nuclei. As a result, the kinetic energy of the neutrinos is sufficiently large so as to induce the following reactions

$$\nu_e + {}^2\mathrm{D} \rightarrow e^- + 2p \qquad \text{(CC)}$$

$$\nu_l + {}^2\mathrm{D} \rightarrow \nu_l + p + n, l = \nu, \mu, \tau \qquad \text{(NC)}$$

The reason why the CC reaction above is sensitive only to the electron-type neutrino is that kinetic energy of the neutrinos produced in the boron reaction is sufficient only to produce electrons (m_e = 0.511 MeV/c^2), in accordance with Einstein's mass–energy equivalence, whereas the muons and the tau-leptons are too massive to be produced in this reaction (m_μ = 105.7 MeV/c^2, m_τ = 1777 MeV/c^2). The NC reaction does not have this kinematic constraint, and is therefore sensitive to all flavours. The combination of the small binding energy of the deuterium nucleus with the NC reaction is capable of producing a characteristic signal which can be detected when the deuterium nucleus is shattered and the neutron is liberated. Nevertheless, the heavy-water detector observed the CC reaction above and the ES reaction rates by 2001, but had to wait until 2002 to observe the NC. The latter required that ultra-pure common salt (NaCl) be introduced into the heavy water so that the neutrons produced in the NC reactions could be absorbed by the Cl nuclei, and then produce a characteristic 8.6 MeV gamma-ray signal. Otherwise neutrons were detected by characteristic 6.25 MeV gamma ray when they get absorbed by deuterium in heavy water. The neutron absorption probability in heavy water is about 25%, which increased to 85% by addition of ultra-pure NaCl. This was achieved and the results subsequently reported[1a]. The final numbers quoted therein translate to 2/3 of the electron-type neutrinos oscillating into muon- and tau-type flavours. Furthermore, the observation of a non-vanishing day–night effect shows that there may be some regeneration of the electron-type neutrino flux in the passage of the neutrinos from the sun through the earth. Such an effect, known as the Mikheyev–Smirnov–Wolfenstein effect, has been studied in the past and is now likely to be constrained quite effectively, or alternative vacuum oscillation scenarios are likely to be constrained as well. For a recent discussion of the impact of the SNO measurements on theoretical scenarios, see Bahcall *et al.*[3].

It must be mentioned again that the advantages of heavy water also leads to the possibility of large backgrounds. In fact, the SNO experiment is located deep underground in nickel mines in Canada, and the heavy water which is stored in a large acrylic container, is also surrounded by jackets containing normal water in order to absorb radiation from the surrounding rock and also from cosmic ray sources which could easily generate spurious signals which serve as a background.

In conclusion, we note that the remarkable experiment at the SNO based on the deep insights of Chen has resolved the solar neutrino problem in favour of a solution arising from neutrino oscillations, rather than from unknown inadequacies of the standard solar model. The SNO collaboration is expected to improve its statistics and bring down uncertainties in its measurements, and will pave the way to confirming and constraining theoretical scenarios which account for neutrino oscillations.

1. a. Ahmad, Q. R. *et al.*, [SNO Collaboration], *Phys. Rev. Lett.*, 2002, **89**, 011301; b. 2002, **89**, 011302; c. 2001, **87**, 071301.
2. Chen, H. H., *Phys. Rev. Lett.*, 1985, **55**, 1534.
3. Bahcall, J. N., Gonzalez-Garcia, M. C. and Pena-Garay, C., arXiv:hep-ph/0204314.

B. Ananthanarayan and Ritesh K. Singh are in the Centre for Theoretical Studies, Indian Institute of Science, Bangalore 560 012, India. *For correspondence (e-mail: anant@cts.iisc.ernet.in).*

COMMENTARY

Auto fuel policy: a question of balance

Uday T. Turaga

The Mashelkar Committee's interim report[1] on auto fuel policy (see Box 1 for a chronology of key events) has created intense controversy, blurring the key issues at stake. Environmentalists consider the report as a sell-out to the so-called diesel lobby, ensuring India's 'return to the era of smoke and fumes'. As a fuel scientist at The Pennsylvania State University, specializing in the removal of sulphur from diesel fuel, I write this to present a different perspective.

The Mashelkar report, surprising as it may be in these frenzied times, is one of the few good pieces of Indian public policy produced in recent times. It is stupefying that key fuel technology and policy players like the oil refineries, automakers, research institutes like the Indian Institute of Petroleum, and the Indian government have, as always, blundered by refusing to react, let alone defend the Mashelkar report against the misplaced fury of the environmentalists' articulate and high-profile media campaign.

Super emitters limit leapfrogging advantages

At the core of the controversy is the Mashelkar report's timeframe for phasing in fuel specifications. The Mashelkar report suggests that:

(1) Euro II regulations be extended no later than 2003 to Bangalore, Hyderabad and Ahmedabad in addition to the four metros they are currently active in.
(2) Euro III (diesel fuel with 50 ppm sulphur) regulations be enforced in these seven mega cities and the entire nation by April 2005 and 2010, respectively.
(3) Euro IV be evaluated for economic feasibility.

The green lobby calls these 'weak', 'incremental' measures and instead desires that India leapfrog to Euro III or IV fuel specifications immediately which alone will, in their view, reduce health hazards.

This, they claim, is because India embarked upon these regulations much after they were enforced in the developed world. There is no denying that India would be implementing these regulations years after they were enforced in Europe. But the argument that leapfrogging to Euro III or IV right away would significantly reduce pollution is flawed.

This is why. The bulk of India's vehicular pollution, besides the highly polluting two-wheelers and three-wheelers (having two-stroke engines), comes from a relatively small fraction of the vehicular fleet I call 'super emitters.' These are, typically, vehicles ten years or older with old engine technology and no emission control devices[2]. As a rule of thumb that has been remarkably accurate in the developed nations, approximately 10% of a nation's passenger car fleet are 'super emitters' and contribute to about 50% of all vehicular emissions[2]. In its presentation to the Mashelkar committee on auto fuel policy, the New Delhi-based Centre for Science and Environment cited data from Delhi's State Transport Authority to conclude that no more than 13–18% of the city's vehicles were compliant with Euro I vehicular emission norms[3]. With that in mind, it could be concluded that at least 70–80% of Delhi's vehicles are 'super emitters', which probably contribute to the bulk of the city's vehicular pollution.

Clearly, howsoever clean a fuel is used in the remaining 20–30% newer vehicles, the expected reduction in air pollution will be marginal. Further, significant changes in emissions become evident only after a significant portion of a city's vehicular fleet is turned over. Such a turnover requires 15 to 25 years. Therefore, instead of the Mashelkar report's recommendations, the immediate reduction in air pollution by leapfrogging to Euro III or IV norms is incremental! Even if these are ballpark estimates, the costs of immediately implementing Euro III or IV clearly outweigh their rewards.

Markets-based approach

The refusal of the Mashelkar report to explicitly endorse any particular fuel or vehicle type for reducing vehicular pollution is the second issue that has disappointed environmentalists. The Mashelkar report's recommendation is a classic markets-based approach to emissions reduction now practised all over the world. For example, following its widely criticized Tier 1 regulations (which specified fuel composition), the United States Environmental Protection Agency moved to emissions-based Tier 2 specifications which predominantly regulate tail-pipe emissions, irrespective of fuel or vehicle type[4].

In addition to catalysing India's movement to the cleanest possible fuel without causing major disruptions in the availability and infrastructure of transportation fuels, the emissions-based regulatory framework shall also make the oil and auto industries *equally* responsible for reducing vehicular pollution. This is important because Indian automakers need to develop advanced engine technology to fully realize the benefits of clean fuels.

The environmental lobby's argument that creation of fiscal incentives to promote compressed natural gas (CNG) would override its availability or cost issues, is wrong. If fiscal incentives alone could eliminate fuel shortages, the US would have never witnessed the massive electricity crisis that hit California in early 2001 (ref. 5). The supply and availability of natural gas became the key stumbling block in the California electricity crisis, notwithstanding America's massive fuels transport infrastructure[6,7].

Indigenous solutions

As pointed out by the Mashelkar report, sustainable improvements in air quality can be achieved only by a holistic approach, of which fuel quality will be just one component. Another important component of this holistic approach should be emissions control technology. While petrol engine emissions control technology (e.g. catalytic converters) was mature and readily available when India got worried about air pollution[8], significant technical progress is still required for effective diesel emissions control technologies. Diesel emissions control is more important and relevant for India, which consumes a lot more diesel in comparison to other hydrocarbon fuels[9].

Box 1. A chronology of the events related to fuel policy in India

Year	Development
1986	M. C. Mehta files a public interest litigation case in the Supreme Court of India (SC) about air pollution in Delhi.
1986–96	SC rulings result in the introduction of unleaded petrol, catalytic converters, CNG-powered government vehicles and low-sulphur diesel.
1991	Government issues first set of emission standards.
1996	Government issues second set of emission standards.
1998	SC appoints the Environment Pollution (Prevention and Control) Authority for the National Capital Region (also known as the Bhure Lal Committee).
	SC directs phasing out 15-year-old vehicles and conversion of buses, old taxis and three-wheelers to CNG-based engines by April 2001.
1999	SC advances emission standards and mandates 500 ppm diesel and petrol.
2000	The Society of Indian Automobile Manufacturers issues a road map for clean fuels; proposes accelerated introduction of Euro III and IV norms.
2001	The Inter-Ministerial Task Force submits its report on fuel quality and vehicular emissions; the proposed timeline and recommendations similar to the Mashelkar report.
	SC extends April 2001 deadline to September 2001.
	SC directs the Bhure Lal Committee to examine polluting potential of ultra-low sulphur diesel (diesel with sulphur less than 50 ppm).
	Bhure Lal Committee concludes that CNG is cleaner than ultra-low sulphur diesel.
	In August 2001, Delhi has the largest fleet of CNG buses in the world.
	The Prime Minister of India constitutes a committee under the chairmanship of R. A. Mashelkar to recommend a national auto fuel policy.
2002	Interim report of the Mashelkar committee on national auto fuel policy is released; the Union cabinet approves and accepts its recommendations.
	SC ruling reiterates its preference for CNG-fuelled buses.

Box 2. Highlights of technical issues involved with fuel policy

Fuel quality is a complex issue that spans fuel science, engine design, oil refining, and public policy.

The bulk of the vehicular pollution in most cities occurs from less than 10% of its passenger car fleet. Other contributors to vehicular pollution are evaporative hydrocarbon emissions, off-cycle operations (during which the catalytic converter's operation is not efficient), off-road vehicles, poor roads, and ineffective inspection and maintenance programmes[2].

The widespread use of CNG as a fuel needs to be evaluated against available technology, infrastructure and supply–demand economics.

Emissions control technologies for petrol engines (e.g. catalytic converters) were a mature and readily available technology in the early 1990s, when India decided to adopt them. Emission control technologies for diesel engines are relatively new, and India should develop a national technology mission to assume a leadership role in this area.

Fuel specifications mandated by recent Euro regulations demand sophisticated petroleum refining technologies which might not be readily available.

I believe that the current fuel policy debate is an opportune moment to launch a national technology mission with the goal of developing two or three world-class diesel emissions control technologies by 2005. This mission should ideally be a partnership between the oil refineries, the automotive industry, and national labs such as the Indian Institute of Petroleum, the National Chemical Laboratory and the Indian Institute of Chemical Technology. Indian science has performed whenever challenged; providing clean air to every Indian is challenging enough for Indian science to deliver.

Selective science

Fuel quality is a complex interplay (see Box 2) of intractable technical issues relating to automobiles, fuel production or oil refining, and emissions control[10]. Articulate environmental groups have taken advantage of these complexities through the use of selective pieces of technical data to push their parochial agenda. Popular media – thanks to the complexities involved – have conveniently done away with independent research to rehash predigested 'fact sheets' issued by environmental groups.

For example, while international studies on CNG have been circulated extensively, there has been little discussion on research initiatives such as the American Partnership for a New Generation Vehicle (PNGV) programme[11]. The goal of the PNGV programme was to develop an automobile with a fuel economy of 34 km/l of fuel (increased fuel economy translates to reduced emissions). Research from the PNGV programme has established that only a diesel-powered automobile would be able to deliver that promise. Further, research that I have been associated with at my university has shown that increased diesel use affords significant reductions in carbon dioxide emissions and overall crude oil consumption[12].

The question of balance

Euro II regulations alone are going to cost oil refineries rupees 35,000 crore to remove sulphur from diesel and petrol[1]. Euro III and IV regulate a slew of fuel specifications besides sulphur and aromatics content, and will demand greater investments[13]. Furthermore, complying with these non-sulphur specifications (e.g. cetane number and fuel density) will require highly sophisticated refining technologies that are still in their infancy in the developed world itself[14]. Equally daunting fiscal investments need to be made in the automotive industry. For a country like India which is looking at a budget deficit of over rupees 100,000 crore or 5.5% of gross national product[15], investments of the kind required by Euro III and IV are not easy to make.

Finally, accusations that the Mashelkar report has diluted other reports on the subject are ridiculous. Unlike the unimplementable utopias that previous reports proposed, the Mashelkar report presents the first feasible framework for a national fuel policy. This, by itself, is a remarkable accomplishment considering that no fuel policy exists now, except for piecemeal measures drawn through judicial activism. While the human health of India is a priority that cannot be compromised, the path towards that goal needs to be paved with policies that are scientifically sound and relevant to the Indian context. The Mashelkar report offers one such path and is a good starting point for a rational and continually evolving national fuel policy.

1. Mashelkar, R. A. *et al.*, Interim Report of the Expert Committee On Auto Fuel Policy, Government of India, New Delhi, 2002.
2. Calvert, J. G., Heywood, J. B., Sawyer, R. F. and Seinfeld, J. H., *Science*, 1993, **261**, 37–45.
3. Presentation to the Committee on Auto Fuel Policy, Centre for Science and Environment, New Delhi, 2001.
4. 'Proposed Tier 2 emission standards for vehicles and gasoline sulphur standards for refineries', Office of Transportation and Air Quality, United States Environmental Protection Agency, Washington DC, 1999.
5. Woo, C.-K., *Energy*, 2001, **26**, 747–758.
6. Oppel, R. A., Jr. *The New York Times*, 5 June 2001, p. A1.
7. Jehl, D., *The New York Times*, 8 March 2001, p. A1.
8. Heck, R. M. and Farrauto, R. J., *Appl. Catal. A: Gen.*, 2001, **221**, 443–457.
9. Prasada Rao, T. S. R., pers. commun., 2002.
10. Kaufmann, T. G., Kaldor, A., Stuntz, G. F., Kerby, M. C. and Ansell, L. L., *Catal. Today*, 2000, **62**, 77–90.
11. Dean, P., *Los Angeles Times*, 29 April 1999, p. 1.
12. Adams, A., Chapman, E., Davis, D., Liu, J., Turaga, U. T. and Wu, X., 'Identification, evaluation and recommendation of short-term technological options for the reduction of environmental impact attributed to the US transportation sector with specific implications to the petroleum fuel cycle', FSc 503 Progress Report No. 3, Department of Energy and Geo-Environmental Engineering, The Pennsylvania State University, PA, 1999.
13. Miller, R. B., Macris, A. and Gentry, A. R., *Pet. Technol. Q.*, 2001, Spring, 69–74.
14. Turaga, U. T., Ph D thesis, The Pennsylvania State University, PA, 2002.
15. *Economic Survey 2001–2002*, Ministry of Finance, Government of India, Publications Division, New Delhi, 2002.

Uday T. Turaga is in the Fuel Science Program, Department of Energy and Geo-Environmental Engineering, The Pennsylvania State University, University Park, PA 16802, USA (e-mail: turagauday@hotmail.com).