

Epoxy Resins

Table of Contents

A Report by **NexantThinking™**

Process Evaluation/Research Planning (PERP) Program

PERP Report 2015S4 – Published June 2015

www.nexantthinking.com

Section	Page
1 Executive Summary	1
1.1 INDUSTRY OVERVIEW AND TECHNOLOGY LICENSING STATUS.....	2
1.2 BUSINESS AND STRATEGIC ANALYSIS REVIEW	3
1.3 EPOXY RESINS, HARDENERS, AND MODIFIERS	4
1.3.1 Epoxy Resins	4
1.3.2 Curing Agents.....	5
1.3.3 Formulation Modifiers.....	6
1.3.4 Regulatory Requirements and Pending Issues.....	6
1.4 COMMERCIAL PROCESSES	7
1.4.1 Liquid Epoxy Resin (LER, DGEBA)	7
1.4.2 Solid Epoxy Resin (SER, DGEBA).....	7
1.4.3 Epoxy Phenol Novolac (EPN) Resins	7
1.4.4 Commercial Process Technologies.....	7
1.5 DEVELOPING TECHNOLOGIES	8
1.5.1 Green Technology Developments.....	8
1.6 PROCESS ECONOMICS.....	9
1.7 COMMERCIAL APPLICATIONS AND MARKET ANALYSIS	10
1.7.1 Demand	10
1.7.2 Supply	11
1.7.3 Supply, Demand, and Trade	12
2 Introduction.....	13
2.1 OVERVIEW OF EPOXY RESINS	13
2.2 BRIEF HISTORY OF EPOXY RESINS.....	14
2.3 OVERVIEW OF INDUSTRY STRUCTURE AND LICENSING STATUS.....	15
2.3.1 Industry Structure	15
2.3.2 Trade Names.....	16
2.3.3 Licensing Status	16
2.4 BUSINESS AND STRATEGIC ANALYSIS REVIEW	17

3	Chemistry and Epoxy Resin Products	19
3.1	KEY PHYSICAL AND THERMODYNAMIC PROPERTIES	19
3.1.1	Properties of Uncured Epoxy Resins	19
3.1.2	Epoxy Curing Process	20
3.1.3	Properties of Cured Epoxy Resins	21
3.2	CATEGORIZATION OF EPOXY RESINS	22
3.2.1	Liquid and Solid DGEBA Epoxy Resins	23
3.2.2	Phenoxy Resins	24
3.2.3	Flame Retardant Epoxy Resins	24
3.2.4	Multifunctional Epoxy Resins	25
3.2.5	Specialty Epoxy Resins	26
3.2.6	Other Epoxy Resins and Derivatives	27
3.3	CURING AGENTS AND MECHANISMS	27
3.3.1	Amines and Amine Derivatives	28
3.3.2	Acid Anhydrides	30
3.3.3	Catalytic Curing Agents	30
3.3.4	Melamine-, Urea-, or Phenol-formaldehyde Resins	31
3.4	FORMULATION MODIFIERS	32
3.4.1	Diluents	32
3.4.2	Thixotropes	33
3.4.3	Flexibilizers	33
3.4.4	Tougheners	33
3.4.5	Fillers	34
3.4.6	Accelerators	34
3.4.7	Pigments and Dyes	34
3.5	REGULATORY REQUIREMENTS AND PENDING ISSUES	35
3.5.1	Volatile Organic Compounds (VOCs)	35
3.5.2	Bisphenol A (BPA)	35
3.5.3	Other Health Risks	37
4	Commercial Processes	38
4.1	PROCESS CHEMISTRY	38
4.1.1	Liquid Epoxy Resins (LER) - Bisphenol A-based	38
4.1.2	Solid Epoxy Resins (SER) – Bisphenol A-based	43
4.1.3	Epoxy Phenol Novolac Resins	45
4.2	COMMERCIAL PROCESS TECHNOLOGY	46
4.2.1	Dow Epoxy	46
4.2.2	Hexion Inc.	47
4.2.3	Huntsman Advanced Materials	49
4.2.4	DIC Corporation	50
4.2.5	Nippon Steel & Sumikin Chemical	50

4.2.6	Other Technology Owners	51
4.3	CONCLUSIONS	51
5	Developing Technologies	52
5.1	EPOXY RESIN TECHNOLOGY DEVELOPMENTS	52
5.1.1	Dow Epoxy	52
5.1.2	Solvay	52
5.1.3	BASF	52
5.1.4	Developments in China	53
5.2	GREEN TECHNOLOGY DEVELOPMENTS.....	53
5.2.1	Bio-based Epoxy Resins	53
5.2.2	Epichlorohydrin via Glycerol.....	53
6	Process Economics	56
6.1	COSTING BASIS	56
6.1.1	Investment Basis	56
6.1.2	Pricing Basis.....	56
6.1.3	Cost of Production Basis	58
6.2	LIQUID EPOXY RESINS PRODUCED VIA EPICHLOROHYDRIN AND BISPHENOL A	58
6.2.1	LER Cost of Production Estimate in the USGC by Level of Integration.....	59
6.2.2	LER Cost of Production Estimate in China	66
6.3	SOLID EPOXY RESINS (SER) VIA EPICHLOROHYDRIN AND BISPHENOL A	69
6.3.1	SER Cost of Production Estimate in the USGC by Level of Integration	69
6.3.2	SER Cost of Production Estimate in China	72
6.4	EPOXY PHENOL NOVOLAC RESINS	75
6.4.1	EPN Cost of Production Estimate in the USGC	75
6.4.2	EPN Cost of Production Estimate in China	75
6.5	SENSITIVITY ANALYSIS.....	79
6.5.1	Sensitivity of Production Cost to Bisphenol A Price	79
6.5.2	Sensitivity of Production Cost to Epichlorohydrin Price	79
6.5.3	Sensitivity of Production Cost to Capital Investment	80
6.6	CONCLUSION	81
7	Commercial Applications Overview	83
7.1	PAINTS AND COATINGS	83
7.1.1	Powder Coatings	84
7.1.2	Marine and Industrial	84
7.1.3	Cans and Coil Coatings	84
7.1.4	Automotive Primers	85
7.1.5	Other Coating Applications	85
7.1.6	Environmental Concerns	85
7.2	ELECTRICAL/ELECTRONICS	86

	7.2.1	Epoxy Molding Components (EMC)	86
	7.2.2	Electrical Laminates	86
	7.2.3	Heavy Electrical.....	86
	7.3	ADHESIVES	87
	7.4	CONSTRUCTION	87
	7.5	WIND TURBINES.....	87
	7.6	COMPOSITES	87
	7.7	TOOLING	88
8		Regional Market Analysis.....	89
	8.1	GLOBAL	89
	8.1.1	Demand	89
	8.1.2	Supply	91
	8.1.3	Supply, Demand, and Trade	92
	8.2	NORTH AMERICA	93
	8.2.1	Demand.....	93
	8.2.2	Supply	94
	8.2.3	Supply, Demand, and Trade	94
	8.3	WESTERN EUROPE	95
	8.3.1	Demand	95
	8.3.2	Supply	95
	8.3.3	Supply, Demand, and Trade	97
	8.4	ASIA PACIFIC	98
	8.4.1	Demand.....	98
	8.4.2	Supply	98
	8.4.3	Supply, Demand, and Trade	101
	8.5	REST OF THE WORLD (ROW)	102
	8.5.1	Demand	102
	8.5.2	Supply	102
	8.5.3	Supply, Demand, and Trade	102
9		Glossary	104
10		References	106

	Appendix	Page
A	Definition of Capital Cost Terms Used in Process Economics	A-1
B	Definition of Operating Cost Terms Used in Process Economics.....	B-1
C	Additional Cost of Production (COP) Estimates	C-1
D	PERP Program Title Index (2006 - 2015)	D-1

Figure	Page
1.1 Epoxy Resin Value Chain.....	1
1.2 Industry Structure of the Top Six Producers	2
1.3 Main Types of Epoxy Resins.....	5
1.4 Comparison of Epoxy Resin Production Costs	9
1.5 Epoxy Resin Applications, 2015.....	10
1.6 Top Epoxy Resin Suppliers by Capacity, 2015	11
1.7 Global Epoxy Resin Supply and Demand (2012-2020)	12
2.1 Epoxy Resin Value Chain.....	13
2.2 Industry Structure (Major Producers)	15
3.1 Generic Time Temperature Transformation (TTT) Diagram	21
3.2 Types of Epoxy Resins.....	22
4.1 Liquid Epoxy Resins via Caustic Coupling	40
4.2 Phase Transfer Liquid Epoxy Resins Process	42
4.3 Upstaging of LER to Higher Molecular Weight Epoxy Resin	44
6.1 LER Cost of Production by Level of Integration	66
6.2 Comparison of LER in the USGC and China	68
6.3 SER Production Costs by Level of Integration	72
6.4 SER Production Costs in the USGC and China.....	74
6.5 Comparison of EPN in the USGC and China.....	78
6.6 Cost of Production Sensitivity to Bisphenol A Price	79
6.7 Cost of Production Sensitivity to Epichlorohydrin Price	80
6.8 Cost of Production Sensitivity to Capital Investment	80
6.9 Comparison of Epoxy Resin Production Costs	82
8.1 Epoxy Resin Applications 2015.....	89
8.2 Epoxy Resin Demand by Region (2012-2020).....	90
8.3 Top Epoxy Resin Suppliers by Capacity, 2015	91
8.4 Capacity by Region (2012-2020)	91
8.5 Global Epoxy Resin Supply, Demand, and Trade (2012-2020).....	93
8.6 North American Epoxy Resin Supply, Demand, and Trade (2012-2020)	94
8.7 Western Europe Supply, Demand, and Trade (2012-2020)	97
8.8 Asia Pacific Epoxy Resin Supply, Demand, and Trade (2012-2020).....	101
8.9 ROW Epoxy Resin Supply, Demand, and Trade (2012-2020)	103

Table	Page
1.1 Epoxy Resin Licensor Status	3
1.2 Strategic/Business Considerations	3
2.1 Epoxy Resin Development Timeline	14
2.2 Main Epoxy Resin Producers and Trade Names	16
2.3 Epoxy Resin Licensor Status	17
2.4 Strategic/Business Considerations	17
3.1 Properties of Uncured Epoxy Resins	19
3.2 DGEBA Epoxy Resins	23
3.3 Properties of Common Epoxy Resin Curing Agents	28
3.4 Typical Epoxy Resin Fillers	34
6.1 Raw Material, Products, Utilities, and Labor Prices	57
6.2 Mass Balance for Caustic Coupling Process	58
6.3 Cost of Production Estimate for: Liquid Epoxy Resin (DGEBA) Process: Continuous Caustic Coupling Process of Epichlorohydrin and Bisphenol A	60
6.4 Cost of Production Estimate for: Liquid Epoxy Resin (DGEBA) Process: Continuous Caustic Coupling Process of Epichlorohydrin and Bisphenol A (Integrated BPA)	61
6.5 Cost of Production Estimate for: Liquid Epoxy Resin (DGEBA) Process: Continuous Caustic Coupling Process of Epichlorohydrin and Bisphenol A (Integrated BPA-Dow)	62
6.6 Cost of Production Estimate for: Liquid Epoxy Resin (DGEBA) Process: Continuous Caustic Coupling Process of Epichlorohydrin and Bisphenol A (Integrated ECH)	63
6.7 Cost of Production Estimate for: Liquid Epoxy Resin (DGEBA) Process: Continuous Caustic Coupling Process of Epichlorohydrin and Bisphenol A (Integrated Bio-ECH)	63
6.8 Cost of Production Estimate for: Liquid Epoxy Resin (DGEBA) Process: Continuous Caustic Coupling Process of Epichlorohydrin and Bisphenol A (Integrated BPA and ECH)	65
6.9 LER Cost of Production	66
6.10 Cost of Production Estimate for: Liquid Epoxy Resin (DGEBA) Process: Continuous Caustic Coupling Process of Epichlorohydrin and Bisphenol A	67
6.11 Comparison of LER in the USGC and China	68
6.12 Mass Balance for Advancement Process	69
6.13 Cost of Production Estimate for: Solid Epoxy Resin (n = 2)* Process: Advancement Reaction of LER and Bisphenol A	70

6.14	Cost of Production Estimate for: Solid Epoxy Resin (n = 2)* Process: Advancement Reaction of LER and Bisphenol A (Integrated LER)	71
6.15	SER Production Costs by Level of Integration	72
6.16	Cost of Production Estimate for: Solid Epoxy Resin (n = 2)* Process: Advancement Reaction of LER and Bisphenol A.....	73
6.17	SER Production Costs in the USGC and China.....	74
6.18	Mass Balance for Epoxy Phenol Novolac Resin Process	75
6.19	Cost of Production Estimate for: Epoxy Phenol Novolac Resin Process: Condensation Reaction of Phenol and Formaldehyde & Epoxidation of Phenol Novolac Resin with Epichlorohydrin	76
6.20	Cost of Production Estimate for: Epoxy Phenol Novolac Resin Process: Condensation Reaction of Phenol and Formaldehyde & Epoxidation of Phenol Novolac Resin with Epichlorohydrin	77
6.21	Comparison of EPN in the USGC and China.....	78
6.22	Summary of Economics for Epoxy Resin Production	82
7.1	Epoxy Resin Applications.....	83
8.1	Epoxy Resin Demand by Region (2012-2020).....	90
8.2	Capacity by Region (2012-2020)	92
8.3	Global Epoxy Resin Supply, Demand, and Trade (2012-2020).....	93
8.4	Major Epoxy Resin Capacity in North America, 2015	94
8.5	North American Epoxy Resin Supply, Demand, and Trade (2012-2020)	95
8.6	Major Epoxy Resin Capacity in Western Europe, 2015	96
8.7	Western Europe Supply, Demand, and Trade (2012-2020)	97
8.8	Major Epoxy Resin Capacity in Asia Pacific, 2015.....	99
8.9	Asia Pacific Epoxy Resin Supply, Demand, and Trade (2012-2020).....	102
8.10	ROW Epoxy Resin Supply, Demand, and Trade (2012-2020)	103

Nexant Thinking™

Process Evaluation/Research Planning



The NexantThinking™ Process Evaluation/Research Planning (PERP) program is recognized globally as the industry standard source for information relevant to the chemical process and refining industries. PERP reports are available as a subscription program or on a single report basis.

Contact Details:

New York: Marcos Nogueira Cesar, Vice President, Global Products, E&CA: Nexant Thinking™
Phone: + 1-914-609-0324, e-mail: mcesar@nexant.com

New York: Heidi Junker Coleman, Global Programs Support Manager
Phone: + 1-914-609-0381, e-mail: hcoleman@nexant.com

Nexant, Inc. (www.nexant.com) is a leading management consultancy to the global energy, chemical, and related industries. For over 38 years, Nexant has helped clients increase business value through assistance in all aspects of business strategy, including business intelligence, project feasibility and implementation, operational improvement, portfolio planning, and growth through M&A activities. Nexant has its main offices in San Francisco (California), White Plains (New York), and London (UK), and satellite offices worldwide.

Copyright © by Nexant Inc. 2015. All Rights Reserved.