

Thermal energy storage (TES) is pivotal to decarbonizing heat and integrating variable renewables because it buffers diurnal/seasonal mismatches between supply and demand; among TES modalities—sensible, latent (Fig. 1.1), and thermochemical—latent heat storage (LHS) with phase change materials (PCMs) offers the highest storage density at near-isothermal operation, enabling compact and efficient systems. Nonetheless, the practical deployment of many inorganic PCMs is constrained by subcooling, phase segregation, leakage, and limited cycling stability. Encapsulation and shape-stabilization—particularly SiO₂-based direct sol-gel routes—mitigate these issues and have been demonstrated to lower subcooling and enhance cycle life for lithium salts such as LiNO₃ and LiCl.

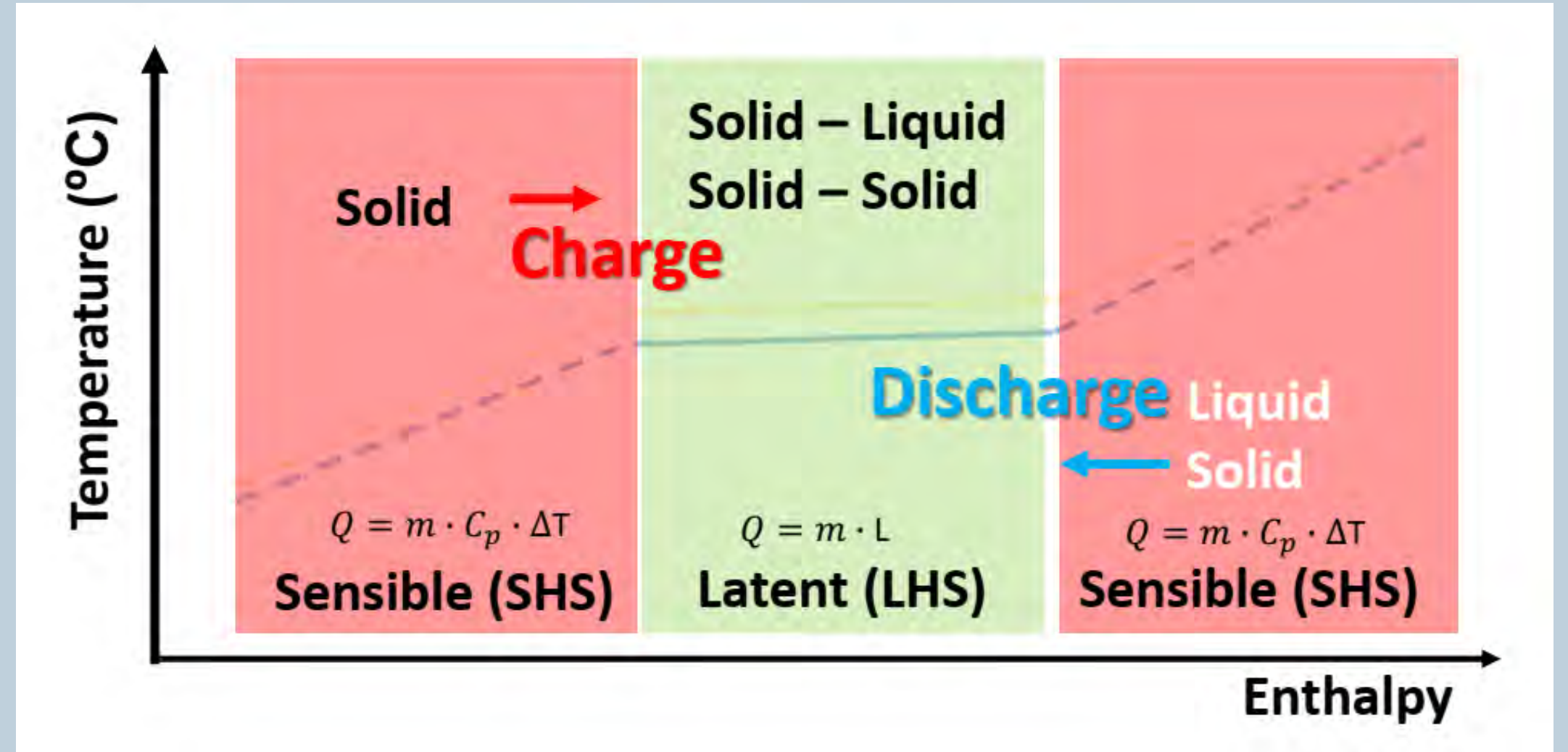


Fig. 1.1 Representation of the mechanism for TES materials.

INTRODUCTION

To sustainably expand the use of PCM-based TES systems, it is crucial to obtain low-cost feedstocks from abundant natural resources and to advance materials engineering (Fig. 1.2). This dual approach not only enhances the efficiency and cost-effectiveness of the technology but also promotes environmental sustainability. Evaporite deposits and natural brines provide abundant chloride-, nitrate-, and sulfate-bearing salts, like bischofite and carnallite, which can be processed into shape-stabilized composites via sol-gel methods. Meanwhile, agricultural activities generate tons of natural biobased waste and byproducts that can be used to produce organic PCMs and/or support materials for encapsulation. This approach lowers costs and environmental impact while maintaining performance. Silica-based supports, readily sourced from natural silica (SiO₂), form porous networks that accommodate molten materials. These principles also enhance supply security for encapsulated PCM slurries used in cold storage and HVAC systems, effectively addressing supercooling, leakage, and heat transfer issues.

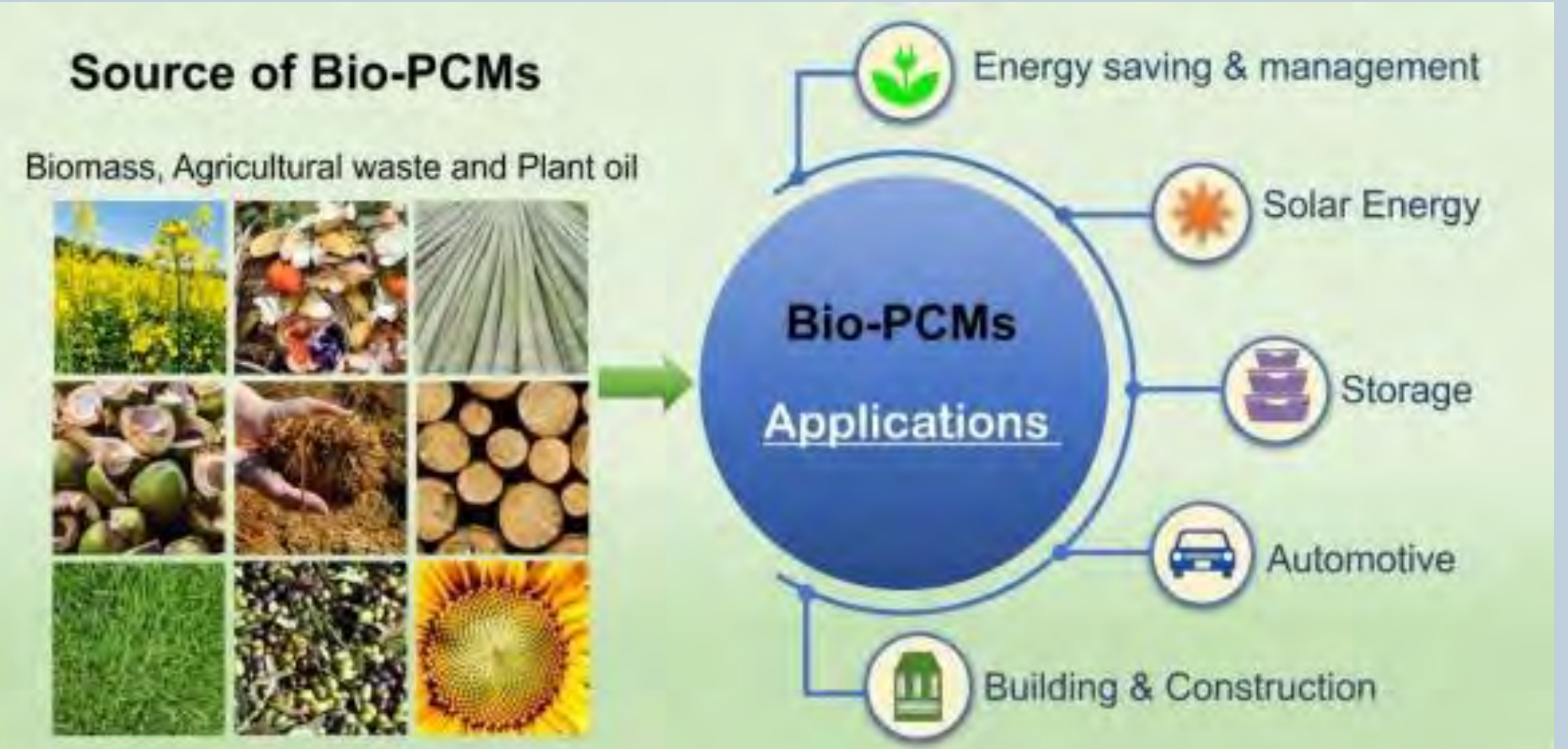


Fig. 1.2 The potential of nature for thermal energy storage systems and sustainability..

Latent Energy Frontiers (CIAE). Research group within the Department of Thermal Energy Storage at the Iberian Center for Research in Energy Storage (CIAE), Cáceres, Spain. The group focuses on latent heat storage using PCMs. **Activities:** design, synthesis, and screening of PCMs (including bio-based and waste-derived options); studies of thermal properties, cycling stability, and durability, and encapsulation. **Infrastructure & context:** CIAE is developing laboratories and pilot plants to span the full value chain of energy storage in Extremadura. **Keywords:** PCM, latent heat storage, encapsulation, industrial integration, bio-PCMs.

MAIN RESEARCH LINES

1

Bio-based PCM

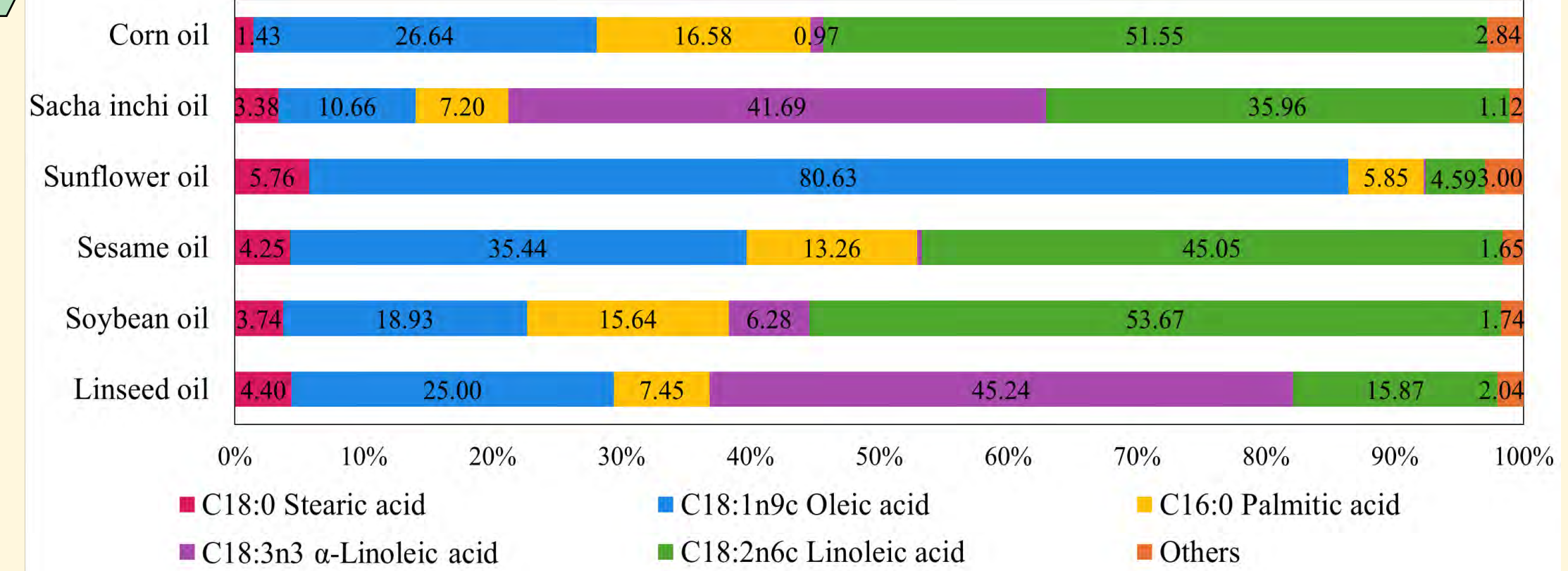


Fig. 1.1 Composition of different vegetable-based oils.

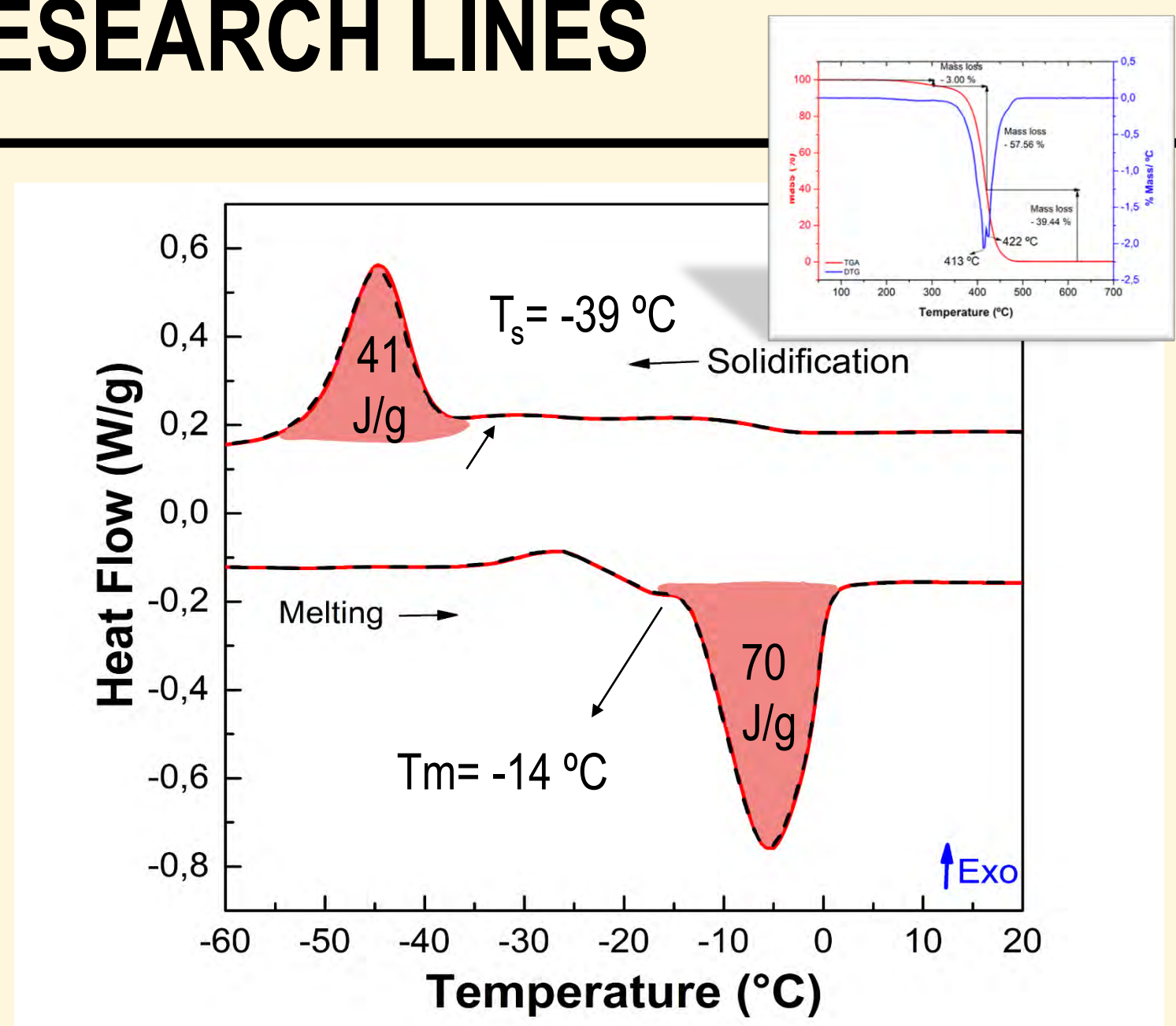


Fig. 1.2 Calorimetry curve for sunflower oil

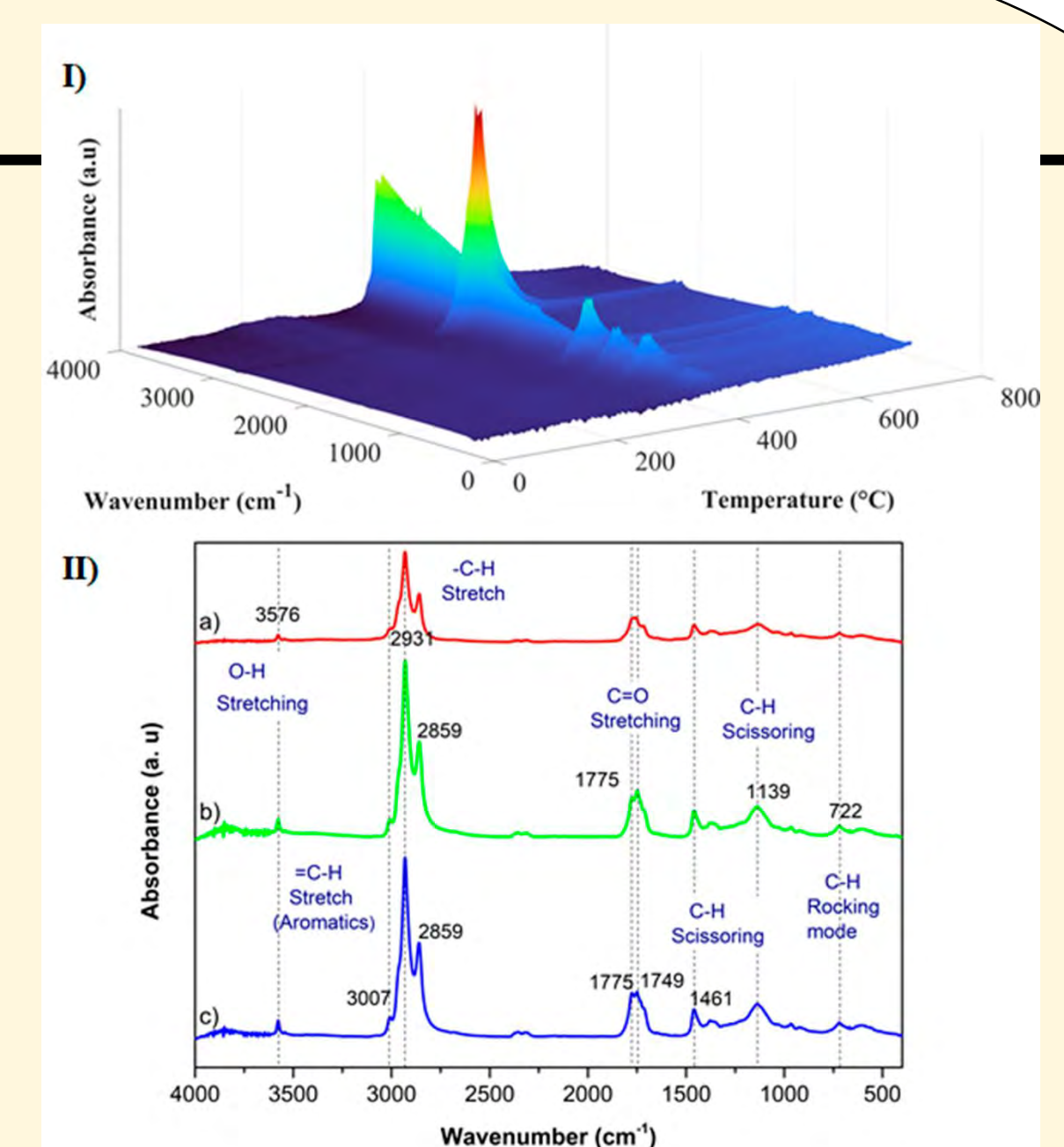


Figure 1.3. The 3D STA-FTIR spectrum (I) and the FTIR spectra at different temperatures (a) 453.0 °C, (b) 422.0 °C, and (c) 419.0 °C of the sunflower oil. (II).

2

Encapsulated PCM

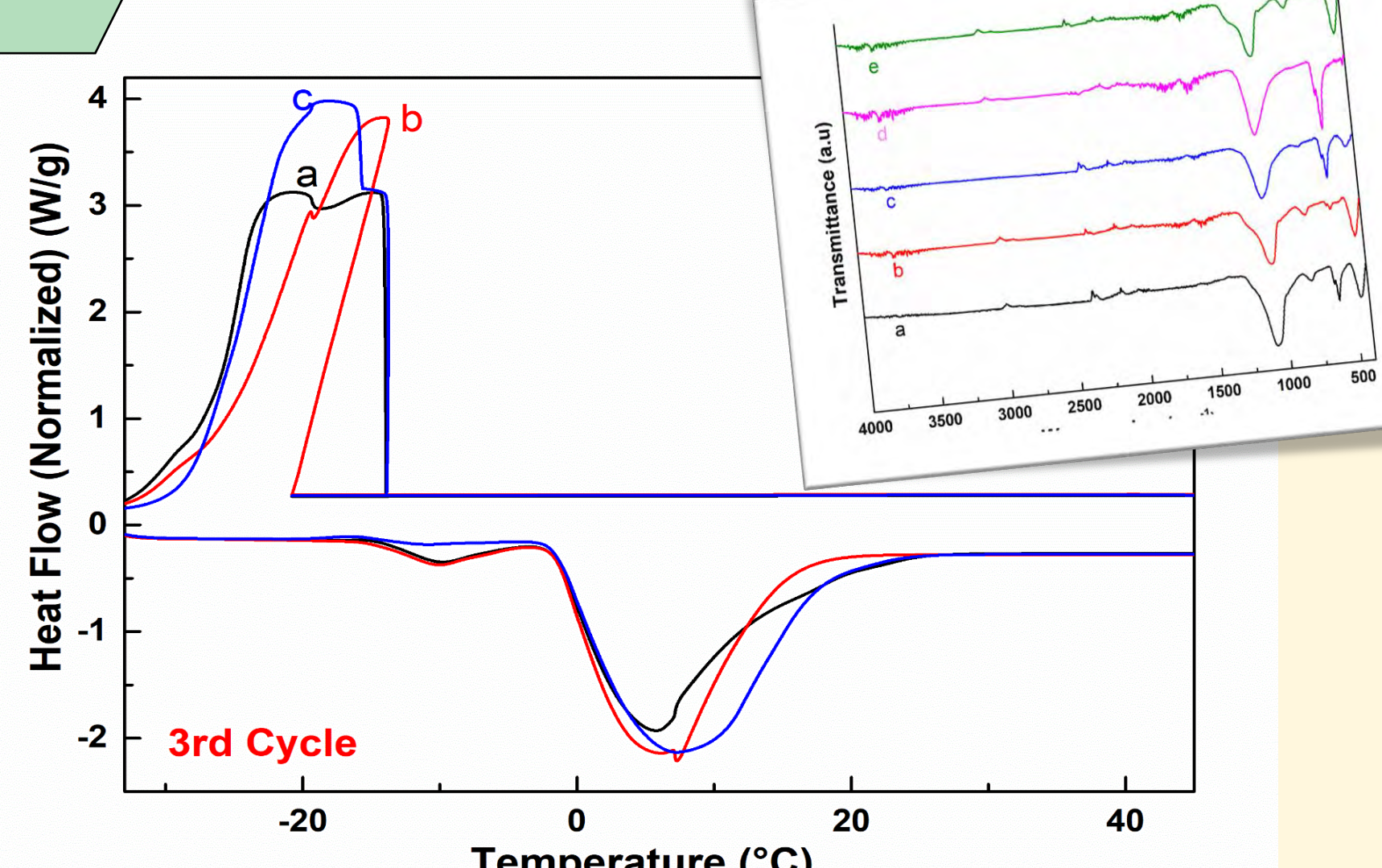


Fig. 2.1: DSC and FTIR for rehydrated bionanomining product enhanced with Cu NPs encapsulated with SiO₂: a) 1:1 Na₂SO₄ · 10 H₂O: SiO₂; b) 1:2 Na₂SO₄ · 10 H₂O: SiO₂; c) 2:1 Na₂SO₄ · 10 H₂O: SiO₂; d) 2:1 Na₂SO₄ · 10 H₂O: SiO₂; e) 2:1 Na₂SO₄ · 10 H₂O: SiO₂.

Table 1: Rehydrated bionanomining product enhanced with Cu NPs encapsulated with SiO₂

Sample	Latent heat (J/g)	T melting (°C)	SC (°C)
Na ₂ SO ₄ · 10 H ₂ O	263.6	-1.71	13.95
1:1 Na ₂ SO ₄ · 10 H ₂ O: SiO ₂	256.9	-1.72	18.74
1:2 Na ₂ SO ₄ · 10 H ₂ O: SiO ₂	261.38	-1.66	17.82
2:1 Na ₂ SO ₄ · 10 H ₂ O: SiO ₂	276.24	-1.53	19.36

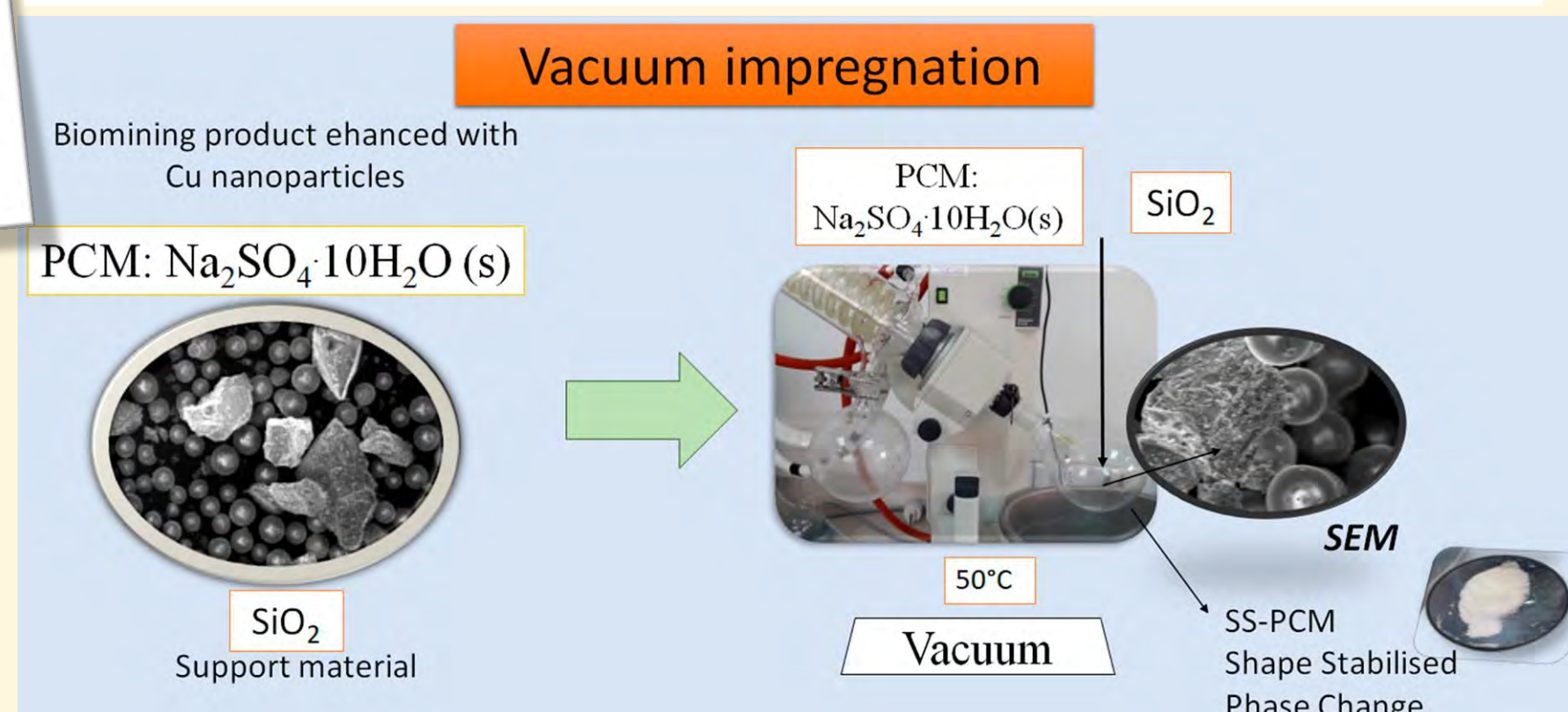


Fig. 2.2 A combination of vacuum impregnation and water addition (rehydration) was proposed and evaluated for bionanomining anhydrous Na₂SO₄ and Cu nanoparticles.

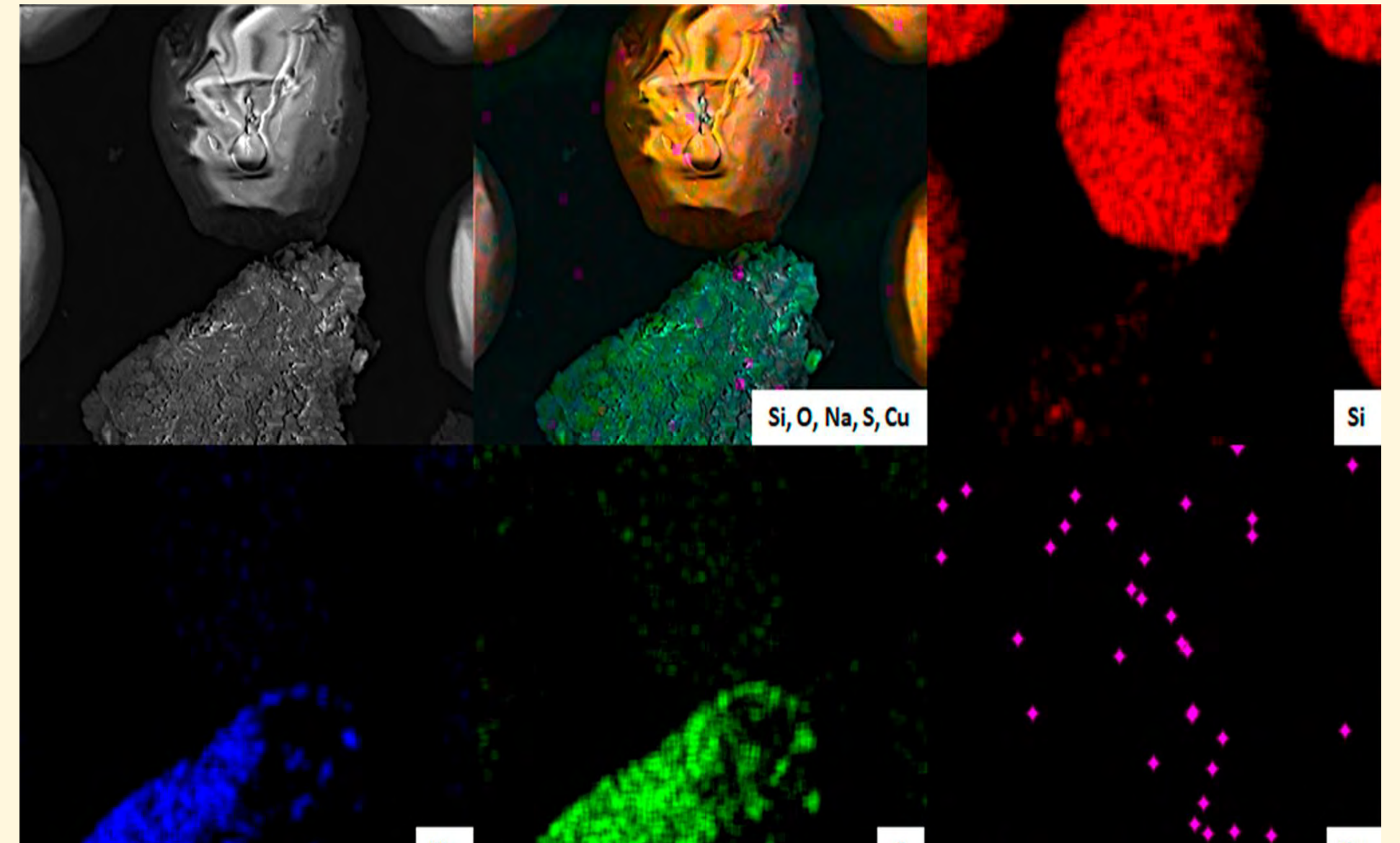


Fig. 2.3 SEM image and EDS mappings of Si, Na, S and Cu of bionanomining product enhanced by Cu nanoparticles and SiO₂ (2:1 Na₂SO₄ · 10H₂O:SiO₂).

3

Nanoparticles

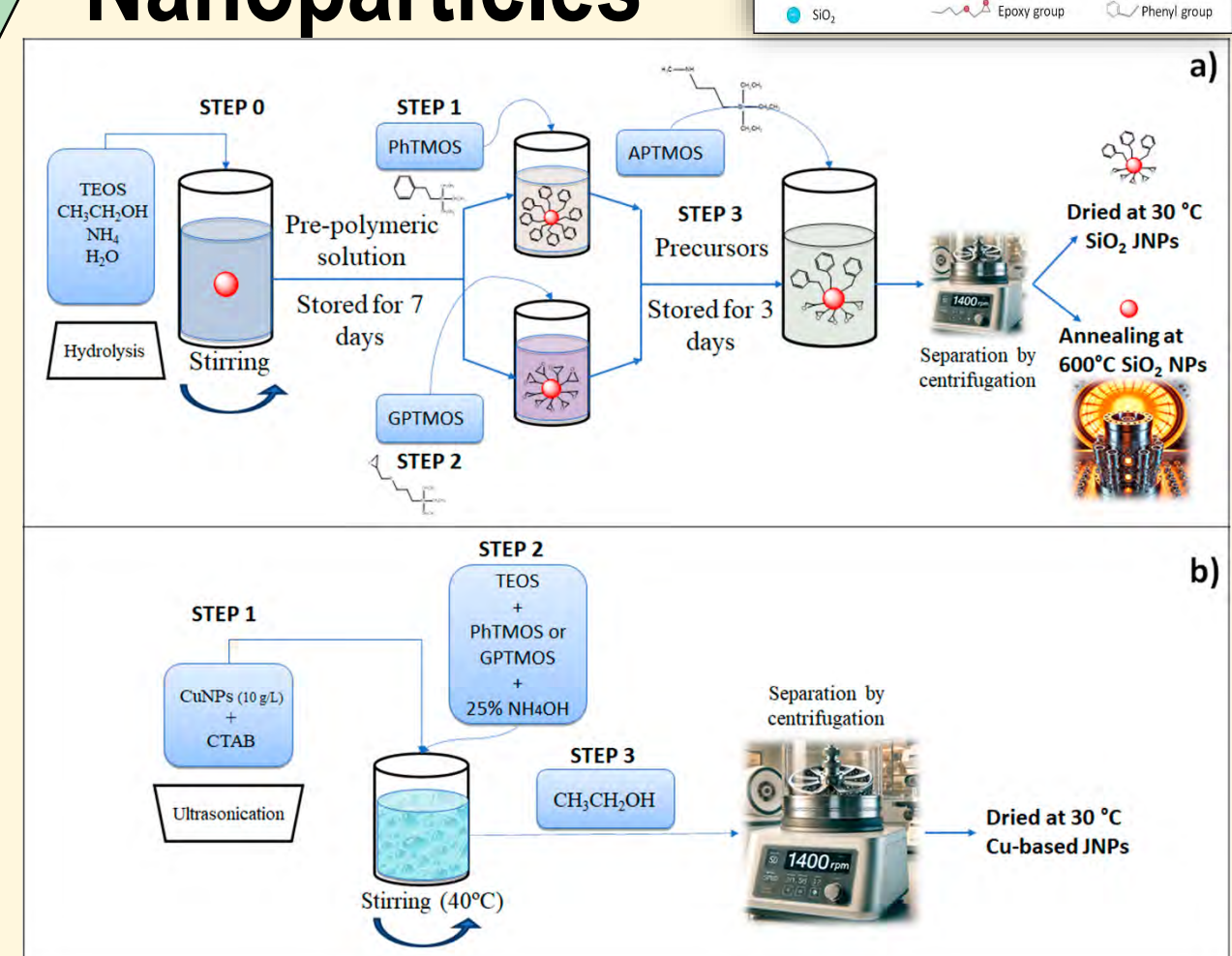


Fig. 3.1 Representation of employed self-assembled synthesis for SiO₂ JNPs, and b) SiO₂@Cu-based JNPs

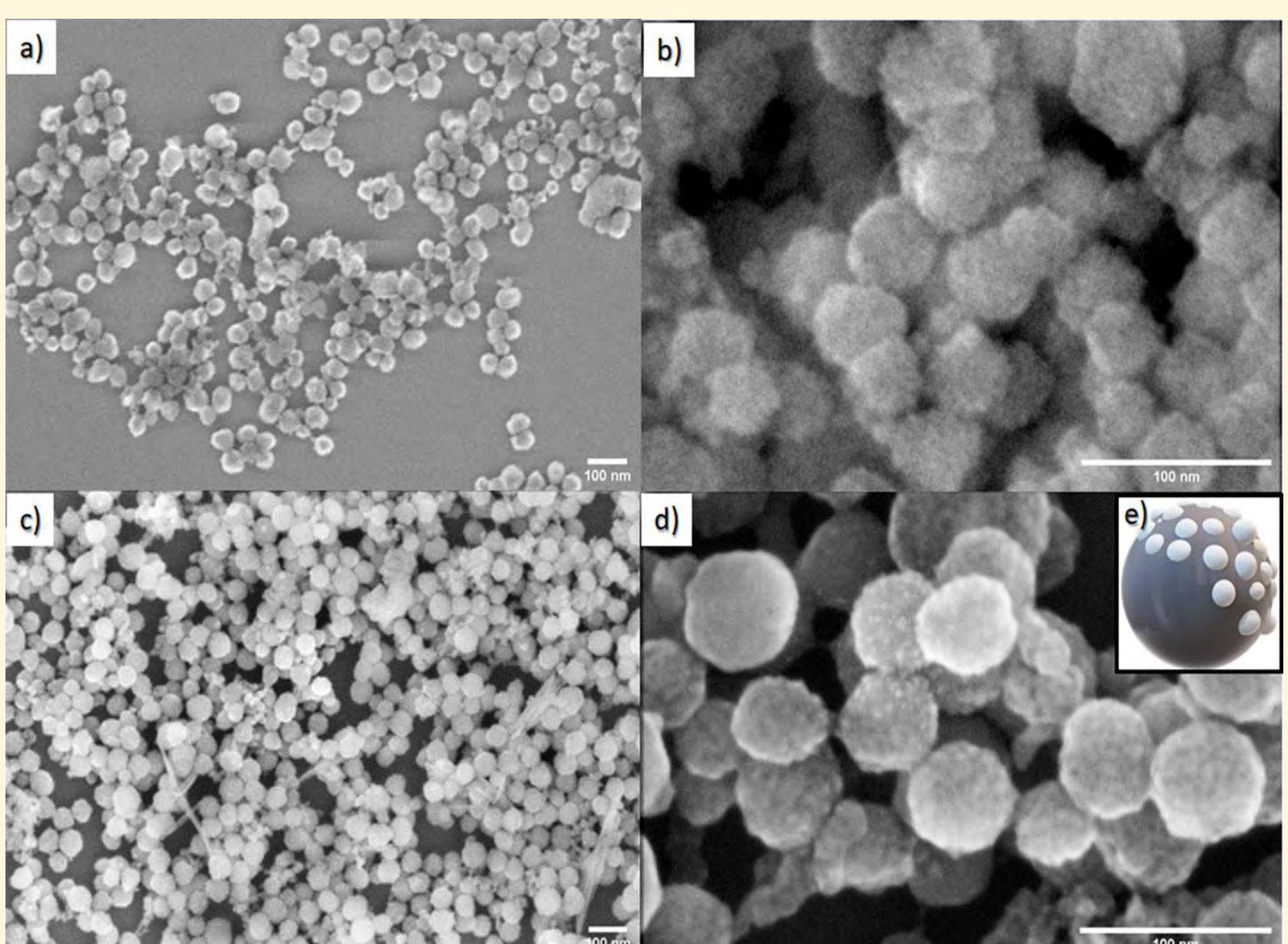


Figure 3.2 SEM images of GPTMOS-SiO₂@Cu [a] and b), and PhTMOS-SiO₂@Cu JNPs [c] and d)].

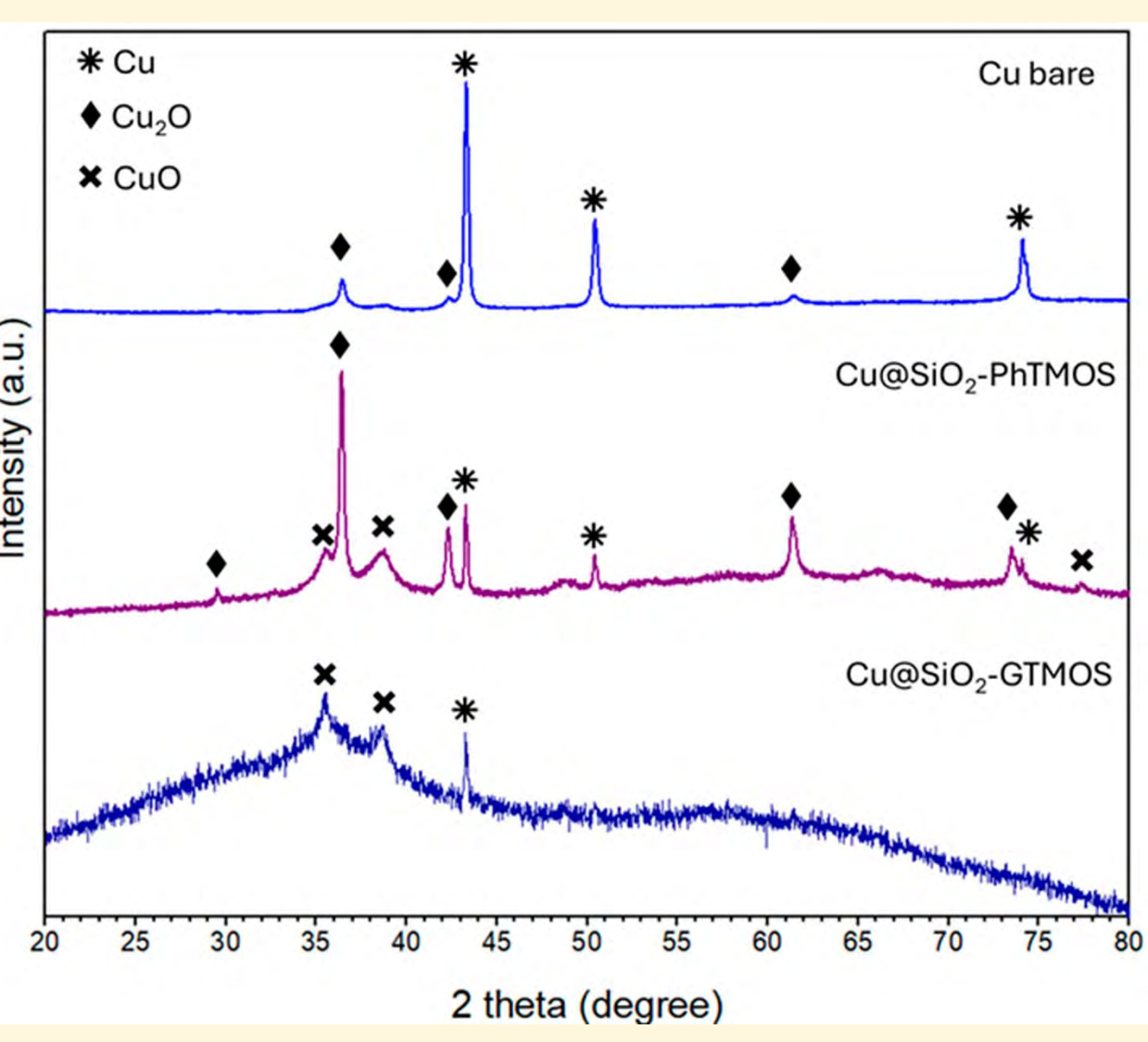


Fig. 3.3 XRD patterns for Cu NPs without modification (light blue line, up pattern), PhTMOS-SiO₂@Cu JNPs (purple line), and GPTMOS-SiO₂@Cu JNPs (dark blue line).

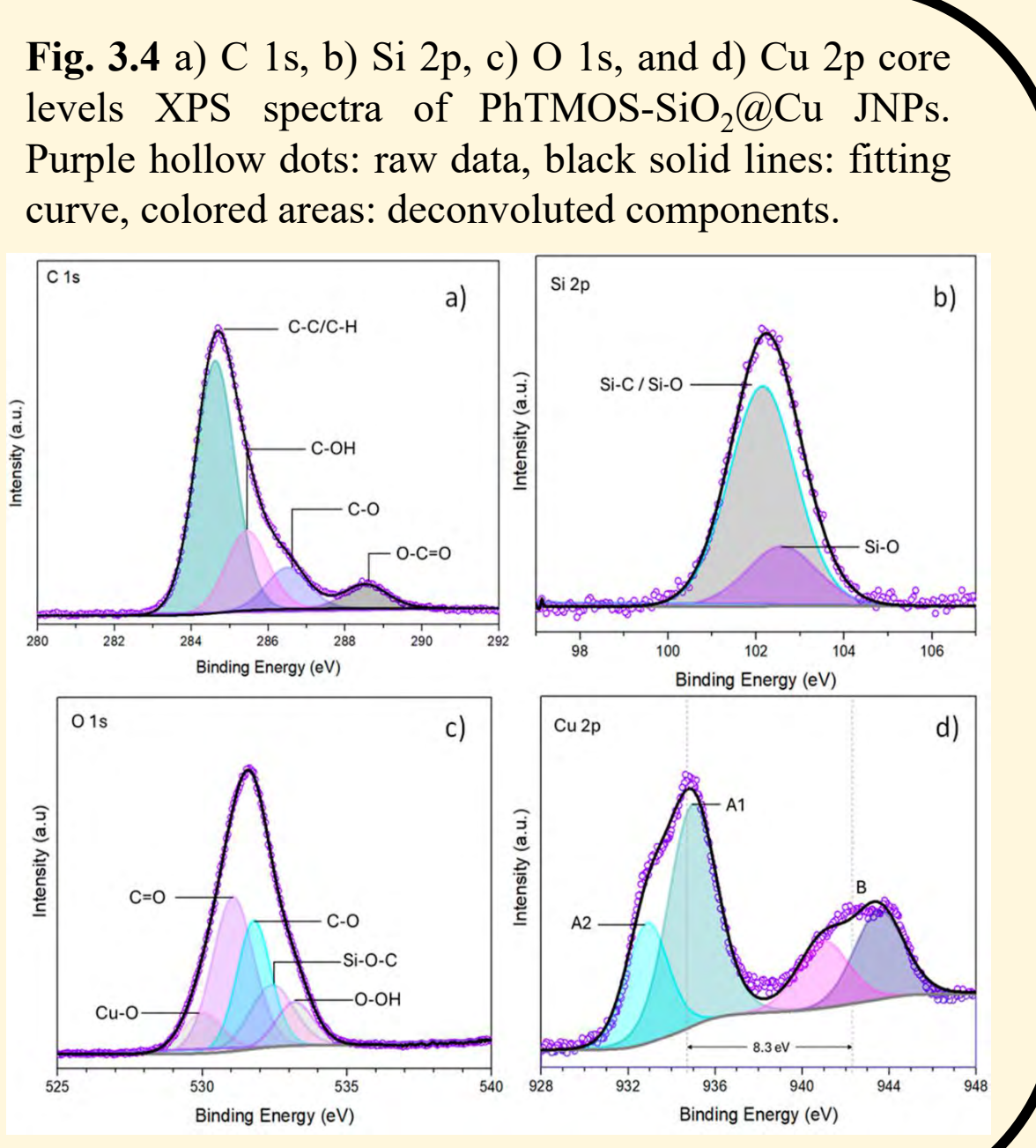


Fig. 3.4 a) C 1s, b) Si 2p, c) O 1s, and d) Cu 2p core levels XPS spectra of PhTMOS-SiO₂@Cu JNPs. Purple hollow dots: raw data, black solid lines: fitting curve, colored areas: deconvoluted components.

Natural raw materials

POTENTIAL APPLICATIONS AND COLLABORATIONS

Greenhouses

Building

BTMS

Ceramics & 3D Printing

H&C SYSTEMS

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