**Targets & Metrics**

# **Introduction to Targets and Metrics**

Targets and metrics are used to quantify objectives of the functions that came from functional decomposition. Targets are numerical values and units used to design around, while metrics are the methods that are proposed to validate functions. The targets and metrics allow for quantifying and validating the functions and give a meaningful measure of how well the design is fulfilling key goals. The key goals are to provide independent control over the inlet temperature of hydrogen, allow the user to measure the physical conditions, and prioritizing streamlined integration into the surrounding subsystems. It is also important to ensure that the temperature control is within an allowable degree of accuracy to prevent inaccurate readings while the user conducts tests.

# **Critical Targets and Metrics**

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| **Critical Functions** | **Target** | **Metric** |
| Power transmission from source to induction coil | 15 kW | Power |
| Regulate power | 5% of max | Power |
| Measure temperature | <1 kelvin resolution | Temperature |
| 0-2300 kelvin range | Temperature |
| Display feedback | 6-inch digital display | Length |
| Convert electrical energy to induction heating | 85% Efficiency | Q\_coil / (Current\*Voltage) |
| Convert analog to digital signals | 12-bit A/D conversion | Resolution |

# **Critical Functions**

The critical functions for the device were chosen from the functional decomposition. The critical functions are: Power transmission from the source to the induction coil, heat transmission from the induction coil to the test article, regulate power, measure temperature, display feedback, convert electrical energy to induction heating, convert control signal to power, and convert analog to digital signals.

# **Summary and Derivation of Targets and Metrics**

For power transmission from source to coil, it was decided that the coil design should have a baseline power rating of 15 kW because the power rating of the existing coils in the test chamber are rated the same. The 84% efficiency of heat transmission from induction coil to test article was chosen after doing research on current induction stovetop efficiencies. Based on other findings, this number seems like a reasonable target. The regulation of power needs to allow for fine adjustment in order to reach the target temperatures, but not too fine where the cost of hardware is excessive. Steps of 5% of max power were determined to be fine enough adjustments. A target temperature resolution is important because it controls the accuracy of the test data and affects the feedback. A temperature resolution of <1 kelvin was chosen for this reason. With a resolution that is too low, the customer would not be able to accurately tell the temperature, and therefore be unable to conduct tests on specific temperatures. The customer requested a temperature range of 0-2500 kelvin. The size was decided after comparing multiple devices and determining legibility from 5 feet. All required information could be seen easily on a display that has at least a 6 inch diagonal size. Finally, a 12-bit analog to digital converter was chosen. This gives the balance of having high enough resolution to reach the <1 kelvin temperature resolution, without sacrificing the speed of acquisition that a high-bit A/D converter would require.

# **Metrics and Method Validation**

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| **Critical Functions** | **Target** | **Tool** |
| Power transmission from source to induction coil | 15 kW | Equations, wattmeter |
| Regulate power | 5% of max power | Potentiometer, voltmeter |
| Measure temperature | <1 kelvin Resolution | Data acquisition unit |
| 0-2500 kelvin range | Temperature sensor |
| Display feedback | 6-inch digital display | Length measurement device |
| Convert electrical energy to induction heating | 85% Efficiency | Equations, analysis software |
| Convert analog to digital signals | 12-bit A/D conversion | Signal analysis comparison |

The most critical areas of validation will be related to the heating, both power and temperature. There are two areas where efficiency is a metric. When the current supplied through the coils gets transferred to heat via induction heating, there will be eddy current losses as well as resistive losses. These losses are calculated theoretically and validated through analysis software. The heat provided to the moving fluid from the surface of the heat exchanger will result in a reduced effectiveness because the flow has a velocity. This can also be calculated theoretically through established equations and then validated through analysis. The temperature is the most important metric as it is the goal of the project. The outlet temperature of the heat exchanger will be measured with radiation measuring devices to validate the system’s ability to heat the fluid to a desired temperature. The temperature is controlled in a reasonable amount of time, which is less than a 5 second settling time. This can be validated through simulation tools of dynamic systems, and validated by plotting the output vs time with experimental data. The function related to power is the induction coil providing 15 kW of power. This actual power output can be determined theoretically using relevant equations and verified experimentally with a wattmeter. To ensure the power to the coil is properly regulated, a potentiometer will be used and a voltmeter to validate the regulation in desired increments. The method of validation for determining the temperature resolution will be a data acquisition system to check the accuracy of each temperature reading. For validating the temperature, a sensor will be used to measure the coils output.

# **Derivation and Validation of Non-Critical Functions**

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| **Function** | **Metric** | **Tool** |
| Weight of heater | Put coils on a weight scale and validate target weight | Weight Scale |
| Maximum length of coil | Measure the total length of the pre heater | Tape measure |
| Maximum current needed | Measure the total amount of current flowing through the coils before running the experiment | Ammeter |
| Heat transmission from induction coil to test article | 84% Efficiency | Equations, analysis software |
| Convert control signal to power | <5 second settling time | Signal vs time plot |

All non-critical functions are labeled in the table above. The first of these targets is weight of the pre-heating device. This is not a critical target because there is not an exact weight limit or target from the sponsor. However, the coils will be mounted on a rail system that can only support a certain weight. So, this will need to be taken into account when designing the device. It will be experimentally validated during the testing phase of the design process. The target for this function should be relatively low so the parameters will allow it to maintain a good strength to weight ratio without removing more material than necessary from the coils. Similar to heat transfer from the induction coil to the test article, a target of 85% was chosen for the efficiency of the conversion of electrical energy to induction heating. Most forms of heat exchangers have anywhere from 80-90% efficiency, and since it is not a priority to have high efficiency, this is a conservative value. A less than five second settling time of the voltage after adjusting the temperature was chosen so that the supplied power reaches ±5% of the desired value within five seconds. This is to allow for quick adjustment of temperature so that the user does not wait unnecessary amounts of time for an adjustment to take effect. The maximum coil length is the measurement of the length of the coils in the x-direction. The reason for this constraint is there is limited space inside the testing chamber and the coil length will still play a role in one of the parameters that govern the heat transfer. The design must fit inside these desired parameters given by the sponsor. Another non-critical function of the heater is the amount of current running through the induction coils. This will also be measured using an ammeter. The amount of current flowing will affect the amount of heat generated by the coils and thus will affect the amount of heat output the system can generate to the hydrogen.

**Summary**

The above listed critical functions have their associated targets and metrics which quantify the function in some way and allow for a benchmark to be placed on previously qualitative data. This is important, as it creates a way to measure the performance of the design and provides a means of validating the project during the design process. The targets and metrics were determined through discussion in the team and some were mentioned in meetings by the sponsor. They were chosen to allow for an appropriate laboratory setting where standards like resolution, response time, and efficiency are high enough to conduct tests and get meaningful data, but not to the point of military or aerospace standards.

**Appendix A**

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| **Functions** | **Target** | **Metric** |
| Power transmission from source to induction coil | 15 kW | Power |
| Heat transmission from induction coil to test article | 80% Efficient | Q(Heat)\_test article / Q\_coil |
| Regulate power | 5% of max | Power |
| Measure temperature | <1 kelvin resolution | Temperature |
| 0-2300 kelvin range | Temperature |
| Display feedback | 6-inch digital display | Length |
| Convert electrical energy to induction heating | 84% Efficiency | Q\_coil / Current\*Voltage |
| Convert control signal to power | <5 second settling time | Time |
| Convert analog to digital signals | 12-bit A/D conversion | Resolution |
| Weight of heater | <470 lbs. | Weight |
| Maximum length of coil | <=12 in. | Length |
| Maximum current needed | 20A-100A | Current |

**References**

Electric Power Research Institute (EPRI), Sweeney, M., Dols, J., Fortenbery, B., & Sharp, F. (2014). *Induction Cooking Technology Design and Assessment*. ACEEE Summer Study on Energy Efficiency in Buildings. <https://www.aceee.org/files/proceedings/2014/data/papers/9-702.pdf>