Supplementary Information

Materials and methods

Particle size reaction control, saline concentration reaction control

Reaction power output was quantified by monitoring temperature change in a vacuum thermos as a calorimeter. 1.00 grams of mechanically alloyed Mg with Fe fuel (Mg-Fe fuel A-131-325, Luxfer Magtech Inc., Cincinnati, OH, USA) were placed into the reaction vessel and reacted with 5 mL of 0.9% by mass saline solution delivered in a single bolus to the fuel bed. Temperature was measured at 1-second intervals using type T thermocouples and National Instruments (NI) SignalExpress software and data acquisition hardware (NI cDAQ-9172 chassis and NI 9211 thermocouple input module, National Instruments Corporation, Austin, TX, USA). The bulk fuel was separated into particle size ranges of 50-55 µm each using a vibrating sieve shaker (Retsch GmbH model AS200, Haan, Germany). A similar calorimetry setup was used to measure the effect of saline concentration on the reaction rate. In this case, the Mg-Fe fuel total mass and particle size was constant using 1.00 grams of 300-355 µm Mg-Fe particles reacted with 5 mL of saline solution with varying percentages (0.6% to 1.4%) of NaCl to water by mass.

Chemical power source fuel pack construction

The fuel packs discussed throughout this paper were constructed with the wick either extending into the full circular section of the fuel pack, or lacking the circular extension and having the rectangular shape of the extended wick element protrude into the fuel approximately 10 mm (see Figure 4A). Wicks were cut from Standard 17 glass fiber (GF/Std17, GE Life Sciences, Piscataway, NJ, USA) using a laser cutter (M360, Universal Laser Systems, Scottsdale, AZ, USA) unless otherwise noted as a different porous medium. The circular tea bag enclosure was punched from 4 inch by 5 inch empty, heat-sealable tea bags (Empty Fillable Teabags, Muslin Bags, CA, USA) using a 25.4 mm diameter punch. The wick was then placed between two punched circles. With the wick enclosed, the two circles were heat sealed around the edge save for a 10 mm opening left open to load the Mg-Fe fuel using a lab-built impulse sealer making a 19 mm wide inner diameter circle for the fuel. The Mg-Fe fuel was measured by mass to ±0.001 g and loaded through the opening in the tea bag fuel pack. The opening in the fuel pack was then heat sealed using an additional custom element wired to the same impulse sealer.

Chemical power source wick geometry

In order to visualize the effects of wick geometry and liquid reactant delivery, fuel packs with Standard 17 wicks shaped as shown in Figure 4A were constructed as described in the paragraph above. The rectangular part of the wick was 6 mm wide and 45 mm long as measured from the flat end of the wick to the intersection with the circular head (making the functional wicking length approximately 40 mm from the top of the saline well to the start of the fuel bed). The head diameter used was 19 mm. Reacting fuel packs were imaged using a thermal camera (SC655, FLIR Systems, Inc., Wilsonville, OR, USA) and a video created using the camera software (FLIR ExaminIR Max 1.30.0). Single frames at approximately the same time into the reactions were used for Figure $B, C, and D to illustrate the difference in reaction rate and geometry.

Chemical power source test fixture

To determine the power output over time of the chemical power source, it is first necessary to quantify the thermal characteristics of the test fixture. The plotted line in Figure S1B represents the temperature recorded beneath the 3.5 cm diameter by 0.5 cm thickness cylinder machined from 6061 aluminum for a 0.8 W electrical heater power input. The electrical heater is composed of three parallel 10 ohm surface mount resistors (756-PWC2512-10RJI, Mouser Electronics, Mansfield, Tx, USA), the composite heater having a resistance of 3.45 ohms. The power was set by voltage-limiting the electrical DC power supply (6612C, Hewlett Packard, Palo Alto, CA, USA) to 1.66 volts. The electrical heater sits in the location of the fuel pack in Figure S1 panel A, affixed to the top of the aluminum cylinder with heat transfer tape (6838A12, McMaster-Carr, Elmhurst, IL, USA).

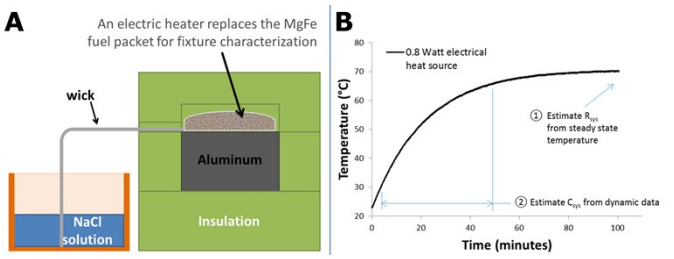

Figure S1: Chemical power source test fixture and characterization. A: Test fixture schematic. The fuel pack is supplied the NaCl solution via wicking from a reservoir and sits atop an aluminum block. The fuel pack warms the aluminum block, and temperature is recorded beneath the aluminum. The entire heater assembly is encased in an insulating shell. An electric heater replaces the fuel packet for test fixture thermal characterization. B: Temperature profile recorded beneath the aluminum block for a 0.8 W electrical power input. C_{sys} is estimated using the numeric model outlined below and the dynamic data. R_{sys} is estimated using the near-steady-state temperature data.

A section of 1.25 inch outer diameter by 0.125 inch wall thickness polymethylmethacrylate (PMMA) tubing (Part #8532K19, McMaster-Carr, Santa Fe Springs, CA, USA) was cut to 1.3 cm height to contain the fuel pack, and a 1.4 cm opening cut lengthwise to accept the wick enclosure. The wick enclosure was created with a 3D printer (Objet30 Pro, Stratasys ltd., Minneapolis, MN, USA and Rehovot, Israel) using the "high temperature" RGD525 material. The liquid reactant reservoir was also 3D printed, using the "transparent" RGD720 material. Fuel packs were constructed as described above. Insulation was machined in a 7.5 cm diameter by 7.6 cm height cylindrical shape split at 3.8 cm for assembly with cut-outs for the aluminum cylinder, PMMA tubing, and wick enclosure. Devices were constructed by first adhering a 36 AWG type T thermocouple (5SRTC-TT-T-36, OMEGA Engineering, Inc., Stamford, CT, USA) to the bottom-center of the aluminum cylinder, and then fitting the aluminum cylinder into the lower insulation in a cavity machined out of the PVC foam (Part #9318K75, McMaster-Carr, Santa Fe Springs, CA, USA) of the same dimensions. The PMMA tubing was then centered and affixed on the top of the aluminum cylinder using double-sided

DCM8 tape (DCM8, MBK Tape Solutions, Chatsworth, CA, USA) The wick enclosure was then lightly press fit into the opening in the PMMA tubing and placed over the liquid reactant reservoir. The fuel pack was then installed inside of the PMMA tubing on top of the aluminum cylinder, and the wick routed through the wick enclosure and bent downwards into the liquid reactant reservoir. Tape (Scotch Magic Tape 810, Scotch, 3M, St. Paul, MN, USA) was then used to cover the open sections of the wick enclosure to minimize evaporation. The top insulation was then installed. A 0.9% NaCl solution was added to the liquid reactant reservoir at time = 0 seconds, and thermocouple temperature data was recorded at 1 Hz using the NI DAQ.

Numeric model

To use the chemical power source test fixture to determine the power profile produced by a given fuel pack/wick combination, a simplified model of the system was devised. This system can be approximated by a thermal mass conducting heat through an insulating shell to an ambient temperature. A power input is applied to this thermal mass. The heat loss to ambient can then be written as:

$$P = \frac{T_{sys} - T_{amb}}{R_{sys}} \quad [1]$$

where R_{sys} is the system insulation value. Changing the temperature of the thermal mass requires

$$P = \frac{dT_{sys}}{dt} C_{sys} \quad [2]$$

where C_{sys} is the system thermal mass. The total power in to the system is then:

$$P = \frac{T_{sys} - T_{amb}}{R_{sys}} + \frac{dT_{sys}}{dt} C_{sys} \quad [3]$$

The Rsys term can be found by holding the power input constant and waiting for the system to reach a steady state where dT/dt = 0. Using the 0.8 W plot from Figure 4B, the temperature appears to be approaching a steady state value of ~80 °C (dT/dt = 0.) , R_{sys} is then:

$$R_{sys} = \frac{T_{sys} - T_{amb}}{P_{tot}} \quad [4]$$

The value of R_{sys} is then 75°C/W. C_{sys} can then be solved for:

$$C_{sys} = \frac{P_{tot} - \frac{T_{sys} - T_{amb}}{R_{sys}}}{\frac{dT_{sys}}{dt}} \quad [5]$$

Using the 0.8 W data with R_{sys} = 75 °C/W, gives C_{sys} = 0.3 [W-s/°C].

These R_{sys} and C_{sys} values were used in equation 3 to solve for chemical power source power output in Excel (Microsoft, Redmond, WA, USA). dT_{sys}/dt was calculated for each time point using the 50th preceding and 50th following data point time and temperature. T_{sys} was measured using the on-device thermocouple, located beneath the aluminum cylinder. T_{amb} was measured using a thermocouple suspended in the laboratory air near the test fixture.

Finite element models

Models were created of the example heater using COMSOL Multiphysics (COMSOL Inc, Los Angeles, CA, USA) using the "Heat transfer in solids" module. Meshes were created using the software default with the mesh element size set to "Fine" . Phase change was modelled using the "Phase change heat transfer" model input. External boundaries were set to convective heat transfer with a 15 or 20 [W/m^{2}K] coefficient and ambient temperature of 21 or 23 [°C]. Power input for the integrated regulated heater was entered as 0*(t<60)+0.5*(t>60)*(t<120)+1.5*(t>120)*(t<180)+2.25*(t>180)*(t<300)+3*(t>300)*(t<420)+3.375*(t>420)*(t<540)+2.75*(t>540)*(t<600)+1.675*(t>600)*(t<720)+1*(t>720)*(t<840)+0.675*(t>840)*(t<1020)+0.125*(t>1020)*(t<1320)+0*(t>1320).

Table S1: Material properties used in finite element models

PVC Foam	Density	48.1 [kg/m^3]
	Thermal conductivity	0.033 [W/m-K]
	Specific heat	1,300 [J/kg-K]
PCM	Density	840 [kg/m^3]
	Specific heat	2,360 [J/kg-K]
	Ratio of specific heats	1
	Thermal conductivity	0.32, 0.6, 0.85, 1.5 [W/m-K]
	Latent heat of fusion	221, 206.5, 192, 172 [kJ/kg]
PMMA	Density	1,190 [kg/m^3]
	Specific heat	1,470 [J/kg-K]
	Thermal conductivity	0.18 [W/m-K]
Aluminum	Density	2,700 [kg/m^3]
	Thermal conductivity	238 [W/m-K]
	Specific heat	900 [J/kg-K]
Air	Density	COMSOL lookup table, 1.1 [kg/m^3]
	Thermal conductivity	COMSOL lookup table, 0.025 [W/m-K]
	Specific heat	COMSOL lookup table, 2000 [J/kg-K]
Fuel pack	Density	990 [kg/m^3]
	Thermal conductivity	0.58 [W/m-K]
	Specific heat	4,181 [J/kg-K]

Differential scanning calorimetry

Differential Scanning Calorimetry (DSC) was used to obtain latent heat values for PCMs used in the models. The DSC tests conducted using a microcalorimeter (Micro DSC VII Evo, Setaram Inc., Newark, CA, USA) confirmed changes in latent heat of PCM composites with varying amounts of graphene nanoparticle additive. For each sample, a conditioning cycle was run first to consolidate the powder and chips from the PCM composite. The conditioning cycle was run at a rate of 1.5°C/min from 30°C to 10-15°C above the nominal PCM melt temperature PCM. After conditioning, the sample was heated at a rate of 0.5°C/min from 30°C to 10-15°C above the nominal PCM melt temperature. The sample was then held at that maximum temperature for 10 minutes and then cooled back down to 30°C at the same controlled rate of 0.5°C/min. Heat input during this ramp cycle was used to calculate latent heat

and exact melt temperature. Figure S2 shows an example plot and software-computed latent heat and peak heat flow values for PureTemp 53 PCM with 10% graphene added.

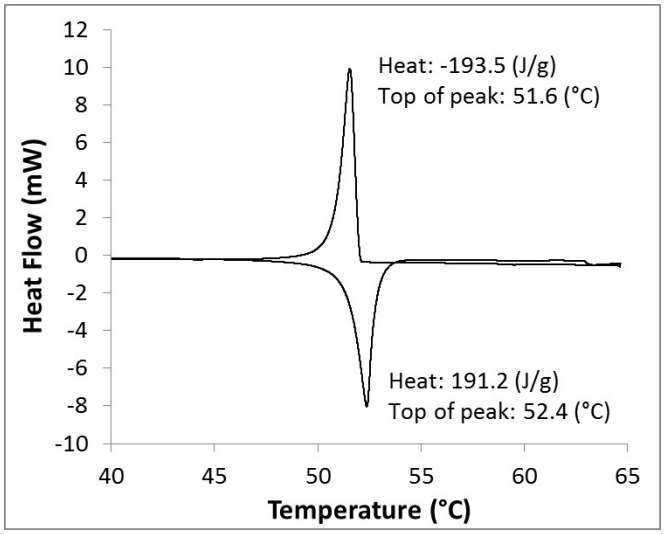

Figure S2: Example differential scanning calorimetry plot for 10% graphene in PureTemp 53 PCM. Latent heat and peak values are calculated by the software.

PCM casting

In general, for any final shape, the PCM casting process used is to heat the PCM, mix the composite components, cast, cool directionally, machine off the top, and cut to size if necessary. The PCM blocks used in test devices as well as the temperature regulator subsystem were cast using these steps. First, solid PureTemp 53 PCM (PT53, Entropy Solutions, Plymouth, MN, USA) was massed to +-0.01g. The PT53 was then melted in an oven at 80°C in a glass beaker covered with aluminum foil. After fully melted, graphene nanoplatelet powder (N008-100-P-10, Angstron Materials, Dayton, OH, USA) was similarly massed and introduced into the liquid PCM at a ratio of 20% graphene to total composite mass unless otherwise noted. Second, the composite was blended using a shear mixer (Model 1750, Arrow Engineering, Hillside, NJ, USA) for a minimum of 10 minutes at approximately 600 RPM. During mixing, the beaker was kept in a hot water bath regulated by a hot plate at 80°C. Third, a glass syringe, pre-heated in the 80°C oven, was used to transport the PCM composite to a similarly pre-heated, machined, rectangular aluminum mold of the intended dimensions with removable end caps and an open top. In our case the mold was 20mm wide, 110 mm long, and 20 mm deep with approximately 3 mm thick sidewalls and a 30 mm thick bottom, allowing us to produce four 20x20x10 mm blocks per cast. Fourth, the filled mold was tapped on a table vigorously for one minute to remove entrained bubbles and air pockets in the corners of the mold. Fifth, the mold was placed in a cold water bath and the top was manually heated with a heat gun for 10 minutes to prevent the top from freezing. Heating the top and cooling the bottom allows the PCM composite to cool directionally from the bottom and sides while the liquid top can sink to avoid cavity formation during solidification. Sixth, the top of the cast stock is faced to the intended height using a jig machined to hold the cast PCM stock tightly and a router with a stand-off bit. After facing, the stock is cut into blocks of the intended length using a band saw. The blocks were then hand sanded more precisely to a consistent mass within 0.01g in order to control total PCM composite available for temperature regulation in each device.

Thermal conductivity

Thermal conductivity of materials was measured using a commercially available instrument (TCi, C-Therm Technologies Ltd., Fredericton, New Brunswick, Canada). Measurements were taken primarily of the PCM composite blocks.

Temperature regulator test fixture

The PCM composite was cast as described above and machined into a 20 x 20 x 10 mm block. The PCM block was fitted into a 3D printed four-sided shell, with a 5 mm thick aluminum bottom affixed with RTV silicone gasket adhesive (Blue RTV Silicone Gasket Maker 80628, Permatex, Hartford, CT, USA). This assembly was then fitted into a 65 x 65 x 29 mm insulation block of two PVC foam layers with a cut-out in the center fitting the assembly. A type T thermocouple was attached to the bottom center of the aluminum plate. The bottom insulation was machined to 65 x 65 x 13 mm, and the top 65 x 65 16 x mm. A 0.5 kg weight was placed on top of the assembled device to avoid gaps between the foam layers. Before assembly, the device components were placed into an oven set to 80°C and allowed to equilibrate. The components were assembled warm (with the PCM melted), with (3) 10 x 10 x 10 mm PVC foam spacers holding the device off of the table and the weight off of the device. Temperature data was recorded from the thermocouple at a frequency of 1 Hz using the NI DAQ.

Integrated, regulated example heater

The integrated heaters are composed primarily of three layers of PVC foam with base dimensions 5.2 x 4.0 cm. Two layers of DCM8 tape seal the three layers together. The 12 mm high center layer is the temperature regulation subsystem. A cavity was punched into the middle foam layer to accommodate the PCM composite block (2.6 x 2.0 x 1.2 cm) placed directly into the foam. The RTV silicone gasket adhesive was again used in a ring on the foam around the PCM and under the top DCM8 tape layer to prevent PCM leakage during melting. A 6 mm deep, 25 mm diameter hole was machined into the lid as well as a 2 mm deep, 6 mm wide channel in the center of the long side of the lid. This channel acted as the wick inlet and the steam outlet for the system. A 1 mm deep 25 x 25 mm square was machined into the bottom foam layer to accommodate the assay hybridization chamber. A 0.5 mil Mylar layer was placed over the chambers and between the adhesive to facilitate removal of tested chambers. The fuel packs were produced as discussed in the chemical power source sections above. The single-piece GE Standard 17 material wicks in this case had a 6 mm wide rectangle wick extending 40 mm past the edge of the wick circle. 0.195±0.001 g of 355-400 µm particle size Mg-Fe fuel powder was placed in the tea bag fuel encapsulation over the wick circle. Before placing the fuel pack onto the device a small rectangle of 2 mil Mylar was placed underneath to keep the adhesive layer from interfering with the wick fluidics.

This three layer foam stack was then set in a simple printed holder made of Objet "transparent" RGD720 material with a connected saline well. After introducing 5 mL of 2.0% by weight saline solution to the well and wick end, a printed lid was placed over the exposed wick without contacting it. The lid was necessary for running the devices in the environmental

chamber (BTL-433, Espec, Hudsonville, MI, USA) to test the performance of an assay in the device at varied ambient conditions. The fans produce enough artificial convection in the chamber to drastically alter the flow properties of uncovered wicking materials due to evaporation (data not shown).

iSDA isothermal NAA assay

Four replicates of the isothermal NAAT (iSDA) reaction[27,28] were prepared at a time for running inside four example heaters running simultaneously inside an environment chamber. Four replicates were run at ambient temperatures of 15, 22.5, and 30°C, for a total of 12 amplification results. Two replicates for positive and negative amplification controls were prepared at a later time for running inside a circulating-water-heated heat block set to 49°C. The iSDA reactions targeting the *ldh1* gene were assembled in four stages. 1) Molecular grade H_2O; K_2HPO_4 and KH_2PO_4 to 42.5 mM and 7.5 mM, respectively; dNTPs to 200 µM each; lateral flow probes; and primers (forward: 1000 nM, reverse: 150 nM, bumper: 50 nM) were added in that order and then the mix was vortexed. 2) 10^4 copies of methicillin-sensitive *Staphylococcus aureus* (MSSA) genomic DNA per reaction (ELITechGroup, Bothell, WA, USA) were added to the mix, and then the mix was vortexed again. 3) 10 U of *Bst* 2.0 WarmStart DNA Polymerase (NEB, Ipswitch, MA, USA) and 0.64 µL per reaction of a modified Nt.BbvC1 (ELITechGroup) were added to the mix in that order and then the mix was vortexed again. 4) $MgSO_4$ to 3.75 mM was added to the mix and then the mix was vortexed again. All iSDA reactions were distributed in 40-µL volumes immediately after preparation to 14-cm diameter punches of Standard 17 glass fiber(GE Life Sciences). The reaction-loaded Standard 17 punches were then placed inside hybridization chambers (Cat. #70333-32, Electron Microscopy Sciences, Hatfield, PA, USA), which were then loaded into the appropriate example heater. Reactions were run in the heater(s) for 30 minutes, then the Standard 17 punches were extracted and spun at 13000 x g for 60 seconds in a collection tube. Lateral flow strips (ELITechGroup) were used to determine whether the amplification occurred, with 9.0 µL of each centrifuged sample mixed with 2.5 µL of 5x lateral flow buffer (3 M NaCl, 4% v/v PVP, and 4% v/v Triton X-100) and 1.0 µL of OD 10, 40-nm diameter, streptavidin-coated, gold nanoparticles (Innova Biosciences, Babraham, Cambridge, UK); added to a well in a deep-well plate; and wicked into a lateral flow strip attached to a cellulose waste pad.

Thermal performance analysis of a traditional tube heater

The temperature profile of a benchtop thermal cycler was characterized as a benchmark for thermal performance. A 0.031" hole was drilled into the cap of a 0.2 mL PCR tube (14230225, Thermo Fisher Scientific, Waltham, MA, USA). A 40 µL volume of water was added to each tube, and a type K thermocouple (5SC-TT-K-36-36, OMEGA Engineering, Stamford, CT, USA) was inserted through this hole so the thermocouple tip reached the bottom of the tube, and the thermocouple wire was taped into a groove cut into the tube cap. Instrumented tubes were loaded into the thermal cycler (MJ Mini, Bio-Rad, Hercules, CA, USA), and the thermal cycler set to hold at 51°C. Temperatures were recorded at 1-second intervals using a data acquisition system (OMB-DAQ-54, OMEGA Engineering).

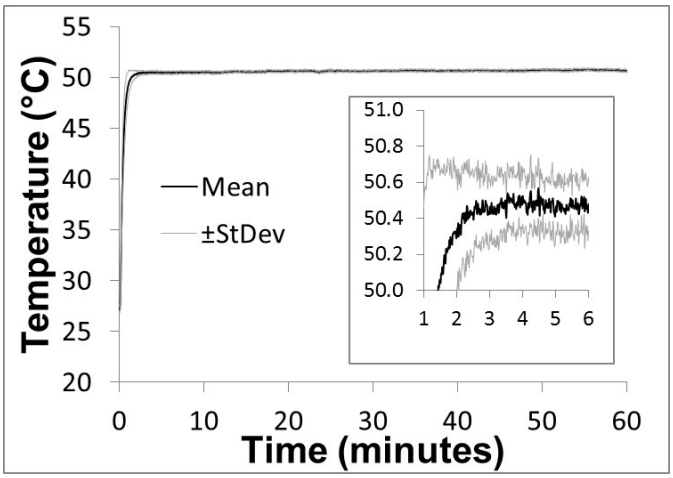

Figure S3: Sample temperature measured over time measured inside of a tube in a benchtop thermal cycler set to 51°C. The thermal cycler samples warm up to the lower assay limit (47°C) in less than one minute, and hold a stable temperature after ~2 minutes. The inset shows the standard deviation for the measured temperatures is quite small. The black line is the data mean, the grey lines are the mean ± one standard deviation, n=3.