# "In the energy scenario of the future all forms of energy must co-exist, each with its own economics and viability"

## - Dr S Sivaram, Director, NCL

**Buffeted by volatile and high oil prices and the spectre of the disastrous consequences of global warming due to increasing carbon emissions from a hydrocarbon based fuel and feedstock driven contemporary industrial system, the world is today truly on the horns of an energy resources dilemma. On the one hand, global energy experts, leaders in government and industry captains are aware of and concerned over the situation; on the other hand they are finding it difficult to shear the world away from its overdependence on hydrocarbons.**

**Several complex issues are involved. Whenever oil prices zoom to stratospheric levels, the media is inundated with reports of myriad range of alternatives that are possible. When the prices decline, it is back to the comfort zone.**

**To understand the complexities involved and the potential of fuel and feedstocks from renewables, Chemical Industry Digest spoke to Dr S. Sivaram, Director of National Chemical Laboratory (NCL) Pune. NCL with its competencies in innovative chemistry, bio-transformations, cataysis and chemical engineering is engaged in pioneering work on bio-derived products and fuels. Dr Sivaram is a leading celebrated scientist of the country and has passionately articulated the need to shift from a fossil fuel economy to viable alternatives based on "carefully assessed and well thought strategies".**

**As he says in this interview, choices for such shifts will have to be country and geography specific and decisions should be based on availability of technology, availability of feedstock and long term sustainability. Dr Sivaram also spoke on the work on bioderived products going on at NCL, the prospects and potential of such processes and on the new emerging exciting field of synthetic biology.**

### Excerpts from the interview:

**Chemical Industry Digest (CID): The recent unabated rise in petroleum prices and its volatility are threatening fast growing global economies. Despite this, transition to other renewable alternatives is hampered by the well entrenched infrastructure of oil & gas.**

**So how can an effective transition to emerging biofuels be expedited so that the world can reduce the stranglehold of oil and gas on its economy?**

**Dr S Sivaram (Dr SS):** Shifting the energy intensity of our civilization from fossil fuels to alternative energy resources is a long and arduous task. Such a shift will not come about in a short time. History teaches us that shift in energy usages in the past has taken over a century or more. For example, shifting from coal as an energy resource to oil and gas took close to one hundred years. There is no reason to believe that the shift from oil and gas to an alternative energy source will be any less shorter. The reason that this process is lengthy is because, several ancillary systems that propel our civilization have mature technologies that have been built around oil and gas. This cannot be dismantled quickly, since substantial investments have been made already in these systems.

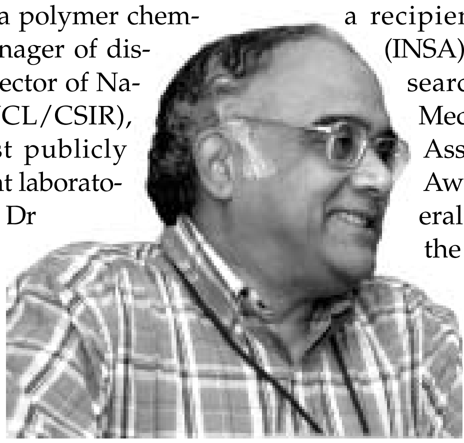
Example: transportation, power generation, chemical building blocks for materials etc. Furthermore, these technologies have matured to the extent that they are the lowest cost options today. Consequently, displacement will not be easy or painless. Alternative energy technologies, on the contrary, are at the early stages of the experience curve and will need substantial new economic investments.

**“A smooth and non-disruptive transition must occur from a fossil fuel dependent economy to an alternative energy based economy. The question is not how long fossil fuels will last; the cost to the environment arising as a result of combusting fossil fuel is too high for us to persist with this practice.”**

Yet, this fact also points out to another danger. Since shifting energy platforms take a long time, they are also, in a sense, irreversible. Once choices are made, they cannot be undone easily. This calls for extreme caution while defining alternatives. Long term consequences of every alternative must be carefully assessed. Only those options which meet the stringent criteria of sustainability must be chosen. Decisions must be made based on careful assessment of “unintended consequences”. Expediency and short term solutions must be assiduously avoided.

A smooth and non-disruptive transition must occur from a fossil fuel dependent economy to an alternative energy based economy. The question is not how long fossil fuels will last; the cost to the environment arising as a result of combusting fossil fuel is too high for us to persist with this practice. While considering the shift, several factors need

## Padma Shri, Dr S Sivaram, India’s leading polymer chemist and distinguished science and technology manager



Dr Swaminathan Sivaram is a polymer chemist, mentor and science manager of distinction. He is presently the Director of National Chemical Laboratory (NCL/CSIR), Pune, India, one of the largest publicly funded research and development laboratories devoted to chemical sciences. Dr Sivaram has over forty years of experience in basic research, process/product R&D and S&T management, both, in industry and academia. He is widely recognized for his contributions to polymer science, technology development, institution building and management of innovation in publicly funded organizations. An alumnus of IIT-Kanpur (M.Sc. 1967), he received his Ph.D in Chemistry from Purdue University, W. Lafayette, Indiana, USA in 1971.

In 1988, he joined NCL as Head of the Polymer Chemistry Division. Dr Sivaram built an impressive portfolio of polymer research activities at NCL, both, with Indian companies and global multinationals, making NCL a preferred destination for companies far and near to explore research collaboration through a partnership model. He also built a globally recognized research group in polymer science at NCL.

Widely decorated with numerous awards, he is a recipient of the Vishwakarma Medal (INSA), Silver Medal of the Chemical Research Society of India, Millennium Medal of the Indian Science Congress Association, Distinguished Alumnus Award of IIT, Kanpur amongst several others. Dr Sivaram was awarded the Padma Shri by the President of India in 2006. He is also the recipient of J.C. Bose Fellowship of the Department of Science and Technology, Government of India for the period 2007-11.

He is an elected Fellow of Indian National Science Academy, New Delhi; Indian Academy of Sciences, Bangalore; National Academy of Sciences, Allahabad and Indian National Academy of Engineering, New Delhi. He is also an elected Fellow of the Academy of Sciences for the Developing World, Trieste, Italy.

He has lectured widely around the world and has been Visiting Professor at universities in France, Germany and USA.

He has mentored the Ph.D thesis of 35 graduate students. He has to his credit close to 200 publications in peer reviewed scientific journals and is cited as an inventor in over ninety patent applications and forty granted US patents.

to be kept in mind. These are (a) availability of technology (b) availability of feedstock or resources and (c) long term sustainability.

The choices are nation and geography specific. Every country must have a well thought out strategy, based on factors listed above and the energy intensity, present and future, of the country. The road map must allow multiple forms of energy to co-exist for a reasonable period of time. The options for transportation fuel, as well as fuel for generating electricity, must be separately delineated.

Whereas, biofuels may in the short run offer reasonable advantages as transportation fuels, renewable resources (wind, solar-thermal, solar PV, nuclear) must be exploited for electricity generation. In the longer term, transportation has to shift to either electricity or hydrogen produced from water.

**"India also faces a disadvantage in that the policy making arms of the government concerning energy is too fragmented cutting across many administrative ministries, namely, agriculture, petroleum and natural gas, coal, renewable energy power etc. Time has come for India to create a National Energy Commission vested with full policy making powers cutting across all forms of energy and fuels."**

**CID: Countries like India are deeply affected by high oil prices though the Government keeps insulating industry, business and the people from its deleterious impact, due to which, the drivers that can catalyse change to alternatives are neutralised. What should be the elements of a long term vision and energy and feedstock policy for the country as well as for individual companies?**

**Dr SS:** Artificially keeping the price of petroleum products low through state subsidy has a detrimental effect on the emergence and sustenance of alternative energy technologies. In India, both fuel as well as electricity is subsidized. Whereas, this insulates the consumer in the short term, the long term impact of such subsidy is detrimental.

For India, some amount of subsidy is inevitable. However across the board subsidy must be avoided. As a first step, the artificially low prices of diesel must be progressively increased and must become equal to that of gasoline. Second, alternative energy production must be incentivized by fiscal incentives such as tax holiday, investment rebates, waiver of excise/import duties etc. All incentives must be free of dependence on production capacities. Similarly, community power generation and distribution must be freed of all regulatory shackles. Investment in renewable energy fuel based captive power generation must be made more attractive than fossil fuel based captive power generation.

Some amount of incentives do exist today. However, they are too fragmented and not adequately focused. India also faces a disadvantage in that the policy making arms of the government concerning energy is too fragmented cutting across many administrative ministries, namely, agriculture, petroleum and natural gas, coal, renewable energy power etc. Time has come for India to create a National Energy Commission vested with full policy making powers cutting across all forms of energy and fuels.

**CID: Different alternatives and scenarios are being widely discussed, globally and in India too: Solar,**

**The National Chemical Laboratory complex in Pune**

> **When viewed in an integrated manner bio-derived chemicals, materials and energy can become cost competitive with the corresponding fossil fuel derived materials.**

**wind energy, nuclear, tidal, coal gasification, coalbed methane, gas hydrates, hydrogen, methanol and ethanol (thru non-fossil fuel sources or thru bio sources), fuels and chemicals from biomass, from food crops as well as from non-food agro residues and energy crops like jatropha. Which ones seem feasible for India and which are likely to see commercialisation in the near future?.**

**Dr SS:** In the energy scenario of the future all forms of energy must co-exist, each with its own economics and viability. Fossil fuels will exist for a long time (gas, oil, coal etc). Usage of these fuels will be increasingly subject to an environmental cost – cost of mitigating $CO_2$ emissions. Nuclear energy will continue to grow, but will need enormous capital per kwh basis. Wind energy will become relevant in select geographical locations. Power generation through solar thermal and solar photovoltaic holds the promise as the most abundant source of renewable energy for India, a country blessed with abundant sunshine. Biomass derived power could be a great asset to rural electrification for small community based systems. Transportation fuel, will continue to be based on fossil fuel for quite some time. Public transportation systems must shift from diesel to CNG, a cheaper alternative. Creation of CNG infrastructure will also be the first step towards a hydrogen based fuel economy, since in the future, hydrogen distribution can utilize the available CNG infrastructure. Biofuels, derived from plants, that do not compete for food could be at best an interim solution. In the long term, transportation should shift to hydrogen or a mixture of $H_2$ and CNG or $H_2$ and electricity.

> **NCL has developed a process to convert sugarcane juice to anhydrous L(+)-Lactic acid. This is the first process of its kind in the world. L(+)-lactic acid is a platform chemical which can be used as additives in food and pharmaceuticals or converted to a polyester which is biodegradable under composting conditions.**

**CID: Your esteemed research institution, National Chemical Laboratory, is a leader in many areas of R&D. We understand that NCL is doing remarkable work in biofuels and bio feedstocks. Specifically in this area, could you please outline the major milestones you have achieved and can the country look forward to a bioprocess breakthrough from NCL in the near future that can be widely deployed in industry?**

**Dr SS:** NCL in the last few years has used its competencies in chemistry and engineering to focus on bio-derived products and fuels. The objective is to validate technologies and establish commercial feasibility. In the end, converting plant products into energy and materials useful to mankind requires innovative chemistry, biotransformation, catalysis and chemical engineering, areas where NCL has traditionally been strong.

Ligno-cellulosic biomass, a waste product of agriculture can be used to generate biofuels, bioderived materials and biopower (heat and electricity). NCL is using a variety of tools to create value out of agricultural wastes and produce chemicals, materials and liquid fuels from them. Much of the basic knowledge in this area exists widely in the literature. The challenge is to develop processes that are commercially viable, tailored to India's needs and can be implemented in an integrated manner close to the source of the raw material.

**CID: We understand that NCL has done significant**

> **NCL is currently engaged in a programme of research with a consortium of research laboratories and industry to develop useful products from glycerol obtained as a by product of biodiesel manufacture. Many products are being examined, namely, epichlorohydrin, acrylic acid, 1,3 and 1,2-propanediol and 3-hydroxy propionic acid. The future of many of these technologies will depend on the price of glycerol and that of the corresponding petroleum derived feedstock, namely, propylene.**

**work on conversion of $\alpha$-cellulose obtained from bagasse into chemicals and that you have put up a pilot plant alongwith Godavari Sugars and Chemicals. Could you please elaborate on this, the platform chemicals that can be produced and the potential this development could have in India? Could you also expand on the concept of the integrated biorefinery?**

**Dr SS:** A bio-refinery is an entire integrated complex in which biomass feed stocks are extracted and converted to a broad spectrum of valuable products, namely, chemicals, materials and energy. In this respect, this is analogous to a modern day petroleum refinery. When viewed in an integrated manner bioderived chemicals, materials and energy can become cost competitive with the corresponding fossil fuel derived materials.

There are three bio-refinery platforms which are under active development, namely, lingo-cellulosic, thermo-chemical (biomass pyrolysis or gasification and biomass to liquid fuels (BTL) analogous to gas to liquids (GTL) or coal to liquids (CTL) and oleochemical (biodiesel).

As a first step, NCL has developed a prefractionation process to separate the constituents of bagasse, namely cellulose, hemicellulose and lignin in near quantitative yields. A demonstration plant has been in operation for about six months. The $\alpha$-cellulose has been found to be of a high quality and can be converted to a variety of derivatives (e.g. cellulose acetates, ethylcellulose, HEC etc). Processes for converting hemicellulose to useful products using solid catalysis are under development. A modified prefractionation process is being studied to make lignocellulosic biomass suitable for enzymatic conversion to ethanol. Research involving collaboration amongst several institutions are also in progress to efficiently convert pretreated biomass to ethanol.

India has significant quantifies of agricultural residues (sugar, rice, wheat etc.). As a rough estimate, 1 tonne of agricultural waste can produce 150 L of ethanol or 0.5 t of fuel oil or 0.8 kw of electricity. Thus, they constitute a very valuable resource.

> **“CSIR is launching a major inter-laboratory effort in synthetic biology, as a platform technology for the manufacture of useful chemicals and designer fuels. A project team is currently drawing out the plans for specific projects and identifying scientific competencies across CSIR who can contribute to this effort. The project could also have participation from industry in a consortium mode, who could further develop commercially important leads emerging from this programme.”**

NCL has also developed a process to convert sugarcane juice to anhydrous L(+)-Lactic acid. This is the first process of its kind in the world. L(+)-lactic acid is a platform chemical which can be used as additives in food and pharmaceuticals or converted to a polyester which is biodegradable under composting conditions. A continuous demonstration plant for validating the technology is currently under design and will be operational by second quarter 2009. These are some of the first building blocks of technologies around a sugarcane complex – to valorize various streams of a sugar industry to produce chemical, polymers and energy. NCL hopes to demonstrate the technical viability of such technologies and derive data on process economics within the confines of a sugar manufacturing complex. There are several more such building blocks awaiting validation. Together, they will establish the viability of a sugarcane biorefinery.

**CID: You have also achieved a significant breakthrough in developing a solid catalyst for biodiesel production through transesterification. We understand that this is the first of its kind in the world. Could you give us more details on this?**

**Dr SS:** NCL has developed several heterogeneous catalyst compositions capable of transesterifying triglycerides of fatty acids to fatty acid methyl esters (biodiesel) and glycerol. The advantage of the solid catalyst is that it functions in a non aqueous environment and produces glycerol free from water. Furthermore, the process can use triglycerides with substantially higher free fatty acid content compared to the aqueous alkali based transesterification process. These catalyst compositions have been patented.

Currently, all operating biodiesel plants are based on an aqueous process. No solid catalyst based process has been commercialized. Recently, Nippon Shokubai, Japan has announced a 60L/day pilot plant at Tsukuba for biodiesel using a solid catalyst. IFP (Axens), France has also developed a solid catalyst based process for biodiesel. NCL's catalyst has been licensed to a start up company. A commercial plant has been engineered based on NCL catalysts.

Several licensing negotiations are in progress for both the catalyst and the process. If these negotiations succeed, we could see a commercial plant in operation by early 2009.

Unfortunately, because of a lack of coherent biofuel policy within India as well as lack of assured feed stocks at reasonable prices, commercial production of biodiesel in India for domestic consumption is still a few years away.

**CID: Increasing biodiesel production in the world is seeing a glut of glycerine. What is the work at NCL on conversion of glycerine into epichlorohydrin and other chemicals? We understand that in this area also NCl has developed a unique solid catalyst based process based on which a plant is being put up in Thailand.**

**Dr SS:** NCL is currently engaged in a programme of research with a consortium of research laboratories and industry to develop useful products from glycerol obtained as a by product of biodiesel manufacture. Many products are being examined, namely, epichlorohydrin, acrylic acid, 1,3 and 1,2-propanediol and 3-hydroxy propionic acid. The future of many of these technologies will depend on the price of glycerol and that of the corresponding petroleum derived feedstock, namely, propylene. Of late, the price of glycerol has substantially hardened, because of the slump in the biodiesel industry. Consequently, much of the opportunities earlier envisaged may not be realizable.

**“Using synthetic biology, one can build an enzyme that digests cellulose or build a bacteria that will feed on sugar to produce a designer hydrocarbon useful as a jet fuel. Synthetic biology is believed to be a disruptive technology. Revolution in biological engineering will advance much faster enabling chemical and energy companies to harness gene synthesis to create new paths for yielding the same products in a way that is less capital intensive and far cleaner.”**

Nevertheless, NCL continues with its efforts towards development of alternative users for glycerol. In any case no large scale biodiesel production can be economically viable without a captive glycerol utilization technology. Merchant sale of byproduct glycerol is not a viable option.

**CID: We understand that there is a major CSIR initiative being undertaken in synthetic biology and fuels where NCL is the prime mover. Could you please give us more details on this initiative and how it is proceeding?**

**Dr SS:** CSIR is launching a major inter-laboratory effort in synthetic biology, as a platform technology for the manufacture of useful chemicals and designer fuels. A project team is currently drawing out the plans for specific projects and identifying scientific competencies across CSIR who can contribute to this effort. The project could also have participation from industry in a consortium mode, who could further develop commercially important leads emerging from this programme.

Synthetic biology involves deliberate, constructive modifications of cells and organisms so as to achieve human objectives. Synthetic biology aims at creation of entirely new organisms *do novo*. The term “synthetic” denotes that organism in question has a genetic code that is not found ordinarily in nature. Synthetic biology integrates disciplines like biology, engineering, computer modeling, IT, control theory, chemistry and nanotechnology. The cost of synthesizing a gene has dropped dramatically in recent years. Specialist “gene foundries” now allow anyone to order any gene and produce an organism from chemically synthesized genes making traditional methods of cloning obsolete. Using synthetic biology, one can build an enzyme that digests cellulose or build a bacteria that will feed on sugar to produce a designer hydrocarbon useful as a jet fuel.

Synthetic biology is believed to be a disruptive technology. Revolution in biological engineering will advance much faster enabling chemical and energy companies to harness gene synthesis to create new paths for yielding the same products in a way that is less capital intensive and far cleaner.

NCL is strengthening its internal competencies in chemistry, biology, chemical engineering and computational science to play an active part in this emerging area.