Abstract

Microwave-Assisted Green Solvolysis of Wind Turbine Blades for Upcycling into Photoluminescent Safety Tiles

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This study offers a transformative approach to managing the growing problem of decommissioned wind turbine blades. It is challenging to recycle due to its thermoset matrix and high mechanical strength, which renders traditional mechanical and thermal recycling methods either energy-intensive or ineffective in preserving fiber integrity. In this study, a novel, circular economy pathway is proposed, wherein composite blade waste is converted into high-performance photoluminescent safety tiles and rubber industrial floor blocks through microwave-assisted solvolysis using a green solvent mixture of H_2O_2 and CH_3COOH.

(a) (b)

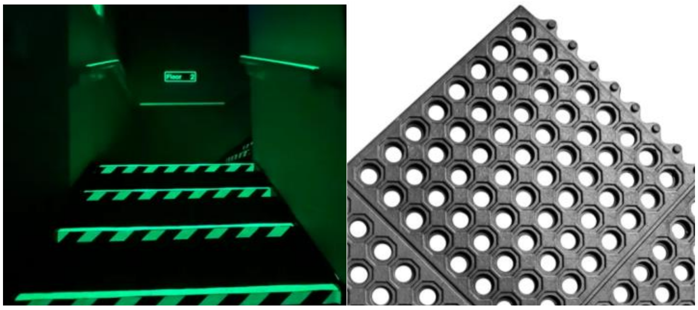


Figure 1. Final product: (a) High performance photoluminescent tiles; (b) Rubber floor block.

The process is carried out in a semi-batch facility, operating four modular solvolysis reactors at 90 °C and 1 atm. These reactors are fed with shredded composite blade material that has undergone preliminary separation to remove wood and metals. Aqueous solvent comprising a defined ratio of H_2O_2 and CH_3COOH is introduced into the reactors, where it forms peracetic acid in situ. Upon microwave irradiation, the peracetic acid decomposes into hydroxyl and acyloxy radicals, which cleave the epoxy resin's crosslinked network. This chemical degradation enables the release of intact glass fibers, which are then recovered and reused. A unique aspect of the system is its integrated microwave delivery setup, which ensures uniform energy distribution and avoids localized overheating, while slurry density sensors and scrappers to optimize reaction control and prevent buildup on reactor walls. The degradation reaction follows pseudo-first-order kinetics with respect to the oxidant ratio φ, defined as $[H_2O_2]/[CH_3COOH]$. ChemCAD simulations confirm that nearly complete degradation of epoxy can be achieved at $\varphi = 0.71$ and a residence time of 3 hours. The kinetic model demonstrates that while φ is a useful descriptor, absolute quantities of both H_2O_2 and CH_3COOH are critical for maintaining radical generation throughout the reaction.

The batch cycle consists of 3 hours of reaction time and 1 hour for discharge, flushing, and charging, totaling 4 hours. With six complete batches processed per day across the four reactors, and 330 operational days per year, the facility executes 1980 batches annually. Under these conditions, the plant processes approximately 4438 tonnes of feedstock and produces an ideal output of 4745 tonnes of photoluminescent safety tiles per year. The balance has been made under steady-state and full glass fiber recovery assumptions.

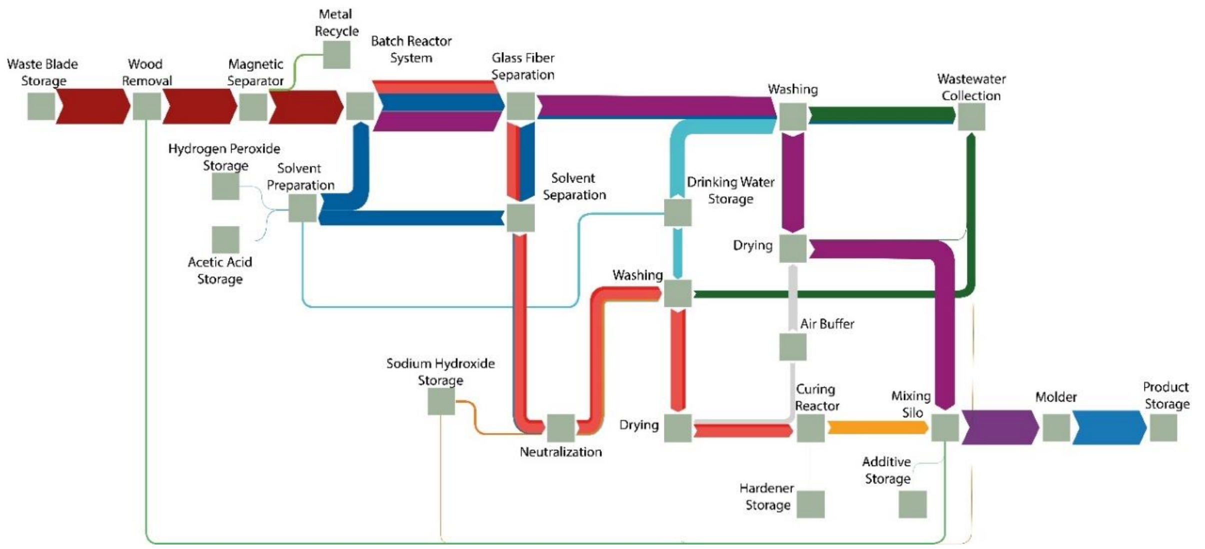


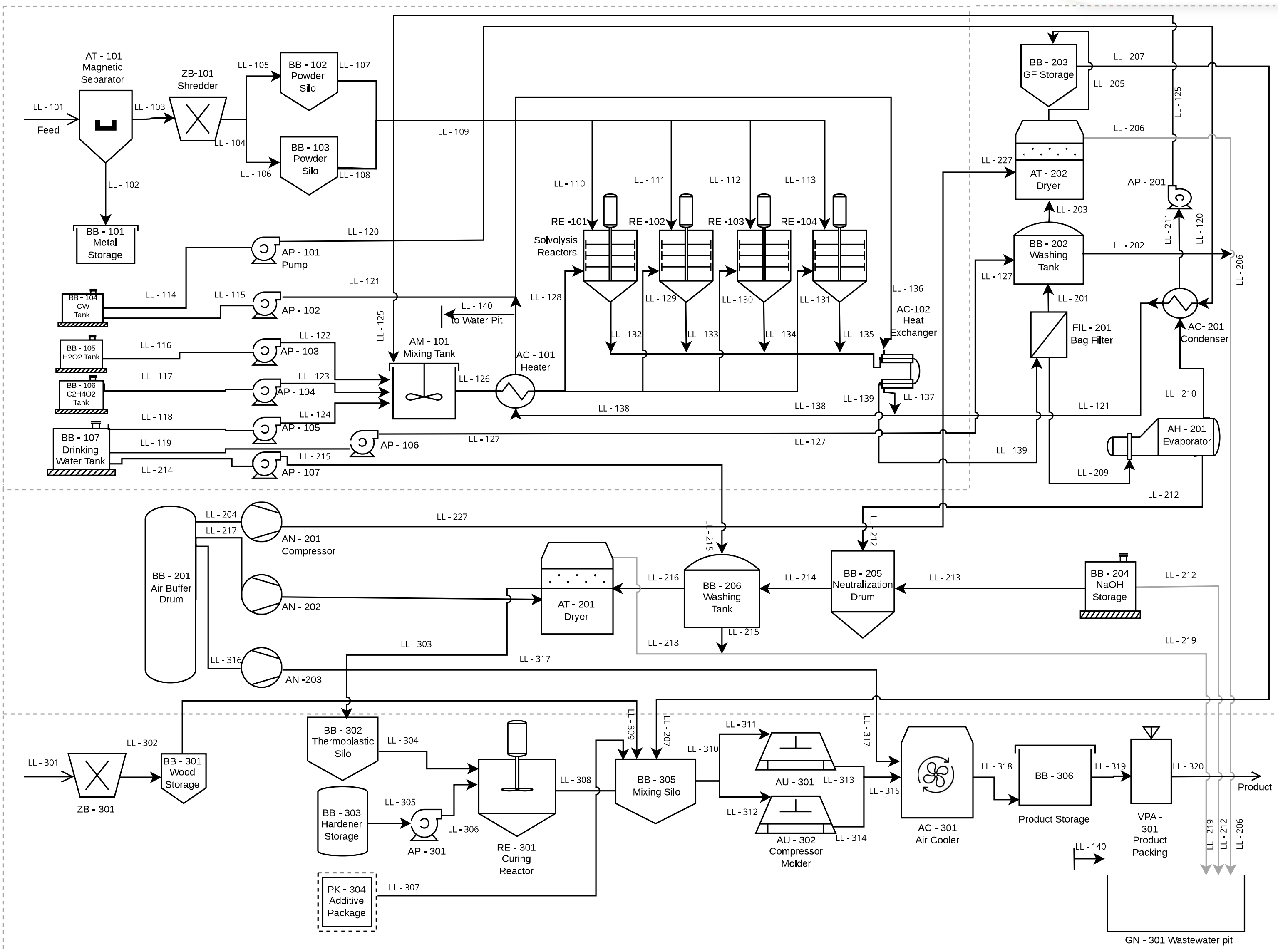
Figure 2. Schematic for solvolysis of composite blade waste

To ensure consistent output, downstream units such as solvent recovery, curing, and molding are operated continuously or semi-continuously. These must be decoupled from the batch cycle to allow stable and uninterrupted production flow throughout the year. This represents the facility's optimal capacity, assuming no unplanned interruptions.

The capital expenditure for the plant is approximately €23.35 million, with major costs arising from land acquisition (€10.50 million), civil works, and equipment purchase. Operational expenditures include raw material consumption (acetic acid, hydrogen peroxide, hardener, additives), utility requirements (renewable electricity, cooling water, nitrogen, air), and labor. The plant achieves a break-even point in year four after production begins, and financial analysis shows a consistently positive net present value throughout the project lifetime, with an internal rate of return of 18.20%. This is significantly above the assumed discount rate of 8%, suggesting strong investment viability.

Solvolysis has relatively low carbon footprint assessed, largely due to the use of biodegradable solvents, solvent recovery systems, and green electricity. Although landfilling has the lowest carbon footprint potential, it is banned because it harms the environment by polluting soil and water, and causing long-term ecological and health risks. Moreover, solvolysis aligns with EU waste management directives and supports long-term circularity by recovering and reintroducing materials into high-value applications. From a market perspective (located in Wilhelmshaven), the safety tiles and floor blocks are targeted toward facilities with elevated safety and compliance requirements, including chemical plants, gas terminals, power stations and refineries. Their higher cost compared to traditional flooring is offset by longer life, reduced maintenance, fire safety compliance, and environmental benefits.

To summarize, the microwave-assisted green solvolysis process transforms end-of-life wind turbine blade waste into high-value, safety-critical products, proving that even the most challenging waste streams can become vital industrial resources in a circular economy; with the glow that guides, the clarion that saves: Glarion lights the way to safety.


AT - 101 Magnetic Separator
ZB-101 Shredder
BB - 102 Powder Silo
BB - 103 Powder Silo
BB - 101 Metal Storage
Feed
LL - 101
LL - 102
LL - 103
LL - 104
LL - 105
LL - 106
LL - 107
LL - 108
LL - 109
LL - 110
LL - 111
LL - 112
LL - 113
RE -101
RE -102
RE -103
RE -104
Solvolysis Reactors
LL - 120
AP - 101 Pump
BB - 104 CW Tank
LL - 114
LL - 115
AP - 102
LL - 121
BB - 105 H2O2 Tank
LL - 116
LL - 122
AP - 103
BB - 106 C2H4O2 Tank
LL - 117
LL - 123
AP - 104
LL - 118
LL - 124
AP - 105
BB - 107 Drinking Water Tank
LL - 119
AP - 106
LL - 214
LL - 215
AP - 107
LL - 125
LL - 140
To Water Pit
AM - 101 Mixing Tank
LL - 126
AC - 101 Heater
LL - 127
LL - 128
LL - 129
LL - 130
LL - 131
LL - 132
LL - 133
LL - 134
LL - 135
LL - 136
AC-102 Heat Exchanger
LL - 137
LL - 138
LL - 139
BB - 203 GF Storage
LL - 207
LL - 205
LL - 206
AT - 202 Dryer
LL - 227
AP - 201
LL - 203
BB - 202 Washing Tank
LL - 202
LL - 211
LL - 120
AC- 201 Condenser
FIL - 201 Bag Filter
LL - 201
LL - 210
AH - 201 Evaporator
LL - 209
LL - 212
BB - 201 Air Buffer Drum
LL - 204
LL - 217
AN - 201 Compressor
AN - 202
LL - 316
AN -203
LL - 303
LL - 317
AT - 201 Dryer
LL - 216
BB - 206 Washing Tank
LL - 218
LL - 213
BB - 205 Neutralization Drum
BB - 204 NaOH Storage
LL - 219
LL - 301
ZB - 301
LL - 302
BB - 301 Wood Storage
BB - 302 Thermoplastic Silo
LL - 304
BB - 303 Hardener Storage
LL - 305
AP - 301
LL - 306
RE - 301 Curing Reactor
LL - 308
LL - 309
BB - 305 Mixing Silo
PK - 304 Additive Package
LL - 307
LL - 310
LL - 311
LL - 312
AU - 301
AU - 302 Compressor Molder
LL - 313
LL - 314
LL - 315
AC - 301 Air Cooler
LL - 318
BB - 306
Product Storage
LL - 319
VPA - 301 Product Packing
LL - 320
Product
GN - 301 Wastewater pit