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Supplementary Information

CoHCF System with Enhanced Energy Conversion Efficiency for Low-grade Heat Harvesting

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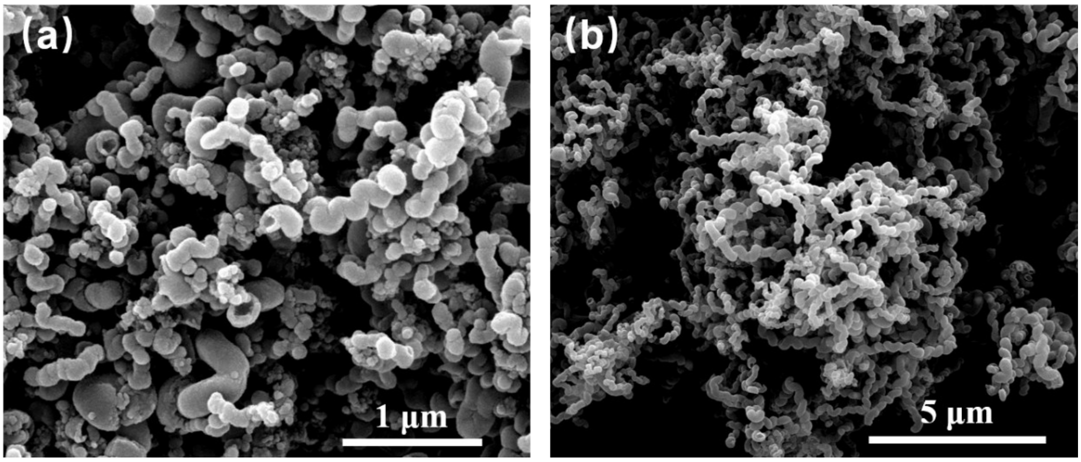

Figure S1 SEM images of HCNTs

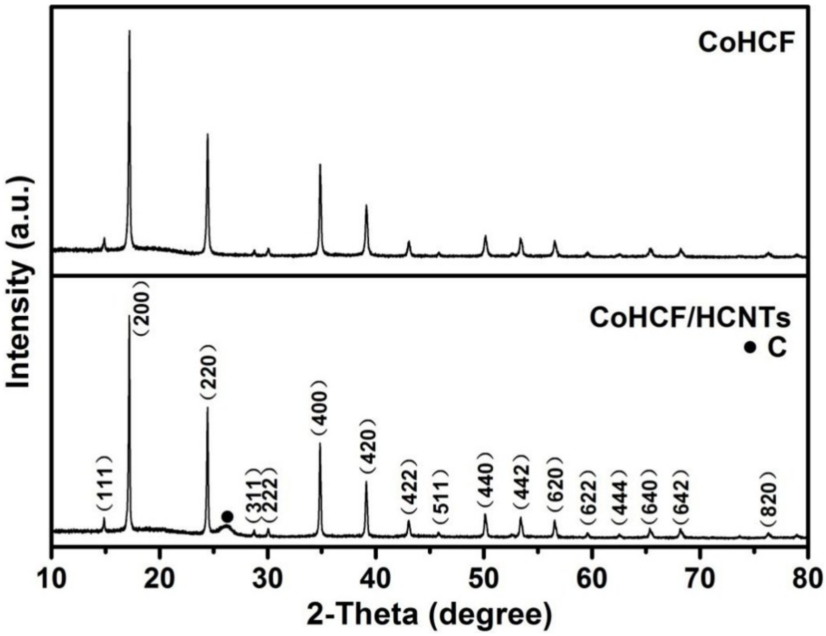

Figure S2. XRD patterns of as-prepared CoHCF and CoHCF/HCNTs composite.

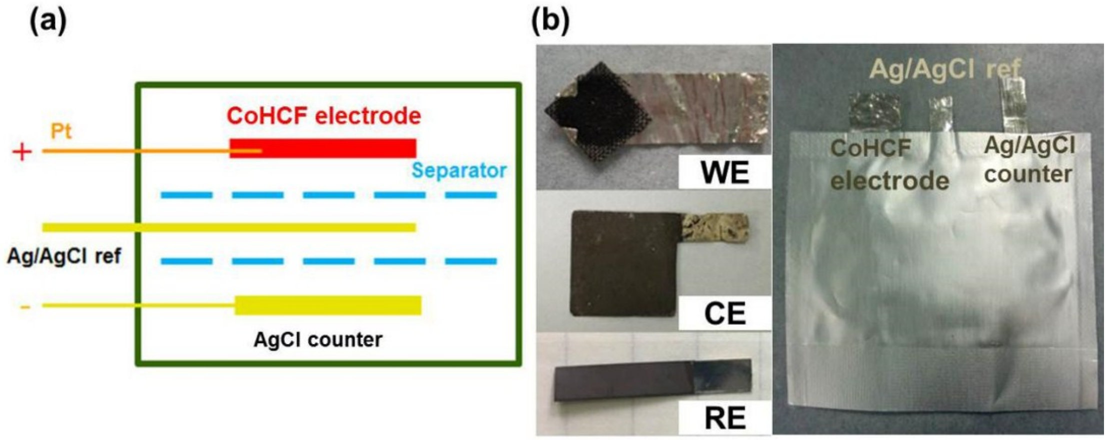

Figure S3. The pouch cell configuration used in electrochemical measurements. (a) Schematic of the pouch cell, (b) Optical images of TREC electrodes and fabricated cell.

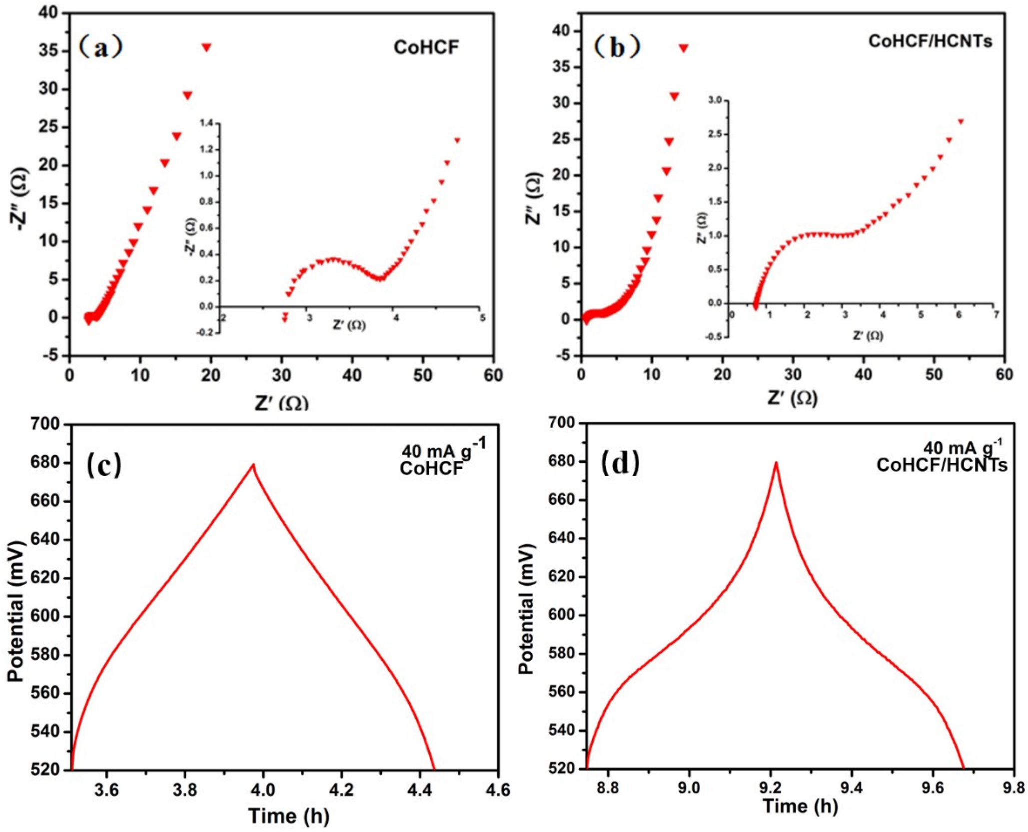

Figure S4. Nyquist spectra of (a) CoHCF electrode and (b) CoHCF/HCNTs electrode (inset shows the magnified), GCD curves of the (c) pure CoHCF and (d) CoHCF/HCNTs electrode.

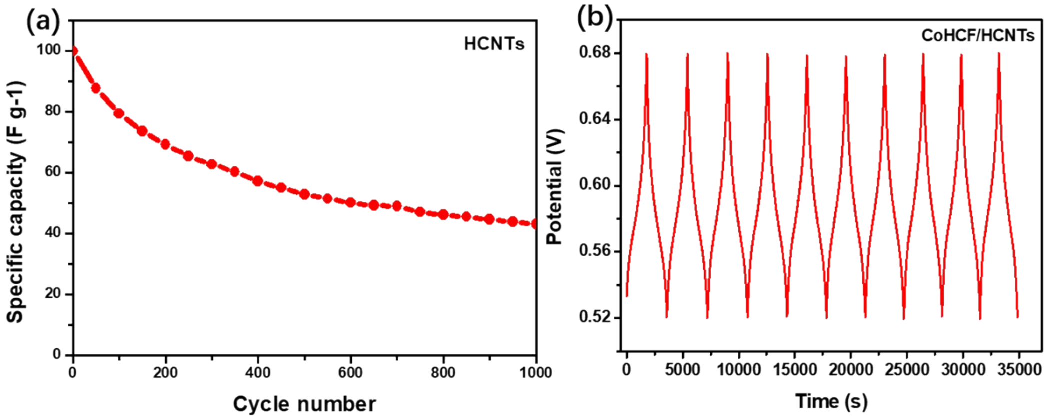

Figure S5 Cycling stability of (a) HCNTs and (b) CoHCF/HCNTs

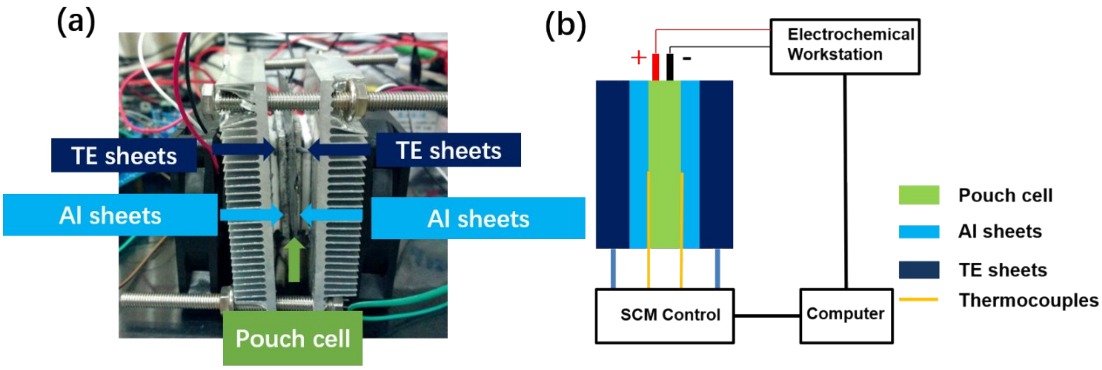

Figure S6 The home-made thermal cycler for temperature measurement and thermal cycling. (a) A camera image of the setup, (b) The structure of the system.

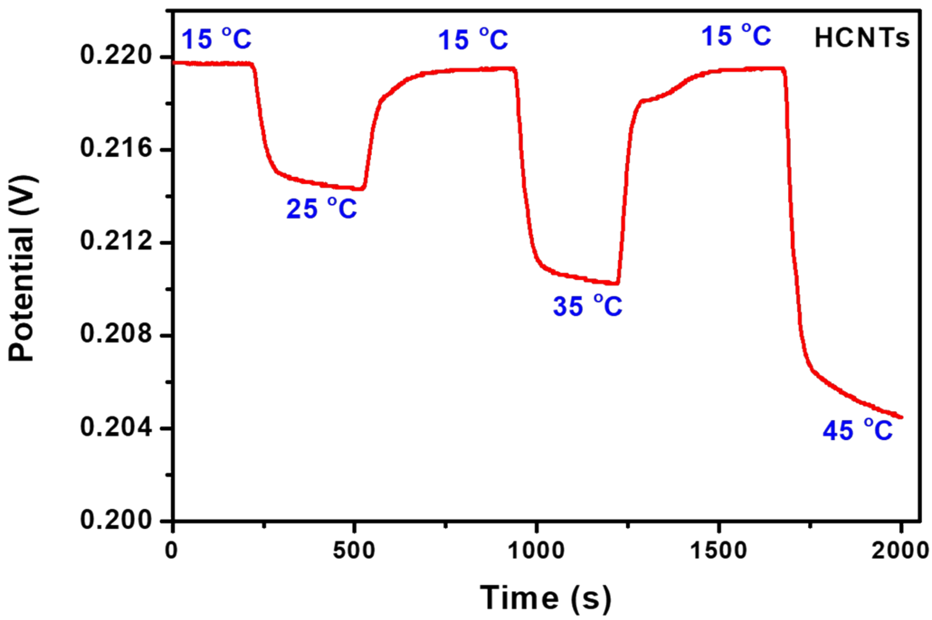

Figure S7. The real time measurement of temperature coefficient of HCNTs

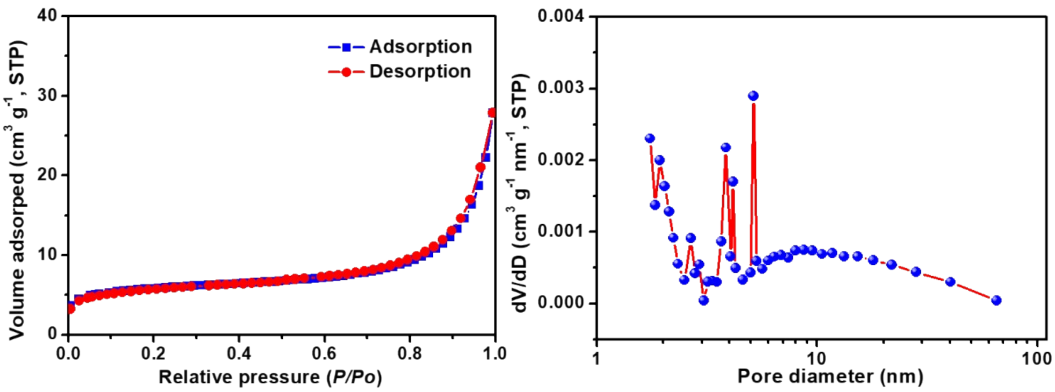

Figure S8 N_2 adsorption/desorption isotherms of HCNTs and the corresponding pore size distributions.

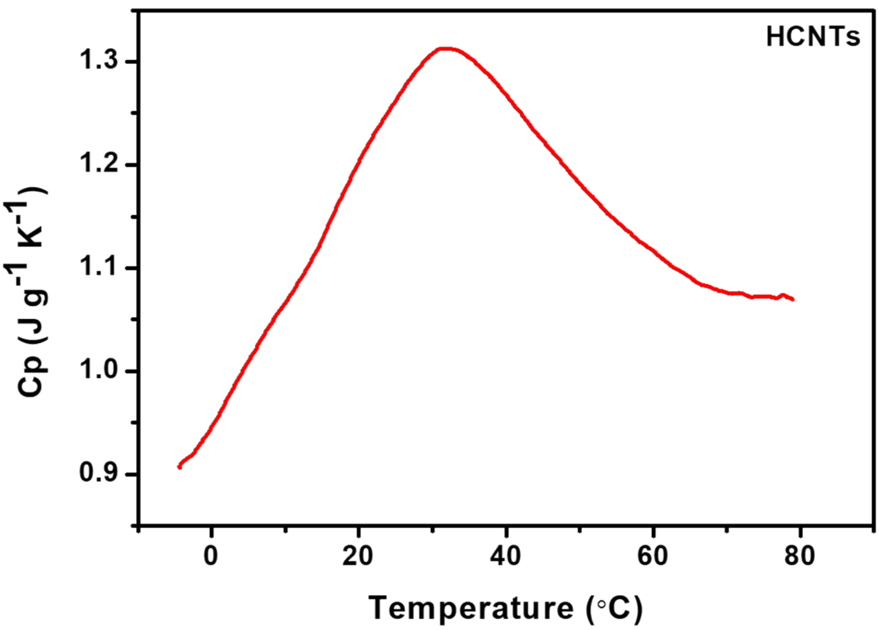

Figure S9. The specific heat of pure HCNTs

Supplementary Note: Calculation on the experiment efficiency of TRECs:

In this note, we are going to explain how experiment efficiency is calculated.

According to the formula:

$$W = \mathrm{Q_{dis}V_{dis}} - \mathrm{Q_{ch}V_{ch}} = \mathrm{Q_{dis}}(\mathrm{V_{dis}} - \frac{\mathrm{V_{ch}}}{CE}) \quad (1)$$

$$\mu = \frac{W}{Q_H + Q_{HR}} = \frac{\Delta S \Delta T - E_{loss}}{|\alpha| T_H Q_C + (1-\mu_{HR})\Delta T C_P} \quad (2)$$

Pure CoHCF: CE stands for coulombic efficiency. W stands for the energy difference between discharge and charge energy in one cycle. C_P is the heat capacity of the cell. The coulombic efficiency of pure CoHCF is about 98.57%. The specific heat of CoHCF is 2.33 J $g^{-1}K^{-1}$. (CE = 98.57% C_p= 2.33 J $g^{-1}K^{-1}$) The absolute temperature coefficient of the CoHCF based on experiment is 0.69 mV K^{-1}. When charged at 45˚C and discharged at 15˚C, the charged capacity*(Q_{ch})* of cell is 17.12 mAh g^{-1} and the discharged capacity(Q_{dis}) of cell is 16.87 mAh g^{-1}. So, we can calculate the coulombic efficiency of the cell. The average discharge voltage of the cell is 629.90 mV and the average charge voltage of the cell is 622.00 mV. Based on a hypothetical higher coulombic efficiency of 99.72% (CE of 99.72% is chosen which is reasonable after futher ptimization, as demonstrated in literature[1]), the heat-to-electricity conversion efficiency is discussed detailed. According to formula (1):

$$W = 16.87\ mAh\ g^{-1} \times (629.90\ mV - \frac{622.00\ mV}{99.72\%}) = 0.1038\ mWh\ g^{-1}$$

$$Q_H = |\alpha| T_H Q_C = 0.69\ mV\ K^{-1} \times 318\ K \times 17.12\ mAh\ g^{-1} = 3.76\ mWh\ g^{-1}$$

$$C_P \times \Delta T = 2.33\ J\ g^{-1}K^{-1} \times 30\ K = 69.9\ J\ K^{-1} = 19.4\ \mathrm{m}Wh\ g^{-1}$$

When recovery rate is 50%, $\eta = \dfrac{0.1038\ mWh\ g^{-1}}{3.76\ mWh\ g^{-1} + 19.4\ mWh\ g^{-1}(1-0.5)} = 0.77\%$

μ_{HR}	**0**	**50%**	**70%**
CoHCF	0.45%	0.77%	1.08%

CoHCF/HCNTs: The coulombic efficiency of CoHCF/HCNTs is about 96.53%. The specific heat of CoHCF/HCNTs is 2.17 J $g^{-1}K^{-1}$. (CE = 96.53% C_p= 2.17 J $g^{-1}K^{-1}$) The absolute temperature coefficient of the CoHCF/HCNTs based on experiment is 0.89 mV K^{-1}. When charged at 45˚C and discharged at 15˚C, the charged capacity (Q_{ch}) of the cell is 20.20 mAh g^{-1} and the discharged capacity (Q_{dis}) of the cell is 19.50 mAh g^{-1}. So, we can calculate the coulombic efficiency of the cell. The average discharge voltage of the cell is 605.30 mV and the average charge voltage of the cell is 589.20 mV. Based on a hypothetical higher coulombic efficiency of 99.72%, the heat-to-electricity conversion efficiency is discussed detailed. According to formula (1):

$$W = 19.50\ mAh\ g^{-1} \times (605.30\ mV - \frac{589.20\ mV}{99.72\%}) = 0.2818\ mWh\ g^{-1}$$

$$Q_H = |\alpha| T_H Q_C = 0.89\ mV\ K^{-1} \times 318\ K \times 20.20\ mAh\ g^{-1} = 5.71\ mWh\ g^{-1}$$

$$C_P \times \Delta T = 2.17\ J\ g^{-1}K^{-1} \times 30\ K = 65.1\ J\ K^{-1} = 18.1\ \mathrm{m}Wh\ g^{-1}$$

When recovery rate is 50%, $\eta = \dfrac{0.2818\ mWh\ g^{-1}}{5.71\ mWh\ g^{-1} + 18.1\ mWh\ g^{-1}(1-0.5)} = 1.91\%$

μ_{HR}	**0**	**50%**	**70%**
CoHCF/HCNTs	1.18%	1.91%	2.53%

Table S1 Calculation of Conversion Efficiency at different μ_{HR}

							conversion efficiency at different μ_{HR}		
species	**V_{dis}(mV)**	**V_{ch}(mV)**	**Q_{dis}(mAh g^{-1})**	**CE**	**W(mWhg^{-1})**	**C_P x ΔT**	**0**	**50%**	**70%**
CoHCF	**629.90**	**622.00**	**16.87**	**99.72%**	**0.1038**	**19.4**	**0.45%**	**0.77%**	**1.08%**
CoHCF/HCNTs	**605.30**	**589.20**	**19.50**	**99.72%**	**0.2816**	**18.1**	**1.18%**	**1.90%**	**2.52%**

Table S2. A survey of performance comparison

Description	Specific Capacity ($mAh\ g^{-1}$)	Specific Heat ($J\ g^{-1}K^{-1}$)	Temperature Coefficient ($mV\ K^{-1}$)
CoHCF	18.4 $mAh\ g^{-1}$ at 40 $mA\ g^{-1}$	2.33	-0.69
HCNTs	68 $F\ g^{-1}$ at 1 $A\ g^{-1}$	1.25	-0.43
CoHCF/HCNTs	18.5 $mAh\ g^{-1}$ at 40 $mA\ g^{-1}$	2.17	-0.89

[1] Y. Yang, J. Loomis, H. Ghasemi, S.W. Lee, Y.J. Wang, Y. Cui, G. Chen, Membrane-free battery for harvesting low-grade thermal energy, Nano letters, 14 (2014) 6578-6583.