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South Coast Air-Quality Management District (SCAQMD)

The Permitting and Commercialization of Landfill Gas-Based Methanol Production Facilities

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ABSTRACT

Current landfills emit copious quantities of methane, which is typically flared on-site. Such flaring results in significant emissions of oxides of nitrogen (NO_x), as well as potentially serious levels of toxics, greenhouse gases, and other flare gas contaminants. The district has worked closely with TeraMeth Industries (TMI) to establish the first demonstration plant in the world that will divert the gaseous waste stream from the BKK Landfill, located in West Covina, CA, through a syngas synthesis process, and produce 50 metric tons/d of methanol. Multiple replication of this technology is projected by TMI to be commercially competitive with worldwide methanol production economics. For example, contractual commitments for the long-term purchased product have been obtained. Permitting issues unique to landfills, such as site-specific gas composition, have also been addressed as part of this project. This article identifies:

1. The air-quality context of this facility;
2. The key permitting issues being addressed to facilitate the construction and operation of this facility; and
3. The commercial and economic implications of the plant design, including the potential future markets for this conversion technology.

Index Entries: Methanol; landfill gas; TeraMeth Industries; South Coast Air-Quality Management District; emissions.

AIR-QUALITY CONTEXT

Over 75% of the ozone exposure in the United States occurs in southern California. The South Coast Air-Quality Management District (SCAQMD) has overseen the introduction of a wide variety of air pollution control measures, which have reduced the exposure to urban ozone from approx 8000 h in the early 1980s to

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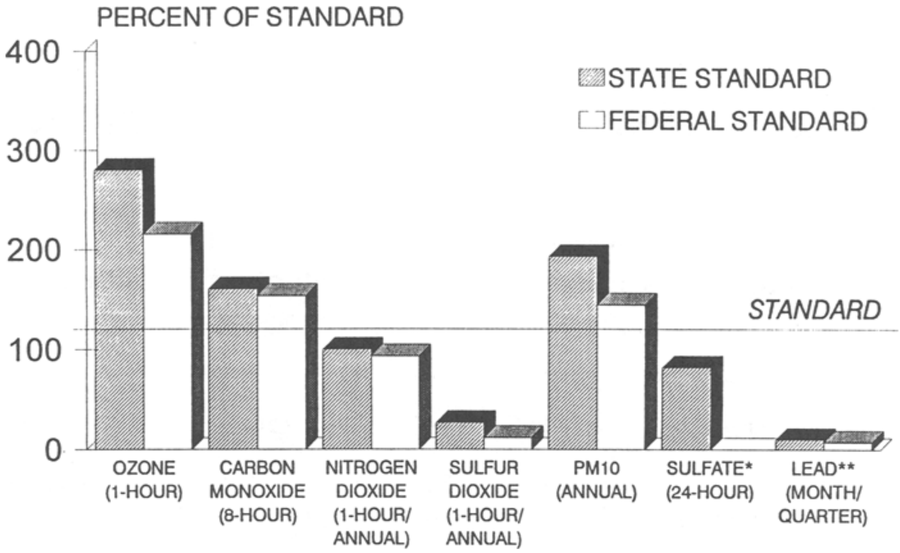

Fig. 1. Relative degree of excess of various air quality standards in the south coast air basin (1994 data).

≤4000 h during the 1990s. However, an additional 80% reduction in volatile organic compounds (VOC) and nitrogen oxides (NO_x) will be necessary to attain the federal ozone air-quality standard. Such reductions are necessary in light of the tremendous growth of population and vehicle miles traveled that has occurred in southern California. Figure 1 presents the percent of standard for each rule on state standards applicable for ambient air-quality. Particulate air pollution has come under increasing focus as a result of recent work by the California Environmental Protection Agency (Cal EPA). Recent Cal EPA studies indicate that for San Bernardino and Riverside counties, over 275 people each year die prematurely owing to ambient air pollution, primarily PM-10 exposure. Arden Pope has also reported on epidemiological studies that suggest that particulate air pollution is capable of reducing life expectancy by 3 yr for the most at-risk populations *(1)*. All of these health data give strong motivation to the SCAQMD to reduce emissions in the most expeditious manner.

The attainment of healthful air quality in southern California depends largely on the deployment of progressively lower emitting vehicles and cleaner burning alternative fuels. These alternative fuels include natural gas, methanol, ethanol, propane, electricity, and hydrogen. The short- and intermediate-term objectives for alternative and reformulated fuels utilization are listed in Table 1 *(2)*. At this point, the largest number of manufacturer-built alternative fuel vehicles in operation in California are methanol-compatible, flexible-fuel vehicles. The SCAQMD sees methanol as a key air-quality strategy, both in terms of light-duty and heavy-duty applications *(3)*.

Current landfills emit copious quantities of methane, which is typically flared on-site *(4)*. Such flaring results in significant emissions of NO_x, as well as potentially serious levels of toxics, greenhouse gases, and other flare gas contaminants *(5)*. SCAQMD has worked with TeraMeth Industries (TMI) to establish the first demon-

Table 1
Motor Vehicle VMT Penetration Assumptions
for 2010 Short- and Intermediate-Term Measures (Percent)

Vehicle class	Electric vehicle	Alternative fuels/ Reformulated fuels
Passenger cars	22	78
Light-duty trucks	15	85
Medium-duty trucks	0	100
Heavy-duty trucks	0	100
Urban buses	30	70

stration plant in the world that will divert the gaseous waste stream from the BKK West Covina Landfill, West Covina, CA, through a syn-gas synthesis process, and produce 50 metric tons/d of methanol *(6)*.

There are significant synergies that exist between the reduction in greenhouse gases and conventional ambient air pollutants, such as reactive organic gases (ROG) and NO_x from landfill operations on the one hand, and the development of renewable and locally generated alternative fuels, like methanol. Specifically, there are six synergistic benefits associated with a landfill gas (LFG) to methanol facility:

1. Mitigation of conventional air pollutant emissions, such as ROG, NO_x, and CO;
2. Mitigated local exposure to toxic LFG emissions, including dioxin;
3. Production of value-added methanol, which can be used as a fuel (M-85 or M-100) or for producing a gasoline additive methyl/tertiary/butyl/ether (MTBE);
4. Indigenous source of methanol for local users, such as Chevron (MTBE), the Los Angeles County Metropolitan Transportation Authority (M-100), and local fleet users of the California Fuel Methanol Reserve (M-85);
5. Reduces greenhouse gas emissions, such as CO_2 and methane; and
6. Renewable feedstock for methanol production, based on the continuing need for landfills and the resulting production of LFG.

It is precisely this synergy, that is at the heart of the SCAQMD's support for converting LFG-to-methanol, as is being pursued at the BKK Landfill facility by TMI. Multiple replication of this technology is projected by TMI to be commercially competitive with worldwide methanol production economics. For example, contractual commitments for the long-term purchased product have been obtained *(7)*. Permitting issues unique to landfills, such as site-specific gas composition, have also been addressed as part of this project. The next section addresses the key aspects of this production facility.

LFG-TO-METHANOL PRODUCTION *(8)*

The SCAQMD undertook a detailed air quality assessment of the conversion of LFG to methanol that compares the capturing of gas for the abatement methanol production process with the current process of flaring LFG as a means of minimizing LFG exposure to nearby resident populations. The basic conclusion of this analy-

Table 2
Emission Reductions Owing to the TMI Project

	Emissions, lb/d[a]						
	VOC	NO_x	CO	SO_x	PM_{10}	CO_2	CH_4
Baseline BKK without TMI	31	174	697	43	190	374,035	1479
TMI project							
Methanol production							
Direct	0.4	22.8	49.9	1.5	0	–171,152[b]	–1479[b]
Indirect	0.9	15.2	11.8	3.8	21.9	71	0
Total	(1.3)	(38)	(61.7)	(5.3)	(21.9)	(–171,081)[b]	(–1479)[b]
Flare emissions remaining	17.6	71.3	363.3	20.7	52.1	171,152	0
Total TMI project	(18.9)	(109.3)	(425)	(26)	(116)	(71)	0
Net changes in emissions	–12.1	–64.7	–27.2	–17	–74	–373,964	–1479

[a]Data from TMI and SCAQMD.
[b]CO_2 and CH_4 taken from flare gas stream for methanol production.

sis indicates that there are significant environmental benefits from LFG-based methanol production. These benefits include reductions in all of the following: toxic air contaminants, such as benzene; ambient air pollutants, such as NO_x, oxides of sulfur (SO_x), and carbon monoxide (CO); volatile organic compounds; and global warming gases, such as methane and carbon dioxide (CO_2). The specific reductions in these pollutants, owing to the conversion of this waste methane and CO_2 stream to methanol production, are detailed in Table 2, and summarized in Fig. 2.

These reductions are estimated based on the TMI proprietary LFG conversion to methanol process *(9)*. In this process, methane is first reformed in the presence of steam and a proprietary catalyst, when two reactions occur *(10)*:

$$CH_4 + H_2O \leftrightarrow 3H_2 + CO \tag{1}$$

$$H_2O + CO \leftrightarrow H_2 + CO_2 \tag{2}$$

The resulting gas, which is referred to as synthesis gas, is then fed into a second proprietary catalyst to form methanol by the following two equations:

$$CO + 2H_2 \leftrightarrow CH_3OH \tag{3}$$

$$CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O \tag{4}$$

Methanol production will be achieved with >99.5% selectivity/catalyst. The methanol is to be produced at US fuel grade—"Grade A" quality, i.e., 99.6% methanol or more *(11)*. This process also incorporates state-of-the-art vapor containment and recycle loops so as to maximize pollution savings over current gas flaring. For example, specific vapor returns lines have been designed from all methanol transfer and storage areas, not just for containment, but for specific addition back (recycle) into process/fuel gas lines within the TMI facility.

The TMI raw LFG is 3.6 million standard cubic feet per day (MMCFD). The plant will produce a maximum of 16,667 gal of methanol, which will have a sufficient quality to supply M100 chemical or MTBE markets. The exact facility is 203 × 77 ft, including on-site product storage. If internally generated power is necessary, 4.3 MMCFD of gas will be used. The project will consume 1.3 MW of electricity and 11,531 gal/d of water intake.

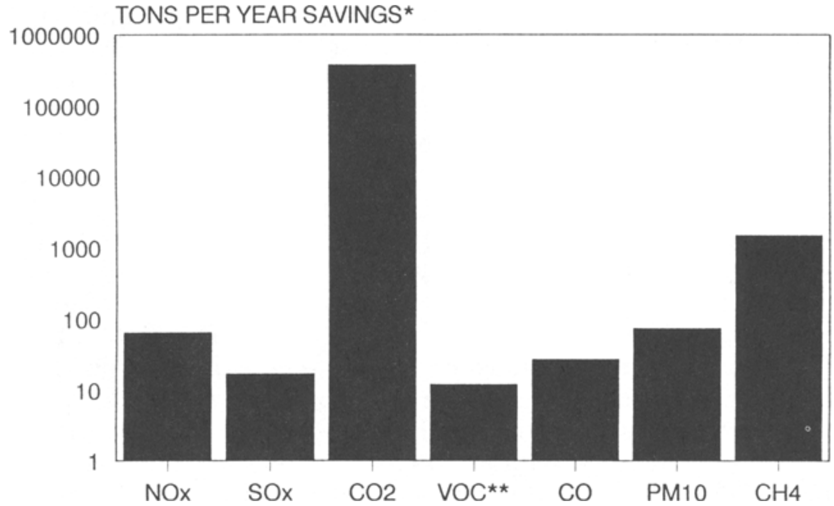

Fig. 2. Emission savings over gas flaring today.

In evaluating the emissions implications of the design for the BKK site, the SCAQMD considered the following two general emission sources: (1) The equipment operating at the landfill, primarily mobile sources with some stationary sources, and (2) the combustion of LFG, which is generated as a decomposition byproduct from the landfill refuse.

The BKK landfill is currently expected to reach its design capacity in 1995 *(12)*. At that time, existing operational activities are expected to cease, although LFG emissions could continue for an estimated 20–40 yr into the future *(13)*. The current LFG flare operated at BKK consumes 9.2 MMCFD of LFG *(14)*. This results in the following emissions:

Pollutant	Pounds per day
Carbon monoxide	697
VOC	31
NO_x	174
Sulfur oxides	4.3
PM-10	190

Significant emissions also occur owing to on-road and off-road material hauling trucks, as well as fugitive dust. The SCAQMD also assessed the solvent usage, storage tanks, and fueling handling, and the indirect emissions from off-site energy production.

Given that the proposed LFG-to-methanol facility is aimed at reducing the LFG emissions, specific analysis was done on the current gas composition from the landfill by BKK, Coast to Coast Analytical of San Luis Obispo, CA, Hurst Labs of Atlanta, GA, and EMSL of New Jersey. The current gas is composed of 30–40% methane, 25–30% carbon dioxide, 25–35% nitrogen, and 3–8% oxygen *(15)*. Pursuant to SCAQMD Rule 1150.1—Control of Gaseous Emissions from Active Landfills, the LFG collection and control system is required at active landfills to reduce LFG emissions. Once the LFG is collected, it is typically sent to a device called a "knockout vessel," which removes moisture (condensate) and some particulates. The condensate removed from the knockout vessel along with any leachate (a liquid rain water, for example, contaminated as a result of contact with the landfill refuse) is then sent to the leachate treatment plant *(16)*. Following microbial degradation of organics to required levels, the water is recycled and used on site. The carbon support for the bacteria is renewed periodically with the residual carbon granules disposed of off site *(17)*. After the condensate is removed from the LFG, it is then disposed of pursuant to SCAQMD Rule 1150.1. The LFG can be disposed of by any of the following methods: combustion, gas treatment and subsequent sale, and processing off site, or other equivalent methods. LFG at the BKK landfill site is disposed of through combustion flares, a turbine, and a boiler as described below. Total daily capacity of these combustion devices is approx 26.6 MMCFD. During LFG combustion, toxic air contaminants are also emitted to the atmosphere *(18)*. SO_x emissions are also formed from sulfur in the LFG. In the LFG, sulfur is found in two forms: active sulfur (hydrogen sulfide and mercaptans) and "organic sulfur" (carbon disulfide, carbonyl sulfides, dimethyl sulfide, dimethyl disulfides, and so forth). Flaring of both active and organic sulfur compounds produces SO_x emissions *(19)*.

According to SCAQMD permits, the flare system's operating capacity is 18.7 MMCFD. It is likely that the flare system does not typically operate at 100% capacity because up to 9.5 MMCFD may be diverted to the boiler. The combustion efficiency of the flare is 98.45% *(20,21)*. In addition, the BKK operates a turbine to generate electricity. The power from this turbine and steam plant is sold to Southern California Edison and not used directly by the existing facilities. A steam boiler utilizing 9.5 MMCFD is also operated at the landfill site. At the BKK site, toxic air contaminant emissions are also generated as a result of combustion of the above-described LFG turbine, boiler, and flare systems *(22)*. Based on data submitted for this facility, in accordance with the toxic emissions reporting requirements of AB 2588 enacted by the California legislature, the total maximum incremental cancer risk (MICR) for the existing boiler operations only is estimated at 3.2×10^{-6} *(23)*. The following toxic compounds are emitted from the total facility: benzene, carbon tetrachloride, chloroform, methylene chloride, vinyl chloride, and ethylene dibromide. These toxic air contaminants are currently regulated by SCAQMD Rule 1401 New Source Review of Carcinogenic Air Contaminants. Table 3 provides the MICR values for the baseline condition of the flares prior to the TMI project. It should be noted that dioxin in LFG flare exhaust in the northern German city of Bielefeld has been measured at up to 14.85 ng/cubic meter, whereas raw gas has been found to be essentially free of dioxin. This datum has been compiled by the German research institute, ITU-Forshung, in collaboration with the Berlin Environmental Office *(24)*. Based on this analysis, it is prudent to extrapolate that dioxin emissions can be reduced by the diversion of flare gas to an LFG-to-methanol facility.

Figure 3 provides a schematic description of the TMI LFG-to-methanol process. The LFG-to-methanol facility will utilize 3.6 MMCFD of LFG for the production of methanol that would otherwise have been sent to the flare system for combustion. Of this gas stream, 7% will be used as combustion fuel in the heat exchanger. The process of converting LFG utilizes a low NO_x burner located inside a heat exchanger to provide heat for a reformer unit. The heating capacity of the low NO_x burner according to the burner manufacturer, John Zinc Co., is 31.74 million BTU/h, whereas the NO_x emission factor for this low NO_x burner is 0.03 lb of NO_x/million of BTU *(25)*. This results in the burner emissions of 22.8 lb of NO_x/d.

Table 3
Toxics From LFG Flare Prior to TMI Project

	Impact from existing system				
Toxic components of LFG	Emissions to atmosphere, lb/d	Unit risk factor, $\times 10^{-6}/\mu g/m^3$	Dispersion factor, X/Q	Multiple pathway factor, MP	MICR value, $\times 10^{-6}$
Benzene	0.000737	29	0.046	1	0.0009831
Carbon tetrachloride	0.001	42	0.046	1	0.001932
Chloroform	0.000737	5.3	0.046	1	0.0001796
Ethylene dichloride (1,2-Dichloroethane)	0.000685	20	0.046	1	0.0006302
Methylene chloride (Dichloromethane)	0.001262	1	0.046	1	0.000058
Trichloroethylene	0.001051	2	0.046	1	0.0000966
Vinyl chloride	0.000474	78	0.046	1	0.0017007
Ethylene dibromide	0.0001211	71	0.046	1	0.0039551
Flare (15.36)	0.007202				0.0095353

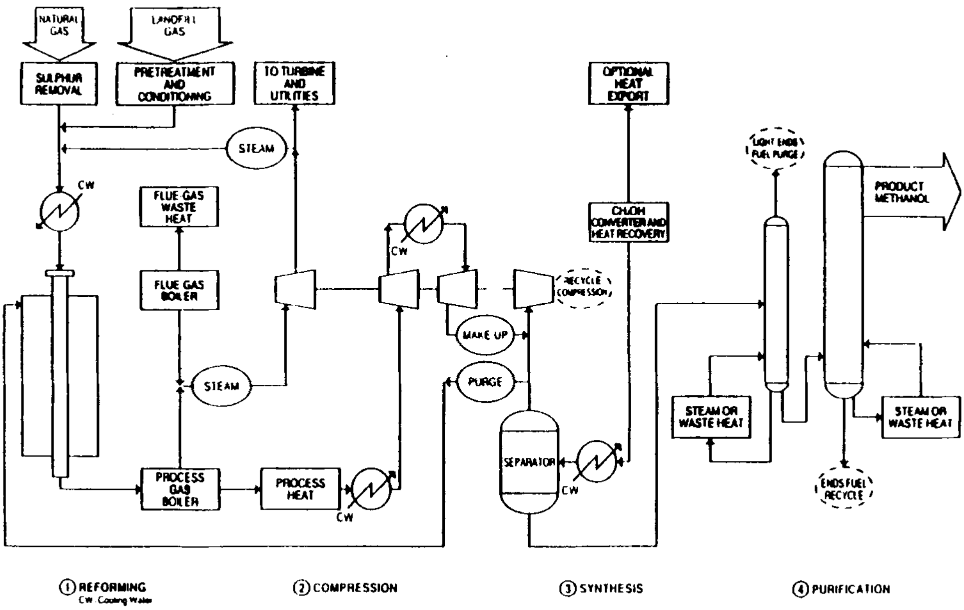

Fig. 3. TMI LFG-to-methanol process.

The carbon monoxide content in the proposed project's final combustion gas stream is 50 ppm for an aggregate exhaust flow rate of 563,570 standard cubic ft/h. Based on this CO emission factor, the LFG methanol project will emit approx 2 lb CO/h. Because the production process avoids combustion of active sulfur compounds by trapping them in an iron-adsorbent bed prior to combustion, SO_x emissions are projected to be approx 1.53 lb/d. Since the TMI process is an enclosed process, any potential particulate emissions from the nickel alloy catalyst used in the reformer are not anticipated. Methanol fuel loading emissions were also estimated to be 0.03 lb of VOC/d *(26)*.

Based on the SCAQMD's comprehensive evaluation of the LFG-to-methanol process, it is clear that eliminating LFG combustion of 3.6 MMCFD produces net emission reductions at the landfill site. Consequently, the proposed project is expected to improve air quality in the basin as a result of emission reductions at the landfill *(27)*. In addition, the toxic emissions from the landfill will be partially mitigated. The MICR for the proposed TMI project is more than 4 orders of magnitude cleaner than the significance threshold, which the SCAQMD uses for Rule 1401. Specifically, the MICR for the TMI project is 6.1×10^{-11}, which is easily in compliance with the SCAQMD's significance threshold criteria of 10×10^{-6}.

The LFG-to-methanol plant will also help reduce global warming gases. The existing flare emits 374 thousand lb/d of CO_2 and 1479 lb/d of nonconverted methane. The proposed project will use the CO_2 from the landfill gas itself at a rate of 171,152 lb/d. In addition, 202,842 lb/d of CO_2 will be utilized from approx 72,458 lb of methane combustion, as well as 1479 lb of nonconverted methane for an existing landfill to manufacture methanol. The proposed project is expected to emit approx 71 lb of CO_2. Thus, the proposed TMI project is expected to produce a net daily reduction of approx 373,964 lb/d of CO_2 and 1479 lb of methane emissions.

COMMERCIAL IMPLICATIONS

There are significant commercial implications for this LFG-to-methanol project. All landfills generate methane as the waste disposed of in the landfill decays. Many landfills have experienced methane release problems *(28–31)*. In response to growing methane-related problems, state and federal regulatory agencies and landfill operators have developed and are increasingly implementing methane control and handling systems to reduce these risks *(32)*. However, low contract prices for power purchases are a serious impediment to LFG turbine projects, especially with the demise of the Standard Offer Four type contracts in California or their equivalent in other parts of the United States. Upgrading gas to pipeline quality is also facing increasingly stringent regulation, particularly in reference to residual vinyl chloride *(33)* and dioxin contaminants. TMI and the SCAQMD have therefore joined in partnership to establish an abatement gas process to produce biomethanol for as long as LFG is being produced at this location. This is estimated to be 20–30 yr, with applicable tax credits for this renewable methanol. Consequently, this project will provide a supply of indigenous and competitively priced methanol. TMI has concluded long-term off-take contracts with Chevron USA for the renewable methanol, which are structured on a take or pay basis. This in turn provides TMI with private sector financing alternatives. This first in the world facility is scheduled for start-up during the first quarter of 1996 according to TMI *(34)*. The city of West Covina has recently determined that a full Environmental Impact Report will not be required for this facility. At this time, the city is pursuing a Mitigated Negative Declaration, which will significantly expedite the permitting of this facility *(35)*. The SCAQMD is working closely with the city of West Covina to expedite its permitting.

The methanol utilized from this facility can be used as a renewable ingredient in MTBE for federal and state reformulated gasoline requirements. The demand for methanol has accelerated markedly in the last year as numerous states have opted into federal requirements for reformulated gasoline. As California moves to the implementation of Phase 2 gasoline in March 1996, this will create additional demand for renewable methanol. As an indigenous regional and renewable methanol source, volume output of the TMI facility can supply approx 1/3 (397 barrels/d) of the renewable oxygenate supply for a 1000 barrel/d MTBE facility at a major refinery. TMI is also in the process of committing to additional sites in California, New Jersey, Pennsylvania, and other nonattainment air quality regions in the US.

The TMI project is eligible for several important incentives. Alcohol fuel credits of 60¢/gal can generate $3.3 million annually; section 29 tax credits of 15¢/CFD of gas will generate $568,000 annually; California investment tax credits and sales tax exemptions will provide lump sum incentives worth $600,000 and $500,000, respectively.

The commercial market for methanol is expected to continue to grow as further commercialization occurs with flexible-fuel vehicles and, in the long term, with methanol-based fuel cells. The following section describes the current status of the methanol vehicle market.

THE MARKET STATUS OF METHANOL VEHICLES

As of April 1995, Ford, GM, and Chrysler have deployed more than 12,000 methanol-fueled flexible-fuel vehicles (FFVs) throughout California. This represents the single largest fleet of original equipment manufactured (OEM) alternative fueled vehicles (AFVs) in the United States. In the 1995 model year, Chrysler is offering the Dodge Intrepid for retail sale; Ford has sold out its allotment of 2500 1995 Taurus FFVs. Ford has marketed these vehicles using innovative incentives, such as free oil changes at 60,000 miles and no differential cost for the FFV option.

Another milestone in AFV commercialization will occur next year, when Ford plans to offer the redesigned 1996 model year Taurus FFV as a standard option in California. Major FFV development and demonstration efforts have also been undertaken at GM, Volvo, Nissan, Toyota, Honda, Mitsubishi, Mercedes Benz, Porsche, and other OEMs.

California's ongoing work with the OEMs to develop FFV technology over the last 7 yr is now paying off with commercialized low-emission vehicles. All three US OEMs have certified FFVs to the Transitional Low-Emission Vehicle (TLEV) standards—including the first midsized passenger cars to be certified as such. When operated on M85, FFVs are 50% cleaner than comparable gasoline vehicles after the lower ozone reactivity of their exhaust is taken into account. Through the California Fuel Methanol Reserve (CFMR), the wholesale price of fuel methanol is expected to be competitive with regular unleaded gasoline on a BTU equivalent basis, after the March 1996 introduction of Phase II gasoline.

Many prominent southern California companies now operate, or have announced plans to operate, FFVs in their fleet. These include such companies as ARCO, Eastman Kodak, IBM, Hewlett Packard, Pacific Bell, Union Bank, and Xerox, to name just a few. Hertz plans to purchase over 8000 FFVs by 1998 as part of their retail rental fleet at Los Angeles, Burbank, John Wayne (Orange County), and Ontario airports. This will be the largest rental company deployment of AFVs in US history. With more than 10,000 FFVs currently in use in California, the first plateau of FFV/M85 commercialization has been achieved. The local Metropolitan Transportation Authority also operates the largest methanol bus fleet in the United States *(36)*.

Achieving significant growth in sales of FFVs and fuel methanol will require expansion of the M85 refueling infrastructure. There are 52 public, 24-h refueling sites now in operation. Wide-scale availability of FFVs and M85 would most likely stimulate OEM development of dedicated M100 vehicles. Such vehicles can be optimized for the favorable combustion characteristics of methanol, and are more likely than M85 vehicles to be certified as ultra-low emission vehicles. Because existing M85 fueling facilities will also be compatible for pure methanol, a smooth transition would be possible over the longer term to a network of M100 stations. Such an expanding methanol infrastructure may also help accelerate the development and utilization of fuel-cell-powered passenger cars capable of operating on reformed methanol. Several OEMs are developing fuel cell passenger cars that operate (or will operate) on methanol, including GM and Mercedes *(37)*.

CONCLUSION

Over the next two decades, clean fuels, such as methanol, will play an increasingly important role in improving air quality. The use of alternative fuels is also a major stimulus to the US economy *(38)*. Urban areas throughout the US face continuing challenges related to urban air pollution, energy diversity, and global technology leadership. The TMI methanol production technology is considered to be a significant option for LFG abatement, which is well timed to coincide with the increasing market penetration of methanol v chides and reformulated gasoline. Vision, commitment, continuity in regulations, entrepreneurial spirit, and shared risk taking will be essential if major applications of this LFG-to-methanol technology are to continue. The international market for this technology is expected to grow. The synergies being created between the SCAQMD and innovative technology companies, such as TMI, are helping to foster this commercialization *(39)*.

REFERENCES

1. South Coast Air Quality Management District, Symposium on the Adverse Health Effects of Air Pollution, March 17, 1995.
2. South Coast Air Quality Management District, Air Quality Management Plan, September, 1994.
3. Wuebben, P., testimony to the U.S. Congress, House Subcommittee on Energy and Power, "Reinventing Baseline—The South Coast Air Quality Management District's Perspective on Low Emission Vehicles and Fuels," October 7, 1993.
4. USEPA Office of Air Quality Planning and Standards, "Air Emissions From Municipal Solid Waste Landfills," EPA Report 450/3-90-011a, March 1991.
5. California Air Resources Board, "Suggested Control Measures for Landfill Gas Emissions," September 13, 1990.
6. USEPA "Engineering Technologies for the Utilization of Landfill Gas; Section 2.3 Production of Methanol From Landfill Gas (TeraMeth Industries)," Report, in press, 1995.
7. New Fuels Report, "Chevron Signs Renewable Methanol Agreement with TeraMeth," *OxyFuel News,* April 24, 1995, "Chevron USA to be Primary Buyer of California Firm's Biomethanol," April 24, 1995.
8. SCAQMD, "Report on TeraMeth Industries Landfill Gas Abatement Facility," correspondence from Jack Broadbent, Director of Planning, to Jeff Collier, City of West Covina, October 4, 1994.
9. Dames and Moore, "TeraMeth Industries, Inc. Landfill Gas Abatement/Methanol Production Facility, Initial Study, to City of West Covina December 15, 1993.
10. Inside EPA's Environmental Policy Alert "Landfill Technology to Capture Some Toxic Emissions, Convert Methanol" April 26, 1995.
11. U.S. Army, Publication O-M-232J November 19, 1990.
12. Dames and Moore, OP. Cit.
13. California Air Resources Board, "The Landfill Gas Testing Program—Second Report to the California Legislature," June 1989. "The Landfill Testing Program: Data Analysis and Evaluation Guidelines," August, 1990.
14. SCAQMD, Op. Cit., October 4, 1994.
15. Dames and Moore, Op. Cit.
16. USEPA "Onsite Engineering Report of Wet Air Oxidation and PACT System Treatability Study at Zimpro/Passavant," Report "Preparation in Connection with Development of BDAT," November, 1989. Three Volume Final BDAT Background Document for F039 per NTIS Documents PB90-234337, 234345, 234352.
17. USEPA, "Simultaneous Sludge Disposal and Powdered Activated Carbon Regeneration. "Contractor/Vendor Report forwarded to TMI July 21, 1994.
18. SCAQMD, Op. Cit., October 4, 1994.
19. Bond, R. G., Straub, C. P., and Prober, R., eds. (1977) Stationary source emission factors, in *Handbook of Environmental Control, vol. 1: Air Pollution,* CRC, Boca Raton, FL.
20. Pohl, J. H., Lee, J., Payne, R., and Tichenor, B. A. (1986), Combustion efficiency of flares. *Combustion Sci. Technol.* **50**, 217–231.
21. Communication from Sanitation Districts of Los Angeles to Alan Bonny, TeraMeth Industries, September 10, 1993.
22. SCAQMD, Op. Cit., October 4, 1994.

23. Ibid.
24. Lahi, U. (1991), PCDD/PCDF balance of different municipal waste management methods. *Chemosphere* **232,** 8–10.
25. Private Communication of John Zinc Co. to TeraMeth Industries, Inc., July 21, 1993 per proprietary vendor burner design and specifications verification.
26. Communication from EMCO Wheaton to TeraMeth Industries, July 20, 1994.
27. SCAQMD, Op. Cit., October 4, 1994.
28. Lisk, D. J. (1991), Environmental effects of landfills. *Sci. Total Environment* **100,** 415–468.
29. Trash Talk About the Atmosphere (Re: Ontario Ministry of the Environment). Globe and Mail, Toronto, Canada, May 10, 1995.
30. Mauch, S. C. and Militana, L. M. Statistical modeling of ambient air toxics impacts during remedial investigations at a landfill site. *Biol. Abstr.* **41.**
31. Tighter Laws Landing on Landfills. *Chicago Tribune,* October 17, 1993, Section 7, p. 7.
32. Repa, E. W. (1995), *Clean Air Act Requirements for Landfills. Waste Age,* pp. 163–170.
33. California Air Resources Board, "Suggested Control Measures for Landfill Gas Emissions," Prepared by California Air Pollution Control Officers, Association Technical Review Group, Landfill Gas Subcommittee, August, 1990, p. 32.
34. TMI Communication to SCAQMD, May 25, 1995.
35. Communication from Jeffrey Collier, City of West Covina to Alan M. Bonny, TeraMeth Industries, April 10, 1995.
36. Wuebben, P. "The Implications of the Clean Fuel Bus Success," World Methanol Conference, November 29, 1993.
37. Wuebben, P. The South Coast Air Quality Management District's Clean Fuels Program: Barriers, Issues and Opportunities, in *International Specialty Conference, Air and Waste Management Association and the Environmental Protection Agency, on PM-10 Standards,* November, 1992.
38. Federal Reserve Bank of Dallas, "Methanol as an Alternative Fuel: Economic and Health Benefits," *Economic Review,* September, 1991.
39. South Coast Air Quality Management District, *Building Markets for Low Emission Technologies and Clean Fuels,* January, 1995.