Optimization of a Thermoelectric Conversion System

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Intoduction: In order to optimize a thermoelectric power converter it is necessary to perform a coupled-design study of the heat source, the thermoelectric material, and the heat sink. Any practical heat source is typically limited in the heat it can provide as well as dependent upon the thermal resistance of the body to which it sinks. Similarly, it is crucial to accurately understand the thermal operating conditions in-situ in order to optimize the power electronics that tune the converted heat signal into useable and practical electricity.

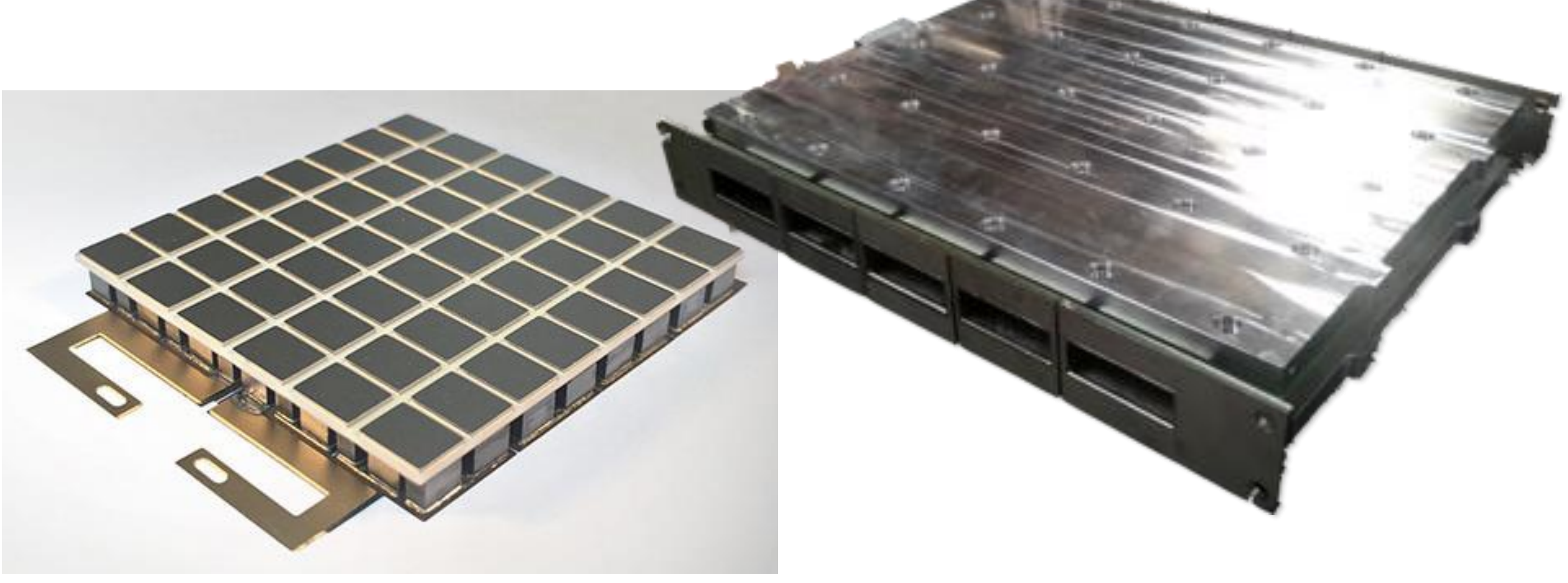

Figure 1. Alphabet Energy Inc. PowerCard^{TM} & PowerModule^{TM}

Computational Methods: The model described covers heat transfer, electric currents, and laminar flow physics. The thermoelectric effect describes the voltage response as a direct function of the temperature gradient between n-p junctions in the TE device. The total temperature gradient across the TE device is dependent on the heat flux, which in turn is budgeted by the mass flow and temperature of hot gas in the hot heat exchanger (HHXR), and the heat capacity of the coolant flow.

Physics 1: Heat Transfer in Solids & Fluids (ht)

$$\rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = \mathrm{Q} \quad \mathbf{q} = -\mathrm{k} \nabla T$$

Physics 2: Electric Curretns (ec)

$$\nabla \cdot \boldsymbol{J} = Qj \quad \boldsymbol{J} = \sigma \mathbf{E} + \boldsymbol{Je} \quad \mathbf{E} = -\nabla V$$

Physics 3: Laminar Flow (nitf)

$$\rho(\mathbf{u} \cdot \nabla)\mathbf{u} = \nabla \cdot [-\mathrm{p}\mathbf{l} + \mu(\nabla \mathbf{u} + (\nabla \mathbf{u})^{\mathrm{T}}]$$
$$\rho \nabla \cdot (\mathbf{u}) = 0$$

Multiphysics 1: Thermoelectric Effect (tee)

$$\mathbf{q} = P\mathbf{J} \quad P = ST \quad \mathbf{Je} = -\sigma S \nabla T$$

A parametric sweep of the current density, along with the illustrated (and additional) boundary conditions results in thermal and electrical characterization of the PowerCard in-situ.

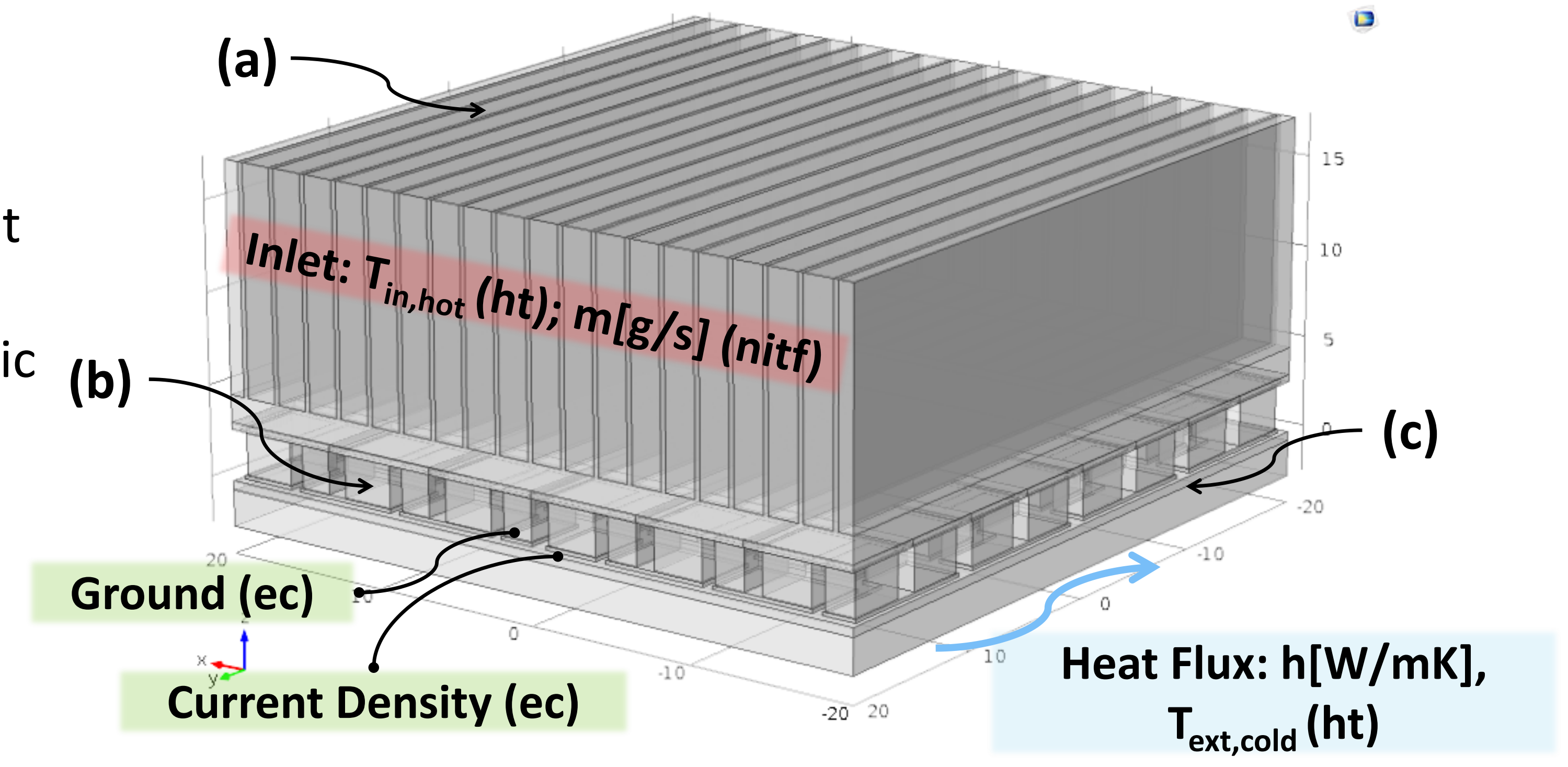

Figure 2.
(a) HHXR with hot gas domains
(b) Thermoelectric device (PowerCard^{TM})
(c) Cold plate for CHXR

Results: Post-processing of the results reveals the electrical resistance of the PowerCard^{TM}, verifies the effectiveness of the heat exchanger per the pressure drop budget allowable for a given engine, and thereby permits mapping of TE conversion performance across varied heat exchanger designs and TE packages.

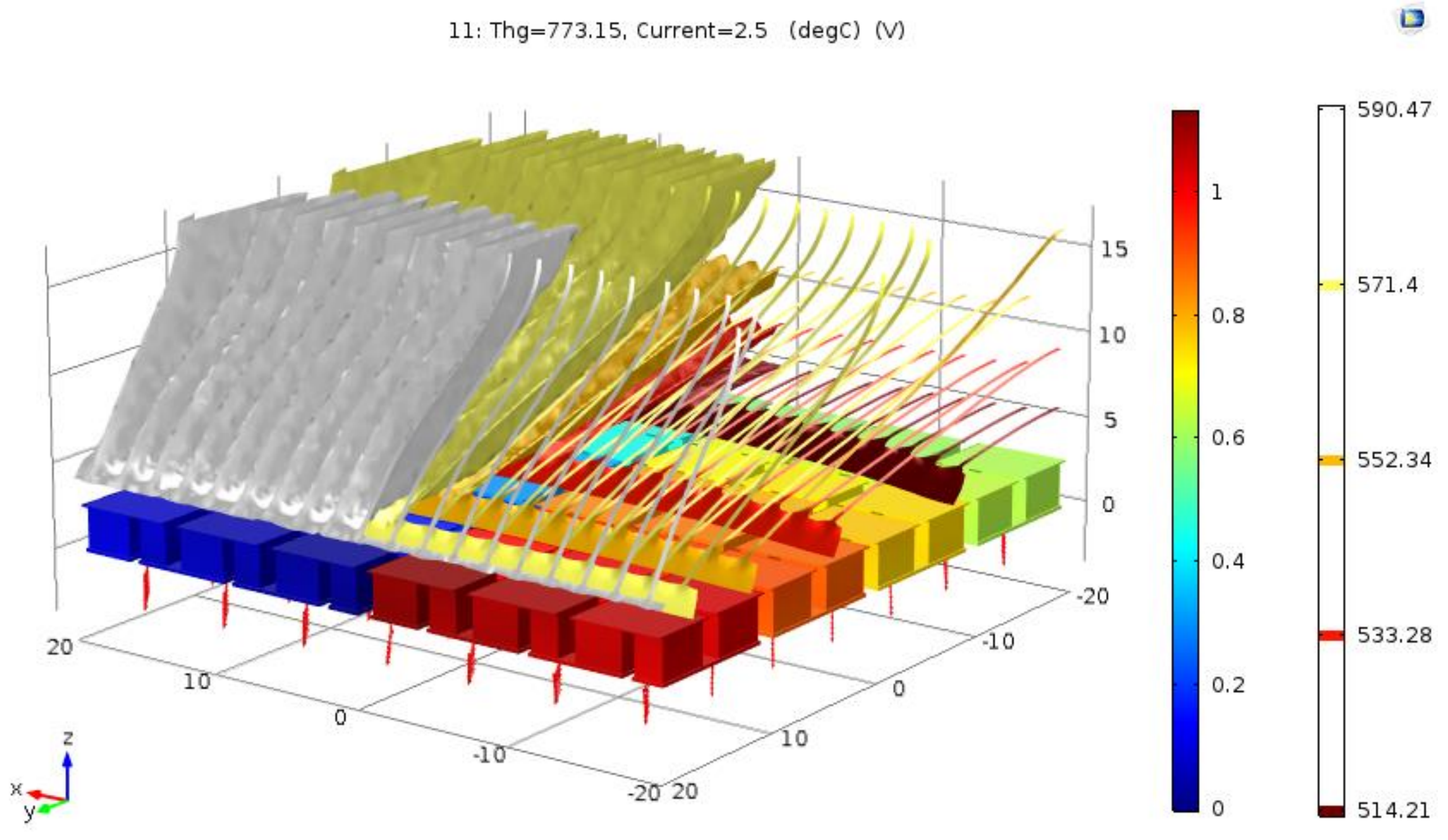

Figure 3. Isotherms of HHXR, Voltage of PowerCard, Heat Flux vector in CHXR

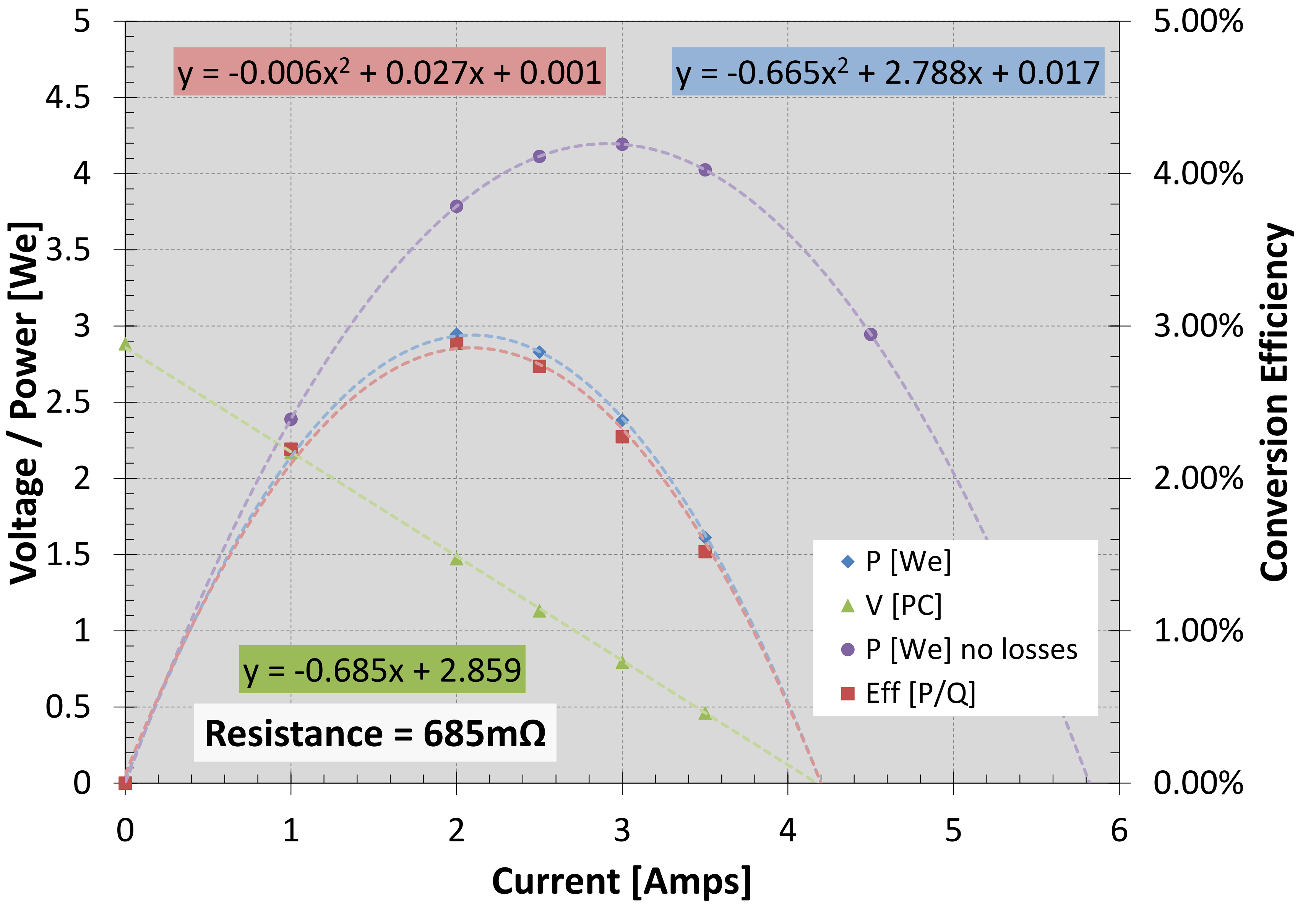

Figure 4. Power Curve for PowerCard at 500C exhaust temperature.

Conclusions: Sweeping multiple mass flow rates and temperatures for the hot fluid, as well as varying coolant conditions, allows for application-based studies of thermoelectric system efficiency relative to the mass flow and temperature of a hot gas stream. This study allows for design decision to be made in terms of viable applications and facilitates optimization of power electronics that render the system practical.

References:

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3. EE. Antonova, D.C. Looman D, Finite Elements for Thermoelectric Device Analysis in ANSYS, Proceedings of the 24th International Conference on Thermoelectrics (2004)s