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Fuel cells and air quality: a California perspective

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Abstract

The continuing challenge to improve the quality of urban air, worldwide, provides many opportunities to introduce cleaner technologies into the industrial energy base. The fuel cell is particularly attractive from an environmental viewpoint because of its inherent efficiency, zero or near-zero emissions, and quiet operation. Since 1991, fuel cells have made major institutional strides in being recognized as part of the solution to the major air-pollution problem in Southern California. Fuel cells and hydrogen are now receiving greater attention in the regulatory planning process. This process seeks to identify lower-emitting technologies and fuels that can assist the region in meeting health-based air-quality standards by the year 2010, and provide for a sustainable, health-grounded regional economy as well. Current demonstration projects involving fuel cells and hydrogen are discussed, as well as necessary plans and incentives for infrastructure development – a critical component of fuel-cell commercialization. Finally, an overview is presented of regulatory efforts that are being considered to support early markets for fuel cells.

Background elements of the California perspective

The South Coast Air Basin (hereafter, Basin) is a 6600-square-mile region in the metropolitan Los Angeles area of Southern California. The Basin is comprised of the non-desert portions of Los Angeles, Riverside and San Bernardino counties, and all of Orange county. The region's population currently exceeds 13 million persons. This comprises half the population of the state of California, or one out of every twenty Americans.

With more frequent exceedances of federal ambient air-quality standards than any other area in the USA [1], the Basin continues to pose a major challenge to regulators charged with providing healthful air quality to the public.

A detailed look at Basin air pollutants and emissions sources was presented by the author at the 1991 Grove Symposium [2]. The following is a brief revisiting of that information as essential background.

Ozone is the principal air pollution concern in the Basin; during the peak smog season, ambient levels can be three times the federal health-based air-quality standard. The Basin also significantly exceeds federal standards for particulate matter and carbon monoxide. Emissions from motor vehicles are a primary contributing factor to these problems. Specifically, on- and off-road motor vehicles contribute most of the ozone precursor emissions, that is, approximately 50% of the reactive organic compounds (ROC) and 75% of the oxides of nitrogen (NO_x). These vehicles are also responsible for about 95% of the carbon monoxide (CO) emissions and 90% of the particulate

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matter less than 10 μm (PM10) produced in the Basin. Emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), that result from the combustion of fossil fuels, also contribute significantly to the greenhouse effect. In this effect, solar radiation is trapped by the earth's atmosphere. Clearly, significant reductions in emissions from all sources, but especially from the transportation sector, are necessary in the fight to achieve healthful air in the Basin.

There is an urgent need to attain health standards expeditiously. One study has indicated [3] that children in the Basin grow up with their lung capacity diminished by as much as 15%. Beyond the cost in human suffering, the price of our unhealthful air quality in real dollars is also staggering. A recent study [4] conducted by California State University, and published in the peer review literature, found that the cost of air pollution – in terms of adverse human health effects alone – is at least US$ 9 billion per year in the Basin.

Per capita emissions have been brought down substantially in the Basin as the result of emission controls, despite major increases in both human and vehicle populations. For example, maximum levels of ozone have been cut to less than half of what they were in the 1950s, and have generally declined over the last twenty years (see Fig. 1). Unfortunately, relentless increases in the number of sources – particularly those growing proportionately to population – can negate the potential air-quality benefits of new controls. Although the growth rate is slowing somewhat, the region's population will continue to increase to an estimated 18 million by 2010; this represents a nearly 40% increase from current levels. The net result is that unless dramatic steps are taken to control air pollution at a much faster rate than ever before, growth will overwhelm the improvements expected from the existing control program.

The South Coast Air Quality Management District (SCAQMD) is the regional regulatory body with primary responsibility for air-pollution control in the Basin. SCAQMD has authority over stationary sources in the Basin, while the California Air Resources Board (CARB) has authority over mobile sources across the state. The SCAQMD is charged with developing and implementing successive updates to the region's mandated Air Quality Management Plan (AQMP), a blueprint for attaining clean air standards in the Basin within twenty years.

Stationary sources targeted by the AQMP include: petroleum refineries; gas utilities; electric utilities, and a wide range of industrial manufacturing operations, both large

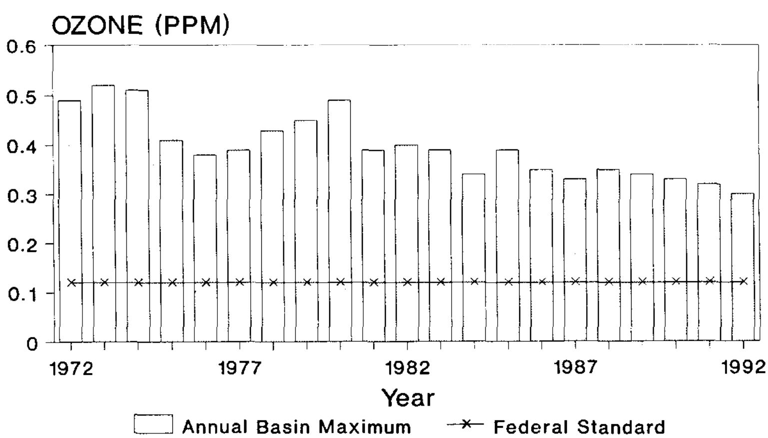

Fig. 1. South Coast Air Basin twenty-year ozone trend.

and small. Mobile source categories include light-duty, medium-duty and heavy-duty vehicles such as passenger cars, vans, trucks and transit vehicles. Also covered are off-road mobile equipment such as agricultural and construction vehicles, and trains. Over a period of about three years, the draft control measures identified in the AQMP have been developed into formal regulations.

The most recent AQMP calls for a significant increase in the use of alternative, cleaner types of energy relative to traditional petroleum-based fuels [5]. One of the key conclusions reached in each updated Plan has been that all identifiable and feasible emission controls for both stationary and mobile sources are needed to achieve federal air-quality standards. In fact, the current AQMP calls for full implementation of known technology (Tier I), advancement of known technology (Tier II), and technological breakthroughs (Tier III) as the overall control strategy (see Fig. 2). These further advancements will be reflected in future AQMP updates through planning assumptions that incorporate higher penetration rates for new technologies and fuels.

Through the AQMP, the SCAQMD and its fellow California regulatory agencies have intensified their commitment towards expediting commercialization of the most environmentally benign fuels and technology. Wide-scale implementation of zero-emission technologies, using some combination of hydrogen and electricity as energy carriers, is essential to restoring healthful air quality to the Basin. This paper will describe the key role that fuel cells can play in this arena and their significant potential for being the cornerstone of sustainable energy, environmental, and economic policies. The potential of fuel cells to provide a quantum improvement in the efficiency and emissions reduction in the automobile has been recognized by President Clinton [6]. His administration's 'Clean Car Task Force' is investigating the use of fuel cells and other technologies to meet the goals of low or zero emissions (including global-warming gases) and high fuel economy.

The remainder of this paper describes SCAQMD work to secure additional financial support for fuel cells, its fuel cell demonstration programs for both mobile and stationary applications, and the complementary work that is ongoing to secure appropriate and

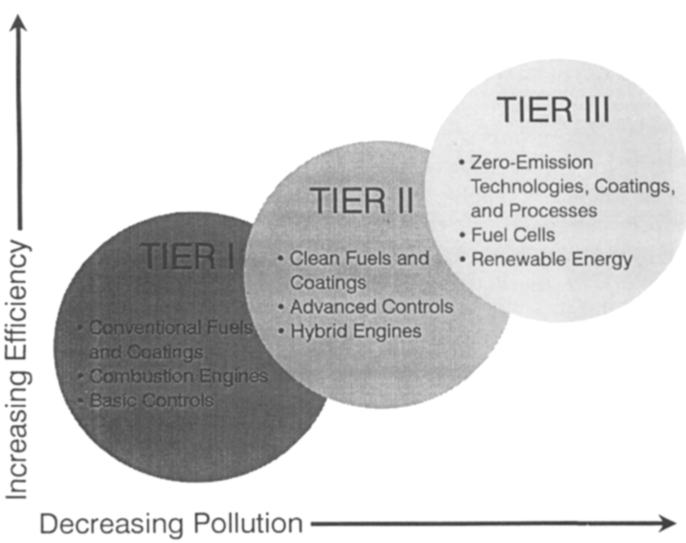

Fig. 2. The AQMP and technology progression.

adequate fuels as precursors to the hydrogen required by fuel cells. Finally, regulatory and legislative initiatives underway in California to encourage fuel cell and equivalent zero-emission technology will be described.

Public–private partnerships towards fuel cell commercialization

As a unique, pro-active approach to assist industry's transition to 'greener' products and processes, SCAQMD created its Technology Advancement Office (TAO) in 1988. The TAO has established a broad-based program to support the research, development, demonstration and commercialization of advanced emissions control technologies and clean fuels [7].

Encompassing both mobile and stationary emission sources, this public-private partnership is an integral part of implementing the AQMP, which emphasizes the need for rapid development and commercialization of progressively lower-emitting technologies and clean-burning fuels.

The SCAQMD's funding is aggressively maximized through cost-sharing with private industry, other government agencies, academia, and research institutes. The aggregate TAO program now totals roughly US$ 80 million.

Proposals for new research, development or demonstration projects are considered for joint funding on a case-by-case basis. The criteria for TAO co-sponsorship are: (i) the potential impact of the clean fuel or advanced technology on reducing emissions in the Basin; (ii) substantial direct and/or in-kind cost sharing from the manufacturer or other organizations, and (iii) the project's potential to lead to commercialized low-emissions technology.

To speed fuel cell applications and infrastructure in Southern California, the SCAQMD is pursuing a three-part strategy of fuel cell advocacy, demonstration, and finally, formal incorporation in regulatory planning measures. These three strategic elements are detailed below.

Fuel cell alliances

SCAQMD has formed, or strongly supports, a number of alliances designed to accelerate the development of specific fuel cell technologies. These include the following.

(i) *The Ad Hoc Coalition on Fuel Cells for Transportation* was formed by the SCAQMD in 1992 as an advocacy group to facilitate the commercialization of fuel cells and related technologies for motor vehicle uses. This coalition is now composed of nearly thirty members, as shown in Table 1.

This year, the Coalition launched the National Initiative on Fuel Cells for Transportation, which is a seven-year plan to develop energy efficient, zero-pollution motor vehicles for the American marketplace. A central objective is to procure more support from the US federal government for fuel cell commercialization. The US$ 4 billion (over seven years) that is sought – about what the USA pays for imported oil in a single month – could commercialize fuel cells by the year 2000 and create tens of thousands of jobs.

(ii) *The Locomotive Propulsion Systems Task Force (LPSTF)*, was established by the SCAQMD Board in May 1992. It consists of about fifty people from government, academia, the fuel cell industry, railroad operators, locomotive builders, and fuel suppliers. Over the course of four two-day meetings in 1992, the LPSTF concluded that fuel cell locomotives have potential to be a less costly alternative to conventional electrified railway in the Basin, and should provide greater emissions reductions. A

TABLE 1

Membership of the Ad Hoc Coalition on Fuel Cells for Transportation

AeroVironment Inc., Monrovia, CA
Allied Signal, Inc., Torrance, CA
Arthur D. Little, Inc., Cambridge, MA
California Air Resources Board, Sacramento, CA
CALTRANS, Sacramento, CA
University of California at Riverside, CA
Clean Air Now, Riverside, CA
Economic Roundtable, Los Angeles, CA
Energy Partners, West Palm Beach, FL
Texas A&M University, College Station, TX
Georgetown University, Washington, DC
H-Power Corporation, Belleville, NJ
Institute of Gas Technology, Chicago, IL
University of California at Davis, CA
University of Southern California, Los Angeles, CA
Los Angeles Metropolitan Transit Authority, Los Angeles, CA
Natural Resources Defense Council, Washington, DC
Northeast States Coordinated Air Use Management, Boston, MA
New York Department of Environmental Conservation, Albany, NY
PACE, Arlington Heights, IL
Pennsylvania Energy Office, Harrisburg, PA
Sacramento Municipal Utility District, CA
Science Applications International Corporation (SAIC), San Diego, CA
South Coast Air Quality Management District, Diamond Bar, CA
Southern California Gas Company, Los Angeles, CA
TECOGEN, Waltham, MA
Transportation Manufacturing Corporation, Roswell, NM
ZTEK Corporation, Waltham, MA

study performed on behalf of the Canadian National Railways found that, within two decades, fuel cell locomotives 'may become the preferred option of rail motive power in North America' [8]. Findings by the LPSTF suggested that, given adequate funding, fuel cell locomotives could help to provide a 90% reduction in railroad emissions by 2010, as targeted in the AQMP. The LPSTF recommended that the SCAQMD commission a detailed study to determine the most appropriate fuel cell technologies and fuel systems, and how to adapt them for the arduous locomotive environment.

Based on the recommendations and conclusions of the LPSTF, the SCAQMD recently joined with the US Department of Energy (DOE) in a cooperative, multi-phase development and demonstration program for fuel cell locomotives. The Jet Propulsion Laboratory (JPL) was selected as the technical consultant to conduct Phase 1, a feasibility evaluation of the most promising fuel cell technologies and fuels for locomotive applications. Upon completion of the Phase 1 final report (expected to be in June 1994), DOE and the SCAQMD will issue a Request for Proposals to conduct Phase 2, a detailed systems design study on the selected fuel cell system(s). Table 2 lists the tentative phases and schedule of the cooperative DOE/SCAQMD locomotive program.

(iii) *The Hydrogen and Renewable Energy Task Forces* were formed by the SCAQMD specifically to promote these clean fuels.

TABLE 2

Cooperative US DOE/SCAQMD fuel cell locomotive program

Phase 1: feasibility and design study Status: underway, completion in June 1994
Phase 2: detailed systems requirement study Projected start: January 1995
Phase 3: build fuel cell propulsion system Projected start: April 1996
Phase 4: demonstration of fuel cell locomotive Projected start: 1998

The Hydrogen Task Force was formed to improve technology transfer and understanding of hydrogen within the Los Angeles Basin and the state of California. This task force consists of representatives from utilities, manufacturer associations, the academic community, and government agencies. It will specifically address how energy, environmental, and utility regulatory bodies can facilitate the introduction of hydrogen. It will also form links with international agencies, and act as a local information clearinghouse on hydrogen technologies.

The Renewable Energy Task Force was formed to identify and quantify the environmental benefits of using solar, wind, hydro, and geothermal power, and to identify niche markets and incentives for such technologies. The task force consists of members of electric utilities, the wind industry, the photovoltaic industry, and the academic and environmental communities. At a Renewables Retreat hosted by the SCAQMD in July 1993, it was determined that geothermal and hydro power are already cost competitive with combined-cycle gas turbines; furthermore, wind is rapidly becoming cost competitive, and photovoltaics and solar-thermal electricity are already competitive in off-grid applications.

(iv) *The Economic Roundtable's Fuel Cell Commercialization Project* is being supported by the SCAQMD along with the Metropolitan Transit Authority and the Southern California Gas Company. This project will provide its sponsors with a five-year technology development strategy for improving and producing multiple generations of fuel cell systems and supporting the needed infrastructure.

(v) *Southern California Edison's Proposed National Fuel Cell Center.* Southern California Edison (SCE), the major utility in the Los Angeles Basin, has proposed a fuel cell center to assist in accelerating the commercialization of fuel cells. The proposed site is at SCE's Highgrove generating station (about 70 miles east of downtown Los Angeles), although activities at several sites are being explored. Among those providing support for this initiative are the SCAQMD and The Gas Company; the latter is the area's major supplier of natural gas. The fuel cell center will pool Basin efforts to demonstrate various fuel cell technologies in a spectrum of applications, including motor vehicles.

Technology development and demonstration projects

The attractive environmental benefits of fuel cells are such that SCAQMD is relying on development of several types to help meet the agency's long-term air-quality goals. SCAQMD believes that fuel cells are likely to be gradually phased in as the primary replacement for internal combustion engines (ICEs), and other combustion sources, in both mobile and stationary applications. To date, the types of fuel cells that are being demonstrated in the various applications include: the phosphoric acid fuel cell (PAFC); the polymer membrane fuel cell (PMFC), and the molten carbonate fuel cell (MCFC). The SCAQMD is also looking at the potential of progressively advanced technologies, such as the solid oxide fuel cell (SOFC), for prospects to provide zero-emissions power over the longer term.

To date, SCAQMD is supporting several programs that involve PAFC and PMFC technology as applied to passenger cars and transit buses. As already noted, locomotives are now being assessed for the optimal type of fuel cell powerplant. In the stationary area, SCAQMD is demonstrating a PAFC unit at agency headquarters and an MCFC at a nearby oil refinery research center, and has conducted feasibility studies for residential PMFC units. Finally, in the area of clean fuels, SCAQMD is also co-sponsoring several projects to demonstrate emerging renewable energy technologies. Demonstration projects from each of these areas of concentration are outlined below.

Mobile source applications

The urban transit bus system is an attractive early entry point for transportation applications of fuel cells, for numerous reasons. A hybrid fuel cell/battery motor is capable of meeting the arduous power demands that are common to the transit bus driving cycle, and provides ultra-low emission levels and a substantial improvement in vehicle energy efficiency. Moreover, the AQMP effectively targets 30% of the Basin's transit buses to be powered by electricity or fuel cells by the year 2010. For these reasons, urban transit buses were one of the SCAQMD's earliest focal points for fuel cell power, and will most likely achieve commercialization first, followed by locomotives and light-duty vehicles.

The following describes key SCAQMD projects that involve transportation fuel cell applications and are currently underway or will soon commence.

(i) *DOE fuel cell/battery hybrid bus*. In 1989, the SCAQMD joined the US DOE and Department of Transportation in cost sharing a four-phase federal program to develop and demonstrate transit buses powered by a PAFC/battery hybrid motor. Phase I, a proof-of-feasibility demonstration, has been successfully completed. Phase II is now in progress, with the objective to build three 27-ft buses and to demonstrate at least one in the Basin beginning in late 1993. This project is described in greater detail in the paper by Patil and Zegers [9].

(ii) *Ballard fuel cell bus*. Shortly after the SCAQMD joined the DOE fuel cell bus program, a second important North American demonstration was initiated. Ballard Power Systems of British Columbia and Science Applications International Corporation (SAIC) began building a proof-of-concept, 20-passenger transit bus powered by 24 Ballard 5-kW PMFC stacks, in cooperation with BC Transit and the British Columbia government. Recognizing the importance of the California market for this zero-emissions bus technology, Ballard invited SCAQMD staff to sit on the BC Fuel Cell Bus Steering Committee during this Phase 1 effort. The bus was completed in early 1993; it has now been successfully demonstrated on the streets of Vancouver, Los Angeles, and Sacramento.

In August 1993, the SCAQMD Board agreed to provide cost sharing for Phase 2 of the Ballard fuel cell bus program. In this multi-year phase, the Ballard/SAIC team will develop at least three additional buses with an advanced PMFC system. The new system will target a lower-cost, more-efficient PMFC, hybridized with a battery pack for added peak power and regenerative braking. The SCAQMD is cofunding this effort based on Ballard's intention to utilize a variety of components manufactured in Southern California, and to demonstrate at least one bus in the Basin. Ballard's work will focus on commercializing its PMFC technology in 1998 for bus applications. Several key areas are being targeted in order to bring down the cost of the PMFC to about US$ 500 per kW. These include a more efficient, lower-cost membrane, more efficient catalyst usage, moulded cell plate production, improved cell performance, and volume production.

(iii) *Energy Partners Green Car.* Energy Partners (EP) of West Palm Beach, FL, has initiated a 'fast-track' program to develop and demonstrate a zero-emission passenger car powered by a fuel cell/battery hybrid. The SCAQMD joined this program as a cosponsor in 1992. EP bought the rights to the Treadwell PMFC and has formed a new company, US Fuel Cells. Three pure-hydrogen, air-breathing 6-kW solid polymer stacks have been fabricated for the Green Car, and were recently integrated into a lightweight monocoque sports car chassis built by Consulier. A lead/acid battery pack provides peaking power requirements for the vehicle. The car has been driven under fuel cell power. EP has successfully operated the vehicle and is now working to optimize performance of the integrated fuel cell stacks and battery pack.

(iv) *Allied Signal SPFC Progam.* SCAQMD expects to join a broad-based consortium, headed up by CALSTART, that will develop and demonstrate a 50-kW SPFC, based on technology from Allied Signal Corporation, for application to light-duty vehicles. (CALSTART is a statewide association of private and public entities aimed at transferring the technologies and labor of the aerospace and defense industries to the production and marketing of electric vehicles [10].) This program was recently submitted for funding under the US Technology Reinvestment Project.

Stationary source applications

Fuel cells hold great promise for clean and efficient stationary power generation. To help demonstrate their technological viability, SCAQMD is currently participating in the following projects:

(i) *International Fuel Cell's PAFC at SCAQMD headquarters.* The SCAQMD contracted with Southern California Gas Company to lease the first of ten 200-kW PAFC units built by International Fuel Cell (IFC) Company. This fuel cell, known as the PC25, was installed at the SCAQMD in April 1992.

During the first year of operation, the PC25 achieved a thermal-to-electrical conversion efficiency of about 40%, but higher efficiencies are being achieved now that SCAQMD is utilizing waste heat to supply hot water for its building. Figure 3 shows NO_x emissions from this technology in comparison with those of existing power plants and SCAQMD Rule 1145.

The major problem experienced by the PC25 was a valve failure that caused water to flood the stack. This led to stack shutdown until the valve was replaced. The stack is now operational again, and has performed well despite some relatively minor problems such as premature replacement of blower fans.

(ii) *M-C Power molten carbonate fuel cell.* M-C Power Corporation located in Chicago, IL, is one of the two leading American MCFC manufacturers. The SCAQMD is cofunding a demonstration and verification of improvements in the MCFC technology at Unocal's Science and Technology center in Brea, CA. Design studies of the project are nearly completed, and construction of the 250-kW fuel cell is expected to be completed by mid-1994. This US$ 3 million demonstration is part of a larger DOE program that is estimated to cost about US$ 35 million. Unocal and Southern California Gas will fund up to US$ 1 million each, and the SCAQMD's contribution will be up to US$ 500 000.

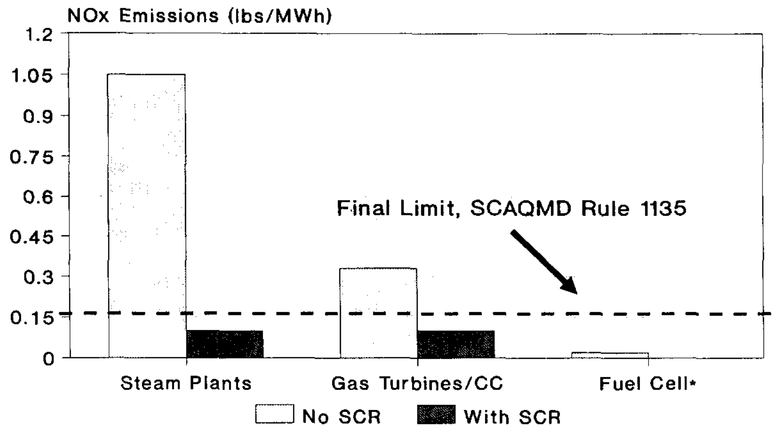

Fig. 3. NO_x emissions of fuel cells in comparison with existing power plants. *Assumes natural gas as fuel.

(iii) *Rolls–Royce residential PMFC.* Residential fuel cells offer the potential to generate electricity, heat and water for home use with very low or zero emissions. The CO_2 emissions can be captured for home greenhouse use. In 1990, SCAQMD joined a consortium that studied the feasibility of a residential fuel cell power system, based on PMFC technology under development by Rolls–Royce Inc. Joining the SCAQMD in the consortium were Rolls–Royce, Johnson–Matthey and Southern California Gas Company.

The study determined that residential fuel cells can be cost-effective in homes with high electricity use: for example, in homes with electric water heating (as opposed to cheaper natural gas water heating), and where electric cars are expected to be charged in the future. Greater cost effectiveness will be achieved once the issue of CO contamination is resolved to allow the use of natural gas fuel. Also determined in the study was the need to revisit reformer designs for home applications.

Fuels

In theory, fuel cells can be operated on a variety of feedstocks. Renewables and biomass are the most attractive sustainable sources for such fuels [11]. SCAQMD is involved in the following projects that demonstrate the feasibility of producing fuels for fuel cells from renewable resources.

(i) *UCR solar hydrogen project.* One of the most visionary projects supported by the SCAQMD is now underway at the University of California's Riverside (UCR) campus. At this facility, America's first solar–hydrogen production facility and refueling station for hydrogen vehicles has been constructed. Electrolyser Corporation, a pioneer in electrolysis, has supplied a 12-cell, unipolar electrolysis unit that is directly coupled with a 3.5-kW photovoltaic array. The hydrogen that is generated by the electrolysis cells is monitored for purity and then stored in a low-pressure gas holder. The holder activates a four-stage compressor when full. After being compressed to 5000 psi, the hydrogen is stored in high-pressure vessels with a maximum capacity of 7500 standard cubic feet. A custom-built hydrogen refuelling station will complete the transfer of fuel to a specially constructed hydrogen vehicle, which is now being optimized by Hydrogen Consultants, Inc. In the future, fuel cell vehicles will be refuelled at this facility. Currently, UCR is monitoring all important parameters of the system, such as voltage, amperage, electrolyser temperature and pressure, hydrogen gas flow, and power generated (W m^{-2}) by the photovoltaic array.

(ii) *SCE/SCAQMD solar chargeport.* Southern California Edison (SCE) recently completed construction of a 'solar chargeport' at SCAQMD headquarters to charge electric vehicles. Approximately 24 kW (d.c.) of fixed-tilt, semi-crystalline, photovoltaic modules have been installed and connected to the utility grid through d.c.-to-a.c. inverters. Electric vehicles are recharged here using conventional on- and off-board chargers. As technology develops, the photovoltaic cells can be upgraded to advanced, high-efficiency, low-cost cells.

This system is sized to provide a minimum of 55 kWh/day throughout the year. The solar chargeport can charge several vehicles per day under optimal solar insolation. Any excess energy is channeled to the building load. On days when sunlight is poor – a low-probability event in Southern California, – energy required to recharge the vehicles will be drawn from the electricity grid.

A sophisticated data acquisition unit, supplied by Sandia Labs, monitors the solar array output, the usage by electric vehicles, and the amount of energy that flows into the building. This information helps analyze the performance of the system and provides feedback for making design improvements.

(iii) *TeraMeth biomass conversion.* SCAQMD is working with TeraMeth Inc., a California company, to produce methanol in a cost-effective manner from landfill gas – a renewable and underutilized feedstock. The project is located at the large BKK landfill 30 miles east of Los Angeles. TeraMeth has developed a technology design to convert 2 million cubic feet per day of landfill gas to methanol for a maximum production of 30 tons per day (10 000 gallons). TeraMeth preconditions the landfill gas collected by an existing system, and then reforms the conditioned gas to methanol.

1994 Air Quality Management Plan

Regulatory mechanisms and technology demonstration programs are interdependent in encouraging the development and use of advanced technologies. Demonstration programs that establish technological viability were discussed above. This section covers how an agency such as the SCAQMD can use its regulatory powers to encourage the use of advanced technologies.

Every three years, an updated AQMP is prepared. The 1989 AQMP provided the backdrop for CARB's now-renowned low-emission vehicle (LEV) regulation that requires the mandatory sale of a certain percentage of zero-emission vehicles (ZEVs) starting in 1998, which in turn, has generated a great deal of interest in electric and fuel-cell powered cars [12].

Traditionally, the AQMP has focussed on control strategies and technologies to reduce 'criteria pollutants' and a range of toxic pollutants. Criteria pollutants include ozone precursors (hydrocarbons, oxides of nitrogen, etc.), oxides of sulfur, particulate matter, carbon monoxide, and lead. Toxic pollutants include benzene, aldehydes and poly-aromatic hydrocarbons.

In addition, earlier Plans developed (and the SCAQMD later adopted) a Stratospheric Ozone Depleting Policy and Global Warming Policy. This policy recognizes that energy use contributes significantly to emissions of global warming gases (i.e., CO_2 and CH_4) and supports actions to reduce such emissions. Several actions have also been adopted since then to reduce, and eventually to phase out, the use of ozone depleting substances such as CFCs, halons and HCFCs. In addition, regulations have also been adopted that encourage recycling, conservation and substitution of these ozone depleters.

In the 1994 AQMP, in addition to continuing to address regional air quality, SCAQMD is expected to make further progress on implementing its global warming policy. Control measures and technologies will be proposed to reduce emissions of carbon dioxide and other global warming gases. These advanced technologies are expected to substantially reduce, if not eliminate, a wide range of harmful air pollutants: criteria pollutants, toxic pollutants, ozone depleters, and global warming gases.

For the first time, market incentives are being recognized as a significant ingredient in the AQMP process. Thus, the 1994 control strategies are also expected to help companies meet emission-reduction targets under a proposed marketable permits program called the Regional Clean Air Incentives Market, or RECLAIM [13]. These targets consist of ceilings that are annually ratcheted down. To meet these stringent ceiling levels, companies are expected to use advanced zero-emission technologies (ZETs) in their equipment mix. The control strategies would propose incentives or mandates to accelerate the use of ZETs such as fuel cells, hydrogen, and renewables.

It is planned that the 1994 AQMP will include measures to encourage: (i) the use of fuel cells in stationary sources such as central power plants, major refineries, and heavy industrial manufacturing sites, and (ii) the development of a hydrogen infrastructure. Options to be considered for proposed regulatory control and/or incentive measures are outlined below.

Measures encouraging fuel cells for stationary aplications

(i) *Multiple credits for retrofit applications.* Under current SCAQMD regulations, zero-emission technologies (ZETs) such as fuel cells and renewables, in theory, could acquire emission reduction credits (ERCs) since ZETs could virtually eliminate ROC, No_x and SO_x emissions. These ERCs could then be used in-house or sold on the market.

However, under the existing system, fuel cells will be eligible only for one-to-one ERCs. That is, for each ton of NO_x reduced, the facility would earn only one ton of ERC that could be used in the facility or sold to others. This one-to-one ERC would probably be inadequate to overcome the perceived cost barriers of fuel cells.

If, instead, fuel cells are offered multiple (say, three-to-one) ERC credits, there may be more interest in these technologies. The system would work as follows: assume a facility replaces a gas turbine with a fuel cell and, thereby, eliminates 4 tons of NO_x each year. The facility, instead of getting 4 tons of ERCs, gets 12 tons, the rationale being that ZETs need encouragement in the short run to ensure their viability in the long run. The 12 tons of ERCs could be used in-house or sold to other firms. The additional ERCs would make fuel cells more attractive.

An objection to this proposal is that the allowance of multiple credits would worsen the air-quality problem in the short run, by allowing increased conventional power generation.

To address this problem, these multiple credits could be phased down and later phased out: for example, three credits in the first few years, two in the next few, and one in the final phase. Moreover, a ceiling could be placed on the total number of credits allowable in a given period: perhaps not to exceed 150 MW (or its BTU equivalent) for all ZETs combined.

By giving extra ERCs, SCAQMD will be able to raise the value of a fuel cell and, thereby, will help the facility to justify purchasing one.

(ii) *BACT with a cost-mitigating option.* Due to the Basin's nonattainment classification, the SCAQMD has the authority to specify the cleanest technologies as Best Available Control Technology (BACT) for new generating sources. If the facility is a large source, SCAQMD can require installation of such technologies irrespective of cost as long as they are technologically proven.

If SCAQMD exercises its option, it can require installation of fuel cells whenever a cogeneration project is proposed.

To mitigate the cost burden of using a fuel cell as BACT, co-sponsors could potentially be asked to fund partially, or wholly, the excess cost of such purchase, installation and operation. A technology fund could be created, and financing obtained from this fund [14]. In addition, the state and federal energy departments and local gas and electric utilities could be requested to underwrite the incremental cost of, for example, the first 20 to 30 fuel cell installations. The DOE or other governmental agencies would be encouraged to extend funds beyond the traditional R&D stage, and these funds could be used for actual commercialization.

In return for a US$ 60 million fund established for such purposes, the manufacturer of the fuel cells would commit to a percent reduction of cost every year.

For example, let us assume that it costs US$ 1000 per kW, including costs for purchasing emission offsets, to install a cogeneration system using a 200-kW gas turbine. The cost of installing a fuel cell, let us say, is US$ 4000 per kW. The incremental cost of US$ 3000 per kW could be defrayed from co-sponsoring agencies. With a US$ 60 million dollar fund, about 100 fuel cell installations could be funded.

Measures encouraging hydrogen and fuel cells for mobile applications

Hydrogen, which has been used in space applications for many years, has long been recognized as the ideal, environmentally benign terrestrial fuel. It does not contain the carbon atom — resulting in near-zero or zero air pollution when converted to power — and its supply is effectively inexhaustible [14]. Virtually all of the world's scientific community has recognized that a 'hydrogen economy' will emerge in the 21st century as fossil fuels become progressively more scarce and the associated environmental pollution can no longer be tolerated.

It is expected that wide-scale use of hydrogen will evolve in at least two ways. One path involves the development or modification of ICEs to use hydrogen. Sometimes, to improve combustion characteristics or lower costs, hydrogen is burned in combination with a fuel containing hydrocarbons (e.g., 'Hythane', which consists of hydrogen and methane). From an emissions standpoint, hydrogen-fueled ICEs will achieve their maximum potential air-quality benefits as they are optimized for pure hydrogen.

A second scenario involves fuel cells. If pure hydrogen is generated through electrolysis of water (the electricity being generated by solar, wind, or hydro power) and used in fuel cells, the result will be a true ZET, from cradle to grave.

A hydrogen infrastructure is needed to support its final use in hydrogen engines or fuel cells. Incentives and mandates can help facilitate the development of such infrastructure. The SCAQMD will be utilizing experience gained with infrastructure issues that arise from the use of natural gas. The following options, for stationary and mobile sources, are being considered for the 1994 AQMP.

(i) *Credits for petroleum companies*. The creation of a hydrogen infrastructure would be primarily driven by the anticipated demand for hydrogen fuel in the mobile sector. To facilitate this evolution, stationary credits could be provided, for example, to oil companies. These credits would provide incentives for these companies to supply hydrogen from their refineries, build hydrogen distribution pipelines or to install reformers at their service stations to dispense hydrogen.

Stationary credits can be justified since hydrogen eliminates refuelling and evaporative emissions. In 1990, exhaust emissions for passenger cars were about 250 tons per day of ROC, whereas evaporative emissions comprised about 165 tons per day of ROC. In 2010, exhaust emissions are projected to be 32 tons per day of ROC, whereas evaporative emissions are expected to be 70 tons per day. Thus, it is anticipated that evaporative emissions will become a more significant component of the ROC emission inventory. (These estimates have been taken from current CARB EMFAC/ BURDEN/7F model runs (see Fig. 4)). Hydrogen distribution, for use in either hydrogen engines or fuel cells, or both, will eliminate these evaporative emissions.

Petroleum companies could be provided credits, perhaps multiple credits, for producing hydrogen used in vehicles. These credits would be used in two ways:

- as Emission Reduction Credits (ERCs) in a marketable permits program. Such credits are given by SCAQMD to companies that retrofit their operations to reduce pollution below their given ceilings.
- as ERCs that could be used by refineries for fuel averaging. CARB currently provides credits on the mobile side for ZEVs, in that ZEVs can be used for fleet averaging to meet ARB's tailpipe standards. There are, however, no such averaging provisions for fuels. It is possible that CARB could recognize hydrogen as a near zero-emission or as a zero-emission fuel, and allow refineries to use hydrogen in a fuel-average provision to meet CARB's various fuel standards for gasoline and diesel.

(ii) *Demand from the mobile sector.* As stated earlier, a hydrogen infrastructure could be created if suppliers of hydrogen can be convinced that an adequate market would emerge for this fuel. To create this market, incentives should be given to car manufacturers to make propulsion systems that use hydrogen. Currently, ARB ZEV mandates are useful in encouraging the manufacture of hydrogen-powered fuel-cell vehicles. Nevertheless, the number of fuel-cell vehicles would probably be too limited to generate a hydrogen infrastructure, at least initially. To facilitate creation of such a structure, and to increase the market utility of hydrogen fuel, other types of hydrogen vehicles may be needed, e.g., dedicated hydrogen vehicles and hybrid hydrogen vehicles.

Vehicles using such technologies, especially once they are optimized, will have very low emissions, with virtually no toxic contaminants. Though they are likely to be cleaner than ULEVs, they will not be ZEVs. Thus, under current standards, manufacturers do not have any incentives to go beyond the ULEV standard by manufacturing extremely low-emitting cars with advanced, clean-fuelled ICEs.

To remove some of these obstacles, concepts are being floated to consider superclean cars at a level matching ZEV cars. This can be done in two ways:

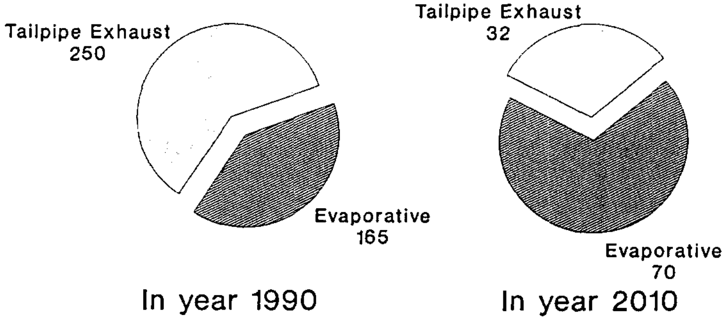

Fig. 4. Basin tailpipe and evaporative ROC emissions in tons/day for passenger cars in district (from CARBS's EMFAC/BURDEN/7F model runs).

TABLE 3

Preliminary estimate of powerplant emissions associated with an electric vehicle (in grams per mile)

Pollutant	ZEV SCAB[a]	ZEV Statewide[b]	ULEV[c]
NO_x	0.004	0.05	0.2
Reactive organic compounds	0.0005	0.0001	0.040

Source: CARB, 1993, preliminary.
[a]SCAB power plants only (20% of total power needed).
[b]Includes out-of-state emissions.
[c]Exhaust emission standards only; does not include evaporative emissions or deterioration.
Assumptions used to calculate emissions from power plants:

- 20% of the power used by EVs in the SCAB will be generated in the SCAB
- EVs use 0.24 kWh per mile
- Utility emission factors (gas-fired): ROC=0.02 lbs/MWh, NO_x=0.15 lbs/MWh, and CO=0.4 lbs/MWh.

- superclean cars can be classified into a separate category to be known as the near-zero-emission vehicle (NZEV) category, and the NZEVs will have the same credits as ZEVs, or
- these superclean cars can be merged within the ZEV category. The latter option acknowledges that electric ZEV cars, despite their zero tailpipe emissions, have powerplant emissions as recognized by CARB. If superclean cars have emissions at or below powerplant emissions per vehicle mile, the cars may qualify as ZEVs. ARB has put forward a draft table (see Table 3) that estimates powerplant emissions associated with an electric vehicle.

ARB has expressed a willingness to consider the second approach. Given that battery or fuel-cell electric vehicles do not experience emission control equipment deterioration, ARB has expressed a desire to see more evidence on the durability of the low emissions in hydrogen engines and hydrogen hybrids before making any final decision on categorizing these vehicles.

Given these activities, there are some hopeful signs that a wider market for hydrogen fuel for mobile sources may slowly evolve in the not too distant future.

Summary

SCAQMD is firmly committed to supporting technology development and to creating a regulatory climate that is favorable to the promotion and development of advanced technologies such as fuel cells. It has drawn on its funding resources to help manufacturers demonstrate their products, and on its regulatory authority to give incentives to potential users of these technologies. This clearly illustrates that regulatory activities can promote both improved environmental quality and sustainable economic development. Knowledge of, and outreach in, fuel cell and hydrogen technologies has grown substantially in California in the past year. The application of fuel cells is expected to expand as the efforts described above come to fruition.

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