

Carbon Monoxide

PERP 09/10S11

December 2010

Alan J. Nizamoff



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

This Report was prepared by Nexant, Inc. ("Nexant") and is part of the ChemSystems Online® suite. Except where specifically stated otherwise in this Report, the information contained herein is prepared on the basis of information that is publicly available, and contains no confidential third party technical information to the best knowledge of Nexant. Aforesaid information has not been independently verified or otherwise examined to determine its accuracy, completeness or financial feasibility. Neither NEXANT, Subscriber nor any person acting on behalf of either assumes any liabilities with respect to the use of or for damages resulting from the use of any information contained in this Report. Nexant does not represent or warrant that any assumed conditions will come to pass.

The Report is submitted on the understanding that the Subscriber will maintain the contents confidential except for the Subscriber's internal use. The Report should not be reproduced, distributed or used without first obtaining prior written consent by Nexant. Each Subscriber agrees to use reasonable effort to protect the confidential nature of the Report.

Copyright © by Nexant Inc. 2010. All rights reserved.

Contents

Section	Page
1 Executive Summary	1
1.1 INTRODUCTION	1
1.2 COMMERCIAL TECHNOLOGIES	1
1.2.1 Production	1
1.2.2 Purification/Recovery	3
1.3 DEVELOPING TECHNOLOGIES	4
1.3.1 Breakdown Carbon Dioxide into Carbon Monoxide Using Visible Light	4
1.3.2 Increasing Yield from Gasification	4
1.3.3 Renewable Hydrogen and Carbon Monoxide from Nonvolatile Fuels	4
1.3.4 Patents	5
1.4 ECONOMIC ANALYSIS	5
1.5 COMMERCIAL ANALYSIS	7
1.5.1 Carbon Monoxide Demand Forecast	8
2 Commercial Technologies	11
2.1 INTRODUCTION	11
2.2 PRODUCTION	15
2.2.1 Steam Reforming	15
2.2.2 Partial Oxidation (POX)	18
2.2.3 Autothermal Reforming (ATR)	22
2.2.4 Gasification	24
2.3 PURIFICATION	29
2.3.1 Introduction	29
2.3.2 Cryogenic Purification	31
2.3.3 Pressure Swing Adsorption	36
2.3.4 Membrane Separation	38
2.3.5 Salt Solution Absorption	43
2.4 STORAGE AND TRANSPORTATION	47

3	Developing Technologies	48
3.1	BREAKDOWN CARBON DOXIDE INTO CARBON MONOXIDE USING VISIBLE LIGHT	48
3.2	INCREASING YIELD FROM GASIFICATION	49
3.3	RENEWABLE HYDROGEN AND CARBON MONOXIDE FROM NONVOLATILE FUELS	50
3.4	PATENTS	52
	3.4.1 Production of Carbon Monoxide	52
	3.4.2 Recovery of Carbon Monoxide	58
4	Economic Analysis	64
4.1	BASIS	64
	4.1.1 Pricing Basis	64
	4.1.2 Investment Basis	64
	4.1.3 Cost of Production Basis	65
4.2	COST OF PRODUCTION	66
4.3	SENSITIVITY ANALYSIS	77
	4.3.1 Sensitivity to Natural Gas Price	77
	4.3.2 Sensitivity to Byproduct Hydrogen Price	79
	4.3.3 Sensitivity to Oxygen Price	80
	4.3.4 Sensitivity to Wood Price	81
	4.3.5 Sensitivity to Economy of Scale	82
	4.3.6 Sensitivity to Capital Investment	83
4.4	CONCLUSIONS	85
5	Commercial Market Analysis	86
5.1	CARBON MONOXIDE CONSUMPTION FACTORS	86
5.2	IMPLIED CARBON MONOXIDE CAPACITY	86
	5.2.1 Acetic Acid/Acetic Anhydride	86
	5.2.2 TDI/MDI	87
	5.2.3 Polycarbonate	87
	5.2.4 Phosgene for Specialty Chemicals	92
	5.2.6 Summary of Implied Carbon Monoxide Capacity	95
5.3	CARBON MONOXIDE DEMAND FORECAST	95

5.3.1	Acetic Acid	95
5.3.2	TDI.....	96
5.3.3	MDI.....	97
5.3.4	Polycarbonate.....	97
6	References.....	98

Appendix		Page
A	List of Acronyms and Abbreviations	A-1
B	Commercial Derivatives of Carbon Monoxide.....	B-1
C	Nexant’s <i>ChemSystems</i> Capital Cost Estimates	C-1
D	PERP Program Title Index (2000/2001-2009/2010).....	D-1

Figure	Page
1.1 Syngas & Carbon Monoxide Cost of Production Summary	6
1.2 Implied Carbon Monoxide Capacity Needed to Satisfy Existing Capacity of Carbon Monoxide Based Organic Chemicals, 2009	7
2.1 Steam Methane Reforming	17
2.2 Partial Oxidation of Methane	20
2.3 Autothermal Reforming	23
2.4 Block Flow Diagram - Conceptual Acetic Acid Production from Biomass Gasification	26
2.5 Process Schematic - CHOREN Syngas Production from Biomass	28
2.6 Carbon Monoxide Recovery by Cryogenic Liquid Methane Wash	33
2.7 Carbon Monoxide Recovery by Cryogenic Partial Condensation	35
2.8 Carbon Monoxide Recovery by PSA Separation	37
2.9 Simplified Flow Diagram for CO/H ₂ Production Employing VSA	39
2.10 Simplified Flow Sheet for the Calcor Economy Process	42
2.11 COPure SM Process	46
3.1 Block Flow Diagram for U.S. Patent 7 351 275	53
3.2 Block Flow Diagram for U.S. Patent 7 731 923	56
3.3 Block Flow Diagram for U.S. Patent Application 2009/0274600	60
4.1 Syngas and Carbon Monoxide Cost of Production Summary	67
4.2 Sensitivity of Syngas Cost of Production to Natural Gas Price	78
4.3 Sensitivity of Carbon Monoxide Cost of Production to Natural Gas Price	78
4.4 Sensitivity of Carbon Monoxide Cost of Production to Hydrogen Price	79
4.5 Sensitivity of Syngas Cost of Production to Oxygen Price	80
4.6 Sensitivity of Syngas and Carbon Monoxide Cost of Production to Wood Price	81
4.7 Sensitivity of Syngas Cost of Production to Economy of Scale	82
4.8 Sensitivity of Carbon Monoxide Cost of Production to Economy of Scale	83
4.9 Sensitivity of Carbon Monoxide Cost of Production to Capital Investment	84
5.1 Implied Carbon Monoxide Capacity Needed to Satisfy Existing Capacity of Carbon Monoxide Based Organic Chemicals, 2010	95

Table	Page
1.1 Acetic Acid Production and Carbon Monoxide Demand by Region.....	8
1.2 TDI Production and Carbon Monoxide Demand by Region	9
1.3 MDI Production and Carbon Monoxide Demand by Region	9
1.4 Polycarbonate Production and Carbon Monoxide Demand by Region	10
2.1 Typical Characteristic Syngas Composition.....	11
2.2 Characteristics of Commercial Coal Gasifiers.....	25
2.3 Typical Compositions of Carbon Monoxide Sources	30
2.4 Specifications of CO/PSA Commercial Plant.....	36
2.5 Typical Gas Compositions for a One Stage Membrane Separation of Syngas.....	38
2.6 Typical CO Purity Using Different Process Combinations	41
4.1 Feedstock, Byproduct and Utility Prices	64
4.2 Cost of Production Estimate for: Synthesis Gas (3:1) Process: Steam Methane Reforming (SMR).....	68
4.3 Cost of Production Estimate for: Synthesis Gas (1.7:1) Process: Partial Oxidation (POX)	69
4.4 Cost of Production Estimate for: Synthesis Gas (2:1) Process: Autothermal Reforming (ATR)	70
4.5 Cost of Production Estimate for: Synthesis Gas (1.7:1) Process: Biomass Gasification (purchased oxygen)	71
4.6 Cost of Production Estimate for: Carbon Monoxide Process: Cryogenic Separation of 3:1 Syngas (from SMR).....	73
4.7 Cost of Production Estimate for: Carbon Monoxide Process: Cryogenic Separation of 1.7:1 Syngas (from POX)	74
4.8 Cost of Production Estimate for: Carbon Monoxide Process: Cryogenic Separation of 2:1 Syngas (from ATR)	75
4.9 Cost of Production Estimate for: Carbon Monoxide Process: Cryogenic Separation of 1.7:1 Syngas (from biomass).....	76
5.1 Carbon Monoxide Consumption Factors in Organic Chemical Production	86
5.2 Implied Carbon Monoxide Capacity to Satisfy Acetic Acid Capacity, Annual Capacity as of 2nd Quarter 2010.....	88
5.3 Implied Carbon Monoxide Capacity to Satisfy TDI Capacity, Annual Capacity as of 2nd Quarter 2010.....	89

5.4	Implied Carbon Monoxide Capacity to Satisfy MDI Capacity, Annual Capacity as of 2nd Quarter 2010.....	90
5.5	Implied Carbon Monoxide Capacity to Satisfy Polycarbonate Capacity, Annual Capacity as of 2nd Quarter 2010.....	91
5.6	Implied Carbon Monoxide Capacity to Satisfy Phosgene Capacity for Use in Specialty Chemical Production, 2010	92
5.7	Capacities for Specialty Carbon Monoxide Applications, Annual Capacity as of 2nd Quarter 2010.....	94
5.8	Acetic Acid Production and Carbon Monoxide Demand by Region.....	96
5.9	TDI Production and Carbon Monoxide Demand by Region	96
5.10	MDI Production and Carbon Monoxide Demand by Region	97
5.11	Polycarbonate Production and Carbon Monoxide Demand by Region	97