FIPI

Federation Of Indian Petroleum Industry

R&D Conclave 2018

'Shaping the future through R&D'

August 22-24, 2018

Knowledge Partner: pwc

Foreword by

Dr. R. K. Malhotra

Director General, FIPI

The energy demand is constantly rising due to increasing population and rapid growth in many parts of the world. Due to the increasing energy demand, we also have a challenge of a larger carbon footprint which is unsustainable for the future. Therefore, it presents an imminent need for us to research and develop alternative fuels, energy efficient equipment, processes and technologies which are environmental friendly.

Towards achieving this, Federation of Indian Petroleum Industry (FIPI) along with industry partners organized a R&D Conclave during August 22-24, 2018 at Goa. the conclave, focusing on the theme 'shaping the future through R&D covered topics like alternative energy & emerging technologies, innovation, production optimization, enhanced oil recovery, heavy oil exploitation, refining technologies, oil spill mitigation and digital applications, encapsulated the entire spectrum of R&D in the upstream, midstream and downstream segments of the oil & gas business.

I sincerely thank Dr. Anil Kakodkar, Chairman, Scientific Advisory Committee (SAC) on Hydrocarbons, MoP&NG to be the Chief Guest at the conclave. He underlined the importance of R&D and emphasized that R&D effort should focus on energy security & sustainability, cutting down of import bill and climate challenge. He also stressed upon the need to create network and collaboration to improve the efficiency of translation of R&D ideas from lab to commercial implementation.

The two-day conclave at Goa received an overwhelming response from the industry with the presence of around 100 delegates from companies representing the entire spectrum of oil & Gas sector. The event attracted scientists and experts from India as well as abroad and as many as 30 papers were presented on various topics at the conclave.

I thank IOC R&D and ONGC for being co-hosts and our sponsors. Their support helped us in successful execution of the conclave. I also thank PwC for being the knowledge partner and their help in summarizing the findings of the conclave in a comprehensive manner.

Preface by

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Energy efficiency and sustainability remains one of the key issues in India. It is imperative to explore indigenous methods and intrinsic resources to meet the increasing energy demand and environmental concerns. R&D is going to play a pivotal role in addressing these challenges. Creating the right ecosystem with the participation of Government, private firms and academia will help in changing the current scenario.

FIPI organized a two-day R&D conclave at Goa that saw policymakers, R&D pioneers, engineers and scientists brainstorm on R&D issues in the oil and gas sector. Emerging technologies in Indian oil and gas sector were discussed. Role of technology adaptation and transfer to mitigate the risks arising in the R&D processes were also discussed. The policymakers paid attention to the stakeholder viewpoint in order to make the consultation process more holistic.

PwC is privileged to be the knowledge partner for this event and has put together this background paper titled 'R&D Conclave 2018: Shaping the future through R&D'.

PwC has assisted FIPI in summarizing the proceedings with the aim of documenting the R&D breakthroughs achieved in Indian oil and gas sector. We sincerely hope that this paper brings out the context for deliberations during the conclave. The proceedings of the conclave will be a useful agenda to work on the way ahead for various stakeholders.

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1. Background Note

India continues to remain one of the fastest growing economies in the world. As per a report of the United Nations titled World Economic Situation and Prospects 2018, "The outlook for India remains largely positive, underpinned by robust private consumption and public investment as well as ongoing structural reforms. Hence, GDP growth is projected to accelerate from 6.7% in 2017 to 7.2% in 2018 and 7.4% in 2019." The growth rate projections for 2018-19 and 2019-20 as per the World Bank's report titled "Global Economic Prospects" are marginally higher at 7.3% and 7.5% respectively.

India's Hon'ble Prime Minister Shri. Narendra Modi has highlighted that India's energy future has four pillars - Energy Access, Energy Efficiency, Energy Sustainability and Energy Security. Towards achieving this, several initiatives have been taken for increasing exploration and production of all domestic petroleum resources. The transfer and adaptation of new technologies can contribute significantly towards achieving these goals. Collaboration with international bodies, and R&D institutions both public & private bodies is an important mechanism for technology development and funding these much-needed solutions.

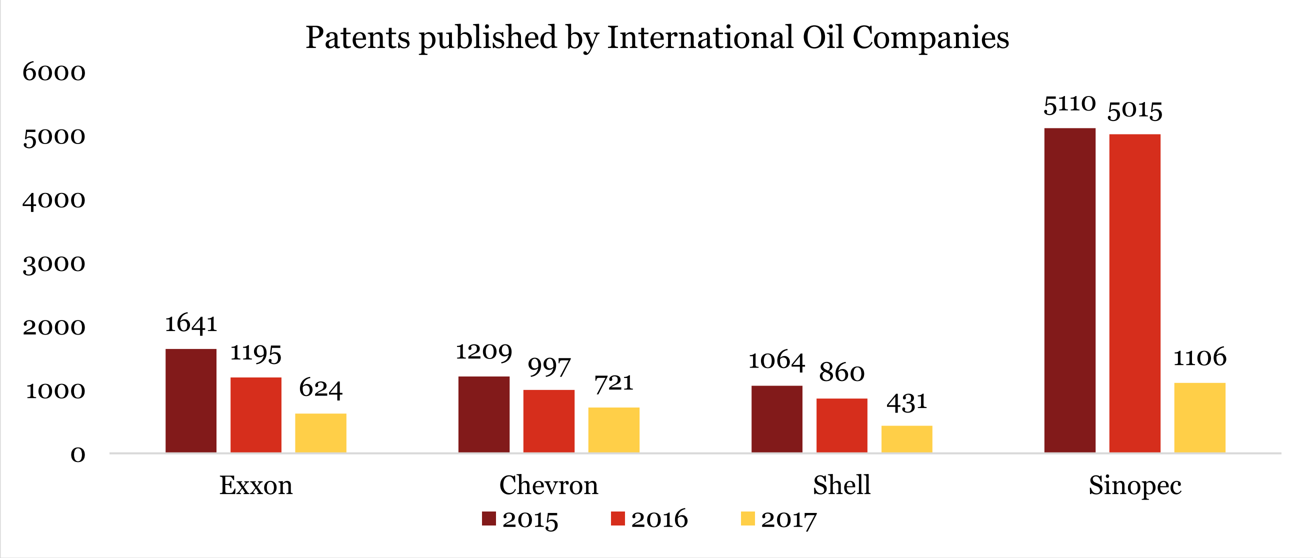
One of the important lessons of the past two decades has been the pivotal role of R&D and innovation in economic development. The R&D processes and their costs vary from industry to industry, from country to country and from year to year. R&D was mostly confined to developed countries in the past. However, in the last few years, the growth in global R&D is being driven by Asian countries, such as India and China.

The global landscape of investment in science and technology as well as in education and human capital has undergone important positive shifts over the last few decades. Today innovation and research and development (R&D) are a serious policy ambition in most developed and developing economies. Global R&D expenditures have continued to rise, more than doubling over the 20-year period between 1996 and 2016, with businesses spending more every year on account of R&D investments.

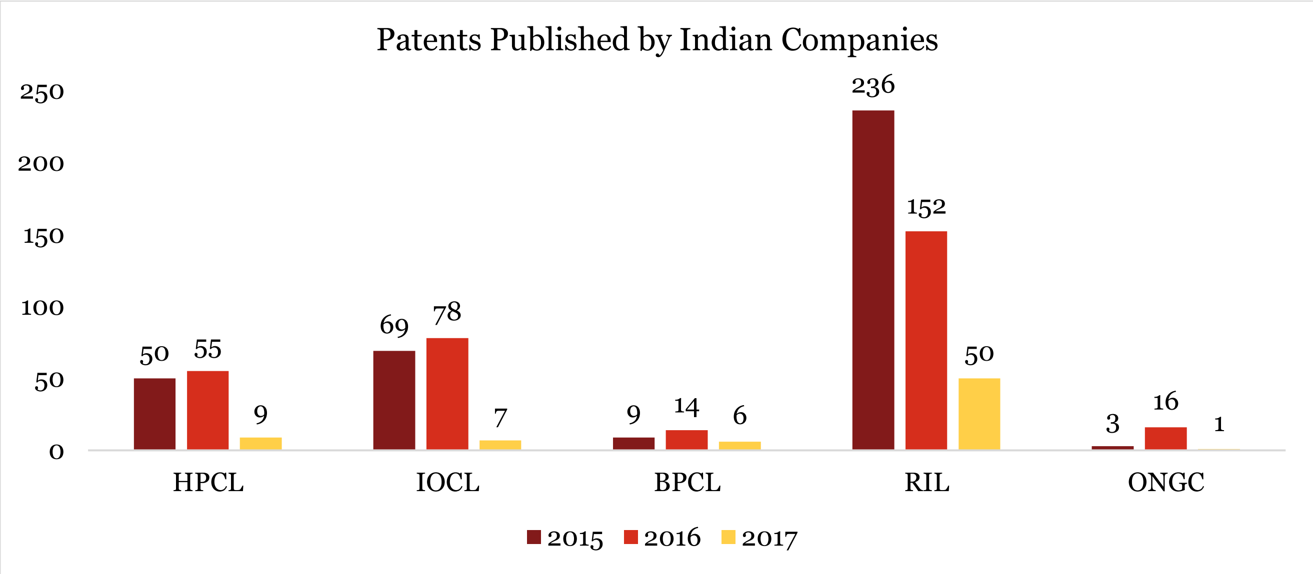
In 2016, worldwide total R&D expenditure grew at 3%. Global R&D intensity too has been stable in the last decade and has even intensified over recent years. Intellectual property (IP) filings reached record levels in 2016; wherein the growth is mainly driven by China. Global business R&D spending increased at a faster pace in 2016 (4.2%) than the previous year. The top 1,000 R&D companies raised their R&D expenditures between 2015 and the first half of 2017.

When it comes to oil & gas sector, Exxon Mobil spent INR 7087 Crore in the year 2017. However, Indian companies have not been able to put significant resources for R&D as compared to their global peers. Indian companies including IOCL, BPCL, HPCL, ONGC and RIL spent a total of INR 2695 Crore in the year 2017. Companies like Total and BP invest 11% of their profits on R&D. While for the Indian companies, the figure ranges between 1-3%.

A large proportion of R&D expenditure goes towards the wages and salaries of the R&D personnel (researchers, technicians and support staff engaged in R&D). Reflecting this, the figures for the indicator 'Researchers per million inhabitants' follow a similar pattern, as the trend in R&D expenditure. According to Global Innovation Index 2018, the number of Full Time Equivalent (FTE) Researchers/Million are the highest in Israel (8250), Denmark (7515), Sweden (7153), the Republic of Korea (7113) and Singapore (6730). However, in terms of absolute numbers (the number of researchers in millions), China (1.69 million), the United States (1.38 million), Japan (0.67 million), the Russian Federation (0.43 million) and Germany (0.40 million) dominate the rankings. Similar trends are observed when we compare the patenting scenario indicators on a global scale.



Source: Thomson Innovation



Source: Thomson Innovation

2. R&D in Indian Oil and Gas sector

Energy demand is reaching unprecedented levels due to growing population, rapid urbanization and industrialization. Higher levels of technological innovation are required to meet this demand, both at exploration, production and consumption stages. To shift dependence from imports and increase domestic production, it is imperative to look at innovative ways of increasing oil & gas production from the domestic fields.

Exploring the geographically challenged fields, improving the subsurface geological understanding are the key drivers for R&D in seismic data acquisition, processing and interpretation in India. Some of the geographically challenged oil fields are located in the eastern offshore region, north east region. North east region is covered with thick boulder beds coupled with difficult topography and dense jungle. Eastern offshore region is characterized by unpredictable reservoir formation and geological traps. Advanced geological modelling technique is required to overcome these challenges.

Major drivers for R&D in the exploration & production sector are exploration & production costs and improvement in recovery ratio for the oil and gas. With declining production levels from the mature fields, key areas where R&D is required on significant scale are reservoir characterization, production enhancement from mature fields, production from high-pressure high-temperature (HPHT) reservoirs and unconventional reservoirs. This must be aimed at improving the production profiles in maturing fields in offshore and onshore blocks.

In the downstream sector, the key drivers for R&D are environmental & social impacts, improvement in efficiency and optimization of cost. Technologies pertaining to upgrading to BS VI grade fuels, usage of resid hydrocracking, catalyst & additive development are some of the immediate needs in the refining sector. Coke gasification is expected to be the game changer for the Indian refiners. Coke gasification involves conversion of lowest-cost fuel into natural gas that can be used in power plants and petro chemical plants. With refineries processing heavier crude oil, the production of petcoke is peaking at refineries. Gasification of petcoke has become an efficient and environmentally safe way of utilizing it.

India is the 7th largest country in the world spanning 328 Million hectares and amply bestowed with renewable sources of energy. It has been estimated that India produces about 450 million tons of biomass per year, of which about 200 million tons is surplus. But it is not the preferred renewable energy source till now, mainly due to the challenges involved in ensuring reliable biomass supply chain. There is the need to evolve a robust organized biomass market through innovative business models, motivating rural entrepreneurs to take up the responsibility of supplying biomass to processing facilities.

Long term focus revolves around conversion of crude to petrochemicals, batteries for energy storage and fuel cells, solar energy (CSV & PV) and CO_2 to fuels and chemicals. While some of the initiatives are on track, others are not feasible in current scenario. Fuel cells and batteries need breakthroughs along their value chain to attain cost viability. Aluminum air battery with high density may also emerge as a potential choice but significant R&D efforts will be required to mitigate range anxiety.

2.1. Exploration and Development

2.1.1. Modelling and Simulation

Meeting the energy needs of the future in a low price environment means making more informed decisions to improve success rates as well as developing and leveraging cutting–edge technologies for better recovery rates — all while boosting overall operational excellence. Our understanding of the subsurface system (an oil/gas field) of the earth is becoming increasingly more sophisticated at the level of the behavior of its components (solid, liquid and gas) as well as their variations in space and time. The implementation of models is essential for the understanding of an increasing number of natural phenomena and in predicting human impact on these, such as depletion/injection activities in an oil/gas field.

2.1.1.1. Geomechanical Modelling

The importance of geomechanics in wellbore stability, hydraulic fracturing, fault-reactivation, early water-cut, top surface subsidence, reservoir compaction and water/gas flooding during an oil/gas field life is well known. The 3D-modeling technology of oil-and-gas fields allows building modern oil-and-gas development projects using information systems and technologies of the world's leading software, and optimizing the modeling process.

Computational tools such as geomechanical modeling offer the opportunity to couple physically realistic and mechanically rigorous numerical analyses with existing geometric and kinematic data to produce testable predictions. Geomechanical modeling is capable of handling complex geometries and realistic material models to spatially analyze stresses and deformations.

Oil and gas exploration and production have many problems that are well-suited to a geomechanical modeling approach, at scales ranging from the field or reservoir down to the borehole. 1D geomechanical modelling forms the backbone for many different types of analysis, from compaction studies to wellbore stability and completion, design and optimal fracture intersection across unconventional, conventional, CO_2 storage and water disposal. These geomechanical models depend on an accurate understanding of the pore pressure distribution, in situ stresses and rock mechanical properties.

Three-dimensional digital models significantly improve the efficiency of solutions during field development. The technology allows optimizing the following tasks:

- Calculation of primary and/or residual hydrocarbon reserves and substantiation of calculation parameters;
- Assessment of the effectiveness of the field development scheme and methods of oil-and-gas selection;
- Formation and selection of an optimal variant of field development;
- Forecast (short-term and long-term) of the level of hydrocarbon production.

2.1.1.2. Data Acquisition, Processing and Interpretation

Seismic Data acquisition involves applying a seismic energy source through vibrator truck or shot-hole dynamite at a discrete location in the field. As these data don’t show the subsurface structure directly, they need to be processed. Seismic Data Processing is aimed at producing a seismic image that represents the substructure geology. These processed data is the used by the interpreter to extract the required subsurface geological information. Integration of workflow across acquisition, processing and interpretation is required to have a clear understanding of the subsurface geology.

One of the primary problems related to reflection seismology is that they have generally low resolution and high signal-to-noise ratio. Therefore, improving the seismic resolution and increasing the S/N ratio is required to produce a high detailed image that represents the subsurface geology.

There are specific acquisition and processing challenges pertaining to Indian context. For example, in Assam Fold Belt Area, areas cover with thick boulder beds or compact hard sediments coupled with rugged topography and dense jungles which make it difficult to drill for energy shot hole. Hard and compact sedimentary rock near to the surface in areas like Jairampur, Deomali, Manabum-Shonking and up to Mizoram with highly dipping beds creates challenges for energy propagation. Significant lateral and vertical velocity variations are the significant challenges in choosing the appropriate algorithm to generate suitable velocity model. Also, conventional 2D and 3D seismic designs are generally impractical in most of the areas of Assam-Arakan fold belt due to logistics challenges. There have been new developments by Indian E&P companies to overcome these challenges. Long offset receivers are found to be more efficient to receive signals instead of limited offset in fold belt areas with highly dipping beds. Incorporation of non-seismic data set such as gravity magnetic data, surface geochemical results, remote sensing data and geological information boreholes (GIB) with geological models have resulted in a meaningful interpretation.

2.1.1.3. Reservoir Simulation

Reservoir Simulation is a multi-disciplinary approach that captures flow of phases in real system through a numerical model for making informed engineering decisions. The main components of a simulation include reservoir representation through appropriate and realistic models, static and dynamic properties of a reservoir, reservoir flow (using appropriate flow equations), surface flow networking and economic evaluation. The objective of reservoir simulation is to have a reliable forecast of future production and recoveries under various scenarios. It also helps to optimize the well spacing and drainage area. The technique of reservoir simulation has evolved over the years. From early 1950s to 1970s, the simulation technique advanced from a 2D simplistic geometry model to a 3D model. 3D model was more realistic and accurate. It incorporated a 3-phase fluid modelling. Conventional EOR was conceptualized during this period. During the 1980s, the technology evolved to manage complex wells and was capable to generate simulation for fractured reservoir. In 1990s, the models had geological upscaling, smaller grids and surface network integration which gave more accurate results. The reservoir simulation currently is based on hybrid grid models, advanced computing, uncertainty analysis, integrated full field management and emerging EORs.

There are a lot of challenges for a realistic representation of the reservoir. One of the challenges is modelling complex geometries and reservoir heterogeneity. There needs to be an appropriate trade-off between speed and accuracy while developing the fluid flow equations for a model. There is also a challenge to represent a reservoir where there are stress changes and rock deformations with change in reservoir pressure. Also, simulating the reservoirs to test the use of emerging EORs like low salinity water flood pose as challenge for the E&P operators in India. There is a variation in fluid composition with pressure and temperature, complex rock fluid interactions, phase equilibrium, mathematical formulations and hardware capacity to handle all the processes make it difficult to understand the behavior of EOR processes on the reservoir.

The global E&P industry has made many developments in this segment. There has been a shift in reservoir gridding from the use of Cartesian and corner point grids to unstructured grids for a more accurate and detailed representation of complex geological formations and engineering features. The unstructured grid confirms volumetric simulation to the structural architecture of the reservoir. It also allows calibrating grid architecture as a fit-for-purpose approach. There is also a need for uncertainty quantification, since uncertainty in input parameters may propagate to over/under prediction of production profiles. A stochastic simulation is required for risk assessment. There are also major developments in the area of high performance computing platforms. There has been a shift from Serial to Parallel Processing (PP). PP model is decomposed into many parts and then solved using multiple computing resources in a coordinated way. The computational load to solve a reservoir model increases non-linearly with model size. There is a continuous improvement in hardware and software technologies that allows building high resolution reservoir model but ensuring high computational efficiency still remains a challenge today. Though Cloud based computing provides opportunity to leverage technology enhancement, it is still at a nascent stage in E&P industry. There has also been a shift from Conventional to Integrated Asset Model (IAM) for reservoir simulation. In a Conventional Asset Model (CAM), there used to be individual simulators for each domain, while Integrated Asset Model integrates reservoir, wellbore, pipeline network, process facilities and economics. IAM has multiple simultaneous online model based workflows with a more accurate recovery forecast than CAM. It has major applications for multi-field development under unified infrastructure and also optimizes injection and production.

2.1.2. Drilling and Completion Challenges in HPHT

As conventional sources of oil and gas decline, operators are increasingly turning their attention to unexplored or underdeveloped areas. High temperatures and/or high pressures are often found in these uncharted territories, presenting complex challenges including casing buckling, accelerated drilling fluid chemical reactions, rock collapse, kick etc.

According to UK Department of Energy, HPHT wells are defined as "Wells where the undisturbed bottomhole temperature at prospective reservoir depth or total depth is greater than 300°F [150°C] and either the maximum anticipated pore pressure of any porous formation to be drilled exceed a hydrostatic gradient of 0.8 psi/ft. or pressure control equipment with a rated working pressure in excess of 10,000 psi is required."

The main challenge that affects the drilling includes conditions that limit the range of suitable materials and affect equipment performance. The well control relies on surface equipment being able to function reliably under extreme conditions. BOP must be rated to withstand the high temperatures and high pressure to prevent blowouts and prevent uncontrolled release of crude oil or natural gas from the well. Evaluating HPHT wells requires special logging and testing, with downhole mechanical and electrical equipment capable of withstanding harsh conditions of elevated temperature and pressure.

The completion of HPHT wells is a further challenging task with reference to equipment selection, especially when significant pipe movement, compression loads and tubing stresses are expected. The effect of HPHT conditions on packers, elastomers, sliding sleeves, injection subs, mechanical & fluid friction and reliability of electronics plays an important role in gathering of downhole data, formation evaluation, completion & testing of such wells. In HPHT environment, it is essential to evaluate effect of pressure-temperature-depth on reliability of safety valves, sliding sleeves, operation of slick line, lubricator packing, coil tubing, remote control, pressure, temperature and flow measurement tools during prolonged exposure.

In India, the KG basin and Cauvery basin have HPHT reservoirs. Indian E&P operators face casing design challenges like abnormal pressure ramps, differential sticking, narrow operating margins, multiple string contingencies etc. The pressure risks include inter alia high collapse pressure, increased partial pressure of CO_2 & H_2S, and requirement of heavy completion fluid. Some of the temperature risks are annular pressure buildup, increased bending, increased effect of CO_2 and derating of pipe yield strength. Operators also face environment risks like the release of corrosive CO_2, H_2S and chlorine, hydrogen embrittlement and sulphide stress cracking.

E&P operators also face challenges with respect to drilling fluids. Mud selection and maintenance are essential to the successful drilling of an HPHT well. The harsh environment presented to the mud has the potential to radically alter its behavior relative to that on a conventional well. The effects of any contaminants greatly increase as the thermal energy pushes reaction faster and further. There is also an impact on the cementing operations in case of HPHT wells. The key issues are high sensitivity of high temperature retarders, thermal thinning of slurry rheology, accurate temperature prediction and accuracy of logging data which pose a challenge to Indian operators in KG basin.

2.1.3. Production Optimization

Most of the crude oil and gas produced in India is from matured and ageing fields. The recent discoveries made are in small and geologically complex structures. Hence, there is a need to implement sound reservoir management practices and fit-for-purpose technology that will lead to sustainable production levels. Globally, a 1% increase of recovery factor would result in around 88 billion barrels of additional reserves which is equivalent to 3 years of world's current consumption. Production Optimization refers to the various activities of measuring, analyzing, modeling, prioritizing and implementing actions to enhance productivity of a field. Optimization is a fundamental practice to ensure recovery of developed reserves while maximizing returns. Production Optimization activities include near-wellbore profile management, maximizing the productivity index, well integrity, well completion design, surface facilities design and effective fluid handling capacity.

Production Optimization, along with Reservoir Management, is a central part of a company's field development and deliverability strategy. There are many developments taking place in E&P industry for production optimization. There is an ongoing research on optimization of artificial lifts which is intended to obtain the maximum production under specified operating conditions. The Indian E&P companies are implementing gas lift with success in Assam Arakan belt. There has been a significant percentage gain in production from the wells wherein the gas lift was implemented. Also, reservoir simulation studies are being conducted to aid in the identification of by-passed /undrainded oil in the reservoir. Some of these studies have led to identification of by-passed oil and the reasons for the same (like reservoir heterogeneity). The industry has also undertaken an extensive horizontal drilling campaign which has resulted in significant increase in ultimate recoveries. The companies have collaborated with international universities for setting up laboratories and studying various techniques of production optimization. Indian E&P companies are undertaking research on many technologies that can be applied in domestic context. Technology like Radial Drilling, wherein 4 laterals can be jetted in any one horizon in vertical as well as highly deviated wells. The result has been encouraging with increased well production due to increased access to the reservoir. Hydraulic fracturing has also been tested as a pilot in fields in Assam Arakan belt with gains in production. Other techniques like Gravel Pack, ESP, Matrix Acidisation, etc. are being deployed to optimize crude and gas production from Indian fields.

2.1.4. Enhanced Recovery Processes

India imports more than 80% of its crude consumption due to rising demand and lack of adequate new domestic discoveries. This presents an urgency to deploy the techniques that enhance oil and gas recovery in the existing fields. Enhanced Oil Recovery (EOR) is a term applied to methods used for recovering oil from a petroleum reservoir which alters the characteristics of hydrocarbons, reservoir rock and rock-fluid interactions. The current recovery factors of ONGC and OIL for crude oil are 27% and 23% respectively. The EOR techniques can increase the recovery by ~10-20% of Original Oil-In-Place (OOIP).

ONGC started the first commercial EOR project in 1996 wherein it deployed Polymer flooding in Sanand field. Further, it implemented In-situ combustion in Santhal, Balol and Lanwa fields in 1997 in Gujarat. It also implemented Water Alternating Gas (WAG) technique in Gandhar and Immiscible Gas injection program in Borholla fields. There are several ongoing EOR projects including Alkaline Surfactant Polymer (ASP) pilots in Jhalora and Kalol fields. Other planned EOR projects include polymer flooding in Bechraji, Cycle Steam Stimulation (CSS) in Lanwa and ASP in Sobhasan fields. In offshore areas, ONGC has completed Simultaneous Water and Gas (SWAG) injection in Mumbai High.

CO_2 injection is one of the major EOR processes that have seen major R&D activity in recent times globally. Increasing concerns over global carbon footprint also makes this technology attractive as an EOR process. Carbon Capture Utilization & Storage (CCUS) offers a unique proposition by reducing CO_2 emissions and its utilization to generate revenue as injector in EOR process. CCUS encompasses methods and technologies to remove CO_2 from the flue gas and recycling CO_2 for utilization. CO_2 is a safe and permanent storage option. It is a supercritical fluid which results in easier miscibility with the reservoir fluid. CO_2 has better sweep and displacement efficiency than other injectants and can extract up to C30+ components from the fluid composition. There has been an increase in CO_2 - EOR projects being implemented worldwide. According to Oil and Gas Journal April'14, there have been 127 active CO_2 miscible projects and 9 active CO_2 immiscible projects in USA. The total length of CO_2 pipeline is in excess of 6,500 Km in USA. Also, CO_2 EOR contributes around 89% of total gas based EOR in the country.

There is a need for CO_2 source-sink matching in India. Major CO_2 sources are thermal power plants, fertilizer plants, refineries, steel plants and cement plants. CO_2 sinks are deep saline formations, oil and gas reservoirs, coal seams and oceans. CO_2 EOR process also faces challenges like high investment at source end to capture high purity CO_2. At sink end, high upfront capital investment, change of metallurgy of wells and modifications of surface facility are also some of the challenges while implementing the process.

2.1.5. Unconventional Reservoirs

Oil remains the world's primary fuel comprising of approximately 33% of the energy mix. The global oil demand is ever increasing and is shortly expected to reach the level of 100 million barrels per day and the substitution of oil in the transportation sector is not yet imminent. Emerging economies account for a major share of global energy consumption. Heavy, extra heavy and bitumen oil resources total about 10 trillion barrels globally which is nearly 3 times the conventional oil in place. The heavy oil resources are mainly present in Canada, Venezuela and Russia. According to a study by Rystad Energy, the average break-even cost of production of heavy oil is USD 47 per barrel.

There have been historical challenges in exploitation of heavy oil. The high viscosity, heat introduction and inadequate distribution, inefficient oil mobilization and production have been major challenges. Also, maintaining well integrity at high temperature, providing adequate water supply for steam generation, heat loss in thin reservoirs, insufficient cap rock, presence of thief zones, reservoir heterogeneity are some of the challenges that are being faced while exploring for heavy oil.

Several technologies are being used commercially for extraction of heavy oil from different types of reservoirs. For moderate thick pays, Cyclic Steam Stimulation (CSS) is being used, while Steam flooding is used for thick low pressured reservoirs. Air injection is used for initial oil mobility. For thin pays, polymer injection is used for reservoirs less than 10,000 cP.

To reduce the environmental constraints, water is reused for steam injection and co-generation. There is an ongoing R&D on intelligent well technology for efficient steam utilization. An example for CSS application is Shell's J-Well. The well is designed such that the heel is above the base of the reservoir and the toe is just below the reservoir top. The trajectory puts steam directly into upper part of reservoir. The wellbore acts as gas liquid separator to retain reservoir drive. The operator is able to access lighter pressure-volume-temperature (PVT) at the top of the reservoir. Multi-lateral wells are also drilled for extraction of heavy oil.

Technology for producing cold heavy oil with sand is also being used wherein the critical pressure gradient for sand production is reduced by foamy oil. This technology has resulted in a recovery factor of approximately 10-12%.

Many hybrid processes have also been developed for commercial production of heavy oil. Liquid Addition to Steam for Enhanced Recovery (LASER) is one such technique which is used as a follow-up process for CSS. This is an alternative to thermal processes. LASER is a cyclic steam process with the addition of a C5+ condensate to the steam during injection. It enhances gravity drainage efficiency by reducing in-situ viscosity beyond thermal limit. Another technique named as Low Pressure Gas-Cap Repressurisation with Air Injection has been developed where the gas cap is repressurised to avoid steam loss.

2.2. Refinery, Chemicals and Petrochemicals

2.2.1. Refining

Catalytic reforming is a chemical process used to convert naphtha distilled from crude oil (typically having low octane ratings) into high-octane liquid products called reformates, which are premium blending stocks for high-octane gasoline. The process converts low-octane linear hydrocarbons (paraffins) into branched alkanes (isoparaffins) and cyclic naphthenes, which are then partially dehydrogenated to produce high-octane aromatic hydrocarbons. The dehydrogenation also produces significant amounts of byproduct hydrogen gas, which is fed into other refinery processes such as hydrocracking. A side reaction in the refining process is hydrogenolysis, which produces light hydrocarbons of lower value, such as methane, ethane, propane and butanes. Chloride free CCR naphtha reforming catalyst has been prepared using nano engineering of support to increase stability and liquid/aromatics yield. Design of a composite CCR naphtha reforming catalyst bringing-in Reforming and EB dealkylation functions in a single pellet to enhance xylenes in the reformate has also been achieved. Catalysts having dual functionality of metal and acid, plays critical role in complex chemistry involved in a reforming process. Chloride free catalyst developed for the first time at RIL.

2.2.2. Multi Catalytic Cracking

Multi zone catalytic cracking MCC is a new process developed for direct cracking of crude along with other distress streams e.g. coker naphtha, slurry oil etc. and low value methanol/DME in sequential manner in a single riser to make substantial Propylene (> 30wt %) and Ethylene (>18wt %) and BTX (15%). This technology combines features of three processes namely Steam Cracking (SC), high severity Fluid Catalytic Cracking (FCC) and Methanol to Olefins (MTO) in a single riser platform, giving advantage of 100-300 $/ton reduction in cost of production per ton of olefins. MCC helps refining crude to chemicals and no fuel as a byproduct.

2.2.3. Refining through Indigenous Technology

Heavier crudes yield higher amount of residue and are loaded with contaminants while, the demand of heavy distillates and bottom of the barrel products are decreasing. The specifications for products are becoming more stringent. Therefore, the foremost challenge to the refiners is to upgrade the residual streams to lighter, more valuable products with lower impurities for sustaining the refinery margins. Considering the above, Indian Oil R&D has developed a novel technology, INDMAX, to produce high yield of light olefins and high octane gasoline from various petroleum fractions. It is forecasted that propylene market share will grow even faster than ethylene market. In view of the recent trend of significant capacity buildup of gas based thermal crackers, need for propylene production from alternative sources is likely to gain momentum.

The INDMAX technology has been demonstrated by setting up a unit of 100,000 MTPA capacity at Guwahati Refinery of Indian Oil in 2003. Since then, the unit is being operated in different modes with heavy feed CCR up to 4 wt% depending on the market demand and contributing significantly to profitability of the refinery. The technology is being globally licensed by M/s Lummus Technology Inc., USA (a CB&I Company). INDMAX unit is designed by Lummus employing proprietary efficient hardware components with basic process design from Indian Oil. Few of the other product treatment technologies developed by Indian Oil are:

- indDiesel

  - Hydrotreatment of diesel
  - Producing ultra-low sulfur product meeting BS VI quality
- indAdept
  - Gasoline absorptive desulfurization
  - Producing Ultra-low sulfur product with lower hydrogen consumption
- indSelect
  - Removal of sulfur & di-olefins from cracked gasoline /naphtha
- indJet
  - Mercaptan S removal from Jet fuel (< 10 ppm)
- indDSN / indDSK
  - Naphtha / Kerosene desulfurization

2.2.4. Commercialization of Additives

In pursuit of greener fuels and expanding energy needs, fuels with stricter norms are being introduced in the market. The Sulphur content in diesel has undergone drastic reduction over time. In ten years starting from 2000, the reduction in Sulphur content is 98% from 2500ppm to 50 ppm. In the next ten years, starting from year 2010 the reduction in Sulphur is expected to be 80% from 50 ppm to 10 ppm.

India is currently consuming about 70 MMT diesel annually which translates to 7000 MT of lubricity additive required per annum domestically. Considering switch to BS VI standards by 2020, the projected demand for lubricity additive would be around 12000 MT annually. Diesel from FTL Based technologies are known to consume a higher quantity of lubricity additive. Improper/ excess addition of diesel fuel additives should be discouraged and their optimization should be encouraged. Mutual incompatibility of various additives have shown retrograde effects in actual vehicle usage. Certain aspects of the engine technology like filtration system have suffered at the cost of these additives. Role of additives in ensuring better driving experience is key to ensure customer delight. The chemistry of Diesel additives need to be relooked to deliver higher value at lower dosages without affecting the vehicular performance.

Superior characterization and modeling technologies, exponential growth in computational speeds significant advances in Data architecture, Data science and IoT emerging technologies are key enablers of digital refining. It helps in molecule management and naphtha pool optimization. It ensures safe and reliable operations, real-time plant utilization and agile business.

2.2.5. Digital Refining

Advanced Modeling techniques are finding good potential applications in various aspects of the refining operations like process control, troubleshooting, new product development and technology development. R&D aspect of Digital and Smart Refinery goes beyond Agility, Reliability and Shared Intelligence. More work is needed for Cognitive linkage between big data analysis, performance parameters and detailed modeling. Frontier developments in ANN, deep machine learning are evolving promising for this purpose. Full potential utilization of deep characterization and advanced modeling is possible by making use of digital and smart platforms to make refining intelligently

2.3. Alternative Energy/ Emerging Technologies

2.3.1. SOEC Technology

Liquid transportation hydrocarbon fuels and various other chemical products can be produced from syngas via the well-known and established catalytic chemical process called Fischer-Tropsch (FT) synthesis. Depending on the source of the syngas, the technology is often referred to as coal-to-liquids (CTL) and/or gas-to-liquids (GTL). Examples of current operating CTL plants include Sasol's Sasolburg I and II plant, and an example of a GTL FT process is Shell's plant in Bintulu, Malaysia. Several world-class GTL and CTL plants are currently at various stages of engineering, construction, and production in Nigeria, Qatar and China, and most recently in the United States as well with the announcement of front-end engineering and design on Sasol's Lake Charles Gas-to-Liquid (GTL) and Ethane Cracker Complex in Louisiana.

Depending on the catalyst, temperature, and type of process employed, hydrocarbons ranging from methane to higher molecular paraffins and olefins can be obtained. Catalysts considered for Fischer-Tropsch synthesis are based on transition metals of iron, cobalt, nickel and ruthenium. FT catalyst development has largely been focused on the preference for high molecular weight linear alkanes and diesel fuels production. Among these catalysts, it is generally known that: Nickel (Ni) tends to promote methane formation, as in a methanation process; thus generally it is not desirable Iron (Fe) is relatively low cost and has a higher water-gas-shift activity, and is therefore more suitable for a lower hydrogen/carbon monoxide ratio (H_2/CO) syngas such as those derived from coal gasification. Cobalt (Co) is more active, and generally preferred over ruthenium (Ru) because of the prohibitively high cost of Ru. In comparison to iron, Co has much less water-gas-shift activity, and is much more costly. Given these constraints, commercially available FT catalysts are either cobalt or iron based. In addition to the active metal, the Fe catalysts at least typically contain a number of promoters, including potassium and copper, as well as high surface area binders/supports such as silica and/or alumina.

Both Fe and Co FT catalysts are sensitive to the presence of sulfur compounds in the syngas and can be poisoned by them. However, the sensitivity of the catalyst to sulfur is higher for Co-based catalysts than for their iron counterparts. This is one reason why Co catalysts are preferred for FT synthesis with natural gas derived syngas, where the syngas has a higher H_2: CO ratio and is relatively lower in sulfur content; Fe catalysts are preferred for lower quality feedstocks such as coal.

The Fischer-Tropsch reaction is highly exothermic; therefore heat removal is an important factor in the design of a commercial reactor. In general, three different types of reactor design might be used for FT synthesis:

(I) Fixed bed reactor

(II) Fluidized bed reactor

(III) Slurry bed reactor.

All three types of reactors are in use commercially. Fluidized-bed FT reactors were developed for high temperature FT synthesis to produce low molecular gaseous hydrocarbons and gasoline. It was originally developed in a circulating mode, e.g., Sasol's Synthol reactors, and they have since been replaced by a fixed fluidized bed type of design called Advanced Synthol reactors. These types of reactors have high throughputs.

2.3.2. Coal Gasification

High ash Indian coal as a feedstock is a highly heterogeneous material. There is significant variation in composition and variance in properties almost as great as the number of coal seams mined. No unique property can adequately predict conversions for all coals. Products & process efficiencies vary depend greatly on the operating parameters of the process, which in turn depend on feedstock characteristics. Feedstock preparation becomes one of the important challenges. Technologies related to ash extraction system and syngas cleaning remains inadequate.

Coal to liquid conversion is an option for clean transport fuels is becoming attractive through technological advances and reduced availability of oil and gas. For India, with abundance of coal, CTL is highly attractive option. Although CTL is known, still there are several issues of design with high ash coal need to be assessed with Indian context. Experience of CTL with high ash coal is an imperative. Various issues to be experienced or to be assessed experimentally. Syngas will remain an answer to chemicals, power, hydrogen, synthetic natural gas in crisis of gas/oil availability.

Gasification of coal can be sustained at the current pilot scale facilities – These are somewhere between POC (proof of concept) to Pilot Scale. The current pilot scale facilities do suffer from such handicaps like “wall effects” and “excessive heat loss” due to small size which the scaled up versions will be able to overcome pressure of gasifier operation at 4-6 bar appears the most optimum and as we go for larger sizes, we can examine higher pressures. Many sub systems & components needs design & development. A knife edge gate valve or dome type slide valve needed for handling solid particles under pressure today costs obscene amount. So is candle filters. So is rotary sir lock valves. We must use the current knowledge to set up few semi commercial scale plants. These may be sub optimum but will build a foundation for subsequent full scale commercial plants. Setting up of Proof of Concept scale R&D gasification plants is the need of the hour. Detailed project planning needs to be done for demonstration of a 100 Tons per day plant. With time, residual R&D issues and major technological issues need to be addressed to scale up the production to 1500-5000 Tons per day plant.

2.3.3. Ethanol Valorisation

Operating a well-performing Microbial Electro synthesis in a planned on/off mode. The cell is being operated under phases where the power supply is be disconnected from the bio cathode and connected after some time. The gaps between “on” and “off” periods are gradually increased so as not to shock the microbial community. The recovery and eventual impact on product formation will be evaluated. This will provide crucial data about the intermittent operation of a MES cell which has been touted as its strength for its link to renewable electricity.

2.3.4. Hydrogen/ Fuel Cell

When it comes to hydrogen as a fuel, combining electrochemical reactions with thermal processes technologies are at lab scale engineering stage. Cost-effective catalysts and membranes are yet to be developed for the process. . Corrosion problems remain the foremost issue. Lack of engineering infrastructure for handling, storage, transportation and safe delivery of hydrogen remains a key concern.

Indigenous Cu-Cl closed loop process has been developed and patented in India and 6 other countries viz., USA, Canada, Japan ,UK ,Korea and China. Cu-Cl process has been demonstrated at engineering lab scale. I-S closed loop process has been developed, demonstrated and patented. Indigenously designed and developed reactors, intermediate processes, membranes, catalysts are in use for Cu-Cl and I-S process. Several engineering/ material challenges are being addressed to make it reliable and cost competitive. OEC is planning to setup pre-pilot plant at a capacity of 1-5 Ton per day. OEC efforts are directed at developing Hybrid Thermochemical water splitting processes using I-S and Cu-Cl cycles, leading to mass scale Hydrogen Production.

2.3.5. Gas Hydrates

Gas hydrate is a solid ice-like form of water that contains gas molecules in its molecular cavities1. In nature, this gas is mostly methane. Methane gas hydrate is stable at the seafloor at water depths beneath about 500 m. Gas Hydrates reserves – as energy resource are more than combined resources of coal, oil and gas. Methane gas is almost 50% more cleanly than coal and almost 25% cleaner than oil.

Basic infrastructure to take up studies on Gas Hydrates in India has been set in three collaborating National laboratories in India and expertise was gained during the 10th and 11th plan activity as per National Gas Hydrate Programme. In the present day energy demand with the increase in crude oil price, gas hydrates is one of the promising alternate viable resources and is a long term prospect. Exploitation of gas hydrates from continental margins of ocean basins is a technological challenge. In the international scenario, a proven field executable methodology for the exploitation is yet to be established, but lots of laboratory scale experimental works are in progress for safe exploitation. Krishna-Godavari basin has evidence of occurrence of huge thickness of gas hydrates demonstrated by shale fracturing mechanism and world's deep seated occurrence of gas hydrates have been sampled in Andaman basin. To prove the developed concepts and technology from the capacity building which happened during 10th and 11th plan period, taking up this program is beneficial.

Production challenges include gas hydration dissociation, sand ingression, water handling, gas hydrate reformation and continuous flow rates.

3. Roadmap Ahead

Historically, India's R&D spend has remained stagnant at around 0.6 to 0.7 % of GDP. In 2015, India became the world's sixth largest country in terms of annual R&D, accounting for 3.53 per cent of global R&D expenditure and is expected to increase it to 3.75 per cent in future. R&D spending in India is anticipated to grow from 0.9 per cent to 2.4 per cent of the country's GDP from 2014 to 2034 respectively. Though access to technology has improved over the years, they come with a higher cost. This pushes the need for indigenous technology to meet the increasing energy demand. International collaborations and government support is necessary for scale up of technology along with reduction in time for commercialization. In the early 2018, Indian Oil Corporation, India's largest fuel retailer signed a collaboration agreement with Israeli firm Phinergy to work on advanced energy systems for mobility and stationary industrial applications. Such international collaborations can help Indian companies develop alternative energy sources. Developing a strong R&D ecosystem through industry academia interface and synergy with science is the need of the hour. Recently, ONGC announced its collaboration with Indian Institute of Technology- Madras to develop software for monitoring ONGC's fixed offshore platforms. This is aimed at enhancing the operational life and reducing fixed costs of the platforms. Establishing such strong academic framework would enhance the rate of innovation. With significant presence of global oilfield service companies like Schlumberger, Halliburton, Baker Hughes, Weatherford and technology companies like Honeywell, ABB, Accenture, etc., Indian oil & gas companies can enter into partnership with these companies for developing indigenous technology to reduce the dependency on energy imports.