

Liquefied Natural Gas

96/97S2

December 1997

TABLE OF CONTENTS

	Page
I EXECUTIVE SUMMARY	1
A. INTRODUCTION	1
B. LIQUEFACTION TECHNOLOGY	3
1. Liquefaction Processes	3
(a) Treatment of Feed Gas	3
(b) Liquefaction of Refrigeration Gas	3
2. The Thermodynamics of Liquefaction	5
3. Process Equipment and Technology Development	6
C. LNG STORAGE, TRANSPORT AND REGASIFICATION	7
1. Storage	7
2. Shipping	7
3. Regasification	7
D. ECONOMICS	8
E. MARKETS	11
1. Demand	11
2. Supply	13
II INTRODUCTION	14
A. THE RATIONALE FOR LNG	14
1. Pipeline and LNG Compared	14
B. THE LNG CHAIN	16
1. Field Production	16
(a) Sources of Natural Gas	16
(b) Field Processing	19
2. Base Load Liquefaction Plants	19
3. Shipping	19
4. Reception and Regasification Terminals	19
C. HISTORICAL DEVELOPMENT OF THE LNG INDUSTRY	20
III BASE LOAD LNG PLANTS AND LIQUEFACTION PROCESSES	21
A. INTRODUCTION	21
B. PRE-TREATMENT	24
1. Gas Reception Facilities	25
2. Acid Gas Removal	25
3. Mercury Removal	26
4. Dehydration	26
5. Heavy Hydrocarbon Removal and Separation	26

TABLE OF CONTENTS (Continued)

	Page
C. LIQUEFACTION PROCESSES	28
1. Introduction	28
2. Pure Refrigerant Cascade Process	29
(a) The Basic Process	29
(b) The Phillips <i>Optimized</i> Cascade Process	32
3. The Single Cycle Mixed Refrigerant (Single-MR) Process	34
(a) The PRICO Process	34
(b) The APCI Single MR Process	36
4. The Propane Pre-Cooled Mixed Refrigerant (C ₃ -MR Process)	36
5. The <i>Tealarc</i> Double Cycle MR Process	38
6. The Integral Incorporated Cascade Process	40
7. Nitrogen Removal	42
D. THE THERMODYNAMICS OF LIQUEFACTION	44
1. The Concept of Exergy	44
2. The Minimum Work for Liquefaction	46
3. Thermodynamic Efficiency of Liquefaction Processes	47
4. The Thermodynamics of Alternative Liquefaction Processes	50
5. Liquefaction Processes Compared	54
E. OPERATING PRESSURE OF LIQUEFACTION PLANTS	55
F. REMOVAL OF HEAVY HYDROCARBONS	57
1. Requirements for Heavy Hydrocarbon Removal	57
2. Impact of Feed Gas Composition	57
3. Base Load LNG Plants that Recover and Export Gas Liquids	57
4. Processing Requirements for Heavy Hydrocarbon Removal	58
(a) Initial Gas Chilling	58
(b) Recovery and Processing of Gas Liquids	58
(1) Simple Knock Out Drum	58
(2) Scrub Column	58
(3) Scrub Column with Heavy NGL Recycle Wash	59
(4) Gas Expansion Followed by a Scrub Column	59
5. Optimum System Operating Pressure	59
6. NGL Fractionation	62
7. Recovery of Ethane for Cracker Feedstock	62
G. LNG STORAGE AND EXPORT	65
1. Rollover	65
H. EQUIPMENT AND TECHNOLOGY DEVELOPMENTS	67
1. LNG Train Sizes and Configurations	67
2. Refrigerant Compressor Drivers	67

TABLE OF CONTENTS (Continued)

	Page
<ul style="list-style-type: none"> (a) Steam Versus Gas Turbines 67 (b) Dual Shaft Gas Turbines 68 (c) Single Shaft Gas Turbines 68 3. Refrigerant Compressors 70 4. Liquid Expanders 70 5. Heat Exchangers 71 <ul style="list-style-type: none"> (a) Spiral Wound Heat Exchangers 73 (b) Aluminium Plate Fin Exchangers 73 (c) Shell and Tube Exchangers 76 6. Ambient Cooling Medium 77 7. Future Technology Developments 77 <ul style="list-style-type: none"> (a) Train Size 77 (b) Pre-Treatment Processes 77 (c) Turbine Configuration 78 (d) Exchanger Type 78 	67 68 68 70 70 71 73 73 76 77 77 77 77 78 78
IV LNG SHIPPING	79
<ul style="list-style-type: none"> A. SHIP SIZE, COST AND SPEED 79 B. SHIP DESIGN 81 <ul style="list-style-type: none"> 1. Tank Design Issues 81 2. Containment Systems 81 3. Multi-Purpose Vessels 83 4. Propulsion System and Fuel 83 C. OPERATION AND SAFETY 84 	79 81 81 81 83 83 84
V IMPORT TERMINALS	85
<ul style="list-style-type: none"> A. INTRODUCTION 85 B. STORAGE 86 C. REVAPORIZATION 87 <ul style="list-style-type: none"> 1. Vaporization Systems 87 2. Use of ACold@ from Vaporization 87 D. VAPOR HANDLING 90 3. GAS QUALITY 91 	85 86 87 87 90 91
VI PEAK SHAVING FACILITIES	92

TABLE OF CONTENTS (Continued)

	Page
VII ECONOMICS	93
A. LNG CHAIN COST MODEL	93
1. Gas Production	93
2. Liquefaction Plant Costs	94
(a) Capital Costs	94
3. Cost of Production	96
4. LNG Shipping	99
(a) Capital Costs	99
(b) Cost of Shipping	99
5. Total LNG Chain Supply Costs	101
B. ECONOMICS OF GAS LIQUIDS REMOVAL	102
1. Impact of Gas Composition	102
2. The Economics of Ethane Extraction	103
(a) Ethane Valuation	103
(1) LNG Project is Gas Limited	103
(2) LNG Project is Market Limited	104
(b) Cost of Ethane Extraction	104
(c) Cost of Ethylene	107
VIII MARKET ANALYSIS	109
A. GLOBAL OVERVIEW	109
B. EAST ASIA	113
1. Demand	113
2. Supply	115
C. EUROPE	117
1. Demand	117
2. Supply	118
D. USA	120
1. Demand	120
2. Supply	120
GLOSSARY	122
REFERENCES	123

TABLES

	Page
Table I.B.1 Major Liquefaction Processes for Base Load LNG Plants	4
Table I.D.1 Key Cost Elements in LNG Chain	8
Table I.D.2 LNG Supply Chain Economics	10
Table I.E.1 World LNG Trade in 1996	12
 Table II.B.1 Natural Gas Compositions	 18
Table III.B.1 Typical LNG Product Specifications	24
Table III.C.1 Major Liquefaction Processes for Base Load LNG Plants	29
Table III.C.2 Application of Liquefaction Processes at Base Load LNG Plants	30
Table III.D.1 Exergy Losses of MR Liquefaction Processes	53
Table III.D.2 Liquefaction Cycle Efficiencies	54
 Table IV.A.1 Typical LNG Ship Parameters	 79
Table IV.B.1 LNG Ship Containment Systems	82
 Table VII.A.1 LNG Plant Capital Cost	 95
Table VII.A.2 Cost of Production Estimate for LNG - Middle East	97
Table VII.A.3 Cost of Production Estimate for LNG - Far East	98
Table VII.A.4 Cost of Shipping Estimate for LNG	100
Table VII.A.5 LNG Shipping Costs	101
Table VII.A.6 LNG Delivered Costs	101
Table VII.B.1 Effect of Feed Gas Composition on LNG Cost of Production	102
Table VII.B.2 NGL Recovery Rates for Base Load LNG Plants	105
Table VII.B.3 Cost of Production Estimate for Ethane from LNG	106
Table VII.B.4 Comparison of Ethylene Cost of Production between Ethane Extracted from an LNG Plant and Ethane Extracted from Associated Gas	108
 Table VIII.A.1 World LNG Trade in 1996	 110
Table VIII.A.2 Historical and Projected LNG Trade	112
Table VIII.B.1 LNG Import Terminals in East Asia	114
Table VIII.B.2 LNG Projects in East Asia	115
Table VIII.B.3 LNG Projects in the Middle East	116
Table VIII.C.1 LNG Import Terminals in Europe	118
Table VIII.C.2 LNG Projects in Africa	119
Table VIII.D.1 LNG Import Terminals in the USA	120
Table VIII.D.2 LNG Projects in the Americas	121

FIGURES

	Page
Figure I.A.1 The LNG Chain	2
Figure I.E.1 Historical and Projected LNG Trade	12
Figure II.B.1 The LNG Chain	17
Figure II.B.2 Terminology and Constituents of Natural Gas	18
Figure III.A.1 Base Load LNG Plant	22
Figure III.A.2 Simplified LNG Process Flowscheme Based on a Generic Liquefaction Process	23
Figure III.C.1 Pure Refrigeration Cascade Process - Simplified Flowscheme	31
Figure III.C.2 Simplified Flowscheme of the Phillips Optimized Cascade Process	33
Figure III.C.3 The APRICO@LNG Process	35
Figure III.C.4 Air Products and Chemicals Inc. Propane Pre-Cooled Mixed Refrigerant Process (Simplified Schematic)	37
Figure III.C.5 Tealarc Double Cycle Mixed Refrigerant Process	39
Figure III.C.6 Integral Incorporated Cascade Process - Gaz de France	41
Figure III.C.7 Subcooling and Flash Schemes for Final LNG Processing	43
Figure III.D.1 Expansion Engine	45
Figure III.D.2 Liquefaction Process Thermodynamics	49
Figure III.D.3 Heat Exchanger Temperature Profiles	51
Figure III.D.4 Liquefaction Process Temperature Profiles	52
Figure III.E.1 Pressure Enthalpy Chart	56
Figure III.F.1 Heavy Hydrocarbon Removal Schemes	60
Figure III.F.2 Alternative Gas Gathering Schemes	61
Figure III.F.3 NGL Fractionation Train	63
Figure III.H.1 Precooled Mixed Refrigerant Process, Using 4 Gas Turbines and 2 Gas Turbines	69
Figure III.H.2 Liquid Expander Application	72
Figure III.H.3 Spiral Wound Exchanger (Technip-Snamprogetti)	74
Figure III.H.4 Plate Fin Exchanger Configurations	75
Figure V.C.1 Import Terminal Schematic	88
Figure VIII.A.1 Growth of the World LNG Trade	111
Figure VIII.A.2 Historical and Projected LNG Trade	111