MonMark Methanal Study

In early 1999 the MonMark consulting group was commissioned to evaluate various aspects of the Australian methanal[a] industry over the following ten years. The results of our investigation are presented in this report, being a more comprehensive treatment than the formal oral presentation delivered to the Chief Executive Officer on the morning 29 May 1999.

Manufacturing Technologies[b, c]

There are three main technologies for the manufacture of methanol. The first two use a silver catalyst with either complete or partial oxidation of methanol, while the second converts methanol using a metal oxide catalyst.

Silver Catalyst Processes

The central reactions are as follows[d]:

1. $CH_3OH(g) + 0.5\ O_2(g) = HCHO(g) + H_2O(g)$ $\Delta H = -159 kJ.mol^{-1}$ (oxidation)
2. $CH_3OH(g) \rightarrow HCHO(g) + H_2(g)$ $\Delta H = +84 kJ.mol^{-1}$ (dehydrogenation)
3. $H_2(g) + 0.5O_2(g) \rightarrow H_2O(g)$ $\Delta H = -243 kJ.mol^{-1}$

These are carried out at ambient pressure. The precise reaction temperature obtained depends upon the extent to which methanol is in excess in the methanol–air feed mixture.

Note that the endothermic dehydrogenation reaction (2.) is highly temperature dependent.

By-products are formed as follows[e]:

4. $HCHO(g) \rightarrow CO_2(g) + H_2(g)$ $\Delta H = +12.5 kJ.mol^{-1}$
5. $CH_3OH(g) + 1.5\ O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$ $\Delta H = -674 kJ.mol^{-1}$
6. $HCHO(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$ $\Delta H = -519 kJ.mol^{-1}$

Other by-products include methyl formate, methane (CH_4) and methanoic acid (HCOOH).

Conversions achieved are 50% at 400°C, 90% at 500°C and ~99% at 700°C. The temperature can be controlled by adjusting the amount of process air input.

The yield can also be improved by addition of inert materials to the reactants[f].

The **BASF[g] process** involves 'complete' conversion of methanol in the presence of silver crystals and steam, and takes place at 680 to 720°C. This gives a methanol conversion of 97 to 98% and a typical yield of 89.5 to 90.5%.

The final product contains 40 to 55%kg.kg^{-1} methanal (as desired) along with a an average of 1.3%kg.kg^{-1} methanol[h] and 0.01%kg.kg^{-1} methanoic acid.

The process of **incomplete conversion and distillative recovery** of methanol is carried out in the presence of silver (as crystals or gauze), steam and excess methanol at 590 to 650°C. This gives a primary[i] conversion of 77 to 80%.

The conversion of methanol is then 'completed' by distilling off and recycling the unreacted methanol. This requires cooling of the reaction gases, which are then fed to an absorption column, with a bottoms product being produced of concentration ~42%kg.kg^{-1} methanal. The bottoms stream is then fed to the distillation column, from the base of which a product stream containing up to 55%kg.kg^{-1} methanal and less than 1%kg.kg^{-1} methanol is drawn and finally cooled.

The main benefit is that the reduced temperature suppresses by-product formation by such secondary reactions as outlined above.

Formox process

Oxidation of methanol with excess air (without dehydrogenation), in the presence of a modified iron–molybdenum–vanadium oxide catalyst, is termed the formox process. It is carried out at between 250 and 400°C.

The process involves reaction in which the catalyst is first reduced in the oxidation of methanol, and then regenerated by oxidation, *viz.*:

7. $CH_3OH(g) + \text{Catalyst}_{\text{OXIDISDED STATE}}(s) \rightarrow HCHO(g) + 2H_2O(g) + \text{Catalyst}_{\text{REDUCED STATE}}(s)$
8. $\text{Catalyst}_{\text{REDUCED STATE}} + 0.5O_2(g) \rightarrow \text{Catalyst}_{\text{OXIDISDED STATE}}(s)$

with $\Delta H = –159 kJ.mol^{–1}$.

Between 270 and 400°C conversion at atmospheric pressure is virtually complete. However above 470°C the following side-reaction increases significantly:

9. $HCHO(g) + 0.5H_2(g) = CO(g) + H_2O(g)$ $\Delta H = –215 kJ.mol^{–1}$

The final product contains $55\% kg.kg^{–1}$ methanal and 0.5 to $1.5\% kg.kg^{–1}$ methanol.

The methanol conversion is 98 to 99% depending on selectivity, activity and spot temperature of the catalyst. The overall plant yield is typically 88 to 91%.

New processes

Several novel processes are being investigated:

- An incentive exists to produce methanal directly from methane by partial oxidation, saving on raw material costs (or capital and operating costs in the case of an integrated facility).
- Producing highly concentrated methanal by dehydrogenation of methanol could minimise operating costs due to energy consumption, effluent generation and losses because of more desirable reaction conditions.
- Methanal could potentially be produced from the methylal ($(CH_3O)_2CH_2$[j]) that is a derivative of methanol and methanal, resulting in the benefit of a more concentrated product. The principal is that methanal from aqueous recycle streams (from other units) can be recovered by reaction with methanol to form methylal, rather than by more costly means.

Product Requirements[k]

Methanal is commercially available primarily as an aqueous solution of concentration 30 to $56\% kg.kg^{–1}$.

Methanal solutions often additionally contain 0.5 to $1.2\% kg.kg^{–1}$ methanol or other stabilisers. The reason for this is that methanal solutions tend to precipitate paramethanal ($(H.CHO)_2$[l]) with an increase in concentration or a decrease in temperature[m]. Also, methanoic acid ($HCOOH$) is formed as temperature increases.

Alcohol stabilisers include methanol (most common), ethanol, propanol and butanol, however the stabiliser must be chosen so as not to interfere with further processing operations (or so that they can be separated off beforehand).

Non-alcoholic stabilisers include urea ($OC(NH_2)_2$), melamine ($N_3C_3(NH_2)_3$[n]), hydrazine hydrate ($N_2H_4.H_2O$[o]), guanamines and bismelamines. These increase the storage life without precipitation of paramethanal, at lower storage temperatures.

The original methanal solutions were of concentration $37\% kg.kg^{–1}$ with 3 to $15\% kg.kg^{–1}$ methanol acting as a stabiliser. The trend in recent years has been toward the production of more concentrated solutions (~50%kg.kg^{-1}) containing as little methanol as possible (0.5 to 1%kg.kg^{-1})

The acidity of a methanal solution can be reduced by passing it through an ion-exchange resin.

Methanal can be stored and transported in stainless-steel, aluminium, enamel or poly-resin containers, as well as lined carbon steel containers.

Other commercial forms of methanal are paramethanal and trioxane. These are both usually prepared from the aqueous solution and thus represent more costly forms.

Industries Upstream & Downstream[p]

The methanol from which Australian methanal is produced comes chiefly from the BHP plant ~20km West of Melbourne – around 70% of the required supply. The remainder coming from New Zealand.

Australian companies manufacturing methanal are Orica, Borden Australia and Dyno Industries.

The main chemical produced from methanal are the UF and PF resins (see below). Unfortunately a detailed breakdown of methanal usage in Australia could not be sourced. However it is known that this general international trend applies equally well in Australia, although certain details with regard to less important derivatives vary from country to country[q].

The derivatives of methanal of commercial significance and their uses are as follows:

- Urea–formaldehyde (UF) resins – adhesives for particle-board, plywood and laminated beams
- Phenol–formaldehyde (PF) resins – moulding compounds in electrical appliances, wiring and dinnerware
- Pentaerythritol, $C(CH_2OH)_4$[r]– for the manufacture of alky resins and floor polish
- Hexamethylene teramine (HMTA), $(CH_2)_6N_4$ – antiseptic and diuretic uses, used in the production of cyclonite, a highly efficient explosive[s]
- UF fertilisers – as fertilisers
- Polymethanal[t] – thermoplastics that have good dimensional stability and are abrasion resistant
- Paramethanal, $(H.CHO)_2$ – used by resins manufacturers seeking low water content, such as in melamine resins where high solids content is desirable
- Melamine formaldehyde (MF) resin– for moulding and laminating[u]
- ethylenediaminetetraacetic acid (EDTA), $CH_2(N(CH_2COOH)_2)_2$ – sequestrants/chelating agent[v]

also 1,2-ethanediol $(CH_2\text{-}OH)_2$ and glycolic acids.

Major companies producing methanal derivatives in Australia are:

- Orica – produces 1,2-ethanediol, MF resin, PF resin (and phenol, melamine & urea)
- Borden-Australia – MF resin, PF resin
- Ciba Specialty Co. Australia – MF resin
- Huntsman Chemical Co. Australia – PF resin.

Projected Market Demand

One means of forecasting methanal demand is to assume that it will grow in line with global gross domestic product (GPD) growth.

For the U.S.A. and Europe this is ~3% (up to 2002)[w], for Eastern Europe it is 4 to 5% (to 2005)[x] and for Asia it was 4 to 7% as at May 1998[y].

Predictions from one source in particular were judged to be reliable, demonstrated in that growth of $3\%.y^{-1}$ was recorded for the period 1985 to 1995, with a forecast of 2 to $3\%.y^{-1}$ to 1999 (as at September 1995)[z], which matched the actual data: the 'historic' growth was updated to $2.7\%.y^{-1}$ for 1988 to 1997 and a new forecast of $3\%.y^{-1}$ to 2002 was made at the end of the last financial year[aa].

One optimistic American methanal producer, possibly with a vested interest, stated in 1997 that, "Demand continues to grow at or above GDP, led by strong housing starts."[bb]

China's forecast of development and market prospects for methanal by 2000 concludes that production capacity needs to be increased by in excess of 2×10^5t[cc]. Thus a global trend of increased demand for methanal is forecast. This trend results in potential increase of market demand for methanal in Australia over the next ten years.

To reference this growth we note that current Australian and New Zealand production capacity is around 362×10^6t.y^{-1}[dd]. However one must be cautious in using design capacity data, as during the 1980's production in the U.S.A. averaged only 67% of capacity[ee].

For comparison American plants have a combined capacity of around 5127×10^6t[ff].

One source that may contradict this growth forecast shows that Japanese shipments of methanal increased roughly linearly from ~45×10^3t.month^{-1} at the start of 1983, but have remained around a **steady** value of ~62×10^3t.month^{-1} since the start of 1990 (with slight 'overshoot')[gg].

Demand for methanal is a function of economic cycle growth. For example, when the economy is in the growth stage, then one generally expects growth in the building/construction sectors, industrial investment, motor vehicle production, plastic packaging industries *et cetera*. The main reason for this strategic dependence is that methanal is an essential chemical 'building block', especially in the so-called 'developed world'.

Adhesives based on methanal, *i.e.* UF resins, PF resins, are the largest uses of methanal. Demand for these products is the result of growth in the building industry and 'housing starts', which can be cautiously implied from new home loans, for example. Despite the current economic down-turn, with Australian interest rates low the climate is suited to the building of new homes in which methanal derivatives are used.

Another indicator may be population growth, with per capita production values being used to compare data across different countries.

These major uses require a suitable demand for UF and PF resins, however to produce those resins urea and phenol are required at a reasonable price, so these two chemicals are also important for methanal demand.

Similarly, the price of the methanol from which methanal is produced is important, as will be shown later in this report.

Other effects such as labour costs or utility costs do not tend to fluctuate as much, and are therefore 'less of a problem' for methanal producers.

In recent years there has been significant growth in the demand for methanal as a raw material for engineering plastics. This has been driven by growth in new product development in plastic packaging industries, durable good production and motor vehicle production.

Methanal demand is also affected by manufacturing products including elastomers, paints, foams and polyurethane.

Manufacturing Costs & Likely Selling Prices

For a plant of a given capacity there are two main influences on the selling price of methanal: quantities ordered and the cost of methanol.

Probably less than 1% of total methanal production would be used in '**laboratory quantities**' for disinfection, preservation (*et cetera*)[hh], however the enormous price differential that exists between that market and the bulk methanal market may still warrant some investigation.

Analysis of current and past editions of catalogues put out by the Sigma and Aldrich companies in Australia shows that prices vary from $10^{3}\$.\mathrm{kg}^{-1}$ (*i.e.* $10^{6}\$.\mathrm{t}^{-1}$(!)) for 25mL lots, down to ~$10\$.\mathrm{kg}^{-1}$ ($10^{4}\$.\mathrm{t}^{-1}$) in 4L or 18L lots. These prices are Free On Board in 1999 Australian dollars, referring to 37% solution containing ~10% methanol (inhibitor).

Note that freightage costs will be significant.

The past pricing (F.O.B.) shows an inflation rate of **roughly** $4\%.\mathrm{y}^{-1}$ (somewhere between $2.4\%.\mathrm{y}^{-1}$ and $9.2\%.\mathrm{y}^{-1}$). Please refer to Appendix for detailed break-down of raw data.

Freight of bulk methanal is also significant[ii], leading to recent trends to transport methanal at higher concentrations (*viz*. 50% or more[jj]).

The **bulk** selling price of methanal, F.O.B., in June 1998 U.S. dollars was ~12 to $13¢.\mathrm{lb}_{m}^{-1}$, which is roughly $470\$_{1999}.\mathrm{t}^{-1}$ (Australian), although the basis chosen was "Gulf [coast]" and methanol-free [kk, ll].

Although the corresponding September 1995 price was ~15 to $21¢.\mathrm{lb}_{m}^{-1}$ [mm], the value of the Australian dollar was 'stronger' at that time, so that this equates to a price of **approximately** $590\$_{1999}.\mathrm{t}^{-1}$ (Australian)[nn].

The Institution of Chemical Engineers (U.K.) website[oo] gives the following bulk price of 35% methanal = $160£_{1998}.\mathrm{t}^{-1}$ (April). Hence this is roughly $455\$_{1999}.\mathrm{t}^{-1}$ for 37%[pp].

A 1990 price of $12¢.\mathrm{lb}_{m}^{-1}$ (U.S.) was quoted for 37% methanal[qq], being equivalent to about $440\$_{1999}.\mathrm{t}^{-1}$ (Australian)[rr].

Taking into account 'import parity' the above estimates of methanal selling price could be used to obtain an upper limit for Australian producers (*e.g.* freightage for acetone may be about $50\$.\mathrm{t}^{-1}$ [ss]). 'Location factors' could also be considered.

We will estimate[tt] that the price of methanal in Australia is $470\$_{1999}.\mathrm{t}^{-1}$ (forecast average for 1999) F.O.B., with inflation of $2\%.\mathrm{y}^{-1}$ **maximum** for the next ten years (*i.e.* roughly in line with the CPI[uu] or below[vv]).

This reduced inflation forecast is reflects concerns about possible oversupply due to 'economic faltering'[ww]; an over-inflated value of stock-market indicators (*i.e.* especially due to internet-based stocks being over-valued by markets in the U.S.A.[xx]); further ramifications of the Asian economic 'crisis', and possibly even fall-out from the so-called Y2k problem[yy] or the current conflict in the Balkans[zz].

Consider also the complicated effects of the proposed Goods and Services Tax (G.S.T.) if it were to be introduced, effectively altering the corporate rate of taxation.

Consider environmental effects and Occupational Health & Safety: while methanal is still suspected of being a carcinogen by some[aaa], others find, "no available data," to indicate ill effects such as those at typical and tolerable exposure levels for humans[bbb]. Obviously changes in regulations could have a significant effect on the manufacturing cost and hence selling price.

While excessive capacity may be a problem, it is probably offset by the fact that "Formaldehyde can seldom, if ever, be replaced by other products"[ccc]. As noted previously, 1980's production in the U.S.A. averaged 67% of capacity[ddd].

Raw material requirements for 37% methanal production:
According to Kharbanda[eee] ~0.47kg(CH_3OH).kg(37% HCHO)$^{-1}$ are required, based on 1947 data.

Perry's "Chemical Business Handbook"[fff] quotes various methanol requirements: 0.53 (1947), 0.47 (1950), 0.50 to 0.53 (1947) and 0.48kg(CH_3OH).kg(37% HCHO)$^{-1}$ (1947), with the figures in parentheses being the year of publication of the data cited by Perry.

However the more recent value (1973/1974) is 0.41kg(CH_3OH).kg(37% HCHO)$^{-1}$ [ggg].

This is above the minimum stoichiometric amount (1mole:1mole, whence ~0.395kg(CH_3OH).kg(37% HCHO)$^{-1}$ theoretical **minimum**) due to inefficiencies.

Due to process improvements since the 1950's, and bearing in mind that 100% conversion is not carried out, a (possibly conservative) methanol requirement of 0.42kg per kg of 37% HCHO will be used.

Taking the density of methanol as 0.792kg.dm^{-3} [hhh], the price of methanol as at August 1998 was ~36¢.gal^{-1} (U.S.)[iii]. This equates to a **value** of approximately 120\$$_{1998}$.t^{-1} (U.S.), or 200\$$_{1999}$.t^{-1} (Australian)[jjj]. This is bulk, Gulf Coast, on barges, F.O.B..

Another source[kkk] gives the bulk **selling price** of methanol as: 200£$_{1998}$.t^{-1} (April), or ~560\$$_{1999}$.t^{-1}.

Comparing to the results from Sinnott[lll]: mid-1992 prices of bulk 37% methanal ~0.15£$_{1992}$.kg^{-1}, which is about 440\$$_{1999}$.t^{-1} [mmm]. However what is more interesting is that the same source gives the price of methanol as ~0.70£$_{1992}$.kg^{-1}, or ~2000\$$_{1999}$.t^{-1} (Australian)!

It appears[nnn] that the price of methanol has been highly variable over (say) the period 1982 to 1997, having a high price more than 4 times greater than its August 1998 price, which in turn was 44% higher than its minimum price.

For comparison, the high price for methanal for the period 1981 to 1997 was 'only' 2.8 times greater than its August 1998 price, which was 69% above its lowest price[ooo].

Circumstantial evidence indicates that a large fluctuation would have occurred around 1986 to 1987. Witness, for example, that – despite both methanol and methanal being considered commodities – methanol registered both the largest production **increase** in 1986 (up 46.5%), as well as the largest output **decline** in the preceding year (down 38.9%) compared to the other 'Top 50' chemicals[ppp].

For manufacturing cost composed of 59% raw materials, 23% depreciation and 18% utilities & labour methanal costs ~ 105\$$_{1987}$.t^{-1} to **manufacture** from methanol (based on 1974 data)[qqq]. This is roughly 200\$$_{1999}$.t^{-1} (Australian)[rrr].

Suppose we take the price of methanol as 500\$$_{1999}$.t^{-1}.

We calculated that 0.42t of methanol were required for every 1t of 37% methanal produced. Thus this methanol price represents a **partial** manufacturing cost, namely 210\$$_{1999}$.t(37% HCHO)$^{-1}$.

It is known that methanol typically makes up at least 60% of methanal's production costs, although the exact proportion depends on the capacity of the plant ('economies of scale') and other factors. Further, the price of methanal normally reflects the methanol price[sss].

If we assume that the proportion is exactly 60%, then this gives a manufacturing cost of 350\$$_{1999}$.t^{-1}.

In fact the **actual manufacturing cost** will also depend on whether the methanol is from a 'captive' supply, in which case the cost to the company may be reduced by (say) 10%, giving $315\$_{1999}.t^{-1}$.

From this it is very clear why the cost of methanol will have a dominant effect on the manufacturing cost (and hence selling price) of methanal.

Taking into consideration the previous manufacturing cost estimate[ttt] of $200\$_{1999}.t^{-1}$, let us say that the actual manufacturing cost is likely to be around 250 to $300\$_{1999}.t^{-1}$ (also bearing in mind that the selling price was estimated at $470\$_{1999}.t^{-1}$).

Conclusions

Methanal is currently produced commercially as an aqueous solution of approximately 50% concentration (by mass) by one of three methanol oxidation schemes, although results are conventionally reported referred back to a 37% basis. Stabilisers such as methanol are added. A guaranteed supply of the methanol feedstock is desired.

The major derivatives of methanal are resins/adhesives, which depend on a supplies of urea and phenol.

Currently growth in production of methanal is 'high' (for a mature good), predicted to be roughly $3\%.y^{-1}$.

The Australian price of methanal is particularly dependent on the size of the lots ordered, the cost of methanol (which fluctuates considerably) and also the capacity of the plant. For 1999 it is forecast to be an average of $470\$_{1999}.t^{-1}$ F.O.B. (between 400 and $500\$_{1999}.t^{-1}$), with inflation of $2\%.y^{-1}$ **maximum** for the next ten years (*i.e.* roughly in line with the CPI at the time, or below).

The manufacturing cost in Australia for 1999 is around 250 to $300\$_{1999}.t^{-1}$.

MonMark recommends retaining existing Australian methanal assets, but does not foresee a benefit in any significant expansion of operations in the next ten years, as increased demand should be able to be met by upgrades of existing facilities and producing closer to the maximum plant capacity.

One area that may warrant further investigation would be increasing the 'value added' by exporting resins produced in Australia. This would need to be a long-term study, and could be expertly handled by the experienced members of the MonMark consulting group.

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[a] Commonly called 'formaldehyde', the 37% solution of which is commonly called 'formalin' [R. P. GRAHAM and L. H. CRAGG; The Essentials of Chemistry; Clarke, Irwin & Co.; Toronto; 1962; p. 524].

[b] H. Robert GERBERICH, *et alii*; "Formaldehyde" in: Jacqueline I. KROSCHWITZ (Executive Ed.), *et alii*; Kirk-Othmer Encyclopedia of Chemical Technology, 4th edition; John Wiley & Sons; New York; 1994; Vol. 11, pp. 935 to 939.

[c] Günter REUSS, *et alii*; "Formaldehyde" in: Wolfgang GERHARTZ (Senior Ed.), *et alii*; Ullmann's Encyclopedia of Industrial Chemistry, 5th edition; VCH; Weinheim; 1988; Vol. A11, pp. 624 to 629.

[d] *e.g.* REUSS (*opere citato*); Vol. A11, p. 624.

[e] *E.g.* REUSS (*opere citato*); Vol. A11, p. 628.

[f] *E.g.* Addition of: water to spent methanol – water-evaporated feed mixtures; nitrogen to air and air–off-gas mixtures, which are recycled to dilute methanol–oxygen reaction mixture.

[g] Badische Anilin- & Soda-Fabrik [name of a German chemical company], with each letter pronounced in turn: the Aniline and Soda Plant of Baden.

[h] Inhibitor/Unreacted.

[i] *I.e.* 'single-pass'.

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[j] Peter M. B. WALKER (General Ed.); Chambers Science and Technology Dictionary; Chambers; Edinburgh; 1988; p. 569.

[k] REUSS (*opere citato*); Vol. A11, pp. 624ff..

[l] WALKER (*opere citato*); p. 647.

[m] Both of which are known to cause a decrease in solubility from elementary physical chemistry.

[n] John MCMURRY; Organic Chemistry, 3rd edition; Brooks/Cole; Pacific Grove, California; 1992; p. 1211.

[o] WALKER (*opere citato*); p. 442

[p] Albert V. HAHN; The Petrochemical Industry (Market & Economics); McGraw-Hill Book Co.; New York; 1970; § 3.1.
Henri ULRICH; Introduction to Industrial Polymers; Hansers Publishers, Macmillan Publishing; New York; 1993.
http://www.vianet.net.au/~acted/prod_company.htm
http://www.chemexpo.com/news/PR
http://www.cibasc.com/bm/mp/mp_01.asp
http://www.orica.com.au/Business/
http://www.huntsman.com/products/polymers/

[q] In particular, such as MDI (methanediphenyldiisocyanate), a monomer with formula $CH_2\text{-}((C_6H_2)\text{-}NCO)_2$ [MCMURRY (*opere citato*), p. 1211], which is not produced commercially in Australia despite comprising ~12% of the methanal consumption in the Federal Republic of Germany (Germany being the major European methanal producer) in 1981/1982 [Günter REUSS (*opere citato*); Vol. A11, pp. 638].

[r] WALKER (*opere citato*); p. 658.

[s] WALKER (*opere citato*); p. 427. Also known as 'hexamin' in the plastics industry and 'urotropin' in the pharmaceutical field.

[t] Same as 'polyacetals' and 'polyformaldehydes' [WALKER (*opere citato*); pp. 693f.].

[u] WALKER (*opere citato*); pp. 562, 570.

[v] WALKER (*opere citato*); p. 286, in which there is a serious misprint in the chemical formula given.

[w] "ChemExpo Chemical Profile" at: www.chemexpo.com/news/newsframe.cfm?frame=/news/profile.cfm

[x] Australia would be expected to be more influenced by local market peculiarities, so that data for Eastern Europe, for example, is unlikely to have a dominant effect on Australian production or consumption of methanal.

[y] "Formaldehyde: Markets & Economics" in: Chemical Week; **160**(17):30. May 6 1998.

[z] http://www.chemexpo.com/news/PROFILEsept11.cfm

[aa] http://www.chemexpo.com/news/PROFile980622.cfm

[bb] "Formaldehyde Market Not Affected by Georgia-Pacific Plant Outrage" in: Chemical Market Reporter; Schnell Publishing; **252**(12):9; 22 September 1997.

[cc] "China's Demand for Organic Chemicals by 2000" at: www.cei.gov.cn/sicnet/sicew/efor/c42g0f20.html

[dd] "Formaldehyde: Markets & Economics" in: Chemical Week; **160**(17):30. May 6 1998.

[ee] GERBERICH (*opere citato*); p. 939.

[ff] http://www.chemexpo.com/news/PROFile980622.cfm

[gg] http://econom10.cc.sophia.ac.jp/needs/index.htm?formaldehyde

[hh] REUSS (*opere citato*); Vol. A11, p. 638.

[ii] GERBERICH (*opere citato*); Vol. 11, p. 940.

[jj] http://chems-energy.sriconsulting.com/pep/reports-reviws/96-2.htm

[kk] http://www.chemexpo.com/news/PROFile980622.cfm

[ll] http://www2.travlang.com/money/money.cgi?curr1=USD&curr2=AUD&span=12

[mm] http://www.chemexpo.com/news/PROFILEsept11.cfm

[nn] David J. BRENNAN; Process Industry Economics – An International Perspective; Institution of Chemical Engineers; Rugby; 1998; p. 277.

[oo] http://www.shef.ac.uk/~cpe/mpitt/costchem.html

[pp] http://www2.travlang.com/money/money.cgi?curr1=GBR&curr2=AUD&span=12

[qq] Philip J. CHENIER; Survey of Industrial Chemistry, 2nd edition; VCH; New York; 1992; §12.

[rr] BRENNAN (*opere citato*); pp. 276, 279.

[ss] CHE3109, 09/10/1998

[tt] Here averages from countries with many methanal plants are translated into Australian data. While the exact algorithm for translating the data is not known, there are still problems with the main alternative estimation procedure of getting Australian 'spot prices' on a given date. Those spot prices are likely to be **unrepresentative**, due to the fluctuations in prices outlined in the body of this report, which would be more 'damped' in the overseas data (*i.e.* a smaller 'relative' standard deviation is expected in the overseas data when taken as an annual average). The import parity condition always applies.

[uu] An esteemed associate of MonMark, Mr. P. Hersbach, who is regarded by many in the industry as an expert in the field of economic indicators has recommended that the GDP be used to predict **industrial** inflation rates such as methanal selling prices. Specifically, that an "implicit price deflator" be used.
The author is concerned that this could possibly add unwarranted complexity to the computation, and justifies the use of a CPI (based primarily on 'consumer goods') by the principle of 'what goes around, comes around'. That is, while

methanal is not directly represented in the CPI, it is assumed that it is vicariously present due to the interdependence of cash flows in both industry and the consumer world.

[vv] Given that economic indicators are composed of products in their development, growth and maturity phases, these will give some weighted average of the inflation rates applicable to those phases, with the weighting varying from one indicator to another. Given that methanal is a mature good, its inflation rate would be expected to be, on average, below such a weighted mean.

[ww] http://www.chemexpo.com/news/PROFile980622.cfm

[xx] For example commentary on the television programme "Nightly Business News," with a example of an internet-stock whose nominal value is increasing very rapidly despite forecast **losses** for the medium term is 'Amazon.com'.

[yy] Being the problems related to computers not being programmed so that they are able to correctly identify certain dates, in particular beginning from 01/01/2000. This will cause many failures if not fixed, but is troublesome and expensive to fix.

[zz] Although historically wars tend to **boost** economies.

[aaa] CHENIER; (*opere citato*); §12.

[bbb] REUSS (*opere citato*); Vol. A11, p. 639.

[ccc] REUSS (*opere citato*); Vol. A11, p. 637.

[ddd] GERBERICH (*opere citato*); p. 939.

[eee] O. P. KHARBANDA; Process Plant & Equipment Cost Estimation; Sevak Publishers; Bombay; 1974; p. 159.
Also **quoted** in: also quoted in Donald E. GARRETT; Chemical Engineering Economics; Van Nostrand Reinhold; New York; 1989; p. 374.

[fff] John Howard PERRY (Ed.); Perry's Chemical Business Handbook; McGraw-Hill Book Co.; New York; 1954; p. 6-190.

[ggg] GARRETT (*opere citato*); p. 365.

[hhh] Robert Howard PERRY (Ed.) *et alii*; Perry's Chemical Engineers' Handbook, 6th edition; McGraw-Hill; New York; 1984; p. 3-38.

[iii] http://www.chemexpo.com/news/PROFILE980803.cfm

[jjj] http://www2.travlang.com/money/money.cgi?curr1=USD&curr2=AUD&span=12

[kkk] http://www.shef.ac.uk/~cpe/mpitt/costchem.html

[lll] R. K. SINNOTT; Coulson & Richardson's Chemical Engineering, Volume 6: Chemical Process Design, 2nd edition; Pergamon Press; U.K.; ; p. 228.

[mmm] BRENNAN (*opere citato*); pp. 276, 279.

[nnn] http://www.chemexpo.com/news/PROFILE980803.cfm

[ooo] http://www.chemexpo.com/news/PROFile980622.cfm

[ppp] Marc S. REISCH; "Top 50 Chemicals Production Steadied in 1986" in: Michael HEYLIN (Ed.); Chemical and Engineering News; Washington D.C.; April 13, 1987; Vol. **65**(15), pp. 21f.

[qqq] GARRETT (*opere citato*); p. 357.

[rrr] BRENNAN (*opere citato*); pp. 276, 278.

[sss] GERBERICH (*opere citato*); p. 940.
Methanal is commonly considered a commodity item, in which case the profit margin would be comparatively low, and hence the manufacturing costs would constitute a very large proportion of its selling price. However the situation is complicated by the fact that methanal is sold in different 'grades', leading to a slightly higher viable profit margin than may otherwise have been expected.

[ttt] From GARRETT (*opere citato*), p. 322 we see that a $300 t.d^{-1}$ methanal plant would cost approximately $3.6\times10^{6}\$_{1987}$ (U.S.) for production from methanol. For a turn-over ratio of 1:1 this corresponds to a selling price of only $33\$_{1987}.t^{-1}$ (U.S.)! This is clearly inconsistent with the other data presented.
Two reasons: plant cost data is out of date or non-representative; turnover ratio not ~1.