

# Miscanthus-Derived Energy Storage System Material Production

Fikret Muge Alptekin, Nurhan Turgut Dunford, and Melih Soner Celiktas\*



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**ABSTRACT:** Carbon derived from various biomass sources has been evaluated as support material for thermal energy storage systems. However, process optimization of *Miscanthus*-derived carbon to be used for encapsulating phase change materials has not been reported to date. In this study, process optimization to evaluate the effects of selected operation parameters of pyrolysis time, temperature, and biomass:catalyst mass ratio on the surface area and pore volume of produced carbon is conducted using response surface methodology. In the process,  $ZnCl_2$  is used as a catalyst to promote high pore volume and area formation. Two sets of optimum conditions with different pyrolysis operation parameters in order to produce carbons with the highest pore area and volume are determined as 614 °C, 53 min, and 1:2 biomass to catalyst ratio and 722 °C, 77 min, and 1:4 biomass to catalyst ratio with 1415.4 m<sup>2</sup>/g and 0.748 cm<sup>3</sup>/g and 1499.8 m<sup>2</sup>/g and 1.443 cm<sup>3</sup>/g total pore volume, respectively. Carbon material produced at 614 °C exhibits mostly micro- and mesoporous pores, while carbon obtained at 722 °C comprises mostly of meso- and macroporous structures. Findings of this study demonstrate the significance of process optimization for designing porous carbon material to be used in thermal and electrochemical energy storage systems.



## 1. INTRODUCTION

Detrimental effects of greenhouse gas emissions and increasing price of fossil fuels have accelerated the search for alternative energy resources, cleaner feedstock conversion technologies and promoted efficient use of energy.<sup>1–3</sup> Although renewable energy resources are clean and abundant, they have natural disadvantages including intermittency and randomness that cause incompatibility between supply and demand.<sup>4</sup>

Thermal energy storage (TES) and electrochemical energy storage (EES) are two types of energy storage systems that can be suitable for meeting the instant energy demand from renewable sources as needed. For instance, TES is used to store heat from solar radiation, waste heat, and gas boilers, while EES stores electricity through supercapacitors and batteries.<sup>5</sup> TES has an important role to play in renewable energy storage systems.<sup>6</sup> Among the other TES technologies, latent heat storage based on phase change materials (PCM) are considered to be the most promising technology due to their high energy storage density and cost effectiveness.<sup>7–10</sup> Although liquid–solid PCM based TES has many advantages, leakage of the PCM out of the supporting material during its phase transition is a problem that requires further research and development work for improvement.<sup>11,12</sup> Biomass-based highly porous carbon materials can be used to encapsulate PCM to address the leakage problem.

High power and energy density, long time stability during charging/discharging cycles, and safety are the key elements required in high performance electrochemical energy storage systems including lithium and sodium-ion batteries and

supercapacitors.<sup>13</sup> Carbon-based materials are considered as suitable electrode materials for supercapacitors and lithium-ion batteries due to their outstanding properties including, high electrical conductivity, chemical stability, and high surface area and pore volume.<sup>14,15</sup>

Biomass derived carbon materials have been utilized in a variety of applications such as soil and wastewater remediation, recovery of plant growth nutrients nitrogen and phosphorous from agricultural runoffs, and adsorption of heavy metals and other pollutants from wastewater streams,<sup>16</sup> as electrodes in supercapacitors, and PCM support materials.<sup>17</sup> However, further research and development work is necessary to develop carbon materials with high specific surface area, pore volume, and thermal conductivity to enhance their functionality in TES systems. Physical, chemical, and physicochemical activation methods have been used to increase the porosity and specific area of the biochar to be used in TES applications.<sup>18</sup> The activation method, impregnation time, process temperature, residence time, and chemical composition of the biomass have significant effects on the final product characteristics.<sup>19</sup>  $H_3PO_4$ ,  $ZnCl_2$ ,<sup>20</sup>  $KOH$ ,<sup>21</sup>  $NaOH$ ,  $K_2CO_3$ ,<sup>22</sup> and  $Na_2CO_3$  are chemicals that are widely used in the chemical activation processes.

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62 and 150 eu 63 98 tc 43 and 99 tc 43 129 te 52 and 128 sb 51 answer b 150 sm 62 and 150 eu 63 explanation because the  
mass number of 150 sm 62 and 150 eu 63 are the same these element pairs are isobars q 2

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web terms in this set 11 a line on a map or chart along which there is a constant value isotherm a line on a map connecting  
points having the same temperature at a given time on average of a given period isobar a line on a map connecting points  
having the same atmospheric pressure at a given time on average of a given period

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web isotherm and isobar maps purpose the purpose of this laboratory exercise is to become familiar with how to construct  
both isotherm and isobar maps vocabulary 10 points isoline isotherm isobar objectives upon completion of this laboratory  
exercise you will be able to 1 define the terms isoline isotherm and isobar 2 construct an

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web be interpreted as temperature therefore isotherm means same temperature isotherms drawn on temperature maps  
connect equal temperatures here are some helpful hints 1 isobars are drawn in 4 millibar intervals 2 always label the isobar



value 3 pressures lower than the isobar value are always on one side of the isobar and higher