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Identification and market analysis of most promising added-value products to be co-produced with the fuels

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PU	Public	**X**
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	

Contents

1. INTRODUCTION

This report is a compilation of the three main activities carried out in the Bioref-Integ project on identification and market analysis of most promising added-value products to be co-produced with biofuels. These are the objectives and contents of Work Package 2. The deliverables that are included in this final report are:

Chapter 2 (D 2.1)	A complete list of added-value biomass-derived products and chemicals that can be derived from biomass processing systems with their technical potential
Chapter 3 (D 2.2)	Results of the market analysis of these products and chemicals
Chapter 4 (D 2.3)	Derivation of a short list of the most interesting chemicals from the viewpoint of the partners. More detailed market analysis of this short list per market sector and reference-case industrial complex

2. COMPLETE LIST OF ADDED-VALUE BIOMASS-DERIVED PRODUCTS AND CHEMICALS THAT CAN BE DERIVED FROM BIOMASS PROCESSING SYSTEMS WITH THEIR TECHNICAL POTENTIAL

A literature analysis has been conducted within the field of biomass-derived products in order to identify current and potential bio-based materials and chemicals. The analysis has been based on the composition of the raw materials of the selected reference case scenarios (WP1), i.e. wood, wheat, straw, sugar beet, potatoes, grass, micro-algae, rapeseed, pulp/paper residues, food industry residues and agro-residues. Information from all expert partners has also been incorporated in the list. Two considerations should be noted with regards to the list:

1. In principle any organic chemical can be derived from biomass if sufficient effort and cost is spent on conversion.
2. The list presented in Table 1 is not exhaustive as it is mostly based on the content and focus of the project and the partners.

2.1 Potential added value biomass derived products

Table 1 lists the potential added value chemicals and products from biorefineries as defined by the partners and derived from relevant literature.

Table 1 Complete list of potential added value biomass derived products

	Products	Route from biomass	Refs
		Exchange rate 1.25 USD per Euro	
1	(2,5)-bis-hydroxymethyl-furan (BHMF)	Reduction of 5-hydroxymethyl furfural or hydroxymethylation of furfuryl alcohol	1
2	1,2 propanediol	Hydrogenation of lactic acid	1, 3, 18
3	1,3 propanediol	Sugars fermentation, currently produced from 3-hydroxypropionic acid	2, 3, 17
4	1,4-butanediol,	Carbohydrates fermenattion or from succinic aicd	17
5	1,4-diaminobutane		17
6	1-amino-2-propanol		17
7	2 chloropropionic acid	From lactic acid	4
8	2,5- dimethyl furan	Hydrogenolysis of 5 hydroxymethyl furfural	5
9	2,5-Dimethyl-1,4-dioxane		17
10	2,5-furandicarboxylic acid	Sugars biochemical transformation	6
11	2-hydroxymethyl tetrahydrofuran		17
12	2-Pyrrolidone	From succinic acid	1, 17
13	3-hydroxybutyrolactone	Sugars chemical transformation	6
14	3-hydroxypropionic acid	Glucose fermentation	7, 2, 3, 6, 17
15	4-decalacton		4
16	5’-IMP (5'-Inosinic acid, disodium salt)		4
17	5-aminolevulinic acid		8
18	5-methyl furan		5
19	Acetaldehyde	From ethanol oxidation	3
20	Acetic acid contract	Sugars fermentation	3, 19
21	Acetoin	Sugars fermentation	6
22	Acetol	Hydrogenolysis of glycerine	4
23	Acetone	Glucose fermentation	3, 20
	Acetone	Glucose fermentation	3, 20
24	Acetylene	From syngas	5
25	Aconitic acid	Sugars fermentation	6
26	Acrolein	From glycerol	4, 21

27	Acrylamide	From 3-hydroxypropionic acid	2, 3, 17
28	Acrylic acid	From 3-hydroxypropionic acid	7, 2, 3, 6, 17, 22
29	Acrylonitrile	From 3-hydroxypropionic acid	2, 17
30	Activated carbon	From biomass pyrolysis	8
31	Adipic acid	From cyclohexanone or succinic acid	7, 2, 17, 31
32	Alanine	From 3 hydroxypropionic acid fermentation product	3
33	Alginate	Extracted from seaweed	9
34	Alkanes	From syngas by Fischer Tropsch	4
35	Alkyd resins	50% based on natural oils/ from propylene glycol	9, 7
36	Alkyl polyglycosides (APG)	From glucose and fatty acids	9
37	Alkyl polypentosides (C5-surfactants)	From hemicelluloses fractions and fatty acids	4, 9
38	Allyl alcohol		4, 23
39	Aminoacids	Carbohydrate fermentation	18
40	Ammonia	From producer gas	8
41	Antibiotics (bulk)	Sugars fermentation	38
42	Antibiotics (specialties)	Sugars fermentation	38
43	Arabinitol	From arabinose	6
44	Arabinogalactan	Extracted from the timber of the larch tree	5
45	Arabinose	From biomass by combined thermochemical treatment, acid hydrolysis and enzymatic treatment	3
46	Arginine	From sugars	3
47	Aspartame	From aspartic acid	4, 25
48	Aspartic acid	Derived from fumaric acid that can be made by fermentation	3, 6
49	Astaxanthine	Part synthetic, part by fermentation, part extracted from micro-algae	4, 9
50	Avermictins	From fermentation	4, 24
51	Benzene	From biomass gasification or catalytic hydrogenation of CO2	10, 31
	Benzene	From biomass gasification or catalytic hydrogenation of CO2	10, 31
52	Biocomposites		17
53	Bionolle 4,4 polyester	Sugars fermentation + fossil fuel	2, 9, 17
54	Bio-oil	Biomass pyrolysis	8
55	BioSyngas	Biomass gasification	6
56	Biotin	Fermentation	3
57	Biphenyls	Biomass thermochemical	11
58	Butanediol (BD)	From fumaric/succinic acid	7, 31
	Butanediol (BD)	From fumaric/succinic acid	7, 31
59	Butanetriol	Xylose or arabinose fermentation	3
60	Butanol	Sugars fermentation	2, 3, 17, 26
61	Butanol derivates	From butanol	8
62	Butyric acid	Sugars fermentation	3
63	Caprolactam	From cyclohexanone	7
64	Caprylic acid (octanoic acid)	From vegetable oil	8
65	Carbon dioxide	From bioethanol production, anaerobic fermentation and all respiration processes	9, 17
66	Carbon fibre	From lignin	11
67	Carbon monoxide	Biomass gasification or catalytic hydrogenation of CO2	10
68	Carboxylic acid	Catalytic hydrogenation of CO2	10
69	Carboxymethyl cellulose	From dissolving pulp	5, 9

70	Catchols, cresols, resorcinols	Biomass thermochemical processes	11
71	Cattle feed (DDGS)	Co-product from bioethanol production	12
72	Cellulose	From biomass	8
73	Cellulose acetate	From dissolving pulp	5, 9
74	Cellulose butyrate	From dissolving pulp	5, 9
75	Cetostearilic alcohol	From vegetable oil	8
76	Cetylic alcohol	From vegetable oil	8
77	Chitin/Chitosan	Extracted from crabs	9
78	Chlorophyll		5
79	Chondroitin	From glucose	3
80	cis cis Muconic acid	From glucose fermentation	3
81	Citric acid	Sugars fermentation	2, 3, 6, 38
82	Citric acid pharma	Sugars fermentation	31
83	Coenzyme Q10		4
84	Coniferols	Extracted from pine tree or biomass thermo-chemical	9, 11
85	Coumaric acid	From lignocellulose	8
86	Crude Tall Oil (CTO)	From forest products (wood)	9, 13
87	Curdlan	Sugars fermentation	3
88	Cyanophycin	Heterogeneous production of this cyanobacterial polymer in bacteria	3
89	Cyclodextrins	Produced from glucose (enzymatic degradation)	3
90	Cyclohexane	Biomass thermochemical	11
91	Cyclohexanone		7
92	Cyclosporine		4
93	Dextran		4, 38
94	D-Gluconic acid		17
95	Dibasic Esters		17
96	Dicarboxylic acids		4
97	Dichloropropanol		4
98	Diesel	Fisher Tropsch synthesis (syngas)	8
99	Diethers		4
100	Dihydroxyacetone		4, 36
101	Dimethyl ether (DME)	Fisher Tropsch synthesis (syngas) or catalytic hydrogenation of CO2	2, 10
102	Dimethyl sulfoxide (DMSO)	From wood pulping	8
103	Diphenolic acid		4, 17
104	Distillated Tall Oil (DTO)	From wood	13
105	DL-Malic Acid		17
106	D-xylaric acid		17
107	D-xylonic acid		17
108	Epoxy resins	From Vegetable oil via epichlorohydrin	3, 8, 31
109	Erithritol (sugar alcohols)	Fermentation from glucose	9
110	Erythorbic acid		4
111	Ethane	Catalytic hydrogenation of CO2	10
112	Ethanol	Sugars fermentation or Fisher-Tropsch synthesis (syngas)	2, 3, 37
113	Ethanol fuel anhydrous		31
114	Ethanol industrial		3, 31
115	Ethoxylated alcohols	From ethylene oxide	4
116	Ethyl acetate	From ethanol	7, 3
117	Ethyl lactate	From lactic acid (glucose fermentation) or from ethanol	2, 3, 17
118	Ethyl levulinate		8
119	Ethyl tert-butyl ether (ETBE)	From ethanol	3
120	Ethylene	From ethanol or catalytic hydrogenation of CO2	3, 10, 31

121	Ethylene diamine disucci-nate	Fermentation (fumaric acid or aspartic acid)	9, 17
122	Ethylene glycol	From ethylene oxide, thermo-chemical derivative of sorbital	7, 2, 17, 34
123	Ethylene oxide	From ethanol	7
124	Eugenol	Extracted from essential oils or biomass thermo-chemical	11
125	Fatty acids		31
126	Fertiliser (slow release) from bio-oil	Biomass pyrolysis	8
127	Fibres from grass		14
128	Fischer-Tropsch liquids	From biomass gasification	2, 17
129	Folic acid	Fermentation	3
130	Formic acid	Catalytic hydrogenation of CO2	10
131	Fructose	From sugar, chicory root or isomerisation from glucose	5, 9, 3
132	Fumaric acid	Fermentation (glucose, succinic acid)	7, 2, 3, 6, 17, 31
133	Functionalized lignin polymers	From wood	9
134	Furan	From furfural	1
135	Furan (2,5)-dicarbonic acid		8
136	Furan(2,5)-dicarboxylic acid (FCDA)	From 5 hydroxymethyl furfural	1
137	Furfural	Xylose thermal transformation	2, 3, 17
138	Furfuryl alcohol	Directly derived from furfural	5, 9, 17
139	Gasoline	Fisher Tropsch synthesis	2
140	Gelatin	Extracted from bones	9
141	Gellan	Fermentation product	9, 3
142	Glucaric acid	Sugars fermentation	6
143	Gluconic acid	Fermentative glucose oxidation	3, 6, 38
144	Glucose	Enzymatic hydrolysis of starch	3
145	Glutamic acid	Sugars fermentation	3, 6, 31
146	Glutamine	From glucose	3
147	Glutaric acid	Fermentation from glucose	9
148	Gluten	From wheat	4, 9, 18
149	Glyceraldehyde		4
150	Glyceric acid	From glycerol oxidation	1
151	Glycerol	From oil/lipids - thermochemical or sugars fer-mentation	2, 6, 17, 18
152	Glycerol carbonate	Oxidative carbonylation of glycerine	1
153	Glycerol dimethacrylate		4
154	Glycerol pharma grade		31
155	Glycerol-1-monoethers		4
156	Glycidol	Internal dehydration of glycerine	1
157	Glycine	From serine and threonine	8
158	Glyoxylic acid	Fermentation	3
159	Guaiacols	Biomass thermochemical	11
160	Guayule	Extracted from plants	17
161	Hemicellulose	Extracted from plants	9
162	Heparin	From glucose	3
163	Hexoses	C6 sugars such as glucose, fructose	4
164	Histidine	From glucose	3
165	HMF (Hydroxymethyl Fur-fural)	Dehydration of hexoses (glucose, fructose)	1
166	Humins		5
167	Hyaluronic acid	Fermentation	3
168	Hydraulic fluids	From vegetable oils	17

169	Hydrogen	Biomass gasification	8
170	Hydroxyacetaldehyde		8
171	Hydroxyethanoic acid		4
172	Hydroxypyruvic acid		4
173	Hyroxyproline	From glucose	3
174	Indigo	Fermentation	3
175	Isoleucine	From glucose	3
176	Isoprene	Fermentation of sugars	7
177	Isopropanol		4, 35
178	Isosorbide	Sugars thermochemical, derived from sorbitol	2, 17
179	Itaconic acid	Xylose fermentation product	2, 3, 6, 17
180	Kerosene	From Fisher Tropsch synthesis (syngas)	8
181	Ketones		4
182	Kojic acid	Fermentation	3
183	Lactate esters	Derived from lactic acid	9
184	Lactic acid	Glucose fermentation	7, 2, 6, 17, 33
185	Lactic amide		17
186	Lactide	Glucose fermentation	17
187	Lactitol	Lactose derivative	4, 9
188	Lactoferrin (proteins)	From milk	8
189	Lactones		8
190	Lactonitrile		17
191	Laurylic alcohol	From vegetable oil	8
192	L-Carnitine	From 3 hydroxy-butyrolactone	7
193	Lecithin	From oil/lipids, thermochemical	2
194	Leucine	From glucose	3
195	Levoglucosan	Sugars chemical transformation	6
196	Levulinic acid	Sugars biochemical	2, 3, 6, 17
197	L-Hydroxyphenylalanine		4, 38
198	Lignin	Extracted from wood	14, 17
199	Linear Alpha Olefins (LAO)		7
200	Lisolesithin		4
201	L-sorbose	Fermentation	3
202	Lubricants		17
203	Lysine	Sugars fermentation	3, 11, 38
204	Maleic anhydride	From succinic acid	2, 17
205	Malic acid	From succinic acid (sugars fermentation)	2, 3, 6, 31
206	Malonic acid	From 3-hydroxy propionic acid, sugars fermentation	2, 3, 6, 17, 32
207	Maltitol	Hydrogenated maltose, cereal derived	4, 9
208	Mannitol	Hydrogenated fructose, cereal derived	4, 9
209	Mannose	From oxidation of mannitol	5
210	Mesoxalic acid		4
211	Methane	Biomass gasification or catalytic hydrogenation of CO2	10, 17
212	Methanol	Fisher Tropsch synthesis (syngas) or catalytic hydrogenation of CO2	2, 10, 31
213	Methionine		7, 38
214	Methyl acetate	From acetic acid and methanol	8
215	Methyl methacrylate (MMA)	Plants as plants approach (genetically modified switchgrass)	7
216	Methyl tetrahydrofuran (MTHF)		17
217	Methyl tetrahydrofuran	From 2-methyl furan	
218	Molasses	Bulk sugar residue	9
219	Monoethers		4
220	Monoglycides	Hydrolysis from natural oils & fats	9

221	Monosodium glutamate (MSG)	Fermentation product	4, 38
222	N-methyl pyrrolidone (NMP)	From succinic acid	2, 17
223	Oil from algae	Extraction	9
224	Oleochemicals (oleic acid)	Extraction & hydrolysis from oilseeds	4, 9
225	Oxalic acid	Oxidation decarboxylation of lactic acid	3
226	Pantothenic acid	Fermentation	3
227	Paraffin waxes	Fisher Tropsch synthesis	2
228	Pentanol		15
229	Pentoses	C5 sugars derived from hemicellulose	9
230	Phenol	Lignin thermochemical	11, 31
231	Phenol formaldehyde	From biomass pyrolysis	8, 17
232	Phenolics	Lignin thermochemical	14
233	Phenylalanine	From glucose	3
234	Phosphate	From DDGS	12
235	Phospholipids	Extraction from eggs, milk	4, 9
236	Phycocyanine	From algae	4
237	Pig feed	From upgrading of DDGS	12
238	Poly-3-hydroxybutyrate (PHB)	Fermentation from glucose; extraction from some plants	4, 9
239	Polyamide 11 (PA11) (not biodegradable)		4
240	Polyethylene (not biode-grable but recyclable)	Produced from bioethanol derived ethylene	7, 31
241	Polyethylene	From Ethylene produced from fermentation ethanol	31
242	Polyglycerol methacry-lates		4
243	Polyhydroxyalkanoate (PHA)	Plants as plants approach (genetically modified switchgrass) or fermentation	7, 3, 17
244	Polylactic acid	From lactic acid (glucose fermentation)	2, 3, 7
245	Polylactide	From lactic acid (glucose fermentation)	17
246	Polymers		17
247	Polyols	Hydrogenation of sugars such as glucose, man-nose, maltose, xylose	4, 9, 18
248	Polypropylene		16, 31
249	Polytetramethylene ether glycol (PTMEG)	From THF	7
250	Polyurethanes	Contains approx. 20% bio-based feedstocks (from oils and lipids) Biobased component is glycerol, glucose, sorbitol, sucrose	9, 2, 17
251	Polyvinyl chloride		7
252	Proline	From glutamic acid	1, 3
253	Propanol		14, 23
254	Propionaldehyde		4, 23
255	Propionic acid	Reduction of lactic acid, sugars fermentation	3, 6, 27
256	Propylene		5, 31
257	Propylene glycol	From glycerol fermentation or thermochemical derivative of sorbitol	7, 2, 17, 28
258	Propylene oxide		4, 29
259	Protein	From all living organisms	14, 9, 17
260	Pullulan	Derived from starch by fermentation	3
261	Pyruvic acid	From lactic acid oxidation (glucose fermentation)	3, 17
262	Quinones	Biomass thermochemical	11
263	Rapeseed oil	From rapeseed, thermochemical	8
264	Rayon	Fibre derived from cellulose	5, 9

265	Resins (phenol formalde-hyde)	From biomass pyrolysis	2
266	RME (Rape Methyl Ester)	Derived from rapeseed oil	8
	RME (Rape Methyl Ester)	Derived from rapeseed oil	8
267	Rosin	Forest derivatives-thermochemical Extracted from pine trees	9, 2
268	R-δ-dodecanolide		4
269	Saccharinic acid		5
270	Scleroglucan	Fermentation	3
271	Serine	From 3 hydroxypropionic acid, sugars fermenta-tion	3, 6
272	Solvents		17
273	Sorbitol	Sugars fermentation or chemical transformation	2, 3, 6, 17, 31
274	Sphingan	Fermentation	3
275	Starch	Extracted from cereals and tubers	4, 9
276	Stearylic alcohol	From vegetable oil	8
277	Steroids		4
278	Styrene		8, 31
	Styrene		31
	Styrene		31
279	Succinamide		17
280	Succinate salts		17
281	Succinic acid	Several fermentation processes available	2, 3, 6, 17, 30
282	Syringaldehyde	Biomass thermochemical	11
283	Syringol	Biomass thermochemical	11
284	Tall Oil Fatty Acids (TOFA)	Extracted from wood	13
285	Tall Oil Pitch (TOP)	Extracted from wood	13
286	Tall Oil Rosin (TOR)	Extracted from wood	13
287	Tars	From biomass gasification	14
288	Tartaric acid	Extracted from wine	9
289	Tartronnic acid		4
290	Tetrahydrofuran (THF)	Can be derived from furfural / Produced from glucose via succinic or fumaric acid	9, 7, 17, 31
291	Threonine	Sugars fermentation	3, 6
292	Toluene	From biomass gasification or catalytic hydro-genation of CO_2	10, 31
293	Triethers		4
294	Trypthophane	Fermentation of glucose	3, 9
295	Turpentine	Forest derivatives-thermochemical	2
296	Valine	From pyruvic acid	3, 8
297	Vanillic acid	Biomass thermochemical	11
298	Vanillin	From guaiacol or lignin (thermochemical)	8, 31
299	Vinasse (biofertiliser)	Sugar co-product	9
300	Vinyl acetate	From acetic acid and ethylene	3
301	Vinyl chloride	From Ethylene produced from biomass	7
302	Vitamin A, B2, B3, B12, C	Fermentation	3
303	Vitamin B12	Fementation	38
304	Vitamin B2	Fermentation	3
305	Vitamin C	Fermentation of sugars	38
306	Xanthan	Fermentation	3, 38
307	Xylene	From biomass gasification	8, 31
308	Xylitol	Hydrogenation of xylose	9, 6
309	Xylonic acid	From xylose	8
310	Xylo-oligomers		8
311	Xylose	From biomass by combined thermochemical treatment, acid hydrolysis and enzymatic treat-	3

		ment	
312	Zeaxanthine	Extraction from plants such as vegetables, maize	4, 9
313	α – monobenzoyl glycerol		4
314	α,γ-dichlorohydrin	From glycerol	8
315	β-carotene	Extraction from plants such as algae, carrots	4, 9
316	γ-amino levulinic acid,		17
317	γ-butyrolactone	Produced from glucose via succinic acid (fermentation)	7, 17
318	γ-valerolactone	From levulinic acid	1

2.2 References for Section 2

1 A. Corma, S. Iborra, A. Velty Korma, Chemical Routes for the Transformation of Biomass into Chemicals, Chem. Rev. 2007, 107, 2411-2502.
2 U.S. Department of Energy, Industrial bioproducts: Today and tomorrow, July 2002
3 Medium and long term opportunities and risks of the biotechnological production of bulk chemicals from renewable resources – The potential of white biotechnology, The BREW project, September 2006.
4 Sofie Dobbelaere, Universiteit Gent (UGent) personal communication April 2008
5 M. Stojanovic, Agrotechnology and Food Innovations B.V. (WUR A&F) personal communication April 2008
6 National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Top Value Added Chemicals from Biomass, Volume I - Results of Screening for Potential Candidates from Sugars and Synthesis Gas, August 2004.
7 NNFCC project 08-008, Biochemical opportunities in the United Kingdom, September 2008
8 AV Bridgwater, ME Gyftopoulou, Aston University contribution April 2009
9 Philippe Willems, Value for Technology bvba (VFT) personal communication April 2009
10 T. Inui, M. Anpo, K. Izui, S. Yanagida, T. Yamaguchi, Research and development on new synthetic routes for basic chemicals by catalytic hydrogenation of CO2, Studies in Surface Science and Catalysis, vol-114, 1998 Elsevier. Contributed by Laura Bermudez Abengoa Bioenergy New Technologies (ABNT)
11 Pacific Northwest National Laboratory, Top Value Added Chemicals from Biomass, Volume II - Results of Screening for Potential Candidates from Biorefinery Lignin, October 2007.
12 Koen Meesters, Agrotechnology and Food Innovations B.V.(WUR A&F) personal communication April 2009
13 Arpiainen Vesa, Valtion Teknillinen Tutkimuskeskus (VTT) personal communication April 2009
14 Herman den Uil, Energy research Centre of the Netherlands (ECN) personal communication April 2009
15 Shiro Saka, Kyoto University, Recent progress in biorefineries as introduced by super critical fluid science and technology, Biorefinica Conference Workshop, January 29, Osnabruck, Germany
16 Telma Teixeira Franco, Advances and opportunities towards a biobased industry in Brazil, Biorefinica Conference Workshop, January 29, Osnabruck, Germany
17 Industrial Bioproducts: Today and Tomorrow. Energetics, Incorporated,
18 Wim Soetaert University of Gent, from Euroview draft report 2008
19 E. Burridge, 2007. Chemical profile: Acetic Acid. Chemical Market Reporter 272, 4. 50.
20 M. Kirschner, 2006. Chemical profile: Acetone. Chemical Market Reporter 269, 26.
21 S. Vollenweider, C. Lacroix. 2004. 3-Hydroxy-propionaldehyde: Applications and perspectives of biotechnological production. Appl. Microbiol. Biotechnol. 64, 16-27.
22 M. Kirschner, 2005. Chemical profile: Acrylic acid. Chemical Market Reporter 267, 50.
23 M. McCoy, 1997. Chemical Prices. Chemical Market Reporter 251, 26-33.
24 http://www.healthoo.com 2007
25 http://www.foodnavigator.com/
26 D.T. Johnson, K.A. Taconi. 2007. The Glycerine Glut: Options for Value-Added Conversion of Crude Glycerol Resulting from Biodiesel Production. Environ. Progress 26, 338-348.
27 M. Kirschner, 2004. Chemical profile: Propionic acid. Chemical Market Reporter 269, 30.
28 M. Kirschner, 2007. Chemical profile: Propylene glycol. Chemical Market Reporter 272, 11, 58.
29 M. Kirschner, 2004. Chemical profile: Propylene oxide. Chemical Market Reporter 255, 31.
30 D.T. Johnson, K.A. Taconi. 2007. The Glycerine Glut: Options for Value-Added Conversion of Crude Glycerol Resulting from Biodiesel Production. Environ. Progress 26, 338-348.
31 ICIS Pricing, http://www.icis.com/home/default.aspx
32 P. Pollack, G. Romeder. 2001. malonic acid and derivatives. In R.E. Kirk & D.F. Othmer, (Eds.), Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 15, 4th ed., New York, Wiley.
33 M. Paster, L.J. Pellergrino, T.M. Carole. 2003. Industrial bioproducts: Today and tomorrow. Report prepared for Energetics, Inc., for the United States department of Energy, Office of Energy Efficiency and Renewable Energy, Office of the Biomass Program, Washington, DC.
34 A. Brice. 2007. Markets Trends & Data. Chemical Market Reporter 272, 6, 65.
35 M. Kirschner, 2004. Chemical profile: Isopropanol. Chemical Market Reporter 267, 27.
36 M. McCoy, 1997. Chemical Prices. Chemical Market Reporter 251, 26-33.
37 I. Lerner, 2007. The Great Ethanol Debate. Chemical Market Reporter 271, 5. 38-39.
38 Wim Soetaert, University of Gent, Private Communication

3. RESULTS OF THE MARKET ANALYSIS

3.1 Introduction

The second part of the market assessment was to ascertain market prices and volumes of the materials and chemicals identified in Section 2. The results of this analysis are presented in the tables below. Table 2 shows the products that can be derived from biomass, routes from which the products are derived and the market size and price available in the open literature. Table 2 lists the products for which both the market size and market price are available. Each table is accompanied by a set of references from where the data was derived.

3.2 Price and market relationship

Figure 1 is a plot between the product prices versus the market volumes. The figure distinguishes products as commodity, specialty, fine and polymers and plastics based on the market and price. Commodity products are the products which have a market price in the order of less than or just above thousand Euro and are produced more than one million tons in volumes. Specialty products are the ones which have the market in the order of a thousand tons and above and priced above thousand Euros. Fine products have the lowest market volume ranging from one tonne to thousand tonnes and always priced above ten thousand Euros. Polymers and plastics form a continuous product spectrum in between the specialty and commodity products.

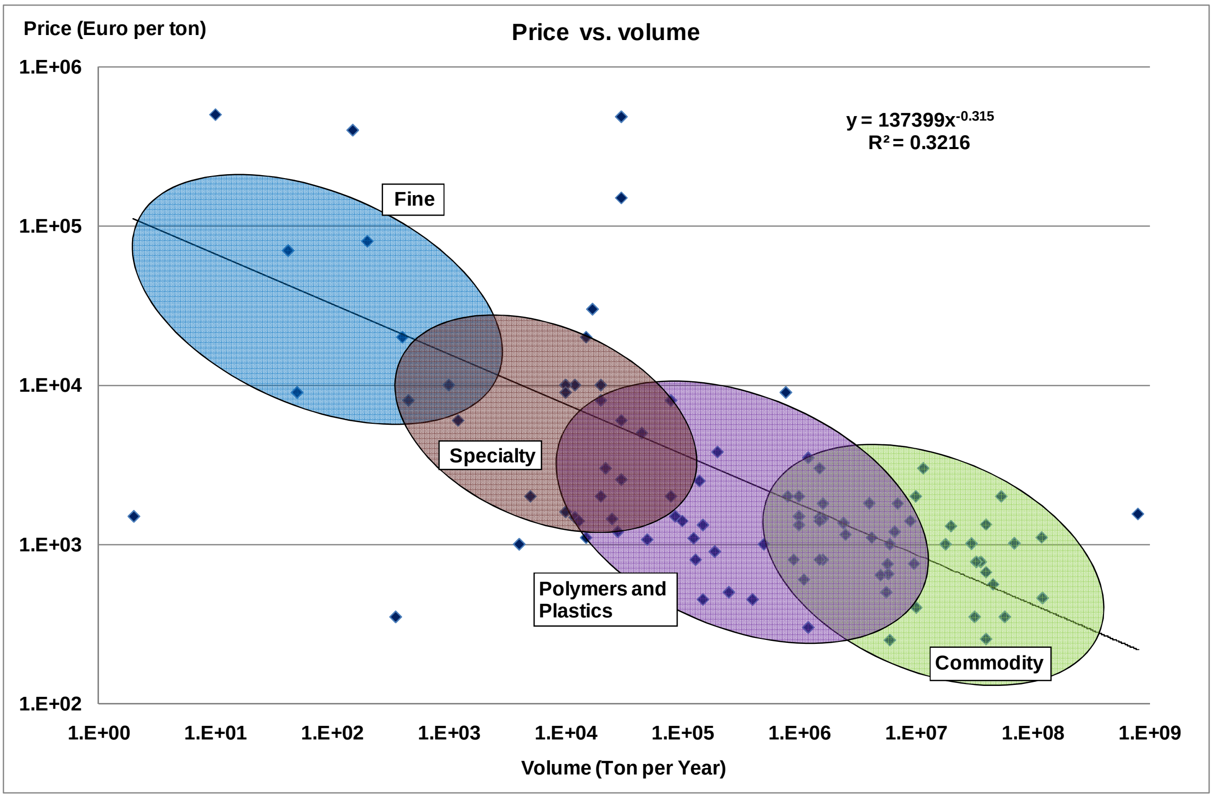


Figure 1 Biomass derived products, Price vs. market volume

A relationship between market price and size can be derived from Figure 1, but the relationship is poor with an R^2 value of 0.322. The relationship can be improved either by removing obvious outliers or by arbitrarily selecting the best fitting 75% of the data. Both approached are shown below for predicting both price as a function of market size

The relationship between market price and size can be derived as an exponential relationship:

Market size = 137399 (Price)$^{-0.315}$
R^2 = 0.322

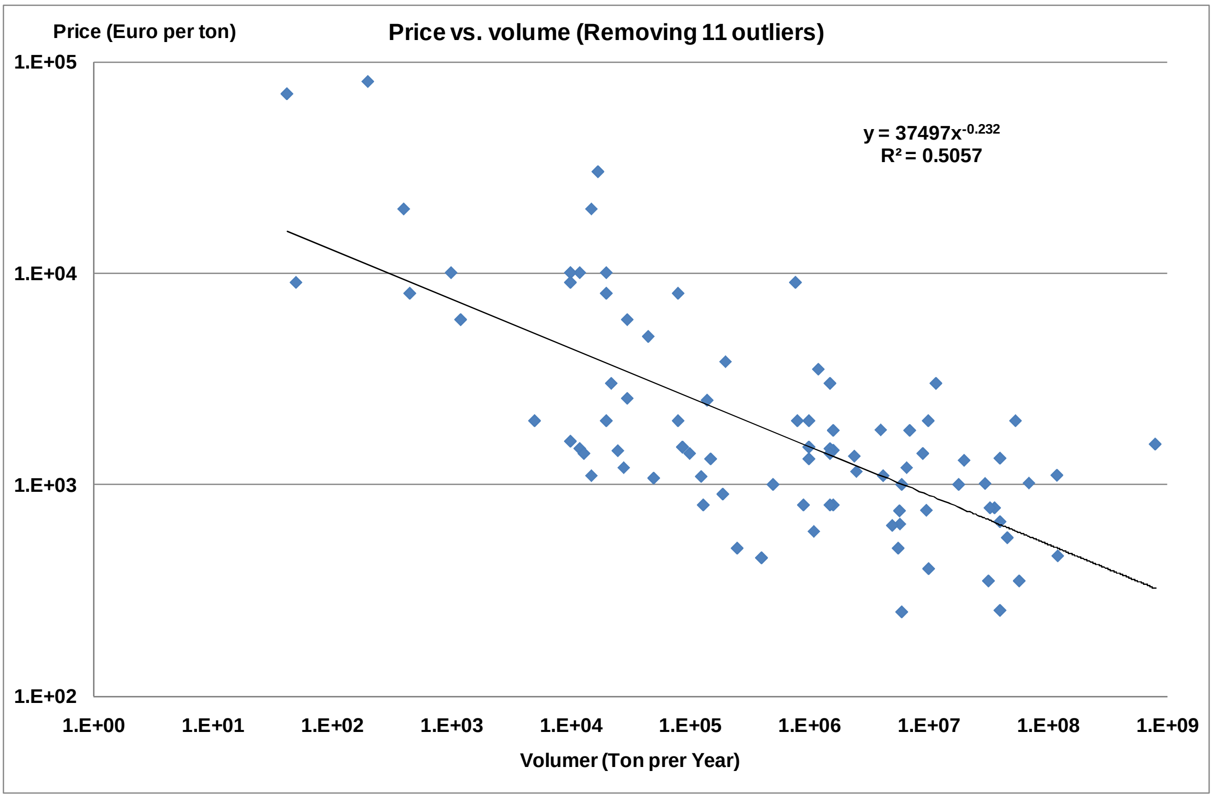


Figure 2 Biomass derived products, Price vs. market volume (removing outliers)

Figure 2 is the plot derived from Figure 1 which removes obvious outliers in order to establish an improved relationship between market price and size. Outliers are defined as the data points which are far away from the trend line. The 11 outliers are arbitrarily chosen in the decreasing order of their deviation from the trend line which accounts for 90% of the observed values. This improves the goodness of fit as measured by the R^2 value from 0.32 to 0.51.

In this case the relationship can be expressed as:

Price = 37497 (market size, t/y)$^{-0.232}$
R^2 = 0.50

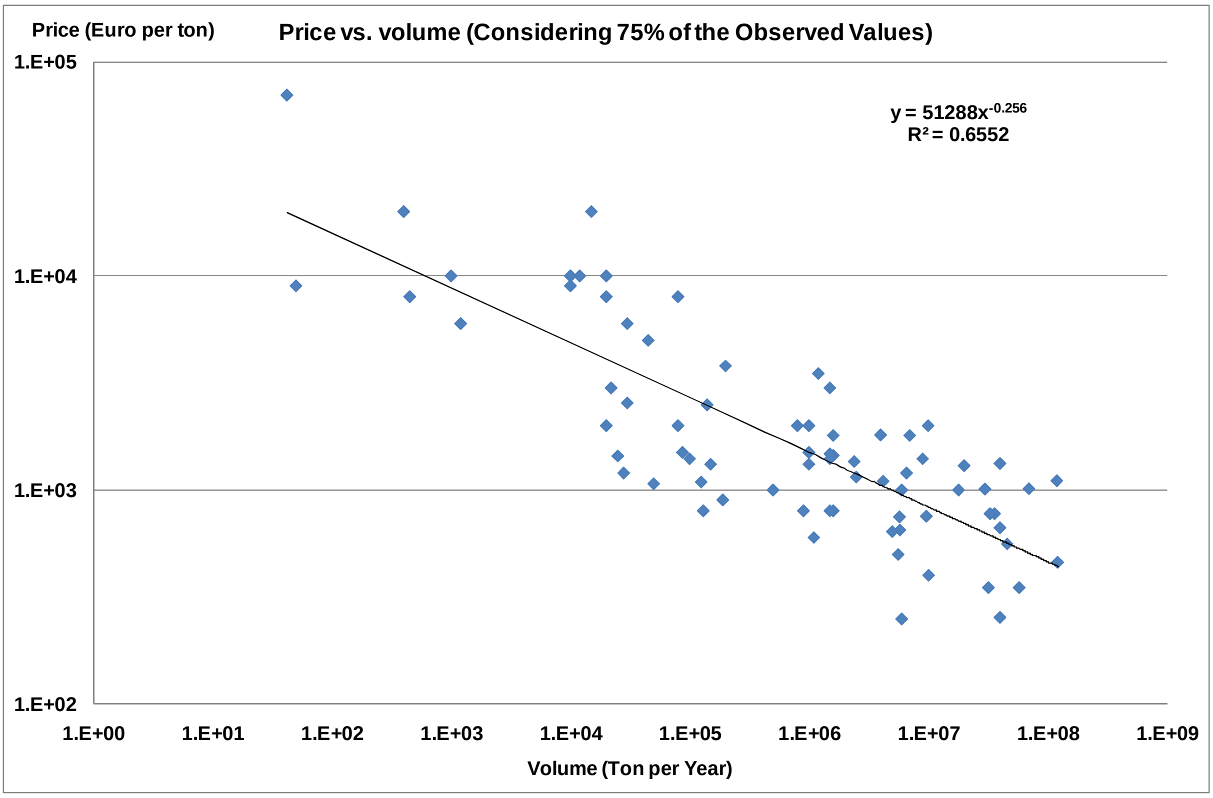


Figure 3 Biomass derived products, Price vs. market volume (Considering 75% of the Observed Values)

Figure 3 is the plot derived from Figure 1 by arbitrarily selecting the best fitting 75% of the data by excluding 26 of the 101 data points. This significantly improves the goodness of fit as measured by the R^2 value.

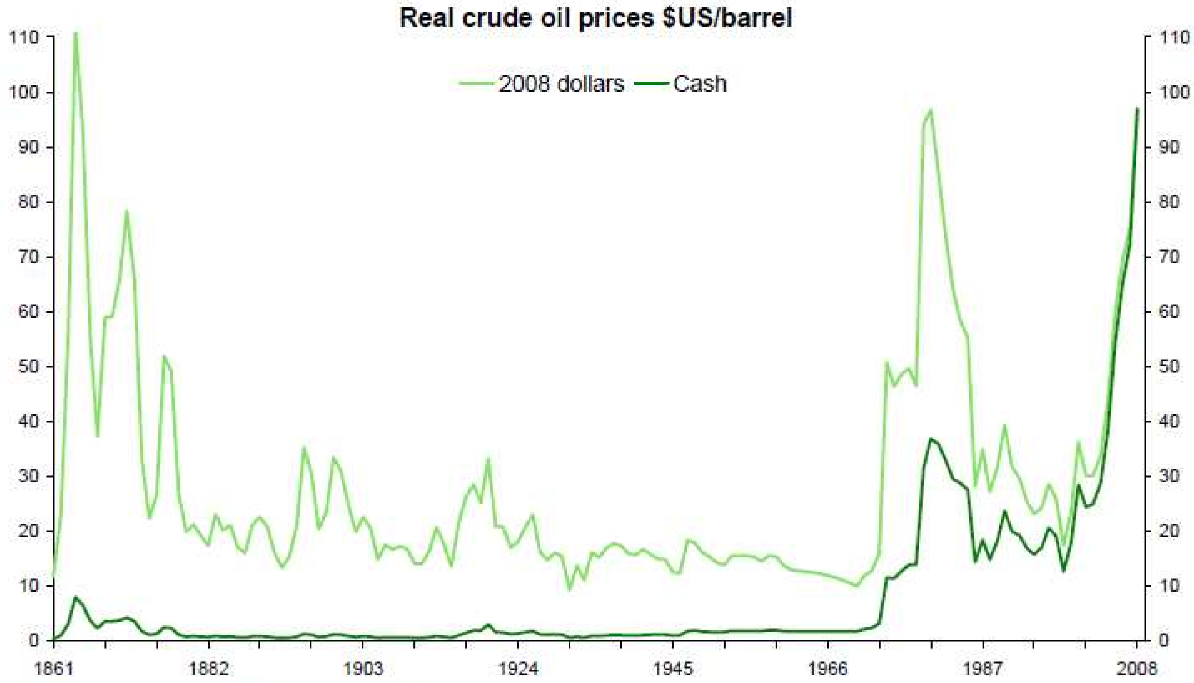
In this case the relationship can be expressed as:

Price = 51288 (market size, t/y)$^{-0.256}$
R^2 = 0.655

3.3 Market size and forecast

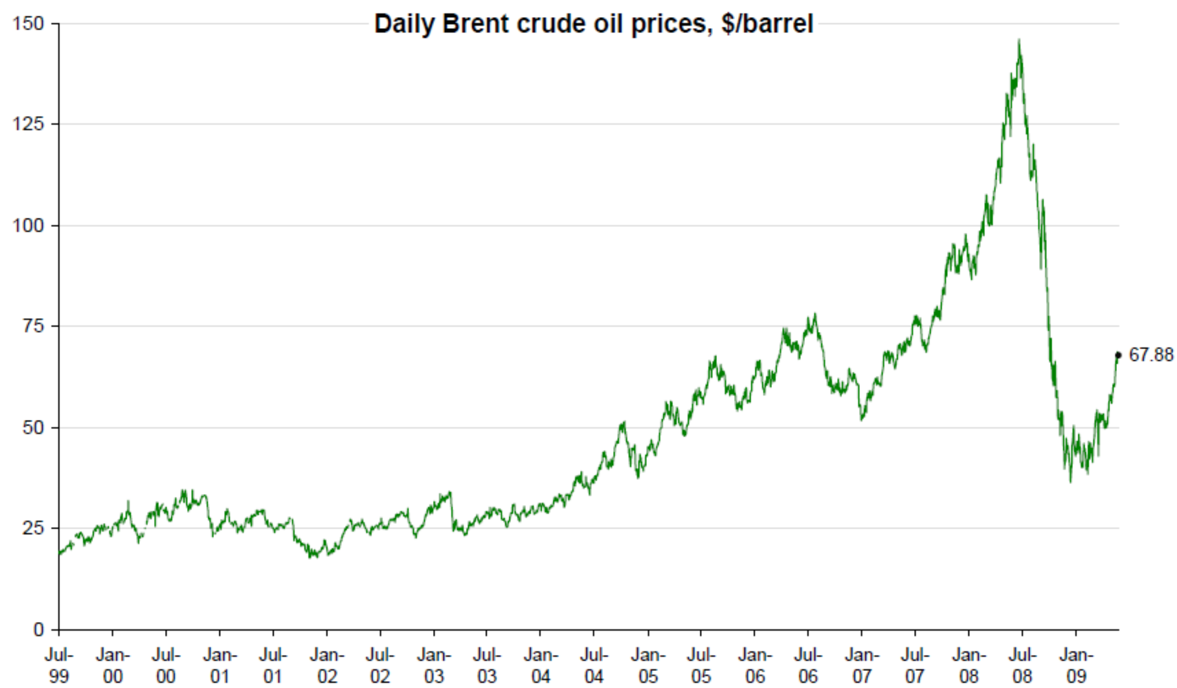
It is difficult to forecast future market size of any commodity as it is dependent on a wide range of political, environmental, financial, technological and social issues according to the product concerned. Many predictions of future market of commodities are based on a no-change scenario, while for specialities

Figure 4 to Figure 6 illustrate the problems of predicting market size or price. Figure 4 shows real and nominal crude oil prices from 1861 to 2008, Figure 5 shows daily Brent crude spot prices converted at spot exchange rates while Figure 6 shows an indexed summary of the actual prices paid by refineries in sterling rather than spot prices at spot exchange rates and shows that price changes are less extreme. This is due to exchange rates being influenced by many factors. Both short and long term price prediction of crude oil is not only difficult but subject to long and deep debates due to its importance in the world economy. Crude oil prices are important due to so many commodities being derived from crude oil



Sources: BP statistical review of world energy 2008

Figure 4 Real oil prices 1861 to 2008 (1)



Source: Financial Times; HoC Library electronic holdings

Figure 5 Daily Brent crude spot prices converted at spot exchange rates

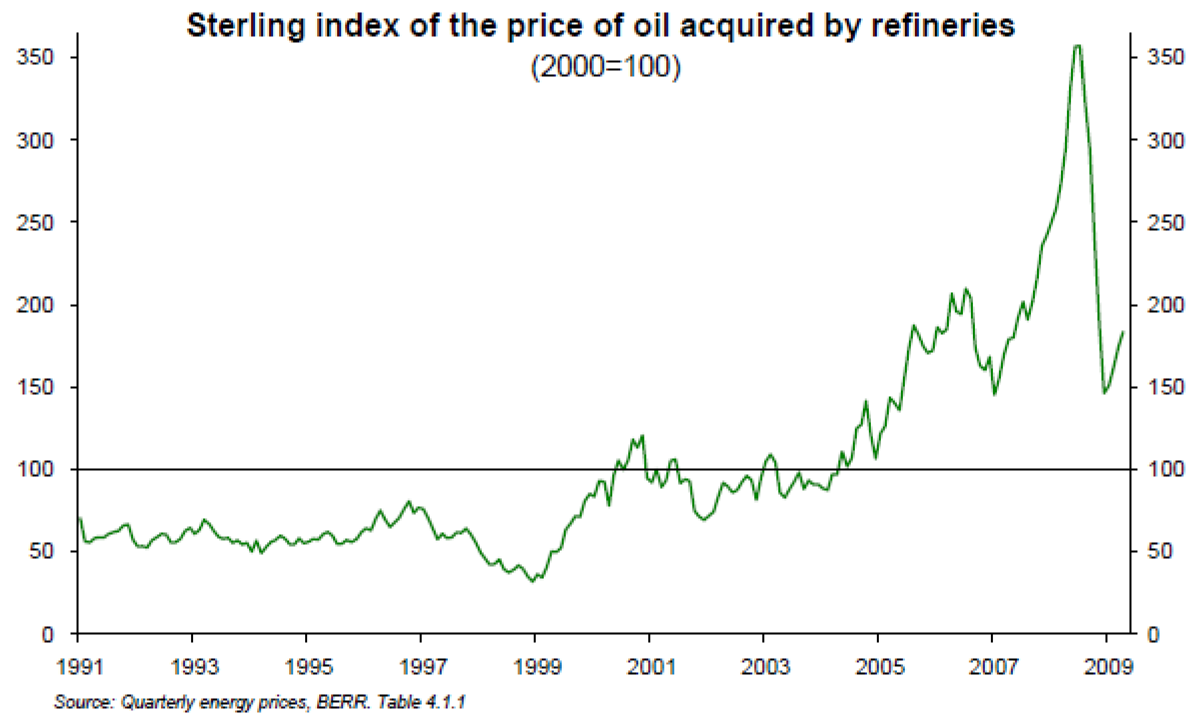


Figure 6 Sterling index of actual prices paid by refineries in the UK (1)

3.4 Prices

There are many influences on price including:

- Most commodity prices are based on crude oil and gas prices, neither of which can be predicted with any confidence as the past few years have shown as illustrated above. Some of the more basic commodities can be directly related to crude oil prices such as gasoline which is reliably constant at around 1.5 to 1.6 times crude oil price.
- Supply and demand relationships can have substantial impact on prices when small changes in availability of commodities can have a disproportionate effect on price. For example a 5% reduction in availability can result in a 50 to 100% increase in price. This is seen for many products including crude oil and is particularly significant for commodities where supply matches demand.
- Competition between companies and between technologies can result in short term reductions.
- There can be substantial differences between contract prices and spot prices. Contract prices tend to lag spot prices by between ½ and 2 years depending on the chemical and conventional practice for that industry.
- Fiscal incentives can distort market prices and volumes as evidenced in may renewable fuels and bioenergy prices.
- Learning effects have been shown to give a long term deflation effect on prices with real terms prices dropping by between 15 and 35% for every doubling of cumulative production.

3.5 References for Chapter 3 excluding Table 2

3.1 Bolton P., UK House of Commons Library 8 June 2009 Report SN/SG/2106

Table 2 Biomass derived products, prices and market volume

	Products	Route from biomass	Price euros/t	Location	Market size	Refs
		Exchange rate	euros/USD	1.25		
1	(2,5)-bis-hydroxymethyl-furan (BHMF)	Reduction of 5-hydroxymethyl furfural or hydroxymethylation of furfuryl alcohol				1
2	1,2 propanediol	Hydrogenation of lactic acid	3000		1500 kt/y	1, 3, 18
3	1,3 propanediol	Sugars fermentation, currently produced from 3-hydroxypropionic acid			>80 kt/y	2, 3, 17
4	1,4-butanediol,	From Succinic acid or Fermentation of sugars				17
5	1,4-diaminobutane					17
6	1-amino-2-propanol					17
7	2 chloropropionic acid	From lactic acid				4
8	2,5- dimethyl furan	Hydrogenolysis of 5 hydroxymethyl furfural				5
9	2,5-Dimethyl-1,4-dioxane					17
10	2,5-furandicarboxylic acid	Sugars biochemical transformation				6
11	2-hydroxymethyl tetrahydrofuran					17
12	2-Pyrrolidone	From succinic acid				1, 17
13	3-hydroxybutyrolactone	Sugars chemical transformation				6
14	3-hydroxypropionic acid	Glucose fermentation				7, 2, 3, 6, 17
15	4-decalacton					4
16	5'-IMP (5'-Inosinic acid, disodium salt)					4
17	5-aminolevulinic acid					8
18	5-methyl furan					5
19	Acetaldehyde	From ethanol oxidation				3
20	Acetic acid contract	Sugars fermentation	867-926			3, 19
	Acetic acid contract	Sugars fermentation	1197		190 kt/y	3, 31
	Acetic acid contract	Sugars fermentation	550-620	Aug 08	190 kt/y	3, 31
	Acetic acid fob USA		600	Aug 08		31
21	Acetoin	Sugars fermentation				6
22	Acetol	Hydrogenolysis of glycerine				4
23	Acetone	Glucose fermentation	220-720			3, 20
	Acetone	Glucose fermentation	830-1350	Aug 08 Rot		3, 20

24	Acetylene	From syngas				5
25	Aconitic acid	Sugars fermentation				6
26	Acrolein	From glycerol	1090			4, 21
27	Acrylamide	From 3-hydroxypropionic acid				2, 3, 17
28	Acrylic acid	From 3-hydroxypropionic acid	760-1730			7, 2, 3, 6, 17, 22
	Acrylic acid		1300-1580	Aug 08 Rot		31
29	Acrylonitrile	From 3-hydroxypropionic acid				2, 17
30	Activated carbon	From biomass pyrolysis				8
31	Adipic acid	From cyclohexanone or succinic acid	1360-1430			7, 2, 17, 31
32	Alanine	From 3 hydroxypropionic acid fermentation product			1200 t/y	3
33	Alginate	Extracted from seaweed				9
34	Alkanes	From syngas by Fischer Tropsch				4
35	Alkyd resins	50% based on natural oils/ from propylene glycol				9, 7
36	Alkyl polyglycosides (APG)	From glucose and fatty acids			50-70 kt/y	9
37	Alkyl polypentosides (C5-surfactants)	From hemicelluloses fractions and fatty acids				4, 9
38	Allyl alcohol		1700			4, 23
39	Aminoacids	From carbohydrate fermentation	750-850			18
40	Ammonia	From producer gas	460			8
	Ammonia	From producer gas	850-880	Aug 08 NWE		8
41	Antibiotics (bulk)	From carbohydrate fermentation	150000		30 kt/y	38
42	Antibiotics (specialties)	From carbohydrate fermentation	1500000		5 kt/y	38
43	Arabinitol	From arabinose				6
44	Arabinogalactan	Extracted from the timber of the larch tree				5
45	Arabinose	From biomass by combined thermochemical treatment, acid hydrolysis and enzymatic treatment				3
46	Arginine	From sugars			1500 t/y	3
47	Aspartame	From aspartic acid	30000		17 kt/y	4, 25
48	Aspartic acid	Derived from fumaric acid that can be made by fermenta-tion			13 kt/y	3, 6
49	Astaxanthine	Part synthetic, part by fermentation, part extracted from micro-algae				4, 9
50	Avermictins	From fermentation	90000			4, 24
51	Benzene	From biomass gasification or catalytic hydrogenation of CO_2	667			10, 31

	Benzene	From biomass gasification or catalytic hydrogenation of CO2	900-1320	Aug 08 NWE		10, 31
52	Biocomposites					17
53	Bionolle 4,4 polyester	Sugars fermentation + fossil fuel				2, 9, 17
54	Bio-oil	Biomass pyrolysis				8
55	BioSyngas	Biomass gasification				6
56	Biotin	Fermentation				3
57	Biphenyls	Biomass thermochemical				11
58	Butanediol (BD)	From fumaric/succinic acid	1373			7, 31
	Butanediol (BD)	From fumaric/succinic acid	1810-1940	Aug 08 NWE		7, 31
59	Butanetriol	Xylose or arabinose fermentation				3
60	Butanol	Sugars fermentation	1890-1990			2, 3, 17, 26
	Butanol		1109			
	Butanol		1800-1850	Aug 08 NWE		
61	Butanol derivates	From butanol				8
62	Butyric acid	Sugars fermentation			50 kt/y	3
63	Caprolactam	From cyclohexanone				7
64	Caprylic acid (octanoic acid)	From vegetable oil				8
65	Carbon dioxide	From bioethanol production; anaerobic fermentation and all respiration processes				9, 17
66	Carbon fibre	From lignin				11
67	Carbon monoxide	Biomass gasification or catalytic hydrogenation of CO2				10
68	Carboxylic acid	Catalytic hydrogenation of CO2				10
69	Carboxymethyl cellulose	From dissolving pulp				5, 9
70	Catchols, cresols, resorcinols	Biomass thermochemical				11
71	Cattle feed (DDGS)	Co-product from bioethanol production				12
72	Cellulose	From biomass				8
73	Cellulose acetate	From dissolving pulp				5, 9
74	Cellulose butyrate	From dissolving pulp				5, 9
75	Cetostearilic alcohol	From vegetable oil				8
76	Cetylic alcohol	From vegetable oil				8
77	Chitin/Chitosan	Extracted from crabs				9
78	Chlorophyll					5
79	Chondroitin	From glucose				3

80	cis cis Muconic acid	From glucose fermentation				3
81	Citric acid	Sugars fermentation	800		1500 kt/y	2, 3, 6, 38
	Citric acid		968			31
82	Citric acid pharma		5632			31
83	Coenzyme Q10					4
84	Coniferols	Extracted from pine tree or biomass thermochemical				9, 11
85	Coumaric acid	From lignocellulose				8
86	Crude Tall Oil (CTO)	From forest products (wood)				9, 13
87	Curdlan	Sugars fermentation				3
88	Cyanophycin	Heterogeneous production of this cyanobacterial polymer in bacteria				3
89	Cyclodextrins	Produced from glucose (enzymatic degradation)			5 kt/y	3
90	Cyclohexane	Biomass thermochemical				11
91	Cyclohexanone					7
92	Cyclosporine					4
93	Dextran		80000		200 t/y	4, 38
94	D-Gluconic acid					17
95	Dibasic Esters					17
96	Dicarboxylic acids					4
97	Dichloropropanol					4
98	Diesel	Fisher Tropsch synthesis (syngas)				8
99	Diethers					4
100	Dihydroxyacetone		3400			4, 36
101	Dimethyl ether (DME)	Fisher Tropsch synthesis (syngas) or catalytic hydrogenation of CO2				2, 10
102	Dimethyl sulfoxide (DMSO)	From wood pulping				8
103	Diphenolic acid					4, 17
104	Distillated Tall Oil (DTO)	From wood				13
105	DL-Malic Acid					17
106	D-xylaric acid					17
107	D-xylonic acid					17
108	Epoxy resins	From biomass based epichlorohydrin	2600		30 kt/y	3, 8, 31
	Epoxy resins		2500-2600	Jul 08 NWE	30 kt/y	3, 8, 31
109	Erithritol (sugar alcohols)	Fermentation from glucose				9
110	Erythorbic acid					4

111	Ethane	Catalytic hydrogenation of CO2				10
112	Ethanol	Sugars fermentation or Fisher-Tropsch synthesis (syngas)	560			2, 3, 37
113	Ethanol fuel anhydrous		414			31
	Ethanol fuel anhydrous		575-600	Aug 08, Rot		31
114	Ethanol industrial		608		32000 kt/y	3, 31
	Ethanol industrial		710-800	Aug 08	32000 kt/y	3, 31
115	Ethoxylated alcohols	From ethylene oxide				4
116	Ethyl acetate	From ethanol				7, 3
117	Ethyl lactate	From lactic acid (glucose fermentation) or from ethanol				2, 3, 17
118	Ethyl levulinate					8
119	Ethyl tert-butyl ether (ETBE)	From ethanol				3
120	Ethylene	From ethanol or catalytic hydrogenation of CO2	1105-1228	Aug 08 NWE		3, 10, 31
121	Ethylene diamine disucci-nate	Fermentation (fumaric acid or aspartic acid)				9, 17
122	Ethylene glycol	From ethylene oxide, thermo-chemical derivative of sorbi-tal	1300-1400			7, 2, 17, 34
123	Ethylene oxide	From ethanol				7
124	Eugenol	Extracted from essential oils or biomass thermochemical				11
125	Fatty acids		96000-124000			31
126	Fertiliser (slow release) from bio-oil	Biomass pyrolysis				8
127	Fibres from grass					14
128	Fischer-Tropsch liquids	From biomass gasification				2, 17
129	Folic acid	Fermentation				3
130	Formic acid	Catalytic hydrogenation of CO2				10
131	Fructose	From sugar, chicory root or isomerisation from glucose			10100 kt/y	5, 9, 3
132	Fumaric acid	Fermentation (glucose, succinic acid)	1478		12 kt/y	7, 2, 3, 6, 17, 31
133	Functionalized lignin polymers	From wood				9
134	Furan	From furfural				1
135	Furan (2,5)-dicarbonic acid					8
136	Furan(2,5)-dicarboxylic acid (FCDA)	From 5 hydroxymethyl furfural				1

137	Furfural	Xylose thermal transformation			200-300 kt/y	2, 3, 17
138	Furfuryl alcohol	Directly derived from furfural				5, 9, 17
139	Gasoline	Fisher Tropsch synthesis (syngas)				2
140	Gelatin	Extracted from bones				9
141	Gellan	Fermentation product				9, 3
142	Glucaric acid	Sugars fermentation				6
143	Gluconic acid	Fermentative glucose oxidation	1500		50 kt/y	3, 6, 38
144	Glucose	Enzymatic hydrolysis of starch				3
145	Glutamic acid	Sugars fermentation	5200		1500 kt/y	3, 6, 31
146	Glutamine	From glucose			1000 t/y	3
147	Glutaric acid	Fermentation from glucose				9
148	Gluten	From wheat	1300			4, 9, 18
149	Glyceraldehyde					4
150	Glyceric acid	From glycerol oxidation				1
151	Glycerol	From oil/lipids - thermochemical or sugars fermentation	80-770			2, 6, 17, 18
	Glycerol		1584		750 kt/y	3, 31
	Glycerol		600-800	Aug 08 NWE	750 kt/y	3, 31
152	Glycerol carbonate	Oxidative carbonylation of glycerine				1
153	Glycerol dimethacrylate					4
154	Glycerol pharma grade		1848			31
155	Glycerol-1-monoethers					4
156	Glycidol	Internal dehydration of glycerine				1
157	Glycine	From serine and threonine				8
158	Glyoxylic acid	Fermentation				3
159	Guaiacols	Biomass thermochemical				11
160	Guayule	Extracted from plants				17
161	Hemicellulose	Extracted from plants				9
162	Heparin	From glucose				3
163	Hexoses	C6 sugars such as glucose, fructose				4
164	Histidine	From glucose			300 t/y	3
165	HMF (Hydroxymethyl Furfural)	Dehydration of hexoses (glucose, fructose)				1
166	Humins					5
167	Hyaluronic acid	Fermentation			50 t/y	3
168	Hydraulic fluids					17

169	Hydrogen	Biomass gasification				8
170	Hydroxyacetaldehyde					8
171	Hydroxyethanoic acid					4
172	Hydroxypyruvic acid					4
173	Hyroxyproline	From glucose			100 t/y	3
174	Indigo	Fermentation			30 kt/y	3
175	Isoleucine	From glucose			550 t/y	3
176	Isoprene	Fermentation of glucose				7
177	Isopropanol		480-840			4, 35
178	Isosorbide	Sugars thermochemical, derived from sorbitol				2, 17
179	Itaconic acid	Xylose fermentation product			4 kt/y	2, 3, 6, 17
180	Kerosene	From Fisher Tropsch synthesis (syngas)				8
181	Ketones					4
182	Kojic acid	Fermentation				3
183	Lactate esters	Derived from lactic acid				9
184	Lactic acid	Glucose fermentation	1190-1450			7, 2, 6, 17, 33
	Lactic acid		1320		150 kt/y	3, 31
185	Lactic amide					17
186	Lactide					17
187	Lactitol	Lactose derivative				4, 9
188	Lactoferrin (proteins)	From milk				8
189	Lactones					8
190	Lactonitrile					17
191	Laurylic alcohol	From vegetable oil				8
192	L-Carnitine	From 3 hydroxy-butyrolactone				7
193	Lecithin	From oil/lipids, thermochemical				2
194	Leucine	From glucose			800 t/y	3
195	Levoglucosan	Sugars chemical transformation				6
196	Levulinic acid	Sugars biochemical				2, 3, 6, 17
197	L-Hydroxyphenylalanine		10000		10 kt/y	4, 38
198	Lignin	Extracted from wood				14, 17
199	Linear Alpha Olefins (LAO)					7
200	Lisolesithin					4
201	L-sorbose	Fermentation			50 kt/y	3
202	Lubricants	From Vegetable oils				17

203	Lysine	Sugars fermentation	1500		800 kt/y	3, 11, 38
204	Maleic anhydride	From succinic acid				2, 17
205	Malic acid	From succinic acid (sugars fermentation)	1443		25 kt/y	2, 3, 6, 31
206	Malonic acid	From 3-hydroxy propionic acid, sugars fermentation	24000			2, 3, 6, 17, 32
207	Maltitol	Hydrogenated maltose, cereal derived				4, 9
208	Mannitol	Hydrogenated fructose, cereal derived				4, 9
209	Mannose	From oxidation of mannitol				5
210	Mesoxalic acid					4
211	Methane	Biomass gasification or catalytic hydrogenation of CO2				10, 17
212	Methanol	Fisher Tropsch synthesis (syngas) or catalytic hydrogena-tion of CO2	254			2, 10, 31
	Methanol	Fisher Tropsch synthesis (syngas) or catalytic hydrogena-tion of CO2	295	Aug 08, Rot		2, 10, 31
213	Methionine		20000		400 t/y	7, 38
214	Methyl acetate	From acetic acid and methanol				8
215	Methyl methacrylate (MMA)	Plants as plants approach (genetically modified switch-grass)				7
216	Methyl tetrahydrofuran (MTHF)					17
217	Methyl tetrahydrofuran	From 2-methyl furan				
218	Molasses	Bulk sugar residue				9
219	Monoethers					4
220	Monoglycides	Hydrolysis from natural oils & fats				9
221	Monosodium glutamate (MSG)	Fermentation product	1500		1000 kt/y	4, 38
222	N-methyl pyrrolidone (NMP)	From succinic acid				2, 17
223	Oil from algae	Extraction				9
224	Oleochemicals (oleic acid)	Extraction & hydrolysis from oilseeds				4, 9
225	Oxalic acid	Oxidation decarboxylation of lactic acid				3
226	Pantothenic acid	Fermentation				3
227	Paraffin waxes	Fisher Tropsch synthesis				2
228	Pentanol					15
229	Pentoses	C5 sugars derived from hemicellulose				9
230	Phenol	Lignin thermochemical	1320			11, 31
	Phenol	Lignin thermochemical	1462-1542	Aug 08, NWE		11, 31

231	Phenol formaldehyde	From biomass pyrolysis				8, 17
232	Phenolics	Lignin thermochemical				14
233	Phenylalanine	From glucose			10 kt/y	3
234	Phosphate	From DDGS				12
235	Phospholipids	Extraction from eggs, milk				4, 9
236	Phycocyanine	From algae				4
237	Pig feed	From upgrading of DDGS				12
238	Poly-3-hydroxybutyrate (PHB)	Fermentation from glucose; extraction from some plants				4, 9
239	Polyamide 11 (PA11) (not biodegradable)					4
240	Polyethylene (not biode-grable but recyclable)	Produced from bioethanol derived ethylene	1550-1590			7, 31
241	Polyethylene		1560-1590	Aug 08, EU		31
242	Polyglycerol methacry-lates					4
243	Polyhydroxyalkanoate (PHA)	Plants as plants approach (genetically modified switch-grass) or fermentation			1000 t/y	7, 3, 17
244	Polylactic acid	From lactic acid (glucose fermentation)			140 kt/y	2, 3, 7
245	Polylactide	From lactic acid (glucose fermentation)				17
246	Polymers					17
247	Polyols	Hydrogenation of sugars such as glucose, mannose, maltose, xylose	1800			4, 9, 18
248	Polypropylene		1330-1350	Aug 08, EU		16, 31
249	Polytetramethylene ether glycol (PTMEG)	From THF				7
250	Polyurethanes	Contains approx. 20% bio-based feedstocks (from oils and lipids) Biobased component is glycerol, glucose, sor-bitol, sucrose				9, 2, 17
251	Polyvinyl chloride					7
252	Proline	From glutamic acid			800 t/y	1, 3
253	Propanol		900			14, 23
254	Propionaldehyde		680			4, 23
255	Propionic acid	Reduction of lactic acid, sugars fermentation	780-1060			3, 6, 27
256	Propylene		1015	Aug 08 NWE		5, 31
257	Propylene glycol	From glycerine Sugars fermentation or thermochemical derivative of sorbital	2320-2390			7, 2, 17, 28

	Propylene glycol		1760			17, 31
258	Propylene oxide		1090-1350			4, 29
259	Protein	From all living organisms				14, 9, 17
260	Pullulan	Derived from starch by fermentation			10 kt/y	3
261	Pyruvic acid	From lactic acid oxidation (glucose fermentation)				3, 17
262	Quinones	Biomass thermochemical				11
263	Rapeseed oil	From rapeseed, thermochemical				8
264	Rayon	Fibre derived from cellulose				5, 9
265	Resins (phenol formalde-hyde)	From biomass pyrolysis				2
266	RME (Rape Methyl Ester)	Derived from rapeseed oil	1148	Aug 08, Rot		8
	RME (Rape Methyl Ester)	Derived from rapeseed oil	1240	Aug 08, Rot		8
267	Rosin	Forest derivatives-thermochemical Extracted from pine trees				9, 2
268	R-δ-dodecanolide					4
269	Saccharinic acid					5
270	Scleroglucan	Fermentation				3
271	Serine	From 3 hydroxypropionic acid, sugars fermentation			300 t/y	3, 6
272	Solvents					17
273	Sorbitol	Sugars fermentation or chemical transformation	1320		1100 kt/y	2, 3, 6, 17, 31
274	Sphingan	Fermentation				3
275	Starch	Extracted from cereals and tubers				4, 9
276	Stearylic alcohol	From vegetable oil				8
277	Steroids					4
278	Styrene		540			8, 31
	Styrene		1232			31
	Styrene		1090-1110	Aug 08, Rot		31
279	Succinamide					17
280	Succinate salts					17
281	Succinic acid	Several fermentation processes available	7900-1174			2, 3, 6, 17, 30
282	Syringaldehyde	Biomass thermochemical				11
283	Syringol	Biomass thermochemical				11
284	Tall Oil Fatty Acids (TOFA)	Extracted from wood				13
285	Tall Oil Pitch (TOP)	Extracted from wood				13
286	Tall Oil Rosin (TOR)	Extracted from wood				13

287	Tars	From biomass gasification				14
288	Tartaric acid	Extracted from wine				9
289	Tartronnic acid					4
290	Tetrahydrofuran (THF)	Can be derived from furfural / Produced from glucose via succinic or fumaric acid	2728			9, 7, 17, 31
291	Threonine	Sugars fermentation			30 kt/y	3, 6
292	Toluene	From biomass gasification or catalytic hydrogenation of CO2	390-415			10, 31
	Toluene		582			31
	Toluene		824	Aug 08, Rot		31
293	Triethers					4
294	Trypthophane	Fermentation of glucose			1.2 kt/y	3, 9
295	Turpentine	Forest derivatives-thermochemical				2
296	Valine	From pyruvic acid			50 t/y	3, 8
297	Vanillic acid	Biomass thermochemical				11
298	Vanillin	From guaiacol or lignin (thermochemical)	14608			8, 31
299	Vinasse (biofertiliser)	Sugar co-product				9
300	Vinyl acetate	From acetic acid and ethylene				3
301	Vinyl chloride					7
302	Vitamin A, B2, B3, B12, C	Fermentation				3
303	Vitamin B12	From fermentation of carbohydrates	25000000		20 t/y	38
304	Vitamin B2	From fermentation of carbohydrates			30 kt/y	3
305	Vitamin C	From fermentation of carbohydrates	8000		80 kt/y	38
306	Xanthan	Fermentation	8000		20 kt/y	3, 38
307	Xylene	From biomass gasification	632			8, 31
	Xylene	From biomass gasification	1540	Aug 08 US		8, 31
308	Xylitol	Hydrogenation of xylose				9, 6
309	Xylonic acid	From xylose				8
310	Xylo-oligomers					8
311	Xylose	From biomass by combined thermochemical treatment, acid hydrolysis and enzymatic treatment				3
312	Zeaxanthine	Extraction from plants such as vegetables, maize				4, 9
313	α – monobenzoyl glycerol					4
314	α,γ-dichlorohydrin	From glycerol				8
315	β-carotene	Extraction from plants such as algae, carrots				4, 9

316	γ-amino levulinic acid,					17
317	γ-butyrolactone	Produced from glucose via succinic acid (fermentation)				7, 17
318	γ-valerolactone	From levulinic acid				1
				Rot = Rotterdam		
				NWE = North West Europe		

3.6 References for Table 2 - Biomass derived products, prices and market volume

1 A. Corma, S. Iborra, A. Velty Korma, Chemical Routes for the Transformation of Biomass into Chemicals, Chem. Rev. 2007, 107, 2411-2502.
2 U.S. Department of Energy, Industrial bioproducts: Today and tomorrow, July 2002
3 Medium and long term opportunities and risks of the biotechnological production of bulk chemicals from renewable resources – The potential of white biotechnology, The BREW project, September 2006.
4 Sofie Dobbelaere, Universiteit Gent (UGent) personal communication April 2008
5 M. Stojanovic, Agrotechnology and Food Innovations B.V. (WUR A&F) personal communication April 2008
6 National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Top Value Added Chemicals from Biomass, Volume I - Results of Screening for Potential Candidates from Sugars and Synthesis Gas, August 2004.
7 NNFCC project 08-008, Biochemical opportunities in the United Kingdom, September 2008
8 AV Bridgwater, ME Gyftopoulou, Aston University contribution April 2009
9 Philippe Willems, Value for Technology bvba (VFT) personal communication April 2009
10 T. Inui, M. Anpo, K. Izui, S. Yanagida, T. Yamaguchi, Research and development on new synthetic routes for basic chemicals by catalytic hydrogenation of CO2, Studies in Surface Science and Catalysis, vol-114, 1998 Elsevier. Contributed by Laura Bermudez Abengoa Bioenergy New Technologies (ABNT)
11 Pacific Northwest National Laboratory, Top Value Added Chemicals from Biomass, Volume II - Results of Screening for Potential Candidates from Biorefinery Lignin, October 2007.
12 Koen Meesters, Agrotechnology and Food Innovations B.V.(WUR A&F) personal communication April 2009
13 Arpiainen Vesa, Valtion Teknillinen Tutkimuskeskus (VTT) personal communication April 2009
14 Herman den Uil, Energy research Centre of the Netherlands (ECN) personal communication April 2009
15 Shiro Saka, Kyoto University, Recent progress in biorefineries as introduced by super critical fluid science and technology, Biorefinica Conference Workshop, January 29, Osnabruck, Germany
16 Telma Teixeira Franco, Advances and opportunities towards a biobased industry in Brazil, Biorefinica Conference Workshop, January 29, Osnabruck, Germany
17 Industrial Bioproducts: Today and Tomorrow. Energetics, Incorporated,
18 Wim Soetaert University of Gent, from Euroview draft report 2008
19 E. Burridge, 2007. Chemical profile: Acetic Acid. Chemical Market Reporter 272, 4. 50.
20 M. Kirschner, 2006. Chemical profile: Acetone. Chemical Market Reporter 269, 26.
21 S. Vollenweider, C. Lacroix. 2004. 3-Hydroxy-propionaldehyde: Applications and perspectives of biotechnological production. Appl. Microbiol. Biotechnol. 64, 16-27.
22 M. Kirschner, 2005. Chemical profile: Acrylic acid. Chemical Market Reporter 267, 50.

23 M. McCoy, 1997. Chemical Prices. Chemical Market Reporter 251, 26-33.
24 http://www.healthoo.com 2007
25 http://www.foodnavigator.com/
26 D.T. Johnson, K.A. Taconi. 2007. The Glycerine Glut: Options for Value-Added Conversion of Crude Glycerol Resulting from Biodiesel Production. Environ. Progress 26, 338-348.
27 M. Kirschner, 2004. Chemical profile: Propionic acid. Chemical Market Reporter 269, 30.
28 M. Kirschner, 2007. Chemical profile: Propylene glycol. Chemical Market Reporter 272, 11, 58.
29 M. Kirschner, 2004. Chemical profile: Propylene oxide. Chemical Market Reporter 255, 31.
30 D.T. Johnson, K.A. Taconi. 2007. The Glycerine Glut: Options for Value-Added Conversion of Crude Glycerol Resulting from Biodiesel Production. Environ. Progress 26, 338-348.
31 ICIS Pricing, http://www.icis.com/home/default.aspx
32 P. Pollack, G. Romeder. 2001. malonic acid and derivatives. In R.E. Kirk & D.F. Othmer, (Eds.), Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 15, 4th ed., New York, Wiley.
33 M. Paster, L.J. Pellergrino, T.M. Carole. 2003. Industrial bioproducts: Today and tomorrow. Report prepared for Energetics, Inc., for the United States department of Energy, Office of Energy Efficiency and Renewable Energy, Office of the Biomass Program, Washington, DC.
34 A. Brice. 2007. Markets Trends & Data. Chemical Market Reporter 272, 6, 65.
35 M. Kirschner, 2004. Chemical profile: Isopropanol. Chemical Market Reporter 267, 27.
36 M. McCoy, 1997. Chemical Prices. Chemical Market Reporter 251, 26-33.
37 I. Lerner, 2007. The Great Ethanol Debate. Chemical Market Reporter 271, 5. 38-39.
38 Wim Soetaert, University of Gent, Private Communication

Table 3 Biomass derived products, prices and market volume

No.	Products	Market (Ton/year)	Price (Euros/Ton)	Ref
1	1,2 propanediol	1,500,000	3,000	1
2	1,4-butanediol,	1,500,000	1,475	2
3	1,4-Diaminobutane	10,000	1,600	3
4	2-Pyrrolidone	20,000	2,000	4
5	3-hydroxypropionic acid	3,600,000	880	5
6	Acetic acid	190,000	900	6
7	Acetone	5,600,000	500	7
8	Acrolein	125,000	1,090	8
9	Acrylamide	100,000	1,400	9
10	Acrylic acid	4,200,000	1,100	10
11	Acrylonitrile	6,000,000	1,000	11
12	Activated carbon	1,200,000	3,500	12
13	Adipic acid	2,500,000	1,150	13
14	Alkyl Polypentosides (C5-surfactants)	2	1,500	14
15	Aminoacids	1,500,000	800	15
16	Ammonia	122,000,000	460	16
17	Antibiotics (bulk)	30,000	150,000	17
18	Antibiotics (specialties)	5,000	1,500,000	18
19	Arginine	15,000	20,000	19
20	Aspartame	17,000	30,000	20
21	Aspartic acid	13,000	1,400	21
22	Astaxanthine	42	70,000	22
23	Benzene	40,000,000	667	23
24	Biocomposites	771,000	9,000	24
25	Bionolle 4,4 polyester	4,000	1000	25
26	Biotin	100	300,000,000	26
27	Butanol	1,100,000	600	27
28	Butyric acid	50,000	1,070	28
29	Caprolactam	4,000,000	1,810	29
30	Carboxylic acid	840,000	800	30
31	Carbon fibre	28,000	1,200	31
32	Catchols	200,000	3,800	32
33	Cellulose	130,000,000	730	33
34	Cellulose acetate	750,000	400,000	34
35	Chitin/Chitosan	20,000	10,000	35
36	Citric acid	1,600,000	800	36
37	Coenzyme Q10	150	400,000	37
38	Crude Tall Oil (CTO)	400,000	450	38
39	Cyclodextrins	5,000	1,000	39
40	Cyclohexane	5,000,000	640	40
41	Dextran	200	80,000	41
42	D-Gluconic acid	87,000	1,500	42
43	Dimethyl ether (DME)	150,000	450	43
44	Epoxy resins	30,000	2,550	44
45	Ethane	120,000,000	24	45
46	Ethanol	4,600,0000	740	46
47	Ethanol industrial	9,660,000	755	47
48	Ethyl acetate	1,000,000	2,000	48
49	Ethyl lactate	5,000	2,000	49
50	Ethyl tert-butyl ether (ETBE)	5,750,000	750	50
51	Ethylene	120,000,000	1,105	51
52	Ethylene glycol	20,000,000	1,300	52
53	Ethylene oxide	18,000,000	1,400	53
54	Eugenol	22,000	3,000	54
55	Fatty acids	100,0000,000	1,500	55
56	Formic acid	500,000	1,000	56
57	Fibres from cellulose	36,000,000	3,500	57
58	Formic acid	500,000	1,000	58
59	Fructose	10,100,000	400	59
60	Fumaric acid	12,000	1,478	60
61	Furfural	250,000	500	61
62	Furfuryl alcohol	350	350	62
63	Gluconic acid	87,000	1,500	63
64	Glucose	167,000,000	470	64
65	Glutamic acid	1,500,000	1,400	65

66	Glycerol	1,200,000	300	66
67	Hydrogen	54,000,000	2,000	67
68	Isoprene	7,000,000	1,800	68
69	Itaconic acid	80,000	2,000	69
70	Lactate esters	10,000,000	2,000	70
71	Lactic acid	150,000	1,320	71
72	Leucine	10	500,000	72
73	Levulinic acid	450	8,000	73
74	L-Hydroxyphenylalanine	10,000	10,000	74
75	Lysine	800,000	2,000	75
76	Maleic anhydride	1,600,000	1,450	76
77	Malic acid	25,000	1,443	77
78	Malonic acid	453	24,000	78
79	Methane	600,000,000	800	79
80	Methanol	40,000,000	254	80
81	Methionine	400	20,000	81
82	Methyl acetate	292,185	400	82
83	Methyl methacrylate (MMA)	24,00,000	1,360	83
84	Methyl tetrahydrofuran (MTHF)	13,952,400	900	84
85	Monosodium glutamate (MSG)	1,000,000	1,500	85
86	Pantothenic acid	301,698	144	86
87	Phenols	9,000,000	1,400	87
88	Phenol formaldehyde	2,300,000	150	88
89	Phenolics	9,000,000	1,400	89
90	Phenylalanine	10,000	1,0000	90
91	Poly-3-hydroxybutyrate (PHB)	50	9,000	91
92	Polyamide	6,000,000	250	92
93	Polyethylene	800,000,000	1,550	93
94	Polyhydroxyalkanoate (PHA)	1,000	10,000	94
95	Polylactic acid	140,000	2,500	95
96	Polyols	1,600,000	1,800	96
97	Polypropylene	40,000,000	1,330	97
98	Polyurethanes	11600000	3,000	98
99	Polyvinyl chloride	30,000,000	1,010	99
100	Propionic acid	130,000	800	100
101	Propylene	70,000,000	1,015	101
102	Propylene glycol	498,000	1,200	102
103	Propylene oxide	6600,000	1,200	103
104	Pullulan	10,000	9,000	104
105	Sorbitol	100,000,000	1,320	105
106	Starch	58,000,000	350	106
107	Styrene	900,000	800	107
108	Succinate salts	15,000	1,100	108
109	Succinic acid	45,000	5,000	109
110	Tall Oil Fatty Acids (TOFA)	400,000	450	110
111	Tall Oil Pitch (TOP)	200,000	400	111
112	Tall Oil Rosin (TOR)	200,000	400	112
113	Tetrahydrofuran (THF)	436,000	2,735	113
114	Threonine	30,000	6,000	114
115	Toluene	36,000,000	775	115
116	Trypthophane	1,200	6,000	116
117	Vanillin	12,000	10,000	117
118	Vinyl acetate	5,800,000	650	118
119	Vinyl chloride	32,000,000	350	119
120	Vitamin B12	20,000	25,000,000	120
121	Vitamin B2	30,000	485,000	121
122	Vitamin C	80,000	8,000	122
123	Xanthan	20,000	8,000	123
124	Xylene	33,000,000	775	124

3.7 References for Table 3 - Biomass derived products, prices and market volume

Ref.	Reference (Price)	Reference (Market Volume)
1	ICIS at www.icis.com	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf,
2	ICIS at www.icis.com	SRI Consulting at www.sriconsulting.com
3	http://www.springerlink.com/content/22506284773t2621/fulltext.pdf	http://www.springerlink.com/content/22506284773t2621/fulltext.pdf
4	http://www.springerlink.com/content/22506284773t2621/fulltext.pdf	http://www.springerlink.com/content/22506284773t2621/fulltext.pdf
5	http://www.ces.clemson.edu/hydro/symposium/2005_present/Bruce.pdf	http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6THB-4SH6BC0-2&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_searchStrId=1145529279&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=551fdd66d14833ed84
6	ICIS at www.icis.com	E. Burridge, 2007. Chemical profile: Acetic Acid. Chemical Market Reporter 272, 4. 50.
7	ICIS at www.icis.com	http://www.icis.com/v2/chemicals/9074858/acetone/uses.html
8	ICIS at www.icis.com	http://www.epa.gov/waterscience/criteria/acrolein/aq-final.pdf
9	http://wbt.dechema.de/Zahlen/BK_Grundchemikalien.html	http://wbt.dechema.de/Zahlen/BK_Grundchemikalien.html
10	ICIS at www.icis.com	Trends in Biotechnology, Volume 26, Issue 2, February 2008, Pages 100-108 (Science Direct)
11	http://www3.interscience.wiley.com/cgi-bin/fulltext/114116444/PDFSTART	http://www3.interscience.wiley.com/cgi-bin/fulltext/114116444/PDFSTART
12	http://novinkor.novo-sibirsk.ru/ZIP1.8_EN.html	http://www.in-pharmatechnologist.com/Processing-QC/Pharma-industry-to-drive-activated-carbon-growth/http://www.icac.com/files/public/McCormick.pdf
13	ICIS at www.icis.com	Trends in Biotechnology, Volume 26, Issue 2, February 2008, Pages 100-108 (Science Direct)
14	http://www.biosynergy.eu/fileadmin/biosynergy/user/docs/WP4-InnovativeChemicalConversion-ZoiNicolaidou-BIOSYNERGYWorkshop_Hamburg_2July2009.pdf	http://www.biosynergy.eu/fileadmin/biosynergy/user/docs/WP4-InnovativeChemicalConversion-ZoiNicolaidou-BIOSYNERGYWorkshop_Hamburg_2July2009.pdf
15	ICIS at www.icis.com	http://ec.europa.eu/enterprise/sectors/chemicals/files/wg_7_8fer08/05jostmann_white_biotech_en.pdf
16	ICIS at www.icis.com	http://en.citizendium.org/wiki/Ammonia_production
17	ICIS at www.icis.com	http://www.foodnavigator.com
18	ICIS at www.icis.com	http://www.foodnavigator.com
19	http://wbt.dechema.de/Zahlen/Aminos%C3%A4uren.html	http://wbt.dechema.de/Zahlen/Aminos%C3%A4uren.html
120	http://www.foodnavigator.com	http://www.foodnavigator.com/
21	http://www.ajiaminoacids.com/product/l-aspartic%20acid.aspx?MaterialNo=32572	Trends in Biotechnology, Volume 26, Issue 2, February 2008, Pages 100-108 (Science Direct)

22	http://www.azte.com/	http://www.azte.com
23	ICIS at www.icis.com	http://petrofed.winwinhosting.net/upload/6march.pdf
24	http://openwetware.org/images/b/b6/IBE_08_swp.pdf	http://eumbio.org/papers/biomanufacturing/HaikoZuidhoff.pdf
25	ICIS at www.icis.com	http://www.forestbioproducts.umaine.edu/documents/37779.pdf
26	http://www.drumlib.com/supp/prod/biotin_01.html	http://www.encyclopedia.com/doc/1G1-187655833.html
27	http://www.ademe.fr/partenaires/agrice/fiches_gb/card.asp?nc=9901C0057	http://www.ademe.fr/partenaires/agrice/fiches_gb/card.asp?nc=9901C0057
28	http://www.ademe.fr/partenaires/agrice/fiches_gb/card.asp?nc=9901C0057	http://www.ademe.fr/partenaires/agrice/fiches_gb/card.asp?nc=9901C0057
29	http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TCW-4R2Y42M-1&_user=153063&_rdoc=1&_fmt=&_orig=search&_sort=d&_docan-chor=&view=c&_searchStrId=1156072730&_rerunOrigin=google&_acct=C000012698&_version=1&_urlVersion=0&_userid=153063&md5=4e58f2f6e4	http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TCW-4R2Y42M-1&_user=153063&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_searchStrId=1156072730&_rerunOrigin=google&_acct=C000012698&_version=1&_urlVersion=0&_userid=153063&md5=4e58f2f6e4
30	ICIS at www.icis.com	http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TCW-4R2Y42M1&_user=153063&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_searchStrId=1156072730&_rerunOrigin=google&_acct=C000012698&_version=1&_urlVersion=0&_userid=153063&md5=4e58f2f6e4
31	Brigit Kamm, Patrick R Gruber, Michael Kamm Biorefineries Industrial Processes and Products , page 394, 2006, WILEY-VCH Verlag GmbH	Brigit Kamm, Patrick R Gruber, Michael Kamm Biorefineries Industrial Processes and Products , page 394, 2006, WILEY-VCH Verlag GmbH
32	http://www.springerlink.com/content/22506284773t2621/fulltext.pdf	http://www.springerlink.com/content/22506284773t2621/fulltext.pdf
33	http://en.mercopress.com/2006/08/24/cellulose-prices-at-their-highest-in-five-years	http://tree-chemicals.csl.gov.uk/review/markets.cfm
34	http://www.aliexpress.com/wholesale/wholesale-cellulose-acetate.html	http://epobio.net/workshop0605/foundationpaper_biopolymers.pdf
35	http://www.icis.com/Articles/1998/01/05/85917/chitin-and-chitosan-markets-set-for-capacity-shot-by-new.html	http://www.icis.com/Articles/1998/01/05/85917/chitin-and-chitosan-markets-set-for-capacity-shot-by-new.html
36	http://wbt.dechema.de/Zahlen/S%C3%A4uren.html	http://wbt.dechema.de/Zahlen/S%C3%A4uren.html
37	ICIS at www.icis.com	http://www.zmc-usa.com/docs/coq10_marketing_trends.pdf
38	http://www.icis.com/Articles/2002/02/18/157159/tofa-outlook-improves-on-tightening-vegetable-oils-and-cto.html	http://www.icis.com/Articles/2002/02/18/157159/tofa-outlook-improves-on-tightening-vegetable-oils-and-cto.html
39	http://wbt.dechema.de/Zahlen/BK_Spezialprodukte.html	http://wbt.dechema.de/Zahlen/BK_Spezialprodukte.html
40	ICIS at www.icis.com	http://www.icis.com/v2/chemicals/9075159/benzene/uses.html
41	ICIS at www.icis.com	http://wbt.dechema.de/Zahlen/BK_Spezialprodukte.html

42	Trends in Biotechnology, Volume 26, Issue 2, February 2008, Pages 100-108 (Science Direct)	Trends in Biotechnology, Volume 26, Issue 2, February 2008, Pages 100-108 (Science Direct)
43	http://www.bateman.co.za/TECHNOLOGY/20080715105033312.pdf	http://www.brain-c-jcoal.info/cctinjapan-files/english/2_4A4.pdf
44	http://www.icispricing.com/il_shared/Samples/SubPage10100083.asp	http://en.wikipedia.org/wiki/Epoxy
45	http://www.icis.com/Articles/2006/03/25/2013261/saudis-face-big-ethane-price-rise-in-2012.html	http://www.sriconsulting.com/nl/Public/2009/0912/0912.html
46	ICIS at www.icis.com	http://www.icrisat.org/Biopower/philippines-event/HenriBardonSupplyChainManagementMay07.pdf
47	ICIS at www.icis.com	http://www.icrisat.org/Biopower/philippines-event/HenriBardonSupplyChainManagementMay07.pdf
48	http://www.icispricing.com/il_shared/Samples/SubPage92.asp	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf
49	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf
50	http://www.icispricing.com/il_shared/Samples/SubPage10100120.asp	http://www.lyondellbasell.com/techlit/techlit/3388.pdf
51	ICIS at www.icis.com	http://petrofed.winwinhosting.net/upload/6march.pdf
52	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf
53	http://www.usda.gov/oce/reports/energy/BiobasedReport2008.pdf	http://www.encyclopedia.com/doc/1G1-135119652.html
54	http://www.icis.com/V2/Chemicals/9075773/ethylene-oxide/process.html	http://monographs.iarc.fr/ENG/Monographs/vol97/mono97-7A.pdf
55	http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VRV-41BV2FD-H&_user=153063&_rdoc=1&_fmt=&_orig=search&_sort=d&_docan-chor=&view=c&_searchStrId=1156143188&_rerunOrigin=google&_acct=C000012698&_version=1&_urlVersion=0&_userid=153063&md5=ae28c142c0	http://jpronline.info/article/download/108/90
56	http://wcm.paprican.ca/newsevt/WCMPublicNews.nsf/Lookup/D43D499F79E3281E8525710E0078E8BA/$file/canada_natural_advantage_web_pres.pdf	http://wcm.paprican.ca/newsevt/WCMPublicNews.nsf/Lookup/D43D499F79E3281E8525710E0078E8BA/$file/canada_natural_advantage_web_pres.pdf
57	http://www.usahops.org/graphics/File/YYang_Textiles_Alt_Use_1-08.pdf	http://business.highbeam.com/industry-reports/chemicals/cellulosic-manmade-fibers
58	http://www.dfcinternational.com/files/DuniaFormicAcidSurvey15June2008.pdf	http://www.dfcinternational.com/files/DuniaFormicAcidSurvey15June2008.pdf

59	http://www.foodanddrinkeurope.com/Financial/Sugar-and-strife-not-so-nice-if-the-price-is-not-right	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf
60	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf
61	http://www3.interscience.wiley.com/cgi-bin/fulltext/121408263/PDFSTART	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf
62	http://www3.interscience.wiley.com/cgi-bin/fulltext/121408263/PDFSTART	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf
63	ICIS at www.icis.com	Trends in Biotechnology, Volume 26, Issue 2, February 2008, Pages 100-108 (Science Direct)
64	http://www.indexmundi.com/commodities/?commodity=sugar-european-import-price	http://www3.interscience.wiley.com/cgi-bin/fulltext/117923014/PDFSTART
65	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf
66	http://www3.interscience.wiley.com/cgi-bin/fulltext/122295437/PDFSTART	http://www3.interscience.wiley.com/cgi-bin/fulltext/122295437/PDFSTART
67	http://en.wikipedia.org/wiki/Hydrogen_economy	http://www.gkss.de/imperia/md/content/gkss/institut_fuer_werkstoffforschung/wtn/h2-speicher/funchy/funchy-2007/5_linde_wawrzinek_funchy-2007.pdf
68	Flagship programme on Biopolymers	Flagship programme on Biopolymers
69	http://www.springerlink.com/content/2m63q7hwt32881g8/fulltext.pdf	http://www.springerlink.com/content/2m63q7hwt32881g8/fulltext.pdf
70	http://www.anl.gov/techtransfer/Available_Technologies/Environmental_Research/faq_ethyl_lactate.html	http://www.anl.gov/techtransfer/Available_Technologies/Environmental_Research/faq_ethyl_lactate.html
71	www.purac.com	www.purac.com
72	ICIS at www.icis.com	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf
73	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf
74	ICIS at www.icis.com	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf
75	http://wbt.dechema.de/Zahlen/Aminos%C3%A4uren.html	http://wbt.dechema.de/Zahlen/Aminos%C3%A4uren.html
76	ICIS at www.icis.com	http://www.osti.gov/bridge/purl.cover.jsp;jsessionid=2AFE2ADF73627D538C316A5A53477BCC?purl=/901298-nfysa5/
77	ICIS at www.icis.com	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf
78	National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Top Value Added Chemicals from Biomass, Volume I - Results of Screening for Potential Candidates from Sugars and Synthesis Gas, August 2004	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf
79	www.physorg.com/news9792.html	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf

80	ICIS at www.icis.com	http://www.celanese.com/databook_2003-corporate.pdf
81	http://wbt.dechema.de/Zahlen/BK_Aminos%C3%A4uren.html	http://wbt.dechema.de/Zahlen/BK_Aminos%C3%A4uren.html
82	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf
83	http://www.icis.com/V2/Chemicals/9076048/methyl-methacrylate/pricing.html	http://chemsystems.com/reports/search/docs/abstracts/0405-2_abs.pdf
84	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf
85	ICIS at www.icis.com	http://technologyconference.kbr.com/2009/Dubai/Conference-Downloads/KBR-Phenol-Leading-the-Industry.pdf
86	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf
87	ICIS at www.icis.com	http://technologyconference.kbr.com/2009/Dubai/Conference-Downloads/KBR-Phenol-Leading-the-Industry.pdf
88	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf	http://www.4fcrops.eu/pdf/Bologna/CHIMAR.pdf
89	ICIS at www.icis.com	http://technologyconference.kbr.com/2009/Dubai/Conference-Downloads/KBR-Phenol-Leading-the-Industry.pdf
90	http://wbt.dechema.de/Zahlen/Aminos%C3%A4uren.html	http://wbt.dechema.de/Zahlen/Aminos%C3%A4uren.html
91	http://www.welshcomposites.co.uk/downloads/biopolymer%20presentation.pdf	http://www.welshcomposites.co.uk/downloads/biopolymer%20presentation.pdf
92	ICIS at www.icis.com	http://www.rhodia.com/en/binaries/investor_day_rhodia_polyamide_presentation_June_2005_en.pdf
93	ICIS at www.icis.com	Qatar Economic Forum at http://www.iktissad.com/events/QEF/1
94	http://www.welshcomposites.co.uk/downloads/biopolymer%20presentation.pdf	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf
95	http://www.welshcomposites.co.uk/downloads/biopolymer%20presentation.pdf	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf
96	ICIS at www.icis.com	http://www.foodnavigator.com/Financial-Industry/Cargill-meets-investment-as-polyol-market-paces-forward
97	ICIS at www.icis.com	http://www.sebi.gov.in/dp/relpetroleum.pdf
98	www.epnoe.eu/content/.../PROBIP2009%20Final%20June%202009.pdf	http://acs.confex.com/recording/acs/green09/pdf/free/4db77adf5df9fff0d3caf5cafe28f496/paper69823_5.pdf
99	http://www.icis.com/v2/chemicals/9074319/polyvinyl-chloride/pricing.html	http://www.solvinpvc.com/static/wma/pdf/7/1/7/6/Presentation%20Cables%202006%20-%20RTM%20&%20RDW%20Graph%20vs%20pict.pdf
100	ICIS at www.icis.com	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf
101	ICIS at www.icis.com	http://petrofed.winwinhosting.net/upload/6march.pdf

102	http://www.jordanecb.org/pdf/investment/pvtsec_proplyleneglycol.pdf	http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/bioref0603.pdf
103	ICIS at www.icis.com	http://www3.interscience.wiley.com/cgi-bin/fulltext/122603439/PDFSTART
104	http://www.welshcomposites.co.uk/downloads/biopolymer%20 presentation.pdf	Medium and long term opportunities and risks of the biotechnological production of bulk chemicals from renewable resources – The potential of white biotechnology, The BREW project, September 2006.
105	http://www.ics.trieste.it/core-programmes/biofuels/meeting--courses.aspx?itemID=2974	http://www.ics.trieste.it/core-programmes/biofuels/meeting--courses.aspx?itemID=2974
106	http://www.starch.dk/isi/stat/eu.asp	http://www.zuckerforschung.at/fenster_en.php?img=images/cist_dia1_g_en.jpg
107	ICIS at www.icis.com	http://www.styreneforum.org/industry_index.html
108	http://www.springerlink.com/content/q8k1778qt6ll4582/fulltext.pdf	http://www.springerlink.com/content/q8k1778qt6ll4582/fulltext.pdf
109	www.bio-amber.com	www.bio-amber.com
110	http://www.icis.com/Articles/2002/02/18/157159/tofa-outlook-improves-on-tightening-vegetable-oils-and-cto.html	http://www.icis.com/Articles/2002/02/18/157159/tofa-outlook-improves-on-tightening-vegetable-oils-and-cto.html
111	http://www.icis.com/Articles/2002/02/18/157159/tofa-outlook-improves-on-tightening-vegetable-oils-and-cto.html	http://www.springerlink.com/content/j37742625p63ggt1/fulltext.pdf?page=1
112	http://www.icis.com/Articles/2002/02/18/157159/tofa-outlook-improves-on-tightening-vegetable-oils-and-cto.html	http://www.icis.com/Articles/2005/12/22/2010699/chemical-profile-tall-oil.html
113	http://repository.upenn.edu/cgi/viewcontent.cgi?article=1000&context=cbe_sdr	http://findarticles.com/p/articles/mi_hb048/is_200410/ai_n13164102
114	http://wbt.dechema.de/Zahlen/Aminos%C3%A4uren.html	http://wbt.dechema.de/Zahlen/Aminos%C3%A4uren.html
115	http://www.icis.com/v2/chemicals/9076549/toluene/pricing.html	http://petrofed.winwinhosting.net/upload/6march.pdf
116	http://wbt.dechema.de/Zahlen/Aminos%C3%A4uren.html	http://wbt.dechema.de/Zahlen/Aminos%C3%A4uren.html
117	http://www.umic.pt/images/stories/mctes/Eduardo.pdf	http://www.foodnavigator.com/Financial-Industry/Borregaard-announces-major-vanillin-price-increase
118	http://www.icis.com/v2/chemicals/9076563/vinyl-acetate/pricing.html	http://www.us.fjfdi.com/en/cn/project.asp?job=showen&id=9483&yuyan=en
119	http://www.icispricing.com/il_shared/Samples/SubPage65.asp	http://www.akersolutions.com/NR/rdonlyres/48EC9BBB-AA1B-4EE1-9A4E-E80C6B2A2534/10336/031208AKProcessCMDFINAL2.pdf
120	http://wbt.dechema.de/Zahlen/Vitamine.html	http://wbt.dechema.de/Zahlen/Vitamine.html
121	http://wbt.dechema.de/Zahlen/Vitamine.html	http://wbt.dechema.de/Zahlen/Vitamine.html
122	ICIS at www.icis.com	http://wbt.dechema.de/Zahlen/Vitamine.html
123	http://wbt.dechema.de/Zahlen/Vitamine.html	http://www.chem.uu.nl/brew/BREW_Final_Report_September_2006.pdf
124	http://petrofed.winwinhosting.net/upload/6march.pdf	http://petrofed.winwinhosting.net/upload/6march.pdf

4. SCOPE OF DETAILED MARKET STUDY

12 chemicals/materials were selected by the project partners as listed in Table 4 and a data sheet prepared for each. Additional chemicals and materials were subsequently added.

Table 4 Scope of detailed BIOREF-INTEG Market Study

Name	Production rate t/year	Feed-stock	Market Growth Rate	Notes
1,2-propanediol (Propylene glycol)	1.18-1.58 million t/y (All sources)	Petrochemical New plants-Glycerine	45%/y	
Epichlorohydrin	1 million t/y (All sources)	Petrochemical New plants-Glycerine	5%/y	Chlorinated product needs chlorine supply. Likely only a few producers
Lactic Acid	250,000 t/y	Sugars, starches	9%/y	Good future in biodegradable plastics
Biodiesel	>11 million t/y	Biomass, future algae	>10 %/y	Limited by disposal of by product glycerine
Biogasoline	Not yet in commercial production	Biomass, future algae various, algae		Lots of development interest.
Biokerosene	Emerging 3-5 years as a commercial product	Babassu nuts (Brazil), vegetable oils, future algae		Jet fuel application drives market
Bio-Ethanol	60 million t/y	Corn, wheat, sugar cane, sugar beet	20%/y (Driven by US & European political rulings)	Brazil and USA main markets (Cellulose based ethanol is expected to commercialize in couple of years)
Methanol	440 million t/y (All sources)	Petrochemical Future glycerine	Market turbulent at present	Growing use in bio-diesel, Gasoline, DME
DME	12 million t/y (all sources)	Coal, methanol	20%/y	Outstanding growth in China
Bio-tar	No market	From Fast Pyrolysis		Potential to convert to phenols and toluene
Wood Pellets (Renewable solid fuels)	10 million t/y	Mainly wood	20%/y	Outstanding growth in Europe
Animal Feed	635 million t/y	Various	2%/y	Efforts now to use glycerine in animal feed
Lignin as Chemical Feedstock	1 million t/y as sulphonates	From wood sulphite pulp	Flat at present	Huge potential for new products and aromatic chemicals
1,3 Propanediol	130,000 t/y	From Glucose, Acrolein and Ethylene Oxide	2%/y	Production from biodiesel glycerol is an important step to decrease prices
Carbon dioxide in Emissions	4811 t/y of CO_2 equivalent	Combustion Plants, Oil refineries, Glass Fibre Industries, Metal Ore Installations, Cement	25%/y	

		Factories, Pulp and Paper Industry		
Carbon dioxide in Merchant Market	20 million t/y	From combustion of wood, thermal decomposition of limestone, By-product of hydrogen production, fermentation, sodium phosphate Directly from natural carbon dioxide springs.	3%/y	New ethanol plants are likely to provide the greatly needed strategic sourcing sought in the CO_2 industry in the years ahead. This trend will likely continue with the growth in the CO_2 industry

4.1 Visualization of Markets

Figure 7 indicates that the sizes of the entire markets (from all sources) for the products studied covers a wide range, and at present is dominated by methanol and animal feed. However, at present these two large markets are served mainly from non-biorefinery production sources.

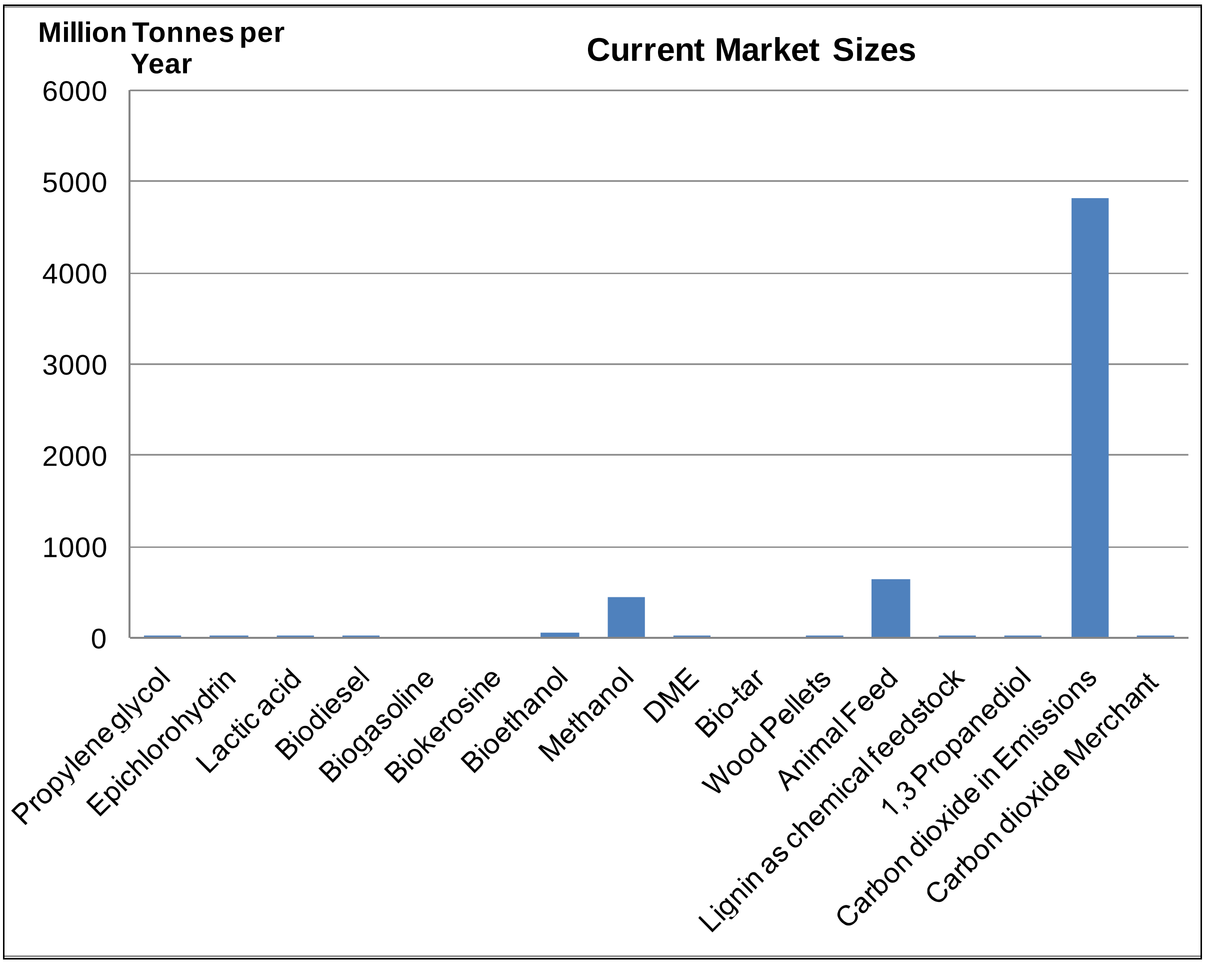


Figure 7 Current Total Market Sizes Millions of Tonnes/Year

When the dominant effect of methanol, carbon dioxide emissions and animal feed is left out (Figure 7), the impact of ethanol, which is currently produced entirely from biomass sources, becomes apparent (Figure 8). This ethanol production is currently mainly in Brazil, where it has been used for many years to offset the use of petroleum products, and more recently major expansion in the USA (and now in Europe) where it has been hugely encouraged by political decrees and subsidies relating to the use of ethanol in gasoline. This serves to illus-

trate the point that political and fiscal drivers are currently vital to the continued development of products made from biomass feedstock sources than petroleum sources.

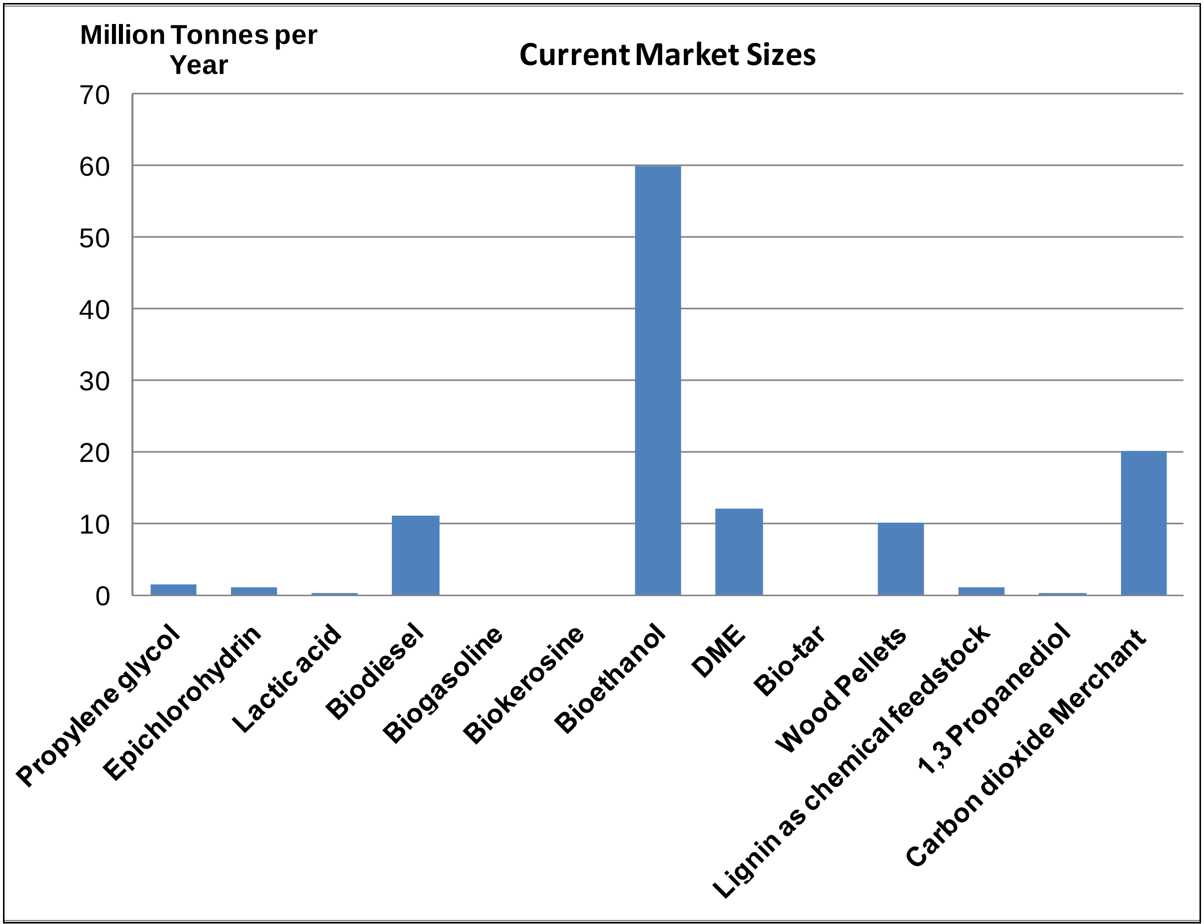


Figure 8 Current Market Sizes for Bio-Refinery Type Products

4.2 Prices

Figure 9 is for comparison purposes only, to indicate the fluctuation in market prices in recent years for the products studied. The prices have all been reduced to US$/tonne. The actual prices can be obtained from the relevant Market Data Sheets that follow.

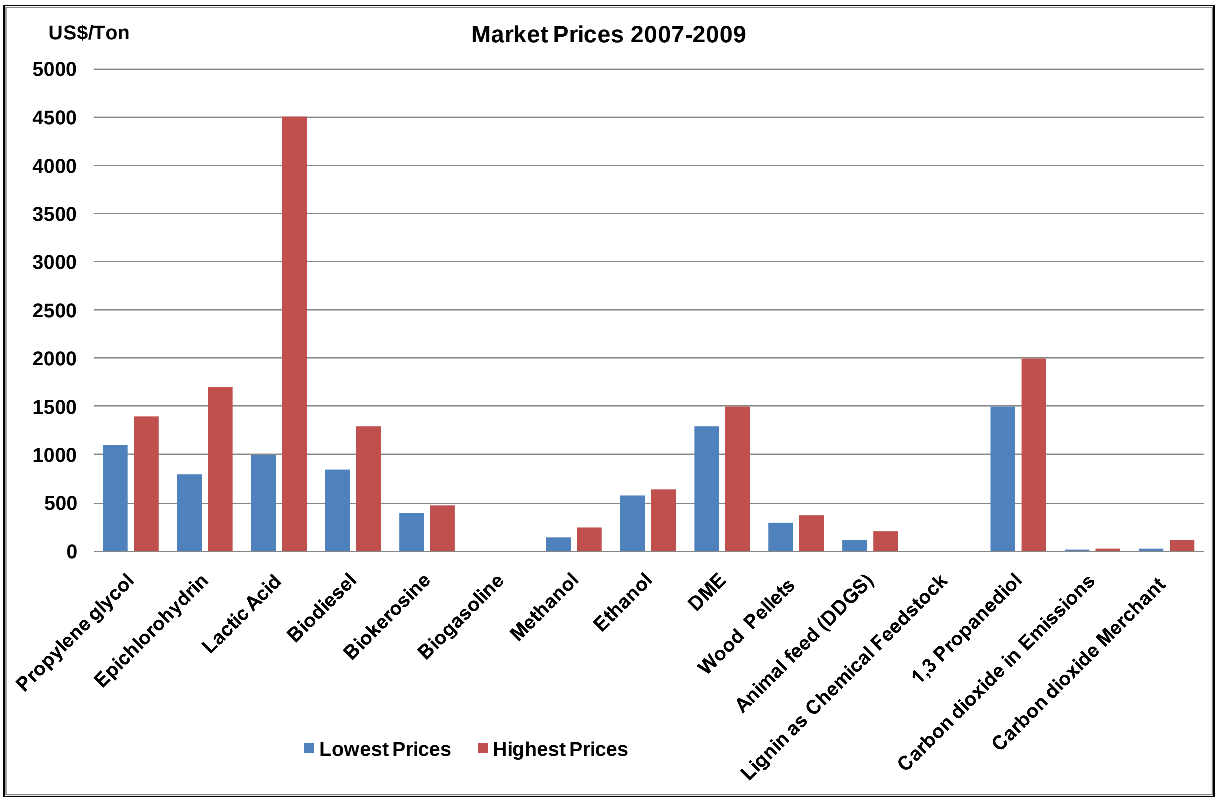


Figure 9 Average Market Price Ranges in Recent Years

4.3 Market Growth Rates

The market for some of the products is turbulent at present (Figure 10) , due to the current world economic turndown, also in some cases the rationalization of the industry by bringing large plants on stream and shutting down small producers (Methanol) , also the change to new feedstocks, with new technology. There are also market distortions caused by the surplus of some by-products (e.g. glycerine) that are currently a disposal problem for some producers and a low cost feedstock opportunity for others.

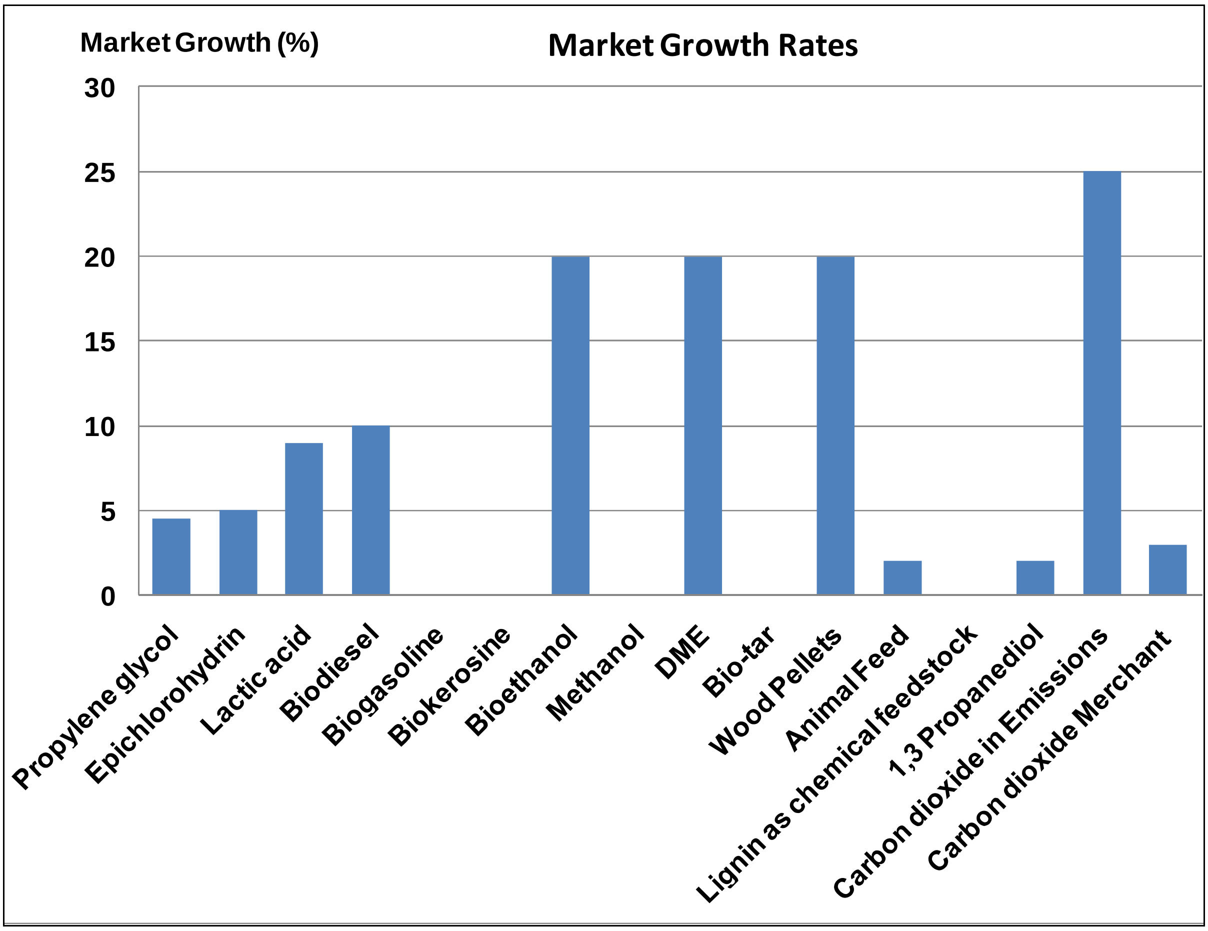


Figure 10 Market Growth Rates – 2007-2009

4.4 Overall Impressions

Biomass resources are still only playing a relatively small part in the whole energy mix Figure 11, and also in the world's demand for chemicals and food.

Lateral thinking in many organizations is identifying new products and opportunities for products. Perhaps the most striking example is DME, whose production and market is developing in China at a great pace (20%/yr+) as a substitute for LPG in home heating and cooking. At the same time the fuel has achieved a "preferred" status with Volvo for their heavy road transport diesel engines.

There is considerable confusion in the technical and market development of products from biomass. Biorefining may produce large volumes of currently unwanted by-products that may hinder production and market development. e.g. glycerine by-product from biodiesel manufacture. New feedstocks such as algae that appear to offer attractive potential for biorefining require new forms of production to be developed. There is a long way to go to realize the advantages to be gained from using biomass as the normal source for almost everything that mankind needs.

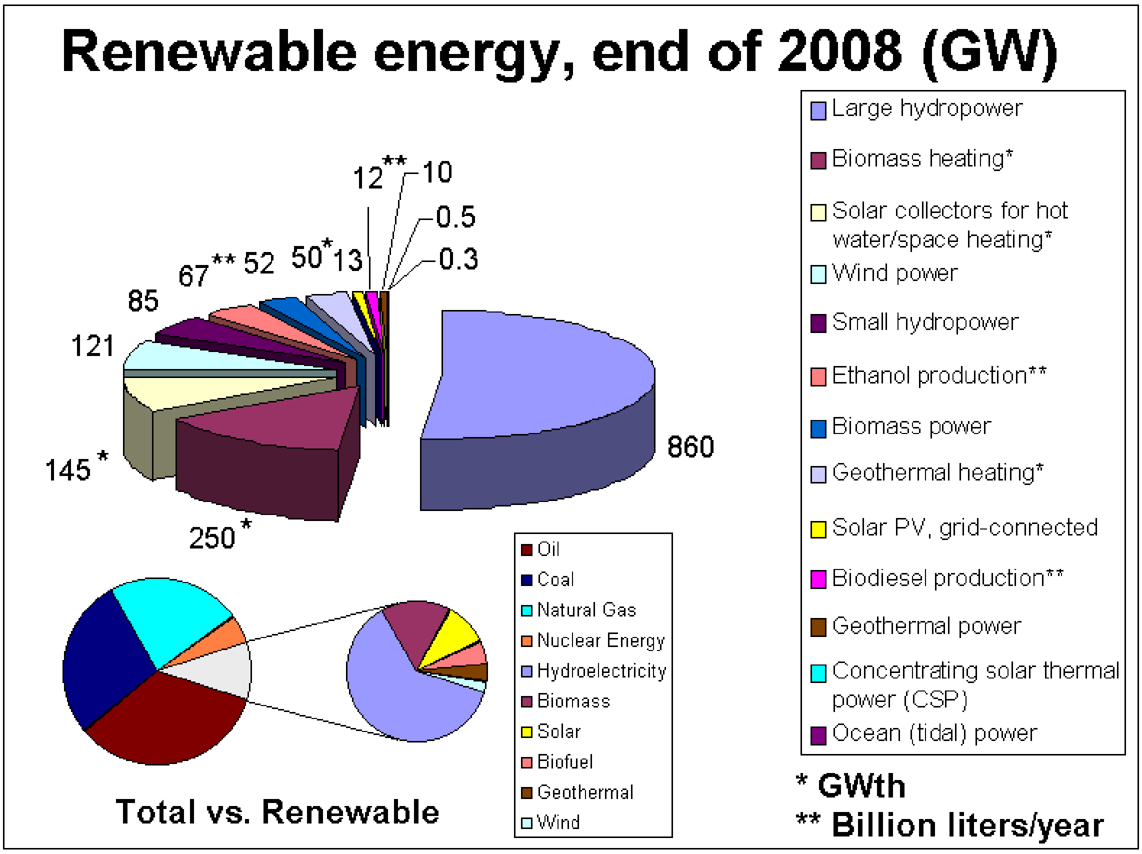


Figure 11 Renewable vs. Total Energy Sources (1)

4.5 Market Study Report Format

Each Market Study is provided below, complete with its own references. In some cases it has been necessary to insert the reference information as a scanned document and in these cases the original document format is maintained. Individual Market Reports are included in the order indicated on the Data Sheet Control, below.

4.6 Note

Care is needed with the term "Billion". US references use "billion" to mean One Thousand Million (1,000,000,000) or 10^9. European references normally use "billion" to mean one million million (1,000,000,000,000) or 10^{12}

4.7 Data Sheet Control

Name	Section	Page
1,2-propanediol (propylene glycol)	5.1	49
Epichlorohydrin	5.2	52
Lactic Acid	5.3	56
Biodiesel	5.4	59
Gasoline	5.5	65
Kerosine	5.6	67
Bioethanol	5.7	70
Methanol	5.8	79
DME	5.9	88

Bio-Tar	5.10	92
Wood Pellets (renewable solid fuel)	5.11	95
Animal feed	5.12	102
Lignin as a chemical feedstock	5.13	108
1,3 Propanediol	5.14	118
Carbon dioxide in emissions	5.15	121
Carbon dioxide in merchant market	5.16	128

4.8 References

http://www.ren21.net/pdf/RE_GSR_2009_Update.pdf

5. DETAILED MARKET ANALYSES FOR PRODUCTS SHORTLISTED

5.1 1, 2-Propanediol (Propylene glycol)

1,2-propanediol (Propylene glycol, (PG) is currently made mainly from propylene oxide. The price of this feedstock has risen considerably in recent years. Plants using new technology to make high quality (>99%) propylene glycol from glycerine, a by-product of bio-diesel manufacture are now the trend. The cost of PG production should fall as 85% of cost is attributed to feedstock, and bio-diesel manufacturers are cutting the price of by-product glycerine feed, simply to be able to dispose of it. (3). The current market is depressed, as the major market for propylene glycol, mainly in unsaturated polyester resins, has been severely affected by the current poor world economy. Worldwide market growth before the recession was put at 4.5%

5.1.1 Technical Data (4)

Product Names	1,2-propanediol Propylene glycol
CAS No EINECS No	57-55-6 200-338-0
Form	Colourless, odourless, viscous oil
Normal industrial quality purity	99.5% New technology 99.8% (5)
Chemical and Physical Properties (2)	Specific gravity at 20℃ 1.038 Boiling point 187.4℃ Refractive index 20℃ 1.4310-1.4330 Water solubility ∞
Formula	CH_3-CH(OH)-CH_2OH ($C_3H_8O_2$)
Shelf life	One year when stored in a closed container away from light and below 40℃
MSDS	See attached
Alternative grades for pharmaceutical, personal care, cosmetic, food and animal feed applications.	Propylene Glycol USP/EP

5.1.2 Uses, Manufacturers and Market Location

End Uses	**Major use** Largest use in unsaturated polyester resins (UPR's) for the marine, construction and transport industries.About 75% of UPR's are reinforced with glass fibre or other fillers to make fibre reinforced plastics (FRP's) which are tough lightweight composites. FRP's are used in residential and commercial construction to make building panels, bathroom components, fixtures and corrosion resistant tanks, pipes and ducts. Transportation uses of FRP's include pleasure boats, cars, trucks, recreational vehicles and major appliances. **Other uses.** Propylene glycol is used as an ingredient in engine coolants and anti-freeze. It has replaced ethylene glycol as the base fluid in aircraft de-icing formulations and as a coolant in the food industry.Industrial grade propylene glycol is used in the production of poly-glycols for hydraulic and brake systems.

	Propylene glycol is used with di-propylene glycol and tri-propylene glycol in the fragrance, cosmetic and personal care industries. It is also used as a non-active ingredient or solvent. Propylene glycol's uses in the personal care, food and pharmaceutical industries are growing steadily
Manufacturers	Dow, Ashland, Huntsman, Zhenhai Chemical, Ashland/Cargill, Archer-Daniels-Midland, LyonellBasell
Suppliers	Many hundreds of suppliers around the world
Market overview	Major swing in market towards production of propylene glycol from glycerine, a by-product of bio-diesel manufacture, with Dow, Huntsman, Cargill, Archer-Daniels-Midland, Senergy, Virent and others building plants New plants avoid increasingly expensive petroleum feed-stocks. New plants estimated to achieve 40c/US gallon savings (3) Forecast additional 1 *billion pounds (1,000,000,000 lbs) of glycerine (feed-stock) over the next two years (2007-2009) likely to depress price.(3) Global growth is put at 4.5% (1) to 2010. However, propylene glycol may see some substitution by glycerine in anti-freeze and de-icing applications as well as a replacement as a humectant in food applications. Glycerine is a by-product of bio-diesel manufacture, and plants are now being built to make "renewable" propylene glycol from glycerine. In the USA, W Europe and Japan the UPR market is mature and growth is slowing with consumption declining in the (2008-2009) due to economic down-turn, and competition from dicyclopentadiene-based resins. Market in Asia is showing higher growth at 7% although this forecast was made before major effects of economic downturn. Recently prices have been softening (1). Dipropylene glycol and tripropylene glycol have higher market growth in personal care products.
Market Location	USA, Europe, Asia, especially China
Market Volume	1.18-1.58 million tonnes/year (2.6-3.5 US billion pounds/year (3))
Market Price	Early 2007 US$1.8/kg (5) **NE Asia Spot Prices** US$1000-1050/tonne cost and freight mid-Feb 09 reducing to Spot Prices $950-1050/tonne in Mid-Feb, early March 09. (1) **Europe Spot Prices** €890-930/tonne , reducing to €790-830/tonne North West Europe in May 09 **USA spot prices** Variable in first half of 2009(1). Manufacturers announced 4c/lb ($88/tonne) price increase in June 2009 due to increased feedstock costs.
Market Price variability	Variability about 12% in first half of 2009 due to lower demand for Unsaturated Polyester Resins.

5.1.3 Market Volume Future Trends

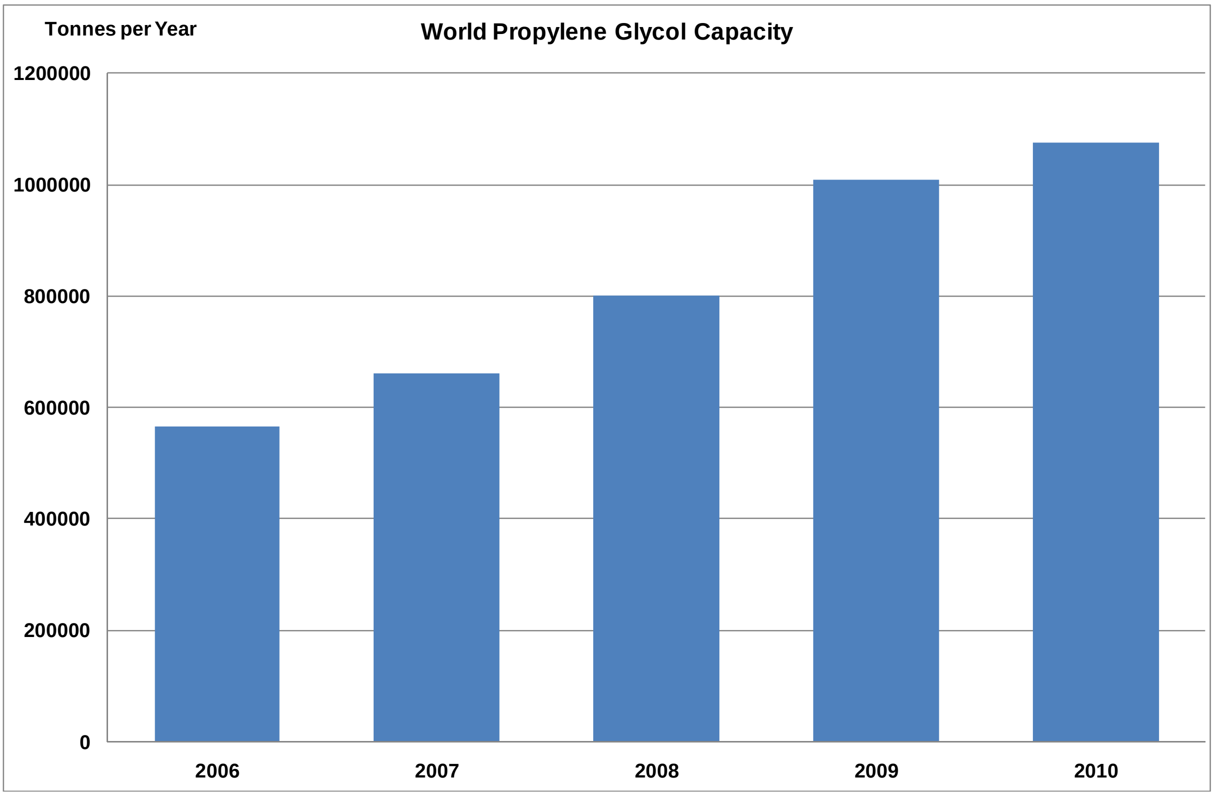


Figure 12 World Propylene Glycol Market Volume Trends. (1,3,5)

5.1.4 Producers

Name	Location	Process	Volume Produced	Feedstock	Ref
Dow	Midland, Michigan, USA	Dow	705,000 tonnes/yr (157 million US gal /yr	Petrochemical feed	3
Dow-Haltermann	Houston, Texas, USA			Glycerol feed	5
Huntsman	Port Neches, Texas, USA		145 million lbs/yr	Petrochemical	3 1
Huntsman	Conroe, Texas, USA	Huntsman	100 million lbs/yr	Glycerin feed	3
Ashland	USA				1
Ashland/Cargill	Europe	Davy and Cargill	65,000 tonnes/y	Glycerol feed	3 5
Archer-Daniels – Midland	USA	ADM Process	Plant announced		3
Senergy	Atlanta, USA 2007 startup (5)	Suppes Process licensed to Senergy	65 million lbs/yr (30,000 tonnes/yr) (7.5 million US gal/yr)	Glycerol feed	5 3
Virent and Future Fuel Co.	Madison, Ill., USA	New technology development			1
Zhenhai Chemical	Zingbo, China		100,000 tonnes/year 2009? (Uncon-	Petrochemical feed	1

			firmed)		
Lyonell Basell	Netherlands				1
UOP/Renewable Energy and Chemicals	Des Plaines, Il USA	Development Of technology			3

5.1.5 Applications

Chemical Name	Direct Use	Intermediate	Other	Potential Future
1,2,propanediol (Propylene glycol) (PG)	Anti-freeze Aircraft de-icing	Unsaturated polyester resins (UPR)	Pharmaceutical, cosmetics, healthcare, fragrance	

5.1.6 Future Trends

Major trend towards use of glycerine feed-stocks from bio-diesel production is predominant with expectedcost savings of $0.40/gal (3) and direct production of high quality product (99.8%) with new technology (3). It is possible the glut in glycerine from bio-diesel manufacture outstripping market demand, and prices of derivatives such as propylene glycol anticipated to drop. It is expected the lower volume high purity products, propylene glycol,di and tri propylene glycols maintaining better growth and price stability. The use of a forecast glut of bio-diesel by-product glycerine as a feedstock could potentially considerably lower the production cost of propylene glycol as 85% of cost is attributed to the feedstock.

5.1.7 References

1. http://www.icis.com/V2/Chemicals/9076440/propylene-glycol.html
2. Perry's Chemical Engineers Handbook 7th edition section 2
3. A Renewable Route to Propylene Glycol (http://www.allbusiness.com/energy-utilities/oil-gas-industry-oil-processing/8915320-1.html)
4. http://www.dow.com/productsafety/finder/prog.htm
5. Mario Pagliaro , Michele Rossi "The Future of Glycerol, New Uses of a Versatile Raw Material" Royal Society of Chemistry 2008

5.2 Epichlorohydrin

Epichlorohydrin is traditionally derived indirectly by reacting propylene with chlorine, and then converting the mix of chlorinated compounds to epichlorohydrin, with an estimated yield of 97% This process also produces large volumes of waste water contaminated with chlorinated compounds. (4).

A more recent hydrochlorination process allows the direct synthesis of 1, 3-dichloroprpoanol from glycerol and hydrochloric acid, and dehydrochlorination using sodium hydroxide yields epichlorohydrin (4) Solvay started using this process in 2007.

Dow is also building a plant in China that will start production of epichlorohydrin from glycerol in 2010. (4) The market for epichlorohydrin is strongly tied to production of epoxy resins used in laminates and plastics. During the economic downturn the production of these products has declined. However in the longer term these products will be used in more applications and the future of epichlorohydrin looks assured.

5.2.1 Technical Data (3)

Product Names	Epichlorohydrin
CAS No	106-89-8

Form	Clear, colourless liquid, sweet pungent odour. Hazardous, carcinogenic (5)
Chemical and Physical Properties (2)	Specific gravity at 20℃ 1.183 Boiling point 117 ℃ Refractive index 20℃ Water solubility <5%
Formula	C2H2O-CH2Cl
MSDS	(7)

5.2.2 Uses, Manufacturers and Market Location

End Uses	**Major use** 76% Epoxy resins, 19%*glycerine manufacture **Solvay now reversing this process and making epichlorohydrin from glycerine* **Other uses** See section 5.2.5	
Manufacturers	Dow, Solvay	
Suppliers (7) Note: (8) also Lists a total of 135 Worldwide suppliers	Suzhou Foreign Trade Co Ltd., Jiangsu, China	rovathin.com
	Parchem Trading Ltd., New York USA	parchem.com
	Alfa Chem New York, USA	alfachemf.com
	Jinan Haohua Industry Co Ltd., Shandong, China	jnhaohus.com
	Neuchem Inc., California USA	neuchem.com
	Spectrum Chemical Mfg. Corp Calif.USA	spectrumchemical.com
	ICC Chemical Corp.,New York, USA	iccchem.com
	Total Specialty Chemicals Inc., Connecticut USA	totaltsc.com
	Solvay Chemicals Inc., Texas, USA	solvaychemicals.us
	Primachem L.L.C.,New Jersey USA	
	Miljac.Inc., Connecticut USA	miljac.com
	Tamilnadu Petroproducts Ltd., Tamil Nadu, India	tnpetro.com
	Kiran Pondy Chem Ltd., Tamil Nadu, India	kiranindia.com
	Bimal Pharma Private Ltd., Maharashtra, India	
	Yik-Vic Chemicals & Pharmaceuticals. Hong Kong	yicvic.comSinopec Int. China
	US Chemicals Inc., Connecticut USA	uschemicals.com
	Richman Chemical Inc. Pennsylvania USA	richmanchemical.com
	Hickson & Welch Ltd., UK	hicksonandwelch.co.uk
	Collinda Ltd., Surrey, UK	collinda.co.uk
	Mitsubishi ChemicaL Corp.,Tokyo, Japan	m-kagaku.co.jp
	Diaso Co. Ltd., Osaka Japan	daiso.co.jp
	Spolchemie., Czech Republic	spolchemie.cz
	Solvay, Belgium	solvay.com
Market overview	Currently changes in production as companies switch to glycerine feed-stock from bio diesel manufacturers away from petrochemical feeds. Market driven by epoxy resins demand that has declined in economic downturn. Prices reduced during past two years.	
Market Location	USA, China, Europe.	
Market Volume	903,000 metric tonnes/year (2006) growing to 1,165,000 metric tonnes/year (2010) (7)	
Market Price (1)	**Europe**	
	Feb 09 spot	€1210-1250 /tonne
	Feb 08 spot	€1680-1720/tonne and US$71.13-73.48 cents/pound
	Reports of special deals €1210-1250/tonne North West Europe	
	Asia (1) Spot China Main Port Drums	
	Feb 09	US$850-900/tonne
	Jan 09	US$850-900

	Spot China Main Port ISO Tank Feb 09 US$800-850/tonne Jan 09 US$800-850/tonne East China Bulk Feb 09 Chinese Yuan (CNY) 7000-7500 Jan 09 CNY5800-6000 (In US$/tonne Feb 09 US$1022-1095 Jan 09 US$847-876) (Conversion using exchange rate CNY1=US$0.146 Aug 09)
Market Price variability	Prices varied 40% in 2009 in economic downturn

5.2.3 Market Volume Future Trends

Figure 13 indicates world production capacity for epichlorohydrin. The actual sales of the chemical are not known, but may be considerably lower as prices have fallen substantially as a result of the current world economic downturn

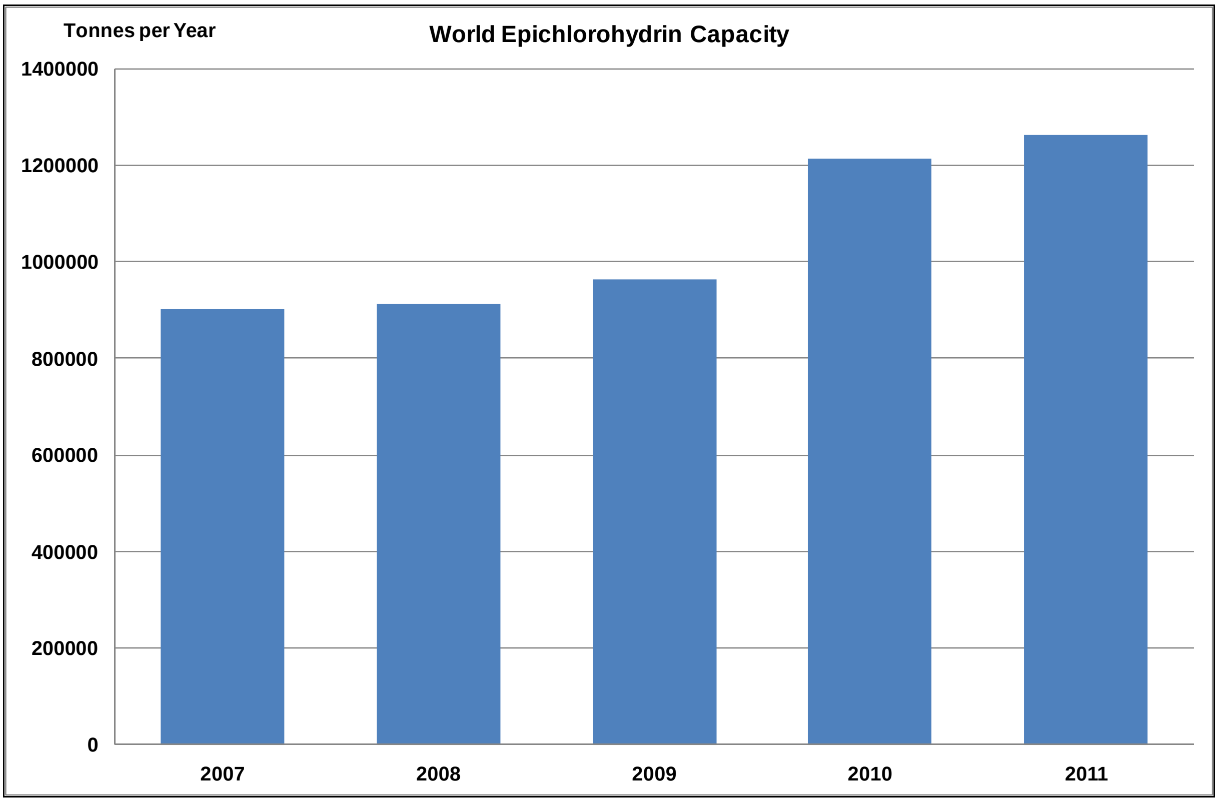


Figure 13 World capacity for epichlorohydrin (4,6)

5.2.4 Producers

US and China are the largest producers (5)

Name	Location	Process	Volume Produced	Comments	Ref
Solvay	France	Solvay	10,000 tonnes/year	First plant using glycerine feed	4
Solvay	Map Ta Phut Thailand	Solvay	100,000 tonnes/year	Planned using glycerine feed	4
Dow	Freeport, Texas USA and Stade, Germany	Dow	453,000 tonnes/year from both plants	Petrochemical feed	5
Dow	Shanghai Chemical Industry Park, China	Dow	150,000 tonnes/year	Start-up planned 2010	
Spoichemie (Czech)	Malaysia			Epoxy resin producer	6

5.2.5 Applications

Chemical Name	Direct Use	Intermediate	Other	Potential Future
Epichlorohydrin	76% of production used in epoxy resins (5) 19% used in synthetic glycerine, 5% balance other uses.	Synthesis of 1-chloro-2,3-propanediol pharmaceuticals Surface-active agents used in cosmetics Rubbers for extreme temperatures Seals and gaskets	Water purification Ion exchange resins (4,5) Textiles to improve wool resistance to moths, and to prepare fibres for dyeing Reinforcement of paper used in teabags Papers, inks, dyes	

5.2.6 Future Trends

Major trend is towards use of glycerine feedstock from bio-diesel production. (Similar trend to that for propylene glycol) There is a possibility of a glut in glycerine from bio-diesel manufacture outstripping market demand, and prices of derivatives such as propylene glycol and probably epichlorohydrin are anticipated to drop. Long term production is expected to increase use of epoxy resins in laminates and plastics. Market dominated by Dow and Solvay (probably because both are chlorine producers), who are both moving to use glycerine feed derived from biomass in new plants.

5.2.7 References

1. http://www.icispricing.com/il_shared/Samples/SubPage10100072.asp
2. Perry's Chemical Engineers Handbook 7th edition section 2
3. Dow Chemical Technical Data Sheet (PG) 117-01540-0604-X-AA
4. Mario Pagliaro , Michele Rossi "The Future of Glycerol, New Uses of a Versatile Raw Material" Royal Society of Chemistry 2008
5. http://www.dow.com/productsafety/finder/epi.htm
6. http://petrochemical-plants.blogspot.com/2007_04_01_archive.html
7. http://www.chemicalregister.com/find/Find.asp?SearchTy=Product&SearchSu=epichlorohydrin&SearchKe=AllKey&SearchLo=ALL&x=0&y=0
8. http://www.chemicalbook.com/Search_EN.aspx?keyword=epichlorohydrin

5.3 Lactic Acid

Lactic acid is commercially produced today through the fermentation of glucose derived from plant starch (1). The United States surpassed Western Europe as the largest consumer of lactic acid in 2001-2002.

In recent years lactic acid consumption in industrial applications has overtaken the food and beverage industry as the leading market. In 2010, industrial applications are forecast to grow to 50% of global consumption. Market growth of lactic acid in industrial applications is driven mainly by its use in bio-degradable polymers and lactate solvents.

The use of polylactic acid in plastic packaging and containers and in detergentsis being highly promoted because of its environmentally friendly characteristics, including biodegradability, composting of waste from lactic acid production and the fact that the biomass feedstock removes CO_2 from the atmosphere. Production from biomass potentially saves energy compared to conventional polymer production.

The world market for lactic acid is forecast to reach 259,000 tonnes/year by 2012 (2).

5.3.1 Technical Data (5)

Product Names	Lactic Acid 100% Note: Lactic acid is also sold in many compounded forms. (5)
CAS No	50-21-5 also 79-33-4 (7)
Form	When pure - colourless, to slightly yellow odourless, viscous oil Normally in aqueous solution, mild acid taste Hazardous chemical, corrosive, causes burns, harmful if swallowed.
Normal industrial quality purity	100%, plus many proprietary variants (5)
Chemical and Physical Properties (4)	Specific gravity 20℃ 1.249 Melting point 17℃ Boiling point 252℃ Water solubility ∞
Formula	$CH_3CH(OH)COOH$
MSDS	See (4)

5.3.2 Uses, Manufacturers and Market Location

End Uses	**Major Uses (8)** Bio-degradable plastics Food additives **Other Uses** Anti-microbial compounds Flavouring agents Substitute for hazardous solvents pH balancer in shampoos and soaps and other alpha hydroxy acid applications
Manufacturers	Archer-Daniels-Midland, CSM NV, Purac, Galactic SA, HenanJindan, Masachino, Jianxi
Suppliers	87 suppliers listed in Chemical Register (9) ICIS.com lists 568 suppliers (10)
Market overview (2)	The use of lactic acid in bio-degradeable plastics is expected to gather momentum, given the rising demand for environmentally friendly packaging.
Market Location	USA, Europe, Asia-Pacific 80% (2008) Largest European market is Germany, followed by France and Italy. (Also see pie chart below based on 2005 data)
Market Volume	Production is forecast to reach 259,000 tonnes/year by 2012 (2)
Market Price	Many products, typical variation between €0.7 - €3.0 /kg spans food grade to higher pharmaceutical grade. (11)

Market Price variability	Prices changing due to price of competitive products derived from oil, but also market expanding as environmental concerns make lactic acid use in biodegradable plastics attractive. No firm price data obtained from any source

5.3.3 Market Overview

Figure 14 shows the world consumption of lactic acid:

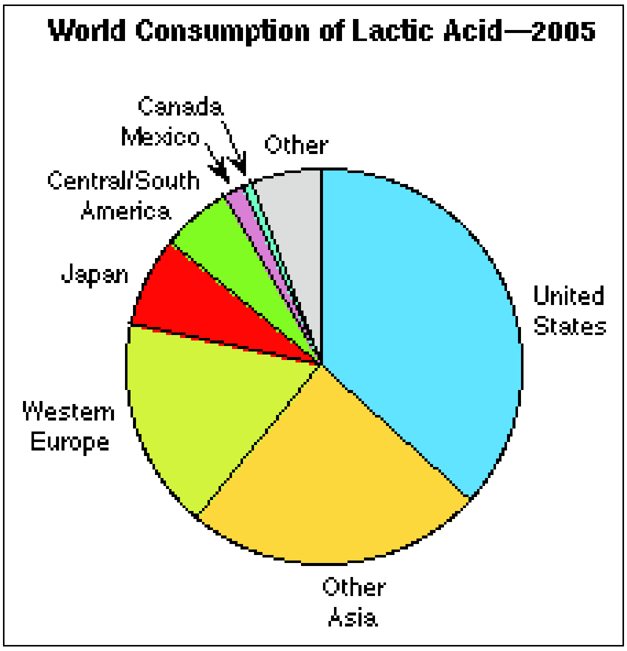


Figure 14 SRI Consulting "Lactic acid consumption worldwide

5.3.4 Market Volume Future Trends

2006 estimate of market growth for the period 2005-2010 (1,3):
Market growth rates in the US and parts of Asia are forecast to experience high annual growth rates of 10-11% with global production increases of about 9% per year in the period 2005-2010.

A more recent estimate (Oct 23 2008) (2) indicates that lactic acid market growth in the biodegradable plastics sector in USA, Europe and Japan is forecast above 6% per year in the period 2011-2015. (2). World market growth in the food and cosmetic sectors is still estimated based on production data in (2) at over 9% per year.

The Japanese market is unusual in that cosmetic products and food additives together account for over 86% of the total consumption of lactic acid. The Japanese market should thus offer good prospects for expansion of the use of lactic acid in the bio-degradable plastics sector.

The lactic acid market expansion overall has slowed down from previous estimates but is still showing good growth.

5.3.5 Producers

Name	Location	Process	Volume Produced	Comments	Ref
PURAC (part of Netherlands Company CSM nv)	Was in Europe. Netherlands and Spain. Production switched in 2007 to Thai-	Fermentation of sugars and starches	Capacity 100,000 tonnes/year	Thailand startup 2008 €98 million invested	6

	land,USA and Brazil to reach cheaper feedstocks				
Archer-Daniels-Midland	USA	Fermentation	40 million pounds/year (1993) (20,000 tonnes/year)	Production probably much larger now but no supporting data	8
Galactic S.A JV with Anhui BBCA Biochem Co (Called B&G)	China	Fermentation of sugars	Capacity 30,000 tonnes/year		8
Henan Jindan Lactic Acid Co Ltd.	Henan, China		Capacity 100,000 tonnes/year		8
Jiangxi Musachino Bio-Chem Co Ltd.	Chinese/Japanese JV Plant in China (2001)	Sweet potatoes feed	Not known	Part of large scale project started 2007	12
Ningxia Haokai Biotech Co Ltd (2007)	China	Fermentation of starch feedstocks	30,000 tonnes/year	China is reported to have more than 70 lactic acid producers	12

5.3.6 Applications

Chemical Name	Direct Use	Intermediate	Other	Potential Future
Lactic Acid	Food additives	Biodegradable plastics	Cosmetics	Biodegradable materials

5.3.7 Future Trends

Lactic acid is used in production of polylactic acid for use in biodegradable plastics used in packaging products that meet environmental concerns. Expansion of this market is driving the market. Emerging application possibilities in cosmetics are additionally expected to prop up market growth in upcoming years. Increasing political and market demands for environmentally friendly products and increasing cost of products derived from petrochemical feedstocks should provide a considerable increase in demand for some years.

5.3.8 References

1. http://www.sriconsulting.com/CEH/Public/Reports/670.5000/
2. http://www.bioplastics24.com/content/view/1339/2/lang,en/
3. http://biopol.free.fr/?p=312
4. www.jtbaker.com/msds/englishhtml/10522.htm
5. http://www.purac.com/EN/Green_chemicals/Products/Biobased_plastics/Products.aspx
6. http://www.ap-foodtechnology.com/Industry-drivers/Purac-to-move-lactic-acid-production-from-Europe
7. www.lactic-acid.com
8. Examine the World Lactic Acid Market Business Wire Jan 6 2009. (http://www.highbeam.com/doc/1G1-191499020.html)
9. http://www.chemicalregister.com/find/Find.asp?SearchTy=Product&SearchSu=lactic+acid&SearchKe=AllKey&SearchLo=ALL&x=0&y=0
10. http://www.icis.com/Search/ProductNumber/114891/WorldWide/Lactic+Acid+(50+21+5).htm?o=50
11. Spiralling costs hit lactic acid prices at Purac (http://www.foodnavigator.com/Financial-Industry/Spiralling-costs-hit-lactic-acid-prices-at-Purac)
12. China Chemical Reporter Sept 6th 2007 (http://www.highbeam.com/doc/1G1-169228365.html

5.4 Bio-Diesel

A fundamental transition in global fuel production is now happening. In the year 2007, there were only 20 oil producing nations supplying the needs of over 200 nations. By the year 2010, more than 200 nations will become biodiesel producing nations and suppliers. The world is entering a new era of participation by emerging market nations in global green energy production for transport fuels." (4)(2007)

5.4.1 Technical Data (5)

Product Names	Bio-Diesel
Specifications (1)	Europe EN 14214:2003 Germany DIN V 51606 USA ASTM D 6751-07b (For Reference: Petroleum Diesel Europe EN 590:1999)
Product Description	Bio-diesel is supplied both as a single product and also in blends with conventional fossil oil diesel. (2) B5- 5% biodiesel B20- 20% biodiesel B100 –pure biodiesel Since April 2005, fuels sold in the UK must contain 2.5% biofuel, rising to 5% in 2013. In the US, there is a volumetric target of 9 *billion gallons of biofuels in 2008, rising to 36 *billion gallons in 2022. (5)
Standards (1)	See Appendix 1 Biodiesel Standards
Normal industrial quality purity	See Appendix 1
Chemical and Physical Properties	See Appendix 1

5.4.2 Uses, Manufacturers and Market Location

End Uses	In diesel engines, primarily for road transport
Manufacturers	Many worldwide, major oil companies and others see
Suppliers	Oil companies with service stations, plus others developing
Market overview	See below 5.4.3
Market Location	Worldwide, major markets USA, Europe, especially Germany. Germany accounts for 50% of world biodiesel production. (2) 2007
Market Volume	See Figs 1,2,3 below
Market Price	**Estimated product costs for biodiesel and bioethanol in 2002 (£/GJ product)** (3)

Option & Fuel type	**Feedstock**	**Product Cost [1]**		**Source country**	**Data source/ assumption**
		£/GJ	**p/l**		
1. Biodiesel	Oil seeds	9.86	33.2	US (soy, likely export price)	Stakeholder
		12.22	41.2	EU15 (Belgian rape)	Stakeholder
2. Biodiesel	Oil seeds - UK production	9.86	33.2	US	Assumed equal to US price above
		12.22	41.2	EU15	Assumed equal to

					EU15 price above

These figures exclude any government subsidies for biofuel production but it is not possible to establish the degree to which agricultural subsidies influence the figures. Costs quoted by studies and stakeholders are based on current costs of feedstocks which will take account of any subsidies for growers of oil seeds, sugar cane etc.

Estimated product costs for 2020 in pence/litre (3)

Option & Fuel type	**Feedstock**	**Product Cost p/litre**			
		US	**EU15**	**Eastern Europe**	**South America**
1. Biodiesel	Oil seeds	32.91	40.78	34.57	-
2. Biodiesel	Oil seeds - UK production	32.91	40.78	34.57	-
3. Biodiesel	Wood - FT processing	18.68	19.05	14.19	-
4. Biodiesel	Straw - FT processing	18.68	19.05	14.19	-

Market Price variability	Price variation in period Nov 06-Nov 07 (8)(2007) US$ per Tonne 850-1300

5.4.3 Market Overview

The global markets for biodiesel are entering a period of rapid, transitional growth, creating both uncertainty and opportunity. The first generation biodiesel markets in Europe and the US have reached impressive biodiesel production capacity levels, but remain constrained by feedstock availability. In the BRIC nations of Brazil, India and China, key government initiatives are spawning hundreds of new opportunities for feedstock development, biodiesel production, and export (4).

Figure 15 World Biodiesel Production and Capacity Millions of US Tons/year (4)
Figure 16 US Biodiesel Production and Capacity Millions of (US) Tons per year (4)
Figure 17 European Biodiesel Production and Capacity, millions of (US) Tons per year (4)

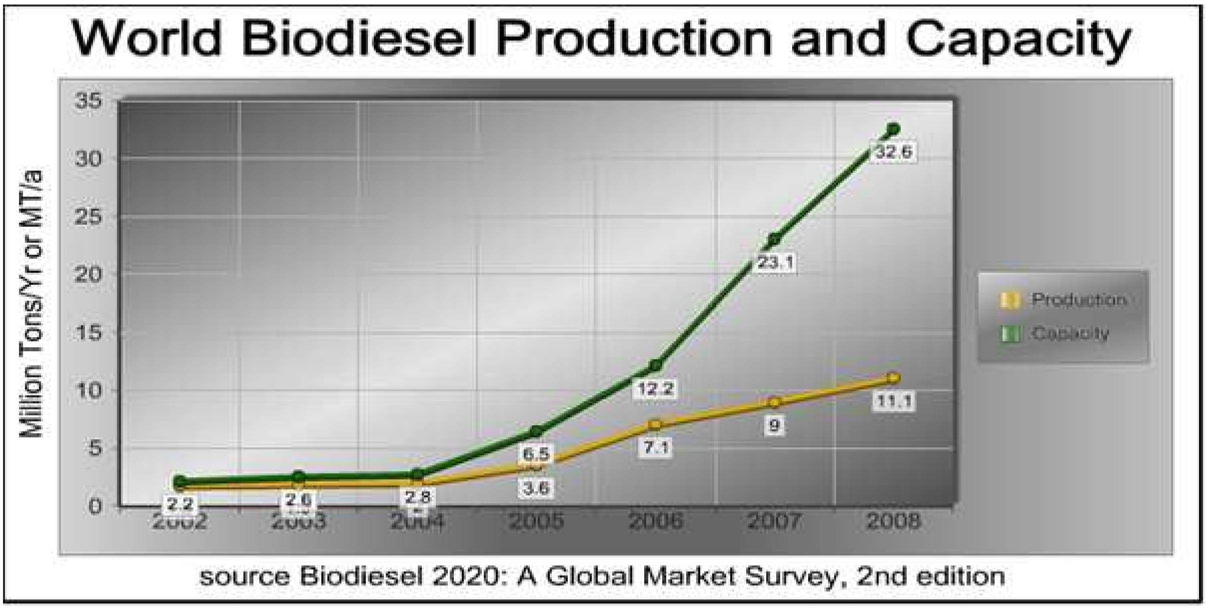


Figure 15 World Biodiesel Production and Capacity Millions of US Tons/year (4)

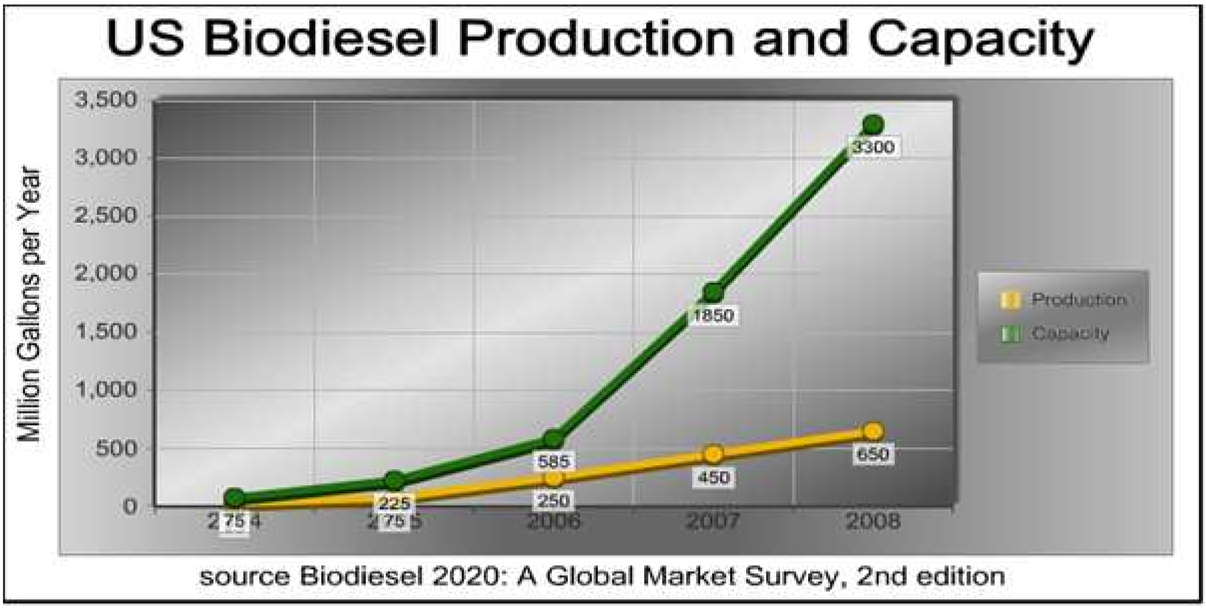


Figure 16 US Biodiesel Production and Capacity Millions of (US) Tons per year (4)

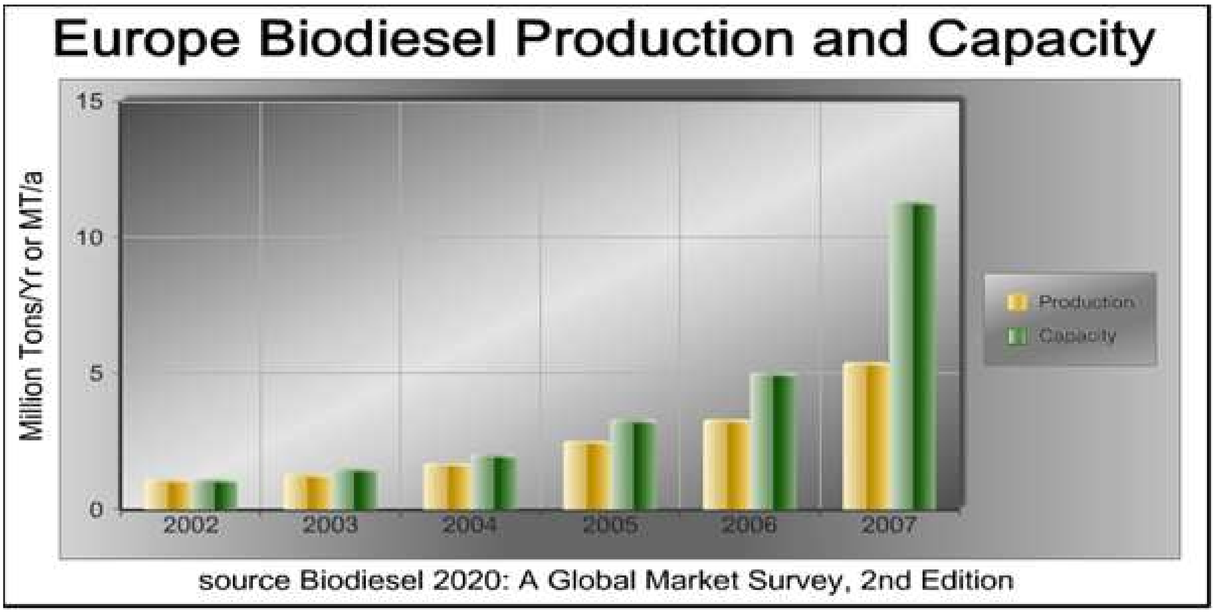


Figure 17 European Biodiesel Production and Capacity, millions of (US) Tons per year (4)

5.4.4 Market Volume Future Trends (4)(2008)

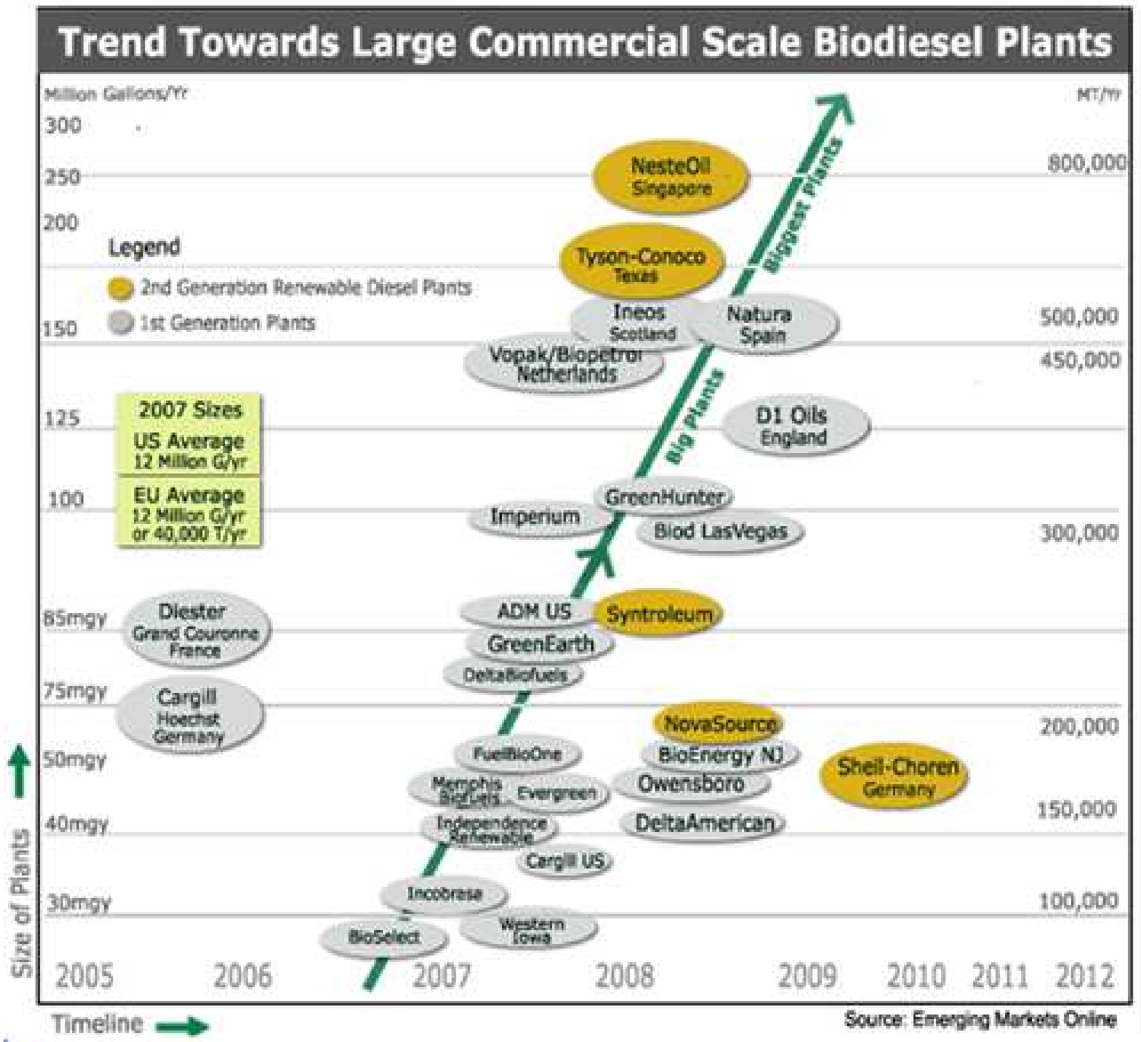


Figure 18 Trend towards large Commercial Scale Biodiesel Plants (4)

5.4.5 Producers

At present (2009) there are many new producers and distributors coming into the market. These are likely to be consolidated into large scale operations backed by existing oil and large agriculturally based companies as indicated in Figure 18 Trend towards large Commercial Scale Biodiesel Plants (4)

5.4.6 Future Trends (4)

Although market growth appears to be very considerable, in fact biodiesel production may be constrained by several factors:

- The price of competitive products made from oil.(8)
- Biodiesel feedstock production land use. (6)(7)
- Use of using feeds that can be used for food (e.g. soy)(8)
- Environmental concerns e.g. clearing the tropical rainforest to grow palms for oil feed to biodiesel plants.(6)
- The disposal of large volumes of by-product glycerine.
- Continuing availability of Government subsidies
- Government tax regimes (8)
- Development of new technologies that use alternative sustainable biomass. e.g. forest residues

Many governments are now revising their biofuels policies in a reactive or a proactive manner. If governments continue to pro-actively support and promote research & development in second generation technologies including renewable diesel, biomass to liquids projects, algae, and cellulosic diesel, and if governments continue to actively support the development of sustainable, alternative, lower-cost feedstocks such as algae, jatropha, castor, used vegetable oil, tallow, and other sustainable feedstocks, the prospects for achieving biodiesel targets may be realized faster than anticipated (4) In the US and the EU, algae-based biodiesel ventures are growing in response to demands for clean fuels. Each of these endeavours clearly demonstrates increased public and private sector interest in non-food, second generation markets (4)

An increasing number of second generation biodiesel projects are now emerging in anticipation of growing sustainability concerns by governments, and in response to market demands for improved process efficiencies and greater feedstock production yields.

The costs of biodiesel are highly dependent on feedstock, credits for by-products, agricultural subsidies, food (sugar) and oil markets. (2)

5.4.7 Opportunities

New developers, farmers, feedstock providers, producers, and investors who can meet growing demands for supply are expected to benefit from this emerging market. (4)
Key advantages in the future will be available to producers and investors to supply future needs (of biodiesel) with

- New and improved technologies.
- Alternative feed stocks with higher yields such as jatropha and algae biodiesel,
- Production scalability and flexibility options.;
- Supply chain, distribution and co-location strategies,
- Innovative risk management strategies,
- Industry-friendly government targets and
- Tax incentives committed to promoting the awareness and growth of the industry

5.4.8 References

1. Biofuel Systems Group Ltd (www.biofuelsystems.com/specification.htm)
2. International Energy Authority (IEA) Energy Technology Essentials (www.iea.org/techno/essentials2.pdf)
3. Department for Transport. International resource costs of biodiesel and bioethanol (http://www.dft.gov.uk/pgr/roads/environment/research/cqvcf/internationalresourcecostsof3833)
4. Biodiesel 2020: A Global market Survey, 2nd Edition 2007 (www.emerging-markets.com/biodiesel)
5. www.bp.com Biofuels (http://www.bp.com/productlanding.do?categoryId=9030593&contentId=7055794
6. Afro-Colombians fight biodiesel projects. (http://news.bbc.co.uk/1/hi/business/7784117.stm)
7. Biodiesel producers should diversify to survive. (http://www.reuters.com/article/idUSJAK19460020080115)
8. US Imports threaten European biodiesel production Crude oil prices boost demand for biofuels- (2008 Society of Chemical Industry and John Wiley & Sons, Ltd | Biofuels, Bioprod. Bioref. 2:7 (2008); DOI: 10.1002/bbb)
9. There is much literature available that provides data on biodiesel manufacture and markets, also (4) - a 2008 book/market study that covers the subject in great detail, is available for single use at US$2950 or multiple use US$4950

5.4.9 Appendix 1

Engine manufacturers and biodiesel plants in different parts of the world use slightly different standards for biodiesel. Virtually all modern diesel engines warranties permit some use of

biodiesel provided it meets certain specifications (International Biodiesel Standards (1) (2003 data)

Table 5 Biodiesel Standards (1)

Biodiesel Standards		Europe	Germany	USA	Petroleum diesel
Specification		EN 14214:2003	DIN V 51606	ASTM D 6751-07b	EN 590:1999
Applies to		FAME	FAME	FAAE	Diesel
Density 15℃	g/cm³	0.86-0.90	0.875-0.90		0.82-0.8 45
Viscosity 40℃	mm²/s	3.5-5.0	3.5-5.0	1.9-6.0	2.0-4 .5
Distillation	% @ ℃			90%,360℃	85%,350℃ - 95%,360℃
Flashpoint (Fp)	℃	120 min	110 min	93 min	55 min
CFPP	℃	* country specific	summer 0 spr/aut -10 winter -20		* country specific
Cloud point	℃			* report	
Sulphur	mg/kg	10 max	10 max	15 max	350 max
CCR 100%	%mass		0.05 max	0.05 max	
Carbon residue (10%dist.residue)	%mass	0.3 max	0.3 max		0.3 max
Sulphated ash	%mass	0.02 max	0.03 max	0.02 max	
Oxid ash	%mass				0.1 max
Water	mg/kg	500 max	300 max	500 max	200 max
Total contamination	mg/kg	24 max	20 max		24 max
Cu corrosion max	3h/50℃	1	1	3	1
Oxidation stability	hrs;110℃	6 hours min		3 hours min	N/A (25 g/m3)
Cetane number		51 min	49 min	47 min	51 min
Acid value	mgKOH /g	0.5 max	0.5 max	0.5 max	
Methanol	%mass	0.20 max	0.3 max	0.2 max or Fp <130℃	
Ester content	%mass	96.5 min			
Monoglyceride	%mass	0.8 max	0.8 max		
Diglyceride	%mass	0.2 max	0.4 max		
Triglyceride	%mass	0.2 max	0.4 max		
Free glycerol	%mass	0.02 max	0.02 max	0.02 max	
Total glycerol	%mass	0.25 max	0.25 max	0.24 max	
Iodine value		120 max	115 max		
Linolenic acid ME	%mass	12 max			
C(x:4) & greater unsaturated esters	%mass	1 max			
Phosphorus	mg/kg	10 max	10 max	10 max	
Alkalinity	mg/kg		5 max		
Gp I metals (Na,K)	mg/kg	5 max		5 max	
GpII metals (Ca,Mg)	mg/kg	5 max		5 max	
PAHs	%mass				11 max
Lubricity / wear	µm at 60℃				460 max

5.5 Bio-Gasoline

Bio-gasoline is potentially attractive as a direct substitute for petroleum based gasoline, as it will be able to use existing distribution systems. Production of bio-gasoline is still in the R&D pilot plant stage, with several companies involved in commercializing a range of technologies using a variety of feed-stocks.

Although Shell are working with Virent in the USA on process (2) development using various biomass feedstocks, ExxonMobil is investing and working with Synthetic Genomics Inc. on producing gasoline and diesel from algae. Biogasoline is likely to compete with other bio fuels, as other major companies (BP, Dupont (4) appear to be more focused on alternatives such as ethanol, biodiesel and biobutanol. Total is working with Gevo on blending components such as octanes from biomass via butanol. (See also Appendix 1)

Bio-gasoline is mentioned in a recent (6) (UruguayApril 2009) presentation by Hart Energy Consulting for the Global Biofuels Center and International Fuel Quality Center "Global Biofuels Developments: Current Status and Future Trends on Biofuels Specifications".

5.5.1 Technical Data (5,6)

Product Names	Biogasoline
Specifications	There are many specifications for gasoline around the world, but many are based on ASTM D-4814-09b (5,6)
Product Description (1)	Gasoline (American), gasolene (Jamaican) or petrol (Commonwealth) is a petroleum-derived liquid mixture, primarily used as fuel in internal combustion engines. It is also used as a solvent, mainly known for its ability to dilute paints. It consists mostly of aliphatic hydrocarbons obtained by the fractional distillation of petroleum, enhanced with iso-octane or the aromatic hydrocarbons toluene and benzene to increase its octane rating. Small quantities of various additives are common, for purposes such as tuning engine performance or reducing harmful exhaust emissions. Some mixtures also contain significant quantities of ethanol as a partial alternative fuel. Most current or former Commonwealth countries use the term petrol, abbreviated from petroleum spirit. In North America, the word gasoline is the common term, where it is often shortened in colloquial usage to simply gas.
Standards	Anticipated to be similar to petroleum based gasoline. Likely ASTM D4814 (7), although many countries have variants to accommodate local climatic conditions and other factors (6)
Normal industrial quality purity	Not yet commercial.
Chemical and Physical Properties	Primarily hydrocarbons with between 6 (hexane) and 12 (dodecane) carbon atoms per molecule. Bio-gasoline can be used directly in internal combustion engines.

5.5.2 Uses, Manufacturers and Market Location

End Uses	As fuel in internal combustion engines for road vehicles, and some piston engine aircraft
Manufacturers	Not yet commercial
Suppliers	Not yet commercial

Market overview	Not yet commercial
Market Location	USA, Europe, Japan
Market Volume	No Commercial volumes
Market Price	No Commercial volumes

5.5.3 Biogasoline Projects Identified 2008-9 (2, 3,)

- Shell-Virent (2.3) (USA) (Cargill also an investor)
- BioForming Technology (Licensed from University of Wisconsin-Madison)
- Process uses a solid-state catalyst to convert plant sugars into hydrocarbon molecules.. (Any carbohydrate that can be made soluble is a potential feed-stock, such as switch grass, wheat straw, sugarcane pulp, in addition to conventional biofuel feedstocks wheat, corn and sugarcane). Pilot production 1 gallon/day (March 2008)
- Amyris Biotechnologies, Emeryville California USA Spin-out from Berkeley University, CA.
- Dynamotive Energy Systems Corporation (Canada) (April 2009)
- BINGO (Biomass Into Gasoil) process produced gasoline and diesel from biomass at its research facilities in Ontario, Canada.
- Process involves pyrolysis of ligno-cellulosic biomass to make primary liquid fuel, BioOil, which is then hydro-reformed into a Stage 1 gas-oil equivalent liquid fuel that can either be used in blends with hydrocarbon fuels or upgraded to transportation grade liquid hydrocarbon fuels with a Stage 2 hydrotreating process.
- Terrabon (Texas, USA) (2008)
- Esting Texas A&M MixAlco technology at 5 dry tons/day of biomass.
- Process involves sorghum feed converted to organic salts with subsequent conversion to ketones and then to renewable gasoline.
- Anellotech (USA) (August 2009)
- Biofuels startup licensed University of Massachusetts' catalytic fast pyrolysis process for producing renewable biogasoline and other renewable fuels
- Total- Gevo (USA) (April 2009)
- Total has invested in Gevo, a company working on advanced biofuels who have already produced isooctene and isooctane for the gasoline market, jet fuel and diesel blending components.

5.5.4 Producers

Not yet in commercial production

5.5.5 Future Trends

Biogasoline must have a good future, given the political drives and potential use of new renewable feedstocks such as algae.

Production and the market especially in the USA should develop very rapidly given the large companies involved in development and the positive views of the current US President and administration to biofuels.

5.5.6 References

1. http://en.wikipedia.org/wiki/biogasoline (Oct 2009)
2. http://www.shell.com/home/content/media/news_and_library/press_releases/2008/biofuels_research_agreements_17092008.html
3. http://cleantech.com/news/2628/virents-biogasoline-gets-big-oil-backing (march 2008)
4. BP's role in the global agrofuel industry (http://www.biofuelwatch.org.uk/docs/BP.pdf)www.bp.com/sectiongenericarticle.do
5. Global biofuels policy developments (http://arpel.clk.com.uy/ppt/JUEVES%2023/Mesa%20Redonda%204/Kosaka.pdf)

6. Standard Specification for Automotive Spark-Ignition Engine Fuel (http://www.astm.org/Standards/D4814.htm)

5.6 Bio-Kerosene

Biokerosene is kerosene derived from biomass. Possible sources for biokerosene include synthetic biofuels made by gasifying biomass liquefied by the Fischer-Tropsch process, and green diesel based on a hydrogenation process of vegetable oils. It is clear from a survey of available references that the aviation industry now has great interest in kerosene (aviation turbine kerosene or ATK) and full scale flight testing has been performed. Brazil currently leads the development and production of bio-kerosene based on hydrogenation process of vegetable and algae oils (10). New Zealand is also advanced in this area, with jet planes already flight tested with the fuel. The main market is as fuel for aviation, turbo-props and jets.

There are still difficulties in making bio-kerosene meet the stringent specifications of the airline industry, and problems with supply. However, major resources are already committed to making and testing bio-kerosene, and it is just starting to become a commercial product.

5.6.1 Technical Data

<table>
<tr><td>Product Names</td><td>Bio-kerosene</td></tr>
<tr><td>Specifications</td><td>Mainly ASTM D1655.
Ref (4) Exxon Worldwide Specifications for Jet Fuels is a 50 page document that provides information on specifications that are often localized to suit weather conditions and other factors. Also Air BP “Handbook of Products” (5) provides data.</td></tr>
<tr><td>Product Description</td><td>Bio-kerosene is produced from a variety of biomass sources using a number of processes. (3).
Bio-kerosine must meet stringent specification s for its main potential use as an aviation fuel. (6)

Kerosene from Petroleum (7)
Kerosene or paraffin is a colourless flammable hydrocarbon liquid. It is obtained from the fractional distillation of petroleum. (Carbon chains from the C12 to C15 range).</td></tr>
<tr><td>Standards</td><td>(Petroleum) Aviation kerosene must normally meet ASTM D1655 requirements, but there are many local variants
At least one biokerosene has met the ASTM D1655 requirements (6)</td></tr>
<tr><td>Normal industrial quality purity</td><td><table>
<tr><td colspan="2">JET A-1 (Petroleum based)</td></tr>
<tr><td>Flash point:</td><td>38 ℃</td></tr>
<tr><td>Auto ignition temperature:</td><td>210 ℃</td></tr>
<tr><td>Freezing point:</td><td>−47 ℃ (−40 ℃ for JET A)</td></tr>
<tr><td>Open air burning temperatures:</td><td>260–315 ℃ (500–599 ℉)</td></tr>
<tr><td>Maximum burning temperature:</td><td>980 ℃ (1796 ℉)</td></tr>
<tr><td>Density at 15 ℃ (60 ℉):</td><td>0.775–0.840 kg/L</td></tr>
</table></td></tr>
<tr><td>Chemical and Physical Properties (18)</td><td>Properties — Values
Sp. gravity — 0.915
Flash point — 250℃
Fire point — 296℃
Cloud point — 11℃
Pour point — -6℃
Viscosity (at 35℃) — 59.8 CentiStoke (0.598m2/sec)
Calorific value (HHV) — 40 MJ/Kg (approx)</td></tr>
</table>

5.6.2 Uses, Manufacturers and Market Location

End Uses	**Petroleum kerosene**:

<table>
<tr><td></td><td>At one time it was widely used in kerosene lamps and for home heating but it is now mainly used as a fuel for jet engines (more technically Avtur, Jet-A, Jet-B, JP-4 or JP-8). A form of kerosene known as RP-1 is burned with liquid oxygen as rocket fuel.

Biokerosene is being tested in similar aviation applications (10,11,12,13,14,15,16,17).</td></tr>
<tr><td>Manufacturers</td><td>Petroleum kerosene:
Oil refining companies around the world.

Bio kerosene –
Tecbio, a large Brazilian biodiesel company, has joined with NASA and Boeing in the U.S. to develop biokerosene to fuel airplanes,

AlgoDyne Ethanol Energy Corp.’s Brazilian office will be leading algae-based bio-kerosene projects with airlines

Existing oil companies also new companies making bio-kerosene from a variety of feed stocks, including algae, babbassu nut that is grown in Brazil (180,000 hectares) and other countries with tropical areas.(2) also Jatropha (3)

Biomass to Liquid (BtL) plants worldwide
<table>
<tr><td>CHOREN, Germany (BTL)</td><td>15,000</td></tr>
<tr><td>Range Fuels, USA (BTL)</td><td>60,000 in 2011</td></tr>
<tr><td>Flambeau River Biofuels (BTL)</td><td>18,000 in 2010</td></tr>
<tr><td>New Page Corporation (BTL)</td><td>40,000 expected</td></tr>
</table></td></tr>
<tr><td>Suppliers</td><td>Oil companies,
Biokerosene will likely follow a similar distribution path, plus new biotech based production companies.</td></tr>
<tr><td>Market overview</td><td>Currently the aviation industry emits around 2% of the carbon dioxide responsible for climate change. But at current growth rates, experts forecast it could contribute up to 20% of emissions permitted under global emissions caps planned for 2050.

International Air Transport Association (IATA) is comited to the airline industry using 10% alternative fuels by 2017. It is also supporting further research into Bio-Fuels because it believes that they have the potential to reduce CO2 emissions from aircraft by 60% over their entire lifecycle. The airline industry currently uses 85 bn gallons of aviation fuel each year. (18)</td></tr>
<tr><td>Market Location</td><td>Worldwide. Main markets Japan, Russia, USA, W Europe, and Asia. The market will be driven by aircraft fuel uses.</td></tr>
<tr><td>Market Volume</td><td>Kerosene Production from Oil Refineries (8, 2005)(Based on UN data)
<table>
<tr><td>Year</td><td>Production
Tons/year</td></tr>
<tr><td>1990</td><td>1,070,770.000</td></tr>
<tr><td>1995</td><td>815,194,000</td></tr>
<tr><td>2000</td><td>985,493,200</td></tr>
<tr><td>2003</td><td>1,037,052,000</td></tr>
<tr><td>2005</td><td>1,037,517,000</td></tr>
</table></td></tr>
<tr><td>Market Price and price variation</td><td>Prices for (Petroleum) Jet Kerosene have been obtained for April 2009. However, there is instability in the market due to falling demands due to the world economic crisis and currency exchange rate variations. The only activity in the market at the reported time was for barge quantities and delivery

Northwest Europe (NWE)
Mediterranean (MED)
Cost Insurance and Freight (CIF)
Free on Board (FOB)</td></tr>
</table>

	Amsterdam, Rotterdam, Antwerp (ARA) NWE/MED spot prices (USD/MT) (9),

Description	Price Range US$/Tonne
CIF Cargoes NWE	472.75-479.75
FOB Barges ARA	477.75-479.75
FOB Cargoes MED	461.30-468.30

5.6.3 Future Trends

Kerosene was one of the first products made by oil refineries at the start of the oil industry about 100 years ago. It was a convenient fuel, and although inflammable it was safe to use as long as reasonable precautions were observed.

It was commonly used for lamps and heating and these uses are still important in Japan and many less developed countries.

However fuel for jet aircraft is now the major use of kerosene and this market has specific requirements for use of the fuel at low temperatures. Major companies are now involved in development of biokerosene for a variety of feed stocks, and biokerosene is now being tested by major airlines (13) and entering initial commercial distribution in Brazil.(2)

5.6.4 References

1. Alternative Fuels in Aviation - Embraer View. Workshop on Aviation Alternative Fuels, ICAO-Montreal Canada Feb 11th 2009-10-14
2. Lipofuels: Biodiesel and biokerosene. Biofuels from Vegetal and Animal Oils as Methyl or Ethyl Esters. Expedito Parente 2005 (www.tecbio.com.br)
3. Biokerosene. (www.bioenergywiki.net/Biokerosene)
4. ExxonMobil Aviation Fuels Worldwide Specifications (www.exxonmobilaviation.com/AviationGlobal/.../product_descriptions.asp)
5. Air BP Handbook of Products bp.com (http://www.bp.com/liveassets/bp_internet/aviation/air_bp/STAGING/local_assets/downloads_pdfs/a/air_bp_products_handbook_04004_1.pdf)
6. Jet Fuel from Algae passes first test. (Sept 9, 2008) (www.scientific American.com/blog/60-second-science)
7. Kerosine description (http://www.nationmaster.com/encyclopedia/Kerosine)
8. Energy Statistics Kerosine Production from Refineries (http://nationmaster.com/graph/ene_ker_pro_fro_ref-energy-kerosene-production-from-refineries&date=2005)
9. Jet Kerosine (Weekly) ICIS pricing 7th April 2009 (www.icispricing.com/il_shared/Samples/Subpage253.asp)
10. NASA and Boeing join Brazil to develop biokerosene aviation fuel (August 2006) (http://news.mongabay.com/bioenergy/2006/08/nasa-and-boeing-join-brazil-to-develp-biokerosene-aviation-fuel)
11. Biofuel test Flight-30 December (2008) (www.airnewzealand.com/aboutus/biofuel-test/biofuel-test)
12. Rolls Royce and British Airways Biofuels Program Suspended due to lack of Supply (http://gas2.org/2009/03/22/)
13. Biofuel Jets: No Longer a flight of Fancy (Oct 28, 2008) (http://greenine.blogs.nytimes.com/2008/10/28)
14. Algae Farm to Produce 4.4 Million Gallons of Experimental Jet Fuel (http://www.wired.com/autopia/2008/04/)
15. Arizona State Spins Out Technology for Algal Bio-K for Jet Fuel. 3 Sept 2008 (www.greencarcongress.com)
16. Bill Gates invests in algae fuel. (http://news.cnet.com/8301-11128_3-10043996-54.html)
17. ExxonMobil to make fuel from Algae. (July 14th 2009)(http://news.cnet,com)
18. http://www.erc.uct.ac.za/jesa/volume19/19-2jesa-chakraborty.pdf

19. http://www.viridasplc.com/trading/aviation.php

5.7 Bioethanol

Bioethanol is the most common biofuel, currently accounting for more than 90% of total biofuel usage worldwide. (1) (Heavily weighted by USA consumption). Compared to the U.S.A. and Brazil, but also to the European biodiesel sector, the EU fuel alcohol sector is rather small. (5). The USA nowadays produces every month more bioethanol than the EU produce in a year. Moreover, the EU biofuel market is still predominantly a biodiesel market (80%). The production of ethanol for fuel is currently increasing at very high rates in the main markets. Imports are at present required to satisfy demand in the EU.

The world's largest producers of bio-ethanol are Brazil, (sugar-cane ethanol) (who have used ethanol in road vehicles for many years), and the United States (corn ethanol). Ethanol derived from sugar cane is accepted as the most efficient and lowest-carbon biofuel available today (4)

Competition with food production (8) and associated use of arable land is a driver in development of new technologies to produce "advanced biofuel" (ethanol from ligno-cellulosic materials such as forest waste, miscanthus and switch grass). This technology is just starting to emerge from the R&D stage but capital and operating costs of the plants remain a problem.

5.7.1 Technical Data

Product Names (3)	Ethanol Synonyms: ethanol, grain alcohol, fermentation alcohol, alcohol, methylcarbinol, absolute alcohol, absolute ethanol, anhydrous alcohol, alcohol dehydrated, algrain, anhydrol, Cologne spirit, duplicating fluid 100C, ethyl hydrate, ethyl hydroxide, jaysol, jaysol s, molasses alcohol, potato alcohol, sekundasprit, spirits of wine, spirit, synasol, tecsol
CAS No (3) EC No:	64-17-5 200-578-6
Chemical formula	C_2H_5OH
Product Description	Ethanol fuel is supplied as a blend with conventional fossil fuel gasoline.
Standards	See Appendix 1
Normal industrial quality purity	Fuel ethanol 99%, beverage 96% - See Appendix 1

5.7.2 Uses, Manufacturers and Market Location

End Uses (10)	10-20% of worldwide ethanol production is used in the industrial sector: • 60% of the total, solvent in the manufacture of pharmaceuticals, paints and laquers. (facing environmental restrictions as it is a volatile organic compound (VOC)and its long-term growth is flat. (10, 2009) • Other uses: Carrier in medicines, Food extracts and flavourings, personal care products, cleaning products can contain up to 70%. • Ethanol is effective in killing organisms and demand has increased for its use in hand sanitizers. • Ethanol also used as an intermediate in manufacture of ethyl acrylate, ethylamines, acetic acid and ethyl acetate. • In Brazil there are plans to produce ethylene from ethanol, and Dow and Braskem plan to build plants to make ethylene from ethanol. • Solvay will use fermentation-based ethylene to make ethylene dichloride

	(EDC)/vinyl chloride monomer (VCM) for PVC production. • Pure beverage ethanol is manufactured as grain neutral spirits which is sold to bottlers and other distillers for blending into other products such as vodka and flavoured alcoholic beverages. **Fuel for road vehicles.** 80-90% of worldwide ethanol production is used as fuel (10). Normally used as an additive in varying proportions to gasoline.
Market Location	Major markets Brazil, USA and Europe
Market price	**Europe:** (Dec 2009) (see tables below)

Beverage grade - 96%		Dec-09	One year ago
	Currency	Price/100 Litres	Price/100 Litres
FD UK	GBP	56.00-57.00	46.00-54.00
FD France	EUR	60.00-64.00	65.00-68.00
FD Germany	EUR	61.00-63.00	66.00-68.00
FD Italy	EUR	60.00-63.00	66.00-68.00

Industrial grade - 99%		Dec-09	One year ago
	Currency	Price/100 Litres	Price/100 Litres
FD France	EUR	64.00-69.00	71.00-74.00
FD Germany	EUR	64.00-70.00	75.00-80.00
FD Italy	EUR	64.00-70.00	74.00-78.00

Note: European industrial grade ethanol prices fell in 3rd Quarter of 2009, as demand weak for paints and packaging which have been hit by economic downturn (13)

Asia (Mid-August 2009) (13)
Hydrous ethanol prices rose from US$580-600 CFR (Cost and freight) to US. $620-640/tonne CFR amid increasing offers from Brazil.

USA (Mid-August 2009) (13)
Prices moved downward (late 2009) with pressure from lower corn prices due to bumper harvest

Live price data on line for US ethanol (9) US ethanol prices US$/US gallon 7 October 2009

Brazil (Mid-August 2009) (13)

Hydrous and anhydrous ethanol Brazilian Reals 860-880/m3 (US$465-476/m3), up from Braz Reals 710-740 in May 09 (US$383.5-392/m3).

Brazil blends anhydrous ethanol in gasoline at 25%,while hydrous ethanol is used as a stand-alone fuel in flexible-fuel vehicles. (FFV's)

Price Variability	Prices varying considerably (25%) due to changes in feedstock costs, economic downturn in associated sectors and currency fluctuations.

5.7.3 Market Location

Brazil has promoted the use of bioethanol for many years and has developed engines that can work efficiently with a high proportion of ethanol in the fuel (Min 22% by law, maybe increasing to 25%). Brazil also exports bioethanol.

The USA has rapidly developed bioethanol supplies in response to Federal Laws requiring a minimum production per year of 9 *billion US gallons in 2008.

EU production is now expanding steadily rapidly but it is very small compared to the USA or Brazil.

5.7.4 Market Volumes

The world ethanol industry produced a record 17.3 billion gallons (52 million tonnes) of ethanol in 2008 and could produce up to 20.4 billion gallons (60 million tonnes) in 2009.
Details of world production up to 2007 are given in .

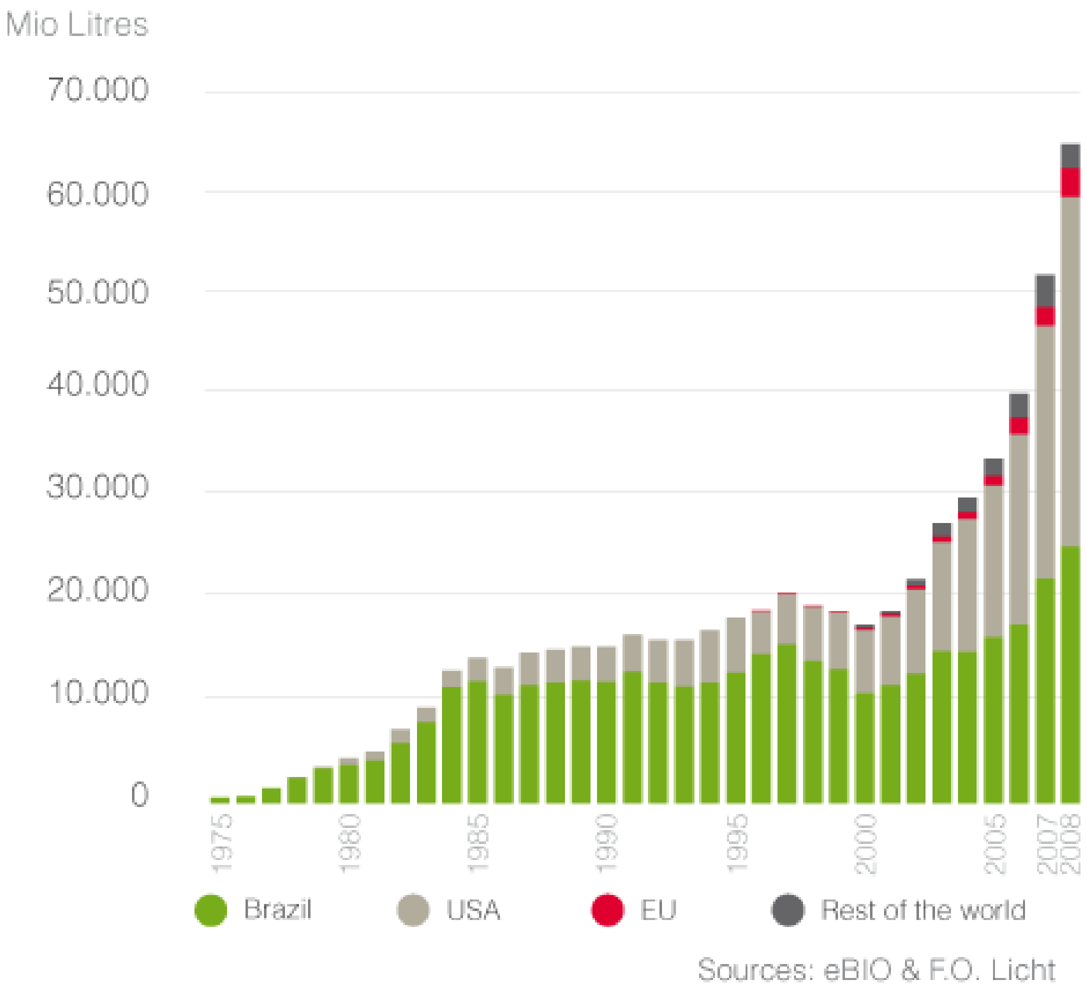


Figure 19 Global Ethanol Production for Fuel (Millions of litres/year) (4)

5.7.5 US Market

The Renewable Fuels Association (7) provides a comprehensive overview of ethanol production in the USA. The data will not be repeated in this study.

5.7.6 European Market

The top 6 consumers are France, Germany, Sweden, the UK, Poland and the Netherlands. 2008 was also a record year in terms of imports. Total imports of bioethanol (fuel and non-fuel) are estimated to have reached 1.9 billion litres in 2008, increasing by 400 million compared to 2007. Thereof, between 1.4 and 1.5 *billion litres came from Brazil only. Approximately 50% of total imports have been used for the fuel sector (approximately 1.1 *billion litres). This equals 39% of total EU production. (5). (The imports seem to indicate that some EU plants are not producing full capacity – see totals in Figs 2 & 3)

5.7.7 Manufacturers in EU ((5)

The top 4 EU producers of ethanol are France, Germany, Spain and Poland, followed by Sweden and the UK.

Table 8 Provides a summary of production in the EU
Table 6 Ethanol producers in individual EU States
Table 7 Ethanol plants under construction in EU

Table 8 Summary of EU Market Production (4)

Millions of litres/year					
EU Member State	**2008**	**2007**	**2006**	**2005**	**2004**
Austria	89	15			
Belgium	51				
Czech Republic	76	33	15		
Finland	50			13	3
France	950	539	293	144	101
Germany	581	394	431	165	25
Hungary	150	30	34	35	
Ireland	10	7			
Italy	60	60	128	8	
Latvia	15	18	12	12	12
Lithuania	21	20	18	8	
Netherlands	9	14	15	8	14
Poland	200	155	120	64	48
Slovakia	94	30			
Spain	346	348	402	303	254
Sweden	78	120	140	153	71
UK	75	20			
Total	2855	1803	1608	913	528

Data are to the best of our knowledge. Sources: Member State reports and industry.
EU Member States not listed do not have production capacity installed.
EU ethanol for fuel consumption in 2008 is estimated at 3.5 billion litres. (Imports making up 23% of EU consumption)

Table 9 EU Production Capacity (PC) in Millions of litres/year (4)

Member State	**Company**	**PC(ML/y)**	**Feedstock**
Austria	Agrana (Pischelsdorf)	240	Wheat, maize
Belgium	BioWanz (Wanze)	300	Wheat, sugar juice
	AlcoBioFuel (Gent)	150	Wheat
	Amylum (Aalst)	32	Wheat
Bulgaria	Euro Ethyl GmbH (Silistra)	10	Maize
Czech Republic	Agroetanol TTD (Dobrovice)*	100	Sugar juice
	PLP (Trmice)	100	Cereals
	Ethanol Energy (Vrdy)	70	Not operating
Finland	St1 (Lappeenranta)	1.5	Organic waste material
	St1(Närpiö)	1.5	Organic waste material
	St1 (Hamina)	1	Organic waste material
	St1 (Hamina)	44	Hydrous alcohol
France	Tereos (Artenay)	40	Sugar juice
	Tereos (Provins)	15	Sugar juice
	Tereos (Morains)	40	Sugar juice
	Tereos (Lillers)	80	Sugar juice
	Tereos (Lillebonne)	250	Wheat
	Tereos (Origny)	300	Sugar juice
	Cristanol (Arcis sur Aube)	150	Sugar juice
	Cristanol I (Bazancourt)	150	Sugar beet, sugar juice

	Cristanol II (Bazancourt)	200	Wheat, glucose
	Cristanol/Deulep (St. Gilles)	40	Raw alcohol
	Saint Louis Sucre	90	Sugar juice
	CropEnergies AG (Dunkerque)	100	Hydrous alcohol
	AB Bioenergy France (Lacq)	250	Raw alcohol, maize
	Roquette (Beinheim)	75	Wheat
Germany	Verbio AG (Zörbig)	125	Cereals
	Verbio AG (Schwedt)	230	Cereals, sugar juice
	CropEnergies AG (Zeitz)	360	Cereals, sugar juice
	Fuel 21 (Klein Wanzleben)	130	Sugar juice
	Prokon (Stade)	120	Wheat
	Danisco (Anklam)	56	Sugar juice
	KWST (Hannover)	40	Raw alcohol
	Müllermilch (Leppersdorf)	10	Diary products
	Wabio	12	
	SASOL (Herne)	76	Raw alcohol
Hungary	Hungrana Kft. (Szabadegyháza)	170	Maize
	Györ Distillery	40	Maize
Ireland	Carbery*	10	Whey
Italy	Silcompa (Correggio)*	60	Raw alcohol
	Alcoplus (Ferrara)*	42	Cereals
	IMA (Bertolino Group)*	200	Raw alcohol
Latvia	Jaunpagastas (Riga)*	12	
Lithuania	Biofuture	45	Rye, Wheat
Netherlands	Royal Nedalco (Bergen op Zoom)	14	C-Starch
Poland	Wratislavia-Bio (Wroclaw)*	170	Raw alcohol
	Destylacje Polskie (Oborniki)*	150	Raw alcohol
	BioAgra (Go	140	Maize
	Cargill (Wroclaw)	36	C-Starch
	Grupa Sobieski*	70	Raw alcohol
	Bioetanol Sp (Nowa Wies Wielka)*	45	Raw alcohol
	Komesr International (Straszyn)*	30	Raw alcohol
	Solanum*	20	Raw alcohol
	PHP Wawrzyniak (Kalisz)*	20	Raw alcohol
	Uni-Malew (Konin)*	10	Raw alcohol
Romania	Amochim	18	Cereals, Not operating
Slovakia	Enviral*	138	Maize
Spain	Ecocarburantes (Cartagena)	150	Barley, wheat
	Bioetanol Galicia (Teixeiro)	176	Cereals
	Biocarburantes C&L (Babilafuente)	195	Cereals
	Acciona (Alcázar de San Juan)	32	Raw alcohol
Sweden	Agroetanol	210	Cereals
	SEKAB	90	Raw alcohol
	SEKAB	10	Pulp
UK	British Sugar plc (Downham)	70	Sugar juice
Total		6362	

Updated: 22 September 2009. Most of the installed production capacity listed is for fuel use only. In those cases where an asterisk is placed it means that part of the production capacity is used for other markets as well (potable or technical/industrial use). All the data are to the best of our knowledge. We would welcome any comments at info@ebio.org

Table 10 EU Plants under construction (2009 data) (4)

Production Capacity (PC) in millions of litres/year

Member state	Company	PC(ML/y)	Feedstock
Bulgaria	Euro Ethyl GmbH (Silistra)	30	Maize
	Crystal Chemicals	13	
Denmark	Dong Energy (Kalundborg)	17.6	Straw, wheat

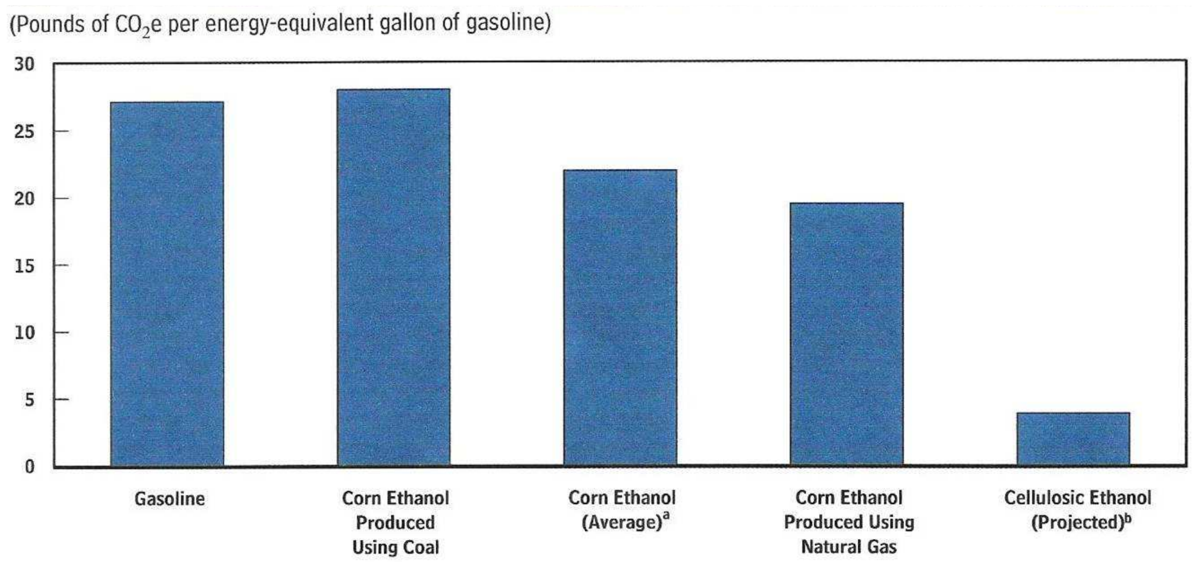
France	Roquette (Beinheim)	35	Wheat
Germany	Wabio Bioenergie (Bad Köstritz)	8.4	Waste
	ESP Chemie GmbH	140	
Hungary	First Hungarian Bioethanol Kft (Elsö Magyar Bio-ethanol Termelökst)	90	Maize
Lithuania	Bioetan	100	Cereals
Netherlands	Abengoa (Rotterdam)	480	Wheat
	Nivoba BV (Wijster)	100	Cereals
Slovenia	Slovnafta (Bratislava)	75	Wheat
Spain	Biocarburantes Castilla & Leon (Salamanca)	5	Ligno-cellulose
	SNIACE II (Zamora)	150	Wheat
	Alcoholes Biocarburantes de Extremadura (Albiex)	110	
UK	Ensus plc (Teesside)	400	Wheat
	Vivergo (Hull)	420	Wheat
Total		2174	

Updated: 9 September 2009

5.7.8 Future trends

Demand in the EU countries is outstripping production in the area and in 2008 imports (mainly from Brazil) of 1.9 *billion litres were equivalent to 39% of EU production. (5)

The capacity of plants under construction during 2009 in the EU amounts to 2.174 billion litres/year (Table 9). With expected market growth of at least 20% to meet targets for use of ethanol in gasoline fuels, the new plants will not supply sufficient ethanol to satisfy demand, and more capacity will be required. The carbon footprint of ethanol production varies with the choice of feedstock:



Source: Congressional Budget Office based on Michael Wang, May Wu, and Hong Huo, "Life-Cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types," *Environmental Research Letters,* vol. 2, no. 2 (2007).

Notes: Life-cycle emissions are those generated during production, distribution, and consumption of gasoline and ethanol.

For the ethanol-based fuels, greenhouse-gas emissions are measured as the pounds of carbon dioxide equivalent (CO_2e) generated by the amount of ethanol—generally about 1.5 gallons—whose energy content corresponds to that of a gallon of gasoline. (Because individual greenhouse gases vary in their warming characteristics and persistence in the atmosphere, researchers commonly measure emissions in CO_2e—an amount of carbon dioxide that would cause an equivalent amount of warming over 100 years.)

Plants that produce ethanol require a source of thermal energy for their operations. Most ethanol-producing plants in the United States that use corn as a feedstock are natural gas-fired facilities. The remainder use either coal or both coal and natural gas.

a. Reflects average greenhouse-gas emissions generated from the mix of U.S. coal- and natural gas-fired facilities that produce corn ethanol.

b. Emissions expected from the use of a future technology that would allow ethanol to be produced from switchgrass

Figure 20 Life-Cycle Greenhouse-Gas Emissions from Selected Fuels (8)

At present the lowest carbon ethanol is made from sugar cane. An example is that BP are moving into the market with a Joint Venture in Brazil to make ethanol from sugar cane. (4). Production of ethanol from lingo-cellulosic biomass such as forest wastes and grass is the goal for both economic reasons and to avoid competition with agricultural land use and use of corn for food. The technology for production of ethanol from such materials is becoming commercial in Europe (6), with over 20 plants under development in the USA.(7). However, there are considerable problems to be resolved as described below*:*

5.7.9 Costs of 2nd Generation Biofuels (6)

The commercial-scale production costs of 2nd-generation biofuels have been estimated by the IEA to be in the range of USD 0.80 – 1.00/litre of gasoline equivalent (lge) for ethanol and at least USD 1/litre of diesel equivalent for synthetic diesel. This range broadly relates to gasoline or diesel wholesale prices (measured in USD /lge) when the crude oil price is between USD 100-130 /bbl

The present widely fluctuating oil and gas prices therefore make investment in 2nd-generation biofuels at current production costs a high risk venture, particularly when other alternatives to conventional oil such as new heavy oil, tar sands, gas-to-liquids and coal-to-liquids can compete with oil when around USD 65/bbl taking into account infrastructural requirements, environmental best practices and an acceptable return on capital but excluding any future penalty imposed for higher CO2 emissions per kilometre travelled when calculated on a life cycle basis.(6)

5.7.10 Land use barriers (8)

The different carbon footprints of ethanol from various feed-stocks and land-use issues indicate that only ethanol from ligno-cellulosic feed-stocks achieve the hoped-for life-cycle carbon reductions and avoidance of food production issues in the long term. It seems clear that considerable Government support is required to make production of ethanol from lingo-cellulosic feed-stocks commercially attractive at present.

How Land Conversion to Grow Crops for Ethanol Production May Delay Reductions in Greenhouse-Gas Emissions Resulting from the Use of Ethanol

Biofuel/Land Converted	Location	Years Until Net Carbon Reduction	Study
Corn Ethanol			
Grassland	United States	93	Fargione and others
Abandoned Cropland	United States	48	Fargione and others
Mix of Forest and Grassland	United States	167	Searchinger and others
Prairie Biomass[a]/Abandoned Cropland	United States	1	Fargione and others
Sugarcane Ethanol			
Forest	Brazil	17	Fargione and others
Grazing Land	Brazil	4	Searchinger and others
Rainforest	Brazil	45	Searchinger and others
Grassland	Brazil	3 to 10	Renewable Fuels Agency
Forest	Brazil	15 to 39	Renewable Fuels Agency
Switchgrass Ethanol[b]/Cropland	United States	52	Searchinger and others
Wheat Ethanol			
Grassland	United Kingdom	20 to 34	Renewable Fuels Agency
Forest	United Kingdom	80 to 140	Renewable Fuels Agency

Source: Congressional Budget Office based on Joseph Fargione and others, "Land Clearing and the Biofuel Carbon Debt," *Science,* ' no. 5867 (2008), pp. 1235–1238; Timothy Searchinger and others, "Use of U.S. Croplands for Biofuels Increases Greenhou: Through Emissions from Land-Use Change," *Science,* vol. 319, no. 5867 (2008), pp. 1238–1240; and Renewable Fuels Age *Gallagher Review of the Indirect Effects of Biofuels Production* (study commissioned by the Secretary of State for Transpor Kingdom, July 2008).

a. Prairie biomass constitutes mixtures of native perennial prairie grasses and other flowering plants.

b. Switchgrass is a type of grass native to North America and used primarily as rangeland forage and hay.

Figure 21 Land use changes (8, 9)

5.7.11 Appendix 1 - International Specifications for Ethanol Fuel (11)

Property	US		Brazil		EU prEN 15376
	D 4806	D 4806 Undenatured	Anhydrous	Hydrous	
Colour	Dye Allowed, but not mandated	Dye Allowed, but not mandated	Dye mandated for in country, but not for export	Dye prohibited for in country	Dye Allowed, but not mandated
Ethanol Content, vol %, min	92.1	93.9	99.6[3]	-	[96.8]
Ethanol + C3-C5 sat. alcohols, vol %, min	-	[98.4][2]	-	-	98.8
Total Alcohol, vol %, min	-	[98.95]	99.6	95.1	[99.76]
C3-C5 sat. alcohols, vol %, max	-[1]	[4.5]	-	-	2.0
Water content, vol %, max	1.0	1.05	[0.4]	[4.9]	0.24
Density at 20C, kg/m³, max	-	-	791.5	807.6	-
Methanol, vol %, max	0.5	0.53	-	-	1.0
Denaturant, vol %, min/max	1.96 / 5.0	No Denaturant	No Denaturant	No Denaturant	Set By Country 0/1.3
Hydrocarbons, vol %, max	-	-	3[4]	3[4]	-
Solvent-washed gum, mg/100mL, max	5.0	5.3	-	-	-
Gum or Resid by Evap, mg/100ml, max	5 (washed gum)	5.3 (washed gum)	-	5 (washed gum)[5]	10 (unwashed)[5]
Electrical Conductivity, uS/m, max	-	-	500	500	-
Sulfate, mg/kg, max*	4	4.2	-	4	Working
Inorganic Chloride, mg/kg, max	40.	42.1	-	1	25
Copper, mg/kg, max	0.1	0.105	0.07	-	0.1
Sodium, mg/kg, max	-	-	-	2	-
Iron, mg/kg, max	-	-	-	5	-
Acidity, mass % (mg/L), max	0.007 (56)	0.0074 (58.9)	0.0038 (30)	0.0038 (30)	0.007
pHe	6.5-9.0	6.5-9.0	-	6.0-8.0	Dropped
Phosphorus, mg/L, max	-	-	-	-	0.5
Sulfur, mg/kg, max	30.	5	-	-	10
Appearance	Clear & Bright	Clear & Bright	Clear & No Impurities	Clear & No Impurities	Clear & Bright

Table 1. Detailed Comparison of Ethanol Specification (ASTM, White Paper, pg 89)

(1) Not specified by can be calculated for US. (Heavy alcohol content = 100 - ethanol content - methanol - water content)
(2) Numbers in [ ] are calculated estimates and not specified limits
(3) Limit only applies to ethanol not produced by fermentation from sugarcane or ethanol contaminated by other types of alcohol
(4) Applies only to imported ethanol
(5) Procedures are likely different.

	n-Butanol	Ethanol	Gasoline
Specific Gravity @ 60°F	0.814	0.794	0.720 - 0.775
Heating Value, MJ/L	26.9 – 27.0	21.1 – 21.7	32.2 – 32.9
Research Octane Number (RON)	94*	106 – 130*	95
Motor Octane Number (MON)	80 – 81*	89 – 103*	85
RVP of 5% and 10% Alcohol/Gasoline Blends, psi	6.4* / 6.4*	31* / 20*	_†
Oxygen, wt%	21.6	34.7	< 2.7
Water Solubility at 25°C, %	9.1	100.0	< 0.01

5.7.12 References

1. International Energy Authority (IEA) Energy Technology Essentials (http://www.iea.org/techno/essentials2.pdf) (Jan 2007)
2. Science Daily (Aug 14, 2007 , absolute (200 proof) (May 2008) (http://www.sciencedaily.com/releases/2007/06/070628073027.htm)
3. BP Biofuels (http://www.bp.com/productlanding.do?categoryId=9030593&contentId=7055794)
4. European BioethanolFuel Association www.ebio.org (2008 updated)
5. From 1st to 2nd- Generation Biofuel Technologies - An overview of current industry and RD&D activities. IEA Biotechnology (OECD/IEA Nov 2008) ((http://www.iea.org/papers/2008/2nd_Biofuel_Gen.pdf)
6. Renewable Fuels Association (www.ethanolrfa.org/industry/statistics/#E)
7. (July 2009)
8. Congress of the United States Congressional Budget Office “The Impact of Ethanol use on Food Prices and Greenhouse-gas emissions” April 2009
9. DTN Ethanol Center (www.dtnethanolcenter.com)
10. ICIS . (www.icis.com/v2/chemicals/9075314/ethanol/uses.html)
11. Biofuel Development and Standardization Biofuel Industry News April/May 2009 (http://worldbiofuelsmarkets.info/)
12. Ethanol Europe Price Report (www.ICISpricing.com/il_shared/Samples/SubPage108.asp)
13. Ethanol Prices and Pricing Information (www.icis.com/v2/chemicals/9075312/ethanol/pricing.html)

5.8 Methanol

Methanol is a basic chemical, produced around the world on a large scale (440,000,000 tonnes/year in 2008 (6)). It was historically produced by distillation of wood (“Wood alcohol”) also from coke oven gas, and now mostly from natural gas. It is formed naturally by decomposition of biomass and has a growing use in biodiesel and gasoline. A recent process (7, 2008) to make methanol from glycerine would tie in with the current glut of glycerine from biodiesel manufacture. Production in the industry was rationalized in the years 20004-2007 and would now appear to be set for more growth with many new projects already announced, (6)

5.8.1 Technical Data (3,4)

Product Names	Methanol, also methyl alcohol, wood alcohol, carbinol	
CAS No	67-56-1	
Form	Liquid, clear, colourless (4)	
Normal industrial quality purity	99-100% (4) (Minimum 99.85 weight % (6))	
Specifications	IMPCA (2008) (6) ASTM – D1152/97 (6)	
Chemical and Physical Properties (3)	Molecular weight	32
	Empirical formula	CH_3OH
	Boiling point	64.7 C (4)
	State at room temperature	Liquid
	Volatility	Vapour pressure = 100 mm Hg at 21.2 ℃
	Specific gravity	0.8 at 20 ℃ (water = 1); vapours are lighter than air at room temperature
	Flammability	Flammable: burns with a non-luminous, bluish flame.
	Explosive limits	Lower 6 % Upper 36.5%
	Water solubility	Fully soluble in water
	Combustion Products (4)	Toxic gases and vapours, oxides of carbon and formaldehyde

	Odour	Slight alcoholic odour
Shelf life	None stated. Likely to be stable out of contact with air.	
MSDS	Methanex MSDS (4)	

5.8.2 Uses, Manufacturers and Market Location (5)

End Uses (See also Appendix 1)	Formaldehyde MTBE & TAME Acetic Acid Methyl Methacrylate Methylamines Chloromethanes DMT DME Uses in fuels (biodiesel and gasoline growing demand)
Manufacturers	Many manufacturers, see Appendix 2
Suppliers	See Appendix 2
Market Location	China, Middle East, Asia, N America, Europe
Market Volume	44,000,000 tonnes/year (6) 2008)
Market Price (1,2)	**Europe (2) (10th April 2009) Contract Prices**

Price		Price Range	One year ago	US CTS/GAL
FOB RDAM Q2	EUR/MT	146.50-146.50	295.00-295.00	57.68-57.6
Europe Spot Prices				
Price		Price Range	One year ago	US CTS/GAL
FOB RDAM T2	EUR/MT	126.00-134.00	216.00-230.00	49.61-52.76

Asia (2) 10th April 2009 - Contract Prices				
Price		Price Range	Four weeks ago	US CTS/GAL
CFR Korea	USD/MT	200-210	195-200	59.92-62.91
CFR Taiwan	USD/MT	200-210	195-200	59.92-62.91
CFR S.E.Asia	USD/MT	185-190	175-185	55.42-56.92
CFR China	USD/MT	225-245	200-205	67.40-73.40
CFR W.C. India	USD/MT	170-180	160-170	64.35-68.14
FOB China	USD/MT	235-250	210-220	70.40-74.89

CFR- Cost and Freight
FOB-Free on Board

USA (2) 10th April 2009 - Contract Prices		Price Range	USD/MT
Barge April09	US c/gal	60.00-65.00	200.28-216.97
Rai/Truck			
US Gulf April-09	US c/gal	55.00-60.00	183.59-200.28
Northeast APR-09	US c/gal	60.00-65.00	200.28-216.97

Market Price variability (1,2)	Considerable price variability, in April, May, June 2009 spot prices were in the range €126-134/tonne FOB Rotterdam. On 15th October 2009, price bid and offers were in the range of 188-195/tonne FOB Rotterdam This appears to be driven by a surge in demand in China that is also reported to be purchasing 60,000 tonnes of methanol from India. (6) 15 Oct 2009

5.8.3 Market Volume Future Trends

There has been a shift in where methanol is being manufactured, and also in its end uses. Large-scale plants of 5000 tonnes/day have recently been built and these are making the market vulnerable to a shutdown and loss of capacity from a "Mega plant" (5). Plants have been shut down in N. America, and production moved closer to sources of natural gas feed-

stocks. Changes in the use of methanol with MTBE being phased out in some markets (N America and Europe) but growing use in biodiesel and gasoline has caused recent turbulence in methanol production. (See section 16 below). China is a driver in the market at present (See "Price variability" above)

5.8.4 Producers

See list in Appendix 1

5.8.5 Applications of Methanol

Chemical Name	Use	Thousands of t/y 2001 (6)	Thousands of t/y 2008 (6)	% Change over 7 y	Potential Future
Formaldehyde	Resins for wood based products	10814	15873	+47	
MTBE & TAME	Octane booster and oxygenate in gasoline	8709	5967	-32	
Acetic Acid	Vinyl acetate monomer and terephthalic acid	2782	5235	+88	
Methyl Methacrylate	Acrylic polymers	813	1156	+42	
Methylamines	Intermediate	852	1020	+20	
Chloro-methanes		1377	1625	+18.0	
DMT		522	393	+25	
DME		148	2301	+1454	
Fuels	Biodiesel manufacture and in gasoline	295	4485	+1420	
Other	Windscreen wash fluids, Water denitrification (6) Olefins (MTO), (5) Propylene glycol (MTP)	5155	6708	+30	MTO and two MTP plant startups in China 2009-10 (5)
Totals		31447	44763	+42	

5.8.6 Future Trends (See Fig 1 also Appendix 1)

The major future uses of methanol are in the fuels sector:

- Diesel
- Gasoline
- DME (Di Methyl Ether)
- Fuel cells

China is taking the lead in the fuel uses of methanol (8)

Forecast changes in the world capacity indicated in Fig 1 of methanol manufacture (6) probably are misleading as many later projects may not have been announced. The dip in the years 2004-7 was likely caused by rationalization of the industry.

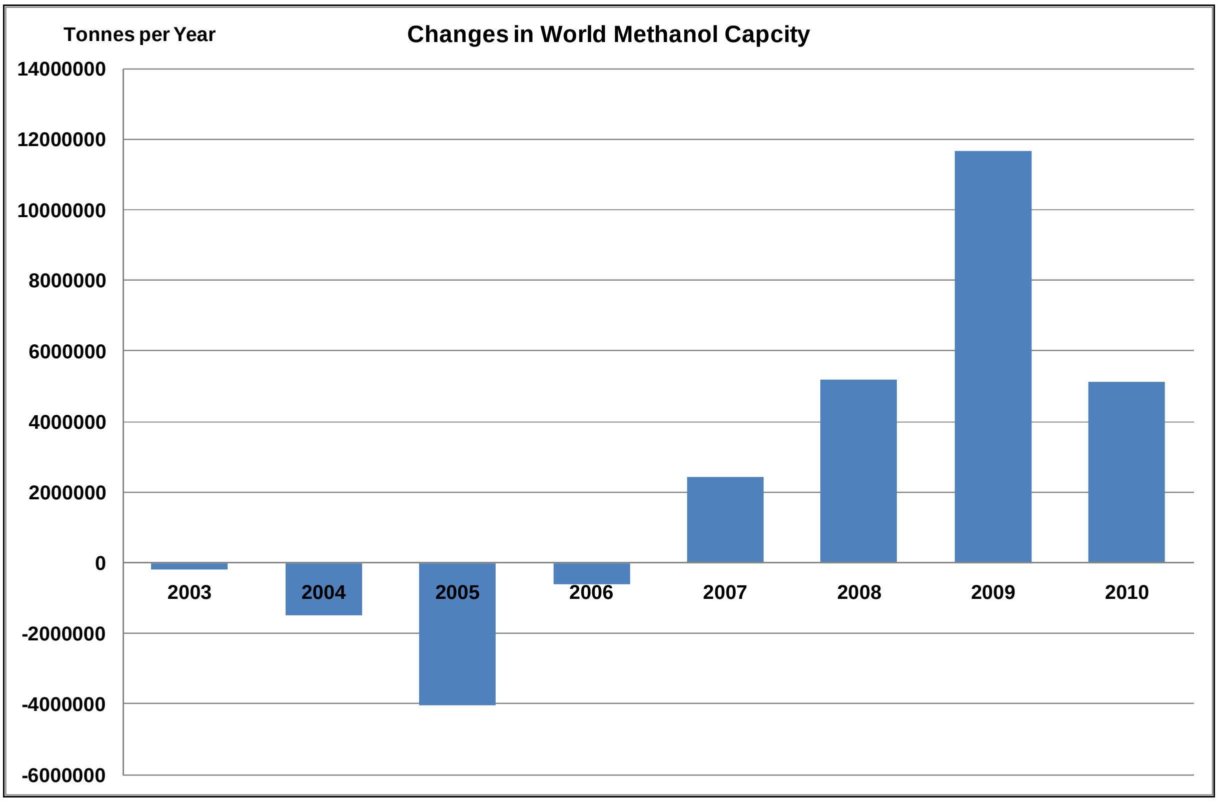


Figure 22 Forecast Changes in World Methanol Capacity (6)

5.8.7 Uses of Methanol (5, 6)

The three largest derivatives of methanol are formaldehyde, methyl tertiary butyl ether (MTBE) and acetic acid. However, methanol is seeing growing demand in fuel applications such as dimethyl ether (DME), biodiesel and the direct blending into gasoline.

Formaldehyde is used mainly to make amino and phenolic resins which are employed in the manufacture of wood-based products such as panels, flooring and furniture.

The main use for MTBE is an octane booster and oxygenate in gasoline. However, it has been phased out in the US following its contamination of underground water supplies and the removal of the oxygenate mandate and liability protection.

In Europe, some MTBE has been replaced by ethyl tertiary butyl ether (ETBE)
There is growth in MTBE consumption in Asia and the Middle East, driven by the need to reduce air pollution.

MTBE is likely to continue to be vital for fuel quality and cleaner emissions. As countries look to remove sulphur and lead and reduce aromatic content in the gasoline pool, MTBE will make a significant contribution to improve fuel quality.

Acetic acid has a number of outlets of which the two largest are vinyl acetate monomer (VAM) and purified terephthalic acid (PTA). Global demand for acetic acid has been growing at a steady 4%/year with PTA sector growth at double this rate driven by polyester demand.

In the area of petrochemical feedstocks, there has been considerable interest in methanol-to-olefins (MTO) and methanol-to-propylene (MTP) technologies with demonstration plants built and the first commercial production imminent in China. One MTO and two MTP projects have

been given approval in China with estimated start-ups in 2009-10. Outside of China, projects are under consideration in Trinidad, Nigeria and Iran.

Methanol is also used for the basis of many other chemical products:

- The largest solvent use for methanol is as a component of windscreen wash antifreeze. It can also be used to extract, wash, dry and crystallise pharmaceutical and agricultural chemicals.
- Methylamines are used as intermediates in a range of speciality chemicals with applications in water treatment chemicals, shampoos, liquid detergents and animal feeds.
- Methyl methacrylate (MMA) is employed in the production of acrylic polymers.
- Dimethyl terephthalate (DMT) is used to make polyesters although PTA is the preferred feedstock.
- Methanol and sodium chlorate are used to produce chlorine dioxide, a bleaching agent for the pulp and paper industry.
- Glycol ethers are solvents used in acrylic coatings and newer high-solids and water-borne coatings.
- Methyl mercaptan is used an intermediate in the production of DL-methionine, an amino acid supplement in animal feeds.
- Fuel uses to grow

The use of methanol in fuel applications is expected to have a big impact on future demand. Methanol can be used in biodiesel production where it is used in the transesterification step of the process. A large number of biodiesel projects are planned or under construction, and some consultants predict that methanol used in this application could replace the demand lost to MTBE by the end of the decade.

Methanol is increasingly being used to make DME, which can be employed as an alternative to diesel, a supplement to liquefied petroleum gas (LPG) and in power generation. The largest DME market is China where DME capacity is expected to surpass 4m tonnes/year in 2009, according to the International DME Association. Projects are also planned in other countries such as Egypt and Papua New Guinea.

In China, methanol is also being blended into gasoline. There are thousands of gasoline stations that offer M10 and M85 alternative fuels. In Shanxi province, over 2,000 taxis and 100 public buses are operating on M100. Two national methanol fuel standards are planned in China while about 40 regional methanol fuel standards will be issued. Methanol blending in gasoline could provide a sink for excess methanol capacity allowing gasoline to set the floor price of methanol, say consultants.

China is also investigating methanol-to-gasoline (MTG) technology which was first developed in the 1980s but at the time proved to be uneconomic. Yunnan Coal Chemical has been operating a 3,500 tonnes/year pilot plant and plans to build a 200,000 tonnes/year commercial unit.

Methanol can also be considered as an alternative to diesel for electricity generation in small communities where the cost of LNG facilities is too high. Methanol Holdings Trinidad (MHTL) and the University of Trinidad and Tobago have developed an 8.5MW methanol-fed power plant that is providing electricity for MHTL’s production site in Trinidad. Methanol-based power is claimed to be competitive with diesel both in terms of fuel and capital costs, and could also have applications in certain densely populated areas with low emission standards and other niche markets.

Fuel cells based on methanol were first targeted at automotive applications but early applications will now be in portable power generation including power for cell phones and laptop

computers. Their use in consumer electronic equipment has been given a boost now that several countries including the US will allow passengers to carry fuel cell cartridges on board airlines. Toshiba plans to launch its direct methanol fuel cell (DMFC) battery charger by April 2009 and DMFC packs for cell phones and personal computers later in the year.

For the methanol industry, this is seen as significant for its psychological impact on consumers and the huge follow-up potential for methanol as a power source for automotive fuel cells. Automobile companies have concentrated on developing hydrogen-based fuel cells but hydrogen poses major problems in handling and the weight of the storage tanks. By 2015 when fuel cell automobiles are ready for the market, consumers will already be familiar with methanol-powered cells in laptops and portable generators.

5.8.8 Manufacturers of Methanol (6)

GLOBAL METHANOL CAPACITY

(Through end of 2006)

Company	Location	Process	Capacity M MT	Capacity MMGALS	Feeds	Built
IFIC						
BHP	Victoria	ICI	**50**	17	NG	1982
Beijing Shiyan	Beijing	PROP/COPY	60	20	wood/coal	1960-1975
Changqing	Changqing Shaanxi		100	33		
Guangzhou	Guangzhou		60	20	Various	1960-1975
Henan Anyang			200	67		
Huainan Chem	Huainan		60	20	Various	1960-1975
Jilin Chem	Jilin		70	23	Various	1960-1975
Kingboard			600	200	NG	SU-Summer 2006
Nanjing Chem	Nanjing		55	18	COAL	1960-1975
Qilu Petrochemical			100	33		
Qilu 2nd Fertilizer			100	33		
Qilu Lunan			100	33		
Quhua Corp			40	13		
Shanghai Coking	Shanghai		220	73	Coal	1960-1975
Shanghai Gaunting	Shanghai		100	33	Coal	1960-1975
Shanghai Pac Chem	Shanghai		80	27	Coal	
Shanni Yulin			90	30		
Sichuan Vinlon			240	80		
Sinopec Lanzhou	Lanzhou		80	27	COAL	1960-1975
Sinopec Qilu	Zibo		80	27	Various	1960-1975
Sinopec Sichuan	Chongqing		100	33	Various	1960-1975
Yuanan Natural Gas			100	33	NG	
Various		Various	4000	1333		
		Subtotal	**6635**	**2212**		
	GUWAHATI					
Assam petrochemical	Guwahati	MGC	40	13	Off Gas	1980
Deepak Fertilizer	Thaloja	ICI	100	33	NG	1970-1980
National Fertilizer	Punjab	Haldor Topsoe	20	7	Off Gas	1970-1980
GNFC	Gujarat	Lurgi	136	45	Naptha	1970-1980
Rashtrya Chemicals	Mummbai		50	17		
Rama Petrochemicals	Patalagana	ICI	60	20		
		Subtotal	**406**	**135**		
MEDCO	Bunyu	Lurgi	330	110	NG	1990
Kaltim Methanol			660	220	NG	1998
		Subtotal	**990**	**330**		
Petronas	Labuan	Lurgi	**660**	220	NG	1993
Methanex Dist. II	Motunui					
Methanex Dist. III	Motunui		0	0	NG	1995
Methanex Dist. IV	Motunui			0	NG	1995
Methanex	Waitara Valley	ICI	530	530	NG	1984
		Subtotal	**530**	177		
		Region Total	**9271**	**3090**		

EUROPE

Germany	BASF	Ludwigshafen	BASF/LURGI	480	160	Off Gas	1978
	DEA (Shell)	Wesseling	Lurgi	450	150	RESID	1980
	Leunawerke	Leuna	Lurgi	660	220	RESID	1978
	Veba/BP	Gelsenkirchen	Lurgi	260	87	RESID	1969
	Schwarze Pumpe			100	33		
			Subtotal	**1950**	**650**		
Netherlands	Bio MCN	Delfzijl	ICI	**980**	327	NG	1980
Norway	Statoil		ICI	**910**	303	NG	1997
Romania	Viromet	Victoria	Lurgi	180	60	NG	1980
	Creova	Craiova	Lurgi	250	83	NG	1980
			Subtotal	**430**	**143**		
Russia	Tomsk		ICI	825	275	NG	1980
	Gubakha		ICI	1000	333	NG	1980
	Togliatti Axot	Volga River		300	100		
	Togliatti Axot			500	167		
	Angarsk Petchems	Eastern Siberia		150	50		
	Novomoskovsk Azot	East Siberia		200	67		
	Novocherkassk Plant	Southern Russia		150	50		
	Nevinnomyssk Azot	Southern Russia		150	50		
	"Akron"	Northern Russia		150	50		
	State		VAR	100	33	Var	
			Subtotal	**3525**	**1175**		
Slovenia	PETROL			150	50		
	Lindava			160	53		
			Subtotal	**310**	**103**		
			Region total	**8105**	**2702**		

Middle East / Africa

Algeria	Almer	Arzew	ICI	**110**	37	NG	1980
Bahrain	GPIC	Bahrain	ICI	**425**	142	NG	1991
Equatorial Guinea	Atlantic Methanol		MGC	**860**	287	NG	2001
Iran	STATE	Shiraz	Lurgi	120	40	NG	1990
	STATE		Lurgi	660	220	NG	1999
	STATE		Lurgi	660	220	NG	2004
	Zagros		Lurgi	1625	542	NG	2006
			Subtotal	**3065**	**1022**		
Libya	Sirte	Marsa Al Brega	ICI	**660**	**220**	NG	1992
Qatar	QAFAC			**850**	**283**	NG	1999
Saudi Arabia	AR-RAZI 1&2	Al Jubail	MGC	1280	427	NG	1991/1997
	AR-RAZI III	Al Jubail	MGC	850	283	NG	1997
	AR-RAZI IV	Al Jubail	MGC	850	283	NG	1999
	IBN-SINA		ICI	1000	333	NG	2001
	IMC		Lurgi	950	317		2004
			Subtotal	**4930**	**1327**		
South Africa	AECI	Modderfontein	UHDE	6	2	COAL	1979
	Sasol	Durban		120	40	COAL	1979
			Subtotal	**126**	**42**		

NORTH AMERICA							
United States	Air Products	Kingsport, TN	Proprietary	96	32	Coal	2000
	Beaumont Methanol	Beaumont, TX	Lurgi	0	0	NG	1977
	El Paso	Cheyenne, WY	ICI	0	0	NG	1989
	Lyondell	Channelview, TX	ICI	0	0	NG	1983
	Celanese	Bishop, TX	Lurgi	0	0	NG	1968
	Clear Lake Methanol	Clear lake, TX	ICI	0	0	NG	1966 995
	Liquid Carbonic	Geismar, LA	ICI	0	0	NG	1979
	Millennium	Deer Park, TX	Lurgi	600	200	NG	1968
	Eastman	Kingsport, TN	Lurgi	195	65	COAL	1987
	Terra International	Woodward, OK	Haldor Topsoe	120	40	NG	1994 onia
			Subtotal	**1011**	**337**		
CANADA	Methanex	Kitimat	ICI	0	0	NG	1978
	Celanese	Edmonton	ICI	800	267	NG	
			Subtotal	**800**	**267**		
MEXICO	PEMEX	Texmelucan	Lurgi	**0**	**0**	NG	
			Region total	**1811**	**604**		
SOUTH AMERICA - Caribbean							
ARGENTINA	Atanor	Rio Tercero		15	5	NG	
	Casco	Pilar	ICI	21	7	NG	
	Mosconi	La Plata		25	8	OG	
	Resinfors	San Martin	Lurgi	50	17	NG	
	YPF			400	133		2002
			Subtotal	**511**	**170**		
BRAZIL	ALBA QUIMICA			34	11		
	HOECHST			6	2		
	METANOR	Camacari, BA	ICI	83	28	NG	
	POLYENKA			6	2		
	PROSINT	Rio de Janeiro	ICI	132	44	NG	Sta
	ULTRAFERTIL			8	3		
	ZENECA			6	2		
			Subtotal	**275**	**92**		
CHILE	Methanex Chile I	Punta Arenas	ICI	1000	333	NG	1989
	Methanex Chile II	Punta Arenas	ICI	1000	333	NG	1996
	Methanex Chile III	Punta Arenas	ICI	1000	333	NG	1999
	Methanex Chile IV	Punta Arenas	Lurgi	840	280	NG	Jun-05
			Subtotal	**3840**	**1000**		
COLOMBIA	ENKA			**25**	**8**		
TRINIDAD	TTMC #1	Point Lisas	ICI	450	150	NG	1989
	TTMC #2	Point Lisas	ICI	550	183	NG	1995
	CMC	Point Lisas	ICI	550	183	NG	1992 Started
	METHANOL IV LTD	Point Lisas	ICI	550	183	NG	1998
	TITAN METHANOL	Point Lisas	Lurgi	850	283	NG	2000
	Atlas Methanol	Point Lisas	Lurgi	1725	575	NG	Jun-05
	M5000	Point Lisas	Lurgi	1900	633	NG	Oct-05
			Subtotal	**6575**	**2192**		
VENEZUELA	METOR	JOSE, ARIZ	MGC	730	243	NG	1995
	SUPERMETANOL	JOSE, ARIZ	ICI/MGC	670	223	NG	1995
			Subtotal	**1400**	**467**		
							Started
			Region total	**12626**	**3929**		Q2 200

5.8.9 References

1. Note: In addition to the references listed below, a book "Beyond Oil and Gas: The Methanol Economy" (2006) (ISBN: 3527312757/3-527-31275-7) has been identified. Unfortunately it was not possible to find this book during the period of this project. A new edition is scheduled to be published early 2010.

2. Methanol Prices (www.methanex.com/products/methanolprice.html)
3. ICIS,com Chemical Pricing Information April 2009 (www.icispricing.com/il-shared/Samples/SubPage57.asp also sub pages 135,190)
4. Methanol Physicochemical Properties Health Protection Agency (www.hpa.org.uk/webw/HPAweb&HPAwebstandard)
5. Methanol MSDS (www.methanex.com/)
6. Methanol uses and Market Data (www.ICIS.com/v2/chemicals/9076035/methanol/uses.html) (Data from 2008 Methanol Forum, 3-5 November 2008,Dubai)
7. Methanol Institute (www.methanol.org)
8. Royal Society of Chemistry (www.rsc.org/chemsitryworld/News/2008/November)
9. China Takes Gold in Methanol fuel (www.ensec.org/index)

5.9 Di-Methyl Ether (DME)

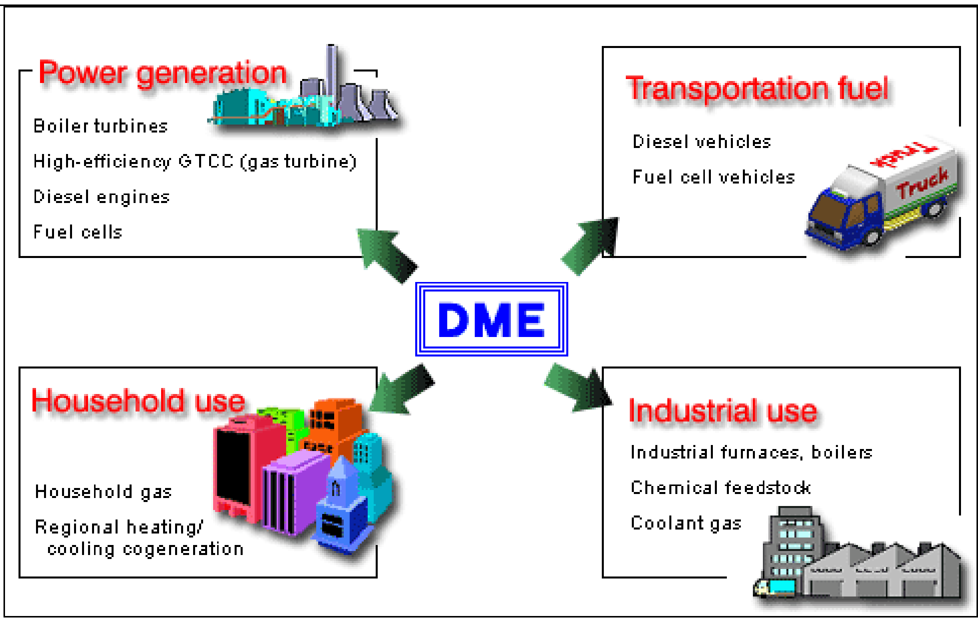
DME has been used since the 1960's as a propellant in aerosols, but it is new as a large scale fuel. DME is similar in its use to LPG –used in 20% blends with LPG, – no changes are required to existing burners. It is an excellent clean-burning fuel, already tested in diesels, gas turbines, and has gained considerable interest around the world. It is already important in China.

5.9.1 Technical Data (5)

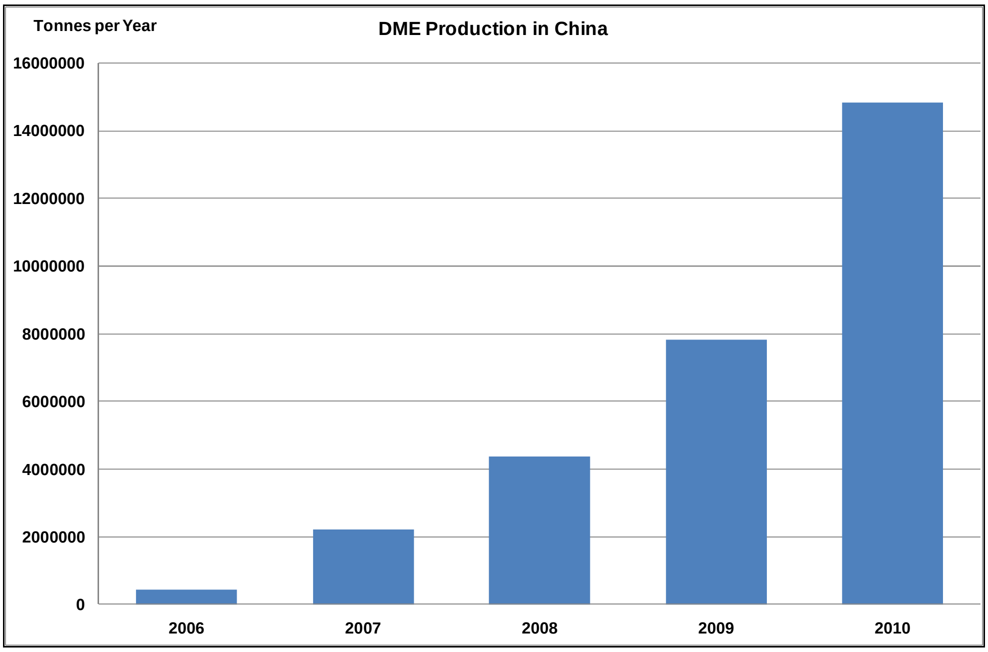
Product Names	Dimethyl ether Synonyms: oxibismethane, wood ether, dimethyl oxide (5,10)
CAS No EC No	115-10-6 204-065-8
Form	Colourless gas
Normal industrial quality purity	
Chemical and Physical Properties	Melting point -138C Boiling point -22C Vapour density 1.62 (air =1) Flash point -41C Explosion limits 3.4%-18% Autoignition temperature 350C Critical temperature 127C Critical pressure 53.5 atm Solubility in water Slight
Formula	C_2H_6O
MSDS	MSDS (5) Stable, extremely flammable. May form peroxides during prolonged storage

5.9.2 Uses, Manufacturers and Market Location

End Uses	DME has uses in several sectors, as indicated below



	Main uses of DME DME/LPG blending as replacement for LPG alone. (Market sector estimated as >200 million tonnes/year (12) DME and Methanol for power generation. Gas turbines exhibit record efficiencies and low emissions (GE and SW provide commercial E and F class gas turbines for DME firing) (12) DME fuel for diesel engines – Volvo state DME is their preferred fuel. (12) Other Uses of DME (13) Propellant in aerosols used for insecticides, styling gels, perfume -original use of DME since 1963 to replace environmentally harmful propellants (12) Feedstock for high added-value chemicals such as dimethyl sulphate, dimethyl sulphide, dimethyl carbonate and polycarbonates as foaming agents Multiple Uses of DME per JFE Holdings Inc., Japan (11)
Manufacturers	China, Iran, Indonesia.
Suppliers	None known
Market Location	China, Indonesia, Iran, Japan (Developing), but markets in other parts of the world developing.
Market Volume	Currently (2009) the main market is China, where demand is projected to grow to 20 million tonnes/year by the year 2020. The growing popularity of DME in China is such that annual production is expected to grow from 2 million metric tons as of last year to 20 million metric tons by 2020. Most of the new Chinese production will be used for transportation. (14). Most of this production is from coal feed-stock Additional plants are coming on stream in Indonesia and Iran (Section 5 below) and these are primarily based on methane feedstock from natural gas. Indonesian companies PT Pertamina and PT Arrtu Mega Energie have announced a joint venture to develop a DME refinery, with a total investment of US$1.9 billion. Production is expected to begin by 2012, with a projected capacity of 1.7 million tons of DME per year produced from low grade coal. Pertamina is conducting a market trial involving the distribution of canisters filled with a DME/LPG blend to homes and home industries in Jakarta. (4)

	 **DME Production in China**
Market Price	There is at present no published price data. Ref 14 Provides estimates for large scale production. (14)
Market Price variability	Not known

5.9.3 Market Volume Future Trends

The major market for DME at present is in LPG for cooking, heating. However it is reported that additional DME capacity coming on stream in China will be used primarily for road vehicles, where it will reduce pollution emissions. DME burns cleanly and it may be possible to leave out some (currently expensive) emissions control systems from truck and cars burning the fuel. N.America and Europe/Scandinavia have already tested the technology (Topsoe, Scandinavia) and developed trucks (Volvo) and large power gas turbines (GE) to use DME fuel ,and find that the fuels. The large US car manufacturers plan to start putting diesel engines into cars about 2012, and this may accelerate the use of DME/Diesel blends for emissions reductions in the US and other developed countries.

5.9.4 Producers

Name	Location	Startup	Process	Feed	Volume Produced	Ref
JFE (NKK)	Japan	1984	JFE	Coke oven gas	Pilot	1,2
JFE	Japan		JFE catalytic Slurry phase Single stage		5 t/day pilot	1,2
JFE/Consortium with Total	Japan	2002	JFE Single stage		100 t/d demo	1
Japan DME (Mitsubishi, Itochu, JGC	Niigata Japan	2008	Single stage	Methanol	100 t/d demo	4
Japan DME (Mitsubishi, Itochu, JGC)	S.E Asia	Planned			Large scale	1
Luthianhua	China	2006	Toyo	Methanol	100,000 t/yr	1,14
Shandongjiutai	China			Coal	several	1
Zagros Petrochem	Iran		Topsoe	Methanol	800,000 t/yr	1,8

Pertamina and Arrtu Mega Energie	Peranap, Indonesia	2012		1 Coal-ethanol 2 Ethanol-DME	1,700,000 tonnes/year DME	3
China National Coal, China Petrolem, Shenergy	Ordos, Mongolia, China	Planned 2008	Topsoe	Coal	2006 120,000 t/y Expand to 3,000,000 t/y	7 (US$ 2.6 bil-lion)
China Energy (3 plants)	Linyi, Guangzhou and Zhangi-jiagang China	2004 to 2008	China En-ergy Low Press dehy-dration	Coal (Metha-nol)	50,000 t/y to 900,000 t/y	6,9

5.9.5 Future Trends

Barriers to DME's extensive uptake are competition from conventional oil, and as oil prices increase also from tar sands and shale oils. DME is less dense than some other fuels and distribution may cost more. However these oil and oil sands sources of fuel have a considerable environmental impact. There would appear to be a major opportunity for DME production from biomass methanol to meet strengthening emissions and CO2 release regulations in many countries.

5.9.6 References

1. Future Prospective of DME. Hubert de Mestier du Bourg 23rd World Gas Conference, Amsterdam 2006 (http://www.igu.org/html/wgc2006pres/data/wgcppt/pdf/WOC%20Working%20Committees/WOC%201/Challenges%20of%20new%20frontier%20gas/1.3EF.07.pdf)
2. A New DME Production Technology and Operation Results Yotaro Ohno, Japan DME Forum 2006 (http://www.brain-c-jcoal.info/cctinjapan-files/english/2_4A4.pdf)
3. Pertamina to Build $1.9 billion DME production plant. (http://blog.chosun.com/blog.log.view.screen?blogId=20831&logId=4039092)
4. DME :Multi-Use, Multi-Source Clean Fuel. International DME Association. (www.aboutdme.org)(2009)
5. Safety data for dimethyl ether (http://msds.chem.ox.ac.uk/DI/dimethyl_ether.html)
6. China to build largest dimethyl ether project. (www.chinadaily.com.cn/bizchina/2006-08/18)
7. Iranian firm plans to build DME plant (dimethyl ether) Zagros Petrochemical Co. (www.highbeam.com/doc/1G1-118892797.html)
8. Dimethyl Ether. (http://en.wikipedia.org/wiki/Dimethyl_ether)
9. Multiple uses of DME. JFE Holdings Inc. (www.jfe-holdings.co-jp/en/dme/03)
10. DME: Developments, Opportunities and Challenges. A.L.Boehman, Penn.State/International DME Association. Conference on the Development and Promotion of Environmentally friendly Heavy Duty Vehicles, such as DME trucks. Washington DC, March 17,2006
11. Dimethyl ether sector develops rapidly –China Chemical Reporter (http://goliath.ecnext.com/coms2/gi0199-6413058/dimethylether)
12. China domestic production of dimethyl ether is expected to reach 4.36 million tons in 2008 (www.reuters.com/article/pressRelease/idUS140041+08)
13. DME: From spray cans to fuel tanks. (www.downstreamtoday.com/X(1)S(cktlgr550vqx41rfj)
14. Fuel DME Plant in East Asia. Toshiyuki MII and Masayuki UCHIDA,Business Planning and Development Department,Toyo Engineering Corporation (TEC) e mail mii@ga-toyo-eng.co.jp
15. Proceedings of 15th Saidi-japan Joint Symposium Dhahran, Saudi Arabia, Nov 27-28 2005

5.10 Bio-Tar

Bio-tar appears to be regarded primarily as a nuisance for the biomass conversion industry as it is formed during gasification and pyrolysis operations, entrains in the gas stream, then fouls downstream equipment.

Present efforts appear to be primarily centred on removal of the tar with catalytic pyrolysis or other cracking processes to produce more gas or a blending stock for bio-diesel. (1) Tar does however contain a number of compounds that may in time become a useful by-product from gasification and pyrolysis plants, with several end uses. (1)

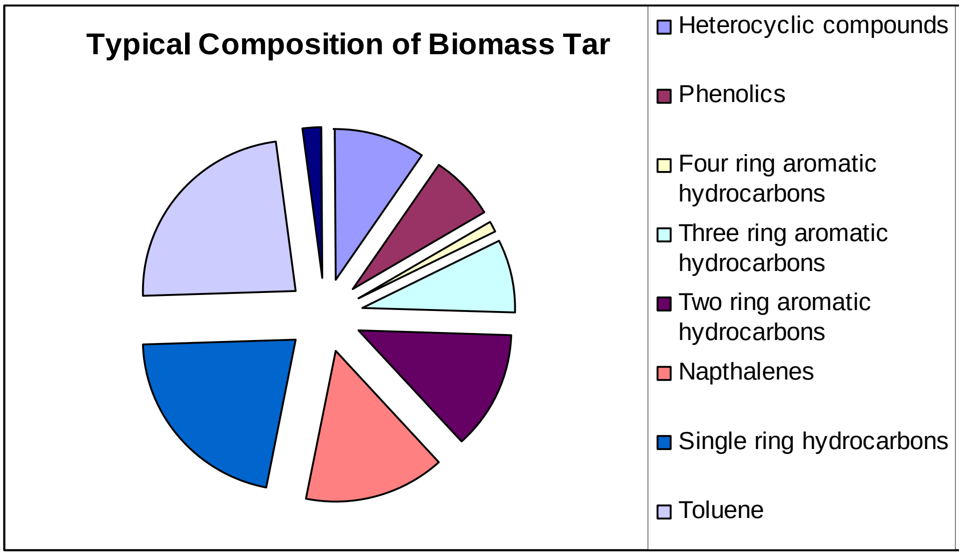
Bio-tar is rich in phenolic compounds, and these are in demand for many uses (5) that find applications in resins and adhesives that were originally made from naturally occurring phenols (3).It is anticipated that making a standardized bio-tar phenol product for such uses would however be a major challenge.

Bio-tar also contains substantial amounts of toluene (1), and this material could also possibly be recovered.

5.10.1 Technical Data (5)

<table>
<tr><td>Product Names</td><td>Bio-Tar
(Tar produced in biomass gasification or pyrolysis processes)</td></tr>
<tr><td>CAS No</td><td></td></tr>
<tr><td>Form</td><td>Biomass tar is a mixture of aromatic hydrocarbons and other compounds such as phenols. The composition of tar varies depending on the type of process that produces it, and the species of wood or other biomass from which it is derived.

One attempt at characterising tar is indicated in Fig 1 below. Other researchers state that tar is predominately phenols with one to three aromatic rings (2) 2005



Biomass Tar Composition (1)</td></tr>
<tr><td>Normal industrial quality purity</td><td>The tar may be refined to produce individual compounds or cuts.</td></tr>
<tr><td>Chemical and Physical Properties (7)</td><td>Product form: Liquid
Color: From dark brown to black
Chemical name: Polymeric polyhydroxy acids complex containing 12 % humic acids
Active ingredients: Humic acids as 120 gr / lt</td></tr>
</table>

	The chemical analysis of the solid part : 71 % Humic acid 20 % Fulvic acid 1 % Humatamelanic acid 8 % Trace elements, vitamins, organic matter pH (at 22 C) 12 - 14 Specific gravity 1.11 gr / cm3 Flash point No flashing below 100 C. Solution stability According to WHO method, at + 15 C with 34.2 PPM standard hard water and with 34.2 PPM soft water, with 5 % V/V prepared solution, the solution stability is more than one hour.
Formula	Not known
MSDS	None available

5.10.2 Uses, Manufacturers and Market Location

End Uses	Two applications for crude bio-tar have been identified: 1. The tar produced from pyrolysed bagasse is soluble in sodium hydroxide, and as an alkaline solution it was successfully used a a foam flotation agent in copper mining, as a foaming agent in foam concrete formation and as a fluidization agent for Portland Cement. (6) 1996. 2. Production of phenol-based resins in a 50/50 mix with pure phenol, for use in wood-panel products like plywood, medium density fibreboard, and laminates. (4) Crude Bio-tar does not appear to have a market at present **Use of Phenols in Bio-Tar** Bio-tar is rich in phenols, and if they could be produced as a by-product of gasification, pyrolysis and other biomass conversion processes, then a market for the tar might be developed. There are likely to be differences between phenols produced from different sources of biomass and also different biomass conversion processes, and lack of consistency could be a major problem in market development. **Phenol Uses** The primary chemical intermediates and derivatives of phenol include phenolic resin, bisphenol-A (BPA), caprolactam, adipic acid and plasticiser. With the growing use of polycarbonate in such sectors as optical media, electrical and electronics and construction, BPA has emerged as the main outlet for much of the phenol production. Globally, BPA accounts for around 35% of phenol output, followed by 30% in phenolic resin and 10% in caprolactam. However, in the US, around 40% of phenol was used in BPA production, while in Western Europe up to 46% went into BPA. Another major downstream application is phenolic resin, which can be used as a wood-binding adhesive in the construction sector; as a bonding agent for foundry and sand moulds in the industrial sector; and for manufacturing insulation and decorative adhesives in the household goods industry. Strong growth is also projected for the use of phenol in polyphenylene oxide engineering plastics, via ortho-xylenol, although from a relatively small base. Phenol is also used as a slimicide (Any pesticide designed to kill organisms that produce slime) a disinfectant; and an anaesthetic in medicinal preparations, including ointments, ear and nose drops, cold sore lotions, throat lozenges, and antiseptic lotions.” (4) **Bio-Bitumen & Bio-Asphalt (8)** GEO320™ is new bio-polymer™ alloy synthetic, bio-bitumen™, biobitumen™, Bioasphalt™ and biopave™ technologies made from non-petroleum renewable

	natural waste material and waste recycled resources, GEO320 is a bio polymer alloy adhesive binder that is made preferably from low molecular weight (Molecular mass) waste and biomass materials such as lignin and cellulose, sugar and molasses, vinasses, natural tree and gum resins, natural latex rubber and vegetable oils, also suitable raw materials are, palm oil waste, coconut waste, peanut oil waste, canola oil waste, potato, wheat and rice starches and GEO320 bitumen can also be made from the distillation bottoms obtained through the process of fractional distillation and or hydrogenation processes derived in the process of cleaning used motor oils and from oil waste prescribed feed stocks materials etc. GEO320 MRH™ bitumen can be manufactured from wide variety of water soluble and non water soluble raw materials and renewable resources (non-petrochemicals) as well as from recycled (Recycling) petrochemical materials, GEO320 MRH Asphalt Bitumen prototype was tested by RTA (Roads and Traffic Authority) South Australia since 1996 and RTA NSW (New South Wales) in a line marking situation, passing AS4049 road marking Standards, Boral Asphalt field trial since 2000 and benchmark tested to AS2008, against Shell's CL320 residue bitumen by ARRB Transport Research in 2002. GEO320 MRH bioasphalt and biobitumen have been proven to exhibit very high durability, fatigue, solvent, cracking, rutting, and skid resistance, the MRH asphalt can be furthermore imbedded with glass spheres (balotini) for reflecting light for night time road safety. GEO320 MRH comes in dry granulated form (no hot storage) required and is non fuming, GEO320 MRH asphalt is compacted at low temperatures (Warm Mix Asphalt) or WMA, and the aggregate mix in GEO320 MRH asphalt can be made from alternative rock sources eg, recycled crushed brick and cementic concrete to preserve our natural rock reserves. The inherently lighter color of GEO320 MRH asphalt helps combat the heat island effect and reduce climate change due to global warming caused by green house gas emissions. In view of the global move towards environmentally friendly renewable resources and sustainability, GEO320 MRH will make a positive contribution not only to the health of asphalt workers in the road paving and construction industries but also to the reduction of green house gas emissions and recycling. **RiMAX Bio's Bio-Asphalt (9)** provides surface stabilization in addition to industrial strength dust control. Bio-Asphalt is ideal for areas where a paved surface is desired, but not within the budget. For residential drives and roadways, Bio-Asphalt is designed to be a single application product that can set a road surface up hard and durable. For industrial uses, it is extremely durable under compaction from large equipment. Bio-Asphalt is the most powerful organic dust suppressant and road base available. Bio-Asphalt dust suppressant surpasses the USDA list of requirements for bio-based content. It is a100% agriculturally derived oil. **APPLICATION:** Bio-Asphalt Dust Suppressant is applied topically as straight oil and begins curing immediately. Bio-Asphalt will not run into waterways or become wet again after curing. Bio-Asphalt is hurricane proof. When this product is applied over a 50/50 mix of loose stone and dust, it will eliminate your dust and bind your stone. You can apply it with our pump and garden hose method for smaller applications. For larger jobs, you can use any agricultural pressure-spraying device or municipal applicator truck. One gallon of Bio-Asphalt covers about 40-50 square feet of prepared surface. For average conditions, a single application will last an entire season. Truck lots may require spot applications in heavy tire turning areas. With diluted maintenance applications of Bio-Dustlocker the surface can last indefinitely. Final appearance will be light gray, and dry to the touch.

	Longevity: A single application of Bio-Asphalt can last 1 – 2 years on straight automobile roadways. Industrial lots will require more frequent applications depending on load requirements and traffic. With maintenance applications of our diluted Bio-Dustlocker product this surface can last indefinitely. **Packaging:** Bio-Asphalt is available in 275 gallon totes, 55 gallon drums, and 5 gallon containers. For larger projects, Bio-Asphalt can be shipped bulk in 18,500 gallon railcars or 4900 gallon tank trucks.
Manufacturers	Bio-tar, rimaxbio,
Suppliers	None known
Market Location	Worldwide Potential
Market Volume	Not yet commercialized
Market Price	Not known
Market Price variability	Not known

5.10.3 Market Volume Future Trends

No data is available

5.10.4 Producers

None known

5.10.5 References

1. Catalytic cracking of tar from biomass gasification. Nicola Sindac, Department of Chemical Engineering, Lund University Sweden (2007) (http://www.chemeng.lth.se/exjobb/E452.pdf)
2. Carbon Fibers and Films Basedf on Biomass Resins. W.M.Qiao,M.Huda,Y.Song et al. Energy Fuels 2005. 19(6) pp 2576-2582 (http://pubs.acs.org/doi/abs/10.1021/ef050046j)
3. Phenolic Resins Technology Handbook. NPCS Board of Consultants. Pub. NIIR Project Consultancy Services. ISBN 9788190568500
4. www.greener-industry.org.uk/.../phenol/5PhenolFeedstock.
5. Phenol Methodology ICIS pricing www.icis.com/StaticPages/Phenol.htm
6. L.E. Brossard Perez and L.A.B. Cortez, Potential for the use of pyrolytic tar from bagasse in industry faculty of Chemical Engineering, Oriente University, Santiago de Cuba, Cuba (1996) www.sciencedirect.com/science/
7. http://www.bio-tar.com/
8. http://www.ecopave.com.au/bio_bitumen_asphalt_concrete_research_ecopave_australia_002.htm
9. http://www.rimaxbio.com/servlet/the-33/BIO-dsh-ASPHALT/Detail

5.11 Wood Pellets (Renewable Solid Fuels)

Lignin Pellets are already an important source of energy for home heating in several countries, and the pellets are being used in increasing amounts in main power generation plants, often being co-fired with fossil fuels.

Lignin (Wood) Pellets are now produced in many countries that produce lumber, as they use the sawdust generated in sawmilling operations. The sawdust is pressed and extruded to make pellets and during this process the contained lignins act as a plasticizer and bind the particles together. The market for pellets is currently expanding at a rate of about 20%/year, with a market size of 10 million tonnes/year, with explosive growth forecast to 150 million tonnes by the year 2020.

Europe is currently the largest market, 8 million tonnes/year in 2008, and this demand can only be satisfied with about 25% of the pellets imported, mainly from Canada and the USA. There is also considerable cross-border European trade in pellets, with about 25% of the pellets not made in the consuming country.Figure 23

Although currently pellets are made from wood waste, renewable materials that may be available on a large scale, (e.g. sawgrass in Ontario, Canada) are being considered for fuel pellet production. There are many additional biomass wastes that could be considered for fuel pellet production but as yet they are not being used. (10)

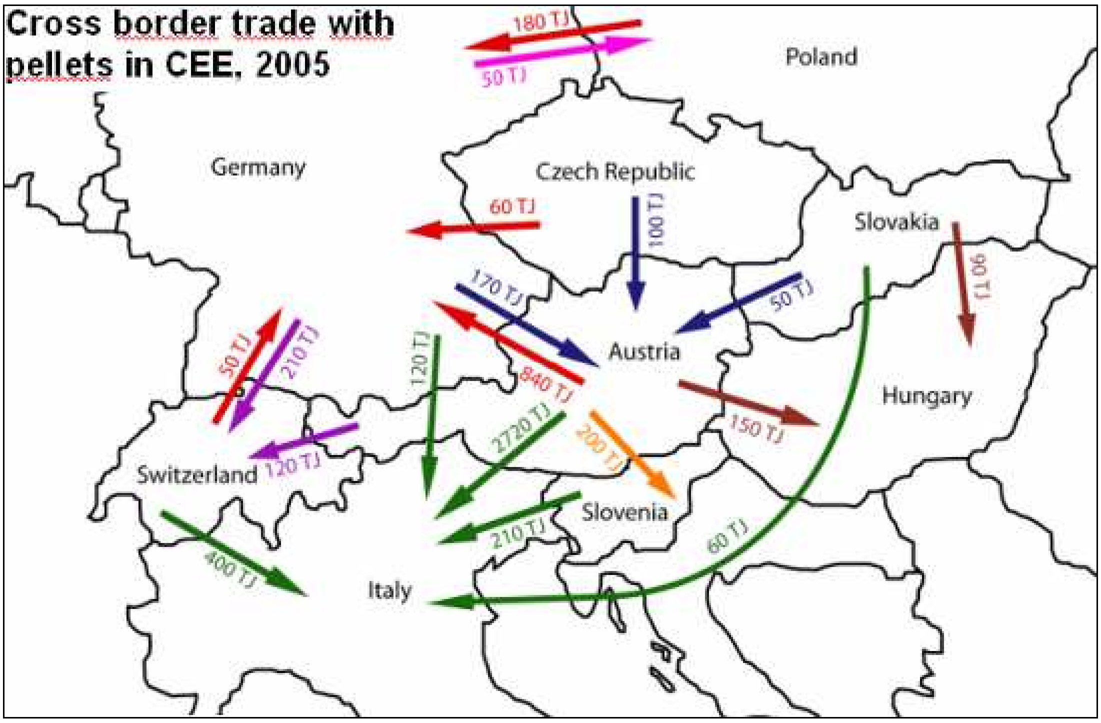


Figure 23 Cross border trade of pellets in the Central European Countries (CEE) in 2005 (Source: Eurostat, MPO, CZSO, EEG)

5.11.1 Technical Data

Product Names	Wood Pellets

<table>
<tr><td>Quality Standards</td><td>

Wood pellets quality norms		ÖNorm M 7135	DIN 51731	DIN plus
Diameter	mm	4 to 10 mm	4 to 10 mm	
Length	mm	5 x D[1]	< 50	5 x D[1]
Density	kg/dm³	> 1,12	1,0 < Dichte< 1,4	> 1,12
Humidity	%	< 10	< 12	< 10
Ash	%	< 0,50	< 1,50	< 0,50
Heating value	MJ/kg	> 18	17,5 < HW< 19,5	> 18
Sulphur	%	< 0,04	< 0,08	< 0,04
Nitrogen	%	< 0,3	< 0,3	< 0,3
Chlorine	%	< 0,02	< 0,03	< 0,02
Abrasion	%	< 2,3	-	< 2,3
Press aid	%	< 2	([2]	< 2
[1]	no more than 20% of the pellets may be longer than 7.5 x Diametre			
[2]	DIN prohibits additional matter. This prohibition however, is not valid for small heating systems			

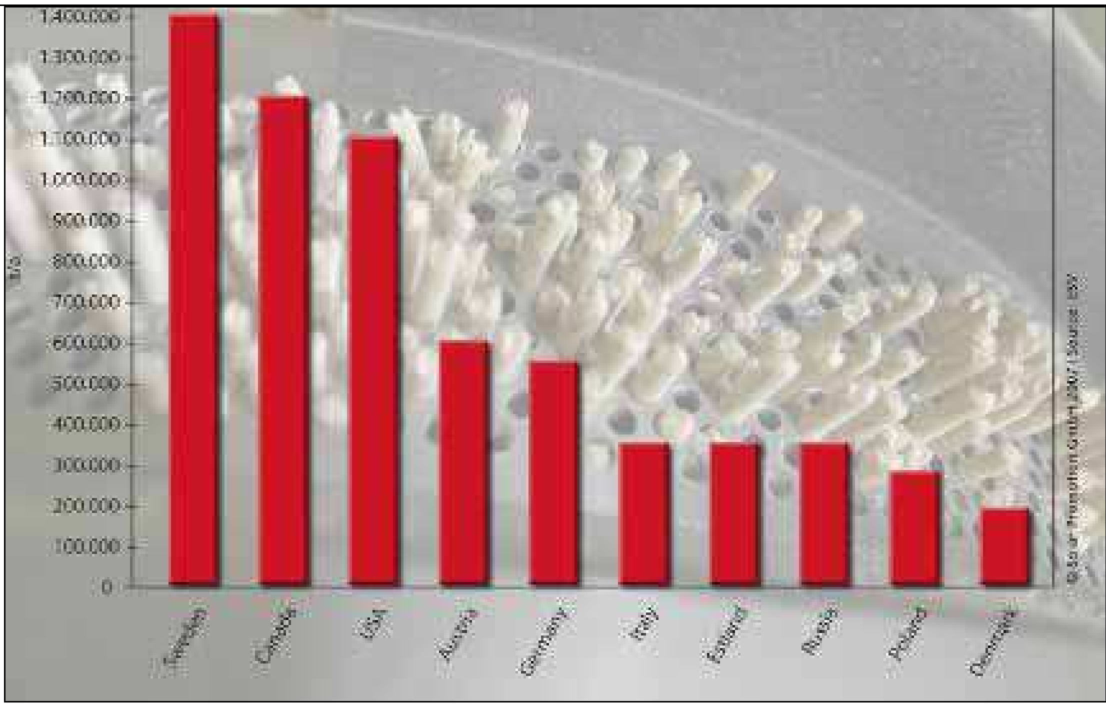
Swedish Pellets are also manufactured to Altener 2002-012-137-160 (6)</td></tr>
<tr><td>Form</td><td>Extruded wood pellets, also Briquettes (13,2009)</td></tr>
<tr><td>Normal industrial quality and characteristics (12)</td><td>Lignin (wood) pellets are a refined biomass fuel. They are produced from forest and sawmill wood co-products by drying and pressing the raw materials. (10)
Pellets
100% wood without added adhesives
Diameters 8mm,10mm,12mm,14mm

Length 5-20mm long (13)
Available in 16kg,25kg bags also
Big Bags 900kg or 1100kg
Moisture 8%
Ash 0.43% (others 0.4-1% (10) 2009)
Sulphur 0.02%
Calorific power 4516kcal/kg
Bulk density 700-750 kg/m3

Briquettes (13)
Diameter 85mm
Length 25-400mm
Moisture 7.8%
Ash 0.5%
Calorific value 4600 kcal/kg</td></tr>
<tr><td>Chemical and Physical Properties</td><td>Lignin in the wood binds the pellet when it is milled and extruded. The pellets are easily handled and work well in automatic feeding systems</td></tr>
<tr><td>Formula</td><td>N/A</td></tr>
</table>

5.11.2 Uses, Manufacturers and Market Location

End Uses	Domestic heating, also large scale heat and power generation
Manufacturers	>450 plants in Europe. (10) **North America** USA – 60 mills in 2006, produced 800,000 tons/year. In 2007, 25 more added (In NE and Pacific NW). In Canada (8) , more in N. America
Suppliers	Many suppliers throughout Europe (5)
Market Location	World, 2006 Wood Pellet Production in 2006 is indicated below



International wood pellets production in 2006. (Tonnes/Year) (16)
Note: Most US and Canadian production exported to European Market)

Europe (10)
Wood pellets are now a major fuel source in many parts of Europe. The manufacture and utilization of pellets is well established in Sweden, Norway, Austria, Denmark, Germany . There are growing markets in Finland, Netherlands, Italy, UK.

A plant to produce 550,000 tonnes/year of pellets for export to Sweden is being built in Florida, USA

Ireland has a rapidly expanding wood pellet market, based on financial incentives. At present there is only one Irish producer of , but three more plants being planned with a capacity of 150,000 tonnes/yr (15)

The UK at present (2009) uses pellets mainly in power plants, with only small use in domestic boilers, and only small amounts of pellets are produced in the UK at present. Recent estimates indicate that by 2010 about 400,000 tonnes/yr of pellets could be produced in the UK .(15)

The UK domestic and power plant market for pellets is likely to expand rapidly under government incentives to cut greenhouse gas emissions. (15) 2009s

In the EU over 180,000 houses /year are being converted to burn wood pellets

Recent industry assessments indicate that the European market could grow to 15 million tonnes by 2010, and to 150 million tonnes/year by 2020. (15)

North America (10)
US market primarily in NE and Pacific NW states (9) 2009, and Canada there are a total of one million small houses are using pellets as a source of heat energy.

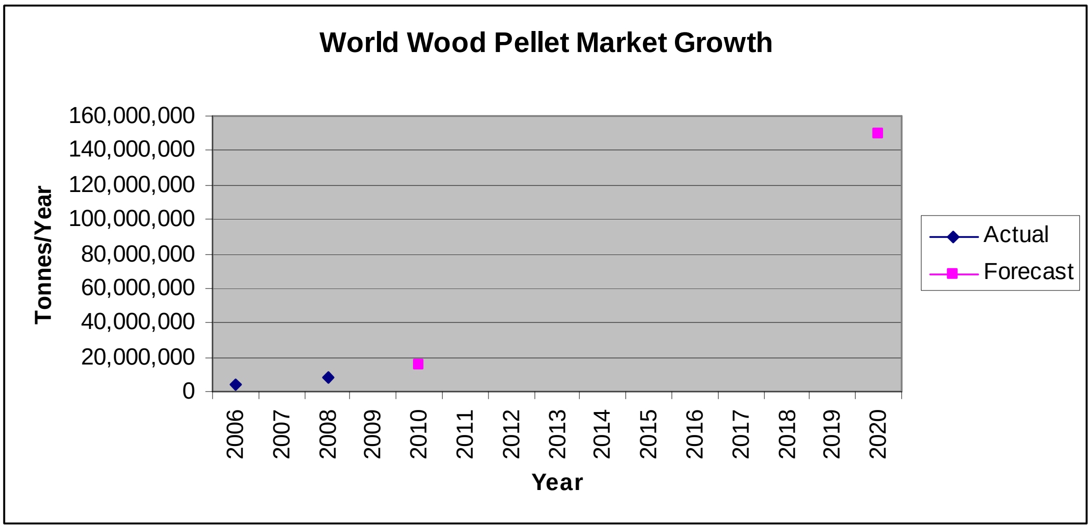
A large pellet plant 550,000 tons/year with Swedish Owners started in Florida in 2008, and all product is being exported to Europe "*Where pellet markets are insatiable*" (Quoted from Biomasss Magazine (9)

The US utility market does not use wood pellets at present, as burning cheap coal. However a new plant of 90,000 tons/year being built in Wisconsin to produce pellets for co-firing in a

utility boiler. Expected new regulations from the US Congress on carbon regulations to improve the US market for wood pellets.

In the US, wood pellets compete well against natural gas, propane and home heating oil but not against coal that is very cheap at present. (9).

Market Volume



World Wood Pellet Production and Forecast (15)

Total world wood pellet production in 2006 was at 4,200,000 tonnes/year (1)

The market grew very rapidly to >8 million tonnes/year in 2008 in Europe, and this has been satisfied only by large amounts of imports. (3,14) 2009
(Swedish consumption alone of pellets required additional imports of about 400,000 tonnes)

World production in 2008 was close to 10 million tons (14) 2009S and 25% of pellet production is exported between countries, a considerable amount from W Canada to Europe, a journey of 15000 kms.The “Green” pellets are being shipped using heavy fossil diesel in ships (14) 2009

Market Price

€200-250/tonne (2) 2008) , (11)2009) (3) 2009

Market Price variability

20% depends on location, volumes purchased and prevailing price of oil. Price variation in years 2006-2007 (See Table 1 below)

Pellet price development from January 2006-May 2007 (price of bulk pellets including VAT; radius 100-200km) (Source: DEPV/Solar Promotion GmbH)

Monat / Jahr	2006 [€ pro Tonne]	2007 [€ pro Tonne]
Januar	187,30	262,28
Februar	194,13	234,48
März	194,13	203,86
April	194,06	194,15
Mai	199,67	188,15
Juni	200,78	
Juli	205,72	
August	222,61	
September	236,11	
Oktober	249,34	
November	256,59	
Dezember	264,73	

5.11.3 Market Volume Future Trends

In 2009, the European market was reported to be growing at a rate of 20%/year. (3)One forecast indicates a market of 150 million t/y by 2020.

The US demand is slowly developing, but it will likely increase rapidly if the US Congress pass laws regarding a "Carbon tax" that would favour non-fossil fuels such as wood pellets. Wood fibre costs, currently the largest component of pellet costs, are likely to decrease in 2009 in both Europe and North America as competition for wood chips and pulpwood from the pulp and wood-panel sectors weakens (3, 7) 2009

Lower fibre costs should allow pellets to become even more competitive against fossil fuels, with an increase in production. Canada is likely to have large volumes of cheap fibre available from harvesting large scale pine forests affected by the Western Pine Beetle. This source of fibre has several uses but the growing demands of the worldwide pellet market would provide an outlet. However, the market remains highly influenced by coal, oil and gas prices

5.11.4 Producers

There are very many producers of pellets around the world, over 450 in Europe alone Details of producers and distributors are generally available from each country's trade association.

5.11.5 Future Trends

Quoted from (14)

> "*Global pellet production was close to 10 million tons in 2008, according to the Wood Resource Quarterly. It is estimated that production will double over the next 4-5 years and some industry experts forecast an annual growth of 25-30% globally over the next ten years. Europe is currently the major market for pellets, but the interest for non-fossil fuels in North America is growing. The new leadership in the US government is going to have a positive impact on alternative fuel usage and the expected change in energy policy could very well result in increased imports of pellets from Canada to the US, which will eventually diminish the flow of biomass from North America to Europe. As a result, European pellet consumers will have to search for alternative supply sources in Asia, Latin America, Africa and Russia."*

5.11.5.1 Replacement of Fossil Fuels with Biomass for Heating and Power Generation

"Even taking into account the fossil fuel emissions from planting, harvesting, processing and transporting the wood, replacing fossil fuels with wood will typically reduce net carbon emissions by over 90%" (4) 2009. Even the ash left over after burning wood pellets is useful. Due to its high mineral content ,it can be recycled to fertilize forests, parks or gardens" (4) 2009

5.11.5.2 Existing Utilization of Biomass Heating

Fig 4 Indicates that biomass heating (including lignin pellets) provides an important (15% in 2008) (1) and growing contribution to the overall sources of renewable energy. (1.5% of *total* energy use)

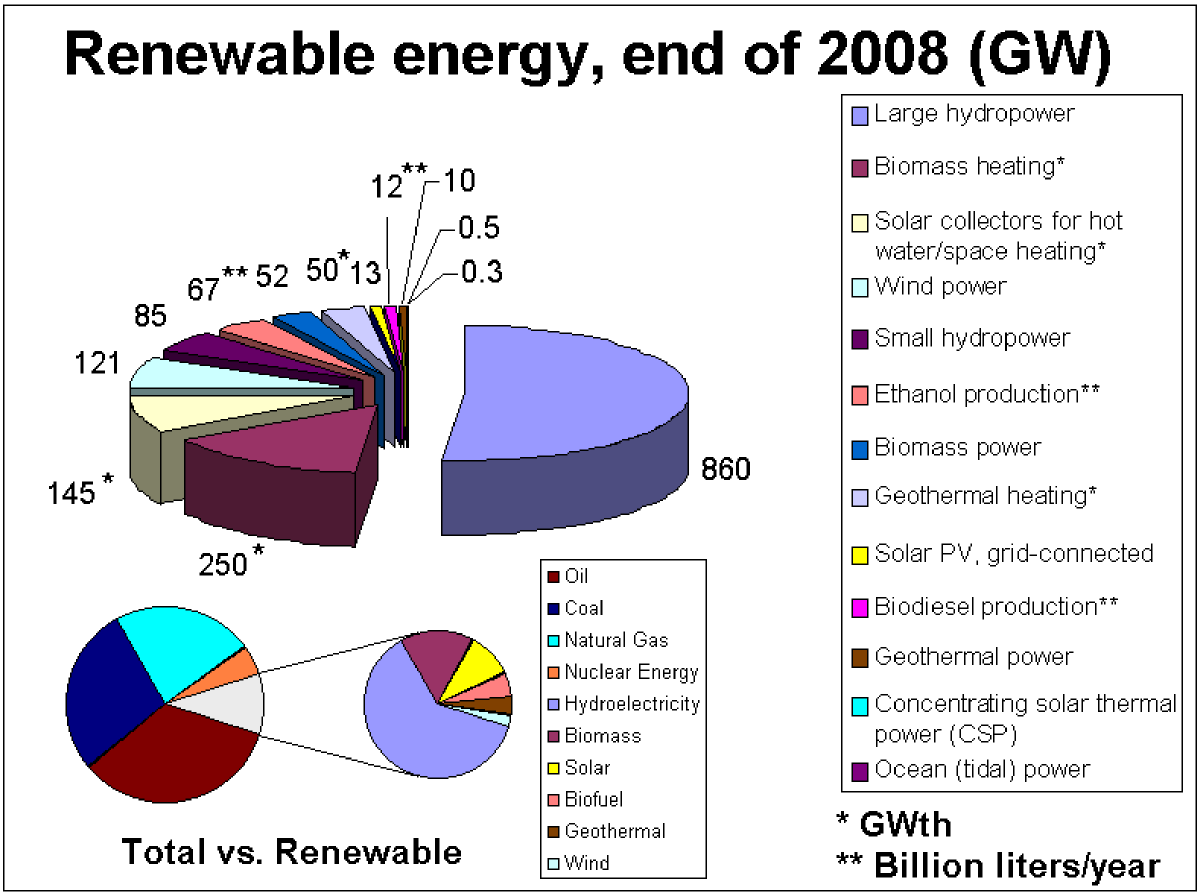


Figure 24 Renewable Energy Sources (17)

5.11.6 New feedstocks for biomass heating

The major raw-material used for pellet manufacturing has traditionally been sawdust and shavings from the sawmilling industry. As this supply source has started to tap out, there is now an increased interest in searching for alternative fibre. It can be expected that European pellet manufacturers will increasingly use forest residues, urban wood waste and fast-growing tree species. They will also begin to compete more aggressively with pulpmills and wood-panel mills for sawmill chips and pulplogs. Imports of wood chips from over-seas may also be an option for some pellet plants. The AURI Fuels Initiative (10, 2009) provides data on many alternative feedstocks, grasses and agricultural wastes.

5.11.7 Pellet Exports

”A surprisingly large share of the global pellet production is being shipped to markets outside the producing country, not only between countries but also intercontinentally. According to the Wood Resource Quarterly, an estimated 25% of world production was exported in 2008. Most of the overseas volume was shipped from British Columbia, Canada to Belgium, the Netherlands and Sweden, despite the seemingly prohibitively costly 15,000-kilometer journey from the Interior of BC to the European market. This situation can be explained by the currently low costs for raw material (shavings and sawdust) in Canada and the high prices for wood pellets in Europe.

The rapid expansion in global trade of biomass (both wood chips and pellets) is likely to continue over the next three to five years as more countries favour renewable energy and as local, relatively inexpensive supplies of biomass reach their limits. The question is how long expansion of the overseas water-borne transport will continue to grow, given the uncertainty

of future costs of oil and the paradox of consuming large quantities of low-refined heavy fuel oils for the shipments of green energy to European customers." (14)2009

5.11.8 References

1. Wood Pellet http://en.wikipedia.org/wiki/Wood_pellet
2. Bioenegie:Großes.Potenzial für Pellets-Märkte in Europa und weltweit (http://www.solarserver.de/news/news-7242html)
3. Pellets for small –scale domestic heating systems (http://www.erecrenewables.org.fileadmin/erec_docs/Project_Documents/RESTMAC/Pellets_-si5/2007)
4. Wood pellets in Finland – technology, economy, and market. Technical Research Centre of Finland, JYVÅSKYLÅ 2002 (http://www.cityofnorthbay.ca/Business/presentations/woodPellets/Wood%20pellets%20in%20Finland%20-%20technology%20economy%20and%20market.pdf)
5. Increase in Demand for Wood Pellets Pushed Prices Upward in Europe in the 4Q/08 ,reports WRQ.(http://www.free-press-release.com/news/200903/1236441733.html)
6. Wood Pellets (http://www.uk-energy-saving.com/wood_pellets.html) (2009)
7. UK National Energy Foundation - Suppliers of Wood Pellets in the UK (http://www.nef.org.uk/logpile/fuelsuppliers/pellets/pelletsuppliers.asp)
8. European Pellet Centre - Experience on critical factor met in Northern Europe. (http://www.pelletcentre.info/CMS/site.aspx?p=2599)
9. Market Development (http://www.engext.ksu.edu/biomass/_MarketDevelopment.htm)
10. Wood Pellet Association of Canada. The Pellet Story (http://www.pellet.org/site/Forms/ViewPage.aspx?PageID=216)
11. Biomass magazine Feb 2009 .Closing the Wood Pellet Gap. (http://www.biomassmagazine.com/article.jsp?article_id=2048)
12. AURI FUELS INITIATIVE. Agricultural renewable Solid Fuels Data Agricultural Utilization Research Institute. PO Box 251, Waseca,MN 56093 (http://www.auri.org/agnews-section.php?sid=79&agnid=52)
13. Integrated Energy Systems International Ltd. New Technologies. Wood Pellets/power from wood. (http://www.integratedenergysystems.co.uk/)
14. WoodBusinessPortal.com (http://wwwwoodbusinessportal.com/en/Messages?Pellets-DI)
15. UK Wood Pellets. (http://www.ukwoodpellets.eu/wood_pellets_2.html)
16. Wood Resources International. Wood Pellet Producers are increasingly competing with pulp manufacturers for wood fiber, reports WRQ. Feb 29, 2009 (http://www.mynewsdesk.com/se/view/pressrelease/wood-pellets)
17. International Wood Pellets Markets – a retrospection on 2008 (27 Aug 2009) (http://forestindustries.eu/de/content/international-wood-pellet)
18. IEA Bioenergy Task 40 Global Wood Pellets Markets and Industry: Policy Drivers, Market Status and Raw Material Potential November 2007 (http://www.canbio.ca/documents/publications/ieatask40pelletandrawmaterialstudynov2007final.pdf)
19. Renewables Global Status Report (http://www.ren21.net/pdf/RE_GSR_2009_Update.pdf)

5.12 Animal Feed

By-product residues from various bio-refining processes are rich sources of fibre, proteins and other nutrients that can be used as valuable supplements in animal feed. Animal Feed from bio-refineries focussed on Brewers Grains, the main by-product from bio-ethanol production. This study considers the markets in animal feed applications for by-products made from the processing of the main EU crops that are going into bio-refining, namely grains, rapeseed, and sugar beet.

Rapeseed oil is the preferred oil stock for biodiesel production in most of Europe, partly because rapeseed produces more oil per unit of land area compared to other oil sources, such as soy beans. Rapeseed is the worlds' second (after soy) leading source of high protein meal

(8) EU bioethanol is generally produced using a combination of sugar beets and wheat. In 2004, EU bioethanol production used 1.2 million MT of cereals out of total EU production of over 289 million MT of grains and 1 million MT of sugar beets out of 123.5 million MT of sugar beet production. (9)

The disposal of bio-refining by-products/wastes into the animal feed market is attractive to bio-refinery operators as the animal feed market is almost worldwide and very large. (1) Bio-refinery by-products can provide valuable additions to animal feeding and may enhance the quality of the animal feed and profitability of bio-refining. There can be issues with the use of bio-refinery products in animal feed that are discussed below. (6, 7)

5.12.1 Technical Data

<table>
<tr><td>Product Names and Form</td><td>Animal feed is produced from many different feed-stocks (1, 2009) and sold under many trade names, for different animals and in different regions of the world.

Rapeseed Cake (sometimes called de-oiled cake or meal) also called Rapeseed Meal. Rapeseed cake is produced from pressing rapeseed to extract rape oil that is going to make bio-diesel. The cake can also be pelletized for easier handling. (3,4,2007). The feed is mostly employed for cattle feeding, but also for pigs and chickens (though less valuable for these). The meal has a very low content of the glucosinolates responsible for metabolism disruption in cattle and pigs. (2, 2009)

Glycerine
The biodiesel process also produces by-product glycerine. This also has applications in feed for cows, pigs and chickens. (3,2007)

Distillers Grains
Distillers grains are produced as dry distillers grains (DDG) and distillers grains with solubles (DDGS). DDGS is the primary product sold by ethanol plants, and about 40% is supplied in a wet form for use in dairy operations and beef cattle feedlots. The remaining 60% of Distillers Grains with Solubles is Dried DDGS and marketed in the US and Internationally for use in dairy, beef, swine and poultry feeds. (1, 2009) provides a recent study on the market for distillers grains.

Sugar Beet Pulp
Sugar beet pulp from sugar extraction is well established as animal feed. It is sold wet directly to nearby customers, and also as Dried Sugar Beet Pulp Pellets (SBPP). SBPP for cattle are available in at least two forms: (12,2009):
• Molassed, with approx. 30% molasses (Trade names of Nordic Sugar - Kossetter and Betford)
• Unmolassed, trade names Pulpetter and Fiber-Betford.

DDGS is a highly digestible feed, and provides about 90% of the energy content of barley. (11)

Mixed Product
One product combining one part distillers grains to four or five parts pressed sugar beet pulp is being marketed by at least one company as “Praize” (10)
This is reported to be better for high yield dairy and beef cattle (12, 2009).</td></tr>
<tr><td>Normal industrial quality purity</td><td>All countries legislate the purity, composition and marketing of animal feed. In the case of the UK/EU, the regulations cover farmed livestock as well as horses, pets, farmed fish, zoo and circus animals (and in certain circumstances, creatures living freely in the wild). The regulations cover all ingredients as well as the finished feed product. (8, 2009)</td></tr>
<tr><td>Chemical and Physical Properties</td><td>Composition of DDGS (Derived from data in (10)

Averages and ranges in Composition of Selected Nutrients (100% Dry Matter Basis) of USA *corn DDGS<table><tr><th>Nutrient %</th><th>Average</th><th>Range</th></tr></table></td></tr>
</table>

Dry matter	89.3	87.3-92.4
Crude Protein	30.9	28.7-32.9
Crude Fat	10.7	8.8-12.4
Crude Fibre	7.2	5.4-10.4
Ash	6.0	3.0-9.8
Lysine	0.9	0.61-1.06
Phosphorus	0.75	0.42-0.99

*"Corn" in the USA is called "Maize" in Europe

Note that many ethanol plants in other countries e.g. Canada and Europe will use wheat or other feedstock for ethanol production.

A comparison between Corn DDGS and Wheat DDGS has been made in Canada (11) with the following conclusions:

- Similar micronutrients found in distillers grains from corn or wheat.
- Corn distillers grains is higher in fat and oil, and lower in protein and fiber than wheat distillers grains.
- Wheat-based product is slightly higher in amino acid content than its corn-based counterpart.
- DDGS from both sources is very similar. in overall nutritional value.

5.12.2 Uses, Manufacturers and Market Location

End Uses	Feed for animals and fish
Manufacturers of animal feeds	**Basic Materials** DDGS is produced by the alcoholic beverages industry and also from industrial/fuel ethanol producers. Rapeseed Cake is produced on many small plants for edible oil pressing in Germany, also on a larger scale by bio-diesel plants using rapeseed feedstock. Sugar Beet Pulp is produced by sugar manufacturers, who will also supply sugar to biorefineries. **Animal Feeds** Animal feeds are produced by farmers for their own use and also by many small and some large companies. (See below). DDGS, rapeseed cake and Sugar beet pulp is sold directly to farmers, and also to animal feed companies **Feed Companies in Europe** There were 4232 Animal Feed production units in the EU in 2008 (11,2009) There are many relatively small production companies, with a few large ones identified: • Cremer Group (Merger of Hamburg based commodity trade firm Cremer and Dusseldorf based Deuka (Deutsche Kraftfutterwerke) produces 3.5 million tonnes/year. (3) 2009 • UK Biorefiner Ensus UK 350,000 tonnes/year high fibre type suitable for cattle (2,2009) • Also subsidiaries of US companies **-** Cargill (75 facilities in 16 countries), Conti Group Companies (world's leading cattle feeder),CHS Inc.,Smithfield Foods, and CP Group Thailand, producing 18 million tonnes/year of compound feed mainly in various locations across East Asia (1)2009
Suppliers	Huge number of suppliers worldwide (5)
Market Location	Worldwide 580 million tonnes *Compound Feed Equivalent* in 2006 ((11) 2009)

<table>
<tr>
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<td>
EU Market
Market size 151 million tonnes Compound Feed Equivalent in 2008 (11 The value of livestock production - amounting to €152 billion - accounts for 40% of the overall EU-27 agricultural output amounting to €381 billion in 2008.Animal feedingstuffs, including feed materials and compound feeds, are the main input into livestock production.

Within the EU-27, about 468 million tonnes of feedingstuffs are consumed by livestock each year. Out of this quantity, 228 million tonnes mostly are roughages grown and used on the farm of origin. The balance, i.e. 240 million tonnes of feed, includes cereals grown and used on the farm of origin (51 million tonnes) and feed purchased by livestock producers to supplement their own feed resources (either feed materials or compound feed).

In 2008, 151 million tonnes of compound feed were produced by EU compounders, accounting for 79% of all purchased feedingstuffs.
The value of all feedingstuffs used by EU livestock producers including forages produced on the farm is estimated at €89 billion in 2008.
This accounts for 39% of all inputs and 56% of the turnover in livestock production.

Purchases of compound feed amounted, in 2007, to €42 billion or 53% of the value of all used feed stuffs. Compound feed are manufactured from a mixture of raw materials designed to achieve pre-determined performance objectives among animals. These raw materials are obtained from a wide variety of sources. Hence, the industry provides a major market for EU cereals, oilseeds and pulses. Some raw materials are obtained from the co-products of the food industry. Other important ingredients which cannot be grown in sufficient quantity in the EU are imported from third countries. These diverse sources of raw material supplies are an important factor in the industry's ability to manufacture feeds of both high quality and at competitive prices for livestock farmers.

The compound feed industry has become capital intensive in recent years and makes use of a very high level of technology. Advanced methods are used to formulate feeds according to the demands of the livestock farmer – which reflects final consumers' demand - and to control the raw materials used, the manufacturing process and the quality of the finished feeds. The compound feed industry is subject to a complex body of both EU and national legislation affecting almost every part of its operation. This legislation is designed to ensure that feeds are of high quality and are safe for both livestock and consumers.
(11)
</td>
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<tr>
<td>EU Market
Growth Rate</td>
<td>
The market for feed stuffs depends on the market for livestock products.

EU Livestock production in 2008 (11,2010)

<table>
<tr><td>EU 27</td><td>2008 Tonnes/year</td></tr>
<tr><td>Meat, total production</td><td>47.6</td></tr>
<tr><td>Beef</td><td>8.0</td></tr>
<tr><td>Pork</td><td>22.5</td></tr>
<tr><td>Poultry</td><td>11.5</td></tr>
<tr><td>Milk</td><td>140.0</td></tr>
<tr><td>Eggs</td><td>7.0</td></tr>
</table>

Average per capita consumption of meat (including horse meat and offals) in 2007 was 93.9 kg, compared to only 50 kg in the EC-6 during the late 1950s.

Compound feed production in the EC-9 grew by over 7.5% per year during the 60s and early 70s. This reflected the development of the demand for animal products closely linked to the increasing purchasing power. In addition, particularly in the
</td>
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pig and poultry sectors, production was becoming more intensive requiring greater use of industrial compound feed to meet high performance and quality requirements.

For the remainder of the 1970s, annual average growth in EC-9 compound feed production slowed down to a rate stabilising at only 4.4%. This lower rate partly reflected the effects of the 1973 "oil price shock" on consumers' incomes.

After a period of steady increase from the mid 80s on, consumption of all livestock products grew more slowly, because of the saturation of the EU-15 market and because of increasing consumer concern about health matters and animal welfare.

From 1996 on, the compound feed production suffered from the impact of the BSE crisis which resulted in a 9% reduction in cattle feed in 1998 compared to 1995. This decrease was offset by a parallel growth of consumers' demand for white meat. As a result, compound feed production in the EU has remained almost stable since 1996. The 2004 and 2007 enlargements of the EU brought some 20 further million tonnes/year of compound feed to the EU production.

Market Volume

Worldwide
US$20 *billion in 2006 (3,2009)
600-630 million tonnes/year in 2006 (3, 4, 2009)

Europe
151 million tonnes in 2008
Over half of EU grain output (300 million tonnes/year) is used for animal feed but higher protein ingredients (>65 mtpa) also needed. EU gets 90% of high protein feeds from South American soy often grown on deforested land - land use change emissions. EU produces 10 million tonnes/year wheat surplus. (1) 2009 Animal feed formulations requires protein concentrates >20%.This is supplied mainly with soya (mainly imports), although rapeseed meal provides 14% of the animal feed demand it constitutes 43% of the EU produced proteins for animal feed.

See Appendix 1 for details of Sources of Proteins in Animal Feed in 2008.(11)
Ref 11 Provides considerable data on animal feed in the EU.

Market Price

There is little to no EU published price information.

DDGS
Ref 1 provides some data on prices for DDGS produced in the USA and sold in bulk for the USA and delivery to Korea and China.
DDGS Price range US$116-208 /Metric Tonne (Euros85-113/tonne at Feb 2010 exchange rate)

Rapeseed Cake
One reference only " up to Euros 160 per tonne" (12)

Data for August, September, October 2009. Derived from data in (11,2009)
Dried DDGS Prices US$/Metric Tonne

Delivery Point	August	September	October
Barge CIF New Orleans	116	118	129
FOB Vessel, Gulf	122	124	135
Rail delivered California	138	139	140
40ft containers to South Korea	N/A	188	194
40ft containers to Yokohama Japan	N/A	201	208
40ft containers to South China ports	N/A	198	205

(12),2009 provides a comparison of wet and dry DDGS, and also a method of calculating the break-even price at the consumer (farm gate) based on nutrient values.

	Europe and Asia No data has been found for European or Asian prices of DDGS
Market Price variability	The price of DDGS is tied to the price of corn in the USA and no doubt wheat in Europe that provide an alternative animal feed. The prices would appear to be highly affected by crop yields and thus weather conditions, also political and environmental pressure group considerations (10) regarding food supplies being diverted to make ethanol fuel.

5.12.3 Market Volume Future Trends

Reported overall worldwide market growth for animal feeds is 2%/year. (1)
However this does not take into account the displacement of imported materials with DDGS and other locally made feed materials such as sugar beet residues from ethanol production.

Table 11 Animal Feed Ingredients Production and Imports in the EU (11, 2009) (Millions of tonnes/year)

Animal Feed Ingredient	Imports 2005	Imports 2006	Imports 2007	Imports 2008	Production 2008	Consumption 2008	Notes
DDGS	722	575	442	221			*Falling imports
Dried Sugar Beet Pulp	262	33	574	395			Falling imports
Rapeseed Meal					9191	9825	94% Self sufficiency

*The EU imported nearly 600,000t of US DDGS in 2004 and 2005. However, imports have decreased significantly, along with all other US maize products due to the slower EU GMO authorisation process..(13, 2009)

5.12.4 Future Trends

- Genetically modified grains are not approved in the EU. (The EU market for DDGS is lost to US producers due to genetically modified grains concerns! (18,2009).
- Expansion of biorefining may produce a glut of some by-products.
- Greater added value products especially fuels, may be developed from the by-products now going into animal feed
- Market expansion is effectively non existent at present.
- Biorefinery by-products may be different in some respects to the same ingredients produced by more conventional means. This will require research into the differences, and re-education of the industry to accept the different products.
- The market will likely change substantially again once a commercial route to ethanol from alternative bio-mass feed-stocks is developed, and less DDGS is produced in biorefineries. (Authors note)
- Bio-refineries must very carefully consider the market concerns when planning the marketing of their by-product streams, and be prepared for resistance from potential consumers.
- If the concerns can be addressed, then the use of bio-refinery effluents and by-products is likely to become a key part of the animal feed business in the EU.

5.12.5 EU Sources of Animal Feed Proteins in 2008 (11, 2010)

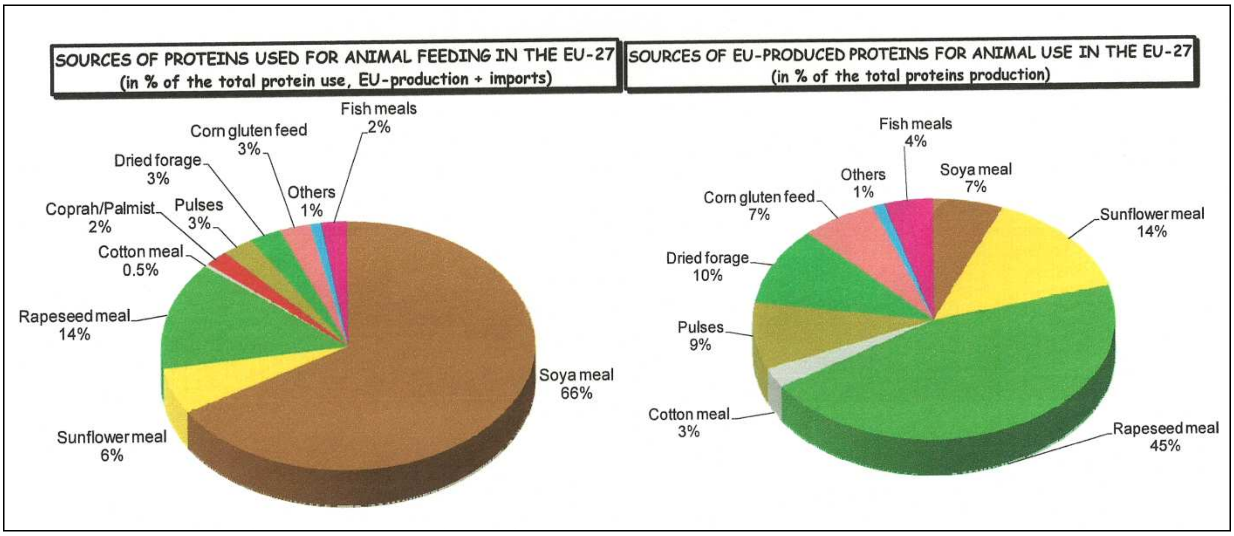


Figure 25 EU Sources of Animal Feed Proteins in 2008 (11, 2010)

5.12.6 References

1. Rapeseed. (http://en.wikipedia.org/wiki/Rapeseed)
2. Glycerol 21 Feb 2007. All About Feed. (http://www.allaboutfeed.net/news/glycerol)
3. Researchers study glycerine as an animal feed. A.K McElroy. July 2007. (http://biodieselmagazine.com/article.jsp)
4. MU study examines effectiveness of glycerines cattle feed. B.C.Daniels 25 May 2007. (http://www.eurekalert.org)
5. Rapeseed meal upgrading. Faudet et al. (http://cat.inist.fr)
6. Genetic Engineering: Feeding the EU's livestock. Dec 7 2006. GMO Compass. (http://www.gmo-compass.org)
7. Rapeseed. Agro Products 2008. (http://www.agriculturalproductsindia.com/fodder/fodder-rapeseed.html)
8. European Union Biofuels Policy and Agriculture – An Overview. March 2006 Randy Schnepf. (http://italy.usembassy.gov/)
9. North British Maize Distillers' Grains. (http://www.kwalternativefeeds.co.uk/resources/North%20British%20Maize%20Distillers%20Grains.pdf)
10. Organic Dairy Production based on Rapeseed, Rapeseed Cake or Cereals as
11. Supplement to Silage ad libitum. Mogensen, L., Ingvartsen, K. L., Kristensen, T., Seested, S., Thamsborg, S.M. (Danish Institute of Agricultural Sciences, Research Centre Foulum,P.O. Box 50, DK-8830 Tjele, Denmark, and Royal Veterinary and
12. Agricultural University, 1870 Frederiksberg C, Denmark). Animal Sci. 54: 81_/93, 2004. # 2004 Taylor & Francis.
13. Feed and Food Statistical Yearbook 2008. European Feed Manufacturers Federation (http://www.fefac.org/statistics.aspx?EntryID=629)
14. Rapeseed . GMO Compass. (http://www.gmo-compass.org)
15. Ethanol By-Products and the Feed Markets (http://www.hgca.coms)
16. DDGS: Supplying Demand. Ethanol Producers Magazine march 2009. (http://www.ethanolproducer.com)
17. Feeding Sugar Beet Byproducts to Cattle. G. Lardy,North Dakota State University, May 2008

5.13 Lignin as a chemical feedstock

There are many potential uses for lignin that will be produced as a large-scale by-product of bio-refining. Unfortunately at the present time (2010) there are only a limited range of technologies available for refining of lignin or its conversion into chemicals. The cost and profitability of proposed conversion processes are largely unknown.

Lignin derived from different biomass sources and isolation processes have significantly differing reactivity, molecular weight distributions, melting points and polyelectrolyte properties. These will be different in turn from the lignin recoverable from pulp mills. Manufacturing of products will thus require some degree of matching the lignin feedstock to its intended final product. The use of lignin as an additive to solid fuels may be one application that can use lignin from a variety of sources. Commercial uses of lignin, other than in fuel, remain largely in the future.

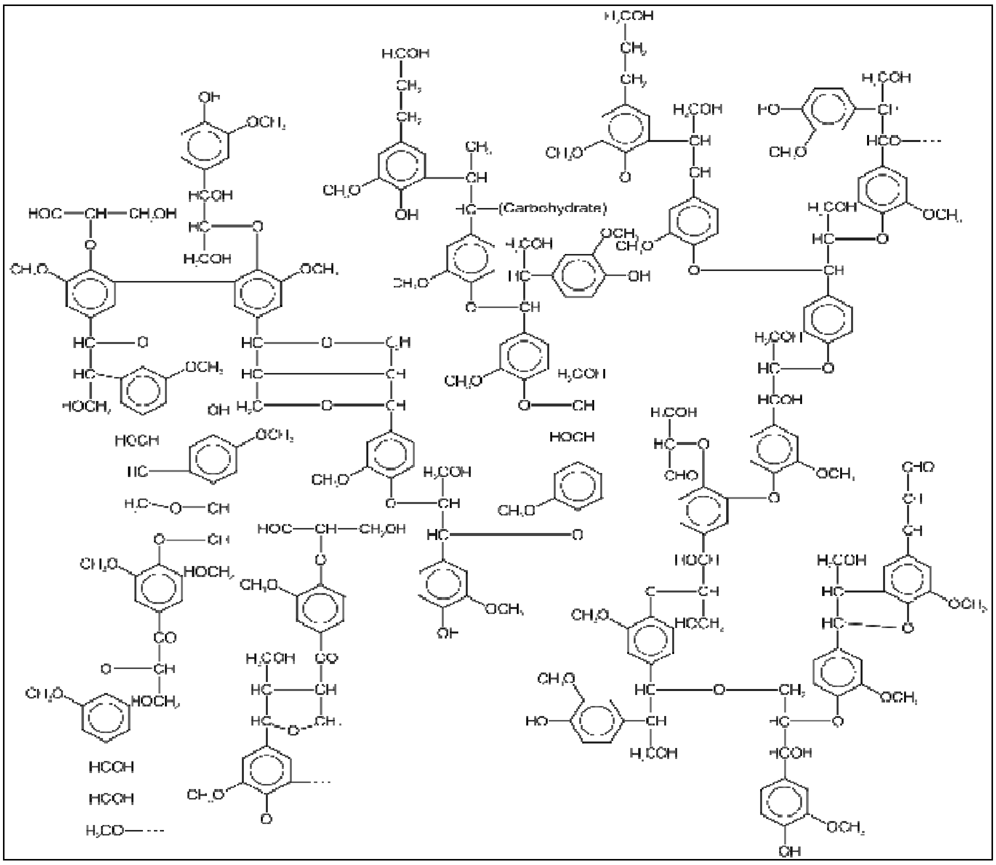
Lignin that is now being recovered mainly as lignosulphonates from conventional chemical pulping operations has established a significant commercial market of about 1 million ton/year in numerous applications. The current lignin market has instability due to the current poor economic health of the chemical pulping companies that produce it. This situation can benefit future biorefineries that will be processing lignocellulosic feedstock. Certain biorefinery pre-treatment technologies, such as organosolv processes, will have the capability to produce a superior form of pure lignin ideal for chemical applications. The marketing of this lignin as a co-product will add substantial revenues and vastly improve the economics of the biorefinery.

The new biorefineries will more than likely be on a considerably smaller scale than world-scale Kraft pulp mills that are now processing 3 000 to 4 000 tonnes of wood on a dry weight basis per day. Consequently biorefineries will be more flexible and better suited to produce and market some of the specialized lignin that will emerge from them.

Past experience from the production of large volumes of Alcell Organosolv pure lignin shows that the availability of commercial quantities of this improved lignin will stimulate sizeable new market opportunities that do not presently exist for lignin from the chemical pulping industry. Some of these new markets are already clearly visible. The need now is the commercial-scale production of the lignin to service these opportunities. (1)

5.13.1 Technical Data

Product Names	Many trade names (3,6) (See examples in section 2 below)
Specifications	Many trade specifications depending on product.
Product Description	Lignin is currently being produced and sold mainly as lignosulphates and in other modified forms depending on its production process and end use.
Standards	None Found
Normal industrial quality purity	Dependent on manufacturer specifications See also Table 1 below
Chemical and Physical Properties	Lignin is an amorphous polymer. It acts as the essential glue that gives plants their structural integrity. Of the three major natural polymers that make up ordinary plants—cellulose, lignin and hemicellulose—lignin is the second most abundant and the only biomass constituent based on aromatic units. Lignin structure varies depending on source material. Lignins are the second most abundant organic chemical on earth, a rich source of aromatics, as indicated in Fig 1 that indicates an overall structure for a lignin molecule. (2)



Characterization of Lignin Structure (2)
(See (2) for details of structure of lignins derived from different sources.)

Comparative Properties of Commercial Lignins (1) (See also Table 2, below)

Property	Softwood Kraft Lignin	Softwood Ligno-sulphonate	SodaLignin from Straw
Carbon %	66	53	56
Hydrogen %	5.9	5.4	7.5
Methoxy %	14	12.5	N/A
Ash %	3	2.5	<2.5
Wood sugars	Low	Up to 50%	2.5-3.5
Sulfur %	1.6	6-7.9	N/A
Water solubility	Low	Very high	Very low
Tg ℃	140	Not detected	150
Softening pt. ℃	Not detected	Not detected	N/A
Mol. wt.Mn	2000 400–150000	400-150000	2300-2900

5.13.2 Uses, Manufacturers and Market Location

End Uses	Product	Application	Secondary	Volume
	Biorefinery Organosolv lignin from hardwoods (Dry powder)	Phenol-formaldehyde (PF) resins (Up to 35% substitution of PF resins)	OSB (Oriented Strand Board)	USA 550,000 t/yr World 1.1 million t/yr
	Dry powder and liquid types of lignin	Panelboard adhesives (Up to 55% substitution of isocyanate resins)	Exterior grade wood panels	
	Liquid types of		Plywood	

	lignin			
		Thermoset resins for moulded products (substitute for PF resins)	Electrical circuit boxes Circuit breakers Pot holders and handles	USA 55,000 t/yr PF resins World 200,000 t/yr PF resins
		Friction materials Lignin can substitute for a significant amount of the PF resins used.	Brake pads Brake shoes	USA 27000 t/yr PF resins World 120,000 t/yr PF resins
		Foundry Resins	Delicate sand casting applications	USA 55-60,000 t/yr World 150,000 t/yr
		Insulation materials	Glass fibre Phenolic foams Mineral wool Waste fibre insulation	USA 110,000 t/yr phenolic resins used
		Decorative Laminates		USA 100,000 t/yr PF resins World 300,000 t/yr PF resins
		Panel and Door binders	Laminated and veneered doors Moulded structural panels	
	Dry powder	Rubber Processing	Phenolic pacifiers (Lignin 50% replacement for PF resins) Reinforcers and Antioxidant Lignin acted as a multi-functional additive to replace two additives normally used	
		Anti-oxidants	Grease Rubber Animal vitamin supplements	BHT US$3/kg (Alcell lignin found effective replacement for BHT in grease, rubber and animal vitamin supplements) Added as anti-oxidant to grease 1-10% (Grease anti-oxidants market in late 1990's 3million kg/yr value US$ 10 million
	Water Soluble Derivatized Lign-	Surfactants Dispersants		

ins	Emulsifiers		
Lignosulphonates Sulphonated bio-refinery lignins	Concrete admix-tures		
Lignosulphonates Sulphonated bio-refinery lignins	Dye dispersants		25000 ton-nes/yr
	Asphalt emulsifiers		World asphalt production >1*billion (US) tonnes/yr (Emulsifiers 1-2% by weight)
Lignosulphonates	Existing Agricul-tural Applications New agricultural applications	Feed pellet bind-ers Dispersants for insecticides, fungi-cides, herbicides Dust suppressant on unpaved roads Enhanced feed efficiency in calves Antidiarretic in cat-tle Antioxidant in vi-tamin supplements Slow release ma-trix for fertilizers etc Improved rumen metabolism Reduced ammonia concentrations in broiler (chickens) operations.	US 50,000 ton-nes/yr surfac-tants (5% lignin based) World 18-20,000 t/yr lig-nin based her-bicide surfac-tants
Organosolv Lign-ins	New and emerging markets	Printed circuit boards Animal Health Treatment of Gas-tro-intestinal prob-lems especially in young animals Replacement for antibiotics	

		Animal Feed supplements	
Organosolv Lignins	Potential very large future market	Carbon fibres	Current worldwide demand 28,000 tonnes/yr at a cost of US$25/kg

Long-Term Conversion Technologies Required for Conversion of Lignin to Aromatics

Aromatic	US Demand Millions of t/y	Lignin feedstock required Theoretical Millions of t/y	Lignin feedstock required Current Technology Millions of t/y
BTX (Benzene, Toluene, Xylene)	20.6	42.3	423
Phenol	2.3	4.6	36.4
Terephthalic acid	5.0	5.9	59.1
Totals	27.9	*52.8	*518.5

*current world production of black liquor solids (primarily Lignins) is 170 million t/y (7)

Examples from the ARBO range of lignin products, mainly lignosulphates, produced by Tenbec Inc. in Canada.(9)

Binder	
Clay brick	ARBO S01, S07, A02, T5
Refractory ceramic tiles	ARBO S01, S07, T5, C12
Carbon black	ARBO SA02, A02, S01, T6P, N75, N9
Animal feed	Canadian Pelstik, Canadian Pelstik Mag, US Pelstik, Superbind, Superbind Mag, T5, AVBIND
Textile dyestuffs	ARBO S01, N9, N18, DN14, DN19
Pesticides/fertilizer	ARBO S01, A02, T5, C12, T11B, C14, N18, DN14, DN19, K18
Mineral pelletizing	ARBO A02, SA02, S01, T5, N9, AVBIND, N18
Fibreglass resins and emulsions	ARBO A02, S01, S05, N9, N18
Steel briquetting	ARBO S01, T5, N9, AVBIND, N18
Dust suppressant	TDS

Dispersant	
Concrete admixtures	ARBO S01, S07, C01, N9, K9, C14, N18, K18
Gypsum and wallboard additives	ARBO S01, S05, S07, T5, C12, N14
Clay brick	ARBO S01, S07, A02, T5
Refractory ceramic tiles	ARBO S01, S07, T5, C12
Textile dyestuffs	ARBO S01, S07, N9, N18, DN14, DN19
Wax/water emulsions	ARBO A02, S05, S01, S07
Ore separation	ARBO A02, S01, C14, N18
Coal gasification/dispersion	ARBO A02, T5, AVBIND
Molded walls	ARBO Aveplast
Corrugating medium	ARBO NT6, Lignex
Active coal	ARBO T5N
Tanning	ARBO T11B, Tartan

<table>
<tr><td></td><td>
<table>
<tr><td colspan="2">Chelating Agent</td></tr>
<tr><td>Site remediation/Water treatment</td><td>ARBO A02, N18, DN19</td></tr>
<tr><td>Micronutrients</td><td>ARBO S01, T5, K9, N9, C12, T11B, C14, N18, DN14, DN19, K18</td></tr>
</table>
Borregaard LignoTech (Norway & USA) produce lignin sulphonates for use in specialized cements used in oil well drilling and completion, as well as many other uses similar to those made by Tenbec. (1)
</td></tr>
<tr><td>Manufacturers</td><td>
Lignosulphonates (2)
Tenbec Inc. (ARBO Products) Canada (570,000 tonnes/year)
Borregaard LignoTech Norway, USA, S Africa (400,000 t/yr)
MeadWestvaco, USA
Fraser Papers, USA (1)
Nippon Papers, Japan (1)
Unsulphonated Kraft Lignin (2)
MeadWestvaco USA
Sulphur Free Lignin (1)
Granit S.A (10,000 tonnes/year)
Pure Lignin
Lignotech Inc. Canada (Pilot plant operations at present)
Pure lignin products have been produced by Alcell Technology developed by Repap in Canada for pulping operations. This technology is now owned by Lignol Energy Corporation of Vancouver, BC, Canada, who are working to commercialize the process in an application that will produce ethanol from the cellulose fraction of the biomass feedstock and pure lignin.
Potential increases in revenue from lignin processing developed from data in (10)
<table>
<tr><td>Lignin Product</td><td>Power Generation</td><td>Syngas alcohols</td><td>Aromatic Chemicals (BTX – Benzene, Toluene, Xylene and derivatives)</td><td>BTX + Syngas Alcohols</td><td>Carbon Fibre + Syngas alcohols</td></tr>
<tr><td>Revenue Increase</td><td>Base Case</td><td>208%</td><td>222%</td><td>378%</td><td>4%</td></tr>
<tr><td>Estimated Schedule</td><td>Practiced now on a large scale – Black Liquor firing on pulp mills</td><td>3-10 years</td><td>20 years+</td><td>20 yrs+</td><td>20yrs+</td></tr>
</table>
</td></tr>
<tr><td>Suppliers (6)</td><td>Borregaard Lignotech Norway, USA and worldwide
Vyborg Cellulose (Via Borregaard) (4)
ARBO Products (Tenbec Inc. Canada and worldwide)
Corsicana Technologies Inc., USA
Kemcare (www.kemcare.com UK)
Merck Chemicals
Jürgen Schmidt Chemievertretung GmbH
Smart Papers LLC USA
EnviroTech Services, USA
Taylor Chemical, USA
Custom Agricultural Formulators Inc. USA</td></tr>
</table>

	Westway Terminal USA
Market overview	The kraft pulping industry currently produces about 70 million tonnes/year of lignin, and more than 99% is burned in chemical recovery boilers. (1) At present the lignin market is about 1 million tonnes/year, of mainly lignosulphates . No more than 100,000 tonnes/year of kraft lignin is marketed for its chemical value worldwide, and a significant amount of this is converted into water-soluble sulphonated lignin that competes with lignosulphates from the sulphite pulping industry. Two pulp companies dominate current manufacture of lignin products (as lignosulphonates) (1), Borregaard Ligno Tech (Norway & USA) , Tenbec (Canada) ,Granit S.A. of Switzerland makes on a smaller scale (10,000 tonnes/year) sulphur-free lignin from soda pulping operations in France and India for higher value applications. (1). Pure lignin is being made on a pilot scale by Lignotech Canada. The company is having difficulties in funding a commercial plant that will produce ethanol and lignin. (8)
Market Location	USA, Norway, Canada, Japan, Europe Likely to be worldwide when lignin production becomes viable and stable.
Market Volume	US$600 million (2) Capacity 975 million tonnes/year (2)
Market Price	No data obtained for pure lignin Lignosulphonates Process Heat and Power : Scandinavian study €15-25/MWh. (5) USA US$6/million BTU (2)
Market Price variability	No published data found

5.13.3 Future Trends

The dominant force in lignin production is the pulp industry, that produces lignins from forest products. As outlined above, it is only very recently that the technology to make alternative products is emerging on a commercial scale. Bio-refineries established to operate on alternative feed-stocks, many from agricultural sources, will produce a variety of lignins with properties different to those from pulping.

It is anticipated that a market for these lignins in fuels, especially in fuel pellets is available now. Further technical and market development of chemical products from these lignins is likely to take in excess of twenty years. References 1 and 2 provide an excellent overview of products that could be developed from lignin and lignosulphonates, also the technical and economic barriers to their establishment in the market.

Some of the products have already been developed, but to date the production of lignins and lignosulphates has been partly unreliable. Until now they have been derived from wood pulping operations whose primary markets of paper type products have declined, with mill closures.

The potential value of lignin in new products and to offset the use of petroleum based materials has now being recognized. However, considerable research, in some cases fundamental research, and development work is required to develop economical lignin production, new products and markets.

A summary of the work required to develop new products from lignosulphates is attached in Appendix 1.

New environmentally friendly chemical pulping technology is being developed using organic solvents (organosolv pulping) that will produce better quality pure lignin, for example:

- Alcell – ethanol
- Acetsolv – acetic acid
- Formacell – Formic acid and phenol
- Organocell – methanol

The Alcell process is the most commercially advanced, developed by Repap Industries in New Brunswick, Canada during 1987-97. It produces a natural "organosolv" lignin. Unfortunately Repap collapsed in 1997. the technology was acquired by Lignol Innovations Corporation (Now Lignol Energy Corp.) of Vancouver, BC, Canada who plan to build a biorefinery technology to produce ethanol and very pure lignin.

Figure 14.2 Some Potential Lignin Products (1)

Some commercial and pre-commercial products made with organosolv lignin from hardwoods. On the left is an automobile brake pad, next to a pot handle made from a molding compound. To the rear are sections of oriented strand board (OSB) and other panel boards, while on the right is a section of rubber belting. In the middle is a sample of the original organosolv lignin powder, with a granulated version to its left.

5.13.4 References

1. B.Kamm, P.R.Gruber, M.Kamm, Industrial Lignin Production and Applications. E. Kendall Pye. Extract from Biorefineries –Industrial Processes and Products. Ed. pub Wiley–VCH 2006
2. J.F Holliday,J.F White, JJ Bozell, D Johnson ,Top Value-Added Chemicals from Biomass. Volume 11-Results of Screening for Potential Candidates from Biorefinery Lignin. Pacific Northwest National Laboratory. Oct 2007
3. Borregaard Ligno Tech (www.lignotech.com)
4. Pair Reach Lignin Products Agreement (http://www.icis.com/Articles/2006/04/28/2013753/pair-reach-lignin-products-agreement.html)
5. Exporting lignin or power from heat-integrated kfat pulp mill:A techno-economic comparison. Nordic Pulp and Paper Research Journal,21 (4) s.476-484. (http://publications.lib.chalmers.se/cpl/record/index.xsql?pubid=)
6. Lignin Sulphonate Suppliers Worldwide (http://www.icis.com/Search/ProductNumber/115009/WorldWide)

7. Michael Rushton ,Cellulosic Ethanol – The Sustainable Fuel, TAPPI International Conference on Renewable Energy, May 2007 (http://www.tappi.org/content/Events/07renew/07ren06.pdf)
8. Lignol,Suncor Suspend plans for Ethanol Distillery (http://www.bloomberg.com/apps/news?pid=20601082&sid=aLagYAw4cZcs)
9. ARBO Lignosulphonates (Tenbec) Products (www.arbo.ca)IEA Bioenergy Task 40 Global Wood Pellets Markets and Industry: Policy Drivers, Market Status and Raw Material Potential November 2007 (http://www.canbio.ca/documents/publications/ieatask40pelletandrawmaterialstudynov2007final.pdf)

5.13.5 Appendix 1 – Uses of lignin

The extended use of lignin is in its early stages, and the mid and long-term uses will depend on the results of fundamental research. Opportunities that arise from utilizing lignin fit into three categories:

- Power, fuel and syngas (generally current and near-term (3-10years) opportunities)
- Macromolecules (generally medium-term (5-20 years) opportunities)
- Aromatics and miscellaneous monomers (long-term (>10years) opportunities)" (2, 2007)

Table 1 – Products Potentially Derived from Lignin Conversions

Lignin Derived Product	Current Technology Status from Lignin*	Expected Difficulty from Lignin*	Market Volume*	Market Value†	Market Risk*	Utility as Building Block*	Expected from Lignin as Mixture?
Process Heat & Power	H	L		$6/10^6$ Btu	L	NA	NA
Syngas	H	L‡	H	Variable	L	H	NA
Syngas Products							
Methanol/Dimethyl ether (DME)	H	L	H	$0.80/gal	L	H or Fuel	Y
Ethanol/mixed alcohols	L	H	H	$1 - $3.5/gal	L - M	H or Fuel	Y
Fischer Tropsch Liquids	H	L	H	$1.5 - $2/gal	L - M	L	Y
Mixed Liquid Fuels	M	M	H	$1.3 - $2/gal	L	L	Y
By-product C1 to C7 gases, hydrocarbons, or oxygenates	L	M - H or as consequence of other transformations	NA	variable	L	Perhaps or use for reforming/ gasification	Y
Hydrocarbons							
BTX and Higher Alkylates	L - M	M		$2/gal	L	H	Y
Cyclohexane	L	M	H	$2.20/gal	L	M	Y
Styrenes	L	M-H	H	$0.70/lb	?	?	?
Biphenyls	L	H	L - M	?	?	L	Y?
Phenols							
Phenol	L-M	M	H	$0.55 - $0.65/lb	L	H	N
Substituted Phenols			M	$0.70 - $2.00/lb	M	M	Y
Catchols, cresols, resorcinols	L	H		>$1.5/lb	?	M	Y
Eugenol	L	H	?	M-H	?	?	Y

Table 1 – Products Potentially Reachable from Lignin Conversions (Continued)

Lignin Derived Product	Current Technology Status from Lignin*	Expected Difficulty from Lignin*	Market Volume*	Market Value†	Market Risk*	Utility as Building Block*	Expected from Lignin as Mixture?
Syringols	L	H	?	M-H	?	?	Y
Coniferols	L	H	?	M-H	?	?	Y
Guaiacols	L	H	?	M-H	?	?	Y
Oxidized Products							
Vanillin	H	L	L	$5.90/lb	H	L	N
Vanilic Acid	M	M	?	?	H	?	?
DMSO	H	L	M	<$1/lb	H	L	N
Aromatic Acids	L	H	H	$0.40 - $0.50/lb	L	H	Y
Aliphatic Acids	L	H	H	$0.45 - $0.65/lb	L	M-H	Y
Syringaldhyde and Aldehydes	L	H	?	?	M-H	M	Y
Quinones	L	H	L-M	> $1/lb	?	L	?
Cyclohexanol/al	L	H	H	> $0.75/lb	L	H	Y
Beta keto adipate			?	?	H	M	?
Macromolecuels							
Carbon Fiber	L - M	M - H	H	ACC Target *= $3 - $5/lb	M	L	N
Polyelectrolites	L - H	M	M	$1.5 - $3/lb	M-L	M	Y
Polymer Alloys	L - M	M	?	$1 - $2/lb	M	NA	Y
Fillers, Polymer Extender	M	H	M	< $1/lb	M - H	NA	Y
Substituted Lignins							
Carbonylated	L	H	?	?	M - H	?	Y
Ethoxylated	L	M	L	$1.50 – 2.50	M - H	?	Y
Carboxylated	L	M	L	$1.50 – 2.50	M - H	?	Y
Epoxidized	L	H	?	?	M - H	?	Y

5.14 1, 3-Propanediol (Trimethylene glycol)

The market for 1, 3-propanediol (PDO), (Trimethylene Glycol) is currently over 130,000 tons per year and is growing rapidly. PDO is a component of industrial polyesters such as Dupont's Sorona and CDP Natureworks or Shell Chemical's Corterra™. Markets for the polyester include thermoplastics, textiles, carpets, and upholstery. (4)

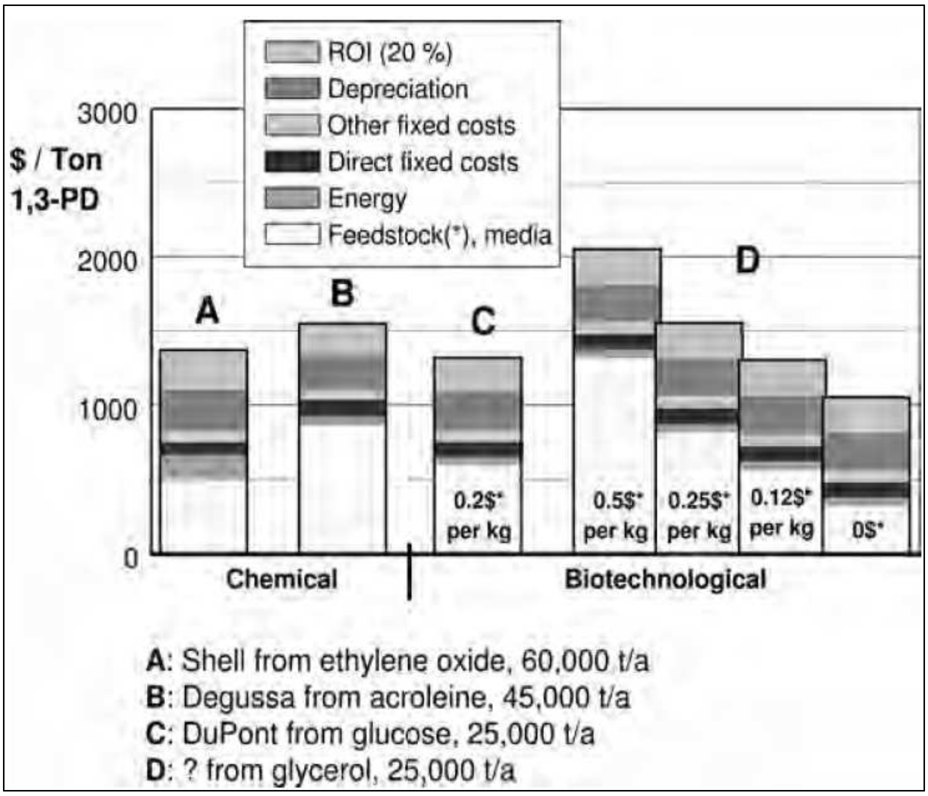
In recent years technological breakthroughs in the preparation of 1,3-propanediol have resulted in lower market prices, currently in the 1500 USD to 2000 USD per ton range (3). This in turn has created an increasing demand from textile, fabric and carpet manufacturers for PDO based polymers. (4)

5.14.1 Technical Data (5)

Product Names	1,3-propanediol Trimethylene Glycol
CAS No	574-63-2
Form	Colourless, odourless, viscous oil
Normal industrial quality purity	99.5% New technology 99.8% (Ref 6)
Chemical and Physical Properties (2)	Specific gravity at 20℃ 1.038 Boiling point 212 ℃ Melting Point -28℃
Formula	$CH_2(CH_2OH)_2$

5.14.2 Uses, Manufacturers and Market Location

End Uses	**Major use** 1, 3-propanediol as a monomer for novel polyester and biodegradable plastics,

	New polyester, 'Corterra™ PTT' based on terephthalic acid and 1,3-propanediol (Shell Chemical Company, Press release, 1995). This polymer, poly(trimethylene terephthalate) (PTT) is an aromatic polyester made by the polycondensation. (1) **Other uses** Application in making transparent ballistic polymer which is a life-saving technology and the war fighter is the primary beneficiary. Ballistic polymer is based on a family of transparent materials whose composition can be tailored to enhance properties such as transparency, impact resistance, and UV stability. Biocide in preventing bio fouling in air conditioner and humidifier system and as a tranquilizer (1)
Manufacturers	Shell, Degussa, Dupont, Metabolic Explorer
Suppliers	More than hundred suppliers around the world (2)
Market overview	The current commercial production of 1, 3 propanediol is from three main raw materials. Currently only Metabolic Explorer has produced 1,3 propanediol (99.5% pure) from glycerol on industrial pilot scale  Production costs for 1,3 propanediol from different raw material sources (3)
Market Location	USA, Europe
Market Volume	130,000 tons per year (1)
Market Price	1500 USD to 2000 USD per ton
Market Price variability	As the production of 1,3 propanediol is commercialized using glycerol as raw material the prices may go down significantly due to the availability of cheap glycerol in the market

5.14.3 Market Volume Future Trends

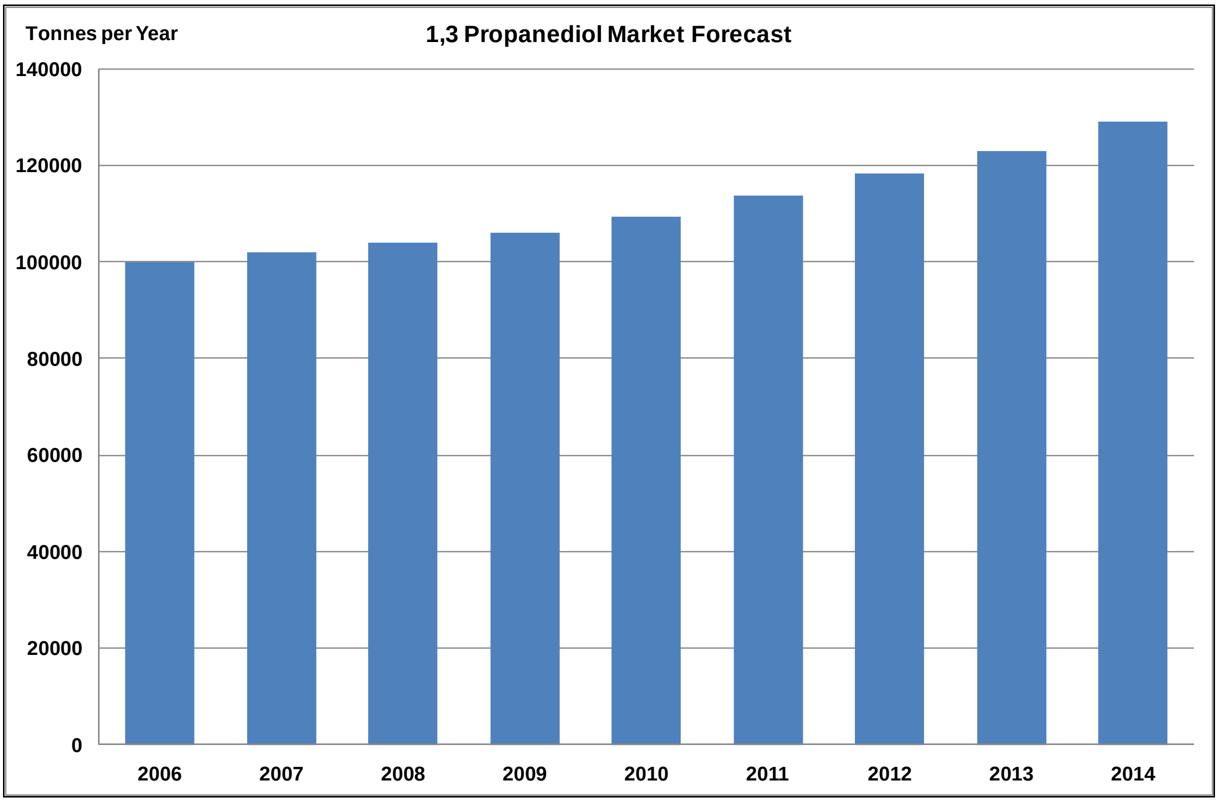


Figure 26 World 1,3 Propanediol Market Volume Trends. (1,3,6)

5.14.4 Producers

Name	Location	Process	Volume Produced (ton per year)	Comments	Ref
Shell		hydroformylation of ethylene oxide	60,000	Petrochemical feed	3,6
Dupont/Degussa		Glucose fermentation/Catlytic hydrogenation of acrolein	70,000	Glucose Feed	3,6
Metabolic Explorer		Glycerol fermentation	1000	Glycerol Feed	3, 6

5.14.5 Applications

Chemical Name	Direct Use	Intermediate	Other	Potential Future
1,3,propanediol (Trimethylene glycol)	Tranqulizer	Monomer for polyester and biodegradable plastics (1)	Industrial biocide in preventing bio fouling in airconditioner and humidifier system	Improve properties for solvents, adhesives, laminates resins and cosmetics

5.14.6 Future Trends

The availability of cheap glycerol from biodiesel production units is viewed as the potential feedstock for the production of 1,3 propanediol. The technology of producing 1,3 propanediol form biodiesel glycerol is currently is only demonstrated by few companies. The current market growth rate is at 2% for 1,3 propanediol and is expected to increase by 4% to 5% end of 2012

5.14.7 References

1. R.K. Saxena ., Pinki Anand 1, Saurabh Saran 1, Jasmine Isar Microbial production of 1,3-propanediol: Recent developments and emerging opportunities, Biotechnology Advances, Elsevier
2. http://www.chemexper.com/index.shtml?main=http://www.chemexper.com/search/cas/504-63-2.html
3. Brigit Kamm, Patrick R Gruber, Michael Kamm Biorefineries Industrial Processes and Products , page 394, 2006, WILEY-VCH Verlag GmbH
4. Kraus GA, "Synthetic Methods for the Preparation of 1,3- Propanediol", 2008, WILEY-VCH Verlag GmbH
5. http://en.wikipedia.org/wiki/1,3-Propanediol

5.15 Carbon Dioxide in emissions

The overall carbon market continued to grow in 2008, reaching a total value transacted of about US$126 billion (€86 billion) at the end of the year, double its 2007 value. Approximately US$92 billion (€63 billion) of this overall value is accounted for by transactions of allowances and derivatives under the EU Emissions Trading Scheme (EU ETS) for compliance, risk management, arbitrage, raising cash and profit-taking purposes.(1)

The second largest segment of the carbon market was the secondary market for Certified Emission Reductions (sCERs), which is a financial market with spot, futures and options transactions in excess of US$26 billion, or €18 billion, representing a five-fold increase in both value and volume over 2007. These trades do not directly give rise to emission reductions unlike transactions in the primary market. (1)

5.15.1 Technical Data (5)

Product Names	Green house gases
CAS No EINECS No	NA
Form	Gaseous
Normal industrial quality purity	NA
Chemical and Physical Properties (2)	NA
Formula	NA
Shelf life	NA
MSDS	NA

5.15.2 Uses, Manufacturers and Market Location

End Uses	
Manufacturers	Government Participation: Allowances by EU ETS, Assigned Amount Units (AAU), Regional Greenhouse Gas Initiative (RGGI), New South Wales, Chicago Climate (1) Private Participation: Combustion Plants, Oil refineries, Glass Fibre Industries, Metal Ore Installations, Cement Factories, Pulp and Paper Industry Chemical Industry etc. (1)
Suppliers	Government Participation: Allowances by EU ETS, Assigned Amount Units (AAU), Regional Greenhouse Gas Initiative (RGGI), New South Wales, Chicago Climate (1) Private Participation: Combustion Plants, Oil refineries, Glass Fibre Industries, Metal Ore Installations, Cement Factories, Pulp and Paper Industry (1)

Market over-view

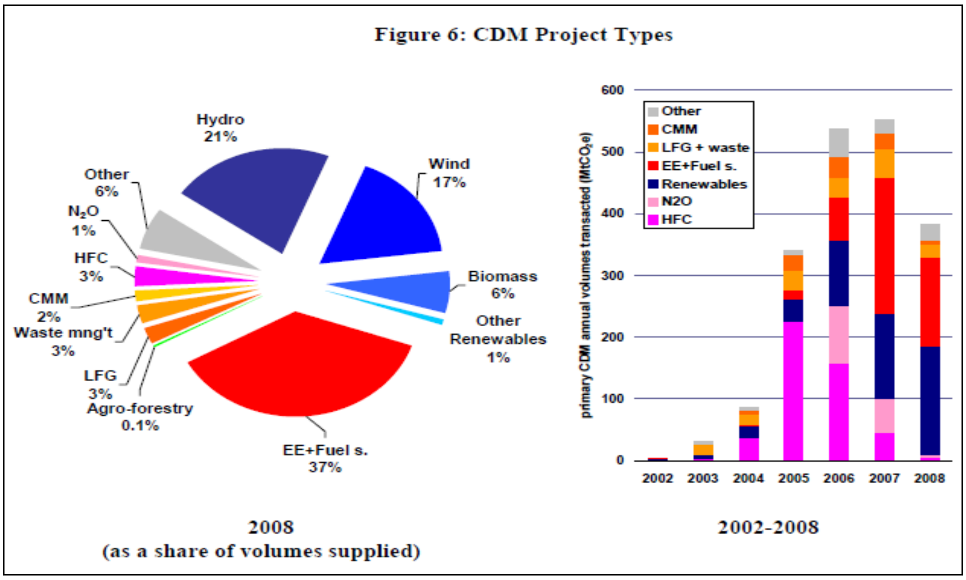
WORLDWIDE CARBON MARKET

Project based Transactions (Primary and Secondary CDM) (1)

Table 4: Annual Volumes and Values (2007-08) for Project-based Transactions

	2007		2008	
	Volume ($MtCO_2e$)	Value (MUS$)	Volume ($MtCO_2e$)	Value (MUS$)
Primary CDM	552	7,433	389	6,519
JI	41	499	20	294
Voluntary market	43	263	54	397
Sub-total	636	8,195	463	7,210
Secondary CDM	240	5,451	1,072	26,277
TOTAL	**876**	**13,646**	**1,535**	**33,487**

Primary CDM projects type (1)



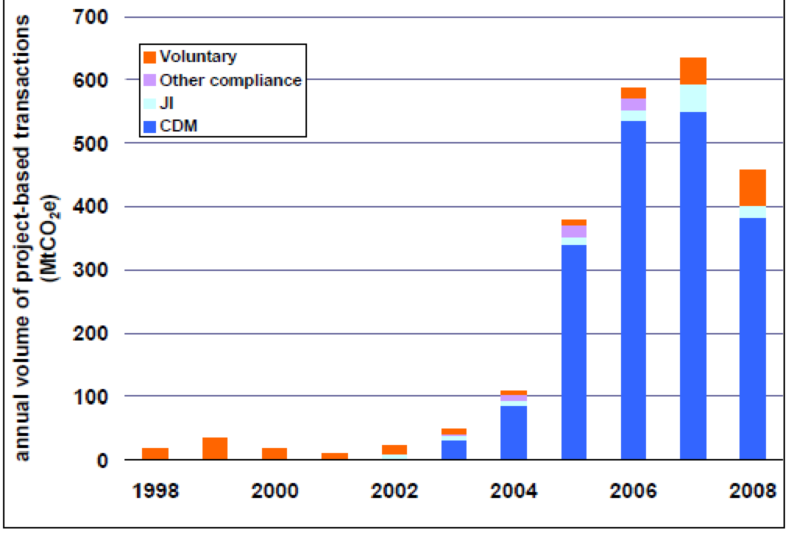
Type of Primary CDM Projects

Joint Implementation (JI)
(JI) is a mechanism provided by Article 6 of the Kyoto Protocol, whereby a country included in Annex I of the UNFCCC and the Kyoto Protocol may acquire Emission Reduction Units when it helps to finance projects that reduce net emissions in another industrialized country (including countries with economies in transition).

Secondary CDM
Secondary CER (sCER) contracts have become more standardized, prices are more transparent and trading is significantly more liquid. More than one billion sCERs were traded on various exchanges and platforms in 200878 for a value of US$26.3 billion (€18.0 billion), representing the largest growth rate of all segments in the carbon market with more than a 350% increase in traded volumes and values over the previous year. These trades do not directly give rise to emission reductions unlike transactions in the primary market.

Project based transactions (1)

Figure 2: Annual Volumes ($MtCO_2e$) of Project-Based Emission Reductions Transactions (vintage up to 2012)



Project based Transactions

Allocation based Markets

Table 2: Annual Volumes and Values of Transactions on the Main Allowances Markets (2007-08)

	2007		2008	
	Volume ($MtCO_2e$)	Value (MUS$)	Volume ($MtCO_2e$)	Value (MUS$)
EU ETS	2,060	49,065	3,093	91,910
New South Wales	25	224	31	183
Chicago Climate Exchange	23	72	69	309
RGGI	Na	na	65	246
AAUs	Na	na	18	211
TOTAL	**2,108**	**49,361**	**3,276**	**92,859**

European Union Emissions Trading Scheme (EU ETS)

European Union Emission Trading Scheme (EU ETS): The EU ETS was launched on January 1, 2005 as the cornerstone of EU climate policy towards its Kyoto commitment and beyond. It regulates emissions from energy-intensive installations. Over 2008-12, emissions are capped on average at 6% below 2005 levels, further decreasing to 21% by 2020, or further in the event of a satisfactory international climate change agreement.

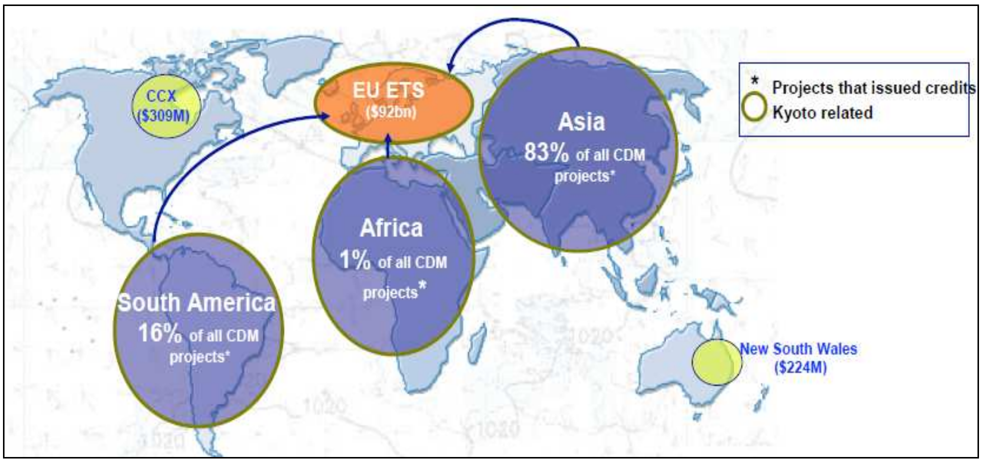
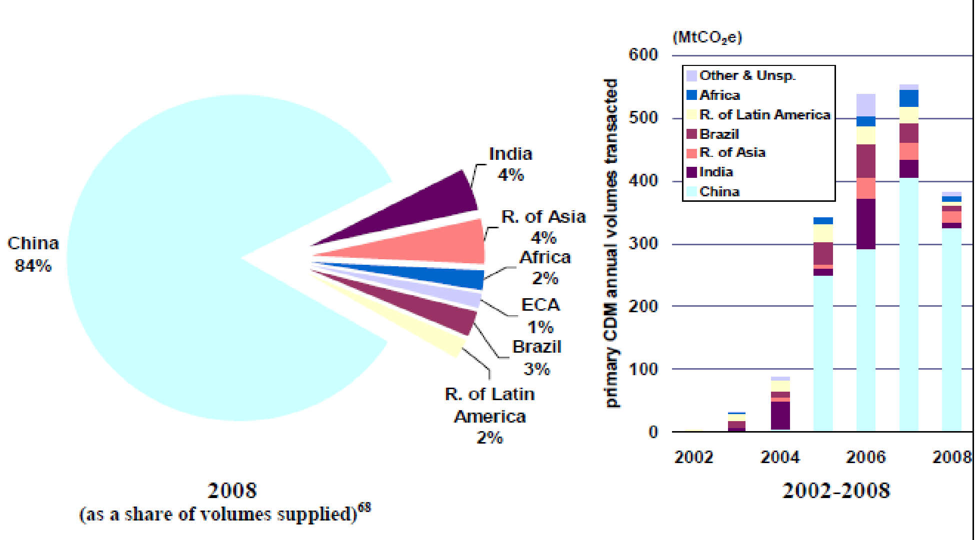
New South Wales

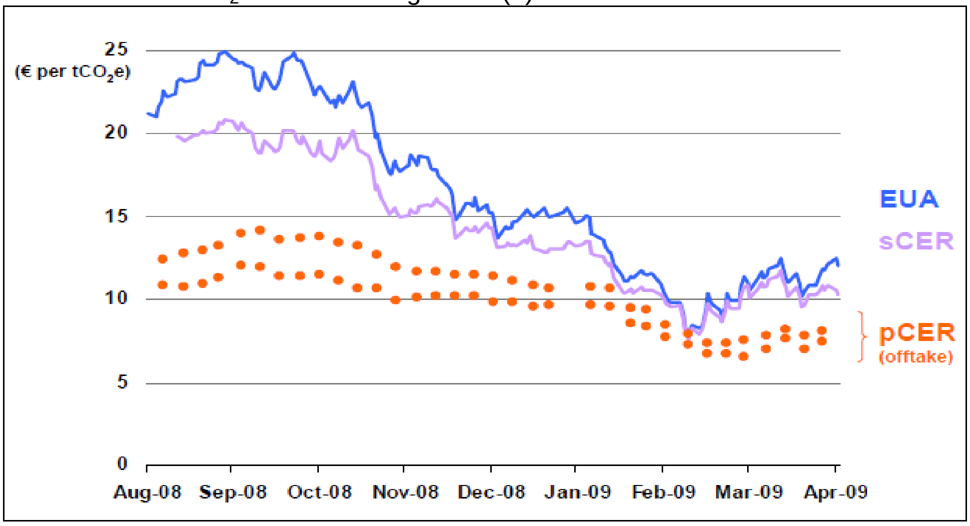
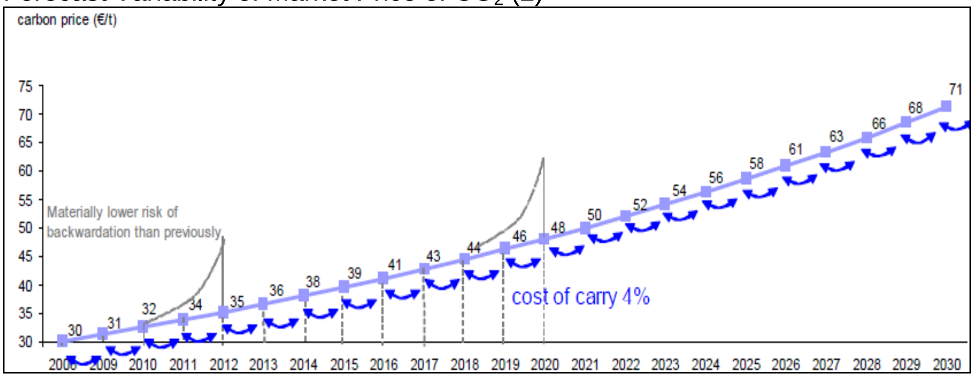
New South Wales Greenhouse Gas Abatement Scheme (NSW GGAS): Operational since 1st January 2003 (to last at least until 2012), the NSW Greenhouse Gas Abatement Scheme aims at reducing GHG emissions from the power sector. It is expected to end upon the commencement of the CPRS.

Chicago Climate Exchange (CCX)

Members to the Chicago Climate Exchange make a voluntary but legally binding commitment to reduce GHG emissions in 2010 by 6% below a baseline period of 1998-200

Regional Greenhouse Gas Initiative (RGGI)

	RGGI targets CO2 emissions from power sector in ten U.S. Northeast and Mid-Atlantic states, with a target of 10% below current levels by 2020. **Assigned Amount Unit (AAU)** Parties are issued AAUs up to the level of their assigned amount, corresponding to the quantity of greenhouse gases they can release in accordance with the Kyoto Protocol (Art.3), during the first commitment period of that protocol (2008-12). AAUs equal one tCO2e.
Market Location	Global Carbon Market Location (2)  Location of CDM Projects (1) **Figure 4: Location of CDM Projects** 
Market Volume	4,811 million tonnes of CO_2 equivalent (1)

Market Price (1)	Market Price of CO_2 in different segments (1) 
Market Price variability	Forecast Variability of Market Price of CO_2 (2) 

5.15.3 Market Volume Future Trends

5.15.3.1 <u>Proposed 2020 targets by major developed countries (1)</u>

Table 7: Proposed 2020 targets by Major Developed Countries

Country or region	2020 target	2020 target (ref: 1990 emissions)	2020 target (ref: 2005 emissions)
EU	20% below 1990 levels, scaling up to 30% if international agreement	-20% to -30%	-14% to -25%
Australia	5% below 1990 levels, scaling up to 15%, possibly 25%, if international agreement	+13% to +1%, possibly -11%	-11% to -21%, possibly -30%
Canada	20 % below 2006 levels	-3%	-22%
US	17% below 2005 levels	-4%	-17%
Overall ambition		**-10% to -15%**	**-16% to -21%**

Note: 1990 and 2005 emissions GHGs excluding LULUCF, Source: UNFCCC

5.15.3.2 <u>Market Revenue Forecasts (3)</u>

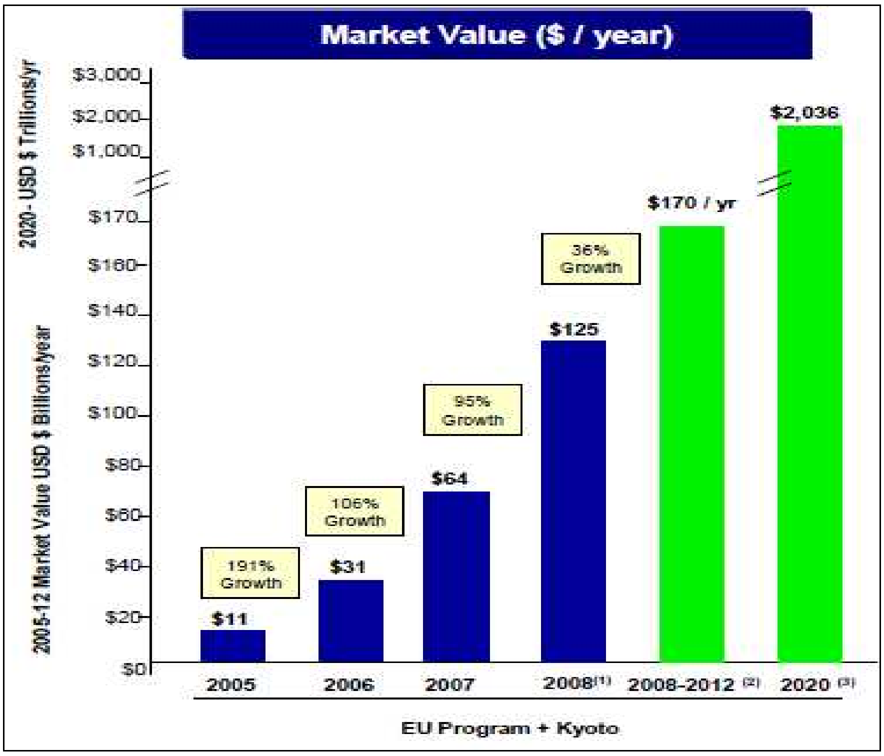


Figure 27 Market Revenue Forecast for Carbon Market

5.15.4 Producers

Name	Location	Process	Volume Produced	Comments
Almost all industries	World	All	See above	None

5.15.5 Applications

Chemical Name	Direct Use	Intermediate	Other	Potential Future
Carbon dioxide	None	None	None	None

5.15.6 Future Trends

Forecast of Supply Demand Analysis (4)

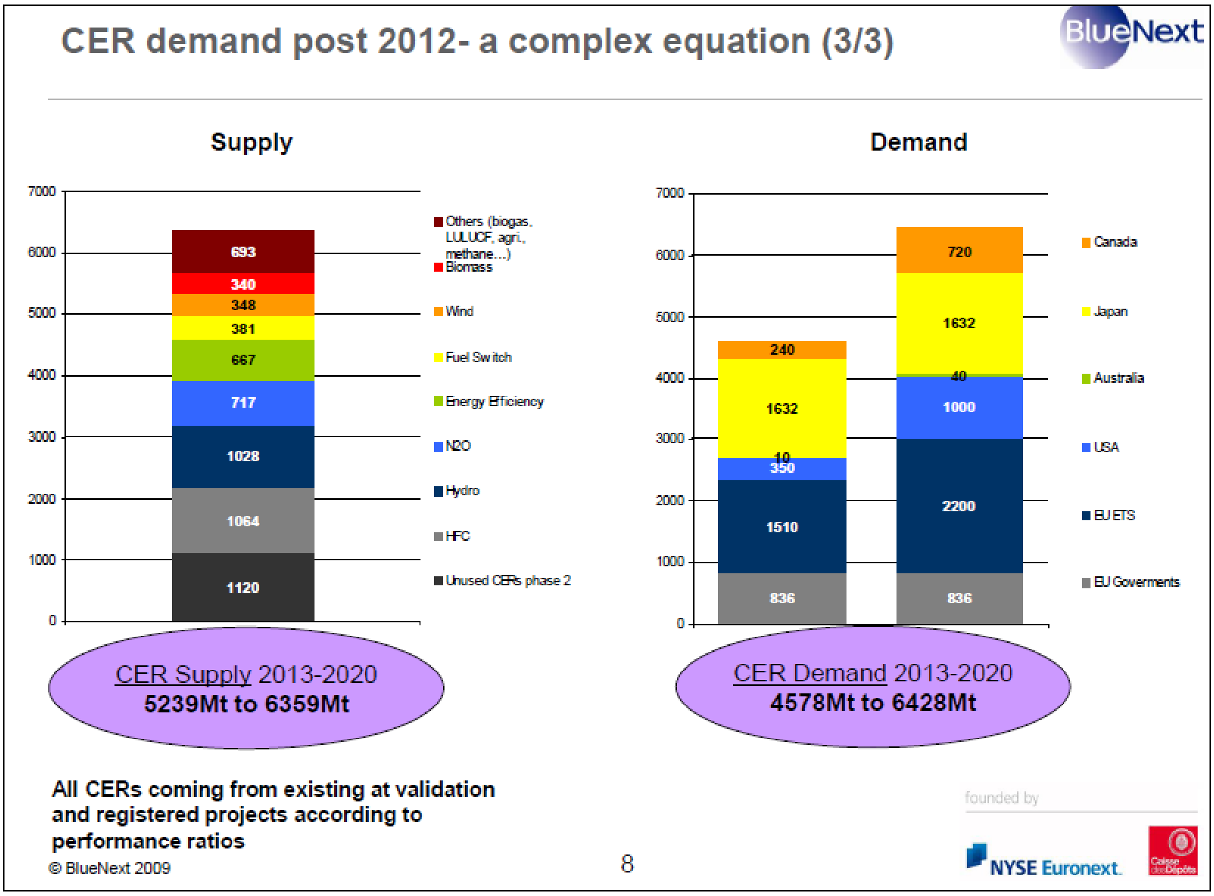


Figure 28 Forecast of supply demand analysis

Global Market trends in the future (2)

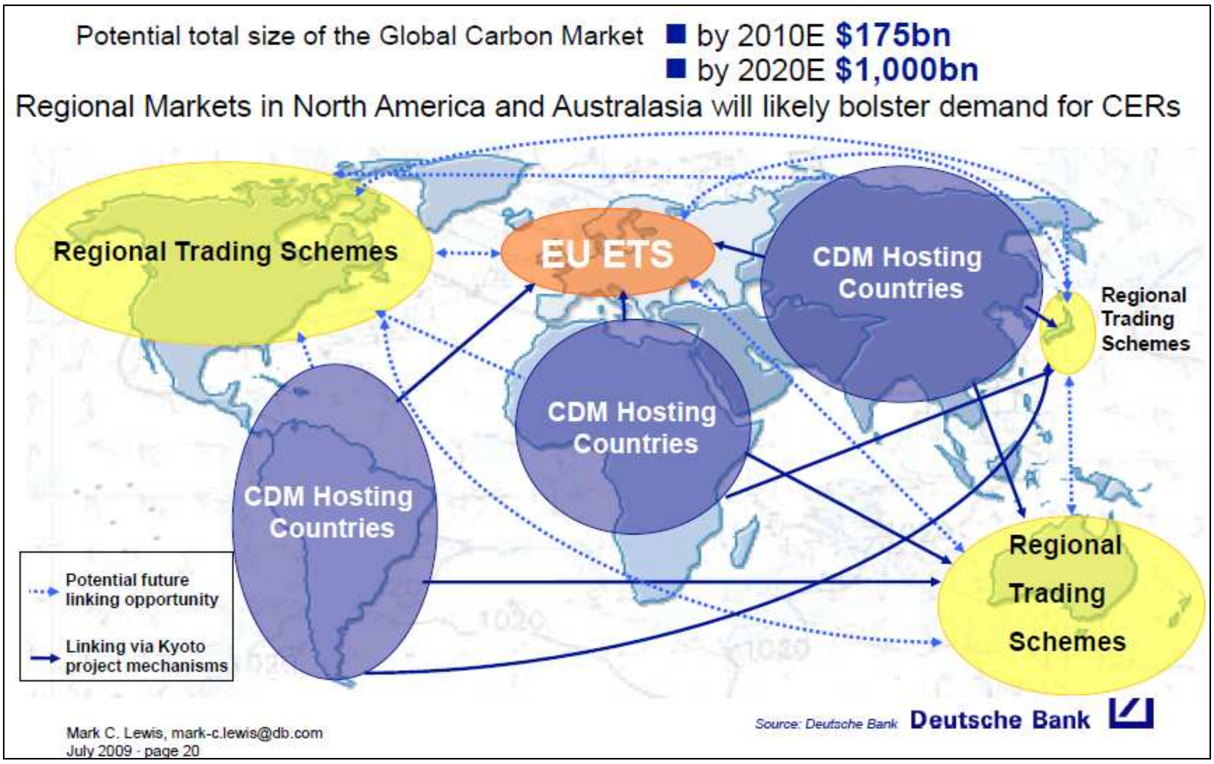


Figure 29 Trend analysis of carbon markets in the future

5.15.7 References

1. State and Trends of the Carbon Market 2009, The World Bank (http://wbcarbonfinance.org/docs/State_Trends_of_the_Carbon_Market_2009-FINAL_26_May09.pdf)
2. Carbon Markets in Downturn June 2009, Deutsche Bank (http://www.iea.org/work/2009/ghget/Lewis.pdf)
3. Carbon Markets in Challenging Times, Natsource LLC, IEA workshop on GHG Emissions Trading (http://www.iea.org/work/2009/ghget/Forrister.pdf)
4. Markets in Downturn, Blue Next SA, IEA workshop on GHG Emissions Trading (http://www.iea.org/work/2009/ghget/Rapin.pdf)

5.16 Carbon dioxide in chemical, food and other merchant markets

Globally, carbon dioxide (CO_2) consumption has reached approximately 20 million tons per year, which is strictly the merchant market, food, beverage, chemical and industrial uses. From this grand total of CO_2 consumption globally, North America consumes some 10 million tons per year in merchant CO_2, of which the United States alone accounts for more than 8 million tons, and Canada less than 2 million tons. (3)

Other significant merchant markets for CO_2 include Western Europe, consuming more than 3 million tons annually, and Japan, at about 4 million tons annually. The balance of the globe consumes the remaining 5 million tons per year. (3)

Beyond the merchant markets are the captive CO_2 markets, including "over the fence" usage for fertilizer production, methanol and sodium bicarbonate plants, which often consume CO_2 in the order of hundreds to thousands of tons per day. Furthermore, CO_2 is consumed in very large quantities in enhanced oil recovery (EOR) projects in North America and elsewhere; the product is usually delivered to such projects via pipeline from a raw gas source. (3)

5.16.1 Technical Data (3)

Product Names	Carbon dioxide
CAS No	124-38-9
Form	Gas and Solid (Dry Ice)
Chemical and Physical Properties (Ref 2)	Critical density, g/L 467 Gas density at 273 K and 101.3 kPaa 1.976 g/L Liquid density at 273 K, 928 g/L at 298 K and 101.3 kPaa CO2, vol/vol- 0.712 A colourless gas with faintly pungent odour and acid taste
Formula	CO_2

5.16.2 Uses, Manufacturers and Market Location

End Uses	Major use (1) **Food and Beverage:** Carbon dioxide is used in beverage carbonation. A natural anti-microbial, carbon dioxide is also used to increase the shelf life of juice and dairy products, protecting taste and texture, and reducing the need for preservatives, natural and artificial. Other applications include: food freezing and chilling, packaging, mixer and blender cooling, ingredient cooling and conveying, and in-transit refrigeration. In its solid form, it is known as dry ice. Many people know carbon dioxide is used in food freezing, carbonated beverages and dry ice. But most don't realize it also helps to clear the air, clean the water and save the trees. **Water/Wastewater Treatment:** Industrial and municipal wastewater must be

	neutralized before being discharged to the environment. Carbon dioxide replaces harsher acids for the alkaline neutralization process. It's safer and cheaper than sulfuric-acid systems, improves controllability, and there's less downtime and no labor to handle chemicals. It also is less corrosive, and easier to handle and store. **Metal Fabrication:** Commonly utilized as a shielding gas during welding. This prevents atmospheric contamination of molten weld metal during gas shielded electric arc welding process. **Plant Growth:** Carbon dioxide systems greatly improve growth and quality of plants in the greenhouse. Increasing concentrations of the gas results in larger, healthier and faster-growing plants and lower operating costs, especially during the winter, when it can reduce heating costs by 50%. Carbon dioxide replaces gas generators, saving fuel costs and eliminating harmful emissions. **Pulp and Paper:** Carbon dioxide is being used for several different applications within paper mills, all developed to reduce costs and recover valuable chemicals used within the mill process. A process using carbon dioxide, instead of sulfuric acid, to treat pitch build-up in screen rooms is proving very successful. **Saving the Forest:** Carbon dioxide is used to make precipitated calcium carbonate (PCC), which is used to reduce the use of virgin wood fiber in paper making. Applications include: supply of carbon dioxide for on-site PCC production and in-situ formation of PCC during the paper-making process. **Energy Source:** Storage of carbon dioxide at its triple point (the temperature-pressure combination at which carbon dioxide can exist simultaneously as a solid, liquid or gas) is being tested as a means of providing closed-loop refrigeration in order to shift electrical-energy demand to off-peak consumption hours. Under test in Japan, the process offers the potential to customers to shift electrical load while maintaining temperatures as low as minus 60℉ (-51℃). **Cleaning and Solvent Extraction:** In its supercritical state (87.9℉ (31.1℃) and 1070.6 psia (7.38MPa)), carbon dioxide becomes a versatile solvent. It can replace chlorinated fluorocarbons to clean equipment components. It also can replace many volatile organic chemicals for operations such as decaffeinating coffee or extracting fat from food products. **Fire Fighting:** Carbon dioxide smothers fires without damaging or contaminating materials and is used for fighting fires when water is ineffective, undesirable or unavailable.
Manufacturers	Airgas, Air Liquide, Air Products, Iwatani, Linde, Matheson Tri-Gas, Messer, and Taiyo Nippon Sanso
Suppliers	More than thousand suppliers around the world (2)
Market overview	Carbon dioxide is produced mainly from six processes (3) • From combustion of fossil fuels and wood • As a by-product of hydrogen production plants, where methane is converted to CO_2 • As a by-product of fermentation of sugar in the brewing of beer, whisky and other alcoholic beverages; • From thermal decomposition of limestone, $CaCO_3$, in the manufacture of lime, CaO • As a by-product of sodium phosphate manufacture • Directly from natural carbon dioxide springs, where it is produced by the action of acidified water on limestone or dolomite

<table>
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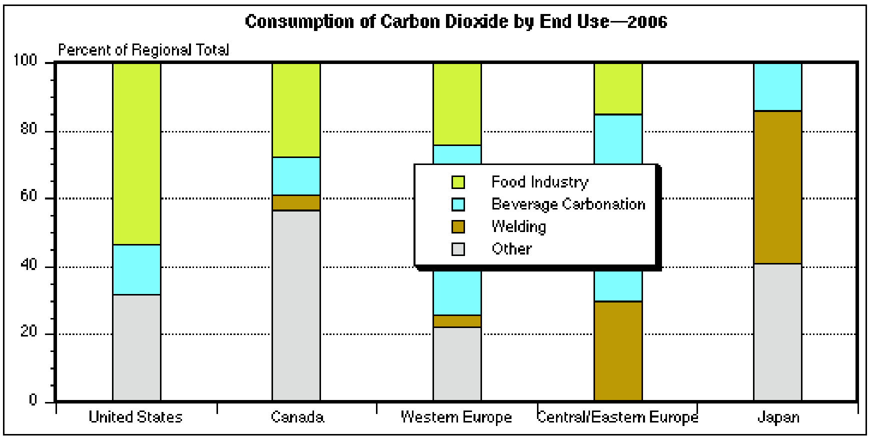
Carbon dioxide value chain (6)</td></tr>
<tr><td>Market Location</td><td>

Worldwide CO_2 Consumption in the Merchant Market (7)</td></tr>
<tr><td>Market Volume</td><td>20 million tons per year in merchant markets(4)</td></tr>
<tr><td>Market Price</td><td>$30 to $120 per ton</td></tr>
<tr><td>Market Price variability</td><td>For larger accounts, selling prices for CO_2 in the merchant market can range from $30 to $120 per ton (delivered bases), depending on the region. CO_2 is fairly sensitive to freight, where most of the product is delivered by over the road trucks as a liquid product within a 200-mile radius of the production plant. Beyond this distance, rail is often employed. (3)</td></tr>
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5.16.3 Market Volume Future Trends (4, 7)

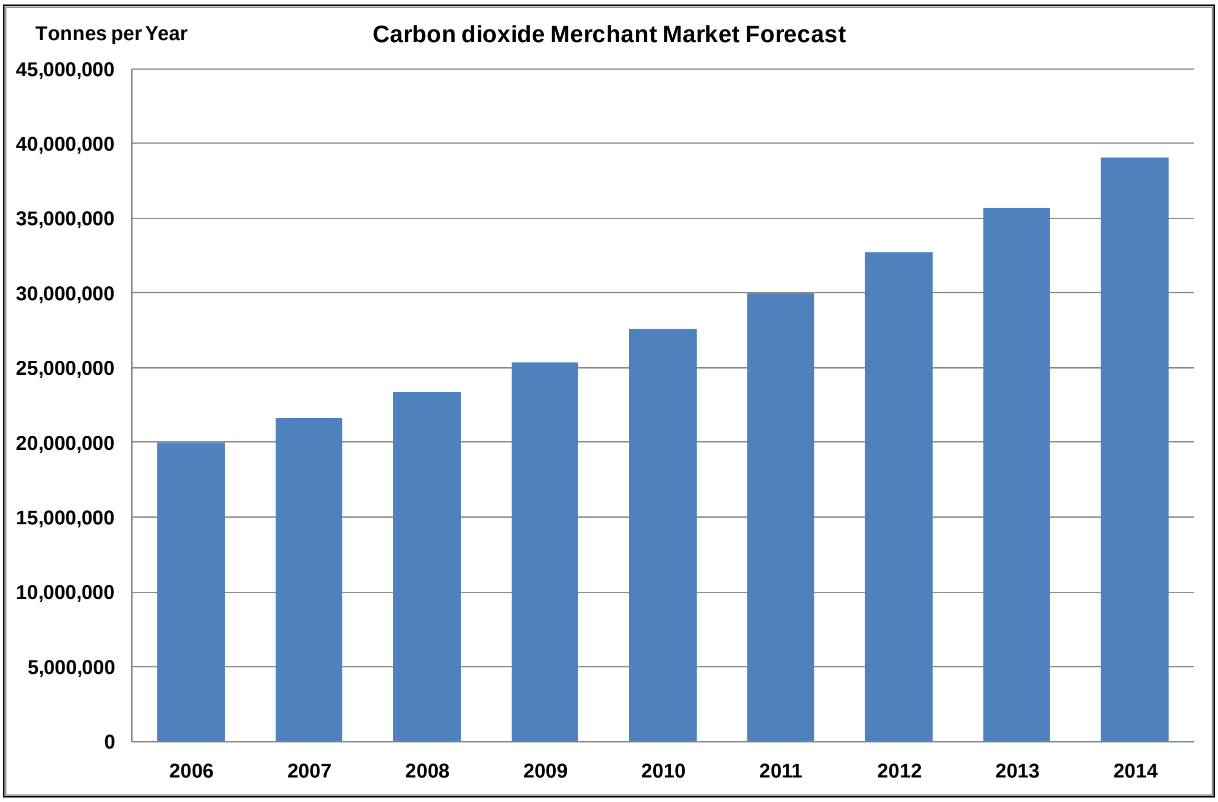

Figure 30 CO_2 Merchant Market Forecast

5.16.4 Producers

Name	Location	Process	Ref
Linde	Worldwide	Recovered from waste products of the production of ethylene oxide, alcohols and fertilizers	5
Air Liquide	Worldwide	Not known	
Praxair	Worldwide	Not known	

5.16.5 Applications (1)

Chemical Name	Direct Use	Intermediate	Other	Potential Future
Carbon dioxide	Beverage carbonation, Shielding gas during welding, using carbon dioxide, instead of sulfuric acid, to treat pitch in the pulp and paper industry	Used to make precipitated calcium carbonate (PCC), which is used to reduce the use of virgin wood fibre in paper making.	Fire fighting, Carbon dioxide systems greatly improve growth and quality of plants in the greenhouse.	Storage of carbon dioxide at its triple point (the temperature-pressure combination at which carbon dioxide can exist simultaneously as a solid, liquid or gas) is being tested as a means of providing closed-loop refrigeration in order to shift electrical-energy demand to off-peak consumption hours. Liquid carbon dioxide's solvent potential has been employed in some dry cleaning equipment as a substitute for conventional solvents.

5.16.6 Future Trends

CO_2 refiners are generally seeking relatively clean and the most strategically sourced raw gas opportunities to purchase raw gas, or a refined liquid product. The preferred CO_2 sources essentially include a handful of chemical and natural sources, including natural pressurized underground wells, co-product from ethanol plants or anhydrous ammonia plants, hydrogen/reformer sources and sometimes raw gas from titanium dioxide or ethylene oxide plants. (4) New ethanol plants are likely provide the greatly needed strategic sourcing sought in the CO_2 industry in the years ahead. This trend will likely continue with the growth in the CO_2 industry. The future of the CO_2 trade in North America may lie within an ever-closer relationship between the ethanol companies (and other source types) and the CO_2projects. Such close relationships can strengthen the economics of CO_2 production, in part due to the raw gas feedstock cost. (4)

5.16.7 References

1. http://www.praxair.com/praxair.nsf/0/B56163D966D26848852568AA006F5036?OpenDocument=
2. http://www.thomasnet.com/products/carbon-dioxide-10671808-1.html
3. Pierantozzi, Ronald (2001). "Carbon Dioxide". *Kirk-Othmer Encyclopedia of Chemical Technology*. Wiley.
4. http://www.ethanolproducer.com/article.jsp?article_id=230
5. http://www.linde-gas.com/international/Web/LG/COM/likelgcom30.nsf/repositorybyalias/pdf_dry%20ice%20cleni ng%20effects/$file/25621_DS_effects_CO2_final.pdf
6. http://www.linde-gas.com/international/Web/LG/COM/likelgcom30.nsf/docbyalias/nav_dryice
7. http://www.sriconsulting.com/CEH/Public/Reports/743.2000/