Twenty-Sixth Lovraj Kumar Memorial Lecture
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# IMPERATIVES IN CHEMICAL, PETROCHEMICAL AND PETROLEUM REFINING INDUSTRIES

by


**PROFESSOR M.M. SHARMA, FRS**
**Emeritus Professor of Eminence,**
**Institute of Chemical Technology, Mumbai**



Organised By
Lovraj Kumar Memorial Trust
in association with
Indian Institute of Chemical Engineers
Northern Regional Centre
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**26th Lovraj Kumar Memorial Lecture**

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## Prologue

I am most grateful to the Trustees for inviting me to give this coveted Lecture. I had the pleasure and privilege to know late Shri Lovraj Kumar since late 1960's and had many interactions with him, including at breakfast. In early 1980's, sequel to the recommendations of the then Scientific Advisory Committee (SAC) to the Cabinet, economic ministries were requested to constitute a SAC for their ministries. Shri Lovraj Kumar jumped at this recommendation and requested me to Chair the SAC. I had great pleasure in Chairing this SAC for several years and in early stages Shri Lovraj Kumar, Joint Secretaries and Directors used to attend these meetings and at that time Petrochemicals was with Petroleum Ministry. I should like to mention some very laudable recommendations of the SAC which the Government accepted. A notable one was that all ethane along with the natural gas should be separated and used for making ethylene and should not go to fertilizer plants and power stations. Thus, IPCL, Nagothane, came into existence and subsequently followed by that at Gandhar (now called Dahej) and by GAIL in (Auraya) Pata, UP. A few years ago, a recommendation that the LNG terminal at Dahej, Gujarat, should separate ethane, where at an early stage the Trust Chairman Shri B.K. Chaturvedi, who was then Petroleum Secretary, took initiative, on my suggestion, and make ethylene. It augurs well that Opal at Dahej has this feature. However, it is a pity that inspite of a large capacity LNG plant at Dahej (has probably crossed 15 mtpa) we do not have the utilization of the refrigeration potential of LNG. Please note that Japan and South Korea which were leaders in importing LNG had hooked these terminals to make $O_2$ for steel plants and even a linkage to the power plant can be done. It is very important that we implement this at Dehej and other terminals.

**Natural Gas Hydrates (NGH) : Fire on Ice**

A major breakthrough will come in coming years, perhaps in less than a decade, when a commercially proven process to recover NGH is implemented. This has an important matter for India as we do have very decent proven reserves and some work has been done but intensive work is required to bring it to fruition. World wide estimates of NGH vary from 10,000 to 40,000 trillion cum which may be compared with proven NG reserves of about 370 trillion cu.m. There is a possibility of using $CO_2$ to displace methane which will also allow safe storage of $CO_2$.

**Meetings of SAC**

The SAC met at several locations in the country, including the oldest refinery location in Digboi, Assam. The idea of linking petrochemicals to petroleum refining was mooted and also fuels should be like Designer's fuels.

Shri Lovraj Kumar was receptive to the idea of the R&D Director to be on the Board of Directors, so that R&D has a strong presence right in the beginning. History was created when in IPCL, even before the production started, R&D was started with the Director on the Board. This concept was then adopted in IOC and EIL.

I spent my lifetime in the University Department of Chemical Technology, Bombay, where the first Indian Director was the formidable Professor K. Venkataraman and his daughter Professor Dharma married Lovraj Kumar. Thus we had connection with Lovraj Kumar in so many ways. An auditorium was named after K. Venkataraman and at inauguration his daughter Radha was present.

**Petroleum Refining and Petrochemicals**

A major change that is expected to happen soon that a substantial part of petroleum products would go for petrochemicals. I hazard a guess that within 5 years it could be to the extent more than 65%, in some refinery + petrochemical complexes. Reliance Refinery in Jamnagar, Gujarat, was the first one in India to have a substantial hook-up with petrochemicals which included para-xylene (and even ortho xylene), cat-cracker propylene for polypropylene, etc and now off-gases from cat-cracker for the production of a part of ethylene of a major cracker with a total capacity exceeding 1.5 mtpa; it could add upto about 50% products of the crude refined. It is laudable that IOC with its own in-house development of high severity cat-cracking has propylene yield which is around 20% and can be higher and thus a large polypropylene plant is about to be commissioned in Paradip, Orissa. Thus, cat-cracking is now in the mode of making petrochemicals rather than fuels as benzene/toluene etc. also come from this source and off-gases, give a substantial amount of ethylene.

There is now a clear case of direct steam cracking of crude oil and a well known global company has adopted this strategy. This will further add to the moto that more and more petroleum refining will be tuned to make petrochemicals. As of now only about 10% of petroleum refining fractions go to petrochemicals. There is a strong possibility of adopting catalytic cracking of naphtha in place of thermal cracking to boost yields of ethylene + propylene.

Historically Benzene/Toluene came from coke-ovens but this course is now irrelevant as the platforming to make high octane gasoline has actually become almost an exclusive source of benzene, toluene and xylenes. Thus, yet another example of refining turned to petrochemicals can be discerned.

**Acrylic acid/esters**

It augurs well that three units in India are planning to make acrylic acid/esters, based on propylene, via acrolein, and this will support ever growing acrylic emulsion paints and much wanted diapers/sanitary towels for hygiene based on polyacrylic acid.

**Acrylonitrile (ACN)**

This is required to make acrylic fibers and Acrylonitrile – Butadiene – Styrene (ABS) and Styrene-Acrylonitride (SAN) polymers. We did start with an ACN plant in IPCL, Baroda, in late seventies, albeit with a capacity around 30,000 tpa, but thus is discontinued and all ACN is imported. There is an urgent need to have atleast one plant of more than 200,000 tpa. It is important to hook-up the use of HCN, a co-product for a variety of applications, besides making sodium cyanide. Acetonitrile, another co-product has multifarious uses, principally as a solvent.

**Additional challenges in this sector**

Valorization of a large amount of C-5 fraction from cat-crackers for petrochemicals is awaited in India. Thus, isoamylenes recovery via tertiary amyl methyl ether (TAME) can be a large source to make isoprene via dehydrogenation of isoamylenes (from TAME) to make synthetic natural rubber.

It would be appropriate here to refer to the C-5 fraction from naphtha crackers at Hazira, Panipat and Haldia and it is pity that this is not valorized. There is an urgent need to recover isoprene, Dicyclopentadene (DCPD), piperylene, etc. (cat-cracker C-5 fraction does not have isoprene, cyclopentadene and piperylene).

A large amount of C-4 olefins is available from cat-crackers and naphtha crackers. Fortunately butadiene in the C-4 fraction of naphtha crackers is being recovered (started with NOCIL, in Mumbai followed by IPCL, Vadodara and then IOC plant as Panipat and Haldia and Opal). In some cases, after isobutylene recovery via MTBE, butane-1 is recovered which goes as a co-monomer in polyethylenes (LLDPE and HDPE). There is a clear need to go for a large capacity butadiene from butanes via dehydrogenation/ oxydehydrogenation. This should be utilised for thermoplastic elastomer SBS (and SIPS).

**Alkyl naphthalenes and Naphthalene**

In cat-cracking a considerable amount of Light Cycle Oil (LCO) is obtained, and a somewhat similar composition is of the cracked fuel oil from naphtha crackers, which ought to be valorized to get alkyl naphthalenes and naphthalene. 2,6 Dimethyl naphthalene should be made to give the corresponding dicarboxylic acid which goes in making the polyester polyethylene naphthalate (PEN) which has very good barrier properties. India imports a sizeable amount of naphthalene and for making PEN the crucial issue is availability of 2,6 Dimethyl naphthalene which can be oxidized to 2,6 naphthalene dicarboxylic acid in replacing smaller PTA plants.

**Recovered Sulphur**

The availability of recovered sulphur from hydrodesulphurization plants, cat-crackers, sour natural gas has made it surplus globally and some value added products should be considered e.g. making polymers; asphalt modification, etc.

**Olefins from Cokers**

The C-3 to C-12 + cuts from cokers contains a fairly high percentage of alpha olefins and there is scope to valorize these to value added products.

**Use of $H_2$ from steam crackers of naphtha and ethane**

In standalone naphtha and ethane crackers hydrogen utilization is not proper and there is a possibility of having a large capacity maleic anhydride plant based on n-butane and use $H_2$ for making 1.4 butanediol/gamma butyrolactone/tetrahydrofuran; this will allow elastomeric fibers (commercially called Spandex) to be made.

**Propane dehydrogenation to propylene (PDH)**

There is an emerging need to adopt catalytic dehydrogenation of propane to propylene rather than steam cracking as the yield is much higher. It is a pity that we missed this opportunity in Vijaypur about 25 years ago. A large number of plants in USA and China have adopted this technology and in some cases the capacity is about 750,000 tpa. It is hartening that two plants are under consideration for GAIL and BASF for this technology.

**Isobutene / n-butane / propylene oxide**

While on the subject of isobutane, which is invariably with n-butane, should be oxidized to tert butyl hydroperoxide which can be used to make propylene oxide as is done by Lyondell Basel. This gives tert butanol which is very easy to dehydrate to pure isobutylene which is used for making polyisobutylenes, butyl rubber, speciality tert butyl/octyl phenols, etc. In any case a large capacity propylene oxide to make polyols for urethanes should be made on a large scale, at least at two or three locations via the $H_2O_2$ route and $H_2$ and pure $O_2$ are available in refineries/petrochemical units.

**Isobutylene to methacrylic acid**

There is a strong case for making methacrylic acid from isobutylene, via methacrolein, and its esters and this will avoid the hazardous route based on acetone and HCN. Atleast 100,000 tpa plant should be considered.

**Toluene**

It is pity that when more toluene that can be recovered in Haldia, Panipat and Opal we continue to import a large amount of toluene and this can be avoided.

**ETBE**

While on the topic of blending MTBE with petrol, why it is that we are making it mandatory to blend ethanol with gasoline, whose extent is being increased, when we are not resorting to making more useful ETBE which comes via reaction of ethanol with isobutylene and all cat-crackers and naphtha crackers have isobutylene in the C-4 fraction.

**Acetic acid and vinyl acetate (VAM)**

We have a very limited capacity for acetic acid and large scale imports take place. We must go for 1 mtpa plant at two locations. A substantial part of this should be linked to make vinyl acetate, which is entirely imported and which goes for making polyvinyl acetate based adhesives (e.g. the well known brand Fevicol). Further, Ethylene-Vinyl acetate polymer should be produced on a large scale. Even more exciting will be to make Vinyl acetate-ethylene emulsion paints which will be cheaper than acrylic emulsion paints and have better resistance to alkalies.

In the case of a vinyl acetate there is an exciting possibility of selective oxidation of cheap ethane to a mixture of ethylene and acetic acid which can then be taken to make VAM. It is reported that a 30,000 tpa plant is operating in Saudi Arabia to make ethylene/acetic acid.

**PVC**

It is a pity that inspite of a decent capacity of caustic / chlorine and where we are struggling for $Cl_2$ utilisation and on the other hand we are heading for imports of PVC approaching 2 mtpa. We must put up, at different locations, at least four 500,000 tpa plants.

While on the subject of caustic / chlorine it is disappointing that proper utilization of hydrogen is not occurring in many plants and it is consigned to burning.

**Xylenes / C9-10 aromatics**

We have created a decent capacity for p-xylene required for making terephthalic acid, for making polyesters, and where hydrogen is usefully employed from platformers for refinery. We still need more capacity. We have only one location making ortho xylene and atleast two other locations should take up ortho xylene production required for making phthalic anhydride.

While on this topic it is a pity that we are not making isophthalic acid which is required for making polyester resin and at least 2% is required in PET resin for bottles. This would require meta xylene and an old p xylene plant, based on adsorptive separation, can be modified and adopted.

In xylenes plants we get the C-9 fraction consisting of pseudocumene, ethyl toluene and mesitylene and it is earmarked as solvent. However, much higher value products can be made, after separation of the components to make trimellitic anhydride, required for alkyd resin, and trimesic acid; even methyl styrene can be made. There is C-10 fraction as well which can be utilized to make durene to make pyromellitic anhydride, required for make speciality resins.

**Styrene**

Our imports may in the near future approach 1 mtpa and it is necessary for India to put up two large size plants; benzene is available in adequate quantity and this can not be blended with gasoline.

### Synthetic Detergents

We in India have a large capacity for linear alkyl benzene (LAB) which is sulphonated and neutralized to make synthetic detergent. C-11-C-13 fraction comes from the kerosene cut and this is dehydrogenated and used for alkylating benzene. We now have a large capacity for polyester fabrics and time has come to have a large capacity fatty alcohol ethoxylates plant and derivatives and these are well suited for polyesters fabrics.

### Need for alphaolefins (AO) plant

AO are made via oligomerization of ethylene and products cover the entire range all the way to wax which has superior properties. AO sulphonates (AOS) can stand brackish/sea water and thus are also useful in oil well drilling. We do have small capacity AOS plants with imported AO. We need to put up a 200,000 tpa AO plant. The global capacity now exceeds 2 mtpa. AO are also used for making synthetic lubricants.

### Need to have a 300,000 to 500,000 tpa polycarbonate (PC) plant

We continue to import large quantities of PC (which also go for ballot boxes) and we should go for a phosgene free plant

### EPDM Rubber

We did put up a 5000 tpa EPDM plant in New Mumbai more than 20 years ago but unfortunately it is not working. In the mean time the use has galloped. It is imperative that our olefin crackers incorporate an EPDM plant of atleast 50,000 tpa capacity. The termonomer DCPD is referred in the valorization of C-5 fraction from naphtha crackers. The other termonomer ethylidene norbornene can also be made.

### Fluoroelastomors

There is an urgent need to take up manufacture of fluoroelastomers which are essential for a variety of applications but are particularly important for tyres used in defense aircrafts, and here a lack of availability can hold up the use of these very expensive aircrafts.

**Urethanes : MDI**

We do have some capacity, albeit inadequate, for TDI but none for MDI for which very large capacity plants exist in the World. We need to put up a 200,000 tpa MDI plant linked to aniline and formaldehyde plants and, of course, its own phosgene (Unlike polycarbonates there is no non phosgene technology for MDI).

**Engineering Nylons**

While Nylon 6 is made in India from caprolactum we do not have any capacity for Nylon 6,6 which requires adipic acid and hexamethylene diamine (HMDA) to be manufactured. HDMA has other applications for diisocyanate.

There is scope for making Nylon 11 from undecylenic acid obtained by cracking of castor oil; also Nylon based on sebacic acid which is also obtained from castor oil of which India is the dominant producer in the World. Even there is a case for Nylon 12 obtained from trimerization of butadiene to cyclododecatriene followed by hydrogenation to cyclododecane and its oxidation to cyclododecanone/ol and oxidation to dodecanedioc acid which is also required to make benign musks.

**Valorization of coal via fluidized bed carbonization followed by combustion; Underground Coal Gasification (UCG); Petcoke IGCC**

India has made a commendable progress in burning coal, containing high ash, in fluidized beds. It would be prudent to consider two stage operation where in the first stage conditions are controlled to recover a substantial part of the volatile matter which, by known technologies, can be upgraded to fuels. This potential is high.

I had the privilege of Chairing, an inter-ministrial committee, to work on UGC in Mehsana, North Gujarat. We did make a lot of progress but it was not followed. It has now been rescheduled and this technology for deep, more than 1000 m, which is unmineable coal seams, whose proven reserved of more than 60 billion tons, will catapult India into a global leader. This technology is environmentally benign and gas can be earmarked for multifarious applications from power generation to chemicals, particularly Fischer-Tropsch synthesis in fuel as well as petrochemical modes.

Assam coals may well be amenable for extraction of hydrocarbon and Light Cycle Oil (LCO) available from nearby refineries could be a potential solvent.

Petcoke gasification via IGCC is most desirable rather than the conventional gasification where all sulphur goes as gypsum whereas in IGCC all sulphur is recovered. The syngas from IGCC can be used for a variety of products as mentioned above. An important product will be the recovery of vanadium and nickel from slag. It augurs well that RIL, Jamnagar, has the world's largest IGCC based on petcoke. The technology for recovering vanadium and nickel is not available and needs to be developed.

**Titanium dioxide and other benign pigments**

We do have enough monazite sand to support a large size $TiO_2$ plant through the $TiCl_4$ route. It is a pity that we continue to import large amounts of $TiO_2$ pigment and we ought to put up a 200,000 tpa plant. Paint factories are critically dependent on $TiO_2$.

We are not fully valorizing our rare earths whose problem has become globally delicate due to the dominance of China. We need to recover fully, not only Ceria, but lanthanum and other rare earths. Pigments based on lanthanum and ceria displace those based on hazardous lead and cadmium.

Even high grade iron oxide pigments, red/yellow, are not made in India due to lack of technology even though, iron sulphate is available in plenty as a starting material.

**Titanium metal**

We have a coastline of almost 7000 km and a large number of power plants and other manufacturing units make use of sea water and some times brackish water for cooling. For heat exchangers titanium tubes/plates are ideal and yet we have practically no commercial production. We should put up atleast a 5000 tpa plant.

**Fertilizers**

We had an unusually long period of more than 12 years when no new fertilizer plant was put up. China has a capacity for ammonia exceeding 40 mpa and we are around 11 to 12 mtpa with comparable population. All the new plants were linked to make urea. It is open to question whether urea is an ideal fertilizer for aerobic cultivation and even some part of the rice production happens under aerobic conditions. I am unable to understand why we have not planned for urea phosphate and urea nitrate production; and even urea sulphate makes sense for sulphur deficient soil; and ammonium phosphates on much larger scale. Ammonium nitrate is an excellent fertilizer for quick and slow release of ammonia but for safety reasons it is not promoted even though it is popular in Europe and USA. Nitrophosphate is good fertilizer but the subsidy formula has affected its growth. It is a pity that inspite of a large number of fairly modern fertilizer plants, we do not have indigenous expertise in technology. Even advances in making nitrophosphate have not taken place.

There is an uncommon source of making ammonia, even though on a smaller scale, in ethane/naphtha crackers having ethylene oxide plants where hydrogen and nitrogen are available and cheapest ammonia can be made in such plants. There is a significant merchant market for ammonia besides fertilizer plants. Since pure $CO_2$ is available from ethylene oxide plants ammonium bicarbonate can also be made.

We can conceive distributed ammonia plants using electrolytic hydrogen and power based pressure swing adsorption to make pure nitrogen and $N_2$ and $H_2$ can be combined to give ammonia; power will come from renewable sources based on solar and wind.

There is a great concern in my mind about potassium based fertilizers where more than 6 mtpa of potassium chloride is imported. Why are we not considering at ports potassium nitrate/phosphate and use HCl for acidulation of imported phosphate rock to make phosphoric acid. We in India should work on the technology for the above ventures even though proven technology exists in the world which we may secure for a start.

Some potash fertilizers be secured from salt works and alcohol distilleries.

A particularly worrying point is about phosphatic fertilizers as the phosphate rock deposits in the global context are depleting and our own contribution from within India is very small. We should look for conservation. An unusual source, even though small, can be sewage wherefrom mixed phosphorus based fertilizer can be obtained. It seems that there are a couple of units in The Netherlands.

**Synthetic Methionine (M); other amino acids**

Racemic M is required in large quantities especially for chicken and it is made in “petrochemical” type plants and the global capacity is approaching 1 mtpa. We need to put up a plant where acrolein, which is an intermediate in making acrylic acid, is available. The other raw material is methyl mercaptan and refineries have $H_2S$ which can be converted with methanol to methyl mercaptan. [In this context a reference can also be made to make other mercaptans.]

We do not make any L-Lysine but for this fermentation route is ideal and petrochemical type route is unviable.

**Bulk drugs**

We are in a very delicate position as imports from China are distressing and our vulnerability is very high. Let us take the case of all the penicillin derivatives we make in India and all these are critically dependent completely on imported penicillin V/G. We did have a penicillin plant as early as mid fifties in Hindustan Antibiotics in Pimpri, near Pune.

The problem for API's is quite acute. Take just two examples of paracetamol and metformin. For the former almost the entire amount of para amino phenol is imported, mostly from China. For the latter Dicyandiamide is also imported. Both can be manufactured in India and dicyandiamide is also useful for other purposes, including in defence chemicals.

It is possible to have a global leadership in bulk drugs in India, with complete backward integration, e.g. in the case of ibuprofen where the starting substance isobutyl benzene also has global leadership.

There is an urgent need to take steps to ensure that we do not continue to be in this critical position.

**Biotransformations**

We have similar position with respect to biotransformations which are in many cases very important to make optically active intermediates. We have had some successes in biosimilars in Biocon and in making erythropoetin.

**Biotechnology**

Biotechnology for heparin, which is essential to prevent clotting of blood, and which comes from pigs with the attendant danger of contamination, is specially relevant for vegetarians in India (Look at the case of renin for making cheese which come from stomach of calves now comes through biotechnology.) Similarly the antioxidant COQ 10 should be made through biotransformation as the synthetic route is not economic.

There is a new concept of dispensable bioreactors for small scale production.

Our molasses from sugar plants are used to make ethanol. It is now relevant to consider this source to make isobutanol, butanediols, itaconic acid.

**Crystallization**

Most bulk drugs involve crystallization in the final step and we do not have expertise in this area by way of a Centre of Excellence. We can have an odd situation where chemistry, involving few steps, is right but the API is not saleable as the particle size distribution, bulk density and loss on drying are not right and these depend on crystallization.

**Membrane separations through nanofiltration**

Similarly, for recovery of products in multistep processes there is a great scope to adopt Nanofiltration membranes but we have very limited expertise, including making membranes for highly polar solvents like dimethyl formamide (DMF).

**Batch Plants to be made continuous**

Our pharma industry should look for continuous plants and not batch processes and this is even favoured by the FDA. Here the inventory is low and hazards are nearly avoided and high heat and mass transfer rates can be realized. Examples include nitration, diazotization, oxidation, etc. This area has got additional impetus through the use of microreactors which can also be made from sophisticated material of construction to avoid problems associated with corrosion. There is a new concept of 3-D printed reactors.

**Electrochemical processes**

Electrons are an excellent example of being clean. With the availability of renewable energy through solar or wind based system there is a scope to make a variety of speciality products through this strategy in a distributed system.

A particularly interesting application is when both anodic and cathodic reactions occur e.g. oxidation of paramethoxy toluene to para ansic aldehyde and simultaneous reduction of phthalic anhydride to phthalide. Monsanto had a breakthrough in commercially carrying out electrohydrodimerization of acrylonitrile to adiponitrile a long time ago. There is scope even in furan chemistry.

**Utilization of $CO_2$/ syngas**

Apart from the use in making urea, the large scale utilization will happen through dry reforming of methane giving syngas which can then be converted to methanol, ammonia, etc. In this context and independent of this route using syngas for Fischer-Tropsch process needs urgent attention particularly in the petrochemical mode to give alcohols/olefins, apart from high cetane diesel and very good quality waxes.

**Renewable raw materials**

There is an emphasis all around the world for using renewable raw materials. It is conveniently forgotten that our organic chemical industries started with ethanol based on molasses, and ethylene/polyethylene/PVC, n-butanol/2-ethyl hexanol, acetic acid, acetone, butadiene, ethyl benzene were made and almost all these plants are shut.

There is a scope in this area particularly for furan chemistry via furfural/hydroxymethyl furfural and a host of products like THF, Furan dicarboxylic acid for polyesters, etc. can be made.

This is a competitive world and with a trend to convert petroleum refineries to make petrochemicals it is doubtful whether large scale products will be made through this route, particularly those based on feedstocks which are used for food like corn, wheat, etc. Lactic acid/ polylactate have not proved to be that great success that was projected.

Bagasse is one very reliable agro product and splitting this into high grade cellulose, to make cellulose acetate, CMC, etc.; hemicellulose for fermentation and lignin (L) has enormous potential. L can be utilized not only for lignosulphonates but there is scope to crack L and make very valuable phenolic compounds. There is a need to usher Lignin Chemistry just as several years ago sucrochemistry was introduced.

Rice husk burning gives silica as ash and this can be valorized to make precipitated silica required in rubber and other industries.

**Li-ion Batteries and recycling used batteries**

India wants to move into EVs in a big way and this critically hinges in the use of Li and Cobalt. We do not have any known reserves of both these materials. However, as elsewhere in world, we should work assiduously in recycling used Li-ion batteries from electronic equipment and initially used mobile phones can be considered.

**Solar and Wind based power**

The chemical industry should work on speciality dyes for solar systems and films based on polyvinylfluoride (Like Tedlar of erstwhile DuPont). Similarly, we should work on composites to take wings of wind power systems beyond 60 m and may be upto 200 m, particularly for off shore application.

**Digitalization**

Globally this is a buzz word and it is becoming increasingly important to adopt this in India. This will usher change in value chains; lead to higher productivity; generate more innovations, etc. We need to remind ourselves that everything is connected through data. Artificial Intelligence (AI) will play a role.

**Acknowledgement**

A part of this talk is based on Professor K. Venkataraman Lecture given in Institute of Chemical Technology, Matunga, in early 2018.