IHS Markit® now a part of S&P Global

Tire Recycling

PEP Report 199I

December 2022

Rajesh Verma
Director

Process Economics Program

Contacts

Rajesh Verma
Director, Process Economics Program
rajesh.verma@ihsmarkit.com

Michael Arné
Vice President, Process Economics Program
michael.arne@ihsmarkit.com

PEP Report 199I

Tire Recycling

Rajesh Verma, Director

Abstract

Energy crises and environmental degradation are among the main problems that humanity is facing today. These two problems owe their origin to a growing population, rapid industrialization, and the huge amounts of solid waste generated daily and the disposal of these solid wastes is a big environmental concern for modern society, especially in developing countries. To improve the environmental degradation situation, it has become imperative to make use of appropriate technologies for the possible recovery of resources from nonconventional organic solid wastes, like municipal and/or industrial wastes, refused plastics, scrap tires etc. Scrap tires are one of the very common and most important hazardous solid wastes all over the world [1, 2].

Widely differing chemical compositions in tires and the cross-linked structures of rubber make tires highly resistant to biodegradation, photochemical decomposition, chemical reagents, and high temperatures. Developed countries have made progress in waste tire management by implementing more efficient and innovative recovery and recycling methods, and with restrictive regulations regarding the management of used tires. However, in many developing countries, the management of waste tires has not received much attention and the processing, treatment, and disposal of waste tires are still in a nascent stage.

Waste tires can be utilized in various rubber applications, such as engineering and construction, environmental protection, and agriculture. Energy and material recoveries may be achieved through thermal and thermochemical processes, such as incineration and pyrolysis, and gasification and liquefaction, respectively. This report will discuss waste tire management and utilization routes, the cost-benefit analysis, environmental impact, feasibility and technology readiness status and will present the product economics (IHS Markit conceptual design) for

- Tire recycling to produce micronized rubber powder (MRP) using the mechanical grinding process
- Tire recycling to produce carbon black and fuel oil using the pyrolysis process
- Tire recycling to produce MRP using the cryogenic grinding process

This report covers the techno-economic comparison of the three processes and their production economics for a 100 kilotons per annum (KTA) plant at a US Gulf Coast location. An iPEP Navigator tool is also attached with the electronic version of this report. The interactive iPEP Navigator module provides an economic snapshot for each process, allowing the user to select and compare the processes, units, and regions of interest.

Confidential. © 2022 IHS Markit. All rights reserved.

Contents

1 Introduction 11
2 Summary 12
Technical aspects 13
Retreading 13
Energy recovery 13
Incineration 13
Coprocessing 13
Gasification 14
Hydrothermal liquefaction 14
Material recovery 14
Ambient grinding 15
Cryogenic grinding 16
Pyrolysis 16
Economic aspects 17
Forward path 20
3 Industry status 22
Scrap tire market 23
European Union 23
Mainland China 23
The United States and Canada 24
Japan 24
Australia 25
Circular economy 25
Development of new markets for tire-derived materials 27
Rubber in concrete 27
Rubberized asphalt 27
Athletic tracks 28
Rail transport 28
Challenges in scrap tire recycling 28
4 Technology review 30
Tire composition 31
Proximate and ultimate analysis 32
History of tire recycle 33
Scrap tire disposal, management, and reuse 35
Recycling of scrap tires 37
Scrap tires grinding routes 38
Different grinding conditions 39
Ambient grinding 39
Micro milling 41
Cryogenic grinding 41
Solution grinding 43
Water pulse technology 43
Berstoff's method 43
Grinding by ozone cracking 44
Elastic deformation grinding 44
Difference between ambient and cryogenic grinding 44
Ultrafine grinding 46
Various ultrafine grinding methods 46
Devulcanization methods for rubber 47

Confidential. © 2022 IHS Markit. All rights reserved.

Chemical devulcanization 47
Mechanical devulcanization 48
Ultrasonic devulcanization 48
Microwave devulcanization 49
Biological devulcanization 49
Molectra® process 50
Other devulcanization techniques 50
Environmental and health hazards of tire recycling 50
Noise pollution 51
Air pollution 51
Control measures 52
By-products of tire recycling 52
Tire-derived fuel 52
Tire-derived aggregate 52
Rubberized asphalt 53
Rubber mulch 53
Crumb rubber 53
Rubber powder 53
Steel 54
Fiber and nylon 54
Thermal recycling processes of tires 54
Incineration for energy recovery 54
Gasification 54
Updraft gasifier 55
Downdraft gasifier 56
Cross-draft gasifier 56
Fluidized-bed gasifier 56
Empty fruit bunch gasifier 56
Hydrothermal liquefaction 56
Pyrolysis 57
Other reactors 60
Catalytic pyrolysis 60
Effect of process parameters on the pyrolysis process 61
Pyrolysis products 63
Environmental and health hazards of the thermal recycling of tires 64
Some commercial examples of scrap tire recycling 65
Recycling of off-the-road tires 68
Scrap tire management guidelines and schemes 72
Waste management in the European Union 72
Waste management in Australia 74
Waste management in Canada 74
Waste management in Japan 75
Waste management in the United States 75
Waste management in mainland China 76
Waste management in India 76
5 Tire recycling to produce micronized rubber powder using mechanical grinding 77
Process design basis 77
Storage and transportation 78
Products 78
Material of construction 79
Process description 79
Process discussion 83
Feedback composition 83
Feed availability 83

Plant capacity and location 83
Unit configuration and feed composition 83
Size reduction equipment section 84
Sidewall cutter 84
Debeader 85
Tire shredder 87
Granulator or grinder 87
Emissions and wastes 88
Cost estimates 88
Fixed capital costs 88
Production costs 89
6 Tire recycling to produce carbon black and fuel oil using the pyrolysis process 94
Process design basis 94
Storage and transportation 96
Products 96
Material of construction 96
Process description 97
Process discussion 102
Reactor type and configuration 103
Temperature 104
Contact time 104
Pressure 104
Heating rate 104
Particle size 105
Emissions and wastes 105
Cost estimates 105
Fixed capital costs 106
Production costs 106
7 Tire recycling to produce micronized rubber powder using cryogenic grinding 114
Process design basis 114
Storage and transportation 115
Products 116
Material of construction 116
Process description 116
Process discussion 118
Cryogen selection 118
Cryogenic grinder 119
Refrigerant section 122
Ideal grinding temperature 123
Liquid N_2 consumption 123
Emissions and wastes 124
Cost estimates 124
Fixed capital costs 124
Production costs 125
Appendix A—Cited references 131
Appendix B—Patents 144
Appendix C—Process flow diagrams 147

Tables

Table 2.1 Comparison of scrap tire recycling processes: Mechanical recycling vs cryogenic recycling vs pyrolysis 18
Table 4.1 Typical composition of tire 32
Table 4.2 Typical proximate and ultimate analysis of scrap tire 33
Table 5.1 Tire recycling to produce MRP using mechanical grinding—Design basis and assumption 78
Table 5.2 Tire recycling to produce MRP using mechanical grinding—Major stream flows 81
Table 5.3 Tire recycling to produce MRP using mechanical grinding—Major equipment 82
Table 5.4 Tire recycling to produce MRP using mechanical grinding—Utility summary 82
Table 5.5 Tire recycling to produce MRP using mechanical grinding—Total capital investment 90
Table 5.6 Tire recycling to produce MRP using mechanical grinding—Capital investment by section 90
Table 5.7 Tire recycling to produce MRP using mechanical grinding—Variable costs 91
Table 5.8 Tire recycling to produce MRP using mechanical grinding—Production costs 91
Table 6.1 Tire recycling to produce carbon black and fuel oil using pyrolysis process—Design basis and assumption 95
Table 6.2 Tire recycling to produce carbon black and fuel oil using pyrolysis process—Major stream flows 98
Table 6.3 Tire recycling to produce carbon black and fuel oil using pyrolysis process—Major equipment 100
Table 6.4 Tire recycling to produce carbon black and fuel oil using pyrolysis process—Utility summary 102
Table 6.5 Tire recycling to produce carbon black and fuel oil using pyrolysis process—Total capital investment 107
Table 6.6 Tire recycling to produce carbon black and fuel oil using pyrolysis process—Capital investment by section 108
Table 6.7 Tire recycling to produce carbon black and fuel oil using pyrolysis process—Variable costs 109
Table 6.8 Tire recycling to produce carbon black and fuel oil using pyrolysis process—Production costs 110
Table 7.1 Tire recycling to produce MRP using cryogenic grinding—Design basis and assumption 115
Table 7.2 Tire recycling to produce MRP using cryogenic grinding—Major stream flows 117
Table 7.3 Tire recycling to produce MRP using cryogenic grinding—Major equipment 118
Table 7.4 Tire recycling to produce MRP using cryogenic grinding—Utility summary 118
Table 7.5 Tire recycling to produce MRP using cryogenic grinding—Total capital investment 125
Table 7.6 Tire recycling to produce MRP using cryogenic grinding—Capital investment by section 126
Table 7.7 Tire recycling to produce MRP using cryogenic grinding—Variable costs 126
Table 7.8 Tire recycling to produce MRP using cryogenic grinding—Production costs 127

Figures

Figure 2.1 Operating cost comparison for the three processes 19
Figure 2.2 Effect of by-product price variation on the net production cost 20
Figure 3.1 Tire circular economy 26
Figure 4.1 Typical structure of a tire with its components 31
Figure 4.2 Advertisement of a rubber recycling business in Leipzig, Germany dating back to 1909 34
Figure 4.3 Schematic representation of ambient grinding 40
Figure 4.4 Schematic representation of cryogenic grinding 42
Figure 4.5 Typical scheme for a scrap tire pyrolysis plant 57
Figure 5.1 Typical scheme for a mechanical tire recycling plant (US 7445170) 84
Figure 5.2 Tire cutting apparatus (WO 2015066753) 85
Figure 5.3 Tire debeading apparatus (US 20180036915) 86
Figure 5.4 Effect of plant capacity on the capital investment 92
Figure 5.5 Effect of scrap tire feed price on the production cost and product value 92
Figure 5.6 Effect of steel wire by-product on the production cost and product value 93

Confidential. © 2022 IHS Markit. All rights reserved.

Figure 5.7 Effect of operating level capacity on the production cost 93
Figure 6.1 Effect of plant capacity on capital investment 111
Figure 6.2 Effect of scrap tire feed price on the production cost and product value 111
Figure 6.3 Effect of steel wire by-product price on the production cost and product value 112
Figure 6.4 Effect of fuel oil by-product price on the production cost and product value 112
Figure 6.5 Effect of operating level capacity on the production cost 113
Figure 7.1 Cryomill system (US 9943854) 120
Figure 7.2 Cryogenic grinding apparatus (US 10766038) 121
Figure 7.3 Cryogenic grinding apparatus (US 5634599) 122
Figure 7.4 Glass transition temperature of rubber 123
Figure 7.5 Effect of plant capacity on the capital investment 128
Figure 7.6 Effect of scrap tire feed price on the production cost and product value 128
Figure 7.7 Effect of liquid N_2 price on the production cost and product value 129
Figure 7.8 Effect of steel wire by-product price on the production cost and product value 129
Figure 7.9 Effect of operating level capacity on the production cost 130

Appendix C Figures

Figure 5.1 PFD 1 of 2 of MRP using mechanical grinding of waste tires 148
Figure 5.1 PFD 2 of 2 of tire recycling to produce MRP using mechanical grinding process 149
Figure 6.1 PFD 1 of 2 of tire recycling to produce carbon black and fuel oil using pyrolysis process 150
Figure 6.1 PFD 2 of 2 of tire recycling to produce carbon black and fuel oil using pyrolysis process 151
Figure 7.1 PFD 1 of 2 of tire recycling to produce MRP using cryogenic grinding process 152
Figure 7.1 PFD 2 of 2 of tire recycling to produce MRP using cryogenic grinding process 153

Confidential. © 2022 IHS Markit. All rights reserved.

Customer Care

CustomerCare@ihsmarkit.com

Asia and the Pacific Rim

Japan: +81 3 6262 1887

Asia Pacific: +604 291 3600

Europe, Middle East, and Africa: +44 1344 328 300

Americas: +1 800 447 2273

Disclaimer

The information contained in this report is confidential. Any unauthorized use, disclosure, reproduction, or dissemination, in full or in part, in any media or by any means, without the prior written permission of IHS Markit or any of its affiliates ("IHS Markit") is strictly prohibited. IHS Markit owns all IHS Markit logos and trade names contained in this report that are subject to license. Opinions, statements, estimates, and projections in this report (including other media) are solely those of the individual author(s) at the time of writing and do not necessarily reflect the opinions of IHS Markit. Neither IHS Markit nor the author(s) has any obligation to update this report in the event that any content, opinion, statement, estimate, or projection (collectively, "information") changes or subsequently becomes inaccurate. IHS Markit makes no warranty, expressed or implied, as to the accuracy, completeness, or timeliness of any information in this report, and shall not in any way be liable to any recipient for any inaccuracies or omissions. Without limiting the foregoing, IHS Markit shall have no liability whatsoever to any recipient, whether in contract, in tort (including negligence), under warranty, under statute or otherwise, in respect of any loss or damage suffered by any recipient as a result of or in connection with any information provided, or any course of action determined, by it or any third party, whether or not based on any information provided. The inclusion of a link to an external website by IHS Markit should not be understood to be an endorsement of that website or the site's owners (or their products/services). IHS Markit is not responsible for either the content or output of external websites. Copyright © 2022, IHS Markit®. All rights reserved and all intellectual property rights are retained by IHS Markit.

now a part of

S&P Global