Tea Leaf Derived Supercapacitors: Investigating Future Development Paths for a Sustainable Energy Storage Device

Masters of Science in Sustainability Management
SSM1100 Research Paper
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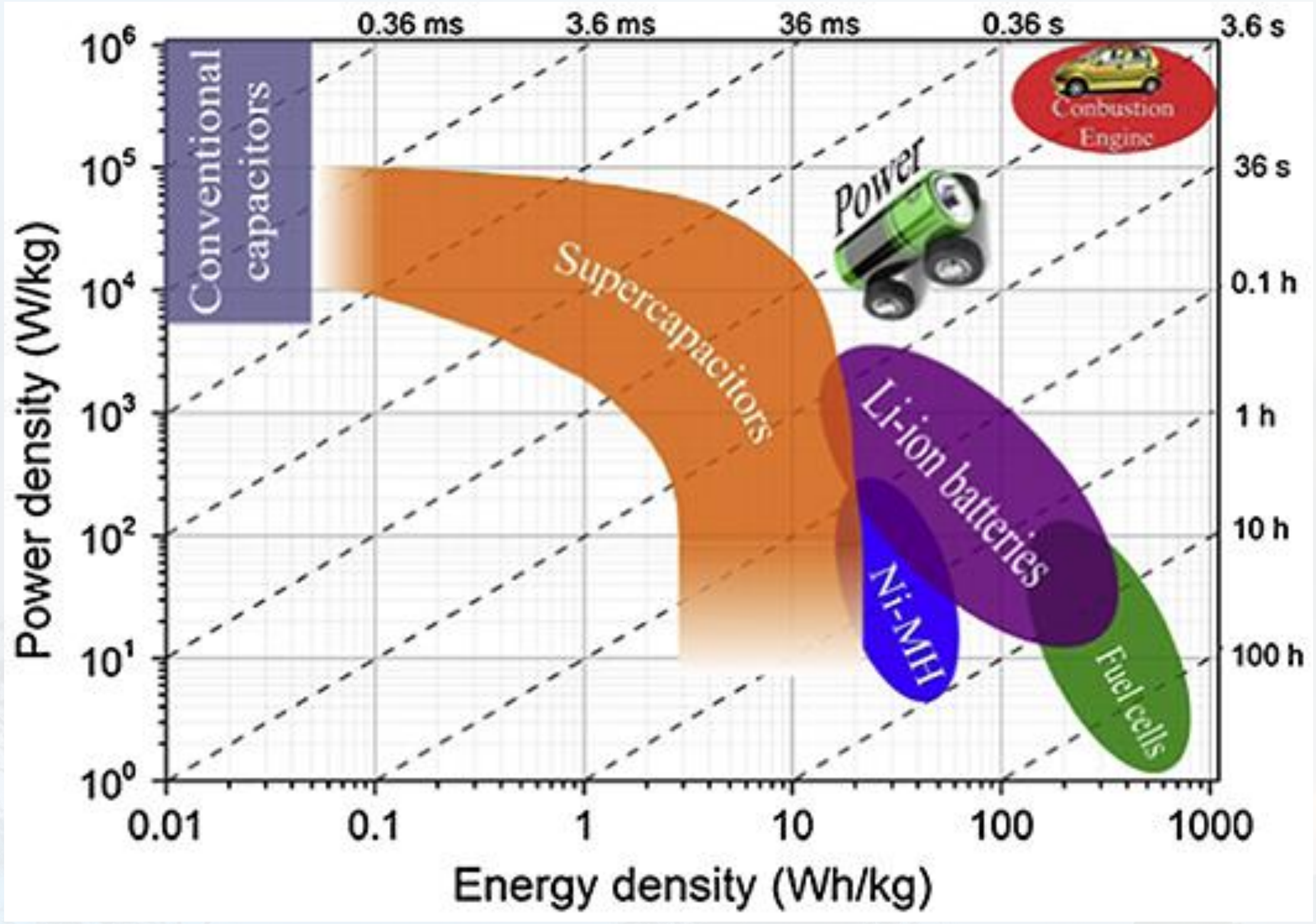
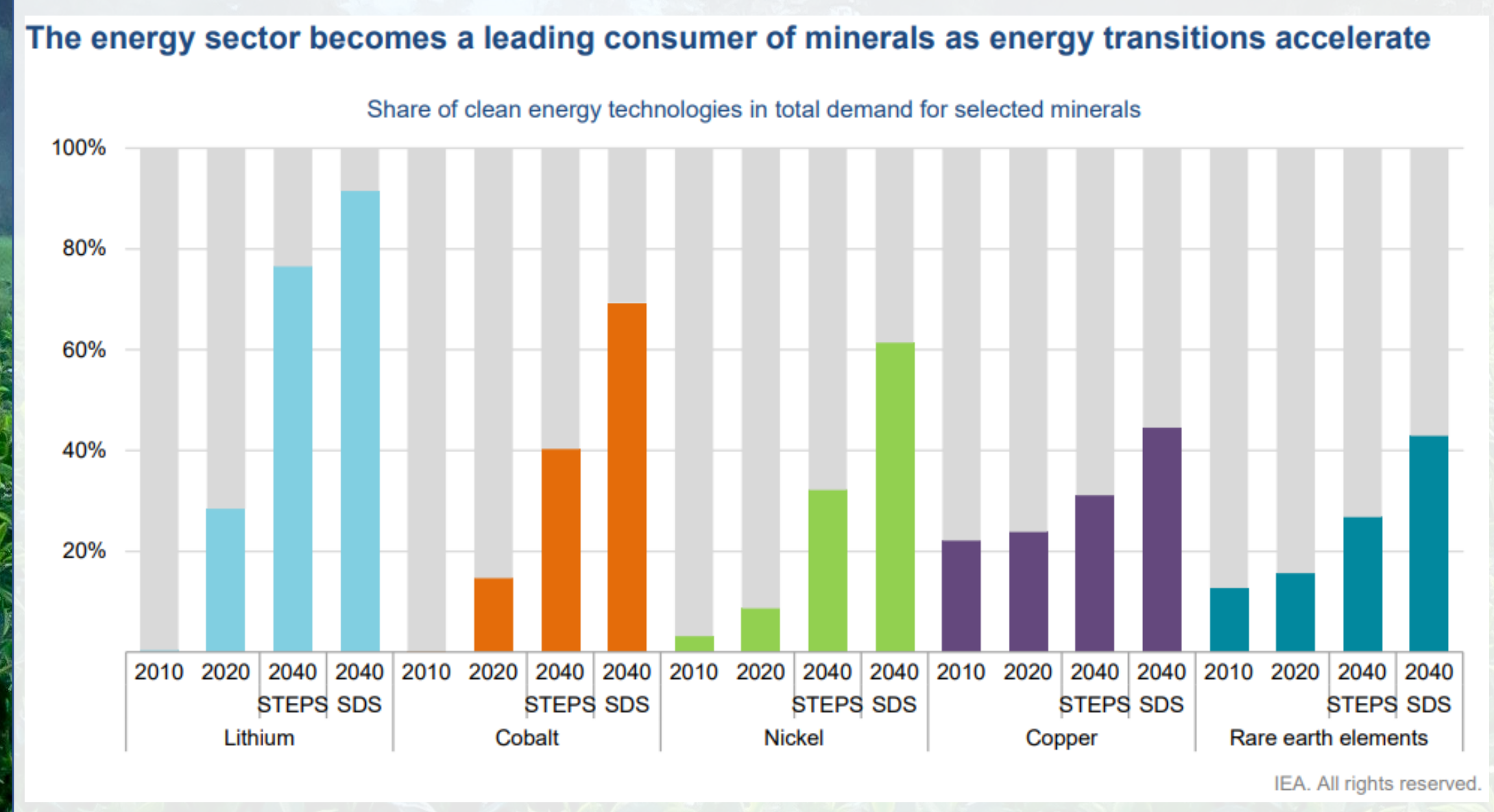
Pursuing higher energy density



Without critical metals or high emissions


The energy sector becomes a leading consumer of minerals as energy transitions accelerate

Share of clean energy technologies in total demand for selected minerals

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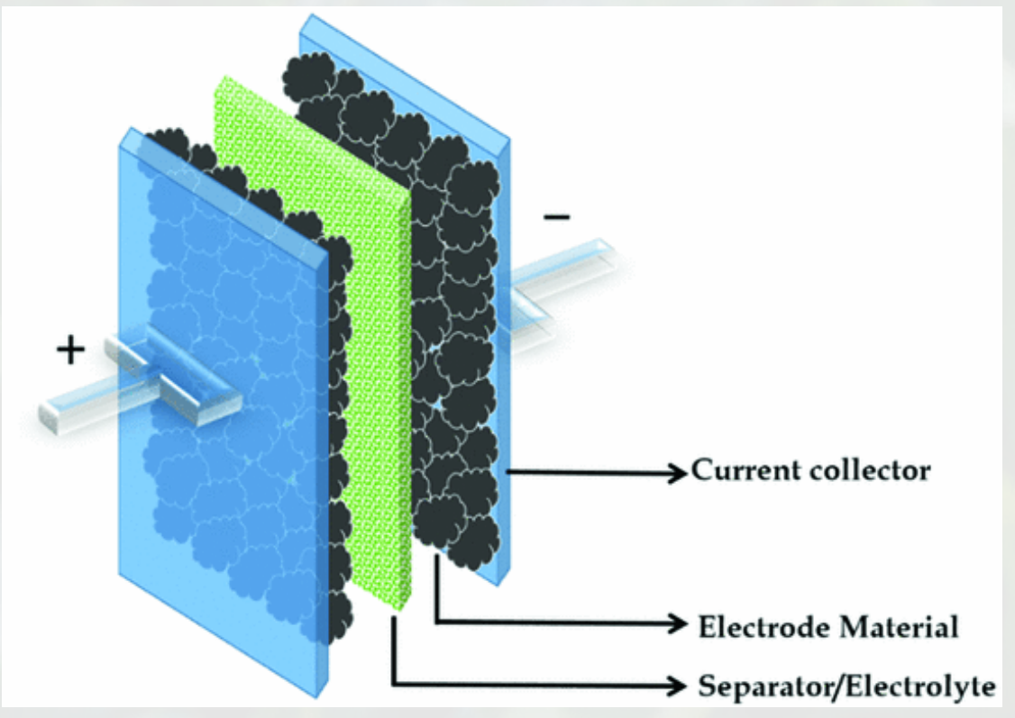
Where we are now

Material	Capacitance	Standard Device Operating Voltage (V)	Energy Density (Wh/kg)	Production Energy Cost (MJ/kg)
One step waste tea biochar	~100 F/g (tested in house)	1	13.9	2160+*
YP50, commercial biochar	~100 F/g (tested in house)	1	13.9	43 – 277 [11]
NMC (Nickel Manganese Oxides)	160 – 200 mAh/g [2]	3.6 [12]	576 - 720	14.4 [13]

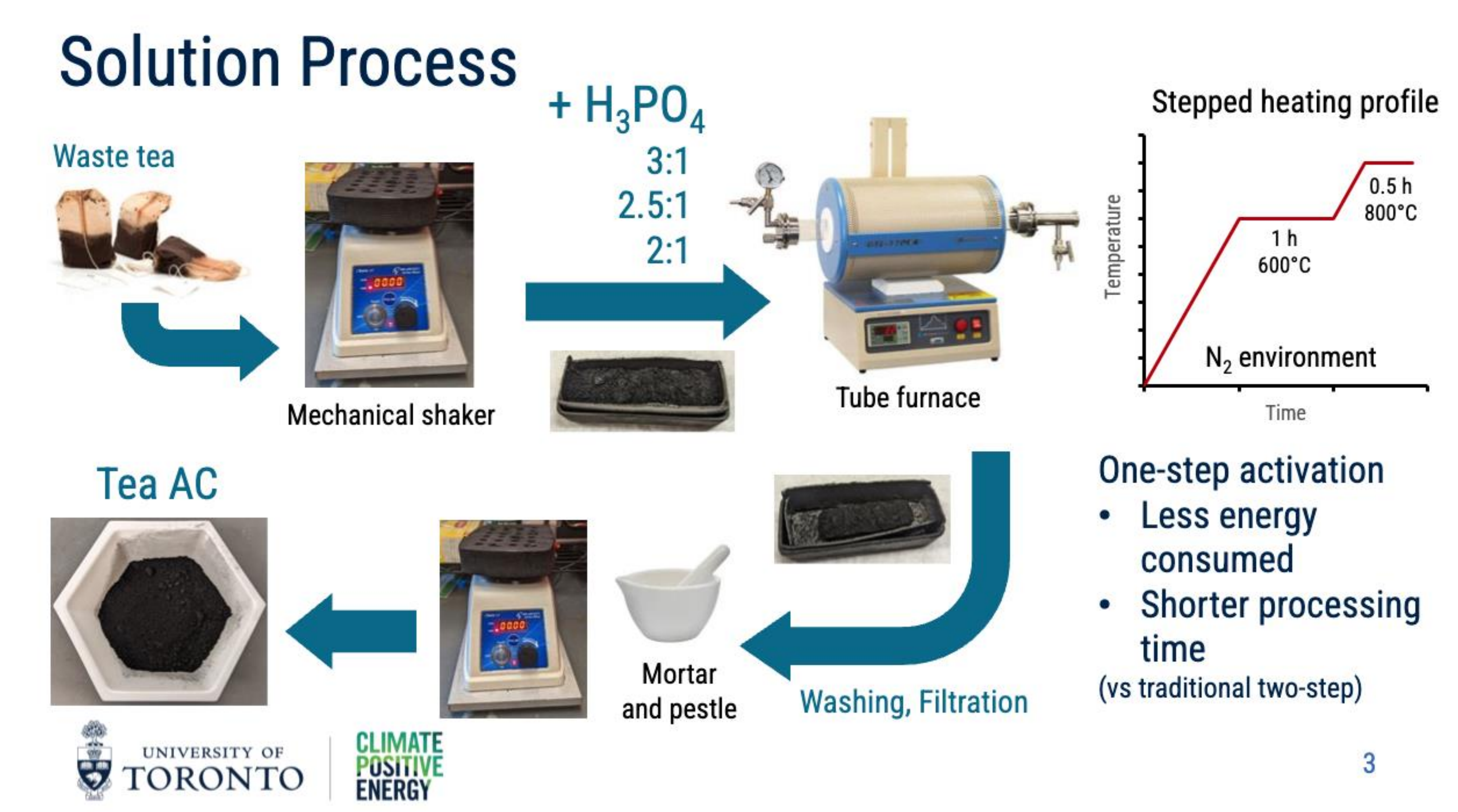
Supercapacitor design principles



$$E = \frac{1}{2}CV^2$$

$$C = \frac{\varepsilon_r \, \varepsilon_0 \, A}{d}$$

Innovating a sustainable future for electrochemical energy storage


Solution Process

Waste tea

Mechanical shaker

+ H_3PO_4
3:1
2.5:1
2:1

Tube furnace

Stepped heating profile

One-step activation
- Less energy consumed
- Shorter processing time

(vs traditional two-step)

Washing, Filtration

Mortar and pestle

Tea AC

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CLIMATE POSITIVE ENERGY

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Research Innovation	Parameter to be Improved	Estimated Values	Trade-offs/Limitations
Increasing Energy Density			
High voltage electrolytes	Operating voltage	Ionic liquids: 2.5 V – 3.5 V [15] Solid polymer: 2 - 3.8 V [21], [22] “Water-in-salt”: 2.3 - 3 V [16], [23]	Needs to be tailored to each electrode/electrolyte system Potentially negative impact on charge transfer dynamics (power density) More expensive than traditional aqueous electrolytes
Mesopore/Nanostructure creation	Capacitance	228 F/g [24] 478 F/g [17] 168 – 374 F/g depending on feedstock [25]	Pore optimization is hard to control and may inhibit electrolyte compatibility Nanostructuring requires complicated production processes and high precision Requires additional chemical inputs
Reducing Energy Use in Production			
Heat recovery	Energy use	~30% energy recovery [18] 21-37% emissions abatement from energy use [19]	Useful only at industrial scale
Microwave heating	Energy use	~50% increase in net energy generation [20]	Reliant on cogeneration systems

What can we expect?

- ❖ Production of activated carbon/biochar becomes a net producer of energy
- ❖ Supercapacitor energy density increases enough to match Li-ion batteries
- ❖ Ultrafast charging (<1 min - <1 hr)
- ❖ Longer lifetime products (10,000+ charge-discharge cycles)
- ❖ Reliable energy storage without the need for critical metals

The roadblocks ahead

- ❖ Intricate interface design between high voltage electrolytes and nanostructures
- ❖ High processing costs
- ❖ Perfecting microwave aided pyrolysis
- ❖ High precision manufacturing

Link to full research paper

References

Refer to full paper link for full list of references

Image sources:
Background
https://www.pexels.com/photo/green-tea-farm-during-golden-hour-2582652/

Ragone Plot
D. Wu et al., “MnO2/Carbon Composites for Supercapacitor: Synthesis and Electrochemical Performance,” Front. Mater., vol. 7, 2020, Accessed: Nov. 03, 2022. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fmats.2020.00002

Critical Metals
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Supercapacitor Design
Samantara, A. K., & Ratha, S. (2018). Components of Supercapacitor. In A. K. Samantara & S. Ratha (Eds.), *Materials Development for Active/Passive Components of a Supercapacitor: Background, Present Status and Future Perspective* (pp. 11–39). Springer. https://doi.org/10.1007/978-981-10-7263-5_3