
15					Property Package:	Aspen Properties (Solids)
16			CONDITIONS	6		
18	Duty Type: Direct Q	Duty Calculatio	on Operation:	AirSweepBlower		
19	Duty SP: 0.1549 MW	Minimum Availa	able Duty:	0.0000 MW	Maximum Available Duty:	
20	Energy Stream:	lighGrad		teoHast	Fluid Package:	Reaction
22	Ellergy Stream. F	ilyilorad	ue Floce:	ssneat	Property Package:	Aspen Properties (Solids)
23			CONDITIONS			
24	Duty Type: Direct O	Duty Colculatio	Constinuit	, 		
26	Duty SP: 102.3 MW	Minimum Availa	able Duty:	0.0000 MW	Maximum Available Duty:	
27						
28						
29						
30						
32						
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61 62						
63	Aspen Technology Inc.	Aspe	n HYSYS Versio	on 12.1		Page 20 of 20
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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.

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1						Case Name:	Pro	duction.hsc			
3	(aspentech	BATTELLE Bedford, M	ENERO A	GY ALLIANCE		Unit Set:	Am	eyS2e			
4		USA				Date/Time:	Fri	Mar 29 15:31:10 2024			
6 7 8	Mater	ial Stre	am:	Steam				Flu	id Package:	Steam NBS Steam	1
9						CONDITIONS					
11				Overall	1	anour Phase					
12	Vapour / Phase Eraction			1 0000		1 0000	-				
13	Temperature:	(C)		450.0		450.0	_			-	
14	Pressure'	(bar)		1.013		1.013				-	
15	Molar Flow	(kamole/h)		4985		4985					
18	Mass Flow	(ka/e)		24.94		24.94	-			-	
17	Std Ideal Lin Vol Flow	(ng/3)		89.98		89.98	-				
18	Molar Enthalny	(k.l/kamole)		-2 259e+005		-2 259e+005				-	
10	Molar Entropy ((kongrioic)		156 5	-	156.5				-	
20	Heat Flow	(MMA)		312.8		312.8	-			-	
21	Lin Vol Flow @Std Cond	(m3/b)	-	-512.0	-	-512.0	-			-	
22	EN VOLTION @Sta Cond	(11.5/11)		03.00	C	OMPOSITION					
24					c	overall Phase			Vapour	Fraction	1.0000
28	COMPONENTS	MOLAREL	OW/	MOLEERACT	ION	MASS ELOW		MASS ERACTION		LIOU	DVOLUME
27	COMPONENTS	(kamole/	h)	MOLEFRACI	ION	(ka/h)		MASS FRACTION	FLOW (m3/h)	FR	ACTION
28	H20	4984	5660	10	000	89797 45	75	1 0000	89 9787		1 0000
20	Total	4984	5660	10	0000	89797 45	75	1,0000	89 9787		1,0000
30	30 31					apour Phase			Phase F	Fraction	1.000
31	COMPONENTS		014/	MOLEEDAGT	ICAL	MICC FLOW		MACC EDICTION		LIOU	DUOLUME
32	COMPONENTS	MOLAR FL	ow	MOLE FRACT	ION	MASS FLOW		MASS FRACTION	ELOW (m3/b)	LIQU	ID VOLUME
33	1120	(kgriole/	() ()		000	(kg/l)		4 0000	PLOW (marn)		ACTION
34	H2O	4984	5660	1.0	0000	89797.45	75	1.0000	89.9787		1.0000
30	lotal	4984	5660	1.0	0000	89797.45	15	1.0000	89.9787		1.0000
30 37 38	Mater	ial Stre	am:	Alloy				Flu	id Package: I operty Package:	Reaction Aspen Prop	erties (Solids)
39 40						CONDITIONS					
41				Overall		Liquid Phase					1
42	Vapour / Phase Fraction			0.0000		1,0000					
43	Temperature:	(C)		450.0		450.0					
44	Pressure:	(bar)		1.013		1.013					
45	Molar Flow	(kgmole/h)		3.988e+004		3.988e+004					
48	Mass Flow	(kg/s)		1241		1241					
47	Std Ideal Lig Vol Flow	(m3/h)		6826		6826					
48	Molar Enthalpy	(kJ/kgmole)		1.850e+004		1.850e+004					
49	Molar Entropy ((kJ/kgmole-C)		40.85		40.85					
50	Heat Flow	(MW)		205.0		205.0					
51	Lig Vol Flow @Std Cond	(m3/h)		3.489e+109 *		3.489e+109					
52											
53					C	OMPOSITION					
54					c	overall Phase			Vapour	Fraction	0.0000
56	COMPONENTS	MOLAR FL	wo	MOLE FRACT	ION	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQU	D VOLUME
57		(kgmole/	h)			(kg/h)			FLOW (m3/h)	FR	ACTION
58	Zinc	4984	5660	0.1	250	325940.77	14	0.0730	46.9437		0.0069
59	Zinc-Oxide	0	0000	0.0	0000	0.00	00	0.0000	0.0000		0.0000
60	Nitrogen	0	0000	0.0	0000	0.00	00	0.0000	0.0000		0.0000
61	Oxygen	0	0000	0.0	0000	0.00	00	0.0000	0.0000		0.0000
62	Water	0	0000	0.0	0000	0.00	00	0.0000	0.0000		0.0000
63	Aspen Technology Inc	A	spen HYSYS Version 12.1 Page 1 of 9								

Image: Section of the sectio	—							_					
Image: Separation Subject 2000 Unit Set AmryS2e Unit Set AmryS2e DaerTime: Pri Mar 29 153 11 0 3024 Image: Marting Set 2000 Material Stream: Alloy (continued) Paul 29 153 11 0 3024 Image: Marting Set 2000 COMPOSITION Paul 29 153 11 0 3024 Image: Marting Set 2000 COMPOSITION Paul 29 153 11 0 3024 Image: Marting Set 2000 COMPOSITION Vacour Fraction 0.000 Image: Marting Set 2001 Overall Phase (continued) Vacour Fraction 0.000 Image: Marting Set 2001 0.0750 4.140224817e-06 0.9270 6778 3551 0.0991 Image: Marting Set 2001 0.0001 4.40795558e-06 0.0000 0.000	1			- FNED		Case Name: Production.hsc							
4 USA Detrime Fild Package: Reaction 0 Material Stream: Alloy (continued) Full Package: Reaction 0 COMPOSITION ComPosition 0000 0 Overall Phase (continued) Vapor Fraction 0000 0 Overall Phase (continued) Vapor Fraction 0000 0 Overall Phase (continued) 0.000 0.000 0.000 10 COMPORENTS MOLAR FLOW MOLE FRACTION MASS FRACTION LOUD VOLUME FRACTION 11 Trav thate 3.997.0231 1.0000 4.487955558-051 1.0000 0.0000	3	(aspentech	Bedford, N		SY ALLIANCE		Unit Set:	Am	eyS2e				
And Stream: Alloy (continued) Plud Package: Reaction Property Package: Agen Properties (Solds) COMPOSITION Vacuum Package: Agen Properties (Solds) Composition Overall Phase (continued) Vacuum Package: Agen Properties (Solds) Composition Mole FRACTION Mole Straction Using Vacuum Package: Agen Properties (Solds) Composition Mole Straction Mole Straction Mole Straction Using Vacuum Package: Agen Properties (Solds) Tox Vitine Mole Straction Mole Straction Mole Straction Using Vacuum Package: Agen Properties (Solds) Tox Vitine Mole Straction Mole Straction Mole Straction Using Vacuum Package: Agen Properties (Solds) Componentition Mole Straction Mole Straction Mole Straction Using Vacuum Package Using Vacuum Package: Mole Straction Using Vacuum Package: Mole Packag	4		USA				Date/Time:	Fri I	Mar 29 15:31:10 2024				
0 COMPONENTION Value // France 0.0000 11 COMPONENTS MOLAR FLOW MOLE FRACTION MASS FRACTION LUCUI VOLUME LUCUI VOLUME LUCUI VOLUME LUCUI VOLUME LUCUI VOLUME 0.0000 10 MOLAR FLOW MOLE FRACTION MASS FRACTION LUCUI VOLUME LUCUI VOLUME 0.0000 0.000	6 7 8	Mate	rial Stre	am:	Alloy (d	on	ntinued)		Flui Pro	d Package: Re perty Package: As	eaction spen Properties (Solids)		
Overall Phase (continued) Vapour Fraction 0.0001 COMPONENTS MOLAR FLOW (ligmodelh) MOLE FRACTION (light) MASS FRACTION (light) MASS FRACTION (light) LIQUID VOLUME FRACTION LIQUID VOLUME (PLOW INC) LIQUID VOLUME FRACTION LIQUID VOLUME (light) LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION LIQUID VOLUME (light) LIQUID VOLUME FRACTION LIQ	9					c	OMPOSITION						
12 COMPONENTS MOLAR FLOW (ligmoleft) MOLE FRACTION (ligmoleft) MASS FRACTION (ligmoleft) LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION 16 hythogen 0.0000	11				Ov	erall	Phase (contin	ue	d)	Vapour F	raction 0.0000		
Image: Second	12	CONDONENTS	10110	014	MOLE EDUCT	-		_					
In. White 3480 18211 0.8750 4 14224817+06 0.8270 6 778 s151 0.9301 IP Storage 0.0000	14	COMPONENTS	(kgmole/	h)	MOLE PRACT	ON	(kg/h)		MASS PRACTION	FLOW (m3/h)	FRACTION		
19 Hydrogen 0.0000 </td <td>15</td> <td>Tin-White</td> <td>34891</td> <td>.9621</td> <td>0.8</td> <td>750</td> <td>4.142024817e+0</td> <td>6</td> <td>0.9270</td> <td>6778.9151</td> <td>0.9931</td>	15	Tin-White	34891	.9621	0.8	750	4.142024817e+0	6	0.9270	6778.9151	0.9931		
Total 38675.231 1.000 4.467965586+06 1.000 625.5588 1.000 10 Liquid Phase Phase Fraction 1.000 <	16	Hydrogen	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000		
100 100 100 100 100 100 100 100 100 100	17	Total	39876	.5281	1.0	000	4.467965589e+0	6	1.0000	6825.8588	1.0000		
20 1 COMPORENTS MOLAF FLOW (kgmoleh) MOLAF FLOW (kgmoleh) MASS FLOW (kgmoleh) MASS FLOW (kgmoleh) MASS FLOW (kgmoleh) UQUID VOLUME FRACTION FRACTION UQUID VOLUME FRACTION 22 Zine 4984.5860 0.1250 235940.7714 0.0730 48.9437 0.0069 23 Zine-Oxide 0.0000 0	18 19					L	iquid Phase			Phase Fr	action 1.000		
22 Zine 4984.5860 0.1250 325940.714 0.0730 46.9437 0.0089 23 Zine-Oxide 0.0000 <td>20</td> <td>COMPONENTS</td> <td>MOLAR FL (kgmole/</td> <td>OW h)</td> <td>MOLE FRACT</td> <td>ON</td> <td>MASS FLOW (kg/h)</td> <td></td> <td>MASS FRACTION</td> <td>LIQUID VOLUME FLOW (m3/h)</td> <td>LIQUID VOLUME FRACTION</td>	20	COMPONENTS	MOLAR FL (kgmole/	OW h)	MOLE FRACT	ON	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION		
23 Discovering 0.0000 0.000	22	Zinc	4984	.5660	0.1	250	325940.771	4	0.0730	46.9437	0.0069		
24 Minogen 0.0000 <td>23</td> <td>Zinc-Oxide</td> <td>0</td> <td>.0000</td> <td>0.0</td> <td>000</td> <td>0.000</td> <td>0</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	23	Zinc-Oxide	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000		
25 Oxygen 0.0000	24	Nitrogen	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000		
28 Water 0.0000	25	Oxygen	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000		
27 The-White 34819.82.1 0.8750 4.14202417+-66 0.9270 6778.9151 0.9331 28 Hydrogen 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 30 Total 39876.5281 1.0000 4.467985589+-06 1.0000 6825.8588 1.0000 Projectly Package: Reaction 31 Projectly Package: Reaction 32 Overall Vapour Phase Liquid Phase Projectly Package: Reaction 33 CONDITIONS 34 CONDITIONS 35 Temperature: (C) 4.511 450.1 0.862.6 CONDITIONS 36 Mater Flow (kgmoleh) 4.486-004 4578 3.988-004 Comperature: 41 St difeat Liq Vol Flow (kulkgmole) -6748 -2.287e+005 1.846e+004 Exection 42 Molar Entropy (kulkgmole, colspan="4">COMPOSITION	26	Water	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000		
28 Hydrogen 0.0000 </td <td>27</td> <td>Tin-White</td> <td>34891</td> <td>.9621</td> <td>0.8</td> <td>750</td> <td>4.142024817e+0</td> <td>6</td> <td>0.9270</td> <td>6778.9151</td> <td>0.9931</td>	27	Tin-White	34891	.9621	0.8	750	4.142024817e+0	6	0.9270	6778.9151	0.9931		
20 Total 39976.5281 1.0000 4.4679655808+06 1.0000 6825.8588 1.0000 Pluid Package: Reaction Property Package: Aspen Properties (Solide) CONDITIONS Section Overall Vapour Phase Liquid Phase CONDITIONS 38 CONDITIONS Section Overall Vapour Phase Liquid Phase CONDITIONS 39 Overall Vapour Phase Liquid Phase CONDITIONS 39 Condettion Outer Information CONDITION 39 Overall Vapour Phase Liquid Phase CONDITION 39 CONDITION Malar Entropy (kgmole) 44.488 COMPOSITION Addar Entropy (kulkgmole) Addar Entropy (kulkgmole) Addar	28	Hydrogen	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000		
Bit Stream: Reactants Fluid Package: Reaction 33 Property Package: Aspen Properties (Solids) 33 CONDITIONS 34 CONDITIONS 35 Vapour / Phase Fraction 0.1110 0.1110 0.8890 36 Vapour / Phase Fraction 0.1110 0.1110 0.6890 37 Temperature: (b) 450.1 450.1 38 Pressure: (bar) 1.013 1.013 1.013 39 Molar Flow (kgmoleh) 4.486e-004 4978 3.988e-004	29	Total	39876	.5281	1.0	000	4.467965589e+0	6	1.0000	6825.8588	1.0000		
38 Overall Vapour Phase Liquid Phase 38 Vapour / Phase Fraction 0.1110 0.1110 0.8890	32 33 34						CONDITIONS		Pro	perty Package: As	spen Properties (Solids)		
38 Vapour / Phase Fraction 0.1110 0.1110 0.8890 37 Temperature: (C) 450.1 450.1 450.1 38 Pressure: (bar) 1.013 1.013 1.013 39 Molar Flow (kgmoleh) 4.486e-004 4976 3.988e+004 40 Mass Flow (kgmoleh) 4.486e+004 4976 3.988e+004 40 Mass Flow (kgmole) -8748 -2.267e+005 1.846e+004 41 Std Ideal Liq Vol Flow (m3/h) 6916 89.85 6826 42 Molar Entropy (kJ/kgmole-C) 34.84 -13.26 40.85 44 Heat Flow (MW) -109.0 -313.5 204.5 44 Heat Flow (MW) -109.0 -313.5 204.5 45 Liq Vol Flow @std Cond (m3/h) 3.489e+109<'	35				Overall	١	apour Phase		Liquid Phase				
37 Temperature: (C) 450.1 450.1 450.1 450.1 450.1 38 Pressure: (bar) 1.013 <td< td=""><td>38</td><td>Vapour / Phase Fraction</td><td></td><td></td><td>0.1110</td><td></td><td>0.1110</td><td></td><td>0.8890</td><td></td><td></td></td<>	38	Vapour / Phase Fraction			0.1110		0.1110		0.8890				
38 Pressure: (bar) 1.013 1.013 1.013 30 Molar Flow (kgmole/h) 4.486e+004 4978 3.986e+004	37	Temperature:	(C)		450.1		450.1		450.1		· · · · · · · · · · · · · · · · · · ·		
30 Molar Flow (kgmole/h) 4.486e+004 4976 3.988e+004 40 Mass Flow (kg/s) 1266 24.91 1241 41 Std Ideal Liq Vol Flow (m3/h) 6916 89.85 6826 42 Molar Enthalpy (kJ/kgmole) -8748 -2.267e+005 1.846e+004 43 Molar Enthalpy (kJ/kgmole) -8748 -2.267e+005 1.846e+004 44 Heat Flow (MW) -109.0 -313.5 204.5 44 Heat Flow @Std Cond (m3/h) 3.489e+109* 89.84 3.489e+109 45 Liq Vol Flow @Std Cond (m3/h) 3.489e+10* 0.98.84 3.489e+109 46 Vapour Form 0.1110 47 MOLA FLOW MASS FLOW MASS FLOW LiQUID VoLUME LiQUID VoLUME FRACTION	38	Pressure:	(bar)		1.013		1.013		1.013				
40 Mass Flow (kg/s) 1266 24.91 1241 41 Std Ideal Liq Vol Flow (m3/h) 6816 89.85 6826	39	Molar Flow	(kgmole/h)		4.486e+004		4978		3.988e+004				
41 Std Ideal Liq Vol Flow (m3/h) 6616 89.85 6626 42 Molar Enthalpy (kJ/kgmole) -8748 -2.267e4005 1.846e4004 43 Molar Enthalpy (kJ/kgmole) -3413.5 204.5 44 Heat Flow (MW) -109.0 -313.5 204.5 45 Liq Vol Flow @Std Cond (m3/h) 3.489e+109 89.84 3.489e+109 46	40	Mass Flow	(kg/s)		1266		24.91		1241				
42 Molar Enthalpy (kJ/kgmole) -8748 -2.267+005 1.846+004 43 Molar Entropy (kJ/kgmole-C) 34.84 -1.328 40.85	41	Std Ideal Lig Vol Flow	(m3/h)		6916		89.85		6826				
Malar Entropy (kJ/kgmole-C) 34.84 -13.28 40.85 44 Heat Flow (MW) -109.0 -313.5 204.5 45 Liq Vol Flow @Std Cond (m3/h) 3.489e+109* 89.84 3.489e+109 46 Liq Vol Flow @Std Cond (m3/h) 3.489e+109* 89.84 3.489e+109 47 COMPOSITION 48 Vapour Fraction 0.1110 49 Vapour Fraction 0.1110 50 COMPONENTS MOLAR FLOW MOLE FRACTION MASS FLOW MASS FRACTION LiQUID VOLUME FRACTION 51 ComPonents M964.5660 0.1111 325940.7714 0.0715 46.9437 0.0068 52 Zine 4984.5660 0.1111 325940.7714 0.0100 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	42	Molar Enthalpy	(kJ/kgmole)		-8748		-2.267e+005		1.846e+004				
44 Heat Flow (MW) 109.0 313.5 204.5	43	Molar Entropy	(kJ/kgmole-C)		34.84		-13.28		40.85				
46 Liq Vol Flow @std Cond (m3/h) 3.489e+109 ⁺ 89.84 3.489e+109 48 COMPOSITION COMPOSITION Vapour Fraction 0.1110 49 Overall Phase Vapour Fraction 0.1110 50 COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION MASS FLOW (kg/h) MASS FRACTION LIQUID VOLUME FLOW (m3/h) LIQUID VOLUME FRACTION 51 COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION MASS FLOW (kg/h) MASS FRACTION LIQUID VOLUME FLOW (m3/h) FRACTION 52 Zine 4984.5660 0.1111 325940.7714 0.0715 46.9437 0.0068 53 Zine-Oxide 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 64 Nitrogen 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 56 Vater 4984.5660 0.1111 89788.323 0.0197 89.9714 0.0130 56 Water 4984.5660 0.1111 89788.323 0.0197 89.9714 </td <td>44</td> <td>Heat Flow</td> <td>(MW)</td> <td></td> <td>-109.0</td> <td></td> <td>-313.5</td> <td></td> <td>204.5</td> <td></td> <td></td>	44	Heat Flow	(MW)		-109.0		-313.5		204.5				
COMPOSITION 48 47 47 48 48 49 Vapour Fraction 0.1110 48 49 49 Vapour Fraction 0.1110 50 51 52 COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION MASS FLOW (kg/h) MASS FRACTION LIQUID VOLUME FLOW (m3/h) LIQUID VOLUME FRACTION 52 Zinc 4984.5660 0.1111 325940.7714 0.0715 46.9437 0.0068 53 Zinc-Oxide 0.0000 <	45	Liq Vol Flow @Std Cond	(m3/h)		3.489e+109 *		89.84		3.489e+109				
48 49 49 49 50 50 51 50 51 50 50 50 50 50 50 50 50 50 50 50 50 50	40					C	OMPOSITION						
50 COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION MASS FLOW (kg/h) MASS FRACTION LIQUID VOLUME FLOW (m3/h) LIQUID VOLUME FRACTION 52 Zinc 4984.5660 0.1111 325940.7714 0.0715 46.9437 0.0068 53 Zinc-Oxide 0.0000 0.0000 0.0000 0.0000 0.0000 54 Nitrogen 0.0000 0.0000 0.0000 0.0000 0.0000 55 Oxygen 0.0000 0.0000 0.0000 0.0000 0.0000 55 Oxygen 0.0000 0.0000 0.0000 0.0000 0.0000 56 Water 4984.5660 0.1111 89798.3523 0.0197 89.9714 0.0130 57 Tin-White 34891.9621 0.7778 4.142024817e+06 0.9088 6778.9151 0.9802 58 Hydrogen 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 60 44861.0941 1.0000 4.557763941e+06 1.0000	48 49					C	verall Phase			Vapour F	raction 0.1110		
Start Control Control <thcontrol< th=""> <thcontrol< th=""> <thcon< td=""><td>50 51</td><td>COMPONENTS</td><td>MOLAR FL</td><td>OW h)</td><td>MOLE FRACT</td><td>ON</td><td>MASS FLOW</td><td></td><td>MASS FRACTION</td><td>LIQUID VOLUME</td><td>LIQUID VOLUME</td></thcon<></thcontrol<></thcontrol<>	50 51	COMPONENTS	MOLAR FL	OW h)	MOLE FRACT	ON	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME		
53 Zinc-Oxide 0.0000 0.0000 0.0000 0.0000 0.0000 54 Nitrogen 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 55 Oxygen 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 56 Water 4984.5660 0.1111 89798.3523 0.0197 89.9714 0.0130 57 Tin-White 34891.9621 0.7778 4.142024817e+06 0.9088 6778.9151 0.9802 58 Hydrogen 0.0000 0.0000 0.0000 0.0000 0.0000 59 Total 44861.0941 1.0000 4.557763941e+06 1.0000 6915.8302 1.0000 60	52	Zinc	4984	.5660	0.1	111	325940.771	4	0.0715	46.9437	0.0068		
54 Nitrogen 0.0000 <td>53</td> <td>Zinc-Oxide</td> <td>0</td> <td>.0000</td> <td>0.0</td> <td>000</td> <td>0.000</td> <td>0</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	53	Zinc-Oxide	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000		
55 Oxygen 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 56 Water 4984.5660 0.1111 89798.3523 0.0197 89.9714 0.0130 57 Tin-White 34891.9621 0.7778 4.142024817e+06 0.9088 6778.9151 0.9802 58 Hydrogen 0.0000 0.0000 0.0000 0.0000 0.0000 59 Total 44861.0941 1.0000 4.557763941e+06 1.0000 6915.8302 1.0000 60 Image: Contract State Sta	54	Nitrogen	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000		
56 Water 4984.5660 0.1111 89798.3523 0.0197 89.9714 0.0130 57 Tin-White 34891.9621 0.7778 4.142024817e+06 0.9088 6778.9151 0.9802 58 Hydrogen 0.0000 0.0000 0.0000 0.0000 0.0000 59 Total 44861.0941 1.0000 4.557763941e+06 1.0000 6915.8302 1.0000 60	55	Oxygen	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000		
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58 Hydrogen 0.0000 0.0000 0.0000 0.0000 0.0000 59 Total 44861.0941 1.0000 4.557763941e+06 1.0000 6915.8302 1.0000 60	57	Tin-White	34891	.9621	0.7	778	4.142024817e+0	6	0.9088	6778.9151	0.9802		
59 Total 44861.0941 1.0000 4.557763941e+06 1.0000 6915.8302 1.0000 60	58	Hydrogen	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000		
60 61 62 63 Aspen Technology Inc. Licensed to: BATTELLE ENERGY ALLIANCE	59	Total	44861	.0941	1.0	000	4.557763941e+0	6	1.0000	6915.8302	1.0000		
Licensed to: BATTELLE ENERGY ALLIANCE * Specified by user	60 61 62 63	Aspen Technology In			A	spen	HYSYS Version	12	1		Page 2 of 9		
appended of aper-		Licensed to: BATTELLE ENER	RGY ALLIANCE		0	-port		16			* Specified by user.		

3 3 3 BATTELE ENERGY ALLIANCE USA Unit Set: AnneySte 0 0 Material Stream: Reactants (continued) Property Parkage: Agen Properties (Solido) 0 0 COMPOSITION Property Parkage: Agen Properties (Solido) 0 0 COMPORENTS MOLAR FLOW Mass PLOW Mass PLOW 10 0 COMPORENTS MOLAR FLOW MASS PLOW	1						Case Name: Pro	duction.hsc		
Instrume User Fild Parkage: Reaction 0 Material Stream: Reactants (continued) Paid Parkage: Agent Properties (Solds) 0 COMPOSITION Composition Composition 0 10 COMPOSITION Mass PRACTION Mole Parkage: Agent Properties (Solds) 12 Composition Mole Praction 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0000 <td< td=""><td>2</td><td>() aspentech</td><td>BATTELLE Bedford, M</td><td>ENERG</td><td>Y ALLIANCE</td><td></td><td>Unit Set: Am</td><td>evS2e</td><td></td><td></td></td<>	2	() aspentech	BATTELLE Bedford, M	ENERG	Y ALLIANCE		Unit Set: Am	evS2e		
6 Date million Printer als Distribution 7 Atterial Stream: Reactants (continued) Private Distribution Reaction 7 0 COMPOSITION Property Package: Agent Properties (Solida) 11 COMPOSITION Wasser Fraction 0.0017 0.0017 0.0017 0.0017 0.0017 0.0017 0.0017 0.0017 0.0017 0.0017 0.0017 0.0017 0.0017 0.0017 0.0017 0.0017 0.0017 0.0000 <	4	Caropentoen	USA			\vdash	Date/Time: Eril	Mar 20 45-24-40 2024		
1 Material Stream: Reactants (continued) Prior Package: Agen Properties (Solds) 0 COMPOSITION Property Package: Agen Properties (Solds) 10 COMPOSITION Nass FLOW Mass FLOW 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0000 <td>5</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>Date/Time: Fn1</td> <td>Mar 29 15:31:10 2024</td> <td></td> <td></td>	5						Date/Time: Fn1	Mar 29 15:31:10 2024		
0 COMPOSITION 11 COMPORENTS Press Praction 0.1110 12 Vapour Phase Press Praction 0.1110 13 COMPORENTS MOLE FRACTION MASS FRACTON USUU VOLUME FRACTON 14 Zine 0.0033 0.0001 20.1560 0.0002 0.0000	6 7 8	Mater	rial Stre	am:	Reactar	nts	(continue	d) Flui Pro	id Package: Rei perty Package: Ass	action pen Properties (Solids)
Vapour Phase Phase Fraction 0.1110 12 COMPONENTS MOLAR FLOW (ligmolefh) MASS FLOW (ligmolefh) MASS FRACTION (ligmolefh) LiQUID VOLUME FLOW (mich FLOW (mich Mich FLOW (mich FLOW (mich Mich FLOW (mich FLOW (mich FLOW (mich Mich FLOW (mich FLOW (mich </td <td>9</td> <td></td> <td></td> <td></td> <td></td> <td>с</td> <td>OMPOSITION</td> <td></td> <td></td> <td></td>	9					с	OMPOSITION			
12 COMPONENTS MOLLAR FLOW (kgmoleh) MOLE FRACTION MASS FLOW (kgmoleh) MASS FRACTION LIQUID VOLUME FLOW (mX) LIQUID VOLUME FRACTION 16 Zne-Oade 0.0001 0.0000	11					v	apour Phase		Phase Fra	ction 0.1110
11 COMPORENTS MOLAR FLOW MALE FRACTION MASS FRACTION LUBUID VOLUME LUDUID VOLUME FRACTION LUDUID VOLUME FRACTION LUDUID VOLUME LUDUID VOLUME FRACTION LUDUID VOLUME FRACTION LUDUID VOLUME FRACTION LUDUID VOLUME FRACTION LUDUID VOLUME	12									
Inc 0.083 0.0001 20:500 0.0002 0.0002 0.0000 0.0000 IS Zin-Cuicke 0.0000	13 14	COMPONENTS	MOLAR FL (kgmole/	ow h)	MOLE FRACTIC	N	MASS FLOW (kg/h)	MASS FRACTION	FLOW (m3/h)	FRACTION
Image Decode Decode <thdecode< th=""> Decode <thdecode< th=""> <thdecode< th=""></thdecode<></thdecode<></thdecode<>	15	Zinc	0	3083	0.00	01	20.1580	0.0002	0.0029	0.0000
Imagen 0.0000	18	Zinc-Oxide	0	0000	0.00	00	0.0000	0.0000	0.0000	0.0000
In Oxogen 0.0000 <td>17</td> <td>Nitrogen</td> <td>0</td> <td>0000</td> <td>0.00</td> <td>00</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	17	Nitrogen	0	0000	0.00	00	0.0000	0.0000	0.0000	0.0000
19 Water 4477.650 0.9990 8967.3131 0.9988 89.8466 1.0000 21 Th-Wnhe 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 21 Total 497.7913 1.000 0.688.39710 1.0000 68.8495 1.0000 21 Coll (tgmideh) MOLAR FLOW MASS FRACTION L/QUID VOLUME FRACTON 22 Zine 4498.2571 0.1230 325920.6134 0.0729 446.9408 0.0009 28 Zine-coxide 0.0000	18	Oxygen	0	0000	0.00	00	0.0000	0.0000	0.0000	0.0000
Diame 0.0000 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 4977.9613 1.0000 8683.9710 1.0000 868.495 1.0000 23 COMPONENTS MOLA FLOW MOLE FRACTION MASS FLOW MASS FRACTION LQUID VOLUME LQUID VOLUME LQUID VOLUME LQUID VOLUME 0.0000 0.	19	Water	4977	6530	0.99	99	89673.8131	0.9998	89.8466	1.0000
21 Hydrogen 0.0000 <td>20</td> <td>Tin-White</td> <td>0</td> <td>0000</td> <td>0.00</td> <td>00</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	20	Tin-White	0	0000	0.00	00	0.0000	0.0000	0.0000	0.0000
22 Total 4977.9613 1.0000 89893.9710 1.0000 89.8495 1.0000 23 Liquid Phase Phase Fraction 0.8890 24 Liquid Phase Phase Fraction 0.8890 25 COMPONENTS MOLAR FLOW (sigmole/h) MOLE FRACTION (sigmole/h) MASS FRACTION (sigmole/h) MASS FRACTION (sigmole/h) LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION 27 Zne 4984.2577 0.1250 325920 6134 0.0729 46.9408 FRACTION (sigmole/h) LIQUID VOLUME FRACTION FRACTION LIQUID VOLUME FRACTION FIGUID PLANE FRACTION LIQUID VOLUME FRACTION FIGUID PLANE FIGUID PLANE <th< td=""><td>21</td><td>Hydrogen</td><td>0</td><td>0000</td><td>0.00</td><td>00</td><td>0.0000</td><td>0.0000</td><td>0.0000</td><td>0.0000</td></th<>	21	Hydrogen	0	0000	0.00	00	0.0000	0.0000	0.0000	0.0000
20 Liquid Phase Phase Fraction 0.8890 24 COMPONENTS MOLAR FLOW (ligmbeth) MASS FLOW (lighb) MASS FLOW (lighb) MASS FLOW (lighb) MASS FLOW (lighb) LIQUID VOLUME FLOW (mSh) LIQUID VOLUME FRACTION 27 Zinc 4984.2577 0.1250 325920.8134 0.0729 46.9408 0.0000<	22	Total	4977	9613	1.00	00	89693.9710	1.0000	89.8495	1.0000
Aligned Liquid Phase Phase Fraction 0.8890 22 COMPONENTS MOLAR FLOW (ligmoide) MOLE FRACTION (ligmoide) MASS FLOW (ligh) MASS FRACTION (ligh) LIQUID VOLUME (FRACTION 2000 LIQUID VOLUME FRACTION 2000 LIQUID VOLUME FRACTION 2000 LIQUID VOLUME FRACTION 2000 LIQUID VOLUME 2000 LIQUID VOLUME 2000 <td< td=""><td>23</td><td></td><td></td><td></td><td></td><td>-</td><td></td><td></td><td></td><td></td></td<>	23					-				
20 COMPONENTS MOLAR FLOW (kgmleh) MASS FLOW (kghl) MASS FRACTION (kghl) LIQUID VOLUME PLOW (m3h) LIQUID VOLUME PROW (m3h) 27 Zine 4984.2577 0.1250 325520.6134 0.0729 46.9408 0.0000 28 Zine-Oxide 0.0000	24					L	iquid Phase		Phase Fra	ction 0.8890
cs (bymolefh) (byh) FLOW (m3/h) FRACTION 27 Zinc 4984.2577 0.1250 325920.6134 0.0729 46.9408 0.0089 28 Zinc-Oxide 0.0000<	25	COMPONENTS	MOLAR FL	ow	MOLE FRACTIC	N	MASS FLOW	MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME
27 Zinc 4494.2577 0.1250 32592.0134 0.0729 449.408 0.0000 27 Zinc-Oxide 0.0000 <td>26</td> <td></td> <td>(kgmole/</td> <td>h)</td> <td></td> <td></td> <td>(kg/h)</td> <td></td> <td>FLOW (m3/h)</td> <td>FRACTION</td>	26		(kgmole/	h)			(kg/h)		FLOW (m3/h)	FRACTION
28 Zinc-Oxide 0.0000	27	Zinc	4984	2577	0.12	50	325920.6134	0.0729	46.9408	0.0069
20 Nitrogen 0.0000 </td <td>28</td> <td>Zinc-Oxide</td> <td>0</td> <td>0000</td> <td>0.00</td> <td>00</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	28	Zinc-Oxide	0	0000	0.00	00	0.0000	0.0000	0.0000	0.0000
30 Oxygen 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.1248 0.0000 31 Thr/White 34891.9621 0.8749 4.142024817e-06 0.9270 677.8151 0.9931 33 Hydrogen 0.0000 </td <td>29</td> <td>Nitrogen</td> <td>0</td> <td>0000</td> <td>0.00</td> <td>00</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	29	Nitrogen	0	0000	0.00	00	0.0000	0.0000	0.0000	0.0000
31 Water 6.9130 0.0002 124.5393 0.0000 0.1248 0.0000 32 Tin-White 34891.9621 0.6749 4.142024817e+06 0.9270 6778.9151 0.9331 34 Total 39683.1328 1.0000 4.468069970e+06 1.0000 6825.9806 1.0000 Material Stream: Products Fuid Package: Reaction CONDITIONS GOVER TOW (Kgnole) CONDITIONS CONDITIONS CONDITIONS CONDITIONS CONDITIONS Madremating (Mathering (Mathering (Mathering (Mathering (Mathering (Mathering (Mathering (Mathering (Mathering (Mather	30	Oxygen	0	0000	0.00	00	0.0000	0.0000	0.0000	0.0000
32 Tin-White 34891,9621 0.8749 4.142024817e+06 0.9270 6778,9151 0.9931 33 Hydrogen 0.0000 0.0000 0.0000 0.0000 0.0000 34 Total 39883,1328 1.0000 4.468069970e+06 1.0000 6625,9806 1.0000 36 Material Stream: Property Package: Reaction 0.0001 0.0001 0.0001 38 Transparature: CONDITIONS Fluid Package: Reaction 40 Overall Vapour Phase Liquid Phase	31	Water	6.9130		0.00	02	124.5393	0.0000	0.1248	0.0000
33 Hydrogen 0.0000 </td <td>32</td> <td>Tin-White</td> <td>34891</td> <td>9621</td> <td>0.87</td> <td>49</td> <td>4.142024817e+06</td> <td>0.9270</td> <td>6778.9151</td> <td>0.9931</td>	32	Tin-White	34891	9621	0.87	49	4.142024817e+06	0.9270	6778.9151	0.9931
34 Total 39883.1328 1.0000 4.468069970e+06 1.0000 6825.9806 1.0000 36 Material Stream: Products Fluid Package: Reaction 37 Property Package: Aspen Properties (Solids) Property Package: Aspen Properties (Solids) 38 0 CONDITIONS CONDITIONS CONDITIONS CONDITIONS 40 Vapour / Phase Fraction 0.1110 0.1110 0.8890 Condition 41 Vapour / Phase Fraction 0.1110 0.1110 0.8890 Condition 42 Temperature: (bcr) 1.013 1.013 1.013 43 Molar Flow (kgmole/h) 4.486e+004 * 4982 3.988e+004 Condition 44 Molar Enthapy (kJkgmole) 1.889 2.426e+004 -1468 Condition 45 Molar Enthapy (kJkgmole) 1.555e+100 3.489e+109 COMPOSITION 56 COMPONENTS MOLAR FLOW MOLE FRACTION MASS FRACTION LiQUID VOLUME FRACTIO	33	Hydrogen	0	0000	0.00	00	0.0000	0.0000	0.0000	0.0000
36 Material Stream: Products Fluid Package: Reaction 37 Property Package: Aspen Properties (Solide) 38 CONDITIONS 40 Overall Vapour Phase Liquid Phase 40 40 Overall Vapour Phase Liquid Phase 40 41 41 Vapour / Phase Fraction 0.1110 0.8890 41 41 42 Temperature: (C) 844.6 844.6 844.6 44 43 Pressure: (bar) 1.013 1.013 1.013 1.013 44 Molar Filow (kgmoleh) 4.488e+004 * 4982 3.986+004 44 45 Mass Flow (kgip) 1266 2.790 1263 44 46 Molar Entropy (kJikgmole) 1389 2.428e+004 -1468 44 48 Molar Entropy (kJikgmole) 1.357 -16.26 44 44 49 Heat Flow (WW) 1.3555+100 3.489e+109	34	Total	39883	1328	1.00	00	4.468069970e+06	1.0000	6825,9806	1.0000
Base Flow Material Stream: Products Instruction 37 Property Package: Aspen Properties (Solids) 38 CONDITIONS CONDITIONS 40 Overall Vapour Phase Liquid Phase	35							Ehri	d Dackane: Re	action
Interformed of a construction of a constructing construction of a construction of a construction	38	Mater	ial Stre	am:	Product	S		110	io raciago. No	800011
SONDITIONS 10 Overall Vapour Phase Liquid Phase Image: Colspan="2">CONDITIONS 40 Vapour / Phase Fraction 0.1110 0.1110 0.8890	37							Pro	perty Package: Asp	pen Properties (Solids)
39 Vapour Phase Liquid Phase Liquid Phase 40 Overall Vapour Phase Liquid Phase Image: Constraint of the constratent of the constraint of the constand of the constraint of the c	38					0	CONDITIONS			
41 Vapour / Phase Fraction 0.1110 0.1110 0.8890 42 Temperature: (C) 844.6* 844.6 844.6 43 Pressure: (bar) 1.013 1.013 1.013 44 Molar Flow (kgmole/h) 4.486e+004* 4982 3.988e+004 45 Mass Flow (kgmole/h) 4.486e+004* 4982 3.988e+004 46 Molar Enthalpy (kJkgmole) 1266 2.790 1263 47 Molar Enthalpy (kJkgmole) 1389 2.426e+004 -1468 48 Molar Enthalpy (kJkgmole-C) 64.87 36.91 66.11 49 Heat Flow (MW) 17.30 33.57 -16.26	39 40				Overall	V	apour Phase	Liquid Phase		
42 Temperature: (C) 844.6 * 844.6 844.6 43 Pressure: (bar) 1.013 1.013 1.013 1.013 44 Molar Flow (kgmole/h) 4.486e+004 * 4982 3.988e+004	41	Vapour / Phase Fraction			0.1110	-	0.1110	0.8890		
43 Pressure: (bar) 1.013 1.013 1.013 44 Molar Flow (kgmole/h) 4.486e+004 * 4982 3.988e+004 445 45 Mass Flow (kg/s) 1266 2.790 1263 455 46 Std Ideal Liq Vol Flow (m3/h) 8014 266.8 7747 475 47 Molar Enthalpy (kJ/kgmole) 1389 2.426e+004 -1468 465 48 Molar Enthalpy (kJ/kgmole-C) 64.87 38.91 68.11 466 49 Heat Flow (MW) 17.30 33.57 -16.26 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 56 57 57 57 57 57 100 0.0000 0.0000 0.0000 56 57 57 57 57 57 57 57 57 57 57 57 57 57	42	Temperature:	(C)		844.6 *		844.6	844.6		
44 Molar Flow (kgmole/h) 4.486e+004 * 4982 3.988e+004 45 Mass Flow (kg/s) 1266 2.790 1263	43	Pressure:	(bar)		1.013		1.013	1.013		
45 Mass Flow (kg/s) 1266 2.790 1263 46 Std Ideal Lig Vol Flow (m3/h) 8014 266.8 7747 47 Molar Enthalpy (kJ/kgmole) 1389 2.426e+004 -1468 48 Molar Entropy (kJ/kgmole) 1389 2.426e+004 -1468 49 Heat Flow (MW) 17.30 33.57 -16.26 50 Lig Vol Flow @Std Cond (m3/h) 3.489e+109 * 1.555e+100 3.489e+109 51 COMPOSITION COMPOSITION 0.1110 53 53 COMPONENTS MOLAR FLOW MOLE FRACTION MASS FLOW MASS FRACTION LiQUID VOLUME FRACTION 54 Stinc-Oxide 4984.5660 0.1111 405690.8368 0.0890 968.4164 0.1208 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 <	44	Molar Flow	(kgmole/h)		4.486e+004 *		4982	3.988e+004		
46 Std Ideal Liq Vol Flow (m3/h) 8014 266.8 7747 47 Molar Enthalpy (kJ/kgmole) 1389 2.426e+004 .1468	45	Mass Flow	(ka/s)		1266		2.790	1263		
47 Molar Enthalpy (kJ/kgmole) 1389 2.426e+004 -1468 48 Molar Entropy (kJ/kgmole-C) 64.87 38.91 66.11 49 Heat Flow (MW) 17.30 33.57 -16.26 50 Liq Vol Flow @Std Cond (m3/h) 3.489e+109 1.555e+100 3.489e+109 51 COMPOSITION COMPOSITION 0.1110 54 0 0.1110 54 Overall Phase Vapour Fraction 0.1110 1.100 55 COMPONENTS MOLAR FLOW MOLE FRACTION MASS FLOW MASS FRACTION LIQUID VOLUME LIQUID VOLUME FRACTION 56 COMPONENTS MOLAR FLOW MOLE FRACTION MASS FLOW MASS FRACTION LIQUID VOLUME FRACTION 57 Zinc 0.0000 <td>48</td> <td>Std Ideal Lig Vol Flow</td> <td>(m3/h)</td> <td></td> <td>8014</td> <td></td> <td>266.8</td> <td>7747</td> <td></td> <td></td>	48	Std Ideal Lig Vol Flow	(m3/h)		8014		266.8	7747		
Initial Entropy (kJ/kgmole-C) 64.87 38.91 68.11 48 Molar Entropy (kJ/kgmole-C) 64.87 38.91 68.11 50 Liq Vol Flow @Std Cond (MW) 17.30 33.57 -16.26 50 Liq Vol Flow @Std Cond (m3/h) 3.489e+109 * 1.555e+100 3.489e+109 51 COMPOSITION 52 Vapour Fraction 0.1110 54 Overall Phase Vapour Fraction 0.1110 55 COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION (kg/h) MASS FLOW (kg/h) MASS FRACTION LIQUID VOLUME FLOW (m3/h) FRACTION 57 Zinc 0.0000 0.0000 0.0000 0.0000 0.0000 58 Zinc-Oxide 4984.5660 0.1111 405690.8368 0.0890 968.4164 0.1208 59 Nitrogen 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 60 Oxygen 0.0000 0.00000 0.0000 0.0000 </td <td>47</td> <td>Molar Enthalov</td> <td>(kJ/komole)</td> <td></td> <td>1389</td> <td></td> <td>2.426e+004</td> <td>-1468</td> <td></td> <td></td>	47	Molar Enthalov	(kJ/komole)		1389		2.426e+004	-1468		
Internation Other	48	Molar Entropy	(kJ/kgmole-C)		64.87	_	38.91	68.11		
Index Index <th< td=""><td>49</td><td>Heat Flow</td><td>(MW)</td><td></td><td>17.30</td><td>_</td><td>33.57</td><td>-16.26</td><td></td><td></td></th<>	49	Heat Flow	(MW)		17.30	_	33.57	-16.26		
Instruction Composition Construction Constructin Construction Construction <td>50</td> <td>Lig Vol Flow @Std Cond</td> <td>(m3/h)</td> <td></td> <td>3.489e+109 *</td> <td></td> <td>1.555e+100</td> <td>3.489e+109</td> <td></td> <td></td>	50	Lig Vol Flow @Std Cond	(m3/h)		3.489e+109 *		1.555e+100	3.489e+109		
Solution COMPOSITION 52 Composition Vapour Fraction 0.1110 54 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 58 Zinc-Oxide 4984.5660 0.1111 405690.8368 0.0890 968.4164 0.1208 59 Nitrogen 0.0000 0.0000 0.0000 0.0000 0.0000 60 Oxygen 0.0000 0.0000 0.0000 0.0000 0.0000 61 Water 0.0000 0.0000 0.0000 0.0000 0.0000 62 Tin-White 34891.9621 0.7778 4.142024817e+06 0.9088 6778.9151 0.849 63 Aspen Technology Inc Aspen HYSYS Version 12.1 Pare 3.659 Pare 3.659	51	Eld tort for Good Cond	(mority		0.1000.100	_	1.0000.100	0.1000.100		
63 54 Overall Phase Vapour Fraction 0.1110 54 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 4984.5660 0.1111 405690.8368 0.0890 968.4164 0.1208 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 61 Water 0.0000 0.0000 0.0000 0.0000 0.0000 62 Tin-White 34891.9621 0.7778 4.142024817e+06 0.9088 6778.9151 0.8459 63 Aspen Technology Inc Aspen HYSYS Version 12.1 Pane 3 of 9	52					C	OMPOSITION			
Overall Phase Vapour Fraction 0.1110 54 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 4984.5660 0.1111 405690.8368 0.0890 968.4164 0.1208 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 34891.9621 0.7778 4.142024817e+06 0.9088 6778.9151 0.8459 63 Aspen Technology Inc Aspen HYSYS Version 12.1 Pane 3 of 9	52									
55 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 4984.5660 0.1111 405690.8368 0.0890 968.4164 0.1208 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 34891.9621 0.7778 4.142024817e+06 0.9088 6778.9151 0.8459 63 Aspen Technology Inc Aspen HYSYS Version 12.1 Pane 3 of 9	54					0	verall Phase		Vapour Fra	action 0.1110
66 (kgmole/h) Index record (kg/h) Edd to for total Edd to for total 56 (kgmole/h) (kg/h) (kg/h) FLOW (m3/h) FRACTION 57 Zinc 0.0000 0.0000 0.0000 0.0000 0.0000 58 Zinc-Oxide 4984.5660 0.1111 405690.8368 0.0890 968.4164 0.1208 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 0.0000 61 Water 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 62 Tin-White 34891.9621 0.7778 4.142024817e+06 0.9088 6778.9151 0.8459 63 Aspen Technology Inc Aspen HYSYS Version 12.1 Pane 3 of 9	55	COMPONENTS	MOLAR EL	ow	MOLE FRACTIC	N	MASSELOW	MASS FRACTION		
S7 Zinc 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 58 Zinc-Oxide 4984.5660 0.1111 405690.8368 0.0890 968.4164 0.1208 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 34891.9621 0.7778 4.142024817e+06 0.9088 6778.9151 0.8459 63 Aspen Technology Inc Aspen HYSYS Version 12.1 Pare 3 of 9	58	COM CHENTS	(kamole/	h)	inore monorite		(kg/h)	in so monon	FLOW (m3/h)	FRACTION
Inc. Dide 0.0000 0.00	57	Zinc	0	0000	0.00	00	0.000	0.000	0,0000	0.000
Encode Horsday Horsday <th< td=""><td>59</td><td>Zinc-Ovide</td><td>4004</td><td>5660</td><td>0.11</td><td>11</td><td>405600 8369</td><td>0.0000</td><td>068 4164</td><td>0.0000</td></th<>	59	Zinc-Ovide	4004	5660	0.11	11	405600 8369	0.0000	068 4164	0.0000
Integration 0.0000 0.	50	Nitrogen	4304	0000	0.00	00	0.0000	0.0030	0.0000	0.0000
Construct Construct <t< td=""><td>80</td><td>Ovvicen</td><td>0</td><td>0000</td><td>0.00</td><td>00</td><td>0.0000</td><td>0.0000</td><td>0.000</td><td>0.0000</td></t<>	80	Ovvicen	0	0000	0.00	00	0.0000	0.0000	0.000	0.0000
or real 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 62 Tin-White 34891.9621 0.7778 4.142024817e+06 0.9088 6778.9151 0.8499 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 3 of 9	81	Water		0000	0.00	00	0.000	0.0000	0.000	0.0000
Aspen Technology Inc Aspen HYSYS Version 12.1 Page 3 of 9	82	Tip White	24004	0000	0.00	78	4 1420249170+00	0.000	6779.0454	0.0000
	82	Aspen Technology Inc	34091	0021	0.77	hen	HYSYS Version 12	1	0//0.9131	Page 3 of 9

1					Case Name: Pro	oduction.hsc		
3	@aspen tech	BATTELLE EI Bedford, MA	NERGY ALLIANCE		Unit Set: An	neyS2e		
4		USA		Ī	Date/Time: Fri	Mar 29 15:31:10 2024		
6 7 8	Mate	rial Strea	m: Produc	ts	(continued	Flui Pro	d Package: Re perty Package: As	action pen Properties (Solids)
9				c	OMPOSITION			
11			Ov	eral	Phase (continue	ed)	Vapour Fr	action 0.1110
12	COMPONENTS	MOLAR FLOW	MOLE FRACT	ION	MASS FLOW	MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME
14		(kgmole/h)			(kg/h)		FLOW (m3/h)	FRACTION
15	Hydrogen	4984.56	60 0.1	111	10048.2869	0.0022	266.9624	0.0333
17	Total	44001.09	41 1.0	000	4.5577639416+06	1.0000	0014.2939	1.0000
18				'	apour Phase		Phase Fra	action 0.1110
19 20	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACT	ION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	FRACTION
21	Zinc	0.00	0.0	000	0.0000	0.0000	0.0000	0.0000
22	Zinc-Oxide	0.00	01 0.0	000	0.0048	0.0000	0.0000	0.0000
23	Nitrogen	0.00	0.0	000	0.0000	0.0000	0.0000	0.0000
24	Oxygen	0.00	0.0	000	0.0000	0.0000	0.0000	0.0000
28	Tin-White	0.00	0.0	000	0.0000	0.0000	0.0000	0.0000
27	Hydrogen	4981.76	48 1.0	000	10042.6401	1.0000	266.8124	1.0000
28	Total	4981.76	49 1.0	000	10042.6468	1.0000	266.8124	1.0000
29 30				1	Liquid Phase		Phase Fra	action 0.8890
31 32	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACT	ION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
33	Zinc	0.00	0.0	000	0.0000	0.0000	0.0000	0.0000
34	Zinc-Oxide	4984.56	60 0.1	250	405690.8320	0.0892	968,4164	0.1250
35	Nitrogen	0.00	0.0	000	0.0000	0.0000	0.0000	0.0000
38	Oxygen	0.00	0.0	000	0.0000	0.0000	0.0000	0.0000
3/	Water Tin White	34891.96	21 0.8	749	4 142024815e±06	0.0000	6778 9151	0.0000
39	Hydrogen	2.80	12 0.0	001	5.6468	0.0000	0.1500	0.0000
40	Total	39879.32	92 1.0	000	4.547721294e+06	1.0000	7747,4815	1.0000
41 42 43 44	Mate	rial Strea	m: Reactio	onl	H2	Flui Pro	d Package: Re perty Package: As	action pen Properties (Solids)
45					CONDITIONS			
46			Overall		Vapour Phase	Liquid Phase		
47	Vapour / Phase Fraction	(0)	1.0000		1.0000	0.0000		
49	Pressure:	(bar)	1.013		1.013	1.013		
50	Molar Flow	(kgmole/h)	4982		4982	0.0000		
51	Mass Flow	(kg/s)	2.790		2.790	0.0000		
52	Std Ideal Liq Vol Flow	(m3/h)	266.8		266.8	0.0000		
53	Molar Enthalpy	(kJ/kgmole)	2.426e+004		2.426e+004	-1468		
54	Molar Entropy	(kJ/kgmole-C)	38.91		38.91	68.11		
58	Lin Vol Flow @Std Cond	(MVV) (m3/b)	1 555e+100 *		33.57 1 555e+100	0.0000		
57 58 59 60 61 62	A T. 1 1							
63	Aspen Technology In	C.	A	spen	HYSYS Version 12	2.1		Page 4 of 9

1				Case Name:	Case Name: Production.hsc							
3	(e)aspentech	Bedford, MA	GY ALLIANCE	Unit Set:	AmeyS2e							
4		USA		Date/Time:	Fri Mar 29 15:31:10 202	4						
6 7 0	Mater	ial Stream	Reactio	nH2 (contin	iued)	luid Package: Re	action pen Properties (Solids)					
9				COMPOSITION								
10				Overall Phase		Vapour Fraction 1.0000						
12	COMPONENTS	MOLAR FLOW	MOLE ERACTIC	MASS FLOW	MASS FRACTION							
14		(kgmole/h)		(kg/h)		FLOW (m3/h)	FRACTION					
15	Zinc	0.0000	0.000	00.000	0 0.0000	0.0000	0.0000					
18	Zinc-Oxide	0.0001	0.000	0.004	8 0.0000	0.0000	0.0000					
17	Nitrogen	0.0000	0.000	000.00	0.0000	0.0000	0.0000					
18	Oxygen	0.0000	0.000	000.00	0.0000	0.0000	0.0000					
19	Water	0.0000	0.000	000.00	0.0000	0.0000	0.0000					
20	Tin-White	0.0000	0.000	0.001	8 0.0000	0.0000	0.0000					
21	Hydrogen	4981.7648	1.000	10042.640	1 1.0000	266.8124	1.0000					
22	Total	4981.7649	1.000	10042.646	8 1.0000	266.8124	1.0000					
23 24				Vapour Phase		Phase Fra	action 1.000					
25	COMPONENTS	MOLAR FLOW (kamole/h)	MOLE FRACTIC	MASS FLOW	MASS FRACTION	LIQUID VOLUME FLOW (m3/b)	LIQUID VOLUME FRACTION					
27	Zinc	0,0000	0.000	00 000	0 0000	0.0000	0 0000					
28	Zinc-Oxide	0.0001	0.000	0.004	8 0.0000	0.0000	0.0000					
29	Nitrogen	0.0000	0.000	0.000	0.0000	0.0000	0.0000					
30	Oxygen	0.0000	0.000	0.000	0 0.0000	0.0000	0.0000					
31	Water	0.0000	0.000	0.000	0 0.0000	0.0000	0.0000					
32	Tin-White	0.0000	0.00	0.001	8 0.0000	0.0000	0.0000					
33	Hydrogen	4981,7648	1.000	10042 640	1 1.0000	266.8124	1.0000					
34	Total	4981,7649	1.000	10042.646	8 1.0000	266.8124	1.0000					
35				Liquid Phase		Phase Fra	action 0.0000					
30	COMPONENTS	MOLARELOW	MOLE EPACTIC	MASS ELOW	MASS EPACTION		LIQUID VOLUME					
38	COMPONENTS	(kamole/h)	MOLETICACIO	(ka/h)	MASSITIACTION	FLOW (m3/h)	FRACTION					
39	Zinc	0.0000	0.00	0.000	0.0000	0.0000	0.0000					
40	Zinc-Oxide	0.0000	0.125	50 0.000	0 0.0892	0.0000	0.1250					
41	Nitrogen	0.0000	0.000	0.000	0.0000	0.0000	0.0000					
42	Oxygen	0.0000	0.000	0.000	0.0000	0.0000	0.0000					
43	Water	0.0000	0.000	0.000	0.0000	0.0000	0.0000					
44	Tin-White	0.0000	0.874	49 0.000	0.9108	0.0000	0.8750					
45	Hydrogen	0.0000	0.000	0.000	0.0000	0.0000	0.0000					
48	Total	0.0000	1.000	0.000	0 1.0000	0.0000	1.0000					
47 48 49	Mater	ial Stream	Loaded	Alloy	F	luid Package: Re roperty Package: As	action pen Properties (Solids)					
50				CONDITIONS								
52			Overall	Vapour Phase	Liquid Phase							
53	Vapour / Phase Fraction		0.0000	0.0000	1.0000							
54	Temperature:	(C)	844.6	844.6	844.6							
55	Pressure:	(bar)	1.013	1.013	1.013							
58	Molar Flow	(kgmole/h)	3.988e+004	0.0000	3.988e+004							
57	Mass Flow	(kg/s)	1263	0.0000	1263							
58	Std Ideal Liq Vol Flow	(m3/h)	7747	0.0000	7747							
59	Molar Enthalpy	(kJ/kgmole)	-1468	2.426e+004	-1468							
60	Molar Entropy (I	kJ/kgmole-C)	68.11	38.91	68.11							
61	Heat Flow	(MW)	-16.26	0.0000	-16.26							
02	Liq Voi Flow @Std Cond	(m3/h)	3.489e+109 *		3.489e+109		Dags 5 at 0					
00	Licensed to: BATTELLE ENERG	SY ALLIANCE	AS	control o version	14.1		* Specified by user.					

1				Case Name: Production.hsc								
3	(aspentech	BATTELLE E Bedford, MA	NERGY ALLIANCE		Unit Set: A	AmeyS2e						
4		USA			Date/Time: F	ri Mar 29 15:31	1:10 2024					
6 7 8	Mater	rial Strea	m: Loade	dAll	oy (contii	nued)	Flui Pro	d Package: Rea perty Package: Asp	action en Properties (Solids)			
9 10				C	OMPOSITION							
11				0	verall Phase			Vapour Fraction 0.000				
12	COMPONENTS	MOLAR FLOW	MOLE FRACT	ION	MASS FLOW	MASS FR	ACTION	LIQUID VOLUME	LIQUID VOLUME			
14		(kgmole/h)			(kg/h)			FLOW (m3/h)	FRACTION			
15	Zinc	0.00	00 0.	0000	0.0000)	0.0000	0.0000	0.0000			
16	Zinc-Oxide	4984.56	60 0.	1250	405690.8320		0.0892	968.4164	0.1250			
17	Nitrogen	0.00	00 0.	0000	0.0000	,	0.0000	0.0000	0.0000			
18	Oxygen	0.00	00 0.	0000	0.0000		0.0000	0.0000	0.0000			
19	Water	0.00	00 0.	0000	0.0000)	0.0000	0.0000	0.0000			
20	Tin-White	34891.96	21 0.	8749	4.142024815e+06	5	0.9108	6778.9151	0.8750			
21	Hydrogen	2.80	12 0.	0001	5.6468	3	0.0000	0.1500	0.0000			
22	Total	39879.32	.92 1.	0000	4.547721294e+06	5	1.0000	7747.4815	1.0000			
23 24	Vapour Phase Phase Fraction 0.000											
25 26	COMPONENTS	MOLAR FLOV (kgmole/h)	MOLE FRACT	NOI	MASS FLOW (kg/h)	MASS FR	ACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION			
27	Zinc	0.00	00 00	0000	0.0000		0.0000	0.0000	0.0000			
28	Zinc-Oxide	0.00	00 0.	0000	0.0000)	0.0000	0.0000	0.0000			
29	Nitrogen	0.00	00 0.	0000	0.0000		0.0000	0.0000	0.0000			
30	Oxygen	0.00	00 0	0000	0.000)	0.0000	0.0000	0.0000			
31	Water	0.00	00 0	0000	0.0000		0.0000	0.0000	0.0000			
32	Tin-White	0.00	00 0	0000	0.0000)	0.0000	0.0000	0.0000			
33	Hydrogen	0.00	00 1	0000	0.000		1 0000	0.0000	1,0000			
34	Total	0.00	00 1	0000	0.0000		1,0000	0.0000	1,0000			
35	- Coldi	0.00						0.0000				
36					iquid Phase			Phase Fra	ction 1.000			
37 38	COMPONENTS	MOLAR FLOV (kgmole/h)	MOLE FRACT	NOI	MASS FLOW (kg/h)	MASS FR	ACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION			
39	Zinc	0.00	0.00	0000	0.0000		0.0000	0.0000	0.0000			
40	Zinc-Oxide	4984.56	60 0.	1250	405690.8320		0.0892	968.4164	0.1250			
41	Nitrogen	0.00	00 0.	0000	0.0000		0.0000	0.0000	0.0000			
42	Oxygen	0.00	00 0.	0000	0.0000		0.0000	0.0000	0.0000			
43	Water	0.00	0.00	0000	0.0000		0.0000	0.0000	0.0000			
44	Tin-White	34891.96	21 0.	8749	4.142024815e+06	5	0.9108	6778,9151	0.8750			
45	Hydrogen	2.80	12 0.	0001	5.6468	3	0.0000	0.1500	0.0000			
46	Total	39879.32	92 1.	0000	4.547721294e+06	5	1.0000	7747,4815	1.0000			
47							Ehri	d Dackage: Re-	action			
48	Mater	ial Stream	m: Oxide	Allo	v		1 100	ar achage. The				
49					,		Pro	perty Package: Asp	en Properties (Solids)			
50												
51				0	ONDITIONS							
52			Overall	L	iquid Phase							
53	Vapour / Phase Fraction		0.0000		1.0000							
54	Temperature:	(C)	550.0		550.0							
55	Pressure:	(bar)	1.013		1.013							
56	Molar Flow	(kgmole/h)	3.988e+004		3.988e+004							
57	Mass Flow	(kg/s)	1263		1263							
58	Std Ideal Lig Vol Flow	(m3/h)	7747		7747							
59	Molar Enthalpy	(kJ/kgmole)	-1.305e+004		-1.305e+004							
60	Molar Entropy	(kJ/kgmole-C)	62.26		62.26							
61	Heat Flow	(MW)	-144.6		-144.6							
62	Lig Vol Flow @Std Cond	(m3/h)	3.489e+109 *		3.489e+109							
63	Aspen Technology Inc		A	spen	HYSYS Version	12.1			Page 6 of 9			
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ed by user.

1						Case Name: Production her								
2	(aspentech	BATTELLE Bedford M		Y ALLIANCE		Linit Set: A	meuS2e							
4	Censperiteen	USA	-			ont oct	1109520							
5						Date/Time: Fi	n Mar 29	15:31:10 2024						
6 7 8	Mater	ial Stre	am:	OxideA	llo	y (continu	ed)	Flui	d Package: Re perty Package: Asy	action pen Properties (Solids)				
9					с	COMPOSITION								
11					0	Overall Phase Vapour Fraction 0.0000								
12					-	i crait i nuse			Tupour I I					
13 14	COMPONENTS	MOLAR FL (kgmole/	OW h)	MOLE FRACT	ION	MASS FLOW (kg/h)	MAS	S FRACTION	FLOW (m3/h)	FRACTION				
15	Zinc	0	0000	0.0	000	0.000		0.0000	0.0000	0.0000				
18	Zinc-Oxide	4984	5660	0.1	250	405690.8320		0.0892	968.4164	0.1250				
17	Nitrogen	0	0000	0.0	000	0.000	_	0.0000	0.0000	0.0000				
18	Oxygen	0	0000	0.0	000	0.0000	_	0.0000	0.0000	0.0000				
19	Water	0	0000	0.0	000	0.0000		0.0000	0.0000	0.0000				
20	Tin-White	34891	9621	0.8	749	4.142024815e+06		0.9108	6778.9151	0,8750				
21	Hydrogen	2	8012	0.0	001	5.6468		0.0000	0.1500	0.0000				
22	Total	39879	3292	1.0	000	4,547721294e+06		1.0000	7747.4815	1.0000				
23 24 Liquid Phase Phase Fraction										ction 1.000				
25	COMPONENTS	NTS MOLAR FLOW			ION	MASS FLOW	MAS	S FRACTION	LIQUID VOLUME	LIQUID VOLUME				
20	Zinc	(ingitioneria)	0000		000	0.0000		0.0000	0.0000	0.0000				
28	Zinc Ovide	4984	5660	0.0	250	405690 8320	-	0.0000	968.4164	0.0000				
20	Nitrogen	4304	4984.5660		000	0.0000	-	0.0002	0.0000	0.0000				
20	Operan	0	0000	0.000		0.0000	-	0.0000	0.0000	0.0000				
31	Water	0	0.0000		000	0.0000	-	0.0000	0.0000	0.0000				
32	Tin White	34901	9621	0.0	740	4 1420249150+06	-	0.0000	6778 0151	0,0000				
22	Hudressen	White 34691.9621		0.0	004	4.1420240136400		0.9100	0//0.9151	0.0750				
24	Total	20070	2202	0.0	000	1.0400		1.0000	7747 4945	0.0000				
25	Total	39019	.5282	1.0	000	4.5477212546+00	_	1.0000	//4/.4015	1.0000				
20	Mator	ial Stro		Overha	ad	บว		Flui	d Package: Ov	erheads				
37	Water	iai Stre	ann.	Overne	au	112		Pro	perty Package: As	pen Properties (Peng-R				
38						CONDITIONS								
39 40				Overall	1	Vapour Phase								
41	Vanour / Phase Fraction			1 0000		1,0000								
42	Temperature:	(C)		844.6		844.6								
43	Pressure:	(bar)		1 013		1 013								
44	Molar Flow	(kamole/h)		4982		4982								
45	Mass Flow	(ka/s)		2 790		2 790								
48	Std Ideal Lig 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	Lig Vol Flow @Std Cond	(m3/h)		6.222e+063 *		6.222e+063								
51									I					
52					C	OMPOSITION								
53					0	verall Phase			Vapour Er	action 1 0000				
54	COMPONENTS	MOLAR EL	004	MOLEERACT		MASSELOW	MAC	EPACTION						
58	COMPONENTS	(kamole/	h)	MOLEFINGT		(kg/h)	MAS	TRACTION	FLOW (m3/h)	FRACTION				
57	Zinc	(ngritole)	0000	0.0	000	0.000		0.0000	0.0000	0,0000				
58	Zinc-Oxide	0	0001	0.0	000	0.0049		0.0000	0.0000	0.0000				
59	Nitrogen	0	0000	0.0	000	0.0040		0.0000	0.0000	0.0000				
60	Oxygen	0	0000	0.0	000	0.0000		0.0000	0.000	0,000				
61	Water	0	0000	0.0	000	0.0000		0.0000	0.0000	0,000				
62	Tin-White	0	0000	0.0	000	0.0018		0.0000	0.0000	0,0000				
63	Aspen Technology Inc			A	spen	en HYSYS Version 12,1 0.0000 0.0000 0.0000 0.0000								

1			201/11/10/25	Case	Name: Pro	oduction.hsc							
3	@aspentech	Bedford, MA	RGY ALLIANCE	Unit S	et: An	neyS2e							
4		USA		Date/T	îme: Fri	Mar 29 15:31:10 202	4						
6						F F	luid Package: O	verheads					
7	Mate	rial Stream	: Overhea	adH2	(contin	ued) _F	Property Package: As	spen Properties (Peng-R					
9				COMP	COMPOSITION								
10							(2) (1) (2)						
12			Over	rall Phas	se (continue	ed)	Vapour F	raction 1.0000					
13 14	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTIO	N M	ASS FLOW (kg/h)	MASS FRACTION	FLOW (m3/h)	FRACTION					
15	Hydrogen	4981.7648	1.000	00	10042.6401	1.0000	266.8124	1.0000					
16	Total	4981.7649	1.000	00	10042.6468	1.0000	266.8124	1.0000					
1/				Vapou	r Phase		Phase Fr	action 1.000					
19 20	COMPONENTS MOLAR FLOW (kgmole/h)		MOLE FRACTIO	N M	ASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION					
21	Zinc	0.0000	0.000	00	0.0000	0.000	0.0000	0.0000					
22	Zinc-Oxide	0.0001	0.000	00	0.0048	0.000	0.0000	0.0000					
23	Nitrogen	0.0000	0.000	00	0.0000	0.0000	0.0000	0.0000					
29	Oxygen	0.0000	0.000	0	0.0000	0.0000	0.0000	0.0000					
28	Tin-White	0.0000	0.000	00	0.0018	0.0000	0.0000	0.0000					
27	Hydrogen	4981.7648	1.000	00	10042.6401	1.0000	266.8124	1.0000					
28	Total	4981.7649	1.000	00	10042.6468	1.0000	266.8124	1.0000					
30 31 32	Material Stream: RxSteam Fluid Package: Reaction 31 Property Package: Aspen Properties (Solids) 32 CONDITIONS												
33			Querell	Vanour	Dhase								
35	Vapour / Phase Fraction		1.0000	vapour	1.0000								
36	Temperature:	(C)	450.0		450.0								
37	Pressure:	(bar)	1.013		1.013								
38	Molar Flow	(kgmole/h)	4985		4985								
39	Mass Flow	(kg/s)	24.94		24.94								
40	Std Ideal Lig Vol Flow	(m3/h)	89.97	21	89.97								
42	Molar Entropy	(kJ/kgmole_C)	-2.2000+005	-2.4	-13.30								
43	Heat Flow	(MW)	-314.0		-314.0								
44	Liq Vol Flow @Std Cond	(m3/h)	89.96 *		89.96								
45 48				COMP	OSITION								
47				Overa	II Phase		Vapour F	raction 1.0000					
49	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTIO	N M	ASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION					
51	Zinc	0.0000	0.000	00	0.0000	0.000	0.0000	0.0000					
52	Zinc-Oxide	0.0000	0.000	00	0.0000	0.0000	0.0000	0.0000					
53	Nitrogen	0.0000	0.000	00	0.0000	0.0000	0.0000	0.0000					
54	Oxygen	0.0000	0.000	00	0.0000	0.000	0.0000	0.0000					
55	Water	4984.5660	1.000	00	89798.3523	1.000	89.9714	1.0000					
57	Hydrogen	0.0000	0.000		0.0000	0.0000	0.0000	0.0000					
58	Total	4984 5660	1.000	00	89798 3523	1,000	89.9714	1.0000					
59 60 61 62 63	Aspen Technology In	c.	Asp	en HYSY	'S Version 12	2.1		Page 8 of 9					
-	Licensed to: BATTELLE ENER	RGY ALLIANCE						* Specified by user.					

1		Case Name: Production.hsc								
3	(aspentech	BATTELLE ENERG Bedford, MA	Y ALLIANCE	Unit Set: An	neyS2e					
4		USA		Date/Time: Fri	Mar 29 15:31:10 20	024				
6						Fluid Package: F	leaction			
7	Materia	I Stream:	RxSteam	(continued	l)	Property Package: A	spen Properties (Solids)			
9				COMPOSITION						
10				COMPOSITION						
12				Vapour Phase		Phase F	raction 1.000			
13	COMPONENTS	MOLAR FLOW	MOLE FRACTION	MASS FLOW	MASS FRACTIO	N LIQUID VOLUME	LIQUID VOLUME			
14	Zinc	(kgmole/h) 0.0000	0.0000	(kg/n) 0.0000	0.00	00 0.0000	0.0000			
18	Zinc-Oxide	0.0000	0.0000	0.0000	0.00	00 0.0000	0.0000			
17	Nitrogen	0.0000	0.0000	0.0000	0.00	00 0.0000	0.0000			
18	Oxygen	0.0000	0.0000	0.0000	0.00	0000.0000	0.0000			
19	Water	4984.5660	1.0000	89798.3523	1.00	00 89.9714	1.0000			
20	Tin-White	0.0000	0.0000	0.0000	0.00	00 0.0000	0.0000			
21	Hydrogen	0.0000	0.0000	0.0000	0.00	0000.0	0.0000			
22	Total	4984,5660	1.0000	89798.3523	1.00	00 89.9714	1.0000			
23						Fluid Package: R	leaction			
24	Energy	v Stream:	ReactorH	leat		Thora Tuchage.				
25		,				Property Package: A	spen Properties (Solids)			
26				CONDITIONS						
27				CONDITIONS						
28	Duty Type:	Direct Q	Duty Calculation	n Operation:	SolveTemp					
29	Duty SP:	-2.941e-011 MW	Minimum Availa	ble Duty:	0.0000 MW Ma	aximum Available Duty:				
30						Fluid Package: F	teaction			
31	Energy	y Stream:	Bottoms	Cooling		Denset Destance	Deserve (California)			
32						Property Package: A	spen Properties (Solids)			
33 34				CONDITIONS						
35	Duty Type:	Direct Q	Duty Calculation	n Operation:						
36	Duty SP:	102.3 MW	Minimum Availa	ble Duty:	0.0000 MW Ma	aximum Available Duty:				
37										
38										
39										
40										
41										
42										
43										
44										
45										
48										
47										
48										
49										
50										
51										
52										
53										
54										
55										
20										
57										
80										
90										
62										
63	Aspen Technology Inc		Asper	n HYSYS Version 12	2.1		Page 9 of 9			
	Licensed to: BATTELLE ENERGY	ALLIANCE	nopol				* Specified by user.			



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

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

1				Case Name:	Name: Production.hsc							
3	(e)aspentech	BATTELLE Bedford, M/	ENERG	Y ALLIANCE		Unit Set:	Am	eyS2e				
4		USA				Date/Time:	Fril	Mar 29 15:40:28 2024				
6	Mator	ial Stree		Pagator	+			FI	uid Package: F	Reaction		
8	Water	ial Strea	un.	Reactal	ns	,		Pr	operty Package:	spen Prop	erties (Solids)	
9						CONDITIONS						
10				Overall		Liquid Phase						
12	Vapour / Phase Fraction		-	0.0000	_	1,0000	_					
13	Temperature:	(C)		550.0		550.0	_					
14	Pressure:	(bar)		1.013		1.013	-					
15	Molar Flow	(kgmole/h)		3.988e+004		3.988e+004						
16	Mass Flow	(kg/s)		1263		1263						
17	Std Ideal Liq Vol Flow	(m3/h)		7747		7747						
18	Molar Enthalpy	(kJ/kgmole)		-1.305e+004		-1.305e+004						
19	Molar Entropy ()	kJ/kgmole-C)		62.26		62.26						
20	Heat Flow	(MW)		-144.6		-144.6						
21	Liq Vol Flow @Std Cond	(m3/h)		3.489e+109 *		3.489e+109						
22 23	COMPOSITION											
24 25					C	verall Phase			Vapour	Fraction	0.0000	
20	COMPONENTS MOLAR FLOW			MOLE FRACTIC	N	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQU		
28	Zinc	0.0	0000	0.00	10	0.000	0	0.0000	0.0000		0.0000	
29	Zinc-Oxide	4984	5660	0.1250		405690.8320		0.0892	968,4164		0.1250	
30	Nitrogen	0.0	0000	0.0000		0.0000		0.0000	0.0000	-	0.0000	
31	Oxygen	0.0	0000	0.00	10	0.000	0	0.0000	0.0000	-	0.0000	
32	Water	0.0	0000	0.00	00	0.000	0	0.0000	0.0000	-	0.0000	
33	Tin-White	34891 9	621	0.87	19	4 142024815e+0	6	0.9108	6778 9151		0.8750	
34	Hydrogen	21	3012	0.00	01	5.646	8	0.0000	0.1500		0.0000	
35	Total	39879.3	3292	1.00	00	4.547721294e+0)6	1.0000	7747,4815		1.0000	
38					L	iquid Phase			Phase F	raction	1.000	
38	COMPONENTS	MOLAR FLO	W	MOLE FRACTION		MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQU	D VOLUME	
39		(kgmole/h)			(kg/h)			FLOW (m3/h)	FR	ACTION	
40	Zinc	0.0	0000	0.0000		0.0000		0.0000	0.0000	-	0.0000	
41	Zinc-Oxide	4984.	5660	0.12	50	405690.8320		0.0892	968.4164		0.1250	
42	Nitrogen	0.0	0000	0.000	00	0.0000		0.0000	0.0000	_	0.0000	
43	Oxygen	0.0	0000	0.00	00	0.0000		0.0000	0.0000	_	0.0000	
44	water Te White	0.0	000	0.000	U	0.000	U S	0.0000	0.0000		0.0000	
40	Hin-white	34091.3	042	0.07	19	4.1420240156+0	0	0.9100	0//0.9151	-	0.0750	
47	Total	20070	2002	1.00	10	4 547721204040	10	1,0000	7747 4945	-	1,0000	
48 49 50	Mater	ial Strea	am:	Product	s	4.047721204040		FI	uid Package: F	Reaction	perties (Solids)	
51						CONDITIONS	_					
52							_			1		
53	Manage (Db. 7			Overall	1	apour Phase		Liquid Phase				
04	Vapour / Phase Fraction	(0)		0.0587		0.0587	_	0.9413				
00	remperature:	(C)		496.6	_	495.6	_	496.6				
50	Molar Flow	(bar)		1.013	_	1.013	_	2.0920-004				
50	Mage Flow	(kgmole/n)		4.2010+004	_	2407	-	3.3008+004				
50	Std Ideal Lin Vol Flow	(Kg/S)		6050	_	122.09	_	6926		-		
60	Molar Enthalow	(kl/kamole)		1960e+004	_	1484e+004	-	1990e+004				
61	Molar Entropy //	(komole C)		42.01		20.57	-	42.70		-		
62	Heat Flow	(MW)		230.7		10.25	_	220.5				
63	Aspen Technology Inc.	(1111)		Asr	en	HYSYS Version	12	.1		F	age 1 of 9	
-	Licensed to: BATTELLE ENERG	SY ALLIANCE		, 10						* Specif	ied by user.	

1					Case Name: Production.hsc								
3	(e)aspentech	Bedford, MA	NERGY ALLIANCE		Unit Set: Am	neyS2e							
4		USA			Date/Time: Fri	Mar 29 15:40:28 2024							
6 7 8	Mater	ial Strea	m: Produc	ts	(continued) Pro	id Package: Re operty Package: As	eaction pen Properties (Solids)					
9					CONDITIONS								
11			Overall	1	Vapour Phase	Liquid Phase							
12	Liq Vol Flow @Std Cond	(m3/h)	3.489e+109 *		4.854e+093	3.489e+109							
13 14				C	OMPOSITION								
15 16				¢	overall Phase		Vapour Fr	raction 0.0587					
17 18	COMPONENTS MOLAR FLOW (kgmole/h)		MOLE FRACTI	ON	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION					
19	Zinc	4984.56	60 0.11	176	325940.7675	0.0717	46.9437	0.0067					
20	Zinc-Oxide	0.00	0.00	000	0.0000	0.0000	0.0000	0.0000					
21	Nitrogen	0.00	0.00	000	0.0000	0.0000	0.0000	0.0000					
22	Oxygen	2492.28	30 0.05	588	79750.0645	0.0175	133.4812	0.0192					
23	Water	0.00	0.00	000	0.0000	0.0000	0.0000	0.0000					
24	Tin-White	34891.96	21 0.82	235	4.142024815e+06	0.9108	6778.9151	0.9741					
25	Hydrogen	2.80	12 0.00	001	5.6468	0.0000	0.1500	0.0000					
28	Total	42371.61	22 1.00	000	4.547721294e+06	1.0000	6959.4900	1.0000					
27	Vapour Phase Phase Fraction 5.870e-002												
29 30	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTI	ON	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION					
31	Zinc	0.51	60 0.00	002	33.7408	0.0004	0.0049	0.0000					
32	Zinc-Oxide	0.00	0.00	000	0.0000	0.0000	0.0000	0.0000					
33	Nitrogen	0.00	0.00	000	0.0000	0.0000	0.0000	0.0000					
34	Oxygen	2483.96	0.99	987	79483.7509	0.9995	133.0355	0.9988					
35	Water	0.00	0.00	000	0.0000	0.0000	0.0000	0.0000					
38	Tin-White	0.00	0.00	000	0.0000	0.0000	0.0000	0.0000					
37	Hydrogen	2.79	80 0.00	0.0011		0.0001	0.1499	0.0011					
38	Total	2487.27	44 1.00	000	79523.1322	1.0000	133.1902	1.0000					
39 40				1	Liquid Phase		Phase Fra	action 0.9413					
41	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTI	ON	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION					
43	Zinc	4984.05	00 0.12	250	325907.0267	0.0729	46.9388	0.0069					
44	Zinc-Oxide	0.00	0.00	000	0.0000	0.0000	0.0000	0.0000					
45	Nitrogen	0.00	0.00	000	0.0000	0.0000	0.0000	0.0000					
48	Oxygen	8.32	26 0.00	002	266.3136	0.0001	0.4457	0.0001					
47	Water	0.00	0.00	000	0.0000	0.0000	0.0000	0.0000					
48	Tin-White	34891.96	21 0.87	748	4.142024815e+06	0.9270	6778.9151	0.9931					
49	Hydrogen	0.00	32 0.00	000	0.0064	0.0000	0.0002	0.0000					
50	Total	39884.33	78 1.00	000	4.468198162e+06	1.0000	6826.2998	1.0000					
51 52 53	Mater	ial Strea	m: Reactio	ono	02	Flu	id Package: Re operty Package: As	eaction pen Properties (Solids)					
54 55	5 CONDITIONS												
56			Overall	1	Vapour Phase	Liquid Phase							
57	Vapour / Phase Fraction		1.0000		1.0000	0.0000							
58	Temperature: (C)		496.6		496.6	496.6							
59	Pressure:	(bar)	1.013		1.013	1.013							
60	Molar Flow	(kgmole/h)	2487		2487	0.0000							
61	Mass Flow	(kg/s)	22.09	_	22.09	0.0000							
62	Std Ideal Liq Vol Flow	(m3/h)	133.2	-	133.2	0.0000		D 0.40					
163	Aspen Lechnology Inc.		As	pen	HTSTS Version 12			Page 2 of 9					

_							_						
1						Case Name:	Pro	duction.hsc					
3	entech	BATTELLE Bedford, M	A	GY ALLIANCE		Unit Set:	Am	eyS2e					
4		USA				Date/Time:	Fri	Mar 29 15:40:28 202	14				
6 7 8	Mater	ial Stre	am:	Reaction	onC	02 (conti	nu	ed)	Fluid Package: F	Reaction Aspen Properties (Solids)			
9					(CONDITIONS							
11				Overall	V	apour 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					
18 17													
18 19 Overall Phase Vapour Fraction													
20	COMPONENTS	MOLAR FL	wo	MOLE FRACT	ION	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME			
21		(kgmole/	h)			(kg/h)			FLOW (m3/h)	FRACTION			
22	Zinc	0	5160	0.0	002	33.74	08	0.000	4 0.0049	0.0000			
23	Zinc-Oxide	0	0000	0.0	000	0.00	00	0.000	0.0000	0.0000			
24	Nitrogen	0	0000	0.0	000	0.00	00	0.000	0.0000	0.0000			
25	Oxygen	2483	9604	0.9	987	79483.75	09	0.999	5 133.0355	0.9988			
26	Water	0	0000	0.0	000	0.00	00	0.000	0.0000	0.0000			
27	Tin-White	0	0000	0.0	000	0.0000		0.000	0.0000	0.0000			
28	B Hydrogen 2.7980			0.0	011	5.64	05	0.000	0.1499	0.0011			
29	Total	1.0	000	79523.13	22	1.000	133.1902	1.0000					
30 31	30 Vapour Phase Phase Fraction 1.0												
32 33	COMPONENTS MOLAR FLOW (kgmole/h)		MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION				
34	Zinc	0	5160	0.0	002	33.74	08	0.000	4 0.0049	0.0000			
35	Zinc-Oxide	0	0000	0.0	000	0.00	00	0.000	0.0000	0.0000			
38	Nitrogen	0	0000	0.0	0000.0 0000			0.000	0.0000	0.0000			
37	Oxygen	2483	9604	0.9	987	79483.75	09	0.999	5 133.0355	0.9988			
38	Water	0	0000	0.0	000	0.00	00	0.000	0.0000	0.0000			
39	Tin-White	0	0000	0.0	000	0.0000		0.000	0.0000	0.0000			
40	Hydrogen	2	7980	0.0	011	5.64	05	0.000	0.1499	0.0011			
41	Total	2487	2744	1.0	000	79523.13	22	1.000	00 133.1902 1.0000				
42 43					L	iquid Phase			Phase F	Fraction 0.0000			
44 45	COMPONENTS	MOLAR FL (kgmole/	OW h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	FRACTION			
48	Zinc	0	0000	0.1	250	0.00	00	0.072	9 0.0000	0.0069			
47	Zinc-Oxide	0	0000	0.0	000	0.00	00	0.000	0.0000	0.0000			
48	Nitrogen	0	0000	0.0	000	0.00	00	0.000	0.0000	0.0000			
49	Oxygen	0	0000	0.0	002	0.00	00	0.000	1 0.0000	0.0001			
50	Water	0	0000	0.0	000	0.00	00	0.000	0.0000	0.0000			
51	Tin-White	0	0000	0.8	748	0.00	00	0.927	0.0000	0.9931			
52	Hydrogen	0	0000	0.0	000	0.00	00	0.000	0.0000	0.0000			
53	Total	0	0000	1.0	000	0.00	00	1.000	0.0000	1.0000			
54 55 56	Mater	ial Stre	am:	AlloyR	ege	n		1	Fluid Package: F Property Package: A	Reaction Aspen Properties (Solids)			
57 58					(CONDITIONS	_						
59	2			Overall	V	apour 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.			A	spen	en HYSYS Version 12.1 Page 3 of 9							

1			Case Name: Production.hsc									
3	@aspentech	Bedford, M	A	SY ALLIANCE		Unit Set:	Am	eyS2e				
4		USA				Date/Time:	Fri	Mar 29 15:40:28 20	024			
6 7 8	Mate	rial Strea	am:	AlloyRe	ege	en (contir	nu	ed)	Fluid Prop	Package: R erty Package: A	Reaction Aspen Pr	operties (Solids)
9 10						CONDITIONS						
11				Overall	,	Vapour Phase		Liquid Phase				
12	Molar Flow	(kgmole/h)		3.988e+004		0.0000		3.988e+004				
13	Mass Flow	(kg/s)		1241		0.0000		1241				
14	Std Ideal Liq Vol Flow	(m3/h)		6826		0.0000		6826				
15	Molar Enthalpy	(kJ/kgmole)		1.990e+004		1.484e+004		1.990e+004				
18	Molar Entropy	(kJ/kgmole-C)		42.79		29.57		42.79				
17	Heat Flow	(MW)		220.5		0.0000		220.5				
18	Liq Vol Flow @Std Cond	(m3/h)		3.489e+109 *		0.0000		3.489e+109				
19 20					C	OMPOSITION	1					
21	1 Overall Phase Vapour Fraction 0.0000											
23	COMPONENTS	MOLAREL	N/C	MOLEERACTI	ON	MASS ELOW		MASS FRACTIO	N		110	
24	COMPONENTS	(komole/		MOLE FRACTI	OIN	(ka/h)		MASS FRACTIO	**	FLOW (m3/h)		FRACTION
25	Zinc	4984	0500	0.12	250	325907.02	67	0.073	29	46 9388		0.0069
26	Zinc-Oxide	0	0000	0.00	000	0.00	00	0.00	00	0.0000	-	0.0000
27	Nitrogen	0	0000	0.00	000	0.00	00	0.000	00	0.0000	-	0.0000
28	Oxygen	8	3226	0.00	02	266.3136		266 3136 0.000		0.4457		0.0001
29	Water	0	0000	0.00	000	0.00	00	0.000	00	0.0000		0.0000
30	Tin-White	34891	9621	0.87	48	4.142024815e+	06	0.927	0.9270 6778.915			0.9931
31	Hydrogen	0	0032	0.00	000	0.00	64	0.000	00	0.0002		0.0000
32	Total	39884	3378	1.00	000	4.468198162e+	06	1.000	00	6826.2998	-	1.0000
33		apour Phase				Phase F	raction	0.0000				
35 38	COMPONENTS	MOLAR FL	WC 1)	MOLE FRACTIO	NC	MASS FLOW (kg/h)		MASS FRACTIO	N	LIQUID VOLUME FLOW (m3/h)	LIC	FRACTION
37	Zinc	0.	0000	0.00	02	0.00	00	0.000	04	0.0000		0.0000
38	Zinc-Oxide	0.	0000	0.00	000	0.0000		0.000	00	0.0000	3	0.0000
39	Nitrogen	0.	0000	0.00	000	0.00	0.00 0000.0		00	0.0000		0.0000
40	Oxygen	0.	0000	0.99	87	0.00	0.0000 0.99		95	0.0000		0.9988
41	Water	0.	0000	0.00	00	0.00	0.000 0.00		00	0.0000		0.0000
42	Tin-White	0.	0000	0.00	000	0.00	00.00		00	0.0000		0.0000
43	Hydrogen	0.	0000	0.00)11	0.00	00	0.000	0.0000		-	0.0011
44	Total	0.	0000	1.00	00	0.00	00	1.000	00	0.0000		1.0000
45 48					I	Liquid Phase				Phase F	raction	1.000
47 48	COMPONENTS	MOLAR FLO	WC 1)	MOLE FRACTIO	NC	MASS FLOW (kg/h)		MASS FRACTIO	N	LIQUID VOLUME FLOW (m3/h)	LIG	UID VOLUME
49	Zinc	4984.	0500	0.12	250	325907.02	67	0.072	29	46.9388		0.0069
50	Zinc-Oxide	0.	0000	0.00	000	0.00	00	0.000	00	0.0000		0.0000
51	Nitrogen	0.	0000	0.00	000	0.00	00	0.000	00	0.0000		0.0000
52	Oxygen	8.	3226	0.00	02	266.31	36	0.000	01	0.4457		0.0001
53	Water	0.	0000	0.00	000	0.00	00	0.000	00	0.0000		0.0000
54	Tin-White	34891	9621	0.87	48	4.142024815e+	06	0.927	70	6778.9151		0.9931
55	Hydrogen	0.	0032	0.00	000	0.00	64	0.000	00	0.0002		0.0000
56	Total	39884	3378	1.00	000	4.468198162e+	06	1.000	00	6826.2998		1.0000
57 58 59 60 61 62												
63	Aspen Technology In	C.		As	pen	HYSYS Version	n 12	.1				Page 4 of 9
	Licensed to: BATTELLE ENE	RGY ALLIANCE									* Spe	cified by user.
2		BATTELLE	ENER			Case Name: P	roduction.hsc					
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3	(1) aspentech	Bedford, M	A	ALLIANCE		Unit Set: A	meyS2e					
4		USA				Date/Time: F	ri Mar 29 15:40:28	2024				
6 7 8	Mater	ial Strea	am:	AlloyRe	cy	/cle		Flui	d Package: R perty Package: A	eaction spen Prope	erties (Solids)	
9						CONDITIONS						
10				Ouerall		Liquid Dhase						
12	Veneur / Dheen Ernetion			Overall 0.0000		1 0000		+				
13	Temperature:	(C)		450.0		450.0		+				
14	Pressure:	(bar)		1.013		1.013		+				
15	Molar Flow	(kgmole/h)		3.988e+004		3.988e+004		+				
16	Mass Flow	(kg/s)		1241		1241						
17	Std Ideal Lig Vol Flow	(m3/h)		6826		6826						
18	Molar Enthalpy	(kJ/kgmole)		1.854e+004		1.854e+004						
19	Molar Entropy (kJ/kgmole-C)		40.90		40.90						
20	Heat Flow	(MW)	_	205.4		205.4						
21	Liq Vol Flow @Std Cond	(m3/h)		3.489e+109 *		3.489e+109						
22 23					C	OMPOSITION						
24 25					C	overall Phase			Vapour F	raction	0.0000	
26 27	COMPONENTS	MOLAR FLC (kgmole/h	W	MOLE FRACTIC	N	MASS FLOW (kg/h)	MASS FRACT	ION	LIQUID VOLUME FLOW (m3/h)	LIQUI		
28	Zinc	4984.	0500	0.12	50	325907.0267	0.0	729	46.9388		0.0069	
29	Zinc-Oxide	0.	0000	0.00	00	0.0000	0.0	000	0.0000		0.0000	
30	Nitrogen	0.	0000	0.00	00	0.0000	0.0	000	0.0000		0.0000	
31	Oxygen	8.	3226	0.00	02	266.3136	0.0	001	0.4457		0.0001	
32	Water	0.	0000	0.00	00	0.0000	0.0	000	0.0000		0.0000	
33	Tin-White	34891.	9621	0.87	48	4.142024815e+06	0.9	270	6778.9151		0.9931	
34	Hydrogen	0.	0032	0.00	00	0.0064	0.0	000	0.0002		0.0000	
35	Total	39884.	3378	1.00	00	4.468198162e+06	1.0	000	6826.2998		1.0000	
38 37					L	iquid Phase			Phase Fr	raction	1.000	
38 39	COMPONENTS	MOLAR FLC (kgmole/h	W (MOLE FRACTIO	N	MASS FLOW (kg/h)	MASS FRACT	ION	LIQUID VOLUME FLOW (m3/h)	LIQUI		
40	Zinc	4984.	0500	0.12	50	325907.0267	0.0	729	46.9388		0.0069	
41	Zinc-Oxide	0.	0000	0.00	00	0.0000	0.0	000	0.0000		0.0000	
42	Nitrogen	0.	0000	0.00	00	0.0000	0.0	000	0.0000		0.0000	
43	Oxygen	8.	3226	0.00	02	266.3136	0.0	001	0.4457		0.0001	
44	Water	0.	0000	0.00	00	0.0000	0.0	000	0.0000		0.0000	
45	Tin-White	34891.	9621	0.87	48	4.142024815e+06	0.9	270	6778.9151		0.9931	
46	Hydrogen	0.	0032	0.00	00	0.0064	0.0	000	0.0002	-	0.0000	
47	Total	39884.	3378	1.00	00	4.468198162e+06	1.0	000	6826.2998		1.0000	
48	Mater	ial Strea	am:	AirFeed	I			Flui	d Package: O	verheads	erties (Peng-R	
51					-	CONDITIONS						
52		T		Quantil		(any Dhave)		-				
03	Vanaur / Dhose Erration			1 0000	1	t coco		-				
55	Temperature:	(0)		42.44		42.44		+				
58	Pressure:	(bar)		1.034		1 034		+				
57	Molar Flow	(kamole/h)		7835		7835		+				
58	Mass Flow	(ka/s)		62.79		62.79		+				
59	Std Ideal Lig Vol Flow	(m3/h)		419.6		419.6						
60	Molar Enthalpy	(kJ/kgmole)		501.6		501.6						
61	Molar Entropy (kJ/kgmole-C)		5.744		5.744						
62	Heat Flow	(MW)		1.092		1.092						
63	Aspen Technology Inc	+		As	pen	HYSYS Version 1	12.1			P	age 5 of 9	
	Licensed to: BATTELLE ENER	GY ALLIANCE								* Specifie	d by user.	

					Case Name: Production.hsc						
3	@aspentech	BATTELLE Bedford, M/	ENERG	SY ALLIANCE		Unit Set: Ar	mey	S2e			
4		USA				Date/Time: Fr	ri Ma	ar 29 15:40:28 2024			
6 7 8	Mater	ial Strea	am:	AirFeed	(0	continued))	Fluid	d Package: Ov perty Package: As	verheads pen Properties (Peng-R	
9					(CONDITIONS					
11				Overall	V	/apour Phase					
12	Liq Vol Flow @Std Cond	(m3/h)		675.1 *		675.1					
13 14					С	OMPOSITION					
15 18					0	verall Phase			Vapour Fr	raction 1.0000	
17 18	COMPONENTS	MOLAR FLC (kgmole/h))	MOLE FRACTIC	N	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
19	Zinc	0.0	* 0000	0.00	00 *	0.0000	•	0.0000 *	0.0000 *	0.0000 *	
20	Zinc-Oxide	0.0	* 0000	0.00	• 00	0.0000	•	0.0000 *	0.0000 *	0.0000 *	
21	Nitrogen	6189.5	5823 *	0.79	• 00	173391.7402		0.7671 *	331.5004 *	0.7900 *	
22	Oxygen	1645.3	3320 *	0.21	• 00	52648.6498	•	0.2329 *	88.1204 *	0.2100 *	
23	Water	0.0	* 0000	0.00	• 00	0.0000	•	0.0000 *	0.0000 *	* 0000.0	
24	Tin-White	0.0	* 0000	0.00	• 00	0.0000) •	• 0000.0	0.0000 *	* 0000.0	
25	Hydrogen	0.0	* 0000	0.00	• 00	0.0000) •	• 0.0000	0.0000 *	* 0000.0	
28	Total	7834.9	9143	1.00	00	226040.3899		1.0000	419.6208	1.0000	
28 Vapour Phase									Phase Fra	action 1.000	
29 30	COMPONENTS	MOLAR FLC (kgmole/h	w(MOLE FRACTIC	N	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
31	Zinc	0.0	0000	0.00	00	0.0000)	0.0000	0.0000	0.000.0	
32	Zinc-Oxide	0.0	0000	0.00	00	0.0000)	0.0000	0.0000	0.0000	
33	Nitrogen	6189.5	5823	0.79	00	173391.7402	2	0.7671	331.5004	0.7900	
34	Oxygen	1645.3	3320	0.21	00	52648.6498		0.2329	88.1204	0.2100	
35	Water	0.0	0000	0.00	00	0.0000		0.0000	0.0000	0.0000	
36	Tin-White	0.0	0000	0.00	00	0.0000		0.0000	0.0000	0.0000	
37	Hydrogen	0.0	0000	0.00	00	0.0000		0.0000	0.0000	0.0000	
38	Total	7834.9	9143	1.00	00	226040.3899		1.0000	419.6208	1.0000	
39 40 41 42	Mater	ial Strea	am:	SweepA	\ir			Fluid	d Package: Ov berty Package: As	verheads pen Properties (Peng-R	
43					-	CONDITIONS					
44				Overall	V	/apour Phase					
45	Vapour / Phase Fraction			1.0000		1.0000					
48	Temperature:	(C)		273.0		273.0					
47	Pressure:	(bar)		1.013		1.013					
48	Molar Flow	(kgmole/h)		7835		7835					
49	Mass Flow	(kg/s)		62.79		62.79					
50	Std Ideal Liq Vol Flow	(m3/h)		419.6		419.6					
51	Molar Enthalpy	(kJ/kgmole)		7331		7331					
52	Heat Flow	(MAN)		22.14		22.14					
55	Lin Vol Eleve @Std Cond	(1111)		675.4.1		13.90					
55	Liq voi riow (@Sta Coña	(m3/n)		0/5.1	c	OMPOSITION	_		I		
57					0	verall Phase			Vapour Fr	raction 1.0000	
				N	MASSELOW		MASS FRACTION				
60	COMPONENTS	(kgmole/h)	MOLE FRACTIC		(kg/h)		INAGO TRACTION	FLOW (m3/h)	FRACTION	
61	Zinc	0.0	0000	0.00	00	0.0000)	0.0000	0.0000	0.0000	
62	Zinc-Oxide	0.0	0000	0.00	00	0.0000		0.0000	0.0000	0.0000	
63	Aspen Technology Inc			As	ben	HYSYS Version 1	12.1			Page 6 of 9	

1				Case Name: Pro	duction.hsc					
3	@aspentech	BATTELLE E Bedford, MA	ENERGY ALLIANCE	Unit Set: An	eyS2e					
4		USA		Date/Time: Fri	Mar 29 15:40:28 2024					
6 7 8	Mate	rial Strea	m: SweepA	ir (continued	flui Pro	d Package: Ov perty Package: Asj	erheads pen Properties (Peng-R			
9				COMPOSITION						
11			Over	all Phase (continue	ed)	Vapour Fr	action 1.0000			
12	COMPONENTS	MOLAR FLO	W MOLE FRACTIO	N MASS FLOW	MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME			
14		(kgmole/h)		(kg/h)		FLOW (m3/h)	FRACTION			
15	Nitrogen	6189.5	823 0.790	0 173391.7402	0.7671	331.5004	0.7900			
16	Oxygen	1645.3	320 0.210	0 52648.6498	0.2329	88.1204	0.2100			
17	Water	0.0	000 0.000	0 0.0000	0.0000	0.0000	0.0000			
18	Tin-White	0.0	000.00	0 0.0000	0.0000	0.0000	0.0000			
19	Hydrogen	0.0	000.00	0 0.0000	0.0000	0.0000	0.0000			
20	Total	7834.9	143 1.000	0 226040.3899	1.0000	419.6208	1.0000			
21 22				Vapour Phase		Phase Fra	action 1.000			
23 24	COMPONENTS	MOLAR FLO (kgmole/h)	W MOLE FRACTIO	N MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION			
25	Zinc	0.0	000 0.000	0 0.0000	0.0000	0.0000	0.0000			
26	Zinc-Oxide	0.0	000 0.000	0 0.0000	0.0000	0.0000	0.0000			
27	Nitrogen	6189.5	823 0.790	0 173391.7402	0.7671	331.5004	0.7900			
28	Oxygen	1645.3	320 0.210	0 52648.6498	0.2329	88.1204	0.2100			
29	Water	0.0	000 0.000	0 0.0000	0.0000	0.0000	0.0000			
30	Tin-White	0.0	000.00	0 0.0000	0.0000	0.0000	0.0000			
31	Hydrogen	0.0	000.0 0.000	0 0.0000	0.0000	0.0000	0.0000			
32	Total	7834.9	143 1.000	0 226040.3899	1.0000	419.6208	1.0000			
34 35 38	Mate	rial Strea	m: RichAir	CONDITIONS	Pro	perty Package: As	pen Properties (Peng-R			
37			Overall	Vapour Phase	Liquid Dhase					
30	Vanour / Phase Fraction		1 0000	1 0000	0.0000					
40	Temperature:	(C)	330.2	330.2	330.2					
41	Pressure:	(bar)	1.013	1.013	1.013					
42	Molar Flow	(kamole/h)	1.032e+004	1.032e+004	0.5159					
43	Mass Flow	(kg/s)	84.88	84.87	9.370e-003					
44	Std Ideal Lig Vol Flow	(m3/h)	552.8	552.8	4.858e-003					
45	Molar Enthalpy	(kJ/kgmole)	9132	9134	-3.636e+004					
46	Molar Entropy	(kJ/kgmole-C)	26.64	26.64	-2.978					
47	Heat Flow	(MW)	26.18	26.19	-5.210e-003					
48	Liq Vol Flow @Std Cond	(m3/h)	858.4 *	858.4	4.929e-003					
49 50		COMPOSITION								
51				COMPOSITION						
02				COMPOSITION Overall Phase		Vapour Fr	action 1.0000			
53	COMPONENTS	MOLAR FLO	W MOLE FRACTIO	Overall Phase N MASS FLOW (kg/h)	MASS FRACTION	Vapour Fr LIQUID VOLUME FLOW (m3/b)	LIQUID VOLUME			
53 54 55	COMPONENTS	MOLAR FLO (kgmole/h)	W MOLE FRACTIO	Overall Phase N MASS FLOW (kg/h) 0 33 7408	MASS FRACTION	Vapour Fr LIQUID VOLUME FLOW (m3/h)	action 1.0000 LIQUID VOLUME FRACTION			
53 54 55 58	COMPONENTS Zinc Zinc-Oxide	MOLAR FLO (kgmole/h) 0.5	W MOLE FRACTIO	COMPOSITION Overall Phase N MASS FLOW (kg/h) 0 33.7408 0 0.0000	MASS FRACTION	Vapour Fr LIQUID VOLUME FLOW (m3/h) 0.0049	action 1.0000 LIQUID VOLUME FRACTION 0.0000 0.0000			
53 54 55 58 57	COMPONENTS Zinc Zinc-Oxide Nitrogen	MOLAR FLO (kgmole/h) 0.5 0.0	W MOLE FRACTION 160 0.000 000 0.000 823 0.599	COMPOSITION Overall Phase N MASS FLOW (kg/h) 0 33.7408 0 0.0000 6 1733017402	MASS FRACTION 0.0001 0.0000 0.5674	Vapour Fr LIQUID VOLUME FLOW (m3/h) 0.0000 331 5004	action 1.0000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.5997			
53 54 55 58 57 58	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxogen	MOLAR FLO (kgmole/h) 0.5 0.0 6189.5 4199.2	W MOLE FRACTION 160 0.000 000 0.000 823 0.599 924 0.400	COMPOSITION Overall Phase N MASS FLOW (kg/h) 0 33.7408 0 0.0000 6 173391.7402 0 132132.4005	MASS FRACTION 0.0001 0.0000 0.5674 0.4324	Vapour Fr LIQUID VOLUME FLOW (m3/h) 0.0009 0.0000 331.5004 221.1558	action 1.0000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.5997 0.4001			
53 54 55 58 57 58 59	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water	MOLAR FLO (kgmole/h) 0.5 0.0 6189.5 4129.2	W MOLE FRACTION 160 0.000 000 0.000 823 0.599 924 0.400 000 0.000	MASS FLOW 0 33.7408 0 0.0000 6 173391.7402 0 132132.4006 0 0.0000	MASS FRACTION 0.0001 0.0000 0.5674 0.4324 0.000	Vapour Fr LIQUID VOLUME FLOW (m3/h) 0.0009 0.0000 331.5004 221.1558 0.0000	action 1.0000 LIQUID VOLUME FRACTION 0.0000 0.5997 0.4001 0.000			
53 54 55 58 57 58 59 60	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White	MOLAR FLO (kgmole/h) 0.5 0.0 6189.5 4129.2 0.0	W MOLE FRACTION 160 0.000 000 0.000 823 0.599 924 0.400 000 0.000 000 0.000	MASS FLOW 0 33.7408 0 0.0000 6 173391.7402 0 132132.4006 0 0.0000 0 0.0000	MASS FRACTION 0.0001 0.5674 0.4324 0.0000 0.0000	Vapour Fr LIQUID VOLUME FLOW (m3/h) 0.0049 0.0000 331.5004 221.1558 0.0000 0.0000	action 1.0000 LIQUID VOLUME FRACTION 0.0000 0.5997 0.4001 0.0000 0.0000			
53 54 55 58 57 58 59 60 61	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen	MOLAR FLO (kgmole/h) 0.5 0.0 6189.5 4129.2 0.0 0.0 0.0 2 7	W MOLE FRACTION 160 0.000 000 0.000 823 0.599 924 0.400 000 0.000 000 0.000 980 0.000	Mass FLOW (kg/h) 0 33.7408 0 0.0000 6 173391.7402 0 132132.4006 0 0.0000 3 5.6405	MASS FRACTION 0.0001 0.5674 0.4324 0.0000 0.0000 0.0000	Vapour Fr LIQUID VOLUME FLOW (m3/h) 0.0049 0.0000 331.5004 221.1558 0.0000 0.0000 0.1499	action 1.0000 LIQUID VOLUME FRACTION 0.0000 0.5997 0.4001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0003			
53 54 55 58 57 58 59 60 61 62	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total	MOLAR FLO (kgmole/h) 0.5 0.0 6189.5 4129.2 0.0 0.0 0.0 2.7 10322.1	W MOLE FRACTION 160 0.000 000 0.000 823 0.599 924 0.400 000 0.000 000 0.000 980 0.000 887 1.000	Mass FLOW (kg/h) 0 33.7408 0 0.0000 6 173391.7402 0 132132.4006 0 0.0000 3 5.6405 0 305563.5221	MASS FRACTION 0.0001 0.5674 0.4324 0.0000 0.0000 0.0000 1.0000	Vapour Fr LIQUID VOLUME FLOW (m3/h) 0.0009 0.0000 331.5004 221.1558 0.0000 0.0000 0.0000 0.1499 552.8109	action 1.0000 LIQUID VOLUME FRACTION 0.0000 0.5997 0.4001 0.0000 0.0000 0.0000 0.0003 1.0000			
53 54 55 58 57 58 50 60 61 62 83	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Aspen Technology In	MOLAR FLO (kgmole/h) 0.5 0.0 6189.5 4129.2 0.0 0.0 0.0 2.7 10322.1 C.	W MOLE FRACTION 160 0.000 160 0.000 1623 0.599 1924 0.400 000 0.000 000 0.000 100 0.0000 100 0.0000 100 0.0000 100 0.0000 100 0.0000 100 0.000	Mass FLOW (kg/h) 0 33.7408 0 0.0000 6 173391.7402 0 132132.4006 0 0.0000 3 5.6405 0 305563.5221 en HYSYS Version 12	MASS FRACTION 0.0001 0.0000 0.5674 0.4324 0.0000 0.0000 1.0000 2.1	Vapour Fr LIQUID VOLUME FLOW (m3/h) 0.0009 0.0000 331.5004 221.1558 0.0000 0.0000 0.1499 552.8109	action 1.0000 LIQUID VOLUME FRACTION 0.0000 0.5997 0.4001 0.0000 0.0000 0.0000 0.0000 1.0000 Page 7 of 9			

1												
2	BATTELLE ENERGY ALLIANCE					Case Name: Production.hsc						
3	eentech	Bedford, MA	4		_	Unit Set: An	neyS2e					
5		CONT				Date/Time: Fri	Mar 29 15:40:28 2024					
6 7 8	Mater	ial Strea	am:	RichAir	(c	ontinued)	erheads pen Properties (Peng-R					
9					C	OMPOSITION						
11					V	anour Phase		Phase Fra	action 1 000			
12						apour r nuse						
13 14	COMPONENTS	MOLAR FLC (kgmole/h) W	MOLE FRACTI	ON	MASS FLOW (kg/h)	MASS FRACTION	FLOW (m3/h)	FRACTION			
15	Zinc	0.0	0001	0.00	000	0.0092	0.0000	0.0000	0.0000			
16	Zinc-Oxide	0.0	0000	0.0	000	0.0000	0.0000	0.0000	0.0000			
17	Nitrogen	6189.5	5823	0.59	997	173391.7402	0.5675	331,5004	0.5997			
18	Oxygen	4129.3	2924	0.40	001	132132.4006	0.4325	221.1558	0.4001			
19	Water	0.0	0000	0.0	000	0.0000	0.0000	0.0000	0.0000			
20	Tin-White	0.0	0000	0.00	000	0.0000	0.0000	0.0000	0.0000			
21	Hydrogen	2.7	7980	0.0	003	5.6405	0.0000	0.1499	0.0003			
22	Total	10321.6	5728	1.00	000	305529.7905	1.0000	552.8061	1.0000			
23 24					L	iquid Phase		Phase Fra	action 4.998e-005			
25 28	COMPONENTS	MOLAR FLC (kgmole/h	W	MOLE FRACTI	ON	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION			
27	Zinc	0.5	5159	1.00	000	33,7316	1 0000	0.0049	1,0000			
28	Zinc-Oxide	0.0	0000	0.00	000	0.0000	0.0000	0.0000	0.0000			
29	Nitrogen	0.0	0000	0.0	000	0.0000	0.0000	0.0000	0.0000			
30	Oxygen	0.0	0000	0.00	000	0.0000	0,0000	0.0000	0.0000			
31	Water	0.0	0000	0.00	000	0.0000	0.0000	0.0000	0.0000			
32	Tin-White	0.0	0000	0.0	000	0.0000	0.0000	0.0000	0.0000			
33	Hydrogen	0.0	0000	0.00	000	0.0000	0 0000	0.0000	0.0000			
34	Total	0.5	5159	1.00	000	33,7316	1.0000	0.0049	1.0000			
35 38 37 38	Mater	ial Strea	am:	Overhe	ad	02	Flui Pro	id Package: Ov perty Package: As	erheads pen Properties (Peng-R			
39					C	ONDITIONS						
40	Version / Dhase Freefer		C	overall	V	apour Phase	Liquid Phase					
41	Vapour / Phase Fraction	(0)		0.9990		0.9990	0.0002					
42	Procesure:	(0)		490.0	_	490.0	490.0					
45	Melas Elaw	(bdi)		2497	_	2497	0.4610					
45	Mass Flow	(kgriole/ii)		22 09		2407	8 3730 003					
48	Std Ideal Lin Vol Flow	(m3/b)		133.2		133.2	4 341e-003					
47	Molar Enthalov	(k.l/kamole)		1481e+004		1.481e+004	-2.883e+004					
48	Molar Entropy (k.l/kamole-C)		29.53		29.53	8.053					
49	Heat Flow	(MW)		10.23		10.23	-3.691e-003					
50	Lig Vol Flow @Std Cond	(m3/h)	_	2.629e+049 *		2.630e+049	4.404e-003					
51					C	OMPOSITION						
53					0	verall Phase		Vanour Fr	action 0.0009			
54 55	COMPONENTS	MOLAR FLC	w			MASSELOW	MASS FRACTION					
58	COMPONENTS	(kgmole/h)	aloce moon		(kg/h)		FLOW (m3/h)	FRACTION			
57	Zinc	0.5	5160	0.00	002	33.7408	0.0004	0.0049	0.0000			
58	Zinc-Oxide	0.0	0000	0.00	000	0.0000	0.0000	0.0000	0.0000			
59	Nitrogen	0.0	0000	0.00	000	0.0000	0.0000	0.0000	0.0000			
60	Oxygen	2483.9	9604	0.99	987	79483.7509	0.9995	133.0355	0.9988			
61	Water	0.0	0000	0.00	000	0.0000	0.0000	0.0000	0.0000			
62	Tin-White	0.0	0000	0.00	000	0.0000	0.0000	0.0000	0.0000			
63	Aspen Technology Inc	-		As	pen l	HYSYS Version 12	2.1		Page 8 of 9			

1				Case Name: Pro	oduction.hsc					
3	(1) aspentech	BATTELLE ENERG Bedford, MA	Y ALLIANCE	Unit Set: An	neyS2e					
4		USA		Date/Time: Fri	Mar 29 15:40:2	28 2024				
6						Fluid	d Package: O	verheads		
7	Mater	ial Stream:	Overhead	O2 (contin	ued)	Prop	perty Package: As	open Properties (Peng-R		
9										
10			L.	OMPOSITION						
11			Overall	Phase (continue	ed)		Vapour F	raction 0.9998		
13	COMPONENTS	MOLAR FLOW	MOLE FRACTION	MASS FLOW	MASS FRAM	CTION	LIQUID VOLUME	LIQUID VOLUME		
14		(kgmole/h)		(kg/h)			FLOW (m3/h)	FRACTION		
15	Hydrogen	2.7980	0.0011	5.6405		1,0000	0.1499	0.0011		
17	Total	2407.2744	1.0000	19929.1922		1.0000	155.1502	1.0000		
18			v	apour Phase			Phase Fr	action 0.9998		
19	COMPONENTS	MOLAR FLOW	MOLE FRACTION	MASS FLOW	MASS FRAM	CTION	LIQUID VOLUME	LIQUID VOLUME		
20	Zinc	(kgmoleni) 0.0550	0.0000	3.5976		0.0000	0.0005	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	0.9989	79483.7509		0.9999	133.0355	0.9989		
25	Water	0.0000	0.0000	0.0000	1	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	2486.8134	1.0000	79492.9890		1.0000	133.1858	1,0000		
30	Liquid Phase Phase Fraction 1.853e-004									
31	COMPONENTS	MOLAR FLOW	MOLE FRACTION	MASS FLOW	MASS FRAM	CTION	LIQUID VOLUME	LIQUID VOLUME		
32	Zinc	(kgmole/n)	1 0000	(kg/l) 30 1432		1 0000	PLOW (m3/n)	1 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		
38	Oxygen	0.0000	0.0000	0.0000	1	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	0.0000		0.0000	0.0000	0.0000		
39	Hydrogen	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000		
40	Total	0.4610	1.0000	30.1432		1.0000	0.0043	1.0000		
41 42 43	Energ	gy Stream:	Reaction	Heat		Fluid	d Package: Re perty Package: As	eaction open Properties (Solids)		
44				CONDITIONS						
48	Duty Type:	Direct Q	Duty Calculation	Operation:	SolveTemp					
47	Duty SP:	475.0 MW	Minimum Availat	ble Duty:	0.0000 MW	Maximu	m Available Duty:			
48 49 50	Ener	gy Stream:	DC Powe	r		Fluid	d Package: Re perty Package: As	eaction spen Properties (Solids)		
51				CONDITIONS						
52			1	Comprisions						
53	Duty Type:	Direct Q	Duty Calculation	Operation:	SolveTemp	Marian	m Ausilable Duty			
55	Duty SP:	475.0 MVV	Minimum Availat	ble Duty:	0.0000 MVV	Maximu	im Available Duty:			
58 57	Ener	gy Stream:	Bottoms	Cooling		Prop	d Package: Re perty Package: As	eaction spen Properties (Solids)		
58				CONDITIONS						
60	Duty Type:	Direct Q	Duty Calculation	Operation: Swe	eep Preheat					
61	Duty SP:	14.86 MW	Minimum Availat	ble Duty:	0.0000 MW	Maximu	m Available Duty:			
62										
63	Aspen Technology Inc. Licensed to: BATTELLE ENERG	ALLIANCE	Aspen	HYSYS Version 12	2.1			Page 9 of 9 Specified by user		



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

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

1				Case Name:	Pro	duction.hsc		
3	@aspentech	BATTELLE EN Bedford, MA	ERGY ALLIANCE	Unit Set:	Am	eyS2e		
4		USA		Date/Time:	Fri	Mar 29 15:46:33 202	24	
6 7	Mater	ial Stream	n: H2Feed				Fluid Package:	Overheads
8							Toporty Fuonage.	open riopenee (rengr
10				CONDITIONS				
11			Overall	Vapour Phase		Liquid Phase		
12	Vapour / Phase Fraction		1.0000	1.0000	-	0.0000		
13	Temperature:	(C)	106.1	106.1	-	106.1		
14	Pressure:	(bar)	0.9731	0.9731	+	0.9731		
15	Molar Flow	(kgmole/h)	4982	4982	+	5.2858-005		
10	Mass Flow	(Kg/S)	2.790	2.790	+	1.1958-006		
10	Std Ideal Lig Vol Flow	(m3/n)	200.0	200.0	+	2.205e+005		
10	Molar Entrany	(Kongiliole)	7 310	7 310	+	-2.20364003		
20	Heat Flow	(MW)	3.256	3 256	+	3 2376-006		
21	Lig Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.222e+063	+	2.650e+063		
22	ert for the gots come	(COMPOSITION	N			
24 25 Overall Phase Vapour Fraction								
28	COMPONENTS	MOLAR FLOW (kamole/h)	MOLE FRACTIC	N MASS FLOW	v	MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME FRACTION
28	Zinc	0.000	0.000	0.0	000	0.000	0.0000	0.0000
29	Zinc-Oxide	0.000	1 0.000	0.0	048	0.000	0.0000	0.0000
30	Nitrogen	0.000	0.000	0.0	000	0.000	0.0000	0.0000
31	Oxygen	0.000	0.000	0.0	000	0.000	0.0000	0.0000
32	Water	0.000	0.000	0.0	000	0.000	0.0000	0.0000
33	Tin-White	0.000	0.000	0.0	018	0.000	0.0000	0.0000
34	Hydrogen	4981.764	8 1.000	00 10042.64	401	1.000	0 266.8124	1.0000
35	Total	4981.764	9 1.000	00 10042.64	468	1.000	0 266.8124	1.0000
38 37				Vapour Phase			Phase	Fraction 1.000
38 39	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTIC	MASS FLOW	v	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
40	Zinc	0.000	0.000	0.0	000	0.000	0.0000	0.0000
41	Zinc-Oxide	0.000	0.000	0.0	005	0.000	0.0000	0.0000
42	Nitrogen	0.000	0.000	0.0	000	0.000	0.0000	0.0000
43	Oxygen	0.000	0.000	0.0	000	0.000	0.0000	0.0000
44	Water	0.000	0.000	0.0	000	0.000	0.0000	0.0000
45	Tin-White	0.000	0 0.000	0.0	018	0.000	0.0000	0.0000
46	Hydrogen	4981.764	8 1.000	00 10042.64	401	1.000	D 266.8124	1.0000
47	Total	4981.764	9 1.000	00 10042.64	425	1.000	266.8124	1.0000
48				Liquid Phase			Phase I	Fraction 1.061e-008
50 51	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTIC	MASS FLOW	v	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
52	Zinc	0.000	0.000	0.0	000	0.000	0.0000	0.0000
53	Zinc-Oxide	0.000	1 0.999	98 0.0	043	1.000	0.0000	1.0000
54	Nitrogen	0.000	0.000	0.0	000	0.000	0.0000	0.0000
55	Oxygen	0.000	0.000	0.0	000	0.000	0.0000	0.0000
58	Water	0.000	0.000	0.0	000	0.000	0.0000	0.0000
57	Tin-White	0.000	0.000	0.0	000	0.000	0.0000	0.0000
58	Hydrogen	0.000	0.000	0.0	000	0.000	0.0000	0.0000
59	Total	0.000	1 1.000	0.0	043	1.000	0.0000	1.0000
60 61 62 63	Aspen Technology Inc		Asr	oen HYSYS Versio	on 12	.1		Page 1 of 13
-	Licensed to: BATTELLE ENER	GY ALLIANCE	715					* Specified by user

_									
1					Case Name:	Produ	uction.hsc		
3	(aspentech	BATTELLE Bedford, M	ENERG A	SY ALLIANCE	Unit Set:	Amey	yS2e		
4		USA			Date/Time:	Fri M	ar 29 15:46:33 2024		
6 7 8	Mater	ial Strea	am:	C1S1out	t		Flu	id Package: C	overheads Spen Properties (Peng-R
9					CONDITIONS				
10				Overall	Vanour Phase				
12	Vapour / Phase Fraction			1 0000	1 0000				
13	Temperature:	(C)		175.0 *	175.0				
14	Pressure:	(bar)		2.543	2.543				
15	Molar Flow	(kgmole/h)		4982	4982				
16	Mass Flow	(kg/s)		2.790	2.790				
17	Std Ideal Liq Vol Flow	(m3/h)		266.8	266.8				
18	Molar Enthalpy	(kJ/kgmole)		4368	4368				
19	Molar Entropy (I	kJ/kgmole-C)		4.198	4.198				
20	Heat Flow	(MW)		6.044	6.044				
21	Liq Vol Flow @Std Cond	(m3/h)		6.222e+063 *	6.222e+063				
23					COMPOSITION				
24 25					Overall Phase			Vapour	Fraction 1.0000
26	COMPONENTS	MOLAR FLO	W	MOLE FRACTION	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME
27		(kgmole/h)		(kg/h)			FLOW (m3/h)	FRACTION
28	Zinc	0.0	0000	0.000	0 0.00	00	0.0000	0.0000	0.0000
29	Zinc-Oxide	0.0	0001	0.000	0.00	48	0.0000	0.0000	0.0000
30	Nitrogen	0.	0000	0.000	0.00	00	0.0000	0.0000	0.0000
31	Water	0.	0000	0.000	0.00	00	0.0000	0.0000	0.0000
33	Tin-White	0.	0000	0.000	0.00	18	0.0000	0.0000	0.0000
34	Hydrogen	4981.	7648	1.000	0 10042.64	01	1.0000	266,8124	1.0000
35	Total	4981.	7649	1.000	0 10042.64	68	1.0000	266.8124	1.0000
38					Vapour Phase			Phase F	raction 1.000
38	COMPONENTS	MOLAR FLC	W	MOLE FRACTION	MASS FLOW		MASS FRACTION	LIQUID VOLUME FLOW (m3/b)	LIQUID VOLUME
40	Zinc	0.	0000	0.000	0.00	00	0.0000	0.0000	0.0000
41	Zinc-Oxide	0.	0001	0.000	0.00	48	0.0000	0.0000	0.0000
42	Nitrogen	0.	0000	0.000	0.00	00	0.0000	0.0000	0.0000
43	Oxygen	0.	0000	0.000	0.00	00	0.0000	0.0000	0.0000
44	Water	0.	0000	0.000	0.00	00	0.0000	0.0000	0.0000
45	Tin-White	0.	0000	0.000	0.00	18	0.0000	0.0000	0.0000
46	Hydrogen	4981.	7648	1.000	0 10042.64	01	1.0000	266.8124	1.0000
47 48 49 50	Mater	ial Strea	am:	C1S1in	0 10042.64	68	1.0000 Fit	id Package: C operty Package: A	0verheads Aspen Properties (Peng-R
51					CONDITIONS				
53				Overall	Vapour Phase	1	Liquid Phase		
54	Vapour / Phase Fraction			1.0000	1.0000		0.0000		
55	Temperature:	(C)		40.00 *	40.00		40.00		· · · · · · · · · · · · · · · · · · ·
56	Pressure:	(bar)		0.9537	0.9537		0.9537		
57	Molar Flow	(kgmole/h)		4982	4982		5.952e-005		
58	Mass Flow	(kg/s)		2.790	2.790		1.345e-006		
59	Std Ideal Liq Vol Flow	(m3/h)		266.8	266.8		1.156e-005		
60	Molar Enthalpy	(kJ/kgmole)		432.9	432.9	_	-2.245e+005		
61	Molar Entropy (I	kJ/kgmole-C)		1.917	1.917		-7.126		
82	Aspen Technology Inc	(MW)		0.5991	0.5991 an HYSYS Varaisa	12.1	-3./11e-006		Page 2 of 12
	Licensed to: BATTELLE ENERG	SY ALLIANCE		Asp		12.1			Specified by user.

1			201111110	Case Name: Production.hsc						
3	(e)aspentech	BATTELLE ENt Bedford, MA	RGY ALLIANCE	Unit Set:	AmeyS2e					
5		000		Date/Time:	Fri Mar 29 15:46:33 20	24				
6 7 8	Mater	ial Stream	: C1S1in	(continued	I)	Fluid Package: Or Property Package: As	/erheads pen Properties (Peng-R			
9 10				CONDITIONS						
11			Overall	Vapour Phase	Liquid Phase					
12	Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.212e+063	5.643e+066					
13 14				COMPOSITION	N					
15 16				Overall Phase		Vapour F	raction 1.0000			
17 18	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTIO	DN MASS FLOW (kg/h)	MASS FRACTIO	N LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION			
19	Zinc	0.0000	0.00	00 0.00	000.000	0 0.0000	0.0000			
20	Zinc-Oxide	0.000	0.00	00 0.00	0.000	0.0000	0.0000			
21	Nitrogen	0.0000	0.00	00 0.00	000.000	0 0.0000	0.0000			
22	Oxygen	0.0000	0.00	00 0.00	000 0.000	0 0.0000	0.0000			
23	Water	0.000	0.00	00 0.00	000.000	0 0.0000	0.0000			
24	Tin-White	0.0000	0.00	00 0.00	018 0.000	0 00000	0.0000			
20	Hydrogen	4981.7648	1.00	00 10042.64	1.000	0 266.8124	1.0000			
20	Total	1.00	Vapour Phase	10042.6468 1.0000 266.8124 Vanour Phase Phase Fraction						
28										
29 30	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTIC	DN MASS FLOW (kg/h)	MASS FRACTIO	FLOW (m3/h)	FRACTION			
31	Zinc	0.000	0.00	00.00	000.000	0 0000.0	0.0000			
32	Zinc-Oxide	0.000	0.00	00 0.00	000.000	0 0.0000	0.0000			
33	Nitrogen	0.0000	0.00	00 0.00	000.000	0 0.0000	0.0000			
34	Oxygen	0.0000	0.00	00 0.00	000.000	0 0.0000	0.0000			
35	Water	0.0000	0.00	00 0.00	000 0.000	0 0.0000	0.0000			
38	Tin-White	0.0000	0.00	00 0.00	0.000	0 0.0000	0.0000			
37	Hydrogen	4981.7648	1.00	00 10042.64	1.000	0 266.8124	1.0000			
38	lotal	4981.7648	1.00	00 10042.64	19 1.000	0 200.0124	1.0000			
40				Liquid Phase		Phase Fr	action 1.195e-008			
41	COMPONENTS	MOLAR FLOW	MOLE FRACTIC	ON MASS FLOW	MASS FRACTIO	N LIQUID VOLUME	LIQUID VOLUME			
42	Zina	(kgmole/n)	0.00	(kg/n)	0.000	PLOW (msm)	PRACTION 0.0000			
43	Zine Ovide	0.000	0.00	0.00	0.000	7 0.0000	0.0000			
45	Nitrogen	0.000	0.99	00 0.00	0.999	0.0000	0.0000			
46	Oxygen	0.0000	0.00	0.00	000 0.000	0.0000	0.0000			
47	Water	0.000	0.00	00 0.00	000.000	0 0.0000	0.0000			
48	Tin-White	0.0000	0.00	02 0.00	000.000	3 0.0000	0.0002			
49	Hydrogen	0.0000	0.00	01 0.00	0.000	0.0000	0.0000			
50	Total	0.0001	1.00	00 0.00	1.000	0.0000	1.0000			
51 52 53	Mater	ial Stream	: C1S2in			Fluid Package: On Property Package: As	/erheads pen Properties (Peng-R			
54 55			<u></u>	CONDITIONS						
56			Overall	Vapour Phase	Liquid Phase					
57	Vapour / Phase Fraction		1.0000	1.0000	0.0000					
58	Temperature:	(C)	40.00 *	40.00	40.00					
59	Pressure:	(bar)	2.492	2.492	2.492					
60	Molar Flow	(Kgmole/h)	4982	4982	5.955e-005					
01	Mass Flow	(Kg/S)	2.790	2.790	1.3468-006					
63	Aspen Technology Inc.	(morn)	200.0 As	pen HYSYS Version	n 12.1		Page 3 of 13			

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1			-			Case Name:	Pro	duction.hsc		
3	(e)aspentech	Bedford, M	A	GY ALLIANCE		Unit Set:	Am	eyS2e		
4		USA				Date/Time:	Fri	Mar 29 15:46:33 2024	ŧ.	
6 7 8	Mater	ial Strea	am:	C1S2in	(C	ontinued)	FI	uid Package: roperty Package:	Overheads Aspen Properties (Peng-F
9					0	CONDITIONS	_			
10				Overall	V	anour Dhase		Liquid Dhase		
12	Molar Enthalov	(k.l/kamole)		433.9	V	433.9	_	-2 243e+005		
13	Molar Entropy (i	kJ/kgmole-C)		-6.074		-6.074		-7.092		
14	Heat Flow	(MW)		0.6005		0.6005		-3.710e-006		
15	Liq Vol Flow @Std Cond	(m3/h)		6.222e+063 *		6.195e+063		4.876e+067		
18					С	OMPOSITION				
17						warall Dhace			Veren	Erection 1 0000
19						verall Phase			Vapour	Fraction 1.0000
20 21	COMPONENTS	MOLAR FLO (kgmole/t	DW 1)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	FRACTION
22	Zinc	0.	0000	0.0	000	0.000	00	0.0000	0.000	0.0000
23	Zinc-Oxide	0.	0001	0.0	000	0.004	48	0.0000	0.000	0.0000 0
24	Nitrogen	0.	0000	0.0	000	0.00	00	0.0000	0.0000	0.0000
25	Oxygen	0.	0000	0.0	000	0.000	00	0.0000	0.0000	0000.0
26	Water	0.	0000	0.0	000	0.000	00	0.0000	0.000	0.0000
27	Tin-White	0.	0000	0.0	000	0.00	18	0.0000	0.000	0.0000
28	Hydrogen	4981.	7648	1.0	000	10042.640	01	1.0000	266.8124	1.0000
29	Total	4981.	7649	1.0	000	10042.64	58	1.0000	266.8124	1.0000
30			_		V	apour Phase			Phase	Fraction 1.000
32 33	COMPONENTS	MOLAR FLO (kgmole/h	WC I)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	FRACTION
34	Zinc	0.	0000	0.0	000	0.000	00	0.0000	0.000	0.0000
35	Zinc-Oxide	0.	0000	0.0	000	0.000	00	0.0000	0.000	0000.0
38	Nitrogen	0.	0000	0.0	000	0.00	00	0.0000	0.000	0.0000
37	Oxygen	0.	0000	0.0	000	0.00	00	0.0000	0.000	0.0000 (
38	Water	0.	0000	0.0	000	0.000	00	0.0000	0.000	0.0000
38	Tin-white	0.	2000	0.0	000	0.00	18	0.0000	0000	0.0000
40	Hydrogen	4981.	7648	1.0	000	10042.640	10	1.0000	266,8124	1.0000
42	Total	4301.	/040	1.0	000	10042.04	19	1.0000	200.012	1.0000
43					L	iquid Phase			Phase	Fraction 1.195e-008
44	COMPONENTS	MOLAR FLO	WC	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME	E LIQUID VOLUME
48	Zinc	0.	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
47	Zinc-Oxide	0.	0001	0.9	992	0.004	48	0.9993	0.000	0 0.9994
48	Nitrogen	0.	0000	0.0	000	0.00	00	0.0000	0.000	0.0000
49	Oxygen	0.	0000	0.0	000	0.000	00	0.0000	0.000	0.0000 0
50	Water	0.	0000	0.0	000	0.00	00	0.0000	0.000	0.0000 0
51	Tin-White	0.	0000	0.0	005	0.00	00	0.0007	0.000	0.0005
52	Hydrogen	0.	0000	0.0	003	0.00	00	0.0000	0.000	0.0001
53	Total	0.	0001	1.0	000	0.004	48	1.0000	0.000	1.0000
54 55 58	Mater	ial Strea	am:	C1S20	ut			FI	uid Package: roperty Package:	Overheads Aspen Properties (Peng-F
58					0	CONDITIONS				
59				Overall	V	apour Phase				
60	Vapour / Phase Fraction			1.0000		1.0000				
61	Temperature:	(C)		175.0 *		175.0				
62	Accor Technology	(bar)		6.646	-	6.646	12	1		Deep 4 -642
63	Aspen Technology Inc.			A	spen	TTSTS Version	112	.1		Page 4 of 13

d to: BATTELLE ENER

fied by user.

				_	Case Name: Production.hsc						
3	@aspentech	BATTELLE Bedford, M	A A A A A A A A A A A A A A A A A A A	E	Unit Set:	AmeyS2e					
4		USA			Date/Time:	Fri Mar 29 15:46	:33 2024				
6 7 8	Mater	rial Strea	am: C1S	2out	(continue	d)	Flui	id Package: O perty Package: A	verheads spen Properties (Peng-R		
9					CONDITIONS						
11			Overall		Vanour Phase						
12	Molar Flow	(kamole/h)	49	82	4982		_				
13	Mass Flow	(kg/s)	2.7	90	2.790						
14	Std Ideal Lig Vol Flow	(m3/h)	26	6.8	266.8						
15	Molar Enthalpy	(kJ/kgmole)	43	72	4372						
16	Molar Entropy	(kJ/kgmole-C)	-3.7	90	-3.790						
17	Heat Flow	(MW)	6.0	51	6.051						
18	Liq Vol Flow @Std Cond	(m3/h)	6.222e+0	63 *	6.222e+063						
19 20					COMPOSITION						
21					Overall Phase			Vanaur	Frantian 1 0000		
22					overan Fliase			vapour r	10000		
23 24	COMPONENTS	MOLAR FLO (kgmole/r	OW MOLE FF	RACTION	MASS FLOW (kg/h)	MASS FR	ACTION	LIQUID VOLUME FLOW (m3/h)	FRACTION		
25	Zinc	0.	0000	0.0000	0.000	00	0.0000	0.0000	0.0000		
28	Zinc-Oxide	0.	0001	0.0000	0.00	48	0.0000	0.0000	0.0000		
27	Nitrogen	0.	0000	0.0000	0.000	00	0.0000	0.0000	0.0000		
28	Oxygen	0.	0000	0.0000	0.000	00	0.0000	0.0000	0.0000		
29	Water	0.	0000	0.0000	0.00	00	0.0000	0.0000	0.0000		
30	Tin-White	0.	0000	0.0000	0.00	18	0.0000	0.0000	0.0000		
31	Hydrogen	4981.	7648	1.0000	10042.64	01	1.0000	266.8124	1.0000		
32	Total	4981.	7649	1.0000	10042.64	58	1.0000	266.8124	1.0000		
33											
					Vapour Phase			Phase F	raction 1.000		
35	COMPONENTS	MOLAR FLO	OW MOLE FR	RACTION	MASS FLOW	MASS FR	ACTION	Phase Fi	LIQUID VOLUME		
35 38 27	COMPONENTS	MOLAR FLO	OW MOLE FR	RACTION	MASS FLOW (kg/h)	MASS FR	ACTION	Phase Fi	LIQUID VOLUME FRACTION		
35 38 37	COMPONENTS Zinc	MOLAR FLC (kgmole/t	0000 MOLE FR	0.0000	Vapour Phase MASS FLOW (kg/h) 0 0.000	MASS FR	0.0000	Phase Fi	LIQUID VOLUME FRACTION 0.0000		
35 38 37 38 39	COMPONENTS Zinc Zinc-Oxide Nitrogen	MOLAR FLC (kgmole/t 0. 0.	0000 MOLE FF	0.0000 0.0000	MASS FLOW (kg/h) 0 0.000 0 0.000	MASS FR	0.0000 0.0000 0.0000	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000		
35 38 37 38 39 40	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxvoen	MOLAR FL0 (kgmole/t 0. 0. 0.	OW MOLE FR 0000 0001 0000 0000	0.0000 0.0000 0.0000	MASS FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000	MASS FR 00 48 00	ACTION 0.0000 0.0000 0.0000	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000		
35 36 37 38 39 40 41	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water	MOLAR FL((kgmole/t 0. 0. 0.	OW MOLE FF 1) 0000 0001 0000 0000 0000 0000 0000	0.0000 0.0000 0.0000 0.0000 0.0000	MASS FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000	MASS FR 00 48 00 00 00	ACTION 0.0000 0.0000 0.0000 0.0000 0.0000	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.000 0.		
35 36 37 38 39 40 41 42	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White	MOLAR FL((kgmole/t 0. 0. 0. 0. 0.	OW MOLE FF 0000 0001 0000 0000 0000 0000 0000 0	0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	MASS FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000	MASS FR 00 48 00 00 00 18	ACTION 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.000 0.0		
35 36 37 38 39 40 41 42 43	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen	MOLAR FL((kgmole/t 0. 0. 0. 0. 0. 4981.	DW MOLE FF 0000 0001 0000 0000 0000 0000 0000 7648	0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000	Mass FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000	MASS FR 00 48 00 00 00 10 18 01	ACTION 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000		
35 38 37 38 39 40 41 42 43 44	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total	MOLAR FL((kgmole/t 0. 0. 0. 0. 0. 4981. 4981.	DW MOLE FF 0000 0001 0000 0000 0000 0000 0000 7648 7649	0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000	Mass FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000	MASS FR 00 18 10 00 00 18 01 58	ACTION 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000		
35 36 37 38 39 40 41 42 43 44 45 46 47	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Mater	MOLAR FL((kgmole/t 0. 0. 0. 0. 0. 4981. 4981.	OW n) MOLE FF 0000 0001 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 7648 7649 am: C2S ²	0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000	Mass FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 10042.64	MASS FR 00 48 00 00 18 01 58	ACTION 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 Flui Pro	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000 266.8124 266.8124 id Package: O perty Package: A	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 Verheads spen Properties (Peng-R		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 49	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Mater	MOLAR FL((kgmole/t 0. 0. 0. 0. 0. 4981. 4981.	OW MOLE FF 0000 0001 0000 0000 0000 0000 0000 0000 0000 7648 7649 C2S	0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 10042.640 CONDITIONS 0.000	MASS FR 00 48 00 00 18 8 01 38	ACTION 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 Flui Pro	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000 266.8124 266.8124 266.8124 id Package: O perty Package: A	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 verheads spen Properties (Peng-R		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Mater	MOLAR FL((kgmole/t 0. 0. 0. 0. 4981. 4981.	OW MOLE FF 0000 0001 0000 0000 0000 0000 0000 0	0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 10042.640 CONDITIONS Vapour Phase Vapour Phase	MASS FR 00 48 00 00 18 18 01 38	ACTION 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 Flui Pro	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000 266.8124 266.8124 id Package: O perty Package: A	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 verheads spen Properties (Peng-R		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Mater Vapour / Phase Fraction	MOLAR FL((kgmole/t 0. 0. 0. 0. 4981. 4981.	OW MOLE FF 00000 0001 00000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 10042.640 Vapour Phase 1.0000 1.0000	MASS FR 00 48 00 00 10 18 38 20 11 38 20 11 38 20 20 20 20 20 20 20 20 20 20 20 20 20	ACTION 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 Flui Pro	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000 266.8124 266.8124 266.8124 d Package: O perty Package: A	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 verheads spen Properties (Peng-R		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 40 50 51 52	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Mater Vapour / Phase Fraction Temperature:	MOLAR FL((kgmole/t 0, 0, 0, 0, 0, 4981, 4981, trial Streat	OW MOLE FF 00000 0001 00000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 10042.640 Vapour Phase 1.0000 40.00	MASS FR 00 48 00 00 10 18 38 20 11 38 20 11 38 20 11 38 20 20 20 20 20 20 20 20 20 20 20 20 20	ACTION 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 Flui Pro se 0000 40.00	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000 266.8124 266.8124 id Package: O perty Package: A	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 verheads spen Properties (Peng-R		
35 36 37 38 39 40 41 42 43 44 45 48 49 50 51 52 53 53	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Mater Vapour / Phase Fraction Temperature: Pressure:	MOLAR FL((kgmole/t 0, 0, 0, 0, 0, 0, 4981, 4981, 4981, trial Streat (C) (bar)	OW MOLE FF 00000 0001 00000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 10042.640 Vapour Phase 1.0000 40.00 6.513	MASS FR 00 18 00 18 00 10 18 10 10 10 10 10 10 10 10 10 10	ACTION 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 Flui Pro 90 90 90 90 1.0000 1.0000 1.0000 1.0000 1.000	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000 266.8124 266.8124 id Package: O perty Package: A	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 verheads spen Properties (Peng-R		
37 38 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Nater Vapour / Phase Fraction Temperature: Pressure: Molar Flow	MOLAR FL((kgmole/t 0, 0, 0, 0, 0, 0, 4981, 4981, 4981, trial Streat (C) (bar) (kgmole/h)	OW MOLE FF 00000 0001 00000 0000 0000 0000 0000 0000 0000 0000 0000 0000	0.0000 0.0000 0.0000 0.0000 0.0000 1.00000 1.00000 1.00000 1.00000000	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 10042.640 Vapour Phase 1.0000 40.00 6.513 4982 1.000	MASS FR 00 18 00 10 18 10 10 138 Liquid Phae 0 1 5.963e	ACTION 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 Flui Pro e 0.000 40.00 5.513 -005	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000 266.8124 266.8124 id Package: O perty Package: A	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 verheads spen Properties (Peng-R		
37 38 37 38 39 40 41 42 43 44 45 48 49 50 51 52 53 54 55 54	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Mater Vapour / Phase Fraction Temperature: Pressure: Molar Flow Mass Flow	MOLAR FL((kgmole/t 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.	OW MOLE FF 00000 0001 00000 0000 0000 0000 0000 00000 0000 0000 0000 000	0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0	MASS FR 00 48 00 00 18 00 10 138 Liquid Phas 0 0 0 0 0 0 0 0 0 0 0 0 0	ACTION 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 Flui Pro 0.000 40.00 5.513 -005 -006	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.000 0.0	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 verheads spen Properties (Peng-R		
35 36 37 38 39 40 41 42 43 44 45 48 49 50 51 52 53 54 55 56	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Matcel Vapour / Phase Fraction Temperature: Pressure: Molar Flow Mass Flow Std Ideal Liq Vol Flow	MOLAR FL((kgmole/t 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.	OW MOLE FF 00000 0001 00000 0000 0000 0000 00000 0000 0000 0000 0000 000	0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 0.0000 1.0000 0.00000 0.000000	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0	MASS FR 00 48 00 00 18 00 10 18 10 10 10 10 10 10 10 10 10 10	ACTION 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 Flui Pro 9 9 9 9 9 9 9 9 9 9 9 9 9	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000 266.8124 266.8124 id Package: O perty Package: A	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 verheads spen Properties (Peng-R		
35 36 37 38 39 40 41 42 43 44 45 48 49 50 51 52 53 54 55 56 57	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Matcel Vapour / Phase Fraction Temperature: Pressure: Molar Flow Mass Flow Std Ideal Liq Vol Flow Molar Enthalpy	MOLAR FL((kgmole/t 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.	OW MOLE FF 0000 0001 0000 0000 0000 0000 0000 0	0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 10042.640 Vapour Phase 1.0000 40.00 6.513 4982 2.790 266.8 436.6	MASS FR 00 18 00 10 10 10 10 10 10 10 10 10	ACTION 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 Flui Pro 0000 40.00 5.513 -005 -006 -005 +005	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.000 0	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 verheads spen Properties (Peng-R		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Matcel Vapour / Phase Fraction Temperature: Pressure: Molar Flow Mass Flow Std Ideal Liq Vol Flow Molar Enthalpy Molar Entropy	MOLAR FL((kgmole/t 0. 0. 0. 0. 0. 4981. 4981. 4981. 4981. 4981. (kg/s) (kg/s) (kg/s) (kg/s) (kJ/kgmole) (kJ/kgmole-C)	OW MOLE FF 0000 0001 0000 0000 0000 0000 0000 0	0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 0.00 - 113 13 82 90 6.8 6.6 6.6	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 10042.640 Vapour Phase 1.0000 40.00 6.513 4982 2.790 266.8 436.6 -14.07	MASS FR 00 18 00 18 01 18 01 18 01 18 01 158 01 158 01 159634 1.3484 1.1586 -2.237e -	ACTION 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 Flui Pro 8e 0000 5.513 5.005 5.005 5.005 5.005	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 266.8124 266.8124 id Package: O perty Package: A	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 verheads spen Properties (Peng-R		
35 36 37 38 39 40 41 42 43 44 45 48 49 50 51 52 53 54 55 56 57 58 59	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Matcel Vapour / Phase Fraction Temperature: Pressure: Molar Flow Mass Flow Std Ideal Liq Vol Flow Molar Enthalpy Molar Entropy Heat Flow	MOLAR FL((kgmole/t 0. 0. 0. 0. 0. 0. 4981. 4981. 4981. 4981. 4981. 4981. (kg/s) (kg/s) (kg/s) (kg/s) (kg/s) (kg/kgmole) (kJ/kgmole-C) (MW)	OW MOLE FF 0000 0001 0000 0000 0000 0000 0000 0	0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 0.00° 1.13 1.13 1.13 1.13 1.13 1.13 1.13 1.1	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0	MASS FR 00 18 00 18 01 18 01 18 01 18 01 18 01 138 0 138 0 138 138 138 138 138 138 138 138	ACTION 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 Filui Pro 8e 0000 5.513 -005 -005 -005 -005 -005 -005 -005 -00	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 266.8124 266.8124 id Package: O perty Package: A	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 verheads spen Properties (Peng-R		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Mater Vapour / Phase Fraction Temperature: Pressure: Molar Flow Molar Entw Molar Entwapy Molar Entropy Heat Flow Liq Vol Flow @Std Cond	MOLAR FL((kgmole/t 0. 0. 0. 0. 0. 0. 4981. 4981. 4981. 4981. 4981. (kg/s) (kg/	OW MOLE FF 0000 0001 0000 0000 0000 0000 0000 0	0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 10042.640 0 10042.641 0 10042.641 0 10042.641 0 10042.641 0 10042.641 0 0.000 40:00 6.513 4982 2.790 2.66.8 436.6 -14.07 0.6042 6.153e+063 63	MASS FR 00 18 00 18 01 18 01 18 01 18 01 18 01 10 10 10 10 10 10 10 10 10	ACTION 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 Filui Pro 40.00 5.513 5-005 5-006 5-005 5-006 5	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.000 0	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 1.000 1.0000		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Mater Mater Vapour / Phase Fraction Temperature: Pressure: Molar Flow Molar Entw Molar Entw Molar Entwpy Heat Flow Liq Vol Flow @Std Cond	MOLAR FL((kgmole/t 0. 0. 0. 0. 0. 4981. 4981. 4981. 4981. 4981. (kg/s) (kg/s) (kg/s) (kg/s) (kg/s) (kg/s) (kg/kgmole) (kJ/kgmole) (kJ/kgmole-C) (MW) (m3/h)	OW MOLE FF 0000 0001 0000 0000 0000 0000 0000 0	0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 0.00 ° 513 56.6 5.8 5.6 5.8 5.6 5.8 5.6	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 0.000 0 10042.640 0 10042.641 Vapour Phase 1.0000 40.000 6.513 49820 2.790 266.8 436.6 -14.07 0.6042 6.153e+063 6.153e+063	MASS FR 00 18 00 18 01 18 01 138 01 138 01 01 01 01 01 01 01 01 01 01	ACTION 0.0000 0.0000 0.0000 0.0000 1.0000 Flui Pro e 0.000 5.513 5.005 5.005 5.005 5.005 5.005 5.006 5	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.000 0.	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 1.000 1.0000		
35 36 37 38 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 80 61 62	COMPONENTS Zinc Zinc-Oxide Nitrogen Oxygen Water Tin-White Hydrogen Total Mater Vapour / Phase Fraction Temperature: Pressure: Molar Flow Molar Entw Molar Entwal Molar Entwal Molar Entropy Heat Flow Liq Vol Flow @Std Cond	MOLAR FL((kgmole/t 0. 0. 0. 0. 0. 4981. 4981. 4981. 4981. (kg/s) (kg/s) (kg/s) (kg/s) (kg/s) (kg/s) (kg/kgmole) (kJ/kgmole) (kJ/kgmole-C) (MW)	OW MOLE FF h) MOLE FF 0000 0000 0000 0000 0000 0000 0000	0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 0.00 - 0.00 - 0.00 - 0.00 - 0.00 - 0.0000 1.0000 0.000000	Vapour Phase 4 MASS FLOW (kg/h) 0 0.000 0	MASS FR 00 18 00 18 01 18 01 18 01 138 01 01 01 01 01 01 01 01 01 01	ACTION 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 Flui Pro se 0.000 40.00 5.513 -005 -005 +005 7.015 -006 +068	Phase Fi LIQUID VOLUME FLOW (m3/h) 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 266.8124 266.8124 id Package: O perty Package: A	raction 1.000 LIQUID VOLUME FRACTION 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 verheads spen Properties (Peng-R		

1				Case Name:	Production.hsc		
2	(aspentech	BATTELLE EN Bedford, MA	RGY ALLIANCE	Unit Set:	AmeyS2e		
4		USA		Date/Time:	Fri Mar 29 15:46:33	2024	
6 7 8	Mater	ial Strean	n: C2S1in	(continued	I)	Fluid Package: Property Package:	Overheads Aspen Properties (Peng-R
9				COMPOSITION	N		
11				Overall Phase		Vapou	Fraction 1.0000
12	COMPONENTS	MOLAR FLOW	MOLE FRACT	ION MASS FLOW	MASS FRACT	FION LIQUID VOLUME	E LIQUID VOLUME
15	Zinc	0.000	0.0	000 0.00	0.0	0.000	0 0.0000
18	Zinc-Oxide	0.000	0.0	000 0.00	048 0.0	0000 0.000	0.0000
17	Nitrogen	0.000	0.0	000 0.00	0.0 0.0	0000 0.000	0.0000
18	Oxygen	0.000	0.0	0.00	0.0	0000 0.000	0.0000
19	Water	0.000	0.0	000 0.00	0.0	0000 0.000	0.0000
20	Tin-White	0.000	0.0	000 0.00	0.0	0000 0.000	0.0000
21	Hydrogen	4981.764	1.0	000 10042.64	1.0	266.812	4 1.0000
22	Total	4981.764	1.0	000 10042.64	168 1.0	266.812	4 1.0000
23 24				Vapour Phase		Phase	Fraction 1.000
25	COMPONENTS	MOLAR FLOW (kamole/h)	MOLE FRACT	ION MASS FLOW	MASS FRACT	TION LIQUID VOLUME FLOW (m3/h)	E LIQUID VOLUME
27	Zinc	0.000	0.0	000 0.00	0.0	0.000	0.0000
28	Zinc-Oxide	0.000	0.0	000 0.00	00 0.0	0.000 0.000	0.0000
29	Nitrogen	0.000	0.0	000 0.00	0.0 0.0	000.0 0.000	0.0000
30	Oxygen	0.000	0.0	000 0.00	0.0	0000 0.000	0.0000
31	Water	0.000	0.0	000 0.00	0.0 0.0	0000 0.000	0.0000
32	Tin-White	0.000	0.0	000 0.00	0.0	0000 0.000	0.0000
33	Hydrogen	4981,764	1.0	000 10042.64	1.0	266.812	4 1.0000
34	Total	4981.764	1.0	000 10042.64	19 1.0	266.812	4 1.0000
35				Liquid Phase		Phase	Fraction 1.197e-008
37	COMPONENTS	MOLAR FLOW	MOLE FRACT	ION MASS FLOW	MASS FRACT		LIQUID VOLUME
38		(kgmole/h)		(kg/h)		FLOW (m3/h)	FRACTION
39	Zinc	0.000	0.0	000 0.00	000 0.0	000.0 0000	0.0000
40	Zinc-Oxide	0.000	0.9	979 0.00	048 0.9	9981 0.000	0 0.9985
41	Nitrogen	0.000	0.0	000 0.00	0.0 0.0	0000 0.000	0.0000
42	Oxygen	0.000	0.0	000 0.00	0.0 0.0	0.000 0.000	0.0000
43	Water	0.000	0.0	000 0.00	0.0	0.000 0.000	0 0.0000
44	Tin-White	0.000	0.0	013 0.00	000 0.0	0.000	0 0.0013
45	Hydrogen	0.000	0.0	009 0.00	000 0.0	0000 0.000	0 0.0002
40	Total	0.000	1.0	000 0.00	1.0	0.000 0.000	0 1.0000
4/ 48 49	Mater	ial Strean	: C2S1o	ut		Fluid Package: Property Package:	Overheads Aspen Properties (Peng-R
50 51				CONDITIONS			
52			Overall	Vapour Phase	Liquid Phase		
53	Vapour / Phase Fraction		1.0000	1.0000	0.000	0	
54	Temperature:	(C)	175.0 *	175.0	175.	0	
55	Pressure:	(bar)	17.36	17.36	17.3	6	
56	Molar Flow	(kgmole/h)	4982	4982	8.186e-00	6	
57	Mass Flow	(kg/s)	2.790	2.790	1.846e-00	7	
58	Std Ideal Lig Vol Flow	(m3/h)	266.8	266.8	1.587e-00	6	
59	Molar Enthalpy	(kJ/kgmole)	4385	4385	-2.153e+00	5	
60	Molar Entropy (I	kJ/kgmole-C)	-11.78	-11.78	14.7	9	
61	Heat Flow	(MW)	6.068	6.068	-4.895e-00	7	
62	Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.222e+063	1.079e+06	3	-
63	Aspen Technology Inc.		A	spen HYSYS Versio	n 12.1		Page 6 of 13
	Licensed to: BATTELLE ENER(ST ALLIANCE					Specified by user.

Image: Instant instant BATTELLE MERCY ALLIANCE USA Image: AnneySce Detrime: Pri Mar 29 1546:33 2024 Material Stream: C2S1out (continued) Pri Mar 29 1546:33 2024 Property Deskage:: Augen Properts (Peng P Augen Property Deskage:: Augen Properts (Peng P COMPORENTS) Overlass: Augen Properts (Peng P Augen Properts (Peng P COMPORENTS) COMPORENTS MOLAR FLOW MOLE PRACTION MASS FLOW Ligutor Volume In Property Deskage:: Augen Properts (Peng P COMPORENTS) 2 znc-0xid 0.00001 0.0000 0.0000 0.0000 0.0000 2 znc-0xid 0.00001 0.0000 0.0000 0.0000 0.0000 0.0000 0 componentities 0.00001 0.0000 0.0000 0.0000 0.0000 0.0000 0 componentities 0.00001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0 componentities 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0 componentities 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1 componentities 0.0000 0.0000 0.0000	1				Case Name: Pr	oduction.hsc			
4 cl Distrime Private 2015.46.03.3.00.4 0 model Material Stream: C2S1out (continued) Private Package: Overheads 0 model COMPOSITION Overheads Appen Properties (Perg.R) 0 model Outcome Nouck FLOW Model Package: Overheads 1 model Outcome Outcome Nouck FLOW Model Package: Overheads 1 model Outcome Model FRACTION MASS FLOW MASS FRACTION LDUID VOLUME FLOW (m3h) 2 znc 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0 model 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0 model 0.0000	2	(aspentech	BATTELLE ENER Bedford, MA	GY ALLIANCE	Unit Set: An	neyS2e			
Image: control Plud Pakage: Mage: Mage Properties (Parg Pakage: Mage Pakage Pakage Pakage: Mage Pakage: Mage Pakage Pakage: Mage Pa	4		USA		Date/Time: Fri	Mar 29 15:46:33 2024			
0 COMPOSITION Vacual Flow Vacua Flow Vacual Flow Vacu	6 7 8	Mater	ial Stream	C2S1out	t (continued) Flui Pro	Fluid Package: Overhe Property Package: Aspen		
Overall Phase Vapour Fraction 1.000 10 COMPONENTS MOLAR FLOW (kgmolefh) MALSS FLOW (kgmolefh) MALSS FLOW (kgmolefh) MALSS FLOW (kgmolefh) LIQUID VOLUME FLOW (mShi) LIQUID VOLUME FRACTION	9				COMPOSITION				
12 COMPONENTS MOLAR FLOW (kgmoleft) MOLE FRACTION (kgh) MASS FLOW (kgh) MASS FRACTION (kgh) LIQUID VOLUME FLOW (m0M) LIQUID VOLUME FRACTION (kgh) LIQUID VOLUME FRACTION LIQUID VOLUME FRACTIO	11				Overall Phase		Vapour Fr	action 1.0000	
14 000000 0	12	COMPONENTS	MOLAR FLOW	MOLE ERACTION	MASS FLOW	MASS FRACTION		LIQUID VOLUME	
jor Doco Doco <thdoco< th=""> Doco Doco D</thdoco<>	14		(kgmole/h)		(kg/h)		FLOW (m3/h)	FRACTION	
10 Concernation 0.0001 0.0000 0.000	15	Zinc	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	
17 Nitrogen 0.0000 <td>16</td> <td>Zinc-Oxide</td> <td>0.0001</td> <td>0.000</td> <td>0 0.0048</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	16	Zinc-Oxide	0.0001	0.000	0 0.0048	0.0000	0.0000	0.0000	
B Oxygen 0.0000	17	Nitrogen	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	
19 Water 0.0000	18	Oxygen	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	
20 Tin-White 0.0000<	19	Water	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	
11 Hydrogen 44981.7648 10000 10042.4011 10000 266.8124 10000 21 Total 4981.7649 10000 10042.4011 10000 266.8124 10000 23 OCMPONENTS MOLAR FLOW MOLE FRACTION MASS FLOW MASS FRACTION LIQUID VICUME LIQUID VICUME FRACTION FRACTION EVAPORT COMPONENTS MOLAR FLOW MOLE FRACTION MASS FLOW MASS FRACTION LIQUID VICUME LIQUID VICUME FRACTION FRACTION EVAPORT COMPONENTS MOLAR FLOW MOLE FRACTION MASS FLOW MASS FRACTION LIQUID VICUME FRACTION FRACTION EVAPORT 0.0000 <td>20</td> <td>Tin-White</td> <td>0.0000</td> <td>0.000</td> <td>0 0.0018</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	20	Tin-White	0.0000	0.000	0 0.0018	0.0000	0.0000	0.0000	
22 Total 4981.7649 10000 10042.6468 1.0000 266.8124 1.0000 23 Vapour Phase Phase Fraction 1.000 Phase Fraction 1.000 24 COMPONENTS MOLAR FLOW (kgmoleň) MOLE FRACTION (kgmoleň) MASS FRACTION (kgmoleň) LIQUID VOLUME FRACTION	21	Hydrogen	4981.7648	1.000	0 10042.6401	1.0000	266.8124	1.0000	
23 bet Vapour Phase Phase Fraction 1.000 25 20 20 21 21 20 21 21 20 21 21 21 21 21 21 21 21 21 21 21 21 21	22	Total	4981.7649	1.000	0 10042.6468	1.0000	266.8124	1.0000	
29 20 COMPONENTS MOLAF FLOW (kgmoleh) MOLE FRACTION (kgmoleh) MASS FLOW (kgmoleh) LIQUID VOLUME FLOW (m3h) LIQUID VOLUME FRACTION FRACTION 21 Zinc 0.0000 <td< td=""><td>23 24</td><td></td><td></td><td></td><td>Vapour Phase</td><td></td><td>Phase Fra</td><td>ction 1.000</td></td<>	23 24				Vapour Phase		Phase Fra	ction 1.000	
27 Dine 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	
22 Zinc-Oxide 0.0001 0.0000<	27	Zinc	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	
29 Ntrogen 0.0000 <td>28</td> <td>Zinc-Oxide</td> <td>0.0001</td> <td>0.000</td> <td>0 0.0042</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	28	Zinc-Oxide	0.0001	0.000	0 0.0042	0.0000	0.0000	0.0000	
30 Oxygen 0.0000	29	Nitrogen	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	
11 Water 0.0000	30	Oxygen	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	
32 Tin-White 0.0000 0.0000 0.0016 0.0000 0.0000 0.0000 31 Hydrogen 4981.7648 1.0000 10042.6401 1.0000 266.6124 1.0000 35 36 Liquid Phase Phase Fraction 1.643e-009 36 2 COMPONENTS MOLAR FLOW (kgmoleft) MOLE FRACTION MASS FLOW (kg/h) MASS FRACTION LIQUID VOLUME FLOW (m3/h) EVALUE LIQUID VOLUME FLOW (m3/h)	31	Water	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	
33 Hydrogen 4981.7648 1.0000 10042.6401 1.0000 266.8124 1.0000 34 Total 4981.7648 1.0000 10042.6461 1.0000 266.8124 1.0000 36 Liquid Phase Phase Fraction 1.643e-009 37 COMPONENTS MOLAR FLOW (kgmoleh) MOLE FRACTION (kgmoleh) MASS FLOW (kgmoleh) MASS FLOW (kgmoleh) MASS FLOW (kgmoleh) LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION 0.0000	32	Tin-White	0.0000	0.000	0.0018	0.0000	0.0000	0.0000	
34 Total 4981.7649 1.0000 10042.6461 1.0000 266.8124 1.0000 38 30 COMPONENTS MOLAR FLOW (kgmolefh) MOLE FRACTION MASS FLOW (kgmol MASS FRACTION LIQUID VOLUME FLOW (m3h) LIQUID VOLUME FRACTION FRACTION 39 Zine 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 40 Zine-Oxide 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 40 Zine-Oxide 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 41 Ntrogen 0.0000<	33	Hydrogen	4981.7648	1.000	0 10042.6401	1.0000	266.8124	1.0000	
30/30 Liquid Phase Phase Fraction 1.643e-009 31 COMPONENTS MOLAR FLOW (kgmoleh) MOLE FRACTION MASS FLOW (kgh) MASS FRACTION LIQUID VOLUME FLOW (m3h) LIQUID VOLUME FRACTION 32 Zinc 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 40 Zinc-Oxide 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 40 Zinc-Oxide 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 41 Nitrogen 0.0000 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 0.0000 44 To-White 0.0000 0.0000 0.0000 0.0000 1.0000 0.0000 0.0000 0.0000 0	34	Total	4981.7649	1.000	0 10042.6461	1.0000	266.8124	1.0000	
Solution COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION (kg/h) MASS FLOW (kg/h) MASS FRACTION (kg/h) LIQUID VOLUME FLOW (m3/h) LIQUID VOLUME FRACTION 38 Zinc 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 39 Zinc-Oxide 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1	35 38				Liquid Phase		Phase Fra	ction 1.643e-009	
38 Channels (kgmolefh) (kg/h) FLOW (m3/h) FRACTION 39 Zinc 0.0000 <td>37</td> <td>COMPONENTS</td> <td>MOLAR FLOW</td> <td>MOLE FRACTION</td> <td>MASS FLOW</td> <td>MASS FRACTION</td> <td>LIQUID VOLUME</td> <td>LIQUID VOLUME</td>	37	COMPONENTS	MOLAR FLOW	MOLE FRACTION	MASS FLOW	MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME	
39 Zinc 0.0000	38		(kgmole/h)		(kg/h)		FLOW (m3/h)	FRACTION	
40 Zinc-Oxide 0.0000 0.9971 0.0007 0.9999 0.0000 0.9992 41 Nitrogen 0.0000	39	Zinc	0.0000	0.000	0.0000 0	0.0000	0.0000	0.0000	
41 Nitrogen 0.0000 <td>40</td> <td>Zinc-Oxide</td> <td>0.0000</td> <td>0.997</td> <td>1 0.0007</td> <td>0.9999</td> <td>0.0000</td> <td>0.9992</td>	40	Zinc-Oxide	0.0000	0.997	1 0.0007	0.9999	0.0000	0.9992	
42 Oxygen 0.0000	41	Nitrogen	0.0000	0.000	0.0000 0	0.0000	0.0000	0.0000	
43 Water 0.0000	42	Oxygen	0.0000	0.000	0.0000 0	0.0000	0.0000	0.0000	
44 Tin-White 0.0000 </td <td>43</td> <td>Water</td> <td>0.0000</td> <td>0.000</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	43	Water	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	
45 Hydrogen 0.0000 0.0029 0.0000 0.0001 0.0000 0.0008 46 Total 0.0000 1.0000 0.0007 1.0000 0.0000 1.0000 47 48 Material Stream: C2S2in Fluid Package: Overheads 49 Property Package: Aspen Properties (Peng-R 50 CONDITIONS 5 52 Overall Vapour / Phase Liquid Phase	44	Tin-White	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	
48 Total 0.000 1.000 0.0007 1.0000 0.0000 1.0000 47 48 Material Stream: C2S2in Fluid Package: Overheads Property Package: Aspen Properties (Peng-R 50 CONDITIONS CONDITIONS Conditional Phase Liquid Phase 51 Conditional Phase Fraction 1.0000 1.0000 0.0000 53 Vapour / Phase Fraction 1.0000 1.0000 0.0000 54 Temperature: (C) 40.00 40.00 40.00 55 Pressure: (bar) 17.01 17.01 17.01 56 Pressure: (bar) 17.01 17.01 17.01 57 Mass Flow (kgmole/h) 4982 4982 5.982e-005 58 Std Ideal Liq Vol Flow (m3/h) 266.8 266.8 1.160e-005 59	45	Hydrogen	0.0000	0.002	9 0.0000	0.0001	0.0000	0.0008	
47 Fluid Package: Overheads 49 Property Package: Aspen Properties (Peng-R 56 CONDITIONS 50 52 Overall Vapour Phase Liquid Phase 53 Vapour / Phase Fraction 1.0000 0.0000 54 Temperature: (C) 40.00 40.00 55 Pressure: (bar) 17.01 17.01 17.01 56 Pressure: (bar) 17.01 17.01 17.01 56 Pressure: (bar) 2.790 2.790 1.352e-005 1.000 57 Mass Flow (kg/s) 2.790 2.790 1.352e-006 1.000 58 Std Ideal Liq Vol Flow (m3/h) 266.8 2.66.8 1.160e-005 1.000 59 Molar Entropy (kJ/kgmole-C) -2.207 -2.207 -6.862 1.000 60 Molar Entropy (kJ/kgmole-C) -2.207 -2.6862 1.000 1.000 61 Heat Flow (MW)<	48	Total	0.0000	1.000	0 0.0007	1.0000	0.0000	1.0000	
50 51 CONDITIONS 52 Overall Vapour Phase Liquid Phase 0 53 Vapour / Phase Fraction 1.0000 1.0000 0.0000 54 Temperature: (C) 40.00 40.00 40.00 54 Temperature: (bar) 17.01 17.01 17.01 55 Pressure: (bar) 17.01 17.01 17.01 56 Molar Flow (kgmole/h) 4982 5.982e-005 1000 57 Mass Flow (kg/s) 2.790 2.790 1.352e-006 1000 58 Std Ideal Liq Vol Flow (m3/h) 2666.8 266.8 1.160e-005 1000 59 Molar Enthalpy (kJ/kgmole) 443.6 -2.222e+005 1000 60 Molar Entropy (kJ/kgmole-C) -22.07 -26.062 1000 61 Heat Flow (MW) 0.6139 0.6139 -3.693e-006 1000 62 Liq Vol Flow @Std Cond (m3/h) 6.222e+063	47 48 49	Mater	ial Stream	C2S2in		Flui	d Package: Ov perty Package: As	erheads pen Properties (Peng-R	
52 Overall Vapour Phase Liquid Phase 53 Vapour / Phase Fraction 1.0000 1.0000 0.0000 54 Temperature: (C) 40.00 * 40.00 40.00 54 Temperature: (D) 17.01 17.01 17.01 55 Pressure: (bar) 17.01 17.01 17.01 56 Molar Flow (kgmole/h) 4982 4982 5.982e-005 57 Mass Flow (kg/s) 2.790 2.790 1.352e-006 58 Std Ideal Liq Vol Flow (m3/h) 266.8 266.8 1.160e-005 59 Molar Entropy (kJ/kgmole) 443.6 -2.222e+005	50 51				CONDITIONS				
53 Vapour / Phase Fraction 1.0000 1.0000 0.0000 54 Temperature: (C) 40.00 * 40.00 40.00 55 Pressure: (bar) 17.01 17.01 17.01 56 Molar Flow (kgmole/h) 4982 4982 5.982e-005 57 Mass Flow (kg/s) 2.790 2.790 1.352e-006 58 Std Ideal Liq Vol Flow (m3/h) 266.8 266.8 1.160e-005 59 Molar Entralpy (kJ/kgmole) 443.6 443.6 -2.222e+005 60 Molar Entropy (kJ/kgmole-C) -22.07 -2.207 -6.862 61 Heat Flow (MW) 0.6139 0.6139 -3.693e-006 62 Liq Vol Flow @Std Cond (m3/h) 6.222e+063 * 6.053e+063 3.086e+069 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 7 of 13	52			Overall	Vapour Phase	Liquid Phase			
54 Temperature: (C) 40.00 * 40.00 40.00 55 Pressure: (bar) 17.01 17.01 17.01 17.01 56 Molar Flow (kgmole/h) 4982 4982 5.982e-005 56 57 Mass Flow (kg/s) 2.790 2.790 1.352e-006 56 58 Std Ideal Liq Vol Flow (m3/h) 266.8 266.8 1.160e-005 56 59 Molar Entralapy (kJ/kgmole) 443.6 -2.22e+005 56 60 Molar Entropy (kJ/kgmole-C) -22.07 -2.207 -6.862 61 Heat Flow (MW) 0.6139 0.6139 -3.693e-006 62 Liq Vol Flow @Std Cond (m3/h) 6.222e+063 * 6.053e+063 3.086e+069 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 7 of 13	53	Vapour / Phase Fraction		1.0000	1.0000	0.0000			
55 Pressure: (bar) 17.01 17.01 17.01 56 Molar Flow (kgmole/h) 4982 4982 5.982e-005 57 Mass Flow (kg/s) 2.790 2.790 1.352e-006 58 Std Ideal Liq Vol Flow (m3/h) 266.8 266.8 1.160e-005 59 Molar Enthalpy (kJ/kgmole) 443.6 443.6 -2.222e+005 60 Molar Entropy (kJ/kgmole-C) -22.07 -2.207 -6.862 61 Heat Flow (MW) 0.6139 0.6139 -3.693e-006 62 Liq Vol Flow @Std Cond (m3/h) 6.222e+063 * 6.053e+063 3.086e+069 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 7 of 13	54	Temperature:	(C)	40.00 *	40.00	40.00			
56 Molar Flow (kgmole/h) 4982 4982 5.982e-005 57 Mass Flow (kg/s) 2.790 1.352e-006 5 58 Std Ideal Liq Vol Flow (m3/h) 266.8 1.160e-005 5 59 Molar Enthalpy (kJ/kgmole) 443.6 443.6 -2.222e+005 5 60 Molar Entropy (kJ/kgmole-C) -22.07 -2.207 -6.862 5 61 Heat Flow (MW) 0.6139 0.6139 -3.693e-006 5 62 Liq Vol Flow @Std Cond (m3/h) 6.222e+063 * 6.053e+063 3.086e+069 5 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 7 of 13 1	55	Pressure:	(bar)	17.01	17.01	17.01			
57 Mass Flow (kg/s) 2.790 2.790 1.352e-006 58 Std Ideal Liq Vol Flow (m3/h) 266.8 266.8 1.160e-005 59 Molar Enthalpy (kJ/kgmole) 443.6 443.6 -2.22e+005 60 Molar Entropy (kJ/kgmole-C) -22.07 -2.207 -6.862 61 Heat Flow (MW) 0.6139 0.6139 -3.693e-006 62 Liq Vol Flow @Std Cond (m3/h) 6.222e+063 * 6.053e+063 3.086e+069 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 7 of 13	58	Molar Flow	(kgmole/h)	4982	4982	5.982e-005			
58 Std Ideal Liq Vol Flow (m3/h) 266.8 266.8 1.160e-005 59 Molar Enthalpy (kJ/kgmole) 443.6 443.6 -2.22e+005 60 Molar Entropy (kJ/kgmole-C) -22.07 -22.07 -6.862 61 Heat Flow (MW) 0.6139 0.6139 -3.693e-006 62 Liq Vol Flow @Std Cond (m3/h) 6.222e+063 * 6.053e+063 3.086e+069 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 7 of 13 Licensed to: BATTELLE ENERGY ALLIANCE	57	Mass Flow	(kg/s)	2.790	2.790	1.352e-006			
59 Molar Enthalpy (kJ/kgmole) 443.6 443.6 -2.22e+005 60 Molar Entropy (kJ/kgmole-C) -22.07 -22.07 -6.862 61 Heat Flow (MW) 0.6139 0.6139 -3.693e-006 62 Liq Vol Flow @Std Cond (m3/h) 6.222e+063 6.053e+063 3.086e+069 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 7 of 13	58	Std Ideal Liq Vol Flow	(m3/h)	266.8	266.8	1.160e-005			
60 Molar Entropy (kJ/kgmole-C) -22.07 -6.862 61 Heat Flow (MW) 0.6139 0.6139 -3.693e-006 62 Liq Vol Flow @Std Cond (m3/h) 6.222e+063 * 6.053e+063 3.086e+069 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 7 of 13	59	Molar Enthalpy	(kJ/kgmole)	443.6	443.6	-2.222e+005			
61 Heat Flow (MW) 0.6139 0.6139 -3.693e-006 62 Liq Vol Flow @Std Cond (m3/h) 6.222e+063 * 6.053e+063 3.086e+069 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 7 of 13 Licensed to: BATTELLE ENERGY ALLIANCE * Sanofied bullance * Sanofied bullance	60	Molar Entropy ()	kJ/kgmole-C)	-22.07	-22.07	-6,862			
62 Liq Vol Flow @Std Cond (m3/h) 6.222e+063 * 6.053e+063 3.086e+069 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 7 of 13 Licensed to: BATTELLE ENERGY ALLIANCE * Second double of the user * Second double of the user	61	Heat Flow	(MW)	0.6139	0.6139	-3.693e-006			
Aspen recinitiology Inc. Aspen misits Version 12.1 Page / of 13 Licensed to: BATTELLE ENERGY ALLIANCE	62	Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	6.053e+063	3.086e+069		Dage 7 442	
CREATER IN ANY TELLE ENERGY ALL MANY	03	Licensed to: BATTELLE ENERGY	SY ALLIANCE	Asp	en more version 1.	2.1		Specified by service	

Bartrelle ENERGY ALLINGE USA Bartrelle ENERGY ALLINGE USA Lint Set: AmerySie Derritme: Fri Mar 29 1546.33 2024 Poart Package: Agen Properties (Perug R Agen Prop	1				Case Name:	Pro	oduction.hsc		
Image: Note of the second s	2	(aspentech	BATTELLE EN Bedford, MA	IERGY ALLIANCE	Unit Set:	An	nevS2e		
Instrument Plaid Parkage: Overheads Product Agen Properties (Perog R ComPONENTS COMPONENTS Vacour Production ComPONENTS MOLAR R-OW Bigmatehin MOLE FRACTION Moss Practice Location ComPONENTS MOLAR R-OW Bigmatehin MOLE FRACTION Moss Practice Location Location ComPONENTS MOLAR R-OW Bigmatehin MOLE FRACTION Moss Practice Location	4	Gar	USA		Date/Time:	Fri	Mar 29 15:46:33 2024		
0 COMPOSITION 0 Overail Phase Vacour Fraction 1.000 10 COMPORENTS MOLAR FLOW MASS FLOTM MASS FRACTION UOUD YOLUME L/CUD YOLUME 10 Znc/Oxde 0.0000	5 6 7 8	Mater	ial Strear	n: C2S2in	(continu	ed)	Flui	id Package: Ov perty Package: As	erheads pen Properties (Peng-R
Overall Phase Vapour Fraction 1.000 2 COMPONENTS MOLAR FLOW (bigmelen) MOLE FRACTION 0.0000 MASS FLOW (bigh) MASS FRACTION 0.0000 LIQUID VOLUME FLOW (m3h) LIQUID VOLUME FRACTION FRACTION 0.0000 0.0000 <t< td=""><td>9</td><td></td><td></td><td></td><td>COMPOSIT</td><td>ON</td><td></td><td></td><td></td></t<>	9				COMPOSIT	ON			
Components MOLAR FLOW (ligmicelin) MOLE FRACTION (lighin) MASS FLOW (lighin) MASS FLOW (lighin) Light Production Charlow FRACTION (lighin) Could volume FRACTION (lighin) Could volume FRACTION FRACTION (lighin) Light Production Could volume FRACTION 10 Zno-Oxde 0.0000	11				Overall Pha	60		Vapour Fr	action 1,0000
COMPONENTS MOLAR FLOW MOLE FRACTION MASS FLOW MASS FRACTION ELGW (nDM) FLOW (nDM) 2 Znc 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 10 Znc 0.0001 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 10 Origin 0.0000 </td <td>12</td> <td>0011001151150</td> <td></td> <td>101550407</td> <td></td> <td>20</td> <td></td> <td>Vapour</td> <td></td>	12	0011001151150		101550407		20		Vapour	
15 Dec. 0.0000	14	COMPONENTS	(kgmole/h)	MOLE FRACT	ION MASS FL (kg/h)	MASS FRACTION	FLOW (m3/h)	FRACTION
19 Znc. Oxde 0.0001 0.0000 </td <td>15</td> <td>Zinc</td> <td>0.000</td> <td>0.0</td> <td>000</td> <td>0.0000.0</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	15	Zinc	0.000	0.0	000	0.0000.0	0.0000	0.0000	0.0000
Introgen 0.0000 0.000	16	Zinc-Oxide	0.000	0.0	000	0.0048	0.0000	0.0000	0.0000
B Oxygen 0.0000	17	Nitrogen	0.000	0.0	000	0.0000.0	0.0000	0.0000	0.0000
Vater 0.0000 </td <td>18</td> <td>Oxygen</td> <td>0.000</td> <td>0.0</td> <td>000</td> <td>0.0000.0</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	18	Oxygen	0.000	0.0	000	0.0000.0	0.0000	0.0000	0.0000
Dir. Number 0.0000 0.0000 0.0018 0.0000 0.0000 0.0000 1 Hydrogen 44817648 1.0000 1042.4481 1.0000 266.8124 1.0000 21 Total 44817649 1.0000 1042.4481 1.0000 266.8124 1.0000 23 Total 49817649 1.0000 MASS FRACTION UQU VOLUME LQU VOLUME LQU VOLUME LQU VOLUME FRACTION FRACTION 0.0000 0.00	19	Water	0.000	0.0	000	0.0000	0.0000	0.0000	0.0000
11 Hydrogen 4981.7448 1.0000 10042.4401 1.0000 2268.124 1.0000 23 Total 4981.7449 1.0000 10042.4468 1.0000 266.8124 1.0000 23 COMPONENTS MCLAR FLOW (kgmoleft) MOLAR FLOW (kgmoleft) MASS FLOW MASS FRACTION LIQUID VOLUME FLOW (m3h) LIQUID VOLUME FRACTION FRACTON LIQUID VOLUME FRACTON LIQUID VOLUME FRACTON LIQUID VOLUME FRACTON COMPONENTS MOLAR FLOW (kgmoleft) MOLAR FLOW (kgmoleft) DO000 0.0000	20	Tin-White	0.000	0.0	000	0.0018	0.0000	0.0000	0.0000
22 Total 4981.7649 1.000 10042.4488 1.000 226.8124 1.000 34 Vapour Phase Phase Fraction 1.000 Phase Fraction 1.000 23 COMPONENTS MOLAR FLOW MASS FRACTION UGUD VOLUME FRACTION FRACTION UGUD VOLUME 27 Znc 0.0000	21	Hydrogen	4981.764	1.0	000 1004	2.6401	1.0000	266.8124	1.0000
Plase Praction 1.000 25 COMPORENTS MOLA R-LOW (kgmole/h) MOLE FRACTION (kgh) MASS FRACTON (kgh) LIQUID VOLUME FLOW (m3h) LIQUID VOLUME FRACTION 27 Zne 0.0000 <t< td=""><td>22</td><td>Total</td><td>4981.764</td><td>19 1.0</td><td>000 1004</td><td>2.6468</td><td>1.0000</td><td>266.8124</td><td>1.0000</td></t<>	22	Total	4981.764	19 1.0	000 1004	2.6468	1.0000	266.8124	1.0000
25 COMPONENTS MOLAR FLOW (kgmoleh) MOLE FRACTION (kgm) MASS FLOW (kgh) MASS FRACTION (kgm) LIQUID VoLUME FLOW (m3h) DUBUD VoLUME FRACTION 0.0000 2 Znc 0.0000 0.0	23 24				Vapour Pha	se		Phase Fra	action 1.000
27 Zine 0.0000	25 26	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACT	ION MASS FL (kg/h	ow	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	FRACTION
28 2ine-Oxide 0.0000<	27	Zinc	0.000	0.0 0.0	000	0.0000.0	0.0000	0.0000	0.0000
Strogen 0.0000	28	Zinc-Oxide	0.000	0.0 0.0	000	0.0000.0	0.0000	0.0000	0.0000
80 Oxygen 0.0000	29	Nitrogen	0.000	0.0	000	0.0000.0	0.0000	0.0000	0.0000
31 Water 0.0000	30	Oxygen	0.000	0.0 0.0	000	0.0000.0	0.0000	0.0000	0.0000
32 Tin-White 0.0000 0.0000 0.0018 0.0000 0.0000 0.0000 31 Hydrogen 4981.7648 1.0000 10042.6401 1.0000 266.8124 1.0000 35 Trial 4981.7648 1.0000 10042.6401 1.0000 266.8124 1.0000 36 COMPONENTS MOLAR FLOW MOLE FRACTION MASS FRACTION LIQUID VOLUME FLOW M300 0.0000 <	31	Water	0.000	0.0	000	0.0000.0	0.0000	0.0000	0.0000
33 Hydrogen 4981.7648 1.0000 10042.6401 1.0000 266.8124 1.0000 4 Total 4981.7648 1.0000 10042.6419 1.0000 266.8124 1.0000 56 Liquid Phase Phase Fraction 1.201e-008 77 COMPONENTS MOLA R FLOW (kgmoleň) MOLE FRACTION (kgmoleň) MASS FLOW (kgmoleň) MASS FRACTION (kgmb LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION D.0000 0.0000	32	Tin-White	0.000	0.0	000	0.0018	0.0000	0.0000	0.0000
34 Total 4981.7648 1.0000 10042.8419 1.0000 266.8124 1.0000 86 Liquid Phase Phase Fraction 1.201e-008 37 COMPONENTS MOLAR FLOW (kgmoleh) MOLE FRACTION MASS FLOW (kgmoleh) LIQUID VOLUME FLOW (m3h) LIQUID VOLUME FRACTION IPRACTION 38 Zine 0.0000 <td< td=""><td>33</td><td>Hydrogen</td><td>4981.764</td><td>48 1.0</td><td>000 1004</td><td>2.6401</td><td>1.0000</td><td>266.8124</td><td>1.0000</td></td<>	33	Hydrogen	4981.764	48 1.0	000 1004	2.6401	1.0000	266.8124	1.0000
30 Description Phase Fraction 1.201e-008 72 COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION MASS FLOW (kg/h) MASS FRACTION LIQUID VOLUME FLOW (m3/h) LIQUID VOLUME FRACTION 92 Zine 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 92 Zine 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 92 Zine 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 92 Zine 0.0000 0.0000 0.0000 0.0000 0.0000 10 Vargen 0.0000 0.0000 0.0000 0.0000 0.0000 11 Tin-Vhite 0.0000 0.0001 0.0000 0.0000 0.0000 12 Hydrogen 0.0001 1.0000 0.0001 0.0000 1.0000 14 Hydrogen 0.0001 1.0000 0.0001 0.0000 1.0000 15 Total 0.0001 1.0000<	34	Total	4981.764	48 1.0	000 1004	2.6419	1.0000	266.8124	1.0000
COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION (kg/h) MASS FRACTION (kg/h) LiQUID VOLUME FLOW (m3/h) LIQUID VOLUME FRACTION 38 Zinc 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 39 Zinc 0.0000	35				Liquid Pha	se		Phase Fra	ction 1.201e-008
Construction Index (relation) Index (relation) <thindex (relation)<="" th=""> <thindex (relation)<="" th=""></thindex></thindex>	37	COMPONENTS	MOLAR FLOW	MOLE FRACT	ION MASS FI	ow	MASS FRACTION		LIQUID VOLUME
39 Zinc 0.0000	38		(kgmole/h)		(kg/h)		FLOW (m3/h)	FRACTION
40 Zinc-Oxide 0.0001 0.9946 0.0048 0.9954 0.0000 0.9962 41 Nitrogen 0.0000 1.0000 0.0000 1.0000 0.0000 1.0000 1.0000 0.0000 1.0000 1.0000 0.0000 1.0000 1.0000 0.0000 1.0000 1.0000 0.0000 1.0000 1.0000 1.0000 1.0000	39	Zinc	0.000	0.0 0.0	000	0.0000.0	0.0000	0.0000	0.0000
Mitrogen 0.0000 0.000	40	Zinc-Oxide	0.000	0.9	946	0.0048	0.9954	0.0000	0.9962
Value 0.0000 </td <td>41</td> <td>Nitrogen</td> <td>0.000</td> <td>0.0</td> <td>000</td> <td>0.0000.0</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	41	Nitrogen	0.000	0.0	000	0.0000.0	0.0000	0.0000	0.0000
43 Water 0.00000 0.00000 0.0000 <td>42</td> <td>Oxygen</td> <td>0.000</td> <td>0.0</td> <td>000</td> <td>0.0000.0</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	42	Oxygen	0.000	0.0	000	0.0000.0	0.0000	0.0000	0.0000
Huite 0.0000 0.0031 0.0000 0.0046 0.0000 0.0031 45 Hydrogen 0.0000 0.0022 0.0000 0.0001 0.0000 0.0000 46 Total 0.0001 1.0000 0.0049 1.0000 0.0000 1.0000 47 Material Stream: C2S2out Fluid Package: Overheads 49 Property Package: Aspen Properties (Peng-R 50 5 CONDITIONS Streams 51 Vapour / Phase Fraction 1.0000 1.0000 0.0000 52 Overall Vapour Phase Liquid Phase 53 Vapour / Phase Fraction 1.0000 1.0000 0.0000 54 Temperature: (C) 175.0 175.0 56 Pressure: (bar) 45.31 45.31 45.31 57 Mass Flow (kgmole/h) 4982 4982 3.857e-005 58 <td>43</td> <td>Water</td> <td>0.000</td> <td>0.0</td> <td>000</td> <td>0.0000.0</td> <td>0.0000</td> <td>0.0000</td> <td>0.0000</td>	43	Water	0.000	0.0	000	0.0000.0	0.0000	0.0000	0.0000
Hydrogen 0.0000 0.0022 0.0000 0.0001 0.0000 0.0006 46 Total 0.0001 1.0000 0.0049 1.0000 0.0000 1.0000 47 48 Material Stream: C2S2out Fluid Package: Overheads 49 Property Package: Aspen Properties (Peng-R 50 CONDITIONS CONDITIONS 52 Overall Vapour / Phase Liquid Phase	44	Tin-White	0.000	0.0	031	0.0000.0	0.0046	0.0000	0.0031
Material Stream: 0.0001 1.0000 0.0049 1.0000 0.0000 1.0000 44 Material Stream: C2S2out Property Package: Aspen Properties (Peng-R 50 CONDITIONS CONDITIONS 1.0000 0.0000 0.0000 52 Overall Vapour Phase Liquid Phase	45	Hydrogen	0.000	0.0	022	0.0000.0	0.0001	0.0000	0.0006
Arr Fluid Package: Overheads Material Stream: C2S2out Property Package: Aspen Properties (Peng-R CONDITIONS CONDITIONS Condition Condition 50 Condition 1.0000 1.0000 0.0000 0.0000 52 Overall Vapour Phase Liquid Phase	46	Total	0.000	1.0	000	0.0049	1.0000	0.0000	1.0000
Sol 50 CONDITIONS Sol 50 Overall Vapour Phase Liquid Phase 52 Overall Vapour Phase Liquid Phase 53 Vapour / Phase Fraction 1.0000 0.0000 54 Temperature: (C) 175.0 175.0 55 Pressure: (bar) 45.31 45.31 45.31 56 Molar Flow (kgmole/h) 4982 3.857e-005	47 48 49	Mater	ial Strear	n: C2S2o	ut		Flui Pro	d Package: Ov perty Package: As	erheads pen Properties (Peng-R
52 Overall Vapour Phase Liquid Phase 53 Vapour / Phase Fraction 1.0000 0.0000 0.0000 54 Temperature: (C) 175.0 175.0 175.0 55 Pressure: (bar) 45.31 45.31 45.31 45.31 56 Molar Flow (kgmole/h) 4982 4982 3.857e-005 10000 57 Mass Flow (kg/s) 2.790 2.790 8.658e-007 100000 1000000 10000000 <td>50</td> <td></td> <td></td> <td></td> <td>CONDITIO</td> <td>VS</td> <td></td> <td></td> <td></td>	50				CONDITIO	VS			
53 Vapour / Phase Fraction 1.0000 1.0000 0.0000 54 Temperature: (C) 175.0 175.0 175.0 55 Pressure: (bar) 45.31 45.31 45.31 45.31 56 Molar Flow (kgmole/h) 4982 4982 3.857e-005 55 57 Mass Flow (kg/s) 2.790 2.790 8.658e-007 56 58 Std Ideal Liq Vol Flow (m3/h) 266.8 7.454e-006 56 59 Molar Enthalpy (kJ/kgmole) 4418 4418 -2.135e+005 56 50 Molar Entropy (kJ/kgmole-C) -19.76 -19.76 14.56 56 51 Heat Flow (MW) 6.113 -2.288e-006 56	52			Overall	Vapour Phase		Liquid Phase		
54 Temperature: (C) 175.0 175.0 175.0 55 Pressure: (bar) 45.31 45.31 45.31 45.31 56 Molar Flow (kgmole/h) 4982 4982 3.857e-005 55 57 Mass Flow (kg/s) 2.790 2.790 8.658e-007 56 58 Std Ideal Liq Vol Flow (m3/h) 266.8 7.454e-006 56 59 Molar Enthalpy (kJ/kgmole) 4418 4418 -2.135e+005 56 50 Molar Entropy (kJ/kgmole-C) -19.76 -14.56 56 51 Heat Flow (MW) 6.113 6.221e+063 4.042e+064 56 52 Lig Vol Flow @Std Cond (m3/h) 6.222e+063 * 6.221e+063 4.042e+064 56 53 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 8 of 13 56	53	Vapour / Phase Fraction		1.0000	1.00	00	0.0000		
55 Pressure: (bar) 45.31 45.31 45.31 56 Molar Flow (kgmole/h) 4982 4982 3.857e-005 57 Mass Flow (kg/s) 2.790 2.790 8.658e-007 57 Mass Flow (kg/s) 2.790 2.790 8.658e-007 58 Std Ideal Lig Vol Flow (m3/h) 266.8 7.454e-006	54	Temperature:	(C)	175.0 *	175	.0	175.0		
66 Molar Flow (kgmole/h) 4982 4982 3.857e-005 67 Mass Flow (kg/s) 2.790 2.790 8.658e-007 68 Std Ideal Liq Vol Flow (m3/h) 266.8 7.454e-006 69 Molar Enthalpy (kJ/kgmole) 4418 4418 -2.135e+005 60 Molar Entropy (kJ/kgmole-C) -19.76 -19.76 14.56 61 Heat Flow (MW) 6.113 6.2113 -2.288e-006 62 Lig Vol Flow @Std Cond (m3/h) 6.222e+063 * 6.221e+063 4.042e+064 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 8 of 13 Issues	55	Pressure:	(bar)	45.31	45.	31	45.31		
57 Mass Flow (kg/s) 2.790 2.790 8.658e-007 58 Std Ideal Lig Vol Flow (m3/h) 266.8 7.454e-006	58	Molar Flow	(kgmole/h)	4982	49	32	3.857e-005		
Std Ideal Liq Vol Flow (m3/h) 266.8 266.8 7.454e-006 99 Molar Enthalpy (kJ/kgmole) 4418 4418 -2.135e+005 90 Molar Entropy (kJ/kgmole-C) -19.76 -19.76 14.56 91 Heat Flow (MW) 6.113 6.2113 -2.288e-006 92 Lig Vol Flow @Std Cond (m3/h) 6.222e+063 6.221e+063 4.042e+064 93 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 8 of 13	57	Mass Flow	(kg/s)	2.790	2.7	90	8.658e-007		
Del Motar Enthalpy (kJ/kgmole) 4418 4418 -2.135e+005 00 Molar Entropy (kJ/kgmole-C) -19.76 -19.76 14.56 01 Heat Flow (MW) 6.113 6.2113 -2.288e-006 02 Lig Vol Flow @Std Cond (m3/h) 6.222e+063 6.221e+063 4.042e+064 03 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 8 of 13	58	Std Ideal Liq Vol Flow	(m3/h)	266.8	266	.8	7.454e-006		
OU Motar Entropy (KJ/kgmole-C) -19.76 -19.76 14.56 61 Heat Flow (MW) 6.113 6.2288e-006 6 62 Lig Vol Flow @Std Cond (m3/h) 6.222e+063 6.221e+063 4.042e+064 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 8 of 13	59	Molar Enthalpy	(kJ/kgmole)	4418	44	18	-2.135e+005		
Interview (MW) 6.113 6.113 -2.288e-006 02 Lig Vol Flow @Std Cond (m3/h) 6.222e+063 6.221e+063 4.042e+064 03 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 8 of 13	60	Molar Entropy (kJ/kgmole-C)	-19.76	-19.	6	14.56		
Cold Liq voi Friow (gista cond (m3/h) 6.222e+063 4.042e+064 Page 8 of 13 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 8 of 13 Page 8 of 13	61	Heat Flow	(MW)	6.113	6.1	13	-2.288e-006		
Aspen most service Aspen most service Aspen most service and the service aspen most service aspenditures and service aspenditures aspendi	62	Liq Voi Flow @Std Cond	(m3/h)	6.222e+063 *	6.221e+0	03 10 17	4.042e+064		Dege 9 of 12
School and the second sec	03	Licensed to: BATTELLE ENERG	SY ALLIANCE	A	spentitions ver	501112	4.1		* Specified by user

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1				Case Name: F	Production.hsc				
3	(aspentech	BATTELLE EI Bedford, MA	NERGY ALLIANCE	Unit Set:	AmeyS2e				
4	C	USA		Date/Time: F	Fri Mar 29 15:46:33 2024				
5									
8	Motor	al Street		t loontinuo	J) Flu	id Package: Ov	erheads		
8	Water	ial Stream	II. CZ5200	it (continued	a) Pro	operty Package: As	pen Properties (Peng-R		
9									
10				COMPOSITION					
11						Variation	10000		
12				Overall Phase		vapour Fr	acuon 1.0000		
13	COMPONENTS	MOLAR FLOW	MOLE FRACTIC	MASS FLOW	MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME		
14	7	(kgmole/h)		(kg/h)		FLOW (m3/h)	FRACTION		
10	Zinc Quide	0.00	0.00	0.0000	0.0000	0.0000	0.0000		
17	Alitrogen	0.00	0.00	0.0040	0.0000	0.0000	0.0000		
18	Oxygen	0.00	0.00	0.000	0.0000	0.0000	0.0000		
19	Water	0.00	0.00	0,000	0.0000	0.0000	0.0000		
20	Tin-White	0.00	0.00	0.0018	8 0.0000	0.0000	0.0000		
21	Hydrogen	4981.76	48 1.00	10042.640	1 1.0000	266.8124	1,0000		
22	Total	4981.76	49 1.00	00 10042.6468	8 1.0000	266.8124	1,0000		
23				Vanaur Phace		Dhaea Era	action 1 000		
24				vapour Phase		Fildocific	1.000		
25	COMPONENTS	MOLAR FLOW	MOLE FRACTIC	MASS FLOW	MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME		
26		(kgmole/h)		(kg/h)		FLOW (m3/h)	FRACTION		
27	Zinc	0.00	0.00	00 0.0000	0.0000	0.0000	0.0000		
28	Zinc-Oxide	0.00	0.00	0.001	0.0000	0.0000	0,000		
28	Oreingen	0.00	0.00	0.0000	0.0000	0.0000	0.0000		
21	Water	0.00	0.00	0.0000	0.0000	0.0000	0.0000		
32	Tin White	0.00	0.00	0.000	3 0.0000	0.0000	0.0000		
33	Hydrogen	4981 76	18 1.00	10042 640	1 1 0000	266 8124	1,0000		
34	Total	4981.76	19 1.00	10042.040	7 1,0000	266 8124	1,0000		
35				Liquid Dhase		Dhave For	7 742+ 000		
36				Liquid Phase	-	Phase Fra	10001 7.743e-009		
37	COMPONENTS	MOLAR FLOW	MOLE FRACTIC	MASS FLOW	MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME		
38	7	(kgmole/h)		(kg/n)	0.0000	FLOW (m3/h)	FRACTION		
38	Zinc Quide	0.00	0.00		0.0000	0.0000	0.0000		
40	Zinc-Oxide	0.00	0.99	26 0.003	0.9998	0.0000	0.9979		
42	Oxygen	0.00	0.00	0.0000	0.0000	0.0000	0.0000		
43	Water	0.00	0.00	0.0000	0.0000	0.0000	0.0000		
44	Tin-White	0.00	0.00	0.000	0.0000	0.0000	0.0000		
45	Hydrogen	0.00	00.00	74 0.0000	0.0002	0.0000	0.0020		
46	Total	0.00	1.00	0.003	1 1.0000	0.0000	1.0000		
47					Flu	id Package: Ov	remeads		
48	Mater	ial Stream	n: Hvdroa	en Product		in a number of	cinculus.		
49					Pro	operty Package: As	pen Properties (Peng-R		
50				CONDITIONS					
51				CONDITIONS					
52			Overall	Vapour Phase	Liquid Phase				
53	Vapour / Phase Fraction		1.0000	1.0000	0.0000				
04	Temperature:	(C)	40.00	40.00	40.00				
58	Molar Flow	(bar)	44.40	44.40	6 027e 005				
57	Mass Flow	(kg/s)	2 790	2 790	1.3596-006				
58	Std Ideal Lin Vol Flow	(m3/h)	266.8	266.8	1 1666-005				
59	Molar Enthalpy	(kJ/kgmole)	462.8	462.8	-2.189e+005				
60	Molar Entropy ()	kJ/kgmole-C)	-30.09	-30.09	-6.628				
61	Heat Flow	(MW)	0.6404	0.6404	-3.665e-006				
62	Liq Vol Flow @Std Cond	(m3/h)	6.222e+063 *	5.849e+063	1.875e+070				
63	Aspen Technology Inc.		As	en HYSYS Version	12.1		Page 9 of 13		
	Licensed to: BATTELLE ENERG	BY ALLIANCE					* Specified by user.		

1				Case Name:	Production.hsc		
2	(aspentech	BATTELLE ENER Bedford, MA	RGY ALLIANCE	Unit Set:	AmeyS2e		
4	0.	USA		Date/Time:	Fri Mar 29 15:46:33 2	024	
6 7 8	Mater	ial Stream	: Hydroge	en Product	(continue	Fluid Package: O Property Package: A	verheads spen Properties (Peng-R
9				COMPOSITION			
11				Overall Phase		Vapour F	raction 1.0000
12	CONDONENTS	HOLAD FLOW			MACC ERACTIN		
14	COMPONENTS	(kgmole/h)	MOLE FRACTIO	(kg/h)	MASS FRACTI	FLOW (m3/h)	FRACTION
15	Zinc	0.0000	0.000	0.00	0.00	0.0000 0.000	0.0000
16	Zinc-Oxide	0.0001	0.000	0.00	48 0.00	0.0000	0.0000
17	Nitrogen	0.0000	0.000	0.00	0.00	0000.0	0.0000
18	Oxygen	0.0000	0.000	0.00	0.00	0000.0 000	0.0000
19	Water	0.0000	0.000	0.00	0.00	0.0000	0.0000
20	Tin-White	0.0000	0.000	0.00	18 0.00	0000.0	0.0000
21	Hydrogen	4981.7648	1.000	0 10042.64	01 1.00	266.8124	1.0000
22	Total	4981.7649	1.000	0 10042.64	58 1.00	266.8124	1.0000
23 24				Vapour Phase		Phase Fr	action 1.000
25	COMPONENTS	MOLAR FLOW	MOLE FRACTIO	N MASS FLOW	MASS FRACTION	ON LIQUID VOLUME	LIQUID VOLUME
27	Zinc	0.0000	0.000	0 0.00	0.00	0.0000	0.0000
28	Zinc-Oxide	0.0000	0.000	0 0.00	0.00	0.0000	0.0000
20	Nitrogen	0.0000	0.000	0 0.00	0.00	0,000 0,0000	0.0000
30	Oxygen	0.0000	0.000	0 0 00	0.00	0,000 0,000	0.0000
31	Water	0.0000	0.000	0 0.00	0.00	0.0000	0.0000
32	Tin-White	0.0000	0.000	0 0.00	18 0.00	0.0000	0.0000
33	Hydrogen	4981,7648	1.000	0 10042.64	1.00	266.8124	1,0000
34	Total	4981.7648	1.000	0 10042.64	19 1.00	266.8124	1.0000
35				Liquid Phase		Phase Fr	action 1.210e-008
30	0011001151150				11100 50105		100000
20	COMPONENTS	(komole/h)	MOLE PRACTIO	MASS FLOW	MASS PRACTI	ELOW (m3/b)	ERACTION
30	Zine	(Ng(100011))	0.000	0 0.00	0.00	0.0000	0.0000
40	Zinc-Ovide	0.0001	0.987	4 0.00	18 0.95	97 0.0000	0.9915
41	Nitrogen	0.0000	0.000	0 0.00	0.00	0,0000	0.0000
42	Oxvaen	0.0000	0.000	0 0.00	0.00	0.0000	0.0000
43	Water	0.0000	0.000	0 0.00	0.00	0.0000 0.0000	0.0000
44	Tin-White	0.0000	0.006	9 0.00	0.01	0.0000	0.0070
45	Hydrogen	0.0000	0.005	7 0.00	0.00	0.0000	0.0016
46	Total	0.0001	1,000	0.00	49 1.00	0000.0 0000	1.0000
47 48 49	Mater	ial Stream	: Saturate	dWater		Fluid Package: S Property Package: N	team BS Steam
50 51				CONDITIONS			
52			Overall	Aqueous Phase			
53	Vapour / Phase Fraction		0.0000	1.0000			
54	Temperature:	(C)	101.1	101.1			
55	Pressure:	(bar)	1.055	1.055			
56	Molar Flow	(kgmole/h)	4985	4985			
57	Mass Flow	(kg/s)	24.94	24.94		1. 2	
58	Std Ideal Lig Vol Flow	(m3/h)	89.98	89.98			
59	Molar Enthalpy	(kJ/kgmole)	-2.792e+005	-2.792e+005			
60	Molar Entropy (I	J/kgmole-C)	23.77	23.77			
61	Heat Flow	(MW)	-386.6	-386.6			
62	Liq Vol Flow @Std Cond	(m3/h)	89.88 *	89.88			
63	Aspen Technology Inc.		Asp	en HYSYS Version	12.1		Page 10 of 13
	Licensed to: BATTELLE ENERG	ALLIANCE					Specified by user.

Image: content in the image in the													
Image: Separation in the second sec	H		DATTO	ENER	ALL MADE		Case Name: Production.hsc						
4 USA Duet/Time: FM ar 29 (546) 53 2004 9 Material Stream: SaturatedWater (continued) FM2 Package: Stam 9 COMPOSITION Property Package: Name Name 10 COMPOSITION Moder Package: Name Name 10 COMPOSITION Moder Package: Name Name 10 COMPOSITION Moder Package: Name Name 100 COMPOSITION Moder Package: Name Name Name 100 489 560 1.000 89777 4575 1.000 89.977 1.000 100 498 560 1.000 8977 4575 1.000 89.977 1.000 100 498 560 1.000 89.777 4575 1.000 89.977 1.000 100 498 560 1.000 89.777 4575 1.000 89.977 1.000 100 49.977 1.000 89.977 1.000 99.977 1.000 100 49.977 1.000	3	(aspentech	BATTELLE Bedford, M	ENERG	SY ALLIANCE		Unit Set:	Am	eyS2e				
International Stream: Control Water (continued) Head Package: Steam 7 CoMPONENTS Composition Composition 0 10 Composition Composition 0 0 11 Composition Mass Front Union 0.000 0.000 0.000 11 Composition Mass Front Union 1.000 0.	4	C	USA				Date/Time:	Eril	Mar 29 15:46:33 20	24			
Production Production Production Production Production COMPOSITION ComPOSITION 0.000 ComPOSITION ComPOSITION 0.000 0.000 0.000 ComPOSITION Mass Fraction Locute Volume Locute Volume 0.000 10 ComPOSITION Mass Fraction Locute Volume Locute Volume 1.000 0.000 100 0.0004/RETCOV Mass Fraction Locute Volume Locute Volume 1.000 0.000 100 0.0004/RETCOV Mass Fraction Locute Volume 1.0000 0.000 0.000 0.0000	5						outer fillio.		na 20 10.40.00 20				
COMPOSITION Value Value Composition 0 COMPOSITION MOLAR FLOW MOLAR FLOW MASS FRACTION LISUE Value FRACTION 1000 6977 4575 1.	6 7	Mate	rial Stre	am:	Saturat	ted	Water (co	on	tinued)	Fluid	Package: Ste erty Package: NB	eam IS Steam	
No. Overall Phase Vagour Fraction 0.0001 12 COMPONENTS MOLAR FLOW (light) MASS FLOW (light) LIQUID YOLUME FLOW (INS) IUQUID YOLUME FRACTION IUQU	9					C	OMPOSITION						
COMPONENTS MOLAR FLOW (lignolefh) MALE FRACTION (lignolefh) MASS FLOW (lignolefh) MASS FLOW (lignolefh) LIGUID VOLUME FRACTION LIGUID VOLUME FRACTION 1 400 4884.5660 1.0000 89777.475 1.0000 89.977 1.0000 10 tail 4884.5660 1.0000 89.977.475 1.0000 89.977 1.0000 20 COMPONENTS MOLAR FLOW (lignolefh) MOLE FRACTION MASS FLOW (lignolefh) LIGUID VOLUME FRACTION EXEMPT LIGUID VOLUME FRACTION FLOW (lignolefh) LIGUID VOLUME FRACTION EXEMPT 1.000 89.977.7 1.0000 21 total 4884.5660 1.0000 89.977.457.5 1.0000 89.977.7 1.0000 21 total 49.845.660 1.0000 89.977.457.5 1.0000 89.977.7 1.0000 22 total Agreeous Phase Plaid Package: Steam Steam 23 MASE Flow Overall Agreeous Phase Plaid Package: NB.5 Read 24 Vagour Phase Flow (lightoth)	11					0	verall Phase				Vapour Fr	action 0.0000	
Image: Second	12						rerun r nuse						
15 HOO 4964 5660 1.0000 89.777 4575 1.0000 89.7787 1.0000 10 Total 4964 5660 1.0000 89.777 4575 1.0000 89.777 1.0000 10 COMPONENTS MOLAR FLOW MOLE FRACTION MASS FLOW MASS FRACTION LIQUID VOLLME LIQUID VOLLME LIQUID VOLLME HQCIO 4964 5660 1.0000 89.9787 1.0000 89.9787 1.0000 21 HCO 4964 5660 1.0000 89.777 4575 1.0000 89.9787 1.0000 21 HCO 4964 5660 1.0000 89.777 1.0000 89.9787 1.0000 22 Total 4964 5660 1.0000 89.777 1.0000 89.977 1.0000 23 Material Stream: WaterFeed CONDITIONS Steam 99.858 99.858 99.858 99.858 99.858 99.858 99.858 99.858 99.858 99.858 99.858 99.858 99.8588 99.8588 99.858 99.8588 <	13	COMPONENTS	MOLAR FL (kgmole/	ow h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTIO	N	FLOW (m3/h)	FRACTION	
Instal 4884.5660 1.0000 89.777.575 1.0000 89.9787 1.0000 10 COMPONENTS MOLAR FLOW MOLE FRACTION MASS FRACTON LOUID VOLUME MOUDU VOLUME FRACTON MASS FRACTON LOUID VOLUME FRACTON B9.9787 1.0000 89.9787 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 </td <td>15</td> <td>H2O</td> <td>4984</td> <td>.5660</td> <td>1.0</td> <td>000</td> <td>89797.457</td> <td>75</td> <td>1.000</td> <td>00</td> <td>89.9787</td> <td>1.0000</td>	15	H2O	4984	.5660	1.0	000	89797.457	75	1.000	00	89.9787	1.0000	
Aqueous Phase Phase Fraction 1.000 10 COMPONENTS MOLAR FLOW MOLE FRACTION MASS FRACTION FUND VOLUME	16	Total	4984	5660	1.0	000	89797.457	75	1.000	0	89.9787	1.0000	
19 COMPORENTS MOLA FLOW (kgmode/h) MOLA FLOW (kgmode/h) MASS FLOTW (kgmode/h) MASS FLOTW (kgmode/h) UOUID VOLUME FRACTION (kgmode/h) UOUID VOLUME (kgmode/h) UOUID VOLUME (kgmode/h) UOUID VOLUME (kgmode/h) Income (kgmode/h) Kgmode/h Income (kgmode/h) Kgmode/h Income (kgmode/h) Kgmode/h Kgmod/h Kgmode/h Kgm	17 18	8				Aq	ueous Phase				Phase Fra	action 1.000	
1 H2D 4484.5660 1.0000 89.797.4575 1.0000 89.9787 1.0000 21 Total 4984.5660 1.0000 89.797.4575 1.0000 89.9787 1.0000 21 Material Stream: WaterFeed Faid Package: NBS Steam 22 Overall Agueous Phase Property Package: NBS Steam 23 Vapour / Phase Fraction Overall Agueous Phase Image: Composition Composition 23 Vapour / Phase Fraction Overall Agueous Phase Image: Composition NBS Steam 24 Vapour / Phase Fraction Overall Agueous Phase Image: Composition Image: Composition 25 Vapour / Phase Fraction Overall Agueous Phase Image: Composition Image: Composition 26 Vapour / Phase Fraction 0.0000 2.850e+005 -2.850e+005 Image: Composition Image: Composition 36 Modar Entropy (Multigrade) -2.850e+005 -2.850e+005 Image: Composition Image: Composition Image: Composition <td>19 20</td> <td>COMPONENTS</td> <td>MOLAR FL (kamole/</td> <td>OW h)</td> <td>MOLE FRACT</td> <td>ION</td> <td>MASS FLOW (kg/h)</td> <td></td> <td>MASS FRACTIO</td> <td>N</td> <td>LIQUID VOLUME FLOW (m3/h)</td> <td>LIQUID VOLUME FRACTION</td>	19 20	COMPONENTS	MOLAR FL (kamole/	OW h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTIO	N	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION	
10al 4884.5860 1.0000 89787 4575 1.0000 89.9787 1.0000 33 Material Stream: WaterFeed Fuid Package: Steam Property Package: NBS Steam 22 CONDITIONS CONDITIONS CONDITIONS Conditional Stream:	21	H2O	4984	.5660	1.0	000	89797.457	75	1.000	0	89.9787	1.0000	
Bit Material Stream: WaterFeed Property Package: Steam 28 Property Package: NBS Steam 29 CONDITIONS Statum Statum 29 CONDITIONS Statum Statum 29 Temperature: (C) 25.00 1000 Image: Statum 30 Temperature: (C) 25.00 25.00 Image: Statum Image: Statum 31 Pressure: (Bar) 1.077 Image: Statum	22	Total	4984	.5660	1.0	000	89797.457	75	1.000	00	89.9787	1.0000	
All Material Stream: WaterFeed Property Package: NBS Steam 20 CONDITIONS 21 CONDITIONS 22 0 23 Vapor / Phase Fraction 0.0000 24 0.0000 1.0000 25 0 2 26 Vapor / Phase Fraction 0.0000 27 0 25.00 28 Vapor / Phase Fraction 0.0000 29 Mader Flow (kgnoleh) 30 Presaure: (bar) 31 Presaure: (bar) 32 Molar Entropy (kJkgmole) 33 Molar Entropy (kJkgmole) 34 Stat local Liq Vol Flow (mMY) -24.50e-005 35 Heat Flow (MW) 46 COMPOSITION 41 40.00 Flow (gStd Cond 0.0000 42 COMPONENTS MOLAR FLOW MOLE FRACTION MASS FLOW LiQUID VOLUME 44 H2O 4984.5660 1.0000 ⁺ 89774.575 1	23						-			Fluid	Package: Ste	am	
3 CONDITIONS 22 CONDITIONS 23 Overall Aqueous Phase 24 Vapour / Phase Fraction 0.0000 1.0000 25 Overall Aqueous Phase	24	Mate	rial Stre	am:	WaterF	eec				Prop	erty Package: NB	Steam	
Answer CONDITIONS 20 Vapour / Phase Fraction 0.0000 1.0000 0 0 30 Temperature: (C) 25.00 25.00 0 0 31 Pressure: (bar) 1.077 1.077 0 0 31 Molar Entropy (kgmole/h) 4985 4985 0 0 32 Molar Entropy (kulkgmole) 24.94 24.94 0 0 0 35 Molar Entropy (kulkgmole) -2.850e+005 0 0 0 0 0 36 Molar Entropy (kulkgmole) -2.850e+005 0 0 0 0 0 36 Molar Entropy (kulkgmole) -2.850e+005 0	25	s ripping amage. Ho count											
28 Overall Aqueous Phase Image: Constraint of the second of the seco	27					C	ONDITIONS						
20 Vapour / Phase Fraction 0.0000 1.0000 25.0	28				Overall	Aq	ueous Phase						
30 Temperature: (C) 25.00 25.00 31 Pressure: (bar) 1.077 1.077 1.077 32 Molar Flow (kgmole/h) 4485 4485	29	Vapour / Phase Fraction			0.0000		1.0000						
31 Presure: (bar) 1.077 1.077 1.077 23 Molar Flow (kgmoleh) 4985 4985 23 Mass Flow (kgmoleh) 4985 4985 34 Stat Ideal Lig Vol Flow (m3h) 89.98 89.98 35 Molar Enthalpy (k.Jkgmole-C) 6.610 36 Molar Enthalpy (k.Jkgmole-C) 6.610 37 Heat Flow (MW) -3.94.6 <td>30</td> <td>Temperature:</td> <td>(C)</td> <td></td> <td>25.00 *</td> <td></td> <td>25.00</td> <td></td> <td></td> <td></td> <td></td> <td></td>	30	Temperature:	(C)		25.00 *		25.00						
Mase Flow (kgmole/h) 44865 44865 4885 Mase Flow (kgmole/h) 44865 4494 4494 Mase Flow (kulkgmole) -2.850e+005 - - Mase Finality (kulkgmole) -2.850e+005 - - Mate Entropy (kulkgmole) -2.850e+005 - - Mate Entropy (kulkgmole) -2.850e+005 - - Mate Flow (MW) -394.6 - - - Mate Flow (MW) -394.6 - - - - Mate Flow (MW) -394.6 -	31	Pressure:	(bar)		1.077	_	1.077			+			
31 Mass Flow (kg/s) 24 34 24.94 33 Mass Flow (kg/s) 24 34 24.94	32	Molar Flow	(kgmole/h)		4985		4985	_		+			
SN SN<	33	Mass Flow	(kg/s)		24.94		24.94	-		+			
Instruction Disconsistion Disconsistion Disconsistion Disconsistion Molar Entropy (kJkgmeletc) 6.610 0 0 0 Heat Flow (MW) -394.6 -394.6 0 0 Idual Charlopy (kJkgmeletc) 6.810 0 0 0 Idual Charlopy (kJW) -394.6 -394.6 0 0 Idual Charlopy (kJW) -394.6 -394.6 0 0 Idual Charlopy (kJW) -394.6 -394.6 0 0 0.0000 Idual Charlopy (kJW) -394.6 -394.6 0 0 0.0000 Idual Charlopy MOLAR FLOW MOLE FRACTION MASS FRACTION LIQUID VOLUME FRACTION 1.0000 89.9787 1.0000 10.000 Idual 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 10.000 89.9787 1.0000 10.000 10.000 10.000 10.000 10.000 10.000 10.000	35	Molar Enthalny	(k.l/kamole)		-2 850e+005		-2 850e+005			+			
37 Heat Flow (MW) .394.6 .394.6 .394.6 38 Lig Vol Flow @Std Cond (m3/h) 89.88 69.88 0 0 39 COMPOSITION COMPOSITION COMPONENTS Vapour Fraction 0.0000 41 COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION MASS FLOW (kg/h) MASS FRACTION LIQUID VOLUME FLOW (m3/h) FRACTION 44 H2O 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 45 H2O 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 46 Total 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 47 GOMPONENTS MOLAR FLOW MOLE FRACTION MASS FLOW MASS FRACTION LIQUID VOLUME FLOW (m3/h) LIQUID VOLUME FLOW (m3	38	Molar Entropy	(kJ/kgmole-C)		6.610		6.610			+			
38 Liq Vol Flow @Std Cond (m3/h) 89.88 * 89.88 99.89 99.99	37	Heat Flow	(MW)		-394.6		-394.6						
30 40 40 40 40 40 40 40 40 40 40 40 40 40	38	Liq Vol Flow @Std Cond	(m3/h)		89.88 *		89.88						
41 42 Overall Phase Vapour Fraction 0.000 43 COMPONENTS MOLAR FLOW (kgnole/h) MOLE FRACTION (kg/h) MASS FRACTION (kg/h) LIQUID VOLUME FLOW (m3/h) LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION FRACTION LIQUID VOLUME FRACTION FRACTION LIQUID VOLUME FRACTION 1.000 1.000 44 COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION (kg/h) MASS FRACTION (kg/h) LIQUID VOLUME FLOW (m3/h) LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION 44 COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION (kg/h) MASS FRACTION (kg/h) LIQUID VOLUME FLOW (m3/h) LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION 55 Total MOLAR FLOW (kgmole/h) MOLE FRACTION (kg/h) MASS FRACTION (kg/h) LIQUID VOLUME FLOW (m3/h) LIQUID VOLUME FRACTION LIQUID VOLUME FRACTION <td< td=""><td>39 40</td><td></td><td></td><td></td><td></td><td>C</td><td>OMPOSITION</td><td>1</td><td></td><td></td><td></td><td></td></td<>	39 40					C	OMPOSITION	1					
43 COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION MASS FLOW (kg/h) MASS FRACTION LIQUID VOLUME FLOW (m3/h) LIQUID VOLUME FRACTION 44 40 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 45 H2O 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 46 Total 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 47 Aqueous Phase Phase Fraction 1.000 1.0000 89.9787 1.0000 48 COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION MASS FLOW (kg/h) MASS FRACTION LIQUID VOLUME FLOW (m3/h) I.000 50 COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION MASS FLOW (kg/h) MASS FRACTION I.000I 000 89.9787 1.0000 51 H2O 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 52 Total 4984.5660 1.0000 89.9787 1.0000 8	41					0	verall Phase				Vapour Fr	action 0.0000	
44 (kgmole/h) (kg/h) FLOW (m3/h) FRACTION 45 H2O 4984.5660 * 1.0000 * 89797.4575 * 1.0000 * 89.9787 * 1.0000 * 89.9787 * 1.0000 * 89.9787 * 1.0000 1.0000 89.9797.4575 * 1.0000 * 89.9787 * 1.0000 46 Total 4984.5660 * 1.0000 * 89797.4575 * 1.0000 * 89.9787 * 1.0000 89.9787 * 1.0000 47 48 Phase Fraction 1.000 89.9787 * 1.0000 48 MOLAR FLOW (kgmole/h) MOLE FRACTION MASS FLOW (kg/h) LIQUID VOLUME FLOW (kg/h) LIQUID VOLUME (kg/h) 51 H2O 4984.5660 * 1.0000 89797.4575 * 1.0000 89.9787 * 1.0000 52 Total 4984.5660 * 1.0000 89797.4575 * 1.0000 89.9787 * 1.0000 53 Fluid Package: Steam Fluid Package: Steam 54 Overall Aqueous Phase Property Package: NBS Steam 56 Overall Aqueous Phase Overall Aqueous Phase 56 Overall Aqueous Phase Overall Overall Aqueous Phase 57 Overall Aqueous Phase Overall Overa	43	COMPONENTS	MOLAR FL	ow	MOLE FRACT	ION	MASS FLOW		MASS FRACTIO	N	LIQUID VOLUME	LIQUID VOLUME	
45 H2O 4984.5660 * 1.000 * 8977.4575 * 1.000 * 89.9787 * 1.000 * 46 Total 4984.5660 1.000 8977.4575 1.000 89.9787 * 1.000 47 48 Aqueous Phase 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 MOLAR SEGO 1.000 89797.4575 1.000 89.9787 1.000 51 H2O 4984.5660 1.000 89797.4575 1.000 89.9787 1.0000 52 Total 4984.5660 1.000 89797.4575 1.0000 89.9787 1.0000 53 Material Stream: CWin Fluid Package: Steam 54 Material Stream: CONDITIONS Fluid Package: NBS Steam 54 Overall Aqueous Phase Outer Outer Property Package: NBS 56 Overall <	44		(kgmole/	h)			(kg/h)				FLOW (m3/h)	FRACTION	
46 Total 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 47 48 Phase 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 MOLA 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 51 H2O 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 52 Total 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 53 Fluid Package: Steam Steam 1.0000 1.0000 89.9787 1.0000 54 Material Stream: CVNIN Fluid Package: NB S Steam NB S Steam 56 Overall Aqueous Phase 58 Overall Aqueous Phase 69 Vapour / Phase Fraction <td< td=""><td>45</td><td>H2O</td><td>4984</td><td>.5660 *</td><td>1.0</td><td>• 000</td><td>89797.457</td><td>75 '</td><td>1.000</td><td>0 *</td><td>89.9787 *</td><td>1.0000 *</td></td<>	45	H2O	4984	.5660 *	1.0	• 000	89797.457	75 '	1.000	0 *	89.9787 *	1.0000 *	
47 48 Aqueous Phase 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 MOLAR FLOW (kgmole/h) MOLE FRACTION MASS FLOW (kg/h) MASS FRACTION LIQUID VOLUME FLOW (m3/h) FRACTION 51 H2O 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 52 Total 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 53 Fluid Package: Steam Steam Property Package: NBS Steam 54 Overall Aqueous Phase	48	Total	4984	.5660	1.0	000	89797.457	75	1.000	0	89.9787	1.0000	
40 COMPONENTS MOLAR FLOW (kgmole/h) MOLE FRACTION MASS FLOW (kg/h) MASS FRACTION LIQUID VOLUME FLOW (m3/h) LIQUID VOLUME FRACTION 51 H2O 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 52 Total 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 53 Material Stream: CWin Fluid Package: Steam 55 Property Package: NBS Steam 56 Overall Aqueous Phase Image: NBS Steam 57 Overall Aqueous Phase Image: NBS Steam 58 Overall </td <td>47 48</td> <td></td> <td></td> <td></td> <td></td> <td>Aq</td> <td>ueous Phase</td> <td></td> <td></td> <td></td> <td>Phase Fra</td> <td>action 1.000</td>	47 48					Aq	ueous Phase				Phase Fra	action 1.000	
61 H2O 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 52 Total 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 53 Material Stream: CWin Fluid Package: Steam 54 Material Stream: CWin Property Package: NBS Steam 56 CONDITIONS Steam Steam 56 Overall Aqueous Phase Image: CONDITIONS 58 Overall Aqueous Phase Image: CONDITIONS 59 Vapour / Phase Fraction 0.0000 1.0000 Image: CONDITIONS 60 Temperature: (C) 25.00 Image: CONDITIONS Image: CONDITIONS 61 Pressure: (bar) 1.200 1.200 Image: CONDITIONS 62 Molar Flow (kgmole/h) 4044 4044 Image: CONDITIONS 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page: 11 of 13 Page: 11 of 13	49 50	COMPONENTS	MOLAR FL (kgmole/	OW h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTIO	N	FLOW (m3/h)	FRACTION	
52 Total 4984.5660 1.0000 89797.4575 1.0000 89.9787 1.0000 53 Material Stream: CWin Fluid Package: Steam 54 Fluid Package: NBS Steam 56 CONDITIONS 57 CONDITIONS 58 Overall Aqueous Phase Steam 59 Vapour / Phase Fraction 0.0000 1.0000 1.0000 60 Temperature: (C) 25.00 Steam 61 Pressure: (bar) 1.200 Page 11 of 13 62 Molar Flow (kgmole/h) 4044 4044 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 11 of 13	51	H2O	4984	5660	1.0	000	89797.457	75	1.000	00	89.9787	1.0000	
53 54 55 Fluid Package: Steam 56 Property Package: NBS Steam 56 CONDITIONS NBS Steam 58 Overall Aqueous Phase 59 Vapour / Phase Fraction 0.0000 1.0000 60 Temperature: (C) 25.00 61 Pressure: (bar) 1.200 62 Molar Flow (kgmole/h) 4044 4044 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 11 of 13	52	Total	4984	.5660	1.0	000	89797.457	75	1.000	00	89.9787	1.0000	
54 Material Stream: CWin Property Package: NBS Steam 56 CONDITIONS <td< td=""><td>53</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Fluid</td><td>Package: Ste</td><td>am</td></td<>	53									Fluid	Package: Ste	am	
Overall Aqueous Phase Image: Condition 56 Overall Aqueous Phase Image: Condition 58 Overall Aqueous Phase Image: Condition 59 Vapour / Phase Fraction 0.0000 1.0000 Image: Condition 60 Temperature: (C) 25.00 * 25.00 Image: Condition 61 Pressure: (bar) 1.200 * 1.200 Image: Condition 62 Molar Flow (kgmole/h) 4044 4044 Image: Condition 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 11 of 13 Page 11 of 13	54	Mate	rial Stre	am:	Cwin					Prop	erty Package: NR	Steam	
CONDITIONS 57 CONDITIONS 58 Overall Aqueous Phase Condition 59 Vapour / Phase Fraction 0.0000 1.0000 Condition 60 Temperature: (C) 25.00 * 25.00 Condition 61 Pressure: (bar) 1.200 * 1.200 Condition 62 Molar Flow (kgmole/h) 4044 4044 Condition Page 11 of 13 12 Description Aspen HYSYS Version 12.1 Page 11 of 13 Page 11 of 13	58							_		. iop	enty i dendge.		
58 Overall Aqueous Phase 59 Vapour / Phase Fraction 0.0000 1.0000 60 Temperature: (C) 25.00 * 25.00 61 Pressure: (bar) 1.200 * 1.200 62 Molar Flow (kgmole/h) 4044 4044 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 11 of 13	57					C	ONDITIONS						
59 Vapour / Phase Fraction 0.0000 1.0000 0 60 Temperature: (C) 25.00 * 25.00 0 61 Pressure: (bar) 1.200 * 1.200 0 62 Molar Flow (kgmole/h) 4044 4044 0 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 11 of 13	58				Overall	Ag	ueous Phase						
60 Temperature: (C) 25.00 * 25.00 61 Pressure: (bar) 1.200 * 1.200 62 Molar Flow (kgmole/h) 4044 4044 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 11 of 13	59	Vapour / Phase Fraction			0.0000		1.0000						
61 Pressure: (bar) 1.200 1.200 62 Molar Flow (kgmole/h) 4044 4044 6044 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 11 of 13	60	Temperature:	(C)		25.00 *		25.00						
Molar Flow (kgmole/h) 4044 4044 Page 11 of 13 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 11 of 13	61	Pressure:	(bar)		1.200 *		1.200	-		-			
Aspen recimology inc. Aspen more sent and a spen mo	62	Molar Flow	(kgmole/h)	L	4044	anon l	4044	12	1			Dago 11 of 12	
Specified by user.	03	Licensed to: BATTELLE ENER	C. RGY ALLIANCE		A	spent	TTOTO Version	112				* Specified by user.	

1				C	ase Name: F	Production.h	sc		
3	(1) aspentech	Bedford, MA	RGY ALLIANCE	U	nit Set: A	AmeyS2e			
4		USA			ate/Time: F	ri Mar 29 1	5:46:33 2024		
6 7 8	Mater	rial Stream	n: CWin (o	on	tinued)		Fluid	d Package: Str perty Package: NE	eam 8S Steam
9				c	ONDITIONS				
10			Overall	An	eous Phase				
12	Mass Flow	(ka/s)	20.24	() de	20.24				
13	Std Ideal Lig 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 19				co	MPOSITION				
20				Ov	erall Phase			Vapour Fr	raction 0.0000
22	COMPONENTS	MOLAR FLOW	MOLE FRACTIO	NC	MASS FLOW	MASS	FRACTION	LIQUID VOLUME	LIQUID VOLUME
24	H2O	4043 911	1.00	00 *	72851 4751		1 0000 *	72 9985 *	1 0000 *
25	Total	4043.911	1.00	000	72851.4751	1	1.0000	72.9985	1.0000
26									
27				Aqu	leous Phase			Phase Fra	action 1.000
28	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTIO	NC	MASS FLOW (kg/h)	MASS	FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
30	H2O	4043.911	1.00	000	72851.4751		1,0000	72,9985	1,0000
31	Total	4043.911	1.00	000	72851.4751	1	1.0000	72.9985	1.0000
33 34 35	Mater	ial Strean	: CWout	C	ONDITIONS		Prop	perty Package: Str	eam 3S Steam
30			Overall	Act	acus Dhasa				
38	Vapour / Phase Fraction		0.0000	Adr	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				
48	Heat Flow	(MW)	-317.2		-317.2				
47	Liq Vol Flow @Std Cond	(m3/h)	72.91 *		72.91				
48				CC	MPOSITION				
49									
50				OV	erall Phase			Vapour Fr	action 0.0000
51	COMPONENTO	MOLED FLORE	MOLEFOR	DNI I	MACO FLOW	11100	ERACTION	HOURD VOLUME	
53	COMPONENTS	(kgmole/h)	MULE FRACTIO	JN	(kg/h)	MASS	FRACTION	FLOW (m3/h)	FRACTION
54	H20	4043.911	1.00	000	72851.4751		1.0000	72.9985	1.0000
55	Total	4043.911	1.00	000	72851.4751		1.0000	72.9985	1.0000
58				Aqu	eous Phase			Phase Fra	action 1.000
58	COMPONENTS	MOLAR FLOW	MOLE FRACTIO	ON	MASS FLOW	MASS	FRACTION	LIQUID VOLUME	LIQUID VOLUME
90	100	(kgmole/n)		00	(kg/n)		4 0000	PLOW (m3/h)	PRACTION
00	Tatal	4043.911	1.00	00	72651.4751	-	1.0000	72.9985	1.0000
01	Iotal	4043.911	1.00	00	72851.4751		1.0000	72.9985	1.0000
en!									
62	Aspon Technology Inc		10	non H	VSVS Varsion	12.1			Page 12 of 12

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Image: Description Description Description Image: Appen Property Stackage: Appen Properties (Solids) Image: Daty Sp: 2.657 MW Minimum Available Duty: 0.0000 MW Maximum Available Duty:	13					Eluid Dackage:	Peaction
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40 Duty SP: 5.500 MW Minimum Available Duty: 0.0000 MW Maximum Available Duty: 41 Energy Stream: CompressionWork Fluid Package: Reaction 43 CONDITIONS Property Package: Aspen Properties (Solids) 44 CONDITIONS	39	Duty Type: Direct Q	Duty Calculatio	on Operation:	Comp2Stage2		
Image: stream: compressionWork Fluid Package: Reaction Property Package: Aspen Properties (Solids) Image: stream Image: st	40	Duty SP: 5.500 MW	Minimum Avai	lable Duty:	0.0000 MW	Maximum Available Duty:	
42 Energy Stream: CompressionWork Property Package: Aspen Properties (Solids) 44 CONDITIONS 46 Duty Type: Direct Q 47 Duty SP: 21.86 MW 48 0.0000 MW Maximum Available Duty: 49 0.0000 MW 50 51 51 53 54 56 55 56 56 57 58 58 59 51 56 57 58 58 59 51 50 Energy Stream: Aspen HYSYS Version 12.1 Property Package: *Specified by user.	41		-			Fluid Package:	Reaction
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46 Duty Type: Direct Q Duty Calculation Operation: 47 Duty SP: 21.86 MW Minimum Available Duty: 0.0000 MW Maximum Available Duty: 48 49 50 51 52 53 54 55 56 50 56	44						
46 Duty Type: Direct Q Duty Calculation Operation: 47 Duty SP: 21.86 MW Minimum Available Duty: 0.0000 MW Maximum Available Duty: 48 49	45			CONDITIONS			
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1 50 51 52 53 54 55 56 57 58 59 60 61 62 63 54 55 56 57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 13 of 13 Licensed to: BATTELLE ENERGY ALLIANCE ' Specified by user.	47	Duty SP: 21.86 MW	Minimum Avai	lable Duty:	0.0000 MW	Maximum Available Duty:	
50 51 52 53 54 55 56 56 57 58 50 61 62 63 64 55 56 57 58 59 61 62 63 Aspen Technology Inc. Aspen Technology Inc. Aspen HYSYS Version 12.1 Page 13 of 13 Licensed to: BATTELLE ENERGY ALLIANCE	49						
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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 $18.6 \text{ kWh-e/kg-H}_2$ (56% thermal efficiency on an LHV basis). A report containing stream conditions and compositions was generated by Aspen HYSYS and included in this appendix.

Equipment	Parameter	Value	Unit
0	Compression Ratio	2.8	_
Compressor	Isentropic Efficiency	75	%
	Net Power	500	MW
Turbine	Isentropic Efficiency	90	%
	Allowable Pressure Drop (shell/tube)	2	%
Recuperator	Minimum Approach	10	°C
	Effectiveness	98.9	%
	Excess Air (burner)	20	%
Combustion Chamber	Adiabatic Flame Temperature (afterburner)	1400	°C
T 1 / A*	Temperature	20	°C
Inlet Air	Relative Humidity	50	%

Table B1.	Combustion-turbine model	parameters.

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

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

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

$$N_2 + O_2 \leftrightarrow 2NO$$

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

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

$$H_2 + O_2 \leftrightarrow H_2O_2$$

1				Case Name:	500MWe_HydrogenTu	bine_recuperated.hsc	
3	(1) aspentech	Bedford, MA	ALLIANCE	Unit Set:	AmeyS2e		
4		USA		Date/Time:	Wed Sep 27 09:15:46 2	2023	
6						Fluid Package: (CombustionTurbineProce
7	Mater	ial Stream:	Fuel				
8						Property Package:	Peng-Robinson
9				CONDITIONS			
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 Mass Flow	(kgmole/n)	7 453 *	1.331e+004 7.453			
17	Std Ideal Lig 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							
25				Overall Phase		Vapour	Fraction 1.0000
26	COMPONENTS	MOLAR FLOW	MOLE FRACTIC	MASS FLOW	MASS FRACTIO		LIQUID VOLUME
27		(kgmole/h)		(kg/h)		FLOW (m3/h)	FRACTION
28	H2O	0.0000	0.00	000.00	0.000	0 0.0000	0.0000
29	Hydrogen	13308.4696	1.00	26829.875	1 1.000	0 384.0570	1.0000
30	Nitrogen	0.0000	0.00	00.000	0.000	0 0.0000	0.0000
31	Oxygen	0.0000	0.00	00.000	0 0.000	0 0.0000	0.0000
32	Methane	0.0000	0.00	0.000	0.000	0 0.0000	0.0000
33	CO2	0.0000	0.00	0.000	0.000	0 0.0000	0.0000
35	N20	0.0000	0.00	0.000	0 0.000	0 0.0000	0.0000
36	NO2	0.0000	0.00	00.000	0 0.000	0 0.0000	0.0000
37	NO	0.0000	0.00	0.000	0.000	0 0.0000	0.0000
38	S02	0.0000	0.00	00.000	0.000	0 0.0000	0.0000
39	H2S	0.0000	0.00	00.000	0.000	0 0.0000	0.0000
40	CO	0.0000	0.00	00 0.000	0.000	0 0.0000	0.0000
41	H2O2	0.0000	0.00	0.000	0.000	0 0.0000	0.0000
42	Ammonia	13308 4696	1.00	0.000	1 1 000	0 384 0570	1 0000
44	Total	15500.4050	1.00	20023.013	1.000	0 004.0010	1,0000
45				Vapour Phase		Phase F	Fraction 1.000
46 47	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTIC	MASS FLOW (kg/h)	MASS FRACTIO	N LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
48	H2O	0.0000	0.00	0.000	0.000	0 0.0000	0.0000
49	Hydrogen	13308.4696	1.00	26829.875	1 1.000	0 384.0570	1.0000
50	Nitrogen	0.0000	0.00	00.000	0.000	0 0.0000	0,0000
51	Oxygen	0.0000	0.00	0.000	0.000	0.0000	0.0000
52	Methane	0.0000	0.00	0.000	0.000	0 0.0000	0.0000
54	CO2	0.0000	0.00	0.000	0 0.000	0 0.000	0.0000
55	N20	0.0000	0.00	0.000	0 0.000	0 0.0000	0.0000
56	NO2	0.0000	0.00	0.000	0.000	0 0.0000	0.0000
57	NO	0.0000	0.00	0.000	0.000	0 0.0000	0.0000
58	S02	0.0000	0.00	0.000	0.000	0 0.0000	0.0000
59	H2S	0.0000	0.00	00.000	0 0.000	0 0.0000	0.0000
60	CO	0.0000	0.00	0.000	0.000	0 0.0000	0.0000
61	H2O2	0.0000	0.00	0.000	0.000	0.0000	0.0000
62	Ammonia	13309 4606	0.00	0.000	0.000	0 0.0000	0.0000
64	rotar	13300.4090	1.00	20029.875	1.000	504.0570	1.0000
65	Aspen Technology Inc		As	pen HYSYS Version	111		Page 1 of 16
	Licensed to: BATTELLE ENER(3Y ALLIANCE	715				* Specified by user.

1				(Case Name: 500	MWe_HydrogenTur	bine_recuperated.hsc	;	
3	(1) aspentech	BATTELLE ENER Bedford, MA	GY ALLIANCE	L	Unit Set: Am	eyS2e			
4		USA		C	Date/Time: We	d Sep 27 09:15:46 2	023		
6				_			Fluid Package:	Com	bustionTurbineProce
7	Mater	ial Stream:	AirIntak	e			Property Package:	Pen	g-Robinson
9				C	ONDITIONS				-
10			Overall	V				_	
12	Versus / Dhase Excelies		d oooo	Vé	apour Phase			-	
12	vapour / Phase Fraction	(0)	1.0000		1.0000			-	
13	Temperature:	(C)	20.00 -		20.00			+	
14	Pressure:	(bar)	1.013		1.013			-	
15	Molar Flow	(kgmole/n)	2.4658+005		2.4656+005			+	
10	Real Ideal Lie Val Flow	(Kg/S)	1907		1907			-	
10	Sta Ideal Liq Vol Flow	(m3/n)	2059		2059			-	
18	Molar Enthalpy	(KJ/Kgmole)	-2958		-2958			-	
19	Molar Entropy ()	(J/kgmole-C)	152.0		152.0			-	
20	Heat Flow	(MVV)	-202.5		-202.5			+	
21	Liq Vol Flow @Std Cond	(m3/h)	5.824e+006 *		5.824e+006			_	
22				CC	OMPOSITION				
24								-	
25				0	verall Phase		Vapor	ur Fra	ction 1.0000
26	COMPONENTS	MOLAR FLOW	MOLE FRACTIO	ON	MASS FLOW	MASS FRACTION	LIQUID VOLUM	1E	LIQUID VOLUME
27		(kgmole/h)			(kg/h)		FLOW (m3/h)	FRACTION
28	H2O	2857.0521 *	0.01	16 *	51470.0804 *	0.007	3 * 51.57	39 *	0.0063 *
29	Hydrogen	0.0000 *	0.00	• 000	0.0000 *	0.000	0.00	00 *	0.0000 *
30	Nitrogen	192493 4427 *	0.78	808 *	5.392318905e+06 *	0.761	5 6687.11	88 *	0.8177 *
31	Oxvgen	51169.1430 *	0.20	76 *	1.637412576e+06 *	0.231	2 1439.25	58 *	0.1760 *
32	Methane	0.0000 *	0.00	* 000	0.0000 *	0.000	0.00	00 *	0.0000 *
33	Ethane	0.0000 *	0.00	000 *	0.0000 *	0.000	0.00	00 *	0.0000 *
34	CO2	0.0000 *	0.00	000 *	0.0000 *	0.000	0.00	00 *	0.0000 *
35	N20	0.0000 *	0.00	000 *	0.0000 *	0.000	0.00	00 *	0.0000 *
36	NO2	0 0000 *	0.00	000 *	0.0000 *	0.000	0.00	00 *	0.0000 *
37	NO	0.0000 *	0.00	000 *	0.0000 *	0.000	0.00	00 *	0.0000 *
38	S02	0.0000 *	0.00	• 000	0.0000 *	0.000	0.00	00 *	0.0000 *
39	H2S	0.0000 *	0.00	000 *	0.0000 *	0.000	0.00	00 *	0.0000 *
40	CO	0.0000 *	0.00	* 000	0.0000 *	0.000	0.00	00 *	0.0000 *
41	H202	0.0000 *	0.00	000 *	0.0000 *	0.000	0.00	00 *	0.0000 *
42	Ammonia	0.0000 *	0.00	• 000	0.0000 *	0.000	0.00	00 *	0.0000 *
43	Total	246519,6378	1.00	000	7.081201561e+06	1,000	0 8177.94	85	1.0000
44									
45				Va	apour Phase		Phase	e Frac	tion 1.000
46	COMPONENTS	MOLAR FLOW	MOLE FRACTIO	ON	MASS FLOW	MASS FRACTION	LIQUID VOLUM	1E	LIQUID VOLUME
40	H20	2957 0524	0.01	16	51470.0904	0.007	3 51 57	39	0.0062
40	Hudroago	2007.0021	0.01	000	0.0004	0.007	0 0.00	00	0.0003
49	Nitrogen	102402 4427	0.00	000	0.0000 5 202219905e+06	0.000	6697.11	00	0.0000
50	Owigen	192493.4427 E1100.1420	0.78	76	1.637413676-100	0.761	0007.11	60	0.0177
51	Oxygen	51169.1430	0.20	000	1.03/4125/00+00	0.231	2 1439.25	00	0,1760
52	Ethana	0.0000	0.00	000	0.0000	0.000	0.00	00	0.0000
53	CO2	0.0000	0.00	000	0.0000	0.000	0.00	00	0.0000
54	N20	0.0000	0.00	000	0.0000	0.000	0.00	00	0.0000
50	NO2	0.0000	0.00	000	0.0000	0.000	0.00	00	0.0000
57	NO	0.0000	0.00	000	0.0000	0.000	0.00	00	0.0000
50	802	0.0000	0.00	000	0.0000	0.000	0.00	00	0,0000
50	U202	0.0000	0.00	000	0.0000	0.000	0.00	00	0.0000
60	0	0.0000	0.00	000	0.0000	0.000	0.00	00	0.0000
61	H202	0.0000	0.00	000	0.0000	0.000	0.00	00	0.0000
62	Ammonia	0.0000	0.00	000	0.0000	0.000	0.00	00	0.0000
62	Total	246510 6379	1.00	000	7.0812015610+06	1.000	0 9177.04	85	1.0000
64	rotal	240313.0378	1.00	50	1.001201001e+06	1.000	0177.94	00	1.0000
65	Asnen Technology Inc.		٨	snen	HVSVS Version 1	1			Page 2 of 16
00	Aspen reunnology Inc.		A	spen	11313 version I	1		-	Fage 2 01 10

1				Case Name:	500MWe_HydrogenTurb	ine_recuperated.hsc	
3	(aspentech	BATTELLE ENER Bedford, MA	GY ALLIANCE	Unit Set:	AmeyS2e		
4		USA		Date/Time:	Wed Sep 27 09:15:46 20	23	
6 7 8	Mater	ial Stream:	Burner	Condensate	FI Pi	uid Package: C roperty Package: P	ombustionTurbineProce eng-Robinson
9 10				CONDITIONS			
11			Overall	Vapour Phase	Liquid Phase	Aqueous Phase	
12	Vapour / Phase Fraction		0.0000	0.0000	0.5000	0.5000	
13	Temperature:	(C)	2387	2387	2387	2387	
14	Pressure:	(bar)	2.730	2.730	2.730	2.730	
15	Molar Flow	(kgmole/h)	0.0000	0.0000	0.0000	0.0000	
10	Mass Flow	(Kg/s)	0.0000	0.0000	0.0000	0.0000	
18	Molar Enthalow	(m3/n)	2.651e+004	2 651e+004	2.651e+004	2.651e+004	
19	Molar Entropy (A	(KJ/Kgmole-C)	233.6	233.6	233.6	233.6	
20	Heat Flow	(MW)	0.0000	0.0000	0.0000	0.0000	
21	Lig Vol Flow @Std Cond	(m3/h)	0.0000 *	0.0000	0.0000	0.0000	
22							
23				COMPOSITION			
24				Overall Phase		Vapour	Fraction 0.0000
25				Overall Fliase		vapouri	140000
26 27	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTIO	N MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	FRACTION
28	H2O	0.0000	0.286	61 0.000	0 0.2072	0.0000	0.1519
29	Hydrogen	0.0000	0.016	52 0.000	0 0.0013	0.0000	0.0138
30	Nitrogen	0.0000	0.654	17 0.000	0.7371	0.0000	0.6691
31	Oxygen	0.0000	0.03	18 0.000	0.0408	0.0000	0.0263
32	Methane	0.0000	0.000	00.000	0.0000	0.0000	0.0000
33	Ethane	0.0000	0.000	00.00	0.0000	0.0000	0.0000
34	CO2	0.0000	0.000	00.000	0.0000	0.0000	0.0000
35	N2O	0.0000	0.000	000.00	0.0000	0.0000	0.0000
36	NO2	0.0000	0.000	0.000	0.0000	0.0000	0.0000
37	NO	0.0000	0.011	12 0.000	0 0.0135	0.0000	0.1389
38	S02	0.0000	0.000	000.00	0.0000	0.0000	0.0000
39	H25	0.0000	0.000	0.000	0.0000	0.0000	0.0000
40	H202	0.0000	0.000	0.000	0.0000	0.0000	0.0000
42	Ammonia	0.0000	0.000	0.000	0.0000	0.0000	0.0000
43	Total	0.0000	1.000	0.000	0 1 0000	0.0000	1 0000
44							
45				Vapour Phase		Phase F	raction 0.0000
46	COMPONENTS	MOLAR FLOW	MOLE FRACTIO	MASS FLOW	MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME
48	H2O	0.0000	0.286	51 0.000	0 0.2072	0.0000	0.1519
49	Hydrogen	0.0000	0.016	52 0.000	0 0.0013	0.0000	0.0138
50	Nitrogen	0.0000	0.654	17 0.000	0.7371	0.0000	0.6691
51	Oxygen	0.0000	0.03	18 0.000	0.0408	0.0000	0.0263
52	Methane	0.0000	0.000	0.000	0.0000	0.0000	0.0000
53	Ethane	0.0000	0.000	0.000	0.0000	0.0000	0.0000
54	CO2	0.0000	0.000	000.00	0.0000	0.0000	0.0000
55	N2O	0.0000	0.000	000.00	0.0000	0.0000	0.0000
56	NO2	0.0000	0.000	000.00	0.0000	0.0000	0.0000
57	NO	0.0000	0.01	12 0.000	0 0.0135	0.0000	0.1389
58	S02	0.0000	0.000	00.000	0.0000	0.0000	0.0000
59	H2S	0.0000	0.000	00.000	0.0000	0.0000	0.0000
60	CO	0.0000	0.000	0.000	0.0000	0.0000	0.0000
61	H2O2	0.0000	0.000	0.000	0.0000	0.0000	0.0000
62	Ammonia	0.0000	0.000	000.00	0.0000	0.0000	0.0000
63	lotal	0.0000	1.000	0.000	1.0000	0.0000	1.0000
04	Acpon Tochnology Inc.		A -	DOD LIVEVE Version	o. 11		Dage 2 of 10
05	Aspen rechnology Inc.		As	pen misis versio			Page 3 of 16

1			Case Name: 500MWe_HydrogenTurbine_recuperated.hsc							
3	(aspentech	Bedford, MA	Y ALLIANCE	Unit Set: A	meyS2e					
4		USA		Date/Time: V	Ved Sep 27 09:15:46	2023				
6			_			Fluid Package: (CombustionTurbineProces			
7	Mater	ial Stream:	BurnerC	ondensate	(continue	Property Package:	Pena-Robinson			
9										
10				COMPOSITION						
11				Liquid Phase		Phase F	Fraction 0.5000			
13	COMPONENTS	MOLAR FLOW	MOLE FRACTION	MASS FLOW	MASS FRACTIO	N LIQUID VOLUME	LIQUID VOLUME			
15	H2O	0.0000	0.2861	0.0000	0.207	72 0.0000	0,1519			
16	Hydrogen	0.0000	0.0162	0.0000	0.00	0.0000	0.0138			
17	Nitrogen	0.0000	0.6547	0.0000	0.73	71 0.0000	0.6691			
18	Oxygen	0.0000	0.0318	0.0000	0.040	0.0000	0.0263			
19	Methane	0.0000	0.0000	0.0000	0.000	0.0000 0.0000	0.0000			
20	Ethane	0.0000	0.0000	0.0000	0.000	0000.0 00000	0.0000			
21	CO2	0.0000	0.0000	0.0000	0.000	0.0000	0.0000			
22	N2O	0.0000	0.0000	0.0000	0.000	0.0000 0.0000	0.0000			
23	NO2	0.0000	0.0000	0.0000	0.000	0000.0 00000	0.0000			
24	NO	0.0000	0.0112	0.0000	0.013	35 0.0000	0.1389			
25	SO2	0.0000	0.0000	0.0000	0.000	0000.0 00	0.0000			
26	H2S	0.0000	0.0000	0.0000	0.000	0000.0 00	0.0000			
27	CO	0.0000	0.0000	0.0000	0.000	0000.0 00	0.0000			
28	H2O2	0.0000	0.0000	0.0000	0.000	0000.0 00	0.0000			
29	Ammonia	0.0000	0.0000	0.0000	0.000	0000.0 00	0.0000			
30	Total	0.0000	1.0000	0.0000	1.000	0.0000	1.0000			
31 32				Aqueous Phase		Phase F	Fraction 0.5000			
33 34	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTIO	N LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION			
35	H2O	0.0000	0.2861	0.0000	0.207	72 0.0000	0.1519			
36	Hydrogen	0.0000	0.0162	0.0000	0.00	13 0.0000	0.0138			
37	Nitrogen	0.0000	0.6547	0.0000	0.73	71 0.0000	0.6691			
38	Oxygen	0.0000	0.0318	0.0000	0.040	0.0000 80	0.0263			
39	Methane	0.0000	0.0000	0.0000	0.000	0000.0	0.0000			
40	Ethane	0.0000	0.0000	0.0000	0.000	0000.0 00	0.0000			
41	CO2	0.0000	0.0000	0.0000	0.000	0000.0 00	0.0000			
42	N2O	0.0000	0.0000	0.0000	0.000	0000.0	0.0000			
43	NO2	0.0000	0.0000	0.0000	0.000	0000.0 00	0.0000			
44	NO	0.0000	0.0112	0.0000	0.013	35 0.0000	0.1389			
45	S02	0.0000	0.0000	0.0000	0.000	0000.0 00	0.0000			
46	H2S	0.0000	0.0000	0.0000	0.000	0000.0 00	0.0000			
47	CO	0.0000	0.0000	0.0000	0.000	0000.0 00	0.0000			
48	H2O2	0.0000	0.0000	0.0000	0.000	0000.0 00	0.0000			
49	Ammonia	0.0000	0.0000	0.0000	0.000	0000.0 00	0.0000			
50	Total	0.0000	1.0000	0.0000	1.000	0.0000	1.0000			
51 52 53	Mater	ial Stream:	Flue			Fluid Package: 0	CombustionTurbineProces Peng-Robinson			
54				CONDITIONS						
55				Senternono	11					
56			Overall	Vapour Phase	Liquid Phase	Aqueous Phase				
57	Vapour / Phase Fraction	101	1.0000	1.0000	0.0000	0.0000				
50	remperature:	(C)	1400	1400	1400	1400				
60	Molar Flow	(bar)	2.730	2.730	2,730	2.730				
64	Mass Flow	(kgmole/n)	2.5520+005	2.5328+005	0.0000	0.0000				
62	Mass Flow	(Kg/S)	19/4	19/4	0.0000	0.0000				
62	Molar Enthaley	(m3/n)	3 0490+004	304904004	3.040-+004	3.049++004				
64	Molar Entropy //	(kangliole)	202 5	3.0430+004	3.0450+004	3.04501004				
65	Aspen Technology Inc	wingmole of	Asn	en HYSYS Version	11	202.0	Page 4 of 16			

1		- FNEDO			Case Name:	500	MWe_HydrogenTurbin	e_recuperated.hsc					
3	entech	Bedford, M	A	Y ALLIANCE		Unit Set:	Ame	eyS2e					
4		USA				Date/Time:	Wed	d Sep 27 09:15:46 202	3				
6 7 8	Materi	ial Stre	am:	Flue (c	on	tinued)		Flu Pro	id Package: Co operty Package: Pe	ombustionTurbineProce eng-Robinson			
9 10						CONDITIONS	CONDITIONS						
11				Overall		Vapour Phase		Liquid Phase	Aqueous Phase				
12	Heat Flow	(MW)		2144		2144		0.0000	0.0000				
13	Liq Vol Flow @Std Cond	(m3/h)		5.977e+006 *		5.977e+006	_	0.0000	0.0000				
14					C	COMPOSITION							
16	0			Overall Phase					Vapour F	raction 1.0000			
17							_		Tupourr	1.0000			
18 19	COMPONENTS	MOLAR FL (kgmole/	OW h)	MOLE FRACTION		MASS FLOW (kg/h)		MASS FRACTION	FLOW (m3/h)	FRACTION			
20	H2O	16165	1670	0.0	639	291217.108	2	0.0410	291.8048	0.0344			
21	Hydrogen 0.3486		3486	0.0	000	0.702	7	0.0000	0.0101	0.0000			
22	Nitrogen 192174.0963		.0963	0.7	591	5.383373054e+0	6	0.7574	6676.0249	0.7874			
23	Oxygen 44194.2520 Methane 0.0000		2520	0.1	746	1.414216065e+0	6	0.1990	1243.0701	0.1466			
24	Methane 0.0000 Ethane 0.0000		0000	0.0	000	0.000	0	0.0000	0.0000	0.0000			
25	CO2 0.0000		0000	0.0	000	0.000	0	0.0000	0.0000	0.0000			
27	N2O 0.0486		0486	0.0	000	2 140	9	0.0000	0.0000	0.0000			
28	NO2 3.0108		0108	0.0000		138.5141		0.0000	0.0942	0.0000			
29	NO2 3.0108 NO 635.5847		5847	0.0	025	19071.3557		0.0027	267.3953	0.0315			
30	SO2	2 0.0000		0.0	000	0.000	0	0.0000	0.0000	0.0000			
31	H2S	0.	0000	0.0	000	0.000	0	0.0000	0.0000	0.0000			
32	co	0.	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000			
33	H2O2	0.	0060	0.0000		0.205	3	0.0000	0.0001	0.0000			
34	Ammonia	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000			
35	Total	253172	.5141	1.0	000	7.108019145e+0	6	1.0000	8478.4022	1.0000			
36					١	apour Phase			Phase Fr	action 1.000			
38	COMPONENTS	MOLAR FL	ow	MOLE FRACT	ION	MASS FLOW		MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME			
39	1120	(kgmole/	h)			(kg/h)		0.0110	FLOW (m3/h)	FRACTION			
40	Hudrogen	16165	3486	0.0	000	291217.108	7	0.0410	291.8048	0.0344			
47	Nitrogen	192174	0963	0.0	591	5 383373054e+0	6	0.0000	6676 0249	0.0000			
43	Oxvaen	44194	2520	0.1	746	1.414216065e+0	6	0.1990	1243.0701	0.1466			
44	Methane	0	0000	0.0	000	0.000	0	0.0000	0.0000	0.0000			
45	Ethane	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000			
46	CO2	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000			
47	N2O	0	0486	0.0	000	2.140	9	0.0000	0.0026	0.0000			
48	NO2	3.	.0108	0.0	000	138.514	1	0.0000	0.0942	0.0000			
49	NO	635	.5847	0.0	025	19071.355	7	0.0027	267.3953	0.0315			
50	S02	0.	0000	0.0	000	0.000	0	0.0000	0.0000	0.0000			
51	H2S	0	0000	0.0	000	0.000	0	0.0000	0.0000	0.0000			
52	C0	0.	0000	0.0	000	0.000	0	0.0000	0.0000	0.0000			
53	H2O2	0	0000	0.0	000	0.205	3	0.0000	0.0001	0.0000			
55	Total	253172	5141	1.0	000	7.108019145e+0	6	1 0000	8478 4022	1 0000			
56	Total	255112		1.0	000	iquid Phase	-	1.0000	Phase Fr	action 0.0000			
57						Liquid Fliase	_		Phase Ph	0.0000			
58 59	COMPONENTS	MOLAR FL	OW h)	MOLE FRACT	ON	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION			
60	H2O	0.	.0000	0.0	639	0.000	0	0.0410	0.0000	0.0344			
61	Hydrogen	0	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000			
62	Nitrogen	0	0000	0.7	591	0.000	0	0.7574	0.0000	0.7874			
63	Oxygen	0	0000	0.1	746	0.000	0	0.1990	0.0000	0.1466			
64	Methane	0.	.0000	0.0	000	0.000	0	0.0000	0.0000	0.0000			
65	Aspen Technology Inc.			A	spe	n HYSYS Version	111			Page 5 of 16			

1				Case Name: 500MWe_HydrogenTurbine_recuperated.hsc									
3	@aspentech	BATTELLE ENERG	SY ALLIANCE	U	Jnit Set:	Amey	/S2e						
4		USA		C	Date/Time:	Wed	Sep 27 09:15:46 202	3					
6	Mater						Flu	id Package:	Con	nbustionTurbineProces			
7 8	Mater	rial Stream:	Flue (C	ont	Property Package: Peng-Robinson								
9				С	COMPOSITION								
10 11				unial P	lhaan (anntin			Dhao					
12	0011001151170		LIC		nase (contin	uea		Phas	e Frad	ction 0.0000			
13	COMPONENTS	(kgmole/h)	MOLE FRACT	ON	(kg/h)		MASS FRACTION	FLOW (m3/h	1)	FRACTION			
15	Ethane	0.0000	0.0	000	0.000	0	0.0000	0.00	00	0.0000			
16	CO2	0.0000	0.0	000	0.000	0	0.0000	0.00	000	0.0000			
17	N20	0.0000	0.0	000	0.000	0	0.0000	0.00	000	0.0000			
18	NO2	0.0000	0.0	000	0.000	0	0.0000	0.00	000	0.0000			
19	NO	0.0000	0.0	025	0.000	0	0.0027	0.00	000	0.0315			
20	502	0.0000	0.0	000	0.000		0.0000	0.00	00	0.0000			
22	0	0.0000	0.0	000	0.000		0.0000	0.00	00	0.0000			
22	H202	0.0000	0.0	000	0.000		0.0000	0.00	00	0.0000			
24	Ammonia	0.0000	0.0	000	0.000	0	0.0000	0.00	00	0.0000			
25	Total	0.0000	10	000	0.000	0	1,0000	0.00	000	1 0000			
26									-				
27	7				ueous Phase			Phas	e Fra	ction 0.0000			
28	COMPONENTS	MOLAR FLOW	MOLE FRACT	ON	MASS FLOW		MASS FRACTION	LIQUID VOLUN	/E	LIQUID VOLUME			
29		(kgmole/h)			(kg/h)			FLOW (m3/h)	FRACTION			
30	H2O	0.0000	0.0	639	0.000	0	0.0410	0.00	00	0.0344			
31	Hydrogen	0.0000	0.0	000	0.000	0	0.0000	0.00	000	0.0000			
32	Nitrogen	0.0000	0.7	591	0.000	0	0.7574	0.00	00	0.7874			
33	Oxygen	0.0000	0.1	746	0.000	0	0.1990	0.00	00	0.1466			
34	Methane	0.0000	0.0	000	0.000	0	0.0000	0.00	000	0.0000			
35	Ethane	0.0000	0.0	000	0.000	0	0.0000	0.00	00	0.0000			
36	C02	0.0000	0.0	000	0.000	0	0.0000	0.00	000	0.0000			
3/	N20	0.0000	0.0000				0.0000	0.00	000	0.0000			
30	NO2	0.0000	0.0	025 0.0			0.0000	0.00	00	0.0000			
40	502	0.0000	0.0	0.0000			0.0027	0.00	00	0.0015			
40	H2S	0.0000	0.0	000	0.0000		0.0000	0.00	00	0.0000			
42	CO	0.0000	0.0	000	0.000	0.0000		0.0000		0.0000			
43	H202	0.0000	0.0	000	0.000	0	0.0000	0.0000		0.0000			
44	Ammonia	0.0000	0.0	000	0.000	0	0.0000	0.00	000	0.0000			
45	Total	0.0000	1.0	000	0.000	0	1.0000	0.00	00	1.0000			
46	Mato	rial Stroom	Exhaus	.+			Flu	id Package:	Con	nbustionTurbineProces			
48	Mater	nai otreani.	Exhaus				Pro	operty Package:	Pen	g-Robinson			
49				с	ONDITIONS								
51			Overall	Ve	apour Phase								
52	Vapour / Phase Fraction		1.0000	10	1.0000								
53	Temperature:	(C)	1095		1095								
54	Pressure:	(bar)	1.033		1.033								
55	Molar Flow	(kgmole/h)	2.532e+005		2.532e+005								
56	Mass Flow	(kg/s)	1974		1974								
57	Std Ideal Liq Vol Flow	(m3/h)	8478		8478								
58	Molar Enthalpy	(kJ/kgmole)	1.960e+004		1.960e+004								
59	Molar Entropy (kJ/kgmole-C) 203.4				203.4								
60	Heat Flow	(MW)	1378		1378				_				
61	1 Liq Vol Flow @Std Cond (m3/h) 5.977e+006 *				5.977e+006								
62													
63													
04	Aspon Tochnology Inc			chan	HVSVS Varaia	0.14				Dago 6 of 16			
00	Licensed to: BATTELLE ENER	GY ALLIANCE	P	spen	TTOTO VEISION				-	* Specified by user			
	CREATE ON DATIELLE ENER									specified by user.			

1				Case Name: 500MWe_HydrogenTurbine_recuperated.hsc							
2	(aspentech	BATTELLE ENERG Bedford, MA	Y ALLIANCE	Unit Set: Am	evS2e						
4	C	USA		Date/Time: We	d Sep 27 09:15:46 202	3					
5 6 7 8	Materia	I Stream:	Exhaust	(continued)	Flui Pro	d Package: Co perty Package: Pe	mbustionTurbineProces				
9				COMPOSITION							
10 11						Verent	4 0000				
12				Overall Phase		Vapour Fr	action 1.0000				
13	COMPONENTS	MOLAR FLOW	MOLE FRACTION	MASS FLOW	MASS FRACTION	ELQUID VOLUME	ERACTION				
15	H2O	16165 1670	0.0639	291217 1082	0.0410	291 8048	0.0344				
16	Hydrogen	0.3486	0.0000	0.7027	0.0000	0.0101	0.0000				
17	Nitrogen	192174.0963	0.7591	5.383373054e+06	0.7574	6676 0249	0.7874				
18	Oxvaen	44194,2520	0.1746	1.414216065e+06	0,1990	1243.0701	0.1466				
19	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
20	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
21	C02	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
22	N2O	0.0486	0.0000	2.1409	0.0000	0.0026	0.0000				
23	NO2	3.0108	0.0000	138.5141	0.0000	0.0942	0.0000				
24	NO	635.5847	0.0025	19071.3557	0.0027	267.3953	0.0315				
25	S02	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
26	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
27	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
28	H2O2	0.0060	0.0000	0.2053	0.0000	0.0001	0.0000				
29	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
30	Total	253172.5141	1,0000	7.108019145e+06	1.0000	8478.4022	1.0000				
31 32	31			Vapour Phase		Phase Fra	action 1.000				
33 34	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION				
35	H2O	16165.1670	0.0639	291217.1082	0.0410	291.8048	0.0344				
36	Hydrogen	0.3486	0.0000	0.7027	0.0000	0.0101	0.0000				
37	Nitrogen	192174.0963	0.7591	5.383373054e+06	0.7574	6676.0249	0.7874				
38	Oxygen	44194.2520	0.1746	1.414216065e+06	0.1990	1243.0701	0.1466				
39	Methane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
40	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
41	CO2	0.0000	0.0000	0.0000	0.0000	0.000	0.0000				
42	N2O	0.0486	0.0000	2.1409	0.0000	0.0026	0.0000				
43	NO2	3.0108	0.0000	138.5141	0.0000	0.0942	0.0000				
44	NO	635.5847	0.0025	19071.3557	0.0027	267.3953	0.0315				
45	S02	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
46	H2S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
47	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
48	H2O2	0.0060	0.0000	0.2053	0.0000	0.0001	0.0000				
49	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
50	Total	253172.5141	1.0000	7.108019145e+06	1.0000	8478.4022	1.0000				
51 52 53	Materia	Stream:	AirFeed		Flui Pro	d Package: Co perty Package: Pe	mbustionTurbineProce ng-Robinson				
54 55				CONDITIONS							
56			Overall	Vapour Phase							
57	Vapour / Phase Fraction		1.0000	1.0000							
58	Temperature:	(C)	151.4	151.4							
59	Pressure:	(bar)	2.836	2.836							
60	Molar Flow ()	(gmole/h)	2.465e+005	2.465e+005							
61	Mass Flow	(kg/s)	1967	1967							
62	Std Ideal Lig Vol Flow	(m3/h)	8178	8178							
63	Molar Enthalpy (k.	J/kgmole)	926.1	926.1							
64	Molar Entropy (kJ/k	gmole-C)	154.4	154.4							
65	Aspen Technology Inc.		Asp	en HYSYS Version 1	1		Page 7 of 16				

1	BATTELLE EN			NALLIANOF.		Case Name:	500	MWe_HydrogenTurbin	ne_recuperated.hsc	
3	(1) aspentech	Bedford, M	IA IA	SY ALLIANCE		Unit Set:	Am	eyS2e		
4		USA				Date/Time:	We	d Sep 27 09:15:46 202	23	
6 7 8	Materi	al Stre	am:	AirFee	d (continued	1)	Flu	iid Package: C operty Package: F	CombustionTurbineProces
9 10						CONDITIONS				
11				Overall		Vapour Phase				
12	Heat Flow	(MW)		63.42		63.42	_			
13	Liq Vol Flow @Std Cond	(m3/h)		5.824e+006 *		5.824e+006	_			
15					(COMPOSITION				
16 17					(Overall Phase		Vapo		Fraction 1.0000
18 19	COMPONENTS	MOLAR FL	.OW (h)	MOLE FRACT	ON	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
20	H2O	2857	.0521	0.0	116	51470.080)4	0.0073	51.5739	0.0063
21	Hydrogen	(.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
22	Nitrogen	192493	.4427	0.7	808	5.392318905e+0	06	0.7615	6687.1188	0.8177
23	Oxygen	51169	.1430	0.2	076	1.637412576e+0	06	0.2312	1439.2558	0.1760
24	Ethane		0000	0.0	000	0.000	0	0.0000	0.0000	0.0000
26	CO2	(0000	0.0	000	0.000	0	0.0000	0.0000	0.0000
27	N20	(.0000	0.0000		0.000	00	0.0000	0.0000	0.0000
28	NO2	(.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
29	NO	(00000	0.0	000	0.000	00	0.0000	0.0000	0.0000
30	S02	SO2 0.0000 H2S 0.0000		0.0	000	0.000	0.0000		0.0000	0.0000
31	H2S	(0.0000		0.0000		0.0000		0.0000	0.0000
32	CO 0.0000		0.0	000	0.000	00	0.0000	0.0000	0.0000	
33	H2O2	(0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
34	Ammonia	246510	6378	0.0	000	7.081201561et	10	1,0000	8177 9485	1.0000
36	Total	240313	.0070	1.0		1.001201301640	0	1,0000	0177.5405	1,0000
37	COMPONENTS	MOLAD FI	OW	MOLEEDACT		Vapour Phase		MASS EDACTION	Phase F	raction 1.000
39	COMPONENTS	(kgmole	h)	MOLE PRACT		(kg/h)		MASSTRACTION	FLOW (m3/h)	FRACTION
40	H2O	2857	.0521	0.0	116	51470.080	04	0.0073	51.5739	0.0063
41	Hydrogen	(0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
42	Nitrogen	192493	1430	0.7	808	5.392318905e+0	16	0.7615	1420 2559	0.81//
44	Methane	51105	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
45	Ethane	(.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
46	CO2	(0.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
47	N20	(0.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
48	NO2	(0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
49	NO	(0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
50	502	0	0000	0.0	000	0.000	U	0.0000	0.0000	0.0000
52	H25		0000	0.0	000	0.000	0	0.0000	0.0000	0.0000
53	H202	(0000	0.0	000	0.000	0	0.0000	0.0000	0.0000
54	Ammonia		.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000
55	Total	246519	.6378	1.0	000	7.081201561e+0)6	1.0000	8177.9485	1.0000
56 57 58 59	Materi	al Stre	am:	Combu	st	ionAir		Flu	id Package: C operty Package: F	CombustionTurbineProces
60						CONDITIONS				
61				Overall		Vapour Phase				
62	Vapour / Phase Fraction			1.0000		1.0000				
63	Temperature:	(C)		1085		1085	_			
64	Aspen Technology Inc.	(bar)	-	2.780	CDC	2.780	n 1-			Page 9 of 16
05	Licensed to: BATTELLE ENERG	Y ALLIANCE		P	spe	anni si si veisio				* Specified by user.

1				Case Name: 500MWe_HydrogenTurbine_recuperated.hsc								
3	(1) aspentech	Bedford, MA	ERGY ALLIANCE		Unit Set:	Ame	yS2e					
4		USA		1	Date/Time:	Wed	Sep 27 09:15:46	2023				
6 7 8 9	Mater	ial Strear	n: Combu	ustionAir (continued)						nTurbîneProce nson		
10				C	ONDITIONS							
11			Overall	V	apour Phase							
12	Molar Flow	(kgmole/h)	3.847e+004		3.847e+004			+				
14	Std Ideal Lig Vol Flow	(m3/h)	1276		1276			1				
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			1	-			
19 20				C	OMPOSITION							
21				0	verall Phase				Vapour	Fraction	1.0000	
23 24	COMPONENTS	COMPONENTS MOLAR FLOW MO (kgmole/h) H2O 445.8506		ION	MASS FLOW (kg/h)		MASS FRACTIO	N	LIQUID VOLUME FLOW (m3/h)	LIQU	ID VOLUME ACTION	
25	H2O	445.850	6 0.0	116	8032.04	38	0.007	73	8.0483	(0.0063	
26	Hydrogen	0.000	0.0	000	0.00	00	0.000	00	0.0000	N	0.0000	
27	Nitrogen	30039.117	0 0.7	808	841485.79	92	0.76	15	1043.5428	×	0.8177	
28	Oxygen	xygen 7985.0817 ethane 0.0000		0.2076		55	0.23	12	224.5997	_	0.1760	
30	Ethane	0.000	0 0.0	000	0.00		0.000	00	0.0000		0.0000	
31	CO2	0.000	0 0.0	000	0.0000		0.000	00	0.0000		0.0000	
32	N2O	0.000	0 0.0	000	0.0000		0.000	00	0.0000		0.0000	
33	NO2	0.000	0.0	000	0.0000		0.000	00	0.0000	2	0.0000	
34	NO	0.000	0.0	000	0.00	00	0.000	00	0.0000		0.0000	
35	SO2	0.000	0 0.0	000	0.00	00	0.000	00	0.0000		0.0000	
36	H2S	0.000	0 0.0	000	0.00	00	0.000	00	0.0000		0.0000	
38	H202	0.000	0 0.0	000	0.00		0.000	00	0.0000		0.0000	
39	Ammonia	0.000	0 0.0	000	0.00	00	0.000	00	0.0000		0.0000	
40	Total	38470.049	4 1.0	000	1.105040459e+	06	1.000	00	1276.1908		1.0000	
41 42				Va	Vapour Phase Phase Fraction							
43	COMPONENTS	MOLAR FLOW	MOLE FRACTI	ION	MASS FLOW		MASS FRACTIO	N	LIQUID VOLUME	LIQU	ID VOLUME	
44	H20	(Kgmole/n)	6 00	116	(kg/n)	28	0.00	73	PLOW (m3/h)	FR	0.0063	
46	Hydrogen	0.000	0 0.0	000	0.00	00	0.000	00	0.0403		0.0000	
47	Nitrogen	30039.117	0 0.7	808	841485.79	92	0.76	15	1043.5428		0.8177	
48	Oxygen	7985.081	7 0.2	076	255522.61	55	0.23	12	224.5997		0.1760	
49	Methane	0.000	0 0.0	000	0.00	00	0.000	00	0.0000	0	0.0000	
50	Ethane	0.000	0 0.0	000	0.00	00	0.000	00	0.0000		0.0000	
51 52	N20	0.000	0 0.0	000	0.00	00	0.000	00	0.0000		0.0000	
53	NO2	0.000	0 0.0	000	0.00	00	0.000	00	0.0000		0.0000	
54	NO	0.000	0 0.0	000	0.00	00	0.000	00	0.0000		0.0000	
55	S02	0.000	0.0	000	0.00	00	0.000	00	0.0000	K.	0.0000	
56	H2S	0.000	0 0.0	000	0.00	00	0.000	00	0.0000		0.0000	
57	CO	0.000	0.0	000	0.00	00	0.000	00	0.0000	_	0.0000	
58	H2O2	0.000	0.0	000	0.00	00	0.000	00	0.0000		0.0000	
60	Total	38470.049	4 1.0	000	1.105040459e+	06	1.000	00	1276.1908		1.0000	
61 62 63 64 65	Aspen Technology Inc		Ą	Aspen	HYSYS Versio	n 11				Pe	age 9 of 16	

1						Case Name: 5	00MWe_Hydrogen	Turbir	ne_recuperated.hsc	
2	(aspentech	BATTELLE B Bedford, MA	ENERGY A	ALLIANCE		Unit Set: A	AmeyS2e			
4		USA				Date/Time: V	Ned Sep 27 09:15:4	46 202	3	
6 7 8	Mater	ial Strea	m: C	Cooling	jAi	r		Flu	id Package: (CombustionTurbineProce Peng-Robinson
9					(CONDITIONS				
10			Ov	erall	1	/anour Phase				
12	Vapour / Phase Fraction		01	1.0000	_	1.0000				
13	Temperature:	(C)		1085		1085				
14	Pressure:	(bar)		2.780		2.780				
15	Molar Flow	(kgmole/h)	2	080e+005		2.080e+005		_		
16	Mass Flow	(kg/s)		1660 *		1660		-		
17	Std Ideal Liq Vol Flow	(m3/h)	2	6902	-	6902		+		
19	Molar Entropy (I	(KJ/Kgmole-C)	3.	191.8	_	191.8		+		
20	Heat Flow	(MW)		1809		1809		-		
21	Lig Vol Flow @Std Cond	(m3/h)	4.915e+006 *		4.915e+006					
22					C	OMPOSITION				
23										
24					C	verall Phase			Vapour	Fraction 1.0000
26	COMPONENTS MOLAR F		WM	OLE FRACTI	ON	MASS FLOW	MASS FRACT	ION	LIQUID VOLUME	LIQUID VOLUME
27	oom on Litto	(kgmole/h))	ore monorm		(kg/h)			FLOW (m3/h)	FRACTION
28	H2O	2411.2	015	0.0116		43438.0365	5 0.0	0073	43.5257	0.0063
29	Hydrogen	0.0000		0.00	000	0.0000	0.0	0000	0.0000	0.0000
30	Nitrogen	162454.3	257	0.780		4.550833105e+06	6 0.1	7615	5643.5760	0.8177
31	Oxygen	43184.0	613	0.207		1.381889960e+06	5 0 .	2312	1214.6561	0.1760
32	Methane	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
33	CO2	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
35	N20	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
36	NO2	0.0	000	0.0000		0.0000	0.0	0000	0.0000	0.0000
37	NO	0.0	000	0.0000		0.0000	0.0	0000	0.0000	0.0000
38	SO2	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
39	H2S	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
40	CO	0.0	000	0.00	000	0.0000	0.0000 0.0		0.0000	0.0000
41	H2O2	0.0	000	0.00	000	0.0000	000 0.00		0.0000	0.0000
43	Total	208049.5	884	1.00	000	5.976161102e+06	5 1,0000		6901.7578	1.0000
44										
45					V	apour Phase			Phase F	raction 1.000
46	COMPONENTS	MOLAR FLO (kgmole/h)	W M	OLE FRACTIO	ON	MASS FLOW (kg/h)	MASS FRACT	NON	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION
48	H2O	2411.2	015	0.01	16	43438.0365	5 0.0	0073	43.5257	0.0063
49	Hydrogen	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
50	Nitrogen	162454.3	257	0.78	808	4.550833105e+06	6 0.1	7615	5643.5760	0.8177
51	Oxygen	43184.0	613	0.20	076	1.381889960e+06	5 O.:	2312	1214.6561	0.1760
52	Methane	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
54	CO2	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
55	N20	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
56	NO2	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
57	NO	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
58	S02	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
59	H2S	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
60	CO	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
61	H2O2	0.0	000	0.00	000	0.0000	0.0	0000	0.0000	0.0000
62	Total	208040 5	884	0.00	000	5.9761611020+00	0.0	0000	6901 7579	0.0000
64	rotat	200049.5		1.00		3.3701011020+00			0301.7570	1.0000
65	Aspen Technology Inc.			A	sper	HYSYS Version	11			Page 10 of 16

1				Case	Name: 500)MWe_HydrogenTu	rbine_recuperated.hsc	
3	@aspentech	BATTELLE ENE Bedford, MA	RGY ALLIANCE	Unit S	iet: Am	eyS2e		
4		USA		Date/	Time: We	ed Sep 27 09:15:46	2023	
6 7	Mater	ial Stream	: Flame				Fluid Package:	Combustion Turbine Proce
8							Property Package:	Peng-Robinson
10				CON	DITIONS			
11			Overall	Vapour	Phase	Liquid Phase	Aqueous Phase	
12	Vapour / Phase Fraction		1.0000		1.0000	0.0000	0.0000	
13	Temperature:	(C)	2387		2387	2387	2387	
14	Pressure:	(bar)	2.730		2.730	2.730	2.730	
15	Molar Flow	(kgmole/h)	4.549e+004	4.5	549e+004	0.0000	0.0000	
17	Std Ideal Lin Vol Flow	(kg/s)	1546		1546	0.0000	0.0000	
18	Molar Enthalov	(kJ/kamole)	2 651e+004	21	651e+004	2 651e+004	2 651e+004	
19	Molar Entropy (kJ/kamole-C)	233.6		233.6	233.6	233.6	
20	Heat Flow	(MW)	335.0		335.0	0.0000	0.0000	
21	Liq Vol Flow @Std Cond	(m3/h)	1.071e+006 *	1.	071e+006	0.0000	0.0000	
22				COMP	ORITION			
23				COMP	OSITION			
24				Overa	II Phase		Vapou	Fraction 1.0000
25			Overa	in r nase		, apour	1.0000	
26 27	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTI	DN M	(kg/h)	MASS FRACTIO	N LIQUID VOLUME FLOW (m3/h)	FRACTION
28	H2O	O 13015.3926 drogen 738.8685		861	234473.6060	0.207	2 234.946	8 0.1519
29	Hydrogen	738.8685	0.0	62	1489.5590	0.001	3 21.322	3 0.0138
30	Nitrogen	29783.6983	0.65	4/	834330.7540	0.73/	1 1034.669	0.6691
31	Oxygen	1444./455	0.03	000	46231.8545	0.040	40.637	0.0263
33	Fthane	0.0000	0.00	000	0.0000	0.000	0.000	0.0000
34	CO2	0.0000	0.00	000	0.0000	0.000	0.000	0.0000
35	N20	0.0287	0.00	000	1.2632	0.000	0.001	5 0.0000
36	NO2	0.2089	0.00	000	9.6125	0.000	0.006	5 0,0000
37	NO	510.5698	0.0	12	15320.1586	0.013	35 214.800	6 0.1389
38	SO2	0.0000	0.00	000	0.0000	0.000	0.000	0.0000
39	H2S	0.0000	0.00	000	0.0000	0.000	0.000	0.0000
40	00	0.0000	0.00	000	0.0000	0.000	0.000	0.0000
41	H2O2	0.05/1	0.00	000	1.9413	0.000	0.001	3 0.0000
42	Ammonia	45493 5707	1.00	00 113	0.0221	1.000	0 1546 385	0.0000
43	Total	45455.5101	1.00	1.1.5	0103077 Te+00	1.000	1540.305	1.0000
45				Vapou	Ir Phase	Phase	Fraction 1.000	
46 47	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTI	ON M	ASS FLOW	MASS FRACTIO	N LIQUID VOLUME FLOW (m3/h)	E LIQUID VOLUME
48	H2O	13015.3926	0.28	861	234473.6060	0.207	2 234.946	8 0.1519
49	Hydrogen	738.8685	0.0	162	1489.5590	0.001	3 21.322	3 0.0138
50	Nitrogen	29783.6983	0.65	547	834330.7540	0.737	1 1034.669	7 0.6691
51	Oxygen	1444.7455	0.03	318	46231.8545	0.040	40.637	0 0.0263
52	Methane	0.0000	0.00	000	0.0000	0.000	0.000	0.0000
53	Ethane	0.0000	0.00	000	0.0000	0.000	0.000	0.0000
54	02	0.0000	0.00	000	0.0000	0.000	0.000	0.0000
55	N2O	0.0287	0.00	000	1.2632	0.000	0.001	5 0.0000
57	NO	510 5698	0.00	112	3.0125 15320 1586	0.000	35 214 900	5 0.1399
58	S02	0.0000	0.0	000	0.0000	0.000	0.000	0.0000
59	H2S	0.0000	0.00	000	0.0000	0.000	0.000	0.0000
60	CO	0.0000	0.00	000	0.0000	0.000	0.000	0.0000
61	H2O2	0.0571	0.00	000	1.9413	0.000	0.001	3 0.0000
62	Ammonia	0.0013	0.00	000	0.0221	0.000	0.000	0.0000
63	Total	45493.5707	1.00	000 1.13	31858771e+06	1.000	1546.385	8 1.0000
64								
65	Aspen Technology Inc.		A	spen HYS	YS Version 1	1		Page 11 of 16

1			Case Name: 500MWe_HydrogenTurbine_recuperated.hsc								
3	@aspentech	BATTELLE ENERG Bedford, MA	YALLIANCE	Unit Set: An	neyS2e						
4		USA		Date/Time: W	ed Sep 27 09:15:46 2023	3					
6 7 8	Mater	ial Stream:	Flame (c	ontinued)	Flui Proj	d Package: Co perty Package: Pe	mbustionTurbineProce				
9				COMPOSITION							
10				Liquid Phase		Phase Fraction 0.0000					
13	COMPONENTS	MOLAR FLOW	MOLE FRACTION	MASS FLOW	MASS FRACTION	LIQUID VOLUME	LIQUID VOLUME				
15	H2O	0.0000	0.286	1 0.0000	0.2072	0.0000	0.1519				
16	Hydrogen	0.0000	0.0163	2 0.0000	0.0013	0.0000	0.0138				
17	Nitrogen	0.0000	0.654	7 0.0000	0.7371	0.0000	0.6691				
18	Oxygen	0.0000	0.0318	B 0.0000	0.0408	0.0000	0.0263				
19	Methane	0.0000	0.000	0.0000 0	0.0000	0.0000	0.0000				
20	Ethane	0.0000	0.0000	0.0000 0	0.0000	0.0000	0.0000				
21	CO2	0.0000	0.0000	0.0000 0	0.0000	0.0000	0.0000				
22	N2O	0.0000	0.0000	0.0000 0	0.0000	0.0000	0.0000				
23	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
24	NO	0.0000	0.0112	2 0.0000	0.0135	0.0000	0.1389				
25	S02	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
26	H2S	0.0000	0.0000	0.0000 0	0.0000	0.0000	0.0000				
27	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
28	H2O2	0.0000	0.0000	0.0000 0	0.0000	0.0000	0.0000				
29	Ammonia	0.0000	0.0000	0.0000 0	0.0000	0.0000	0.0000				
30	Total	0.0000	1,000	0,0000	1.0000	0.0000	1.0000				
31 32	31 32			Aqueous Phase		Phase Fra	action 0.0000				
33 34	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	0.286	1 0.0000	0.2072	0.0000	0.1519				
36	Hydrogen	0.0000	0.0162	2 0.0000	0.0013	0.0000	0.0138				
37	Nitrogen	0.0000	0.654	7 0.0000	0.7371	0.0000	0.6691				
38	Oxygen	0.0000	0.0318	8 0.0000	0.0408	0.0000	0.0263				
39	Methane	0.0000	0.0000	0.0000 0	0.0000	0.0000	0.0000				
40	Ethane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
41	CO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
42	N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
43	NO2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
44	NO	0.0000	0.0112	2 0.0000	0.0135	0.0000	0.1389				
45	S02	0.0000	0.000	0.0000	0.0000	0.0000	0.0000				
46	H2S	0.0000	0.000	0.0000	0.0000	0.0000	0.0000				
47	CO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
48	H2O2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
49	Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
50	Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000				
51 52 53	Mater	ial Stream:	Process	Air	Flui Pro	d Package: Co perty Package: Pe	mbustionTurbineProces				
54 55				CONDITIONS							
56			Overall	Vapour Phase							
57	Vapour / Phase Fraction		1.0000	1.0000							
58	Temperature:	(C)	1085 *	1085							
59	Pressure:	(bar)	2.780	2.780							
60	Molar Flow	(kgmole/h)	2.465e+005	2.465e+005							
61	Mass Flow	(kg/s)	1967	1967							
62	Std Ideal Lig Vol Flow	(m3/h)	8178	8178							
63	Molar Enthalpy	(kJ/kgmole)	3.130e+004	3.130e+004							
64	Molar Entropy (kJ/kgmole-C)	191.8	191.8							
65	Aspen Technology Inc.		Asp	en HYSYS Version 1	1		Page 12 of 16				

1	(aspentech BATTELLE E Bedford, MA					Case Name: 500MWe_HydrogenTurbine_recuperated.hsc						
3	(aspentech	Bedford, N	IA	ALLIANCE		Unit Set:	Ame	eyS2e				
4		USA				Date/Time:	Wed	1 Sep 27 09:15:46 20	23			
6 7 8	Materi	al Stre	am:	Proces	sA	ir (contin	ue	e d)	uid Package: C	CombustionTurbineProces Peng-Robinson		
9 10						CONDITIONS						
11				Overall	١	/apour Phase						
12	Heat Flow	(MW)		2143		2143				1		
13 14	Liq Vol Flow @Std Cond	(m3/h)		5.824e+006 *		5.824e+006						
15					C	OMPOSITION						
16	6 7				C	verall Phase			Vapour	Fraction 1.0000		
18	COMPONENTS	MOLAR FL	OW h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION		
20	H2O	2857	.0521	0.0	116	51470.08	04	0.0073	51.5739	0.0063		
21	Hydrogen	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
22	Nitrogen	192493	.4427	0.7	808	5.392318905e+	06	0.7615	6687.1188	0.8177		
23	Oxygen	51169	.1430	0.2	076	1.637412576e+0	06	0.2312	1439.2558	0.1760		
24	Methane	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
25	Ethane	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
20	N20		0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
28	NO2	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
29	NO	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
30	SO2 0.0000		.0000	0.0	000	0.0000		0.0000	0.0000	0.0000		
31	H2S	0.0000		0.0	000	0.000	00	0.0000	0.0000	0.0000		
32	CO	0.0000		0.0	000	0.000	00	0.0000	0.0000	0.0000		
33	H2O2 0.0000		.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
34	Ammonia	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
35	Total	246519	.6378	1.0	000	7.081201561e+0	06	1.0000	8177.9485	1.0000		
36 37				Vapour Phase					Phase F	raction 1.000		
38 39	COMPONENTS	MOLAR FL (kgmole/	OW h)	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	LIQUID VOLUME FLOW (m3/h)	FRACTION		
40	H2O	2857	.0521	0.0	116	51470.08	04	0.0073	51.5739	0.0063		
41	Hydrogen	0	.0000	0.0	000	0.00	00	0.0000	0.0000	0.0000		
42	Nitrogen	192493	.4427	0.7	808	5.392318905e+0	06	0.7615	6687.1188	0.8177		
43	Oxygen	51169	.1430	0.2	076	1.03/4125/60+0	00	0.2312	1439.2558	0.1760		
44	Ethane	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
46	CO2	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
47	N20	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
48	NO2	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
49	NO	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
50	S02	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
51	H2S	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
52	CO	0	.0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
53	H2O2	0	0000	0.0	000	0.000	00	0.0000	0.0000	0.0000		
54	Total	246510	6379	0.0	000	7.081201561c+4	00	1.0000	8177 0495	0.0000		
56	Total	240313	.0070	1.0	000	1.00120130164	00 1	1.0000	10 111.5405			
57 58	Materi				Pi	roperty Package: F	combustion LurbineProces Peng-Robinson					
59						CONDITIONS						
61				Overall	١	/apour 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.			A	sper	HYSYS Versio	n 11			Page 13 of 16		

2					Case Name: 500MWe_HydrogenTurbine_recuperated.hsc						
3	(1) aspentech	BATTELLE E Bedford, MA	NERGY ALLIANCE		Unit Set:	Am	eyS2e				
4		USA			Date/Time:	We	d Sep 27 09:15:46 20	23			
6 7 8	Mater	ial Strea	m: Stack (co	ntinued)		FI	uid Package: (CombustionTurbi Peng-Robinson	ineProce	
9 10					CONDITIONS						
11			Overall	1	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	-					
17	Host Flow	(MM/)	702.0		702.0	-					
18	Lin Vol Flow @Std Cond	(m3/b)	5 977e+006 *		5 977e+006						
19	Eld Forthon @ota conta	(insity)	0.0110.000		0.0110.000		1				
20				0	OMPOSITION						
22				C	overall Phase			Vapour	Fraction	1.0000	
23	COMPONENTS	MOLAR FLOW	MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	FLOW (m3/b)	LIQUID VO	LUME	
25	H2O	16165.16	70 0.0	639	291217.10	82	0.0410	291.8048		0.0344	
26	Hydrogen	0.34	86 0.0	000	0.70	27	0.0000	0.0101		0.0000	
27	Nitrogen	192174.09	63 0.7	591	5.383373054e+	06	0.7574	6676.0249	0	0.7874	
28	Oxygen	44194.25	20 0.1	746	1.414216065e+	06	0.1990	1243.0701		0.1466	
29	Methane	0.00	0.0	000	0.00	00	0.0000	0.0000	Q	0.0000	
30	Ethane	0.00	0.0	000	0.00	00	0.0000	0.0000	11	0.0000	
31	CO2	0.00	0.0	000	0.00	00	0.0000	0.0000	() · · · · · · · · · · · · · · · · · ·	0.0000	
32	N20	0.04	86 0.0	000	2.14	09	0.0000	0.0026		0.0000	
33	NO2	3.01	08 0.0	000	138.51	41	0.0000	0.0942	-	0.0000	
34	NO	635.58	347 0.0	025	19071.35	57	0.0027	267.3953		0.0315	
35	502	0.00	0.0	000	0.00	00	0.0000	0.0000		0.0000	
37	n25 CO	0.00	00 0.0	000	0.00	00	0.0000	0.0000		0.0000	
38	H2O2	0.00	0.0	000	0.20	53	0.0000	0.0001		0.0000	
39	Ammonia	0.00	0.0	000	0.00	00	0.0000	0.0000		0.0000	
40	Total	253172.51	41 1.0	000	7.108019145e+	06	1.0000	8478.4022		1.0000	
41					anour Phase			Phase	raction	1 000	
42					apour Filase	_		Thasen	Taction	1.000	
43 44	COMPONENTS	MOLAR FLOW (kgmole/h)	V MOLE FRACT	ION	MASS FLOW (kg/h)		MASS FRACTION	FLOW (m3/h)	LIQUID VO FRACTIO	LUME	
45	H2O	16165.16	0.0	639	291217.10	82	0.0410	291.8048		0.0344	
46	Hydrogen	0.34	86 0.0	000	0.70	27	0.0000	0.0101		0.0000	
47	Nitrogen	192174.09	0.7	591	5.383373054e+	06	0.7574	6676.0249		0.7874	
48	Oxygen	44194.25	0.1	746	1.414216065e+	06	0.1990	1243.0701		0.1466	
49	Fithane	0.00	0.0	000	0.00	00	0.0000	0.0000		0.0000	
51	CO2	0.00	0.0	000	0.00	00	0.0000	0.0000		0.0000	
52	N20	0.00	186 0.0	000	2 14	09	0.0000	0.000		0.0000	
53	NO2	3.01	0.0	000	138.51	41	0.0000	0.0942		0.0000	
54	NO	635.58	47 0.0	025	19071.35	57	0.0027	267.3953		0.0315	
55	SO2	0.00	0.0	000	0.00	00	0.0000	0.0000		0.0000	
56	H2S	0.00	0.0	000	0.00	00	0.0000	0.0000		0.0000	
57	CO	0.00	0.0	000	0.00	00	0.0000	0.0000		0.0000	
58	H2O2	0.00	060 0.0	000	0.20	53	0.0000	0.0001		0.0000	
59	Ammonia	0.00	0.0	000	0.00	00	0.0000	0.0000		0.0000	
60	Total	253172.51	41 1.0	000	7.108019145e+	06	1.0000	8478.4022		1.0000	
61 62 63 64 65	Aspen Technology Inc		1	Asper	n HYSYS Versio	n 11	1		Page 14	of 16	
1				Case Name: 500MWe_HydrogenTurbine_recuperated.hsc							
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3	(1) aspentech	BATTELLE ENERGY ALLIANCE Bedford, MA USA		Unit Set:	Unit Set: AmeyS2e						
4				Date/Time:	Date/Time: Wed Sep 27 09:15:46 2023						
6 7 8	Mater	ial Stream	: Afterbu	rnerCond	ensa	te Pro	id Package: C operty Package: P	ombustionTurbineProce eng-Robinson			
9 10				CONDITION	S						
11			Overall	Vapour Phase	L	iquid Phase	Aqueous Phase				
12	Vapour / Phase Fraction		0.0000	0.0000		0.5000	0.5000				
13	Temperature:	(C)	1400	1400		1400	1400				
14	Pressure: Melar Elaw	(bar)	2.730	2.730		2.730	2.730				
16	Mass Flow	(kg/s)	0.0000	0.0000		0.0000	0.0000				
17	Std Ideal Lin Vol Flow	(m3/b)	0.0000	0.0000		0.0000	0.0000				
18	Molar Enthalpy	(kJ/kgmole)	3.049e+004	3.049e+004		3.049e+004	3.049e+004				
19	Molar Entropy (I	kJ/kgmole-C)	202.5	202.5		202.5	202.5				
20	Heat Flow	(MW)	0.0000	0.0000	1	0.0000	0.0000				
21	Liq Vol Flow @Std Cond	(m3/h)	0.0000 *	0.0000		0.0000	0.0000				
22				COMPOSITIC	N						
23				Com Com							
24				Overall Phas	e		Vapour F	raction 0.0000			
25	CONDONENTS	MOLAD FLOW				MASS EDACTION					
27	COMPONENTS	(kamole/h)	MOLE FRACTI	(ka/h)	vv	MASS FRACTION	FLOW (m3/h)	FRACTION			
28	H2O	0.0000	0.06	39 0.	0000	0.0410	0.0000	0.0344			
29	Hydrogen	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
30	Nitrogen	0.0000	0.75	591 0.	0000	0.7574	0.0000	0.7874			
31	Oxygen	0.0000	0.17	746 0.	0000	0.1990	0.0000	0.1466			
32	Methane	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
33	Ethane	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
34	CO2	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
35	N20	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
30	NO2	0.0000	0.00	00 0.	0000	0.0000	0.0000	0.0000			
38	S02	0.0000	0.00	0.00	0000	0.0027	0.0000	0.0315			
39	H2S	0.0000	0.00	00 0.	0000	0.0000	0.0000	0.0000			
40	co	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
41	H2O2	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
42	Ammonia	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
43	Total	0.0000	1.00	000 0.	0000	1.0000	0.0000	1.0000			
44		Vanour Phase Phase Erastian 0.00									
45	COMPONENTO	NOL 4D DLOW	MOLE EDITOR			MADO EDIOTION					
46	COMPONENTS	(kgmole/h)	MOLE FRACTIO	MASS FLO	VV	MASS FRACTION	FLOW (m3/b)	FRACTION			
48	H2O	0.0000	0.06	i39 0	0000	0.0410	0 0000	0.0344			
49	Hydrogen	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
50	Nitrogen	0.0000	0.75	591 0.	0000	0.7574	0.0000	0.7874			
51	Oxygen	0.0000	0.17	746 0.	0000	0.1990	0.0000	0.1466			
52	Methane	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.000			
53	Ethane	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
54	CO2	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
55	N20	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
56	NO2	0.0000	0.00	0.	0000	0.0000	0.0000	0.0000			
50	S02	0.0000	0.00	00 0.	0000	0.0027	0.0000	0.0315			
59	H2S	0.000	0.00	000 0	0000	0.000	0.0000	0.000			
60	CO	0.0000	0.00	000 0	0000	0.0000	0.0000	0.0000			
61	H2O2	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
62	Ammonia	0.0000	0.00	000 0.	0000	0.0000	0.0000	0.0000			
63	Total	0.0000	1.00	000 0.	0000	1.0000	0.0000	1.0000			
64											
65	Aspen Technology Inc. Aspen HYSYS Version 11 Page 15 of 16										

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1	-			Case Name: 500MWe_HydrogenTurbine_recuperated.hsc								
3	(aspentech	BATTELLE ENERG Bedford, MA	Y ALLIANCE	Unit Set: AmeyS2e								
4		USA		Date/Time: Wed Sep 27 09:15:46 2023								
6 7 8	Materi	al Stream:	Afterburn	erCondens	ate (con	Fluid Package: Co Property Package: Pe	mbustionTurbineProces					
9 10	COMPOSITION											
11	Liquid Phase Phase Fraction 0.5000											
13	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	N LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION					
15	H2O	0.0000	0.0639	0.0000	0.041	0.0000	0.0344					
16	Hydrogen	0.0000	0.0000	0.0000	0.000	0.0000	0.0000					
17	Nitrogen	0.0000	0.7591	0.0000	0.757	4 0.0000	0.7874					
18	Oxygen	0.0000	0.1746	0.0000	0.199	0.0000	0.1466					
19	Methane	0.0000	0.0000	0.0000	0.000	0.0000	0.0000					
20	Ethane	0.0000	0.0000	0.0000	0.000	0 0.0000	0.0000					
21	02	0.0000	0.0000	0.0000	0.000	0.0000	0.0000					
22	N2O	0.0000	0.0000	0.0000	0.000	0.0000	0.0000					
23	NO2	0.0000	0.0000	0.0000	0.000	0.0000	0.0000					
24	NO 802	0.0000	0.0025	0.0000	0.002	0.0000	0.0315					
25	502	0.0000	0.0000	0.0000	0.000	0 0.0000	0.0000					
20	H25	0.0000	0.0000	0.0000	0.000	0.0000	0.0000					
28	H202	0.0000	0.0000	0.0000	0.000	0.0000	0.0000					
20	Ammonia	0.0000	0.0000	0.0000	0.000	0 0.0000	0.0000					
30	Total	0.0000	1,0000	0.0000	1 000	0 0000	1,0000					
31	Aqueous Phase Phase Fraction 0.5000											
33 34	COMPONENTS	MOLAR FLOW (kgmole/h)	MOLE FRACTION	MASS FLOW (kg/h)	MASS FRACTION	N LIQUID VOLUME FLOW (m3/h)	LIQUID VOLUME FRACTION					
35	H2O	0.0000	0.0639	0.0000	0.041	0.0000 0.0000	0.0344					
36	Hydrogen	0.0000	0.0000	0.0000	0.000	0.0000	0.0000					
37	Nitrogen	0.0000	0.7591	0.0000	0.757	4 0.0000	0.7874					
38	Oxygen	0.0000	0.1746	0.0000	0.199	0.0000	0.1466					
39	Methane	0.0000	0.0000	0.0000	0.000	0.0000 0	0.0000					
40	Ethane	0.0000	0.0000	0.0000	0.000	0.0000	0.0000					
41	CO2	0.0000	0.0000	0.0000	0.000	0 0.0000	0.0000					
42	N2O	0.0000	0.0000	0.0000	0.000	0.0000	0.0000					
43	NO2	0.0000	0.0000	0.0000	0.000	0 0.0000	0.0000					
44	NO	0.0000	0.0025	0.0000	0.002	7 0.0000	0.0315					
40	502	0.0000	0.0000	0.0000	0.000	0.0000	0.0000					
40	H25	0.0000	0.0000	0.0000	0.000	0.0000	0.0000					
48	H202	0.0000	0.0000	0.0000	0.000	0.0000	0.0000					
49	Ammonia	0.000	0.0000	0.000	0.000	0 0.000	0.0000					
50	Total	0.0000	1.0000	0.0000	1.000	0.0000	1.0000					
51 52 53	Energy Stream: GrossPower Property Package: Peng-Robinson											
54 55	CONDITIONS											
56	Duty Type:	Direct Q	Duty Calculation	Operation:	Turbine							
57	Duty SP:	e Duty: 0.0000 MW Maximum Available Duty:										
58 59	Energ	Fluid Package: CombustionTurbineProce										
60 61	CONDITIONS											
62 63	Duty Type:	Direct O	Duty Calculation	Operation: C	ompressor							
64	Duty SP: 266.0 MW Minimum Available Duty: 0.0000 MW Maximum Available Duty:											
65	Aspen Technology Inc	200.0 1111	Aspe	n HYSYS Version 1	I max	contraction of the state of the	Page 16 of 16					
	in the service of the		1.500	The second			1 490 10 01 10					

* Specified by user.