The Clean Air LA301 electric vehicle for the Los Angeles electric vehicle initiative

Sir John Samuel
Clean Air Transport, 11 Hazelwood Close, Worthing, Sussex BN14 8NP (UK)

Introduction

'By the year 2010, 70% of all vehicles in Southern California must be electric' – this was the remarkable conclusion reached by the Californian air quality regulators in 1988. Faced with continual violation of Federal air quality standards, with air pollution in Los Angeles ten times worse than any other US City, it had become obvious that progressively tighter control of internal combustion (IC) engine emission controls could not and would not solve the problem.

What was the reasoning behind this conclusion? Why is it so important to tackle vehicle emissions when there are other obvious sources of emissions? Would not electric vehicles (EVs) simply shift emissions from tailpipe to power station? Might not alternative liquid fuels provide a simpler and cheaper solution? Would not carbon dioxide emissions from fossil fuelled power stations increase the risk of global climate change?

This paper will summarize some of the conclusions reached on these complex issues and the reasoning which led to the launch of the Los Angeles Electric Vehicle Initiative in May 1988 (Fig. 1).

With the first stage objective of bringing 10 000 EVs to the roads of Southern California by 1995, the City of Los Angeles, Department of Water and Power, awarded a US $7 million contract to Clean Air, specifically for the development of a purpose

• Originated:	May 1988 by Councilman Marvin Braude
• Objective:	10,000 Electric cars & vans on L.A. streets by 1995
• Finalists:	Clean Air Transport AB - LA301 Unique Mobility Inc. - "TE VAN" Vehma International - G-VAN
• Sponsors:	City of Los Angeles, Los Angeles Department of Water & Power, Southern California Edison.
• Incentives:	- Development grants - Market entry subsidies - Tax Concessions - "Diamond" lane privileges - Free parking/charging etc.
• Regulations:	Fleet purchase (Rule 1601) California Air Resources Board

Fig. 1. The Los Angeles electric vehicle initiative.

0378-7753/92/$5.00

built electric passenger car which would be attractive to Californian buyers and which would 'spark' an entirely new breed of clean electric passenger car.

What were the design objectives for this project and how would these objectives be achieved? A number of mule test vehicles and two semi-engineered prototype four-seater electric hybrid passenger cars – code named LA301 – have been built and are now under development for Clean Air by International Automotive Design (IAD) of Worthing, UK. Features of the LA301 are described together with some performance and energy efficiency forecasts.

Vehicle emissions – why electric cars are the best solution

California's vast and growing transportation fleet is responsible for more than 75% of the Los Angeles basin's air pollution (Fig. 2) Reducing transport fleet emissions must therefore be the first priority in improving ground level pollution in California. Utilities only contribute 0.7% of total emissions in the Los Angeles basin itself. We will return to this point shortly.

At first sight, it might seem that conversion of existing cars and trucks to an alternative clean fuel such as methanol would be a cost-effective solution. An extensive study of alternative fuels (Fig. 3) show that electricity is the cleanest 'fuel' by a wide margin.

Converting the existing fleet to liquified petroleum gas (LPG), methanol or CNG would have limited emission benefits because the continuing rapid growth in traffic would quickly negate these limited emission benefits. This study, which takes account of emissions from power stations in the Los Angeles basin, concluded that the pure electric, zero-emission vehicle (ZEV), is some 97% cleaner than current gasoline cars. A hybrid car which would operate as an ultra-low-emission vehicle (ULEV) is expected to be some 95% cleaner. For the time being the electric hybrid (ULEV) can provide a practical solution.

Why are utility emissions so low in Los Angeles, only 0.7% of the total (Fig. 4)? One good reason is that 64% of the city's power is not generated in the basin at all. In addition the 36% that is generated within the basin is mostly derived from natural gas – the cleanest of available fossil fuel energy sources.

Will EVs simply export pollution to the rest of the state? Not so, if we look at California as a whole (Fig. 5); nearly half of the power generated comes from zero emission nuclear and other renewable sources such as geothermal, solar, wind and hydro. Nationally in the USA, there is a greater proportion of coal generation,

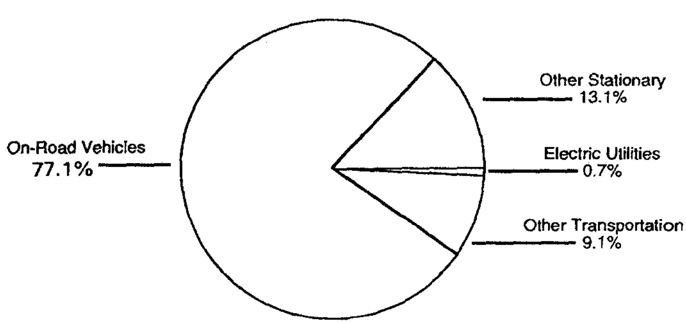

Fig. 2. Emissions – ROG, CO and No_x, South Coast Air Basin 1985. Source: SCAQMD data.

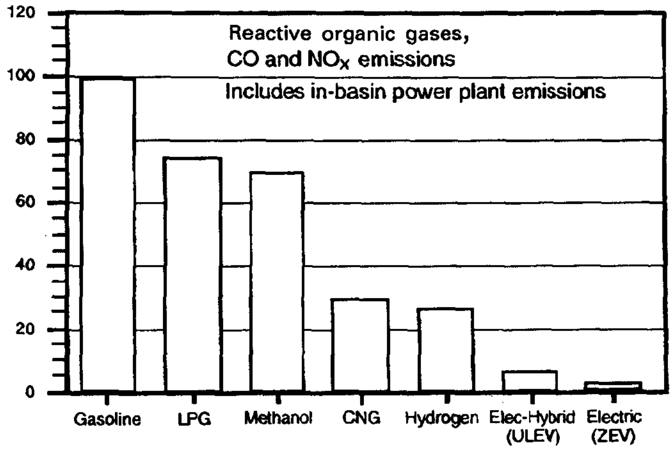

Fig. 3. Alternate fuels emissions, percent of gasoline emissions. Source: California Air Resources Board, 1989.

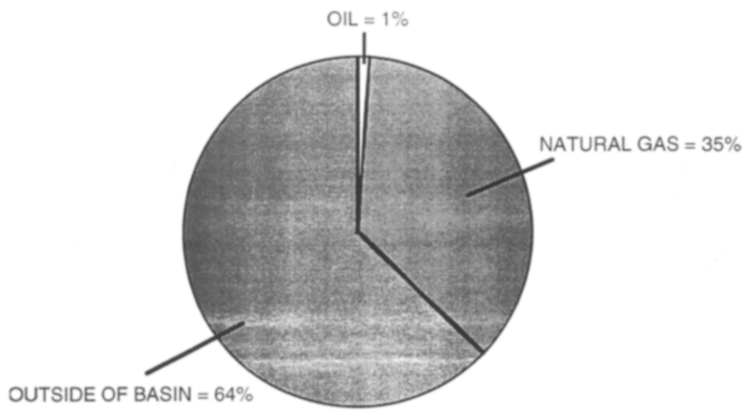

Fig. 4. Los Angeles basin generation mix – 1989. Source Electric Power Research Institute.

which is not as clean, but still one third is generated from nuclear and renewable sources. There is also a steady move toward cleaner sources driven by the environmental needs of the nation.

Certainly for the California area, EVs are undoubtedly the best long-term solution to ground-level pollution and this has now led on to the 1998 mandatory ZEV legislation.

Global warming – can EVs help to reduce CO_2 emissions?

Can the EV help to reduce global warming from CO_2 emissions? Carbon dioxide accounts for about 55% of greenhouse gases and is, therefore, a major contributor to the global warming problem. The extent of CO_2 emissions from the burning of gasoline in the US transportation fleet is immense (Fig. 6) – some 400 million tons of carbon per year being released into the air from this source. The Environmental Protection Agency (EPA) has decreed that a reduction of 70 to 80% in these emissions

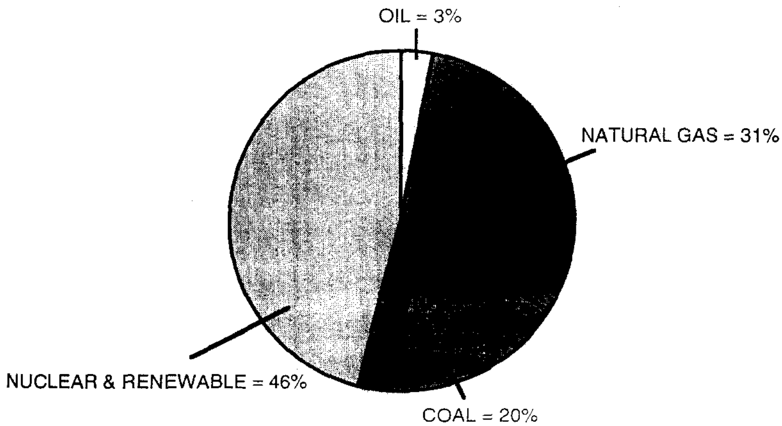

Fig. 5. California + imported generation mix — 1989. Source Electric Power Research Institute.

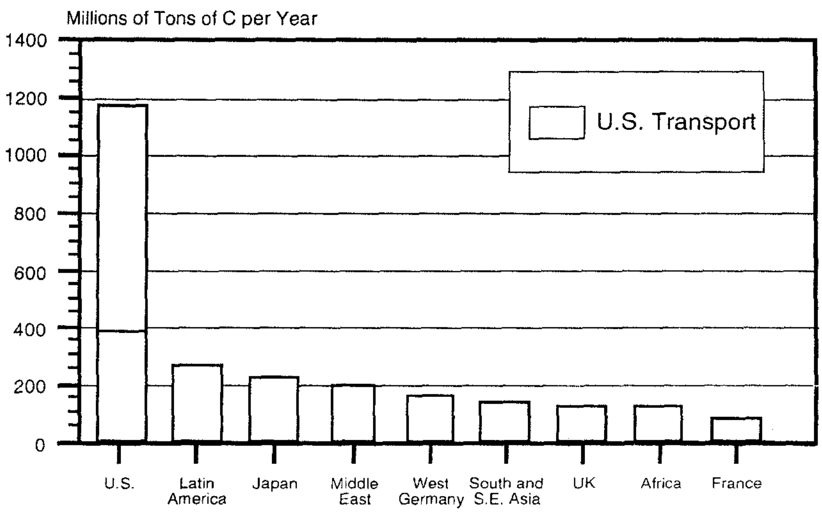

Fig. 6. CO_2 emissions from fossil fuels for selected regions (1985). Source: World Resources Institute, US Department of Energy.

figures will be necessary in order to stabilize atmospheric conditions but the extent of reductions to be achieved by a switch to EVs is as yet unclear.

The degree of CO_2 emissions from power stations used to charge EVs depends entirely on the mix of fuels used in the generation process, the mix varies from country to country and from day to night. The European association of electric utilities (UNIPEDE) recently carried out a comparative study of CO_2 emissions from power stations used to recharge EVs versus an average IC engine (Fig. 7) which showed a 40% potential reduction for the electric car. It was further concluded by Eastern Electricity in the UK that, by 1995, with advances in battery technology and with further improvements in power station efficiency, the reduction in CO_2 emissions could well be improved to 75%.

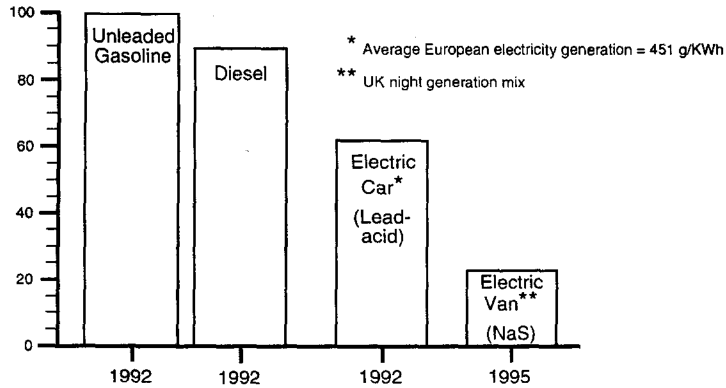

Fig. 7. CO_2 emissions (Europe) – International Union of Electric Producers and Distributors UNIPEDE/UK Eastern Electric comparative study.

Much controversy surrounds the whole global warming issue but there is no question that improvements in power station efficiency and increased use of renewable and nuclear energy in more efficient EVs will greatly help to reduce emissions of CO_2.

New regulations – resulting market demand

The overwhelming conclusion is therefore that, if growth is to continue in California, EVs must be introduced as soon as possible. The state has therefore passed new laws late last year which mandate a 2% "zero-emission vehicle" (ZEV) content in all auto manufacturer's sales by 1998 (Fig. 8). There is also a major requirement for ultra-low–emission vehicles (ULEVs) which is the emission certification standard to be reached by Clean Air's hybrid LA301 vehicle for Los Angeles. If car sales continue to grow at the present rate this could mean statewide mandatory EV sales of more than 30 000 in 1998 rising rapidly to over 150 000 units by the year 2003. Adding in

Percentages of manufacturers' sales required to be:

MODEL YEAR	LOW-EMISSION	ULTRA-LOW EMISSION	ZERO-EMISSION
2003	75	15	10
2002	85	10	5
2001	90	5	5
2000	96	2	2
1999	73	2	2
1998	48	2	2
1997	25	2	0

Low-emission vehicles
Must meet both a hydrocarbon standard of 0.075 grams a mile and a nitrogen oxide level of 0.2 grams a mile

Ultra-low-emission vehicles
Must meet the same 0.2 grams a mile nitrogen oxide standard as low-emission vehicles, as well as hydrocarbon levels of 0.04 gram a mile and a carbon monoxide standard of 1.7 grams a mile

Zero-emission vehicles
Electric cars: Must account for 2% to 10% of new-car production. 1998-2003

Fig. 8. California's drive for cleaner cars, percentages of manufacturers' sales required. Source: Financial Times.

the nine Northeastern states which are currently considering adoption of the Californian standards brings the total potential EV demand forecast for the USA in 2001 to a massive 850 000 vehicles.

Design objectives

Clear Air's first priority, working with the team at IAD, was to conceive an entirely new high-quality EV which would meet the exacting demands of the Californian consumer by overcoming the traditional problem of limited EV range and performance.

Careful study of market requirements in conjunction with the City of Los Angeles resulted in the following design objectives for the LA301 electric car:

- range of over 150 miles (battery and auxiliary power unit), emissions within 'ULEV' standard
- range of 60 miles (battery only) 'ZEV' (later, 150 miles with advanced battery only)
- freeway performance, maximum speed over 70 miles/h
- compliance with all Federal safety standards
- high-quality product aimed at 'lower luxury' market, selling at around US $25 000.

Clean Air chose the parallel hybrid design with an auxiliary power unit (APU) range extender providing a near-term practical solution to the range and performance limitations associated with commercially-available batteries. The design philosophy was based on the fact that 90% of all journeys in Los Angeles are under 40 miles (US Department of Energy); it is anticipated that the majority of driving in Los Angeles will, therefore, be done electrically with ZEVs.

Parallel hybrid drivetrain configuration

There are two basic configurations for hybrid drives:

(i) Series hybrid: IC engine drives a generator at a fixed speed; electric motor drives wheels. The advantage is that an IC engine can run at its lowest emission point. The disadvantages are that the engine is noisy at low road speeds, weight and cost of generator and its controller are high, and the drive efficiency of system is poor.

(ii) Parallel hybrid: IC engine drives the wheels directly in parallel with electric motor. The advantages are: high efficiency, simpler system, lower cost, sounds and feels like a conventional car. The disadvantages are that the IC engine speed varies and harder to optimize emissions.

Extensive research shows that the parallel hybrid configuration is the most efficient for Los Angeles traffic conditions. The drive is programmed so that, under certain preset conditions of battery charge and driver demand and at speeds above 25 to 30 miles/h the IC engine automatically starts up and engages, relieving the electric motor load and thereby extending driving range to 150 miles or more.

The driver can program the control system (Fig. 9) for journeys of less than 50 miles or so in the all-electric mode (Mode 1) so that the APU is inhibited from operation until the battery falls to 20% state-of-charge (SOC) or lower. For longer journeys the extended range mode (Mode 2) will allow the APU to operate at every opportunity where it can operate cleanly and follow the optimum engine emission 'map'.

A remote recharge (Mode 3) control position is available for recharging with the vehicle parked where a charge point is not available.

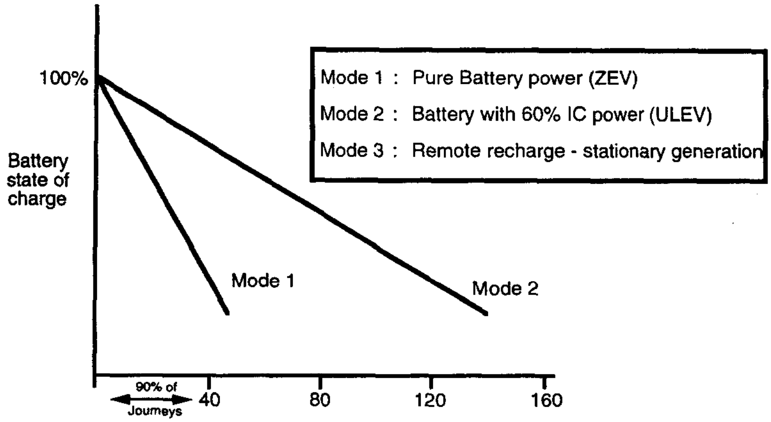

Fig. 9. Auxiliary power unit operation in LA301. (Note, 90% of all journeys will be under 40 miles).

Styling and design features

The LA301 is a full four-passenger two-door hatchback with distinctive aerodynamic styling. IAD has developed skilfully the concept of an agile city vehicle with good visibility and a small car 'wheel at each corned' look. The overall dimensions of the new car are comparable with a BMW '5' Series Sedan; a very spacious, comfortable and high safety-rated result has been obtained. LA301 is not a small city car; it is a versatile all-round car which has space enough for shopping or delivering children to school together with plenty of performance and style for freeway commuting and general executive use.

A high level of comfort combined with performance which allows safe acceleration and cruise capability on freeway is an essential element of the design. The smooth, quiet acceleration from the electric drive system gives starting torque equivalent to a 3-litre engine and a maximum speed of around 70 miles/h. Maximum acceleration requirement arises when joining a freeway and blending with traffic; this is achieved smoothly and with minimal noise from the 216 V d.c., 45 kW motor.

Technical features

Motor and controller

The 45 kW d.c. electric motor drives the front wheels through a specially developed two-speed automatic transmission (Fig. 10). The electric motor is in fact capable of powering the LA301 to over 90 miles/h but the electronic control system limits speed to about 70 miles/h for economy reasons. The separately-excited motor also acts as a generator during braking and is used to progressively slow the vehicle down to very low speeds where the hydraulic power brakes take over.

Evaluation of a new a.c. drive system is continuing and is likely to be introduced before the start of production. The advantages of this technology, which has only recently become available through the advent of relatively low cost power electronic devices, are: (i) reduced motor weight and cost, with motor able to spin up to 12 000 rpm, and (ii) fixed-ratio, high-efficiency transmission.

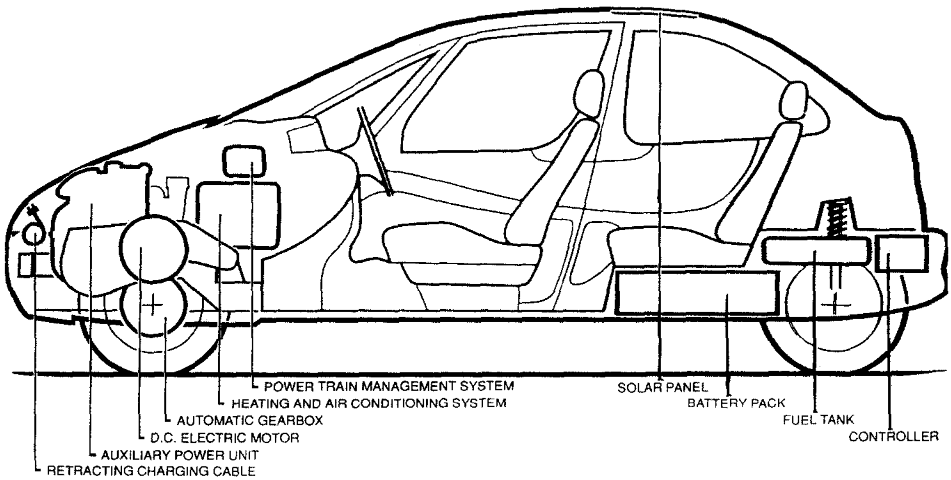

Fig. 10. LA301 component layout drawing.

Batteries

Sealed maintenance-free lead/acid batteries are considered essential for safety and convenience in electric passenger cars. Eighteen 12 V modules are centrally located and low-mounted for stability and safety, providing up to 15 kW h at 216 V and weighing about 480 kg (30 W h/kg. Battery life is expected to be around four years. It has been found essential to provide battery temperature equalization through a continuous-flow water jacket. The water system can also be linked to cooling or heating circuits according to market climate conditions.

Alternative advanced sodium–sulphur batteries storing up to 27 kW h at about half the weight of existing batteries are expected to become available during 1993. This will increase the all-electric range to more than 100 miles and will represent a major step toward the introduction of a zero emission (ZEV) version of the car. Advanced lead/acid and nickel–cadmium are also under study as promising advanced battery systems.

Auxiliary power unit (APU)

This is quiet and clean 650 cm^3 four-cylinder, water-cooled gasoline engine of Japanese microcar origin. It is fuelled with 'reformulated gasoline' through an electronic multipoint fuel-injection system system with electrically-heated three-way catalytic converter for minimum emissions. The engine can also be used to recharge the batteries away from base where there is no mains charging available.

Power-train management system (PTMS)

The PTMS is a microprocessor-based electronic-control system which controls the blend of power from the electric motor and the APU to the wheels. The system makes decisions based on the state-of-charge (SOC) of the battery, driving conditions (city or freeway), driver demands for acceleration or regenerative braking, etc. The system also monitors and informs the driver continually of all vehicle function conditions, at the same time storing information for service diagnostic purposes. This is a true 'drive by wire' system, perhaps one of the first to be featured on a production car.

Electric air conditioning and heating

An energy-efficient electric air conditioning and heating system is being developed for the LA301. This will use new ozone-friendly working fluids and will have programmable climate control; it will be possible to precool or preheat the car and also to leave the system on standby for short periods while parked.

On-board charge

The automatic on-board charger is a lightweight high-frequency device which will recharge the battery overnight and can be used for opportunity charging when required from a 22 or 11 V outlet.

Equipment

Power brakes and power steering are standard equipment. Interior cooling can be assisted by an optional roof-mounted solar panel and fan which maintains a flow of ambient air through the car when parked – this substantially reduces the pull-down load on the system. A Bosch 'Travelpilot' navigation system is available to advise the driver of his map position and to provide information on location of charging/parking facilities, etc.

Development, manufacture and marketing plans

Clean Air has contracted with IAD or Worthing, UK, for all engineering development, proving an safety certification. IAD are one of the largest and most well-established design and development consultants in the world, with facilities and offices in USA (California and Detroit), Japan, South Korea, France, Germany, Russian Federation, etc.

The development program has progressed through full-size exterior and interior clay models to two complete working semi-engineered prototypes. Drivetrain development is being carried out on mule vehicles. Extensive durability testing and safety certification work will be carried out over the next eighteen months.

Two prototype LA301 vehicles have been shown at major autoshows around the world – Frankfurt, Los Angeles, Tokyo, Hong Kong and Gothenburg – and have received wide acclaim from the automotive press and from the auto industry itself. It may be true to say that the high level of activity in EV development that is apparent in almost every auto manufacturer's forward plans is directly attributable to the Los Angeles Electric Vehicle Initiative and the subsequent Californian legislation.

Manufacturing and pilot assembly is planned to start in the UK late next year at production rates starting at 20 units per week. Full-scale US production is being planned for 1994.

The new cars will be marketed through a quality dealer network which will emphasize skilled sales and service using state-of-the-art computer diagnostic equipment. A very high level of customer care is regarded as essential for buyers of Clean Air's advanced products.

A high level of comfort, combined with performance which allows safe acceleration and cruise capability on freeways, is an essential ingredient for success in the marketplace. Targeted at the 'lower luxury' consumer market at a price around US $25 000 fully equipped, the LA301 is expected to gain wide acceptance among environmentally conscious and discerning consumers.

All this can be achieved with remarkable energy efficiency. Fuel consumption projections show that on a journey of 100 miles the LA301 will achieve around 75

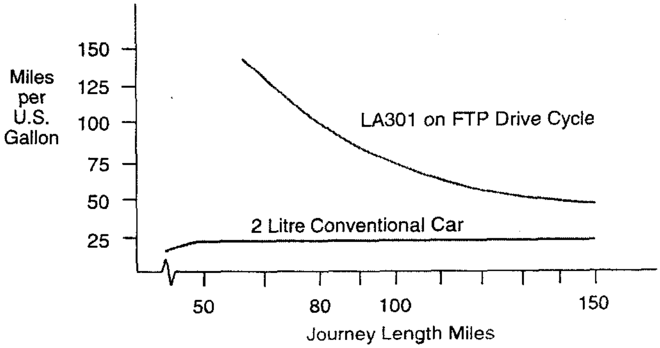

Fig. 11. LA301 projected fuel economy vs. journey length.

miles per US gallon or 0.03 l/km (Fig. 11). Clearly, on journeys of less than 50 miles the only energy consumed is electrical. This means that a 50-mile all-electric journey consuming about 15 kW h of power at around 7 dollar cents per kW h (Los Angeles rates) would be at an energy cost of only a little over one dollar!

Conclusion

There are more than 500 000 new cars sold per year in Los Angeles area but, as yet, the customer has not clean alternative to a gasoline car. The EV has been

Fig. 12. The Clean Air LA301 electric vehicle.

shown to be the preferred long-term solution; the state authorities have reacted with 'technology-forcing legislation' to ensure its introduction; now is the time, perhaps more than at any time in history, to react to popular demand and to bring the EV to the market.

Electric-vehicle technology has not been able to keep up with the massive investment that has been made in the IC-engined car over the last forty years. But now priorities are changing rapidly, investment in EV development is increasing – the US 'Big 3' manufacturers are teaming up to develop a new 'Superbattery' – and Los Angeles has taken the lead in providing a focus for a whole new EV market; Europe and the rest of the world's major urbanized areas must soon follow this lead.

Clean Air's new LA301 electric vehicle (Fig. 12) can provide a near-term solution to ground level pollution problems in our cities and can in time help in the fight against global climate change. If we are to continue to live in cities alongside the motor car, if industry is to continue to grow, for the sake of our future prosperity and health, we have to go electric!