

***PERP Report***

***Thermoplastic Polyurethanes (TPUs)***  
**02/03S7**

*May 2003*



44 South Broadway, White Plains, New York 10601, USA  
Tel: +1 914 609 0300    Fax: +1 914 609 0399

# **Contents**

---

<b>Section</b>		<b>Page</b>
<b>1</b>	<b>Summary.....</b>	1
1.1	INTRODUCTION .....	1
1.2	CHEMISTRY .....	7
1.3	PROCESS DESIGN - TPUs.....	9
1.4	ECONOMICS.....	12
1.5	GLOBAL SUMMARY.....	15
<b>2</b>	<b>Introduction.....</b>	18
2.1	BACKGROUND ON THERMOPLASTIC POLYURETHANES (TPUs).....	18
2.2	OVERVIEW OF THERMOPLASTIC ELASTOMERS (TPEs).....	24
2.2.1	Background .....	24
2.2.2	Properties and Performance: Definitions .....	29
2.2.3	Definition of TPE Polymers.....	31
2.2.4	General Characteristics of TPEs .....	35
<b>3</b>	<b>Technology.....</b>	42
3.1	CHEMISTRY .....	42
3.2	PROCESS DESIGN.....	45
3.2.1	Thermoplastic Polyurethanes.....	45
3.2.2	Polyester Polyols.....	48
3.2.3	Polyether Polyols .....	51
3.3	TRENDS IN TECHNOLOGY.....	51
<b>4</b>	<b>Process Economics .....</b>	54
4.1	BASIS .....	54
4.2	INVESTMENT .....	55
4.3	ECONOMICS .....	56
4.4	RAW MATERIAL COST SENSITIVITY – EFFECT OF BACK INTEGRATION .....	70
<b>5</b>	<b>Commercial Analysis.....</b>	75
5.1	END USES.....	75
5.1.1	Extrusion Applications .....	76
5.1.2	Solution and Adhesives .....	77

5.1.3	Injection Molding .....	78
5.1.4	Other Applications .....	78
5.2	REGIONAL DEMAND ANALYSIS .....	79
5.2.1	North America .....	79
5.2.2	Western Europe.....	80
5.2.3	Japan .....	82
5.2.4	Rest Of World (ROW) .....	83
5.2.5	Global Summary .....	84
5.3	GLOBAL SUPPLY .....	86
<b>6</b>	<b>References .....</b>	<b>88</b>
<b>7</b>	<b>Glossary .....</b>	<b>89</b>

<b>Appendix</b>		<b>Page</b>
<b>A</b>	<b>Elements of Nexant/Chem Systems' Capital Cost Estimates.....</b>	<b>A-1</b>
<b>B</b>	<b>PERP Program Title Index .....</b>	<b>B-1</b>

<b>Figure</b>	<b>Page</b>
1.1 Thermoplastic Polyurethane Morphology .....	2
1.2 Benefits and Drawbacks of Various TPUs .....	3
1.3 Tear Resistance of Thermoplastic Elastomers.....	4
1.4 Taber Abrasion Resistance Comparison.....	5
1.5 Polyester and Polyether TPUs .....	7
1.6 Commonly Used TPU Raw Materials .....	9
1.7 TPU Prepolymer Manufacturing Processes .....	10
1.8 TPU Manufacture Via The “One-Shot” Process .....	11
1.9 Ester-TPU: Cost Comparison of Twin Screw Reactive Extrusion Equipment.....	14
1.10 Ether-TPU: Cost Comparison of Twin Screw Reactive Extrusion Equipment .....	14
1.11 Global TPU Demand by End-Use Process, 2002 .....	16
1.12 Regional Demand Pattern for TPUs .....	17
2.1 Thermoplastic Polyurethane Morphology .....	19
2.2 Benefits and Drawbacks of Various TPUs .....	20
2.3 Tear Resistance of Thermoplastic Elastomers.....	21
2.4 Taber Abrasion Resistance Comparison.....	22
2.5 Elastomer Industry Growth, 1938-2003 .....	25
2.6 Phase Arrangement In Crystalline Block Copolymers .....	27
2.7 Phase Arrangements Of Polymer/Elastomer Blends .....	28
2.8 TPE Product Life Cycle .....	35
2.9 Global TPE Scope: Demand Versus Growth.....	36
2.10 Thermoplastic Elastomers – Performance Regimes .....	37
2.11 TPE Performance Regimes .....	37
2.12 Functional Determinants Of Rubber Products.....	40
2.13 Replacement Of Competing Materials as a Component of TPE Growth .....	41
3.1 Thermoplastic Polyurethane Morphology .....	42
3.2 Polyester and Polyether TPUs .....	43
3.3 Commonly Used TPU Raw Materials .....	45
3.4 TPU Prepolymer Manufacturing Processes .....	46

3.5	TPU Manufacture Via The “One-Shot” Process .....	47
3.6	Polyester Polyol Preparation Section.....	49
3.7	1,4-Butanediol Recovery Section .....	50
3.8	Polyoxytetramethylene Ether.....	52
4.1	Ester-TPU: Cost Comparison of Twin Screw Reactive Extrusion Equipment.....	57
4.2	Ether-TPU: Cost Comparison of Twin Screw Reactive Extrusion Equipment .....	58
4.3	Comparison of Ester-TPU and Ether-TPU Production Costs By Line Size .....	59
4.4	Comparison of Integrated Versus Non-Integrated TPU Production Costs.....	71
4.5	Effect of Ester Polyol Price on Ester TPU Economics .....	71
4.6	Effect of Ether Polyol Price on Ether – TPU Economics .....	72
5.1	North American TPU Demand by End-Use Process, 2002 .....	80
5.2	West European TPU Demand by End-Use Process, 2002.....	81
5.3	Japanese TPU Demand by End-Use Process, 2002 .....	82
5.4	ROW TPU Demand by End-Use Process, 2002 .....	84
5.5	Global TPU Demand by End-Use Process, 2002 .....	85
5.6	Regional Demand Pattern for TPUs .....	86

Table	Page	
1.1	Thermoplastic Polyurethane Physical Properties .....	4
1.2	Thermoplastic Polyurethane Physical Properties .....	6
1.3	Effect of Curing on TPU Properties.....	6
1.4	Ester-TPU: Cost Comparison Of Twin Screw Reactive Extrusion Equipment.....	13
1.5	Ether-TPU: Cost Comparison Of Twin Screw Reactive Extrusion Equipment .....	13
1.6	Global Demand Summary for TPUs.....	15
1.7	Regional Demand Summary for TPUs .....	16
2.1	Thermoplastic Polyurethane Physical Properties .....	21
2.2	Thermoplastic Polyurethane Physical Properties .....	23
2.3	Effect of Curing on TPU Properties.....	24
2.4	Hard Polymer/Elastomer Blend Combinations.....	29
2.5	Comparison of TPU Properties Versus Selected Competing Materials .....	33

2.6	Intermaterial Substitution Competitive Grid .....	38
4.1	Reactive-Extruder Twin Screw Capital Cost Estimates for TPU Production .....	55
4.2	Ester-TPU: Cost Comparison Of Twin Screw Reactive Extrusion Equipment.....	56
4.3	Ether-TPU: Cost Comparison Of Twin Screw Reactive Extrusion Equipment .....	57
4.4	Cost of Production Estimate for: Ester TPU Process: Reactive Extrusion - 40 mm Twin Screw.....	60
4.5	Cost of Production Estimate for: Ester TPU Process: Reactive Extrusion – 58 mm Twin crew .....	61
4.6	Cost of Production Estimate for: Ester TPU Process: Reactive Extrusion – 70 mm Twin Screw .....	62
4.7	Cost of Production Estimate for: Ester TPU Process: Reactive Extrusion – 92 mm Twin Screw .....	63
4.8	Cost of Production Estimate for: Ester TPU Process: Reactive Extrusion – 133 mm Twin Screw .....	64
4.9	Cost of Production Estimate for: Ether TPU Process: Reactive Extrusion – 40 mm Twin Screw .....	65
4.10	Cost of Production Estimate for: Ether TPU Process: Reactive Extrusion – 58 mm Twin Screw .....	66
4.11	Cost of Production Estimate for: Ether TPU Process: Reactive Extrusion – 70 mm Twin Screw .....	67
4.12	Cost of Production Estimate for: Ether TPU Process: Reactive Extrusion – 92 mm Twin Screw .....	68
4.13	Cost of Production Estimate for: Ether TPU Process: Reactive Extrusion – 133 mm Twin Screw .....	69
4.14	Cost Comparison of Integrated Versus Non-Integrated TPU Production .....	70
4.15	Cost of Production Estimate for: Polyester Polyol Process: Batch.....	73
4.16	Cost of Production Estimate for: PTMEG Process: DuPont.....	74
5.1	TPU Property Advantages and Applications by Polyol.....	75
5.2	Key TPU Attributes by End-Use Market.....	76
5.3	Engineering Thermoplastic Polyurethane Resin Types, Properties, and Application..	79
5.4	North American Demand Summary for TPUs.....	79
5.5	West European Demand Summary for TPUs .....	81
5.6	Japanese Demand Summary for TPUs.....	82

5.7	ROW Demand Summary for TPUs .....	83
5.8	Global Demand Summary for TPUs.....	84
5.9	Regional Demand Summary for TPUs .....	85
5.10	Global TPU Capacity, 2002.....	87