The objects of this paper are:

- To review the manufacture of ethanol and methanol.
- To compare current costs of manufacture.
- To look at current use situation.
- To comment on the current government subsidies for methanol and ethanol produced from renewable resources.
- To consider the possibilities of making methanol and ethanol from various renewable resources.

**METHANOL**

Methanol, known as "Wood Alcohol" for generations, was initially produced as a by-product from the destructive distillation of wood. Pyrolygenous liquor, from heating wood in the absence of air, contains some 4 percent methanol and 7 percent acetic acid. Thus, wood produced the majority of methanol (and other by-products such as charcoal and fuel gas) until the mid 1920's.

Synthesis of methanol directly from H2 and CO appeared in the 1920's (in some cases methanol was a step in the purification of H2/N2 mixtures on route to ammonia synthesis). Methanol is still made directly from H2 and CO, which can be made from any hydrocarbon source. At present, natural gas is the major source, however, coal, oil, solid waste, and wood can and are being used to make methanol.

Methanol use (and price) have climbed, particularly in the past few years as shown in Figure #1. Figure #1 also illustrates that MTBE has been the significant driver of methanol demand in recent years.

The overall methanol market in the U.S. is expected to continue increasing by perhaps 10% in the next four years. At the same time, because of gas limitation in the U.S., imports are projected to increase from low priced gas locations with relatively low shipping costs to the U.S.

MTBE, the major driver in the past few years, has recently suffered some setback but is expected to continue growing at a moderate rate instead of the explosive rate of 1990 through 1995. The ETBE/Ethanol situation, briefly discussed below, has and will have considerable effect on the MTBE and methanol demand.

Federal Tax Credits in the past years for so-called renewable feed based fuel and gasoline additives (currently 54¢/gal. for ethanol and 60¢ for methanol) from 1978 raised production of ethanol from 800,000 short tons to 3,500,000 short tons by 1984. The credits or subsidies boosted the uneconomic use of corn based ethanol (food to fuel) but, unfortunately, did nothing for the biomass to methanol industry which makes considerable sense in the U.S. for several reasons:

1. Biomass* is available up to a large percent of our fuel use.
2. Methanol produces the most economical fuel oxygenate, MTBE.
3. Methanol itself is an efficient, clean burning fuel. As the biomass to fuel industry develops, it will compete with gasoline with no subsidy.

*Biomass includes:
- Solid waste
- Wood
- Agricultural residues (see Table 5)

**ETHANOL**

Known as "Grain Alcohol" for the millennia, ethanol has been the basis of recreational beverages forever. It can be made from fruit or sugar containing materials such as

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Keywords: Methanol, Ethanol, Manufacture
molasses. For fuel use in the USA, it is made from starchy materials such as corn, barley and sorghum. These are all renewable resources and require, for example, about 0.38 bushel of corn per gallon of 100% ethanol. There are various by-products depending upon which system is used.

The "Wet Mill" system produces by-products such as germ, gluten and a small amount of CO2. The "Dry Mill" process produces DDGS (an animal feed supplement) and a small amount of CO2. There are disagreements in the industry as to which process is most economical. Apparently, it depends largely on the return from by-products at any particular time in the overall economy.

Ethanol is also made from petroleum sources by reaction of ethylene to ethyl sulfates and then hydrolysis to crude ethyl alcohol and dilute sulfuric acid (which is then concentrated for re-use). Another process produces ethanol directly from ethylene via hydration over a catalyst.

Subsidies to the ethanol industry have resulted in rapid changes in the past 15 years. Plant capacity in 1979 of only 20 MM gallons PA became 750 MM gallons PA in 1986 and in 1994 was some 1,400 MM gallons (renewable resource based). At the same time, because of variations in the cost of grain, raw materials (approximately 45% in 1994) and apparent reduction in demand (July 1994 data show 8% reduction in demand over 1993), many U.S. Government loan guaranteed ethanol plants have had difficulty.

The dramatic changes in ethanol demand in the USA over the last 30 years are illustrated in Figure #2.

In the recent past two things have happened to the ethanol/fuel industry:

1. The corn price has gone up from $2.75 in August 1995 to a current price of $3.90/bushel. At .38 bushels per gallon, this equals some 38¢ per gallon net increase (see Figure 9).
2. The public is at last becoming aware of the give-away of public funds by both political parties to corporations using corn uneconomically to make ethanol.

PRODUCTION COSTS

Methanol

Although methanol can be produced from various raw materials, natural gas remains the major raw material for production of methanol as illustrated in Figure #3.

This, of course, is the result of lower capital and operating costs for natural gas based methanol production versus methanol produced from other feedstocks as shown in Figure #4.

The result is that locations with low cost natural gas are able to make methanol and ship it to markets. This provides a means of using remote natural gas and shipping it to market as methanol for low polluting direct fuel use or as a raw material for MTBE (36% methanol), the leading current gasoline additive.

If it were decided to make methanol from wood, then costs might be some $200/Ton or $80.00/Ton above the cost from natural gas (approximately 25¢ per gallon above natural gas cost). Given the government tax credit of 60¢ per gallon for methanol made from sources other than petroleum, natural gas or coal, production from wood may be a very attractive option.

Ethanol

Assume corn as the feed stock and other utilities as follows:

<table>
<thead>
<tr>
<th>Utility</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam</td>
<td>$6.00/2000 lb. ton</td>
</tr>
<tr>
<td>Power</td>
<td>$0.05/KWH</td>
</tr>
<tr>
<td>Corn</td>
<td>$2.25/bushel [now $3.90]</td>
</tr>
<tr>
<td>By-product Sales</td>
<td>65% of corn cost (Wet Mill)*</td>
</tr>
<tr>
<td></td>
<td>50% of corn cost (Dry Mill)*</td>
</tr>
<tr>
<td>Depreciation, Taxes, Insurance and Maintenance</td>
<td>= 13% PA</td>
</tr>
</tbody>
</table>

*Assume 50% increase in by-product return with $3.90/bushel corn.
Capital costs versus plant capacity are as given in Figure #5 for methanol plants based upon conventional reforming of natural gas, wet mill ethanol process plants, and dry mill ethanol process plants. Then production costs versus plant capacity are as given in Figure #6.

Thus, methanol can be made from natural gas ($2.00/MM BTU Gas) versus ethanol from corn ($2.25/bushel) [$3.90/bushel] for approximate prices shown in Table 1.

However, if corn based ethanol receives 54¢ per gallon credit, in the $2.25/bushel corn it is somewhat less expensive than methanol per gallon. Also, since methanol has only 73% of the heating value of ethanol, ethanol should then win hands down as a direct fuel.

On the other hand, if renewable resourced methanol were used at 78¢ per gallon with a 60¢ per gallon credit, it would compete well with 98¢ ethanol (i.e. 78 - 60 = 18¢ methanol versus 98 - 54 = 44¢ ethanol). Also, methanol is 50% oxygen versus ethanol at 34.7%. Thus, if the water separation problem with direct methanol addition is solved with other additives, oxygen addition is easier with methanol.

Both the above paragraphs are considerably changed by the current $3.90 per bushel corn price. Thus, methanol without the tax credit is clearly ahead of ethanol on price at $3.90/bushel for corn with the tax credit (see Table 1 and Figure 9).

**MTBE and ETBE**

Major gasoline additives containing methanol and ethanol are MTBE (Methyl Tertiary Butyl Ether) and ETBE (Ethyl Tertiary Butyl Ether).

Table 2 shows the cost of production for MTBE based on:
1. approximate cost of methanol production at 50¢ per gallon
2. current methanol market price of 45¢ per gallon
3. subsidized methanol price of 78¢ - .60 (tax credit) = 18¢ per gallon

*Methanol from renewable resources (biomass)*

The same table also shows the production cost of ETBE based on:
1. approximate cost of ethanol production at $1.10 per gallon [1.35]*
2. subsidized price of $1.10 [1.35] - .54 (tax credit) = 56¢ per gallon [81¢]

*[ ] = based on corn at $3.90/bushel

Figure #7 is a plot of estimated production costs of MTBE and ETBE versus plant capacity showing the variation of production costs with ethanol / methanol feedstock prices. It shows relative per ton costs of MTBE (36% Methanol) and ETBE (45% ethanol). It does not show the effect of oxygen content on RFG mixtures. Oxygen contents are as follows:

<table>
<thead>
<tr>
<th>Ethanol</th>
<th>MTBE</th>
<th>ETBE</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.7%</td>
<td>18.2%</td>
<td>15.7%</td>
</tr>
</tbody>
</table>

Thus, for 2.0% and 2.7% oxygen mixtures the costs per gallon of RFG are shown in Table 3 for Ethanol, ETBE and MTBE.

In spite of the above figures, which show that ethanol is by far the most economical oxygogenate of these three, particularly with the U.S. Government subsidy and other State benefits, and that ETBE (with the Tax Break) and MTBE are quite competitive, the published information to date shows that marketers are choosing MTBE by some 80% to 10% with another 10% undecided. There is some indication that ethanol may be in short supply, however, prices do not show as much variation in ethanol price as has occurred in methanol, for example. Thus, a more important consideration for ethanol may be the vapor pressure effects in summer and the problems with switching from one oxygogenate to another as well as the question of who makes which material and whether blenders are concerned with cost of production or market price.

US Gulf Coast market prices for MTBE and Ethanol are illustrated in Figure #8.
ENERGY USE

A brief review of the cost of energy use in the manufacture of ethanol and methanol (see Table 4) indicates that per gallon of either energy costs are similar neglecting the energy required to make corn fed into the ethanol process.

While manufacture of methanol from natural gas seems to use the least energy, methanol from wood (including the wood), costs only 40% more for energy than the dry mill ethanol system (excluding the cost of corn).

Figures prepared by the U.S. Dept. of Energy indicate that some 40 quadrillion BTU/year can be available through wood utilization in our forests. Another 4.2 quads is available from forest residues. Of this, the Department of Energy estimates that 6 quads can be captured. Other agricultural residues and municipal solid waste add up to some 4 quads for a total of some 10 quads that can be converted to ethanol or methanol.

Table 5 shows the estimated production of ethanol or methanol from these materials. The projected amounts are $54 \times 10^9$ gallons of ETOH in the year 2000 or $154.7 \times 10^9$ gallons of MEOH in the year 2000 (equals 8.7 quads of energy). Total energy use in the U.S. in 1992 has been estimated at 82 quads.

CONCLUSIONS

1. Methanol can be made for about half the cost of ethanol per gallon.
2. More methanol than ethanol (about 3 times as much) can be made from renewable raw materials available.
3. Subsidies and loan guarantees to ethanol producers have benefitted a few but by and large they have not brought about a strong ethanol based fuel sector. (Note the upset in ethanol caused by the high price of corn this year.)
4. It appears that encouraging ethanol production from corn over methanol from natural gas actually results in use of more fossil fuel for energy than if the energy were used directly. Further, it appears that methanol from wood using 16¢ worth of power per gallon will consume less fossil fuel energy than ethanol from corn (20¢/gal., excluding the energy used in growing the corn).
5. The current tax subsidy for renewable resource based methanol and MTBE, the use of wood as a feedstock may be an attractive option.
6. Use of corn to make fuel seems to be a waste. Corn is a food. It could be used to feed people in areas of the world suffering from lack of basic food.

LITERATURE CITED

### TABLE 1
CORN AT $2.25 / BUSHEL

<table>
<thead>
<tr>
<th>CAPACITY</th>
<th>METHANOL $/GAL</th>
<th>ETHANOL $/GAL</th>
<th>AVERAGE DELTA $</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 STD</td>
<td>64.50</td>
<td>[135.00]</td>
<td>[140.00] 99.00</td>
</tr>
<tr>
<td>1000 STD</td>
<td>53.25</td>
<td>[126.00]</td>
<td>[133.00] 92.00</td>
</tr>
<tr>
<td>1500 STD</td>
<td>48.61</td>
<td>[122.00]</td>
<td>[130.00] 89.00</td>
</tr>
</tbody>
</table>

[@ $3.90/bushel. Includes 50% increase in by-product sales price]

### TABLE 2
MTBE and ETBE PRODUCTION COST

<table>
<thead>
<tr>
<th>PLANT CAPACITY (STD)</th>
<th>MTBE</th>
<th>ETBE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>607</td>
<td>704</td>
</tr>
<tr>
<td>Units</td>
<td>Unit Price</td>
<td>Unit Cons.</td>
</tr>
<tr>
<td>Isobutylene for MTBE</td>
<td>$200</td>
<td>0.64</td>
</tr>
<tr>
<td>Methanol</td>
<td>$200</td>
<td>0.55</td>
</tr>
<tr>
<td>Ethanol</td>
<td>$200</td>
<td>0.364</td>
</tr>
<tr>
<td>Steam</td>
<td>$0.006</td>
<td>1,000</td>
</tr>
<tr>
<td>Power</td>
<td>$0.05</td>
<td>$80</td>
</tr>
<tr>
<td>Cooling Water</td>
<td>$0.113</td>
<td>$97</td>
</tr>
<tr>
<td>Operating</td>
<td>$480</td>
<td>$480</td>
</tr>
<tr>
<td>Overhead (150%)</td>
<td>$720</td>
<td>$720</td>
</tr>
<tr>
<td>REPAIR &amp; MAINTENANCE</td>
<td>$698</td>
<td>$768</td>
</tr>
<tr>
<td>LABORATORY, SUPPLIES, &amp; MISC.</td>
<td>$175</td>
<td>$175</td>
</tr>
<tr>
<td>TOTAL OPERATING COST</td>
<td>$29,256</td>
<td>$29,488</td>
</tr>
<tr>
<td>INTEREST (10% Debt)</td>
<td>$1,396</td>
<td>$1,536</td>
</tr>
<tr>
<td>TAXES &amp; INSUR. (2%)</td>
<td>$465</td>
<td>$512</td>
</tr>
<tr>
<td>DEPRECIATION</td>
<td>$2,327</td>
<td>$2,560</td>
</tr>
<tr>
<td>NET PRODUCTION COST WITHOUT MEOH/ETHOH</td>
<td>$33,445</td>
<td>$34,095</td>
</tr>
<tr>
<td>PRODUCTION COST / ST MTBE WITHOUT MEOH</td>
<td>$166.96</td>
<td></td>
</tr>
<tr>
<td>PRODUCTION COST / ST ETBE WITHOUT ETHOH</td>
<td>$146.76</td>
<td></td>
</tr>
<tr>
<td>PROD. COST / ST MTBE - MEOH AT $0.50 / GAL.</td>
<td>$221.56</td>
<td></td>
</tr>
<tr>
<td>PROD. COST / ST MTBE - MEOH AT $0.45 / GAL.</td>
<td>$216.10</td>
<td></td>
</tr>
<tr>
<td>PROD. COST / ST MTBE - MEOH AT $0.18 / GAL. (.78, 60)</td>
<td>$186.62</td>
<td></td>
</tr>
<tr>
<td>PROD. COST / ST ETBE - ETHOH AT $0.95 / GAL. [at 1.35/gal]</td>
<td>$276.11</td>
<td></td>
</tr>
<tr>
<td>PROD. COST / ST ETBE - ETHOH AT $0.39 / GAL. (with $0.54/gal Tax Subsidy) [$0.81/gal]</td>
<td>$199.86</td>
<td></td>
</tr>
</tbody>
</table>

885
### TABLE 3
**CORN AT $2.25/BUSHEL**

<table>
<thead>
<tr>
<th></th>
<th>2%</th>
<th>2.7%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$/Gal.</td>
<td></td>
</tr>
<tr>
<td>Ethanol - Wet Milled (TB)</td>
<td>[7.25]</td>
<td>5.24</td>
</tr>
<tr>
<td>Dry Milled (TB)</td>
<td>[7.66]</td>
<td>5.30</td>
</tr>
<tr>
<td>ETBE - (ETOH Cost)</td>
<td>[14.04]</td>
<td>11.75</td>
</tr>
<tr>
<td>MTBE - (MEOH Cost)</td>
<td>[10.92]</td>
<td>8.12</td>
</tr>
<tr>
<td>&amp;</td>
<td>[8.84]</td>
<td>6.68</td>
</tr>
</tbody>
</table>

**TB** = With Tax Break

[ ] = Corn at $3.90/bushel

### TABLE 4
**ENERGY COST PER GALLON OF PRODUCT**

<table>
<thead>
<tr>
<th></th>
<th>$/GAL.</th>
<th>NET CORN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>COSTS</td>
</tr>
<tr>
<td>Ethanol Wet Mill Steam &amp; Power</td>
<td>0.24*</td>
<td>30$/gal. [52]</td>
</tr>
<tr>
<td>Dry Mill Steam &amp; Power</td>
<td>0.20*</td>
<td>45.5$/gal. [79]</td>
</tr>
<tr>
<td>Methanol From Natural Gas Natural Gas &amp; Power</td>
<td>0.186** (1.78 from gas)</td>
<td>**Includes Natural Gas at $2.00/MM BTU and wood at $20.00/Ton</td>
</tr>
<tr>
<td>From Wood</td>
<td>0.28** (.12 from wood)</td>
<td></td>
</tr>
</tbody>
</table>

[ ] = corn at $3.90/bushel

### TABLE 5
**Projected Maximum Alcohol Production from U.S. Biomass Resources**
(Source: U.S. Department of Energy)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ETOH</td>
<td>MEOH</td>
<td>ETOH</td>
<td>MEOH</td>
</tr>
<tr>
<td>Wood</td>
<td>23.5</td>
<td>86.3</td>
<td>21.8</td>
<td>80.2</td>
</tr>
<tr>
<td>Agricultural residues</td>
<td>9.1</td>
<td>33.4</td>
<td>10.3</td>
<td>38.1</td>
</tr>
<tr>
<td>Grains</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>2.3</td>
<td>2.1</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Wheat</td>
<td>1.2</td>
<td>1.4</td>
<td>1.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Grain Sorghum</td>
<td>0.4</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Total Grains</td>
<td>3.9</td>
<td>3.8</td>
<td>2.8</td>
<td>2.3</td>
</tr>
<tr>
<td>Sugars</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cane</td>
<td>0.2</td>
<td>0.2</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Sweet Sorghum</td>
<td>0.2</td>
<td>0.2</td>
<td>3.0</td>
<td>8.3</td>
</tr>
<tr>
<td>Total Sugars</td>
<td>0.4</td>
<td>3.7</td>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>MSW</td>
<td>2.2</td>
<td>8.8</td>
<td>2.3</td>
<td>9.2</td>
</tr>
<tr>
<td>Food Processing Waste</td>
<td>9.2</td>
<td>0.9</td>
<td>2.5</td>
<td>9.9</td>
</tr>
<tr>
<td>Citrus</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Cheese</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>All Other</td>
<td>0.2</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Total Processing Waste</td>
<td>0.7</td>
<td>0.9</td>
<td>1.7</td>
<td>2.9</td>
</tr>
<tr>
<td>TOTAL</td>
<td>39.2</td>
<td>128.3</td>
<td>39.2</td>
<td>127.5</td>
</tr>
</tbody>
</table>

Based on following biomass-alcohol conversion factors: Wood and agric. residues-173 gal methanol per dry ton, 47 gal ethanol per dry ton, Corn-2.86 gal ethanol per bushel. Wheat-2.7 gal ethanol per bushel. Grain sorghum-2.6 gal ethanol per bushel. Sugars-136 gal ethanol per ton fermentable sugars. MSW-100 gal methanol per dry ton, 25 gal ethanol per dry ton. Citrus waste-107 gal ethanol per dry ton. Cheese waste-95 gal ethanol per dry ton. Other food processing waste-90 gal ethanol per dry ton.
Figure #1: US METHANOL CONSUMPTION
By End Products

Figure #2: US ETHANOL CONSUMPTION
By End Product

Figure 3: WORLD METHANOL PRODUCTION
BREAKDOWN BY FEEDSTOCK

Methanol consumption from other markets range from 0.82 - 1.35 MM short tons Per Year
Total methanol consumption in the US in 1995 approximately 8 MM short tons

(77.8%) NATURAL GAS
(13.9%) OTHER/UNSPECIFIED
(1.2%) COAL
(7.3%) RESIDUAL OIL

Source: Various
Figure #4: MEOH PRODUCTION COST VS. FEEDSTOCK COST
NATURAL GAS, COAL, WOOD, & RESIDUAL OIL

- Coal: $10 to $51/MMBTU
- Oil: $5 to 35/MMBTU

Based on 2000 MTD Methanol Plant

Figure #5: PLANT CAPITAL COSTS VERSUS CAPACITY
METHANOL & ETHANOL

- MEOH - REFORMING
- ETOH - WET MILL
- ETOH - DRY MILL

Figure #6: PRODUCTION COSTS VS PLANT CAPACITY
METHANOL & ETHANOL

Ethanol production cost based upon $2.25 per bushel corn price
See table 1 for $3.90 per bushel corn
Figure #7: ESTIMATED PRODUCTION COSTS
MTBE VERSUS ETBE

$300

$300

$250

$200

$150

PLANT CAPACITY - SHORT TONS PER DAY

MTBE (MEOH $0.90/gal)

ETBE (ETOH $1.35/gal)

ETBE (ETOH $1.10/gal)

MTBE (MEOH $0.50/gal)

ETBE (ETOH $0.61/gal)

MTBE (MEOH $0.18/gal)

FIG. 8: MTBE & ETHANOL SPOT PRICES
US GULF COAST

$1.2

$1

$0.8

$0.6

$0.4

$0.2

Oct-93
Feb-94
Jun-94
Oct-94
Feb-95
Jun-95
Oct-95
Feb-96

MTBE

Ethanol

Ethanol Price is less $0.54 / gal tax subsidy

Figure #9: ETHANOL FEEDSTOCK PRICES

$4.5

$4

$3.5

$3

$2.5

$2

$1.5

May-94
Sep-94
Jan-95
May-95
Sep-95
Jan-96

Barley

Sorghum

Corn