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From the Desk of the

Director General

Dear Members and Leaders of the Energy Fraternity,

It gives me immense pleasure and pride to welcome you to this quarterly edition of FIPI journal. As the global energy landscape navigates an era of unprecedented transition balancing the immediate demands of energy security, affordability, and sustainability—the need for strategic insights, and collaborative thinking has never been more urgent.

Today, India stands as a pivotal anchor of the global energy narrative. Backed by robust industrial expansion, India's energy demand is projected to grow faster than almost any other major economy through 2035, and the country is expected to account for over 23 % of global incremental energy demand by 2050, the highest for any country. To maintain the momentum of this growth, India is simultaneously expanding domestic exploration, scaling its world-class refining and petrochemical hubs, reinforcing underground rock and salt caverns for strategic petroleum reserves, and aggressively accelerating the transition to clean energy via renewables, biofuels, CBG, green hydrogen etc.

Such a rapidly evolving energy landscape calls for leadership that is not only responsive to immediate challenges but also equipped to anticipate emerging trends, assess global developments and shape long-term strategic responses. Recognising the importance of informed leadership and meaningful industry dialogue, FIPI has been strengthening its platforms for knowledge sharing and strategic engagement across the energy fraternity. It is in this spirit that FIPI has conceptualised two Leadership Talk Series—one 'For the Leaders' and the other 'By the Leaders'.

The '**Leadership Talk Series for the Leaders**' is designed to equip senior executives with forward-looking strategic intelligence, bringing global perspectives and expert insights on the evolving energy sector, emerging trends and strategic issues. The '**Leadership Talk Series by the Leaders**', on the other hand, reverses the lens by placing industry leaders at the centre of the conversation, providing an opportunity to share their experience, insights and lessons with senior and mid-level executives.

The inaugural session of the Leadership Talk Series was held on 24th June 2026 in New Delhi and was inaugurated by Dr. Neeraj Mittal, Secretary, Ministry of Petroleum & Natural Gas. The theme of the event was—“Energy Security Rewritten – A Strategic Leadership Dialogue on India's Energy Security in a Fractured World.”

Dr. Mittal highlighted India's exceptional resilience during the Strait of Hormuz crisis, where seamless coordination between government and industry kept energy supplies stable. In partnership with S&P Global, the program utilized expert scenario analysis to evaluate the impact of global maritime chokepoints and India's exposure across the energy value chain. FIPI will continue this journey with the support of Knowledge Partners of repute in near future as well.

This journal is designed to be a living, evolving platform for ideas, insights and perspectives from across the energy sector. As we embark on this new edition, I invite each of our esteemed readers to share their feedback and suggestions so that we can continuously enhance the value this publication brings to the energy fraternity.

I express my sincere gratitude to all our members for their steadfast support to FIPI. I hope this edition inspires new perspectives and contributes to the collaborative action required to power India's energy future.

Warm regards,

V. Satish Kumar

Unlocking Operational Excellence in Power-Constrained Offshore Fields: Advanced ESP Optimization with PMM and Smart-Edge Real-Time Monitoring



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Abstract

Oil production in the Offshore Southeast Sumatra field is constrained by limited power supply, restricting simultaneous well operations. With over 90 Electric Submersible Pumps (ESPs) in operation, optimizing energy efficiency is critical. Permanent Magnet Motor (PMM), combined with smart-edge real-time monitoring, has emerged as a game-changer which significantly reduces power consumption, enhances ESP performance, and lowers operational costs. In this power-constrained environment, optimizing energy efficiency is not just beneficial—it is essential for sustaining production.

The research evaluates the impact of PMM technology on reducing power consumption and operational costs. Unlike IM-driven ESPs, which require extra energy to generate magnetic field, PMMs use built-in permanent magnets, eliminating this loss and significantly lowering electricity consumption leading to cost savings. Furthermore, integration with smart-edge real-time monitoring enables continuous performance tracking, remote adjustments, and quicker response to changes. Following a thorough evaluation, four high-potential wells were selected for PMM technology implementation based on barrel oil per kilowatt performance.

The findings confirm that PMM systems significantly outperform IM-driven ESPs, achieving higher efficiency and delivering power savings of up to 20%. This improvement translates to a reduction in power consumption from 1,396 kW to 1,185 kW—a saving of 211 kW—resulting approximately \$200K in potential annual power cost reductions. The enhanced efficiency of PMM technology reduces power required to lift each barrel of fluid from 0.0303 kW/BFPD to 0.0256 kW/BFPD, highlighting its superior performance and energy efficiency. The deployment of 24/7 proactive real-time monitoring further reduces operational costs, particularly fuel boat expenses previously required for periodic sensor data retrieval. With seamless data access via the website, on-site visits are no longer necessary. Additionally, remote control capabilities also contribute to extended ESP run life, helping to optimize uptime and minimize equipment downtime—ultimately generating additional monthly operational cost savings and improving overall production reliability.

Following the successful deployment of four PMM-driven ESPs, more installations are planned this year. As adoption grows, PMM technology integrated with real-time monitoring will solidify its role as a key innovation in offshore oil production—enhancing efficiency and reducing operational costs. In a field where every barrel counts, embracing energy-efficient technology is more than just a technological shift—it represents a smarter way, more sustainable approach to powering offshore operations while ensuring long-term cost savings.

Keywords: Power-Constrained, Energy Efficiency, Permanent Magnet Motors, Real-Time Monitoring, Operational Excellence

Introduction

Electric Submersible Pumps (ESPs) have long been a cornerstone of artificial lift systems in offshore oil production, particularly in mature fields where reservoir pressure is insufficient to sustain natural flow. Traditionally, these ESPs are powered by Induction Motors (IMs), which, while reliable, suffer from inherent inefficiencies due to rotor slip and the energy required to generate magnetic fields. These losses become especially problematic in power-constrained environments, where every kilowatt matters. Despite their widespread use, IM-driven ESPs often lead to higher energy consumption, increased heat generation, and reduced motor lifespan—factors that collectively impact operational costs and production reliability.

The Offshore Southeast Sumatra field, in production since 1980s, is a mature asset internally divided into three operational zones. This paper focuses on the North zone, which hosts the highest-producing wells and, consequently, the highest power demand. More than 90 ESP-assisted wells operate in this zone, powered by electricity generated from gas production via turbines. However, the number of turbines is fixed, and no additional units can be installed, capping the available power at 22 MW for the North zone. This limitation forces operators to prioritize well operations, leaving many wells shut-in because they are uneconomical to run under current energy constraints. Surface piping infrastructure also imposes a physical constraint, limiting the maximum flow rate per well to 14,500 BFPD. While some wells reach this upper limit, most exhibit water cuts exceeding 90%, making them economically unattractive under the current setup.

The ESPs in the North zone are driven by conventional Induction Motors (IMs), which are known for their high energy consumption due to rotor slip and magnetic field generation. These motors require substantial power to lift high fluid volumes, and in a power-limited environment, this results in a trade-off between maximizing production and staying within the energy budget. As a result, many high-rate wells remain idle, not because they lack potential, but because the energy cost to operate them outweighs the economic return. To address this, the customer has expressed a need for ESP motors that can handle medium to high fluid rates while consuming lower horsepower. This requirement aligns with the broader goal of improving energy efficiency across the field. To unlock the full production potential of the North zone, an innovative shift in field development strategy is essential—one that prioritizes energy efficiency and intelligent operations. When combined with smart-edge real-time monitoring systems, operators gain real-time visibility into ESP performance and the ability to track performance, detect anomalies early, enable proactive decision-making, and optimize production strategies. This

integrated solution enables more wells to be operated within the existing power envelope, reduces carbon emissions, and delivers substantial cost savings. The North zone, with its high-rate wells and constrained power supply, presents an ideal candidate for this innovation, setting a new benchmark for sustainable and efficient offshore field development.

Several field trials and technical studies have explored alternatives to conventional ESP systems, with Permanent Magnet Motors (PMMs) emerging as a promising solution. Research has shown that PMMs can reduce motor losses by up to 20%, offering a substantial improvement over IMs. Field implementations in various offshore and onshore assets have demonstrated not only energy savings but also enhanced equipment durability and reduced maintenance frequency.

The core objective of this paper is to demonstrate the benefits of converting existing ESP systems from IMs to PMMs and enhancing them with smart-edge monitoring in the Offshore Southeast Sumatra field. This innovation represents a strategic advancement in field development, enabling operators to unlock more value from existing assets while reducing carbon emissions and achieving meaningful cost savings. By leveraging high-efficiency motor technology and digital intelligence, offshore fields can transition toward more sustainable and economically viable operations.

PMM and Smart-Edge Real Time Monitoring Technology Overview

Permanent Magnet Motors (PMMs) are synchronous motors that use embedded rare-earth magnets—such as Neodymium Iron Boron or Samarium Cobalt—in the rotor to generate magnetic field. Unlike Induction Motors (IMs), which require electrical energy to induce rotor magnetism, PMMs operate without slip, meaning the rotor speed matches the stator's magnetic field. This synchronous operation results in several key advantages: zero rotor copper losses, significantly reduced heat generation, and lower operating current. PMMs also offer a higher power factor, reaching up to 0.99, which minimizes reactive power and transmission losses. Their compact design and high torque density allow for smaller, lighter motors that deliver greater mechanical output. These features make PMMs particularly well-suited for offshore applications where power is limited, and efficiency is critical—such as the North zone of the Offshore Southeast Sumatra field.

While Permanent Magnet Motors (PMMs) offer inherent energy efficiency, their full value is enhanced when integrated with smart-edge real-time monitoring systems. These systems provide continuous data on key parameters such as motor

winding temperature, vibrations, running ampere, and intake pressure—and in many cases, discharge pressure as well. Crucially, it also enables real-time monitoring of power consumption, allowing operators to track exactly how much energy is being used by each ESP system. This visibility empowers dynamic adjustments to pump speed and load, helping prevent overloading and overheating, optimize energy use per barrel lifted, and extend ESP run life.

Remote control capabilities further enhance operational agility, enabling immediate responses to changing well conditions and reducing the need for manual intervention—especially important in offshore environments where access is limited. Additionally, web-based access to sensor data eliminates the need for fuel-consuming boat trips and on-site visits, reducing logistics costs and personnel exposure to offshore hazards. This shift from reactive to predictive maintenance planning not only improves reliability but also contributes to monthly operational savings.

Together, PMMs and smart monitoring represent a powerful innovation in offshore field development, enabling more wells to operate within existing power limits while improving sustainability and cost-efficiency. This integrated approach not only enhances equipment reliability and run life but also reduces energy consumption per barrel lifted. Particularly in fields like Offshore Southeast Sumatra—where energy limitations restrict simultaneous well operations and contribute to production losses—there is a pressing need for a holistic solution that addresses both motor efficiency and operational intelligence.

Field Implementation and Case Study

To evaluate the effectiveness of Permanent Magnet Motors (PMMs) combined with smart-edge real-time monitoring, the operator selected four wells within the North zone of the Offshore Southeast Sumatra field. These wells were chosen based on their lifting potential relative to power consumption (BFPD/KW), making them ideal candidates for maximizing energy savings. The selection process prioritized wells with high fluid rates and historically high energy draw under Induction Motor (IM) systems, ensuring that the impact of PMM conversion could be clearly measured and significant. The deployment involved replacing existing IM-driven ESPs with PMM units and installing the necessary infrastructure to support real-time monitoring.

Prior to PMM installation, production and power consumption data from the existing IM systems were collected to establish a baseline for comparison. This included daily fluid rates, water cut percentages, motor current, voltage, and surface parameters. After PMM deployment, a modem was installed at each site to enable real-time data transmission from the ESPs to the central monitoring system. Below tables present key ESP data from the IM system for four candidate wells, along with relevant well information, serving as a foundation for PMM design considerations.

Table 1 – IM system ESP Data

Parameter	A-07	N-11	NC-19	NC-20
Motor HP	418	386	418	466
Running Amp	103	83	102	106
Nameplate Volt	2,340	2,736	2,340	2,610
Rate, BFPD	8,635	13,812	12,472	12,704
PF (estimated)	0.82	0.82	0.82	0.82
KW (calculated)	342.3	322.5	339.0	392.9
BFPD/KW	25.22	42.82	36.79	32.33
KW/BFPD	0.0396	0.0234	0.0272	0.0309

Table 2 – Well data for PMM installation candidates

Parameter	A-07	N-11	NC-19	NC-20
Test Q, BFPD	9,940	13,812	8,336	13,904
WC, %	99.5	99.2	99.3	99.6
SBHP, psi	1,288	986	1,014	1,103
API	32	32	32	32
Gas SG	0.6137	0.6137	0.6137	0.6137
Water SG	1.0121	1.0121	1.0121	1.0121
Target Q, BFPD	10,000	14,500	14,500	14,500
PSD, ft MD	9,000	4,400	4,837	5,600
TP, psi	350	450	340	350
CP, psi	30	0	0	40
PBHP, psi	654	843	985	878
Problem	Sand	Sand	Sand	Sand

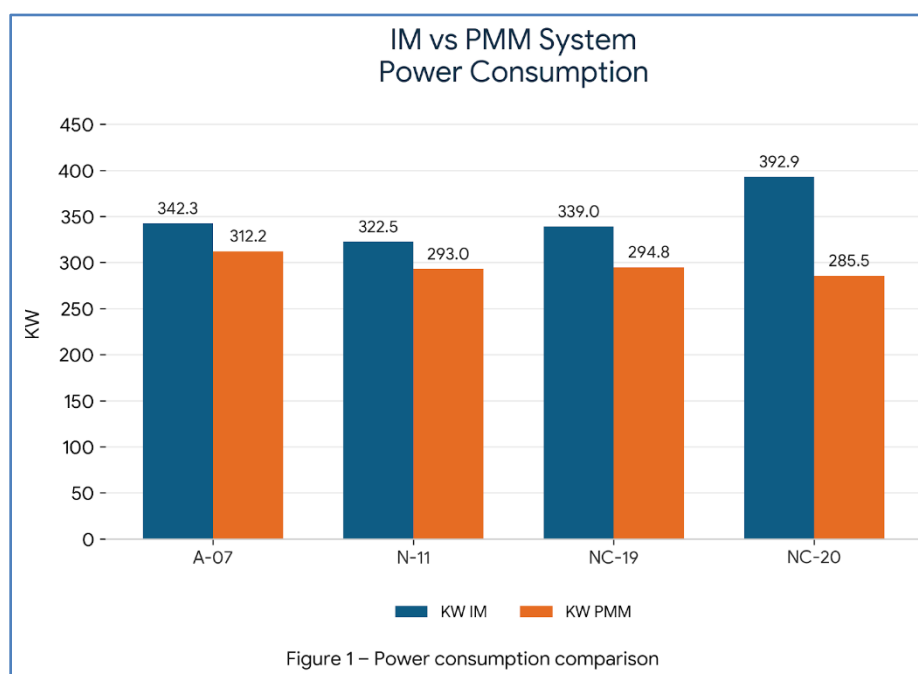
The pilot implementation was designed to run over a defined period, during which performance data from the PMM wells would be compared against historical IM data. This comparison will quantify energy savings, production efficiency, and reliability improvements. The rollout strategy includes ongoing monitoring, periodic data validation, and feedback loops for optimizing pump settings. This methodology ensures a robust evaluation of the technology's impact and supports future scalability across other wells in the field.

Performance Analysis: Results and Discussions

The deployment of Permanent Magnet Motors (PMMs) in four high-potential wells within the North zone of the Offshore Southeast Sumatra field yielded measurable improvements in energy efficiency and operational performance. The power consumption data can be monitored from the real-time monitoring system and summarized as follows.

Parameter	A-07	N-11	NC-19	NC-20
Motor HP	425	425	425	425
Running Amp	58	60	58	59
Nameplate Volt	3,335	3,335	3,335	3,335
Rate, BFPD	8,460	14,334	13,024	12,636
PF	0.86	0.88	0.88	0.86
KW	312.2	293.0	294.8	285.5
BFPD/KW	27.10	48.91	44.18	44.26
KW/BFPD	0.0369	0.0204	0.0226	0.0226

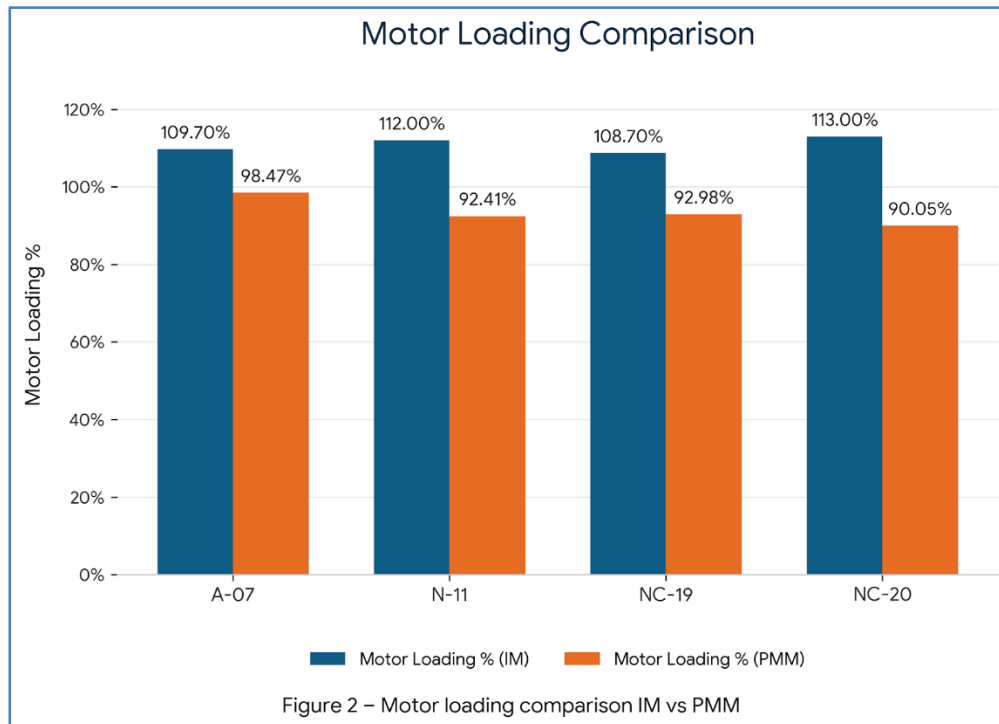
The comparison of Induction Motor (IM) and Permanent Magnet Motor (PMM) systems across four candidate wells reveals significant differences in power savings, driven by variations in motor loading, torque demand, and system efficiency. Figure 1 summarizes the results as follows.



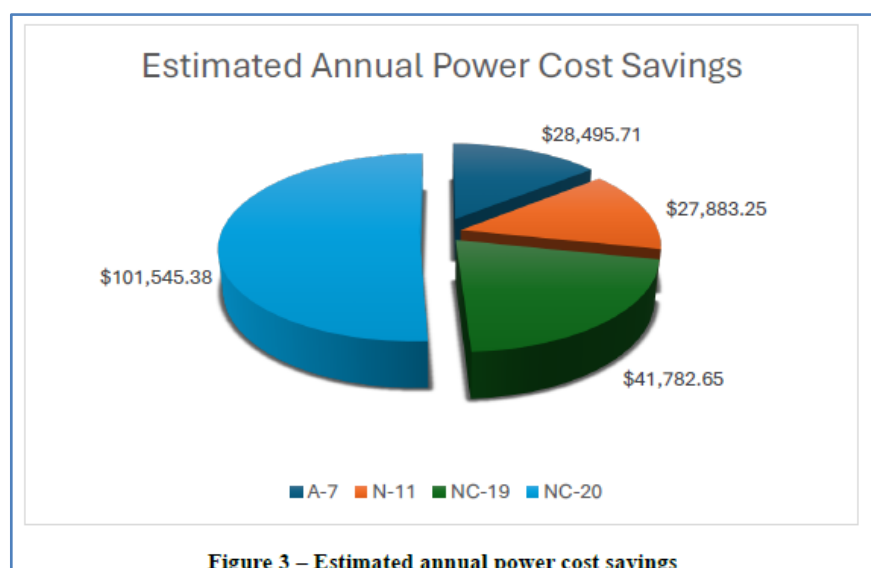
The variation in power savings among wells is influenced by several factors, one of the most critical being motor loading in IM versus PMM systems. Analysis shows that all four wells equipped with Induction Motors (IM) operated above their rated capacity, with loading ratios ranging from 108.7% (NC-19) to 113.0% (NC-20). This consistent overload forced IM motors to draw higher amperage, increasing rotor slip and magnetizing losses. These inefficiencies not only raised power consumption—particularly evident in NC-20—but also generated excess heat, accelerating wear and reducing equipment life. Operating beyond design limits introduces additional operational challenges, including higher failure risk and maintenance costs.

In contrast, the PMM system shows a much more balanced load distribution. All PMM motors operated between 90% and 98% of their rated capacity, which is ideal for efficiency and reliability. Unlike IMs, PMMs maintain high efficiency across a wide torque range because they eliminate rotor slip and magnetizing current losses. Even at high loads, PMMs deliver torque more effectively, resulting in lower power draw for the same hydraulic load. This is evident in NC-20, where the motor loading dropped from 113% under IM to 90% under PMM, yet the well achieved the highest power saving of 27.34%. The reduction in kW consumption is primarily due to PMM's synchronous operation and improved power factor (from 0.82 to 0.86), which reduces reactive power losses.

Conversely, A-07, which had the highest PMM loading (98.47%), recorded the lowest power saving (8.81%). This is because A-07's IM was already operating near its optimal efficiency point for its load, so the relative improvement from PMM conversion was smaller. N-11 and NC-19 showed moderate savings. Interestingly, N-11 had a higher IM motor loading (112%) than NC-19 (108.7%), yet its power saving was lower (9.15% vs. 13.04%). This is attributed to NC-19's higher energy consumption per barrel (KW/BFPD), indicating greater inefficiency. Additionally, NC-19 may have experienced higher system head or friction losses, increasing torque demand and amplifying IM inefficiencies. These findings confirm that the magnitude of power savings depends not only on motor technology but also on the operating conditions of each well—particularly the degree of overload in the IM system and the torque requirements of the pump.



The estimated annual power cost savings for the four wells are shown in Figure 2. The cost analysis highlights the substantial economic benefits of converting Induction Motors (IM) to Permanent Magnet Motors (PMM) in offshore operations. Across the four candidate wells, annual power cost savings totalled approximately \$199,706.99, driven by reductions in power consumption ranging from 30.1 kW in A-07 to 107.4 kW in NC-20. NC-20 emerged as the largest contributor, accounting for more than 50% of total savings (\$101,545.38) due to its significant drop in motor loading from 113% under IM to 90% under PMM. NC-19 followed with \$41,782.65, while A-07 and N-11 delivered moderate savings of \$28,495.71 and \$27,883.25, respectively. The economic case for PMM adoption is further strengthened by its ability to maintain high efficiency across a wide torque range, reducing reactive power losses and improving reliability.



The decision to use a 425 HP PMM for all wells was driven by logistical constraints rather than ideal sizing. In addition, standardizing motor size simplifies inventory management and accelerates deployment. While this approach may not perfectly match every well's hydraulic load, the efficiency gains from PMM technology still deliver substantial cost reductions. Space constraints on offshore platforms also influence equipment selection. PMMs paired with VSDs must fit within existing footprints, and their compact design compared to IMs makes them suitable for retrofits in mature fields like Offshore Southeast Sumatra. This compatibility ensures that power-saving initiatives do not require costly structural modifications. By enabling faster deployment and maintaining optimal motor sizing, PMM logistics act as a key enabler for scalable energy optimization across power-constrained offshore assets.

While PMMs inherently consume less power, their full potential is unlocked through integration with smart-edge real-time monitoring systems. These systems continuously track motor temperature, vibration, intake pressure, and other key parameters, allowing operators to detect inefficiencies early and respond proactively. Pump speed can be adjusted to match inflow conditions, preventing over-pumping and unnecessary energy use. Maintenance planning shifts from fixed schedules to condition-based strategies, reducing unplanned shutdowns and extending equipment life. In offshore settings, remote access to real-time data eliminates the need for fuel-intensive boat trips and minimizes personnel exposure to operational hazards.

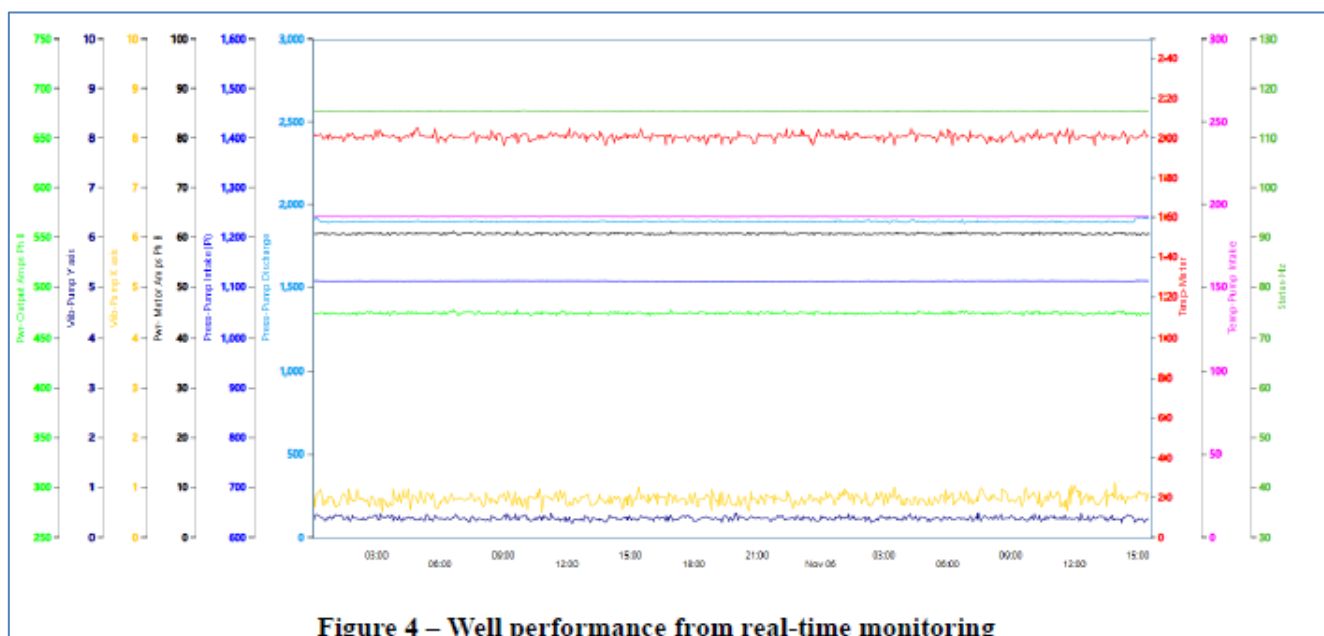


Figure 4 – Well performance from real-time monitoring

Beyond technical performance, this approach represents a strategic shift in field development philosophy. By enabling more wells to operate within existing power limits, operators can unlock previously uneconomic production zones—especially those with high water cut but substantial fluid rates. The success of the pilot demonstrates that PMM with monitoring integration is scalable and adaptable to other wells within the same field and across similar offshore assets. As power infrastructure remains fixed, this solution offers a sustainable path forward for maximizing output without expanding energy supply. It aligns with broader business objectives by reducing operational costs, improving asset utilization, and supporting long-term production targets. At the same time, it contributes to environmental goals by lowering carbon emissions per barrel lifted, reinforcing the operator's commitment to responsible energy development.

The transition from IM to PMM technology offers clear advantages in terms of power savings, efficiency, and electrical performance. The observed reductions in power consumption, coupled with improved KW/BFPD ratios and higher power factors, underscore the economic and technical benefits of PMM systems for ESP applications. These findings strongly support PMM adoption as a strategy to optimize artificial lift operations, reduce operating costs, and contribute to sustainability objectives.

To assess the potential impact on a broader scale, savings were projected for an additional six wells scheduled for PMM installation in 2026. Using the average annual savings per well from the initial batch (\$49,926), the projected savings for six wells amount to approximately \$299,560. When combined with the existing four wells, the total annual savings for ten wells is estimated at \$499,267. This represents a near half-million-dollar reduction in operating costs per year, excluding additional benefits such as reduced greenhouse gas emissions.

and improved electrical system stability. The implications of these findings are significant. If similar savings are replicated across a larger field or multiple assets, the economic impact becomes substantial, potentially reaching several million dollars annually. Furthermore, the improved power factor and energy efficiency contribute to sustainability objectives, aligning with industry goals for lower carbon footprints and optimized energy use.

Conclusion

The integration of Permanent Magnet Motors (PMMs) with smart-edge real-time monitoring systems marks a significant advancement in offshore field development. The pilot implementation in the North zone of the Offshore Southeast Sumatra field demonstrated clear benefits: a 211-KW reduction in power consumption across four wells, a 14.6% improvement in energy efficiency per barrel lifted, and an estimated \$200,000 in annual power cost savings. These results confirm that PMMs, with the synchronous operation, zero rotor copper losses, high power factor, and compact high-torque design, are ideally suited for offshore ESP applications where space, reliability, and energy efficiency are critical.

Beyond technical performance, the real-time monitoring system proved essential in unlocking the full value of PMMs. By enabling dynamic control, early fault detection, and predictive maintenance, it enhanced operational reliability and minimized downtime—especially important in offshore environments with limited access. This synergy between motor technology and intelligent monitoring not only improves production outcomes but also supports broader sustainability goals by reducing carbon emissions and optimizing energy use.

This approach represents more than a technical upgrade—it redefines field development strategy. It enables operators to bring previously uneconomical wells online, maximize output within fixed power limits. The success of this pilot paves the way for broader adoption across similar offshore assets. As a direct result of the pilot's success, the customer has committed to installing PMMs in six additional wells in 2026—demonstrating clear acceptance of the technology's impact and value. This expansion reinforces the solution's scalability and long-term viability, positioning it as a key enabler for future offshore operations.

Dicky Alviansyah is an Application Engineer for Electric Submersible Pump (ESP) systems within the Production Solutions business at Baker Hughes. He supports the selection, deployment, and performance optimization of ESP technology to ensure reliable and efficient production operations across multiple fields and customers. In his role, Dicky works closely with operators to diagnose production challenges, evaluate well conditions, and recommend fit-for-purpose ESP configurations that maximize uptime and operational efficiency. He is committed to delivering solutions safely, responsibly, and in alignment with Baker Hughes' high operational standards.

Marda Vidrianto - Results-driven Oil & Gas professional with 17+ years of progressive experience in artificial lift systems and production optimization. Currently leading artificial lift operations at PHE OSES, with demonstrated success in ESP contract management, budget control, operation excellence, and team development. Passionate about implementing innovative solutions to maximize well productivity while maintaining cost efficiency. Open to connecting with fellow professionals for knowledge exchange and collaboration opportunities in upstream operations.

Tri Chandra Setyo Wibowo brings over 15 years of experience in Oil & Gas Production Systems, beginning his career as a Field Engineer with Weatherford International, specializing in Production Optimization and Intelligent Completion technologies, including ESP, PCP and Rod-Lift optimizations. He later advanced into Technical Sales and Project Management roles with Baker Hughes Production Solutions, delivering comprehensive ESP solutions spanning conventional, rigless, surface, and automation systems. He holds a Bachelor's degree in Engineering Physics from Institut Teknologi Bandung and a Master's in Electrical & Electronics Engineering from Universiti Teknologi Petronas.

Arief Bakhtiyar is an Indonesian electrical engineer with more than two decades of experience in Electric Submersible Pump (ESP) technology, artificial lift systems, and well optimization across global oil and gas operations. Beginning his career in 2004 with Schlumberger, he built a strong foundation in ESP design, troubleshooting, and field operations for major clients such as Chevron, CNOOC, Petrochina, and Medco. His responsibilities included ESP commissioning, optimization, VSD operations, failure analysis, and field crew supervision, consistently ensuring equipment reliability and production efficiency. Arief holds a Bachelor's and Diploma in Electrical-Electronics Engineering from Brawijaya University and is trained in artificial lift engineering, VSD systems, well completion, and QHSE practices.

Seismic Trace to Impedance: Supervised 1D U-Net Deep Learning for Seismic Acoustic Impedance Inversion



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Abstract

Accurate estimation of acoustic impedance from seismic reflection data is fundamental to subsurface reservoir characterization. In this work, we present a supervised deep learning framework for seismic acoustic impedance inversion based on a one-dimensional U-Net architecture. The network takes raw seismic amplitude as input and learns a direct mapping to the corresponding acoustic impedance trace using well-log measurements as ground truth. The encoder progressively compresses the input through four down-sampling stages (128 to 2048 channels), while the decoder reconstructs the full-resolution impedance profile via transposed convolutions and skip connections that preserve fine-scale layer contrasts.

The model is trained end-to-end using mean squared error loss and evaluated on a blind test trace using R^2 and MSE metrics. Results demonstrate that the proposed architecture effectively captures both the broad low-frequency impedance trend and sharp boundary contrasts, offering a computationally efficient and geologically meaningful alternative to classical inversion methods for full-volume impedance prediction.

Introduction

Hydrocarbon exploration depends heavily on our ability to characterize the subsurface. One of the most important properties for this purpose is acoustic impedance, a measure that combines rock density and seismic wave velocity. Because acoustic impedance is directly linked to lithology, porosity, and fluid content, it helps identify reservoir boundaries and distinguish hydrocarbon-bearing zones from surrounding formations [1]. Accurate seismic impedance inversion therefore plays a critical role in reducing exploration uncertainty and guiding field development.

Seismic inversion is the process of estimating subsurface rock properties from surface-recorded seismic data. Mathematically, the relationship between the measured data and the model can be written as:

$s = \mathcal{G}(p) + \varepsilon$ where s is the observed seismic data, p is the subsurface property model (here, acoustic impedance), $\mathcal{G} : P \rightarrow S$ is the forward operator describing seismic wave propagation, and ε is additive noise. Estimating p from s is an ill-posed inverse problem [2], small data errors can produce large, unrealistic model perturbations. Regularization is therefore essential [8], and a widely adopted strategy casts the problem as a Bayesian optimization:

$$\hat{p} = \arg \min_{p \in P} [L(\mathcal{G}(p), s) + \lambda \cdot R(p)]$$

where L is a data misfit function, R is a regularization term encoding prior geological knowledge, and λ balances the two. The solution can be sought deterministically or stochastically [5,7].

Machine learning and deep learning have recently emerged as powerful alternatives to classical inversion. Instead of solving equation (2) anew for each dataset, a parameterized mapping:

$$G_{\theta}^{-1} : S \rightarrow P$$

is learned from data, so that given seismic input S , the output $\hat{p} = G_{\theta}^{-1}(s)$ approximates the true impedance. In supervised learning, this is achieved using measurement, model pairs $\{s, p\}$ from well locations [6,10], by minimizing:

$$J(\theta) = \mathcal{D}(p, G_{\theta}^{-1}(s))$$

where $\mathcal{D}$ is a distance measure between the predicted and true impedance. Various architectures have been explored for this task, including support vector regression [3], artificial neural networks [10], convolutional neural networks (CNNs) [6,11], and recurrent neural networks [4]. CNNs have shown particular promise for capturing local and multi-scale patterns in seismic traces [6].

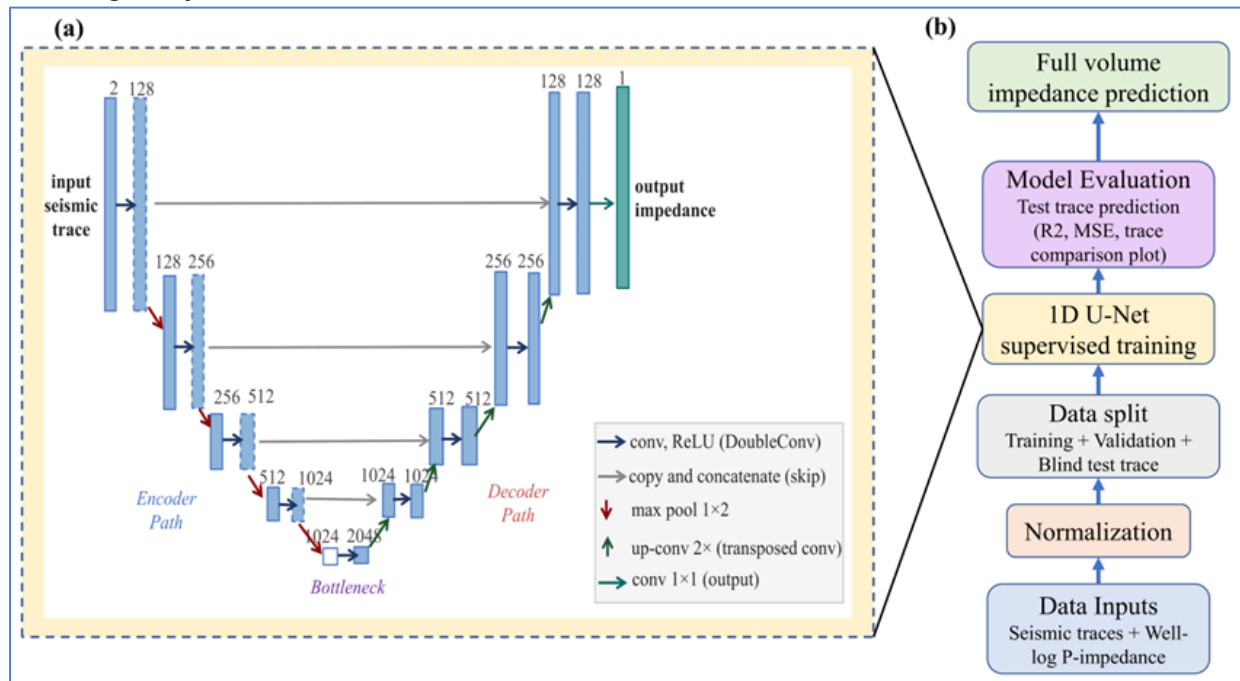
In this paper, I present a supervised 1D U-Net [12], originally developed for biomedical image segmentation and here adapted for seismic trace inversion. Its encoder-decoder structure with skip connections simultaneously captures broad low-frequency impedance trends and fine-scale layer contrasts, both of which are critical for accurate inversion. The following sections describe the dataset, network design, training procedure, and results.

2. Methodology

2.1 Overview

The proposed workflow follows a supervised learning pipeline where pairs of seismic traces (measured at or near well locations) and their corresponding acoustic impedance logs (measured from well-log data) are used to train a deep neural network. Once trained, the network is applied to seismic traces away from the wells to predict impedance throughout the survey. The overall workflow is illustrated in Fig. 1(b).

Fig. 1. (a) Architecture of the proposed 1D U-Net for seismic acoustic impedance inversion, showing the encoder-decoder structure with skip connections. (b) End-to-end supervised training and prediction workflow.



3.2 Input Features

Each seismic trace is treated as a one-dimensional time series and forms a two-channel input tensor. All inputs (seismic amplitude) and output labels (acoustic impedance) are normalized before training using a standard scaler trained only on the training set to prevent data leakage.

3.3 Network Architecture

The proposed model is a 1D U-Net [12], adapted from the original 2D formulation. It follows a symmetric encoder-decoder structure, where the encoder progressively compresses the input trace into a compact high-level representation, and the decoder reconstructs the impedance profile at the original resolution. Skip connections between encoder and decoder stages preserve spatial detail that would otherwise be lost during downsampling.

The proposed U-Net architecture consists of an encoder-decoder framework designed for one-dimensional seismic trace processing. Each feature extraction block employs two consecutive 1D convolutional layers with a relatively large kernel size of 25 and appropriate padding to preserve the input length, followed by ReLU activation functions. The large kernel size enables the network to capture broader temporal features and seismic wavelet characteristics. In the encoder path, Down blocks combine max-pooling and convolution operations to progressively reduce the sequence length while increasing the number of feature channels, allowing the network to learn higher-level representations. In the decoder path, Up blocks utilize transposed convolutions for upsampling, followed by concatenation with the corresponding encoder features through skip connections, which help preserve fine-scale information lost during downsampling. Finally, a 1×1 convolution layer maps the reconstructed 128-channel feature representation to a single output channel, producing the predicted acoustic impedance trace.

The full channel progression is: Input $\rightarrow 128 \rightarrow 256 \rightarrow 512 \rightarrow 1024 \rightarrow 2048$ (bottleneck) $\rightarrow 1024 \rightarrow 512 \rightarrow 256 \rightarrow 128 \rightarrow$ Output, with sequence length halving at each encoder stage from 1880 to 117 samples and doubling back through the decoder (Fig.1(1a)).

2.4 Loss Function

The network is trained using the Mean Squared Error (MSE) loss between the predicted impedance trace and the true impedance trace from the well log. For a training batch of N traces, each of length T samples, the loss is defined as:

$$J(\theta) = \frac{1}{N \cdot T} \sum_{i=1}^N \sum_{t=1}^T (\hat{p}_{i,t} - p_{i,t})^2$$

where $\hat{p}_{i,t}$ is the network's predicted impedance at sample t of trace i , $p_{i,t}$ is the corresponding true impedance value from the well log, and θ represents all learnable parameters of the network. The network is optimized by minimizing $J(\theta)$ using the Adam optimizer.

2.5 Training Setup

The full training procedure is supervised and carried out as follows. One trace is held out entirely as the final test trace. The remaining traces are split into a training set and a validation set. During each training epoch, the network sees only the training traces; the validation set is used after each epoch to monitor generalization performance, and the validation loss and R^2 score are computed at the end of every epoch without any gradient updates.

Model performance is tracked using two metrics. The first is the MSE loss defined in equation (5). The second is the coefficient of determination, R^2 , which measures how much of the variance in the true impedance is explained by the predicted impedance:

$$R^2 = 1 - \frac{\sum_{t=1}^T (p_t - \hat{p}_t)^2}{\sum_{t=1}^T (p_t - \bar{p})^2}$$

where $\bar{p}$ is the mean of the true impedance values. An R^2 of 1 indicates a perfect prediction; values closer to 0 indicate a poor fit.

After training is complete, the best model checkpoint is saved and applied to the held-out test trace for final evaluation. Training and validation loss and R^2 curves are plotted to assess convergence and detect overfitting.

3. Case Study

3.1 Model Training

The proposed U-Net inversion model was evaluated using both a synthetic dataset and a real field dataset. The synthetic dataset allows the model performance to be tested under controlled conditions where the true acoustic impedance is known, while the field dataset provides an assessment of the model on real seismic data.

3.1.1 Synthetic Study

The synthetic experiments were carried out using the Marmousi 2 model [9], a widely used benchmark model in seismic inversion studies. The model was first converted into the time domain and then used to generate the training data. To simulate a realistic exploration scenario with limited well information, only 20 acoustic impedance traces were selected as training labels, while the remaining seismic traces were treated as unlabeled data.

During training, seismic traces were passed through the U-Net model to predict acoustic impedance. The predicted impedance was then used to generate synthetic seismic data through forward modelling. The network was trained by minimizing the difference between the generated and observed seismic data, along with the difference between the predicted and known impedance at the training locations. The model parameters were updated iteratively until the training loss reached a stable value.

3.1.2 Real Field Study

To evaluate the proposed method on real data, the F3 block dataset from the North Sea was used. This open-access dataset contains four wells: F02-1, F03-2, F03-4, and F06-1. The acoustic impedance log from well F03-4 was excluded from the training process and used as a blind test well for validation. The remaining three wells were used as training data.

This blind-well testing strategy is commonly used in geophysical studies to assess the generalization capability of inversion models. Accurate predictions at the blind well indicate that the model has learned meaningful relationships between seismic data and acoustic impedance rather than simply memorizing the training data.

3.2 Results and Discussion

3.2.1 Synthetic Study

Fig.2. shows the training and validation loss curves over 400 epochs. Both losses drop sharply within the first 50 epochs and then stabilize at low values, with no sign of overfitting. This smooth convergence confirms that the network trained well.

Fig. 2: Training (blue) and validation (orange) loss convergence curve for 400 epochs for the Marmousi-II dataset swing, which shows that the trained model is not overtrained and can be further applied to the whole dataset.

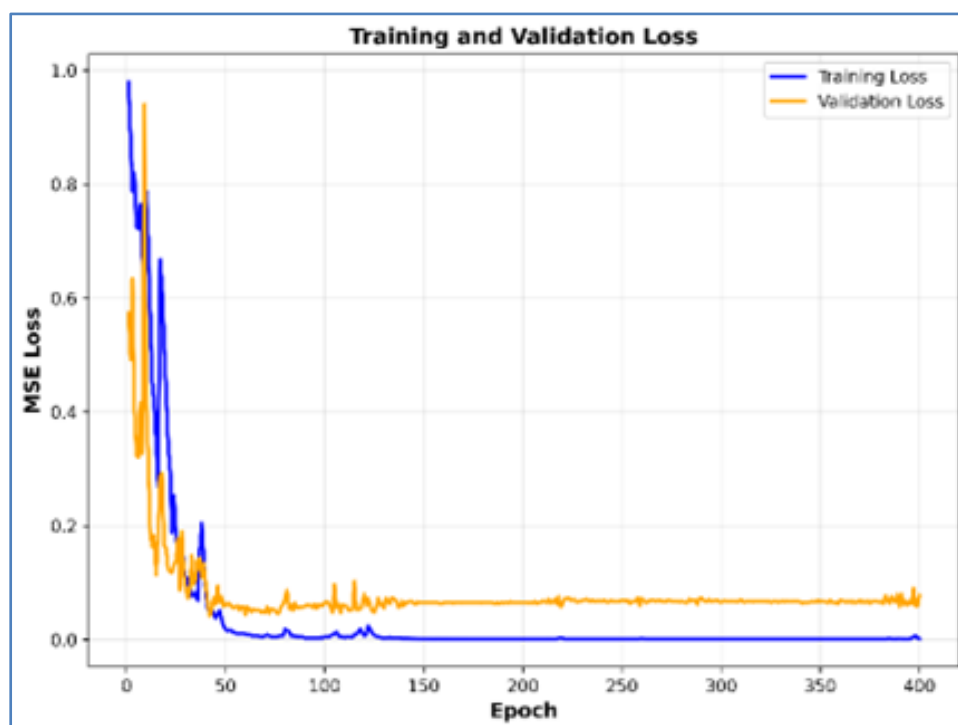


Fig. 3(a) compares the predicted and true AI at a representative trace. The two curves match closely throughout the entire depth range, capturing both large-scale trends and smaller impedance variations. Fig. 3 2(b) shows the relative difference. The difference stays near zero for most of the section, with only minor deviations in zones of sharp impedance contrasts, and the curve quickly recovers even in those regions.

Fig. 2: Training (blue) and validation (orange) loss convergence curve for 400 epochs for the Marmousi-II dataset swing, which shows that the trained model is not overtrained and can be further applied to the whole dataset.

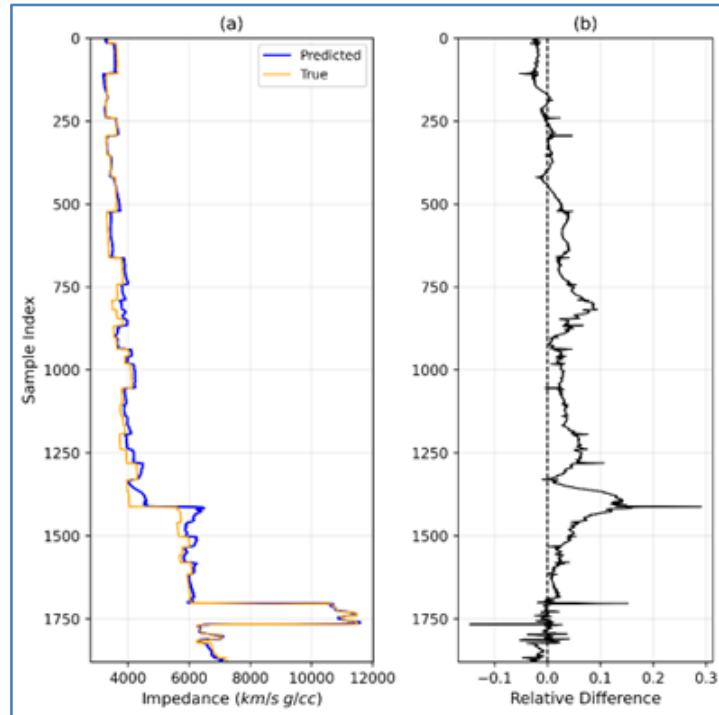


Fig. 4: Correlation plot between true and predicted impedance, along with performance metrics for the complete Marmousi-II model.

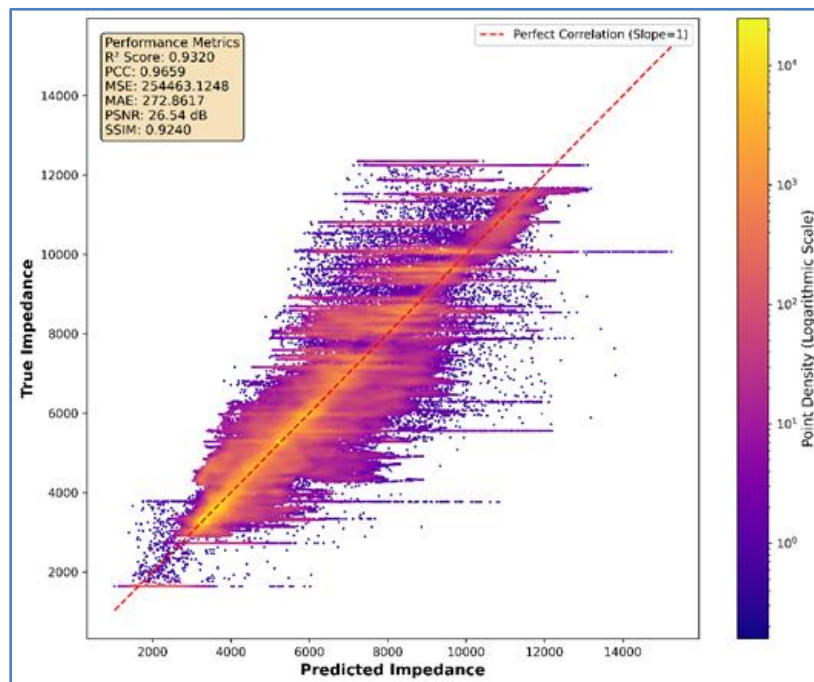
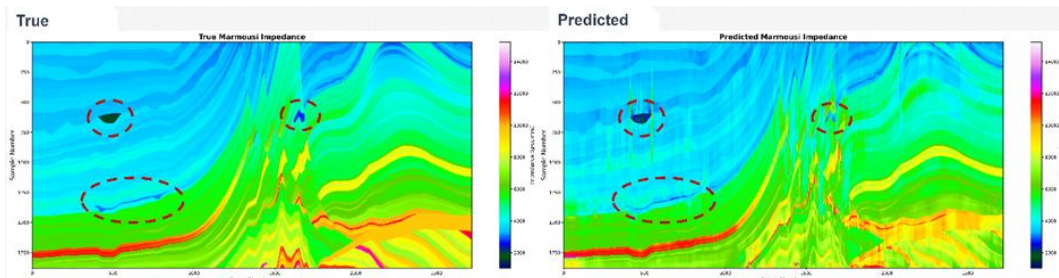


Fig. 4 shows the crossplot between predicted and true AI values across the entire section. The data points cluster tightly along the ideal 1:1 line, and the performance metrics confirm strong prediction accuracy: $R^2 = 0.9320$, $PCC = 0.9659$, $MSE = 254463.12$, $MAE = 272.86$, $PSNR = 26.54$ dB, and $SSIM = 0.9240$. These results show that the network generalizes well beyond the 20 training traces to all 2721 unseen traces in the survey, demonstrating the reliability and effectiveness of the proposed workflow on synthetic data.

Fig. 5 compares the full 2D true and predicted impedance sections. The predicted section reproduces the overall geological structure well, including the major layering patterns and the three highlighted anomalies (marked with dashed circles). Some trace-to-trace variability is visible, which is expected since the network processes each trace independently without any lateral spatial constraint.

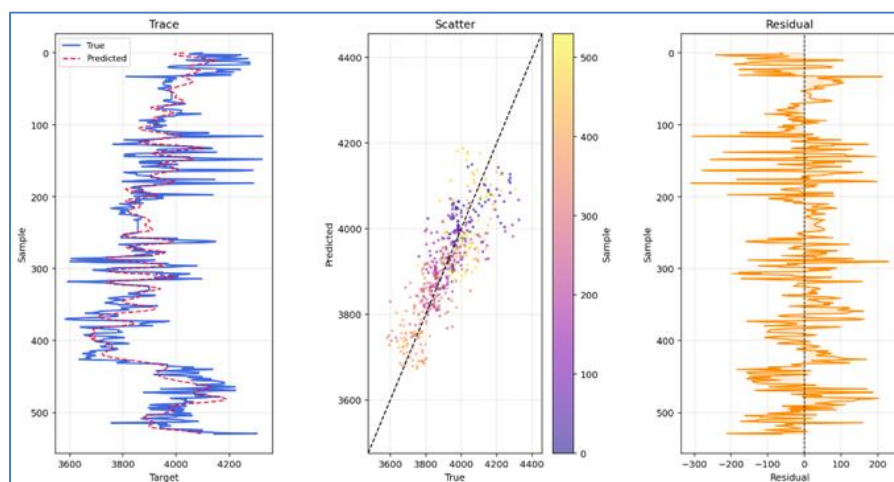
Fig. 5: Result of the predicted impedance section of the synthetic Marmousi-II dataset, and it is very clear that every tiny/ small/ thin layers or features that is present in the dataset are clearly resolved in the inverted model (marked as red circles on the true and predicted models).



3.2.2 Real Field Study

Fig. 6 shows the results on the blind well F03-4, which was kept completely unseen during training. The left panel compares the true (blue) and predicted (red dashed) AI traces side by side. The predicted trace follows the general trend of the true trace reasonably well across most of the depth range, capturing the major impedance variations. The middle panel shows the scatter plot between true and predicted values, where the points cluster around the ideal diagonal line, indicating a positive linear relationship between the two. The right panel shows the residual plot, where most residuals are scattered closely around zero, meaning the errors are relatively small and unbiased for most samples.

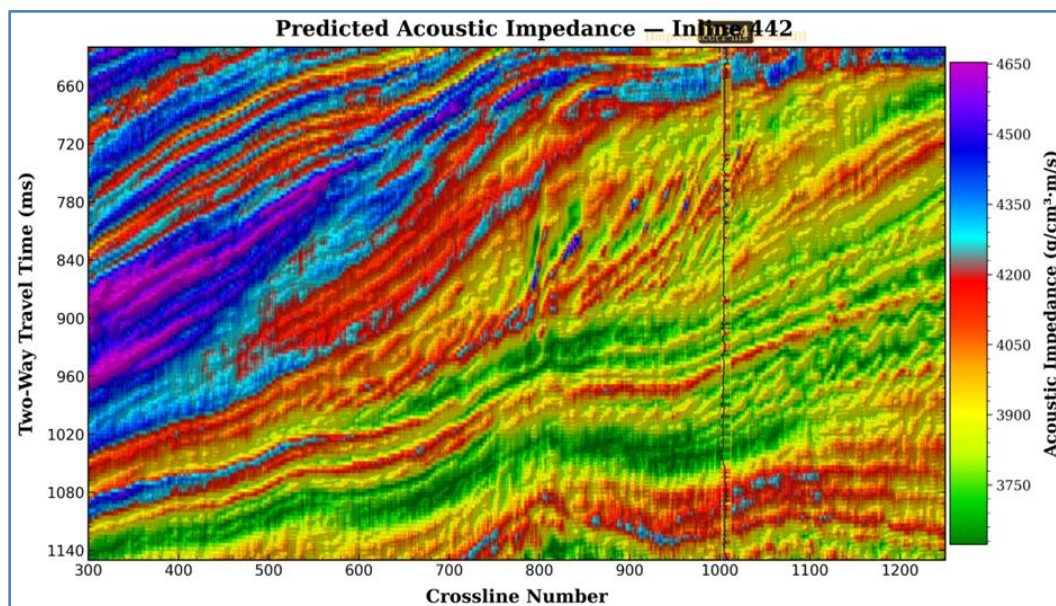
Fig 6: (a) Comparison of the predicted and the true impedance of a single well data that has been taken as pure blind data for the real filed application for F3 data, North sea (Blue line is the true well log data and the red dashed line is the predicted well data). and (b) correlation scatter plot. (c) The relative difference between the true and the predicted well log data.



The performance metrics reported for the blind well are: $R^2 = 0.647$, $PCC = 0.806$, $MSE = 7209.16$, $RMSE = 84.91$, $MAE = 65.22$, $MAPE = 1.65\%$, $Bias = -4.62$, and $NRMSE = 11.42\%$. The R^2 and PCC values confirm a moderate to good correlation between the predicted and true impedance at the blind well, which is encouraging given that the network had absolutely no exposure to this well during training.

Fig. 7 presents the predicted acoustic impedance section along Inline 442 of the F3 block. The section covers a two-way travel time range of 620 ms to 1150 ms and spans crosslines 300 to 1250. The predicted section shows well-defined, laterally continuous impedance layering across most of the section. The dipping reflector patterns visible in the upper portion of the section (around 630-760 ms) and the relatively flat layering in the middle and lower portions are both captured clearly. The vertical dashed line at approximately crossline 1007 marks the location of the blind well F03-4, and the predicted impedance values in that region are consistent with what the trace-level comparison in Fig. 6 already showed. Overall, the predicted section looks geologically reasonable and spatially consistent, demonstrating that the trained network can produce meaningful impedance volumes from real seismic data with only three well logs used for supervision.

Fig. 7: Result of the predicted impedance 2d section (inline - 442) of the real data of the F3 block from the North Sea dataset. The well F03-4 is inserted horizontally at its location inside the inverted impedance model section.



Conclusions

In this work, a semi-supervised U-Net based deep learning workflow was proposed for acoustic impedance (AI) inversion from seismic data. The method was validated on both a synthetic dataset and a real field dataset. For the synthetic case, the Marmousi 2 model was used, and the network achieved strong prediction accuracy across the entire section with $R^2 = 0.93$ and $PCC = 0.97$, even though only 20 labeled traces were used for training out of 2741 total traces. For the real field case, the F3 block dataset from the North Sea was used, where three wells guided the training and the fourth well (F03-4) was kept completely blind for testing. The blind well results showed a reasonable agreement with $PCC = 0.81$ and $R^2 = 0.65$, confirming that the model can generalize to unseen locations in a real geological setting. In both cases, the network learned a reliable mapping from seismic data to subsurface impedance using very limited well log supervision. The proposed workflow is not limited to AI inversion alone and can be further extended to full elastic inversion and reservoir property estimation, making it a promising tool for practical subsurface characterization.

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A Case Study – 12” Pipeline Rupture Due to Flash Flood During Monsoon Season 2025 and Restoration Through India’s Longest Horizontal Directional Drilling (HDD) Using the Intersection Method

GAIL (India) Limited



Ravi Kant



Prafulla Pankaj



Rahul Kr Mittal

Highlights:

- Heavy Rainfall / High Discharge Water from the Upstream Barrage
- River Meandering
- Pipeline Rupture
- Immediate Measure for Restoration of Gas supply
- India Longest HDD Via Intersection Method

Abstract:

GAIL (India) Limited operates a cross-country 12” natural gas pipeline supplying natural gas to the states of Uttarakhand and Uttar Pradesh with an approximate transmission capacity of 2.5 MMSCMD. During the monsoon season of 2025, the pipeline experienced a rupture, resulting in natural gas leakage. The pipeline rupture was attributed to the washout of the Right of Use (RoU) caused by heavy rainfall, flooding, and a subsequent change in the river course. Due to intense rainfall and cloudburst events in the hilly upstream region, a heavy discharge of water was observed in the main river. At a natural river meandering location (close to the pipeline rupture location) the river changed its course towards a nearby minor stream (i.e. Nala) effectively converting it into the main channel. This sudden increase in water flow in the Nala stream caused severe erosion of the riverbank and riverbed, resulting in extensive washout and exposure of the pipeline laid parallel (~200 metre apart) from the nala. The combined effects of pipeline exposure, loss of soil support, and hydrodynamic forces led to cracking and eventual rupture.

Due to the Pipeline rupture, the natural gas supply to a total of 18 consumers, including four City Gas Distribution (CGD) entities, three power plants, and eleven large industrial consumers connected to this pipeline was affected. To restore gas supply on an emergency basis, a temporary arrangement was established to the Downstream end of the GAIL Pipeline through an existing 6-inch CGD pipeline within the Geographical Area (GA).

As a permanent mitigation measure, a Horizontal Directional Drilling (HDD) crossing of 4,218 meters was executed using the intersection method enabling the crossing of both the river and the Nala in a single stretch.

Keyword's:

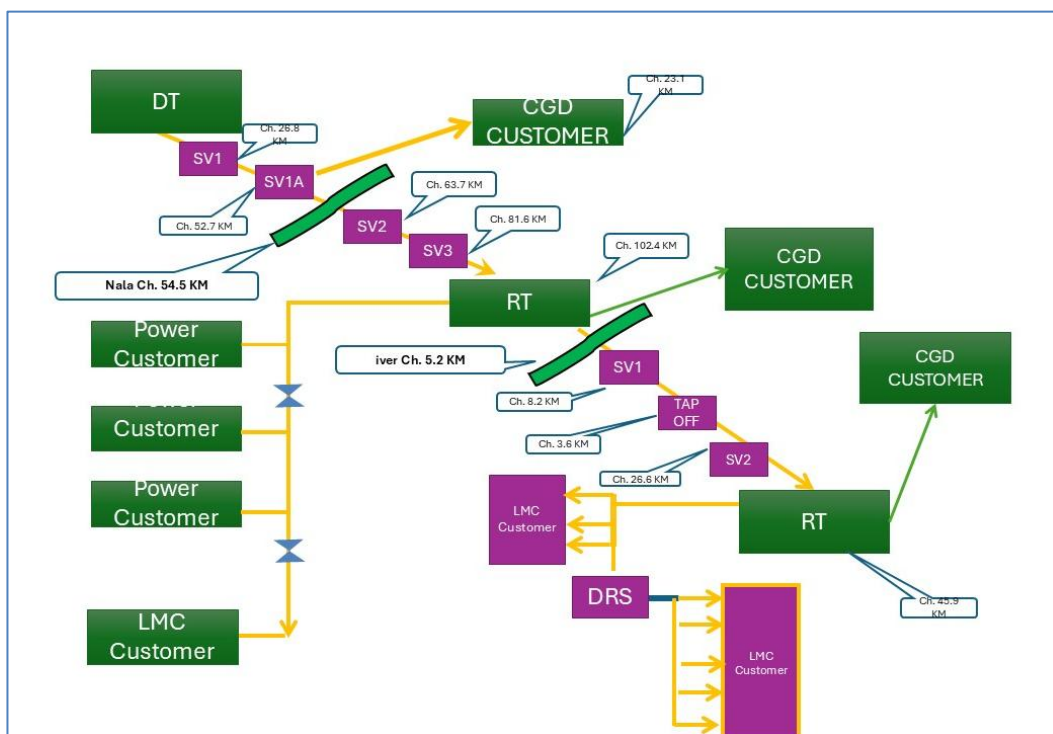
River Meandering; Approach; Damage section Identification; RoU Clearance; Material Arrangement; HDD Works

1.0 Introduction

India's energy infrastructure is at a critical juncture, with ambitious plans to expand its natural gas pipeline network significantly under initiatives **“One Nation, One Gas Grid.”** The transportation of petroleum, petroleum products, and natural gas is key elements for India's rapid infrastructure growth which demands an efficient legal framework for swift project execution, maintenance and expansion thereof. Government of India with a view to establishing a mechanism for efficient and economical mechanism for transportation and distribution of petroleum and petroleum products enacted a statute known as Petroleum and Minerals Pipelines (Acquisition of Right of User in land) Act, 1962 (in short “PMP Act”).

The Act governs with laying of pipelines for transportation of petroleum products, Natural gas, and minerals. GAIL (India) Ltd laid and operates 12" X 102 Km Cross Country Pipeline in the state of U.P & U.K since 2011. The pipeline was laid as per National Standards (PNGRB/OISD) and International Standards (ASME B31.8). This pipeline traverses the diverse terrains states of Uttar Pradesh and Uttarakhand and crossing major water bodies. This pipeline supplies Natural gas to 18 Customers located in state of Uttar Pradesh & Uttarakhand.

Figure 1 Schematic



2.0 The Incident

On 10.08.2025, during the early morning hours, information regarding a suspected gas leak was received from residents and through a low-pressure alarm generated in the centralized C-SCADA system at Noida. Immediately upon receipt of the information, all relevant dispatch stations and sectionalizing valves along the affected pipeline section were closed. Natural gas supply in the pipeline was stopped immediately and the pipeline pressure in the section between SV-01A and SV-02 dropped from approximately 58 kg/cm² to near zero. GAIL's maintenance teams from Uttarakhand and Headquarters, Noida, were immediately mobilized and rushed to the suspected leakage location. Upon reaching the site, the teams observed indications of gas leakage in the vicinity of the river crossing between SV-01A and SV-02, approximately at Chainage 54.5 km. Initial information regarding the incident was communicated telephonically to the local district administration during the morning hours. The exact location of the leakage could not be determined due to severe flooding and heavy water flow conditions in & around the affected pipeline section and access to the suspected leakage point was not available. On prima-facia, it was suspected that intense rainfall in Uttarakhand had resulted in flash-flood conditions and significant changes in the course of the river (i.e. River meandering), in the vicinity of pipeline. The resulting erosion and washout had exposed and adversely affected the pipeline stability; actual site photos as below:

Figure 2: Pipeline Rupture Location



3.0 Approach to the Incident Location

Due to the continuous and intense rainfall in the state of Uttarakhand on 9th, 10th & 11th August 2025 the whole area surrounding the pipeline alignment was submerged under water. The approach road was completely inundated and no longer visible, and the area was waterlogged to a depth of approximately 5–6 feet. Furthermore, due to the prevailing sandy soil conditions, the surface had become extremely slippery, making it highly challenging for maintenance personnel and equipment to safely and swiftly access the incident site.



4.0 Temporary Measures -Restoration of Gas Supply

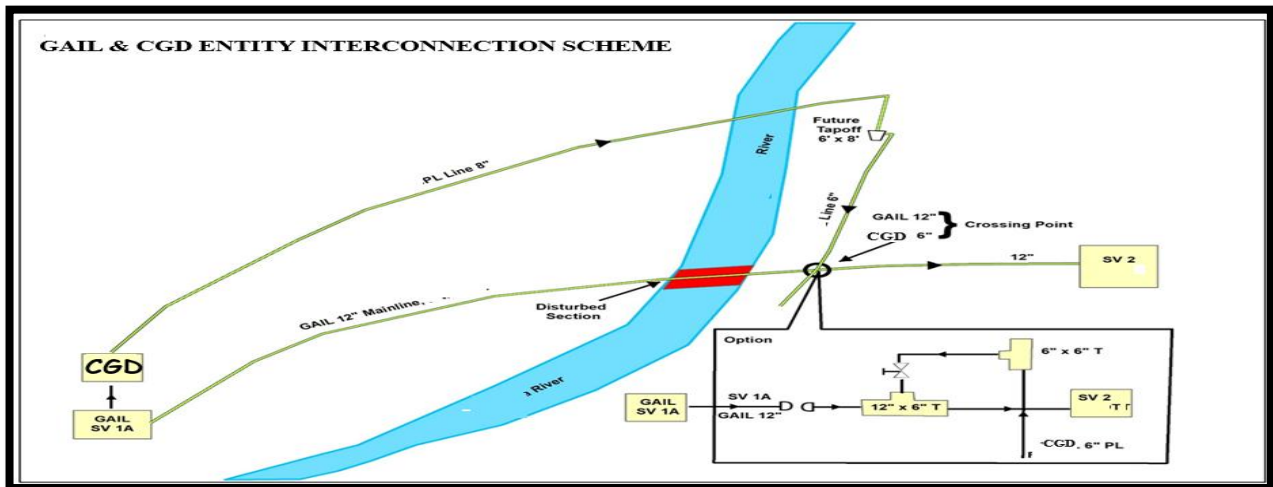
Ensuring timely restoration of gas supply to all critical consumers in the region including CGD, power plants, and other priority sectors was of paramount importance. Such actions were essential not only for maintaining operational reliability, but also for safeguarding the uninterrupted supply of natural gas to downstream segments such as PNG, CNG, and power generation. Prompt restoration measures directly contribute to public service continuity, industrial stability, and stakeholder confidence during contingency situations. Accordingly, various contingency measures were evaluated for rapid restoration of gas supply, including temporary laying of a 4-inch bypass pipeline parallel to the riverbank, in-situ repair of the damaged section through controlled underwater welding, downstream hook-up with another utility pipeline, replacement of the damaged pipe section, mechanical clamps, and rerouting through alternate networks. All options were technically assessed for hydraulic capacity, Maximum Allowable operating Pressure (MAOP), material, weld integrity, stress limitations, execution timeline and operational risks.

Based on the prevailing site conditions and the urgent requirement for early resumption of gas supply to the anchor customers, temporary restoration was undertaken through interconnection of the GAIL natural gas pipeline with the CGD operator's pipeline network.

GAIL team coordinated with the management of the CGD operator for establishing temporary interconnectivity between the upstream 12-inch GAIL pipeline and the downstream 12-inch GAIL pipeline across the river stretch through the CGD operator's existing 6-inch network near GAIL pipeline Chainage 62.00 km. This interim arrangement facilitated restoration of partial gas supplies to CGD entities and industrial customers on priority basis which were dependent on the GAIL natural gas pipeline.

Accordingly, the emergency welding contractor, Non-Destructive Testing (NDT) teams, and associated resources were mobilized immediately and required materials were arranged on priority from the Uttarakhand pipeline store. Necessary approvals for temporary laying of 4-inch × 303 m pipeline were obtained from the district administration on fast-track basis. Through effective planning, round-the-clock execution, dedicated manpower, and management support, the work was completed, tested, and commissioned on 16.08.2025, within six days of the incident, restoring gas supply to CGD and power sector customers.

Figure 3 Interconnection Scheme



5.0 Permanent Mitigation through new HDD:

To determine the length, and depth of the permanent mitigation measures, the following studies were carried out::

- Detailed baseline assessment of Geomorphology, including study of landforms, their processes, history & classification of the river area.
- Detailed baseline assessment of hydrology, including study of River and Nala & its movement, distribution, change of course, etc.
- Flood frequency, inundation mapping, and vulnerability analysis using historical data, including High flood levels.
- Identification of erosion-prone stretches, floodplain dynamics, and soil/strata conditions relevant to pipeline stability.
- GIS-based thematic maps (hydrology, topography, geomorphology, flood hazard zones) for decision-making and route planning
- River dynamics and Avulsion study, along with future analysis near the ROU
- Assessment of bank erosion and river meandering based on historical satellite imagery

Figure-4 Toposheet Map (Existing Pipeline)

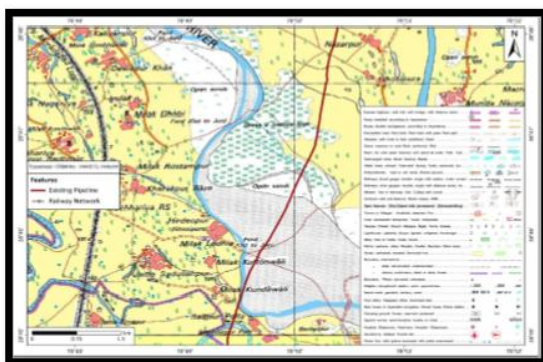


Figure-5 Geomorphology map of the study area

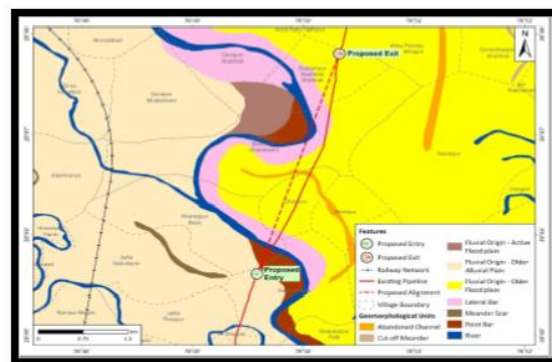


Figure-6 NDVI Map – 2010 (Study Area)



Figure-7 NDVI Map – 2015 (Study Area)



Figure- 8: NDVI Map – 2020 (Study Area)



Figure-9: NDVI Map – 2024 (Study Area)

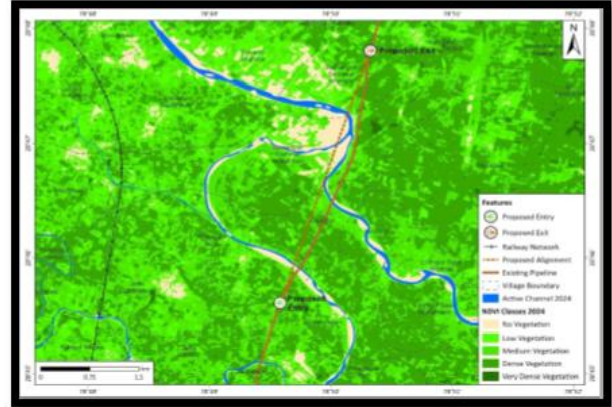
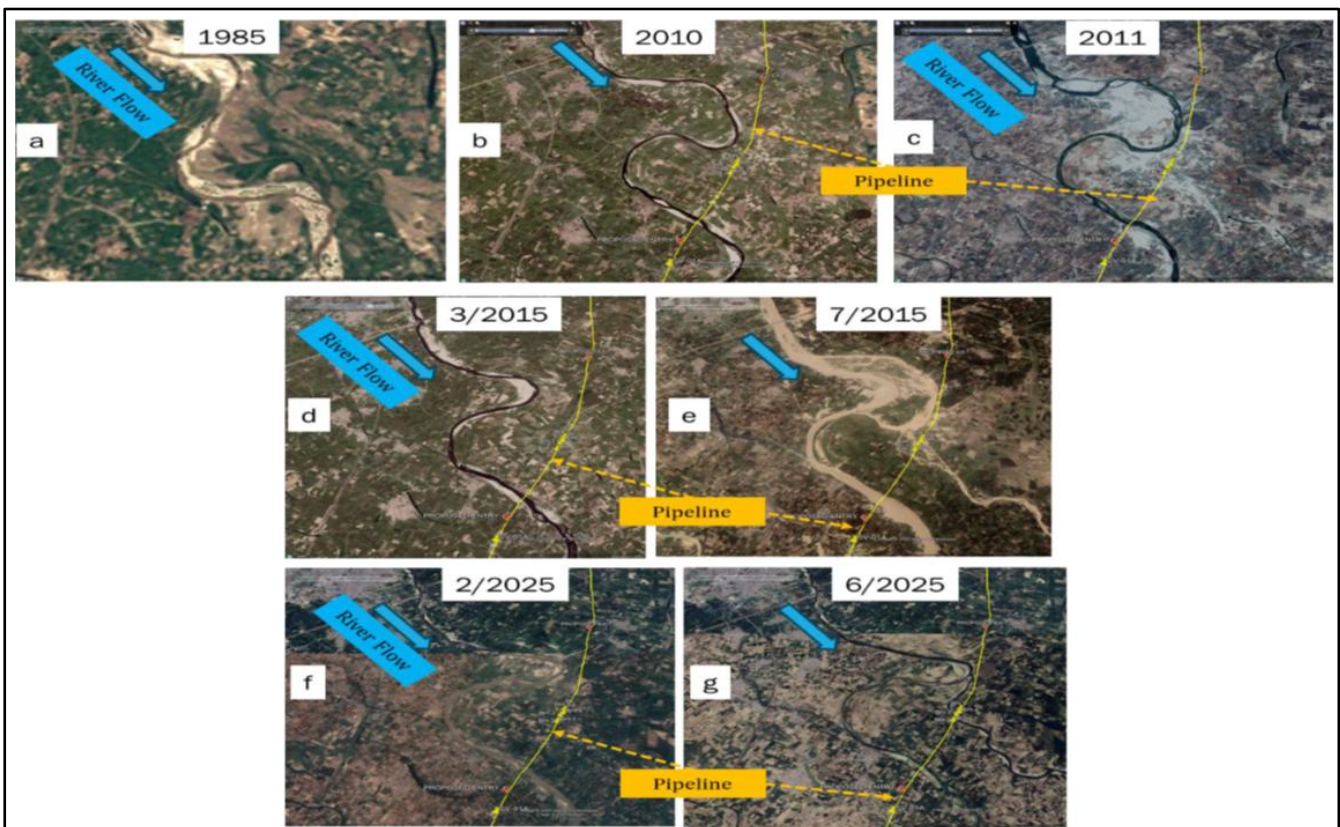


Figure-10 Spatial distribution of the river between 1985 and 2025 concerning the existing GAIL pipeline network. The analysis highlights progressive shifts in the river's course driven by variations in flow dynamics, rainfall intensity, and seasonal hydrological regimes

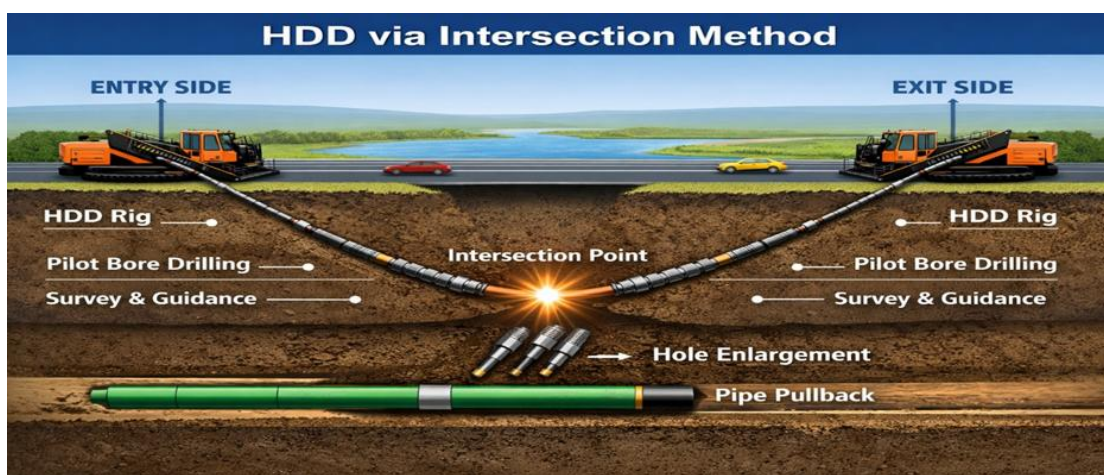


From the above geotechnical, geomorphological and hydrological study following key observations were made: The river exhibits a highly dynamic and unstable nature.

- The existing pipeline alignment, as observed from successive satellite imagery, intersects areas of active meander migration and is therefore highly vulnerable to erosion, flooding, and scour, and potential pipeline exposure.
- Surface-based mitigation measures were considered inadequate to ensure long-term security under these conditions.
- Given the persistent and progressive lateral migration of the river, it was concluded that the pipeline section should be permanently rerouted through an appropriate subsurface crossing (covering both the river and the river Nala) using a Horizontal Directional Drilling (HDD) crossing. The proposed HDD alignment was to be extended beyond the present meander belt and designed to be installed at a depth significantly below the maximum calculated scour level and lateral migration corridor. Implementation of the proposed HDD crossing length and depth would ensure long-term stability, minimize exposure to geomorphic hazards, and provide a permanent mitigation solution for the pipeline infrastructure.

6.0 Horizontal Directional Drilling (HDD) Execution

As per the subsurface lithological soil data of the river crossing, along with the geomorphological and hydrological studies, an HDD crossing length of approximately 4,100 m and a depth of approximately 22 m were envisaged to ensure the overall safety and integrity of the pipeline. Since the envisaged HDD length was exceptionally long, drilling, reaming, and pullback operations from a single end were not feasible. Therefore, the HDD crossing was planned to be executed using the Intersection Method, wherein drilling was carried out simultaneously or sequentially from both ends of the crossing alignment, and the bore paths were designed to meet/intersect at a predetermined underground point. The work order for the HDD installation of the pipeline along with the OFC duct was awarded to the contractor on 01.09.2025



RoU Clearance:

Considering the critical restoration timeline, opening of the RoU for preparation and stringing of the 12" line pipe of length over ~4,100 metre was a key execution challenge. The corridor was required for stringing, welding, coating repairs, and pullback readiness for the HDD package. GAIL had earlier acquired a 20 metre RoU under the provisions of the Petroleum and Minerals Pipelines (Acquisition of Right of User in Land) Act, 1962. However, the affected stretch lies within the river floodplain, where land use is dominated by agro-forestry plantations with intercropped sugarcane and wheat. Presence of agro-forestry plantations and standing crops restricted construction access and mechanical movement.

Since such plantations were high-value assets, farmers resisted RoU opening and demanded appropriate compensation. To minimize delay, an approach was adopted wherein only 2.5 km RoU from the punch-in side was prioritized initially, while two pipe strings of ~2.5 km and ~1.7 km were planned simultaneously. Meanwhile, the HDD contractor had mobilized two rigs with complete accessories and manpower. Delay in RoU handover was directly impacting string preparation and HDD execution schedule. With intervention of the District Administration and Revenue Authorities, the compensation issues were resolved through stakeholder meetings on 06.10.2025. RoU opening activities commenced from 07.10.2025, enabling accelerated execution of the emergency HDD crossing works



HDD Works:

String preparation and pilot drilling from both entry and exit sides commenced on 08.10.2025 and were executed continuously on a 24×7 basis under adverse weather conditions, including rainfall and low temperatures, affecting operational efficiency and logistics. The work was carried out in accordance with API RP 1110 for HDD crossings and ASME B31.8, ensuring compliance with safety, alignment control, and drilling tolerances.

Intermittent constraints were encountered in the form of localized farmer agitation related to compensation, posing risks to schedule continuity. However, through structured stakeholder engagement, administrative coordination, and real-time issue resolution, disruptions were minimized and drilling progression was maintained in line with the planned HDD execution programme.

Timeline for the Completion of the Job:

SI No	Job	Completion date
1	Incident	10.08.2025
2	WO Award for the HDD Works	31.08.2025
3	Commencement of the 10.75" Pilot as String preparation	06.11.2025 (Intersection done on 03.11.2025)
4	20" Rimming for Line Pipe	03.12.2025
5	20" Clean Pass for the Line Pipe	10.12.2025
5	Pulling of Line Pipe	13.12.2025
6	Hook-Up with the Existing Pipeline & pipeline Re-commissioning	30.12.2025

Figure 11 - HDD Commencement



Figure 14 Work Under Progress & Real Time issue resolution



Figure 15 GT Joint



Figure 12 String Preparation



Figure 13 Pulling



Figure 16 Hook Up with Existing Pipeline



7.0 Conclusion and Recommendation:

- Rupture of the 12" NG pipeline crossing is attributed to high flow/flash flood conditions causing channel migration, bank erosion, and bed scour, leading to loss of cover and exposure. The exposed pipeline experienced hydrodynamic loading and stress concentration, resulting in crack initiation and rupture of the pipeline.
- River crossings should be aligned along straight with crossing angles ~90°, avoiding meander bends. Where unavoidable, mitigation measures (longer HDD, bank/bed protection) shall be implemented as per API RP 1110 and OISD guidelines.

- c) Parallel routing of pipelines in proximity of rivers should be avoided to minimize exposure to erosion and channel migration risks.
- d) Installation of the Geotagged markers with RFID integration are to be installed for all crossings at riverbanks and HDD/open-cut tie-in points to enable monitoring of morphological changes.
- e) For pipelines within 100 m of riverbanks, pipeline markers should be installed at 50–100 m intervals for tracking river course variation and erosion progression.
- f) For ascertaining the pipeline depth beneath the riverbed, the sonar survey like Bathymetry, Sub-Bottom Profile, CAT-RTK survey(s) needs to be carried out periodically.
- g) Site-specific mitigation (bank/bed protection, rerouting, or conversion to HDD) shall be implemented in accordance with API RP 1110 and OISD.
- h) Regular meetings should be conducted with the Irrigation Department/Water Resources authorities to coordinate water release from dams/barrages. Meetings should also be held with district administration, NDRF, SDRF, etc., to create awareness regarding pipeline river crossings and associated emergency scenarios.

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2. *American Petroleum Institute – API RP 1110 Recommended Practice for HDD Crossing of Pipelines.*
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4. *American Society of Civil Engineers (HEC Guidelines – HEC-RAS / HEC-18)- For Hydrological studies.*
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7. *OISD Guideline – 2025 on Guidelines for preventing Pipeline Failure due to heavy rainfall/ floods.*

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Institutionalizing Energy Sovereignty Through Deterministic Verification Infrastructure

The QSAS Governance Model for Hydrogen, Decarbonisation and Cross-Border Market Trust



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Abstract

The global energy transition is increasingly constrained not by technological capability, but by governance fragmentation. Hydrogen production, renewable energy deployment, carbon management systems, sustainability reporting frameworks, and emerging international certification mechanisms continue to expand across jurisdictions. However, verification, traceability, regulatory interoperability, and cross-border recognition remain uneven throughout industrial value chains.

As hydrogen markets mature, confidence in production claims, emissions attributes, sustainability declarations, and compliance records is becoming a strategic requirement. Future competitiveness may therefore depend not only upon production capacity, but also upon the ability to establish trusted verification infrastructure capable of supporting domestic deployment and international market acceptance.

This paper introduces the Quantum Spectrum Allocation System (QSAS) as a governance architecture designed to support deterministic Measurement, Reporting and Verification (dMRV), sovereign hydrogen traceability, infrastructure-native compliance coordination, and cross-border interoperability. The framework proposes a transition from certificate-based assurance toward continuously verifiable industrial environments in which trust becomes embedded within operational systems.

Using India's evolving hydrogen ecosystem as a reference case, the paper examines how deterministic verification architectures may strengthen energy sovereignty, improve market confidence, support export readiness, and enable scalable decarbonisation pathways. The paper concludes that trusted verification infrastructure may become as strategically important to future energy systems as generation, storage, transportation, and logistics infrastructure themselves.

Executive Summary

The global hydrogen economy is entering a period of rapid development. Governments, industries, and investors are committing substantial resources toward renewable energy deployment, hydrogen production, industrial decarbonisation, and energy transition initiatives. Yet as hydrogen value chains become increasingly interconnected, the challenge of establishing trust across production, storage, transportation, certification, financing, and international trade is becoming more complex.

Current verification systems remain heavily dependent upon periodic reporting, certification schemes, retrospective audits, and fragmented compliance processes. While these mechanisms have supported early market development, they face increasing limitations as hydrogen ecosystems scale across multiple jurisdictions and regulatory environments.

This paper argues that the next stage of hydrogen market development requires verification infrastructure rather than verification administration. Deterministic Measurement, Reporting and Verification (dMRV) transforms verification from a periodic exercise into a continuous operational capability. Within this model, evidence is generated, validated, preserved, and assessed throughout the lifecycle of industrial activities.

The Quantum Spectrum Allocation System (QSAS) is proposed as a governance architecture capable of coordinating sovereign oversight, supervisory coordination, verification governance, industrial operations, market interoperability, and financial confidence within a common framework. The model is supported by the HygKen industrial trust infrastructure and complemented by the Hydrogen Verification Readiness Index (HVRI), a framework designed to assess the maturity of verification ecosystems alongside production readiness.

India's National Green Hydrogen Mission provides an important context in which these concepts can be examined. As India expands its hydrogen production capabilities and export ambitions, trusted verification infrastructure may strengthen competitiveness by improving regulatory confidence, supporting international recognition, and enhancing market trust.

The central proposition of this paper is straightforward: future hydrogen competitiveness will increasingly depend not only on who can produce hydrogen, but on who can verify it.

Keywords

Hydrogen; Energy Sovereignty; Deterministic MRV; Verification Infrastructure; Hydrogen Governance; Industrial Traceability; QSAS; Decarbonisation; Export Readiness; Cross-Border Recognition.

1. Introduction

The Emerging Governance Challenge of Energy Transition

The energy transition is often discussed through the lenses of technology deployment, emissions reduction targets, renewable energy expansion, and capital mobilisation. These factors remain fundamental to achieving global decarbonisation objectives. However, a less visible but increasingly important challenge is emerging alongside technological progress: governance.

Hydrogen production facilities, renewable power assets, carbon accounting systems, certification frameworks, logistics networks, sustainability reporting mechanisms, and international trade corridors are expanding simultaneously. Yet the governance structures responsible for coordinating these systems remain fragmented across jurisdictions, regulatory agencies, standards bodies, and market participants.

As industrial ecosystems become increasingly interconnected, a series of critical questions emerges. How can sustainability claims be independently verified? How can emissions

attributes be preserved throughout complex supply chains? How can compliance records remain credible across multiple regulatory environments? How can importing markets trust information generated thousands of kilometres away?

These challenges illustrate a broader reality. The energy transition is no longer solely a question of producing low-carbon energy. It is increasingly a question of establishing trusted mechanisms capable of coordinating verification, traceability, compliance, and market recognition across increasingly sophisticated industrial systems.

Hydrogen presents a particularly important case. Unlike conventional energy commodities, hydrogen markets require confidence not only in the physical product but also in the information associated with that product. Producers, regulators, financiers, certification bodies, and industrial consumers all require assurance regarding origin, sustainability characteristics, emissions intensity, and compliance status. Consequently, trust itself is becoming infrastructure.

Historically, trust has been established through contracts, institutions, standards, and regulatory oversight. While these mechanisms remain essential, future hydrogen ecosystems may require additional capabilities capable of maintaining verifiable continuity throughout the lifecycle of industrial activities. Verification therefore becomes more than an administrative function; it becomes a strategic enabler of market confidence and international competitiveness.

Within this context, deterministic verification architectures offer a potential pathway toward infrastructure-native trust. By embedding verification directly into industrial operations, such architectures seek to transform trust from a periodic outcome into a continuous capability. The Quantum Spectrum Allocation System (QSAS), explored throughout this paper, represents one proposed framework for achieving this objective.

2. India's Strategic Opportunity in Hydrogen Leadership

India is entering a decisive phase in its energy transition. Through the National Green Hydrogen Mission and broader decarbonisation initiatives, the country has positioned itself among the world's most ambitious emerging hydrogen economies. Unlike many jurisdictions that approach decarbonisation primarily as an environmental obligation, India increasingly views clean energy development as a strategic industrial opportunity capable of strengthening long-term economic resilience, energy security, and export competitiveness.

Several structural advantages support India's ambitions:

- First, India continues to expand renewable energy capacity at one of the fastest rates globally. Large-scale solar and wind deployments provide an increasingly attractive foundation for future hydrogen production pathways.
- Second, India benefits from strong public-sector energy institutions that possess decades of operational experience across production, transportation, storage, refining, and energy distribution. These institutions represent important foundations for future hydrogen ecosystem development.
- Third, India's industrial manufacturing base provides opportunities for hydrogen adoption across multiple sectors, including refining, fertilizers, steel production, chemicals, transportation, and heavy industry.
- Fourth, India's geographic position offers strategic access to emerging hydrogen trade corridors connecting South Asia, the Gulf region, Europe, and East Asia.

However, future hydrogen leadership will depend upon more than production capacity alone. International markets increasingly require confidence regarding sustainability claims, emissions characteristics, production pathways, and regulatory compliance. Hydrogen producers must therefore demonstrate not only their ability to produce low-carbon hydrogen, but also their ability to verify and communicate the integrity of that production.

This creates an opportunity for India to lead in both hydrogen production and hydrogen governance. As hydrogen markets mature, countries capable of combining production capability with trusted verification infrastructure may enjoy significant competitive advantages. Verification readiness, regulatory confidence, and cross-border recognition are likely to become increasingly important factors in international market access.

Within this context, deterministic verification architectures may provide a useful framework for strengthening India's position within emerging global hydrogen markets.

3. Why Conventional MRV Is Reaching Its Limits

Measurement, Reporting and Verification (MRV) frameworks have played a central role in supporting carbon management, emissions accounting, sustainability reporting, and environmental compliance initiatives. These frameworks have helped establish confidence in reported outcomes and provided important mechanisms for regulatory oversight.

However, hydrogen ecosystems introduce new levels of operational complexity. Production facilities, renewable energy assets, storage systems, transportation networks, certification bodies, financial institutions, regulators, and international markets increasingly interact within interconnected value chains. As a result, verification requirements extend beyond periodic reporting and isolated audit exercises.

Several limitations are becoming increasingly apparent. Verification often occurs after operational events have already taken place. Data reconciliation can become complex when multiple stakeholders maintain independent systems. Regulatory requirements may differ between jurisdictions. Certification methodologies may not always align across markets. Most importantly, continuity between production, transportation, export, and final utilization can be difficult to maintain. While conventional MRV remains necessary, it was not originally designed to support highly interconnected international hydrogen ecosystems. The challenge is therefore evolving from measuring emissions toward preserving trust across entire industrial lifecycles.

4. Deterministic MRV as Infrastructure

Deterministic Measurement, Reporting and Verification (dMRV) represents a structural evolution in how industrial verification can be approached. Rather than relying primarily upon periodic reporting and retrospective assessment, deterministic architectures seek to establish continuous evidence generation, validation, and preservation throughout operational environments.

Under this model, industrial activities generate verifiable evidence as they occur. Verification logic can be applied continuously. Compliance assessments become synchronized with operational processes. Auditability becomes embedded within infrastructure rather than dependent upon periodic reconstruction of historical events.

The objective is not merely improving reporting efficiency. The objective is creating trusted industrial environments in which relevant operational events can be measured, validated, and preserved throughout their lifecycle. Deterministic MRV therefore shifts verification from an administrative process toward an infrastructure capability.

As hydrogen ecosystems expand internationally, such capabilities may become increasingly important for supporting regulatory confidence, market acceptance, export readiness, and long-term competitiveness.

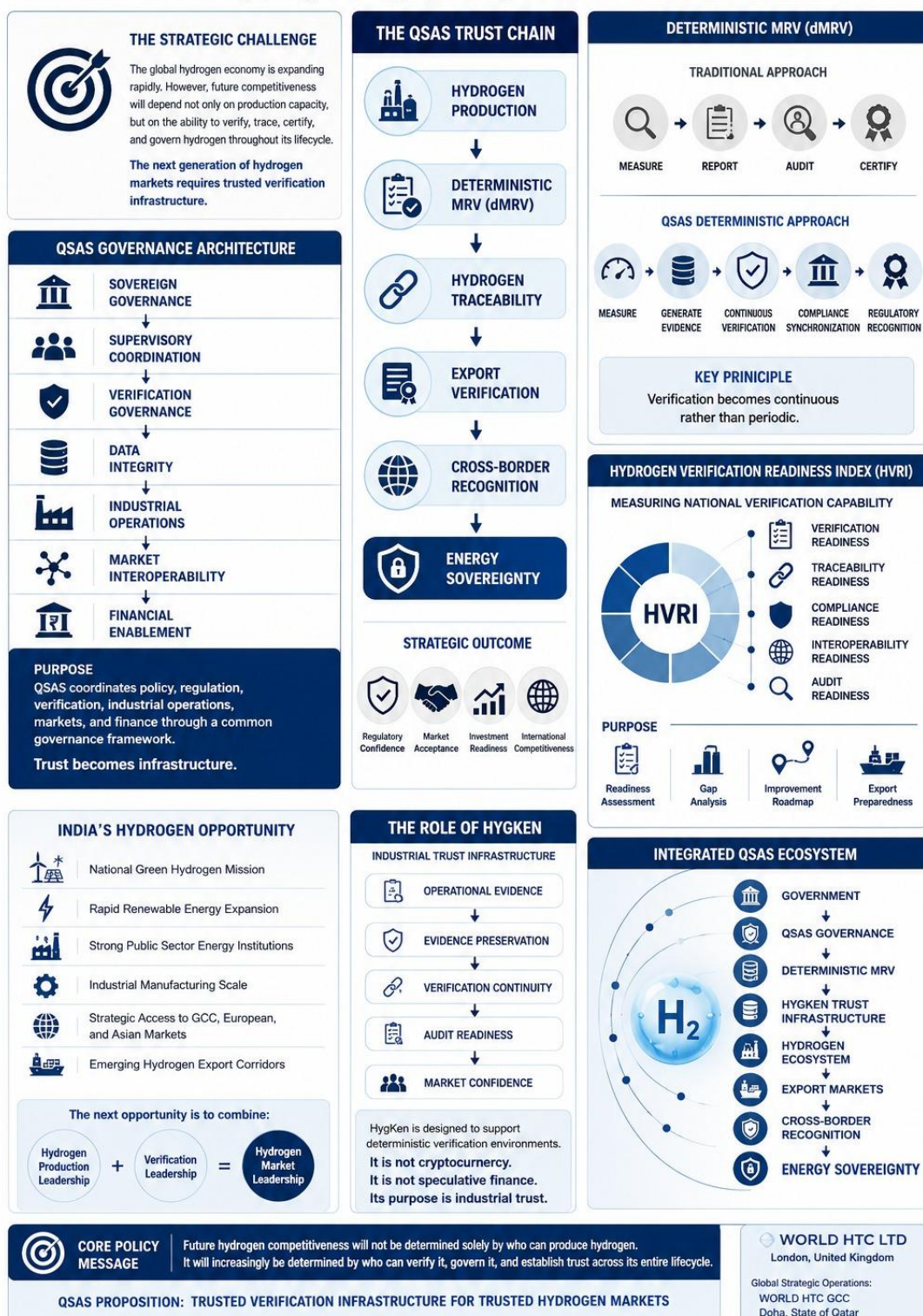
5. The QSAS Governance Model

The Quantum Spectrum Allocation System (QSAS) is proposed as a governance architecture designed to coordinate industrial operations, verification processes, regulatory requirements, and market expectations within a common framework.

QSAS does not seek to replace existing regulations, certification systems, or industrial control environments. Instead, it provides a coordination architecture through which these systems can operate within a shared verification environment.

QSAS FRAMEWORK FOR TRUSTED HYDROGEN ECOSYSTEMS

Institutionalizing Energy Sovereignty Through Deterministic Verification Infrastructure



The model is built upon several interconnected layers. At the highest level, sovereign governance establishes strategic policy direction, energy priorities, sustainability objectives, and national interests. Supervisory coordination enables alignment between regulatory authorities operating across environmental, industrial, transportation, financial, and trade domains.

Verification governance defines the rules, methodologies, and assurance mechanisms through which industrial activities are evaluated and recognized. The data integrity layer supports the preservation, consistency, and traceability of information generated throughout industrial operations. Industrial operations represent the physical hydrogen ecosystem itself, including production facilities, storage systems, transportation infrastructure, industrial consumers, and export environments.

Market interoperability supports continuity between domestic verification frameworks and international market requirements. This capability becomes increasingly important as hydrogen trade expands across multiple jurisdictions.

Finally, financial enablement connects trusted operational performance with investment confidence, financing mechanisms, and broader market participation.

A central principle underlies the entire architecture: Trusted markets require trusted infrastructure. Historically, trust has often been established through declarations, certifications, and institutional relationships. While these mechanisms remain important, future hydrogen ecosystems may increasingly depend upon operational environments capable of continuously generating and preserving evidence regarding industrial activities.

Within the QSAS framework, verification becomes an enabling capability that supports governance, industrial competitiveness, regulatory confidence, and market trust simultaneously. The result is a governance architecture designed to strengthen the relationship between operational reality and institutional confidence.

6. Sovereign Hydrogen Traceability

Hydrogen markets require more than production capability. They require confidence. As international hydrogen trade expands, importing jurisdictions, industrial consumers, certification bodies, financial institutions, and regulators increasingly require assurance regarding the origin, sustainability attributes, emissions characteristics, and compliance status of hydrogen throughout its lifecycle.

This requirement introduces a new strategic dimension to hydrogen competitiveness: traceability. Historically, energy markets have focused primarily on production, transportation, and delivery. Future hydrogen markets will increasingly depend upon the ability to maintain trusted continuity between physical hydrogen flows and the information associated with those flows.

The challenge extends beyond tracking movement. The objective is preserving confidence from production to final utilization.

Hydrogen may pass through multiple operational environments, storage facilities, transportation networks, export terminals, shipping systems, import infrastructures, and industrial consumers before reaching its final destination. Each stage generates information that contributes to the credibility of sustainability claims and compliance declarations.

Under conventional approaches, these records may be fragmented across different systems and organizations. As a result, continuity can become difficult to maintain.

Sovereign hydrogen traceability seeks to address this challenge by establishing verifiable continuity throughout the lifecycle of the hydrogen asset. Within a deterministic verification environment, operational activities generate evidence that remains linked across production, storage, transportation, export, import, and utilization. This continuous chain of evidence can support regulatory review, sustainability validation, certification processes, audit activities, and commercial transactions. Such capabilities strengthen confidence among producers, regulators, financiers, infrastructure operators, and international offtakers.

As hydrogen markets mature, traceability may become as important to competitiveness as production efficiency itself. The ability to demonstrate trusted continuity between operational reality and market claims is likely to become a defining characteristic of successful hydrogen-exporting economies.

7. PSU Deployment Logic for India

The transition from conceptual governance frameworks to operational hydrogen ecosystems requires practical deployment pathways. Within India, Public Sector Undertakings (PSUs) occupy a unique position within the national energy landscape and therefore provide an important reference environment for evaluating future verification architectures.

Organizations such as Indian Oil Corporation (IOC), Oil and Natural Gas Corporation (ONGC), Bharat Petroleum Corporation Limited (BPCL), and GAIL (India) Limited collectively operate across significant portions of the energy value chain. Their experience in production, transportation, storage, refining, distribution, and infrastructure management provides valuable institutional capability for supporting future hydrogen development.

This paper does not propose implementation by any specific organization. Rather, it presents an illustrative deployment perspective demonstrating how deterministic verification infrastructures may be evaluated within real-world industrial environments.

Hydrogen deployment introduces new requirements that extend beyond production technology. Verification, traceability, compliance coordination, export readiness, and cross-border interoperability all require institutional capability and operational integration.

A representative hydrogen value chain may include renewable energy generation, hydrogen production, storage systems, transportation networks, industrial utilization, export infrastructure, and international markets.

Within conventional models, these stages often operate through independent reporting and compliance mechanisms. Deterministic verification architectures seek to provide continuity across these environments by maintaining synchronized evidence and verification processes throughout the operational lifecycle. Potential benefits of pilot evaluation environments may include improved transparency, enhanced traceability, stronger compliance consistency, increased buyer confidence, and greater export readiness. For India, verification capability may become an increasingly important complement to production capability. The future hydrogen economy is unlikely to be defined solely by who can produce hydrogen. It may also be shaped by who can verify it with confidence.

8. Hydrogen Verification Readiness Index (HVRI)

As hydrogen ecosystems evolve, governments and industry stakeholders increasingly require mechanisms capable of evaluating not only production readiness, but also verification readiness. Most existing hydrogen readiness assessments focus on infrastructure development, production targets, renewable energy capacity, policy frameworks, and investment commitments. While these indicators remain important, they do not fully address a critical question:

How prepared is a hydrogen ecosystem to verify itself? The Hydrogen Verification Readiness Index (HVRI) is proposed as a conceptual framework designed to assess the maturity of verification infrastructure within hydrogen ecosystems.

The framework evaluates five interrelated dimensions. The first is Verification Readiness, which examines the ability of an ecosystem to generate, validate, and preserve evidence regarding industrial activities and sustainability claims. The second is Traceability Readiness, which evaluates continuity throughout the hydrogen lifecycle and the ability to maintain trusted information flows across operational environments. The third is Compliance Readiness, which considers alignment with regulatory requirements, certification frameworks, and supervisory expectations. The fourth is Interoperability Readiness, which assesses the ability of systems to support recognition across jurisdictions, standards, and market environments. The fifth is Audit Readiness, which evaluates evidence preservation, transparency, accountability, and review capability. Together, these dimensions provide a structured perspective on governance maturity within hydrogen ecosystems.

The purpose of HVRI is not to establish a universal ranking system. Rather, it provides a framework through which strengths, weaknesses, risks, and development priorities can be identified. For governments, HVRI may support policy evaluation and infrastructure planning. For regulators, it offers a governance-oriented perspective on verification capability. For investors, it may provide additional insight into institutional readiness and risk management. For exporters, it highlights factors influencing international recognition and market acceptance.

The central proposition of the framework is straightforward: Hydrogen competitiveness depends not only upon production readiness, but also upon verification readiness. As hydrogen markets become increasingly global, the ability to establish trusted verification environments may become a defining characteristic of successful hydrogen economies.

9. Hydrogen Export Competitiveness

The emergence of hydrogen as an internationally traded energy commodity is reshaping the relationship between energy production, industrial policy, and global trade. While production capacity and cost competitiveness remain important, future hydrogen markets are increasingly expected to evaluate suppliers on a broader set of criteria that includes sustainability assurance, traceability, verification integrity, and regulatory confidence.

In this evolving environment, export competitiveness is becoming closely linked to trust. Historically, energy commodities have been traded primarily on the basis of availability, quality, logistics, and price. Hydrogen introduces additional dimensions. Buyers increasingly seek confidence regarding production pathways, emissions intensity, renewable energy sourcing, environmental attributes, and compliance with certification requirements.

The challenge is therefore not only producing hydrogen at scale. The challenge is demonstrating, with confidence, that hydrogen meets the expectations of increasingly sophisticated international markets. This trend is particularly relevant to three strategically important regions.

The Gulf Cooperation Council (GCC) is rapidly expanding its role within the hydrogen economy through investments in production capacity, industrial decarbonisation, logistics infrastructure, and export corridors. For India, the GCC represents both a potential export destination and a strategic partner in future hydrogen trade.

The European Union continues to develop comprehensive hydrogen certification and sustainability requirements. Producers seeking access to European markets increasingly need to demonstrate transparent verification, lifecycle traceability, and credible sustainability assurance.

East Asian economies, including Japan, South Korea, and Singapore, are pursuing hydrogen strategies that place strong emphasis on reliability, quality assurance, and long-term supply security. These markets are likely to reward suppliers capable of providing trusted information alongside physical product delivery.

As hydrogen trade expands internationally, verification continuity becomes increasingly important. Hydrogen may pass through multiple jurisdictions, transportation systems, certification environments, and regulatory frameworks before reaching final consumers. Without continuity, information integrity can become fragmented. Deterministic verification architectures seek to address this challenge by preserving evidence and maintaining trusted information flows throughout the lifecycle of the hydrogen asset.

In this context, export competitiveness should be viewed not only as a function of production economics, but also as a function of governance capability. Future hydrogen markets may ultimately reward those producers capable of demonstrating both operational excellence and verification excellence.

10. HygKen as Industrial Trust Infrastructure

The effectiveness of any verification architecture ultimately depends upon the integrity, continuity, and accessibility of the information it relies upon. As hydrogen ecosystems expand across multiple organizations, jurisdictions, and regulatory environments, preserving trust in industrial information becomes increasingly important.

Within the QSAS governance framework, this role is performed by HygKen. HygKen is proposed as an industrial trust infrastructure designed to support evidence preservation, verification continuity, traceability, and auditability across complex operational environments. Its purpose is not cryptocurrency, speculative finance, or decentralized trading. Its purpose is industrial trust.

Hydrogen ecosystems generate large volumes of information, including production records, measurement data, sustainability attributes, compliance evidence, certification documentation, transportation records, and audit materials. The value of this information depends not only on its accuracy when generated, but also on its ability to remain trustworthy over time. HygKen supports this requirement by maintaining continuity between operational activities and verification outcomes. Within such environments, industrial evidence can remain synchronized across multiple stakeholders, reducing fragmentation and supporting transparency throughout the lifecycle of industrial operations.

As hydrogen ecosystems become increasingly data-intensive, trusted information environments may become essential components of governance architecture. Verification requires more than data storage. It requires confidence in the integrity of evidence itself.

11. Conclusion

The global energy transition is entering a new phase defined not only by technological innovation, but by institutional capability. Hydrogen production, renewable energy deployment, industrial decarbonisation, and sustainability initiatives continue to expand worldwide. Yet as these systems become increasingly interconnected, the ability to verify, trace, and govern industrial activity is emerging as a strategic challenge.

This paper has argued that future hydrogen competitiveness will depend not only upon production capacity, but also upon trusted verification infrastructure.

Deterministic Measurement, Reporting and Verification (dMRV) provides one pathway toward infrastructure-native trust by embedding verification directly into industrial operations. The Quantum Spectrum Allocation System (QSAS) has been presented as a governance architecture capable of coordinating sovereign oversight, industrial activity, verification processes, regulatory requirements, and market expectations within a common framework.

The Hydrogen Verification Readiness Index (HVRI) extends this concept by introducing a structured approach for evaluating verification maturity alongside production readiness. For India, these developments carry particular significance. As the National Green Hydrogen Mission advances and international hydrogen trade expands, trusted verification infrastructure may strengthen competitiveness, improve market confidence, support export readiness, and contribute to long-term energy sovereignty.

The central proposition of this paper is therefore straightforward: The next generation of energy infrastructure must include verification infrastructure. Hydrogen competitiveness will increasingly depend not only on who can produce clean energy, but on who can prove it.

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The 80% Your AI Agents Can't Skip Data Readiness Is Where Agentic AI Succeeds or Fails in Process Industries



dDriven Solutions Pte Ltd

Partha Ray

Artificial Intelligence — particularly the emerging class of autonomous AI agents — is being positioned as the next great lever for operational efficiency and margin improvement in oil and gas.

The promise is compelling: agents that advise you on planning your next major turnaround, flag risks, advise you on optimal crude basket, help you on prepare capital & revenue budget, flag over/under utilization of current budget, suggest how to minimize quality-give-away, autonomously manage inventory across terminals, and even navigate demurrage windows without constant human intervention.

Yet behind this promise lies an inconvenient reality. The vast majority of AI projects fail not because of inadequate algorithms or insufficient CPU / GPU / NPU power. They fail because the data these agents depend on is simply not ready. This article examines why data readiness — not AI model sophistication — is the true determinant of AI success in process industries.

The Agentic AI Gold Rush

The adoption numbers are staggering. Close to 80% of companies have deployed AI agents in some form. Gartner projects that 40% of enterprise applications will embed AI agents by end of 2026. The agentic AI market is projected to reach nearly \$11 billion this year, and nearly nine out of ten executives plan to increase their AI budgets.

In our industry, this translates to refineries piloting AI-driven crude evaluation, petrochemical complexes experimenting with yield optimisation agents, and gas processing plants exploring predictive maintenance agents for compressors and heat exchangers. The enthusiasm is real — but enthusiasm and capital allocation are not the same as business value delivery.

The Agentic AI Gold Rush

Everyone is building AI agents. The numbers are staggering.

79%

of companies have deployed AI agents in some form

40%

of enterprise apps will embed AI agents by end of 2026

\$10.9B

projected agentic AI market size in 2026

88%

of executives plan to increase AI budgets

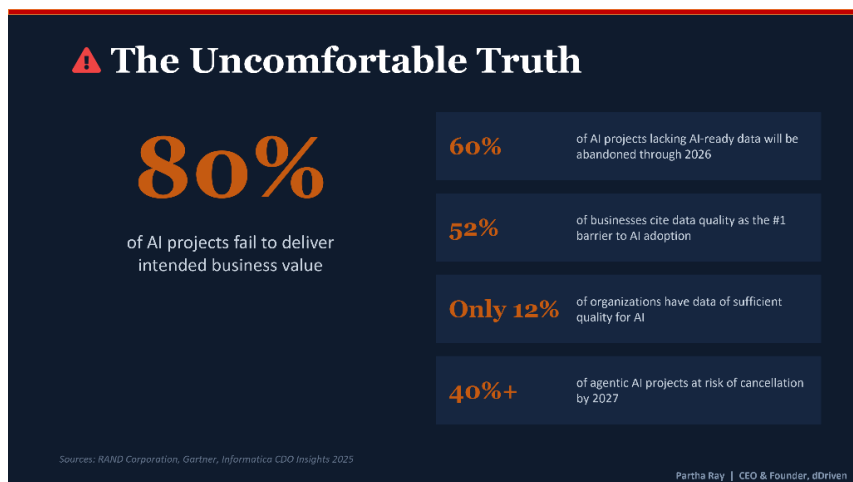
Sources: Gartner, Precedence Research, NVIDIA State of AI 2026

Partha Ray | CEO & Founder, dDriven

The Uncomfortable Truth

Despite this surge, failure rates remain alarmingly high. Research by RAND Corporation and others consistently shows that approximately 80% of AI projects fail to deliver intended business value. Gartner warns that **60% of AI projects lacking AI-ready data will be abandoned** through 2026. Over half of businesses cite data quality as their number one barrier, and only about 12% of organisations have data of sufficient quality for AI at scale. For oil and gas, these statistics carry particular weight. With refining margins often in the \$3–8 per

barrel range, a confidently wrong AI recommendation on crude slate, blend optimisation, or inventory positioning can translate to millions of dollars in margin erosion within days. The stakes for getting data right are not academic — they are operational and financial.



It's Not the Model. It's the Data.

You can buy the best catalytic cracker in the world. But if you feed it contaminated crude, you get contaminated product; i.e. GIGO – Garbage in garbage out. AI is the multiplier; with bad data it only “Generates” hallucination.

Where Companies Invest

70% of AI budget → Models & algorithms	✗
15% → Infrastructure & compute	✗
10% → Talent & training	✗
5% → Data readiness	✗

What Causes Failure

85% cite poor data quality	✓
63% lack proper data management	✓
Only 48% of AI projects reach production	✓
Data remediation costs 2.8x more later	✓

The lesson: Budget ~ 50% of AI resources for data work. Not 5%.

Partha Ray | CEO & Founder, dDriven

It's Not the (AI / LLM) Model. It's the Data.

Consider a simple analogy from your own operations: you can install the most advanced catalytic cracker in the world, but if you feed it contaminated crude, you get contaminated product. Garbage in, garbage out has governed process engineering for decades.

AI amplifies this principle — a sophisticated model operating on poor data does not merely produce poor results; **it produces poor results with high confidence, i.e., hallucinations.**

Yet roughly **70% of AI budgets go toward models and algorithms**, 15% toward infrastructure, 10% toward talent, and **only about 5% toward data readiness**. Meanwhile, 85% of failed projects cite poor data quality as the root cause, and remediation after the fact costs nearly three times as much as getting it right from the start. The lesson: allocate approximately **50% of AI resources to data work**. Not 5%.

What “Agent-Ready Data” Actually Means

Think of AI agents as exceptionally brilliant new hire arriving on Day 1 at your refinery. Before they can contribute anything, they need access to the right information, that information must be trustworthy and consistent, and it must come with operational context — understanding that a specific pressure reading belongs to a specific reactor, tied to a specific product grade and customer commitment.

Agent-ready data has five characteristics. It must be **accessible**: retrievable from across OT and IT without navigating silos. **Trustworthy**: cleansed, validated, homogenised, and harmonised. **Contextualised**: bound with the CFO's chart of accounts hierarchy, the operations manager's asset hierarchy, and the commercial team's regional structures. **IT/OT agnostic**: unified data from historians, DCS, SCADA, IoT, SAP, ETRM and the entire MES stack (LIMS, PIMS, HYSIS, etc.). And **fresh**: synchronised with the current state of the enterprise across finance, production, inventory, logistics, and market conditions. This is the boring 80% of the work. This is what most companies skip. **We call this foundation an Enterprise Data Twin** — a unified, contextualised, continuously refreshed digital representation of the enterprise's data.

The Industrial Data Challenge

In process industries, the data problem is an order of magnitude harder than in typical enterprise IT. A production or process complex has three data worlds. The OT world, the MES world and the IT world.

AI agents need one unified data layer across these three worlds — not three segregated kingdoms with different languages, timestamps, hierarchies, and owners. And to be clear: a unified data layer is not a data lake. The data lake

concept - popular in IT circles — is essentially a dump. Imagine your EPC contractor has delivered every vessel, pipe, tower, valve, motor, and heat exchanger to your site and simply unloaded them in the yard. That is your data lake. It is all there, but nothing is connected, nothing flows, and nothing produces. A unified data layer is what you have after piping, cabling, instrumentation, and commissioning are complete — when you can trace the path from the crude oil entering your CDU to the cracked diesel in your product tank to the HSD loaded onto the truck. Building this connected, contextualised data layer — is precisely the work that most AI roadmaps underestimate.



The Data Readiness Architecture

From raw chaos to agent-ready intelligence: The Medallion Architecture pathway



The Key Insight: Most companies try to jump straight from Bronze to deploying AI agents. That's like hiring a new analyst and handing them a box of unsorted receipts of last 10 years from 500 different types of retail outlets. Each layer exists because the next one depends on it. Skip a layer, and your agent hallucinates, fails silently, or — worst case — makes confidently wrong decisions that cost millions.

KPIs, key operating parameters, and critical process variables. Diamond serves as the feature store for machine learning applications. The AI feeds on Gold & Platinum layers.

The key insight: most companies jump straight from Bronze to deploying agents. That is like hiring a new analyst and handing them ten years of unsorted receipts from 500 retail outlets, expecting a margin analysis by evening. Each layer exists because the next one depends on it. Skip a layer, and your agent hallucinates, fails silently, or makes confidently wrong decisions that cost millions.

Five Questions Every CEO Must Ask

- **First:** Can our AI agent access all data it needs — OT and IT — in the right time? Furnace temperatures every minute, inventory and dispatches every 15 minutes, the up to date financials daily.

If the answer involves manual extracts, the agent is already working blind.

- **Second:** Is our data homogenised, harmonised, and **contextualised** — or are we feeding raw chaos into a sophisticated model?

- **Third:** Do we have a unified data layer, or are we asking agents to navigate fifteen disconnected systems? Do ETL and relate sales order, nomination, dispatch note, blend batch, certification, etc. If the answer is yes, you are doomed.
- **Fourth:** What percentage of our AI budget goes to data readiness versus model development? If less than 50%, you are building on sand.
- **Fifth:** Can we measure what our AI agent actually changed in operations — in monetary terms? If you or your AI agent (Yes, we can make the agents do that) cannot measure it, we are running an experiment, or a technical PoC.

The Data / Fundamental -First Playbook

The companies that succeed follow a deliberate three-phase sequence.

Phase 1 — Data Foundation: unify OT, IT, MES, and unstructured data into a single, contextualised, continuously refreshed Enterprise Data Twin.

This phase is not glamorous, but it determines whether everything that follows will succeed or fail.

Phase 2 — AI Framework: build the scaffolding around the large language model — guardrails, harness, API layer, and user interface. AI does not work in a vacuum, just as your best process engineer cannot work without access to the DCS process flow diagrams, process / product quality results, SOPs, etc.

Phase 3 — Agent Deployment: only now deploy agents for specific, measurable outcomes — optimising inventory, reducing working capital, minimising demurrage, improving energy efficiency. Because the data foundation is complete, use-case / purpose agnostic (you can ask any question, assign any task) and the framework is in place, these agents deliver results that are trustworthy, measurable, and sustainable.

The sequence matters. Companies that skip Phase 1 invariably enter a costly cycle of remediation, rework, and disillusionment — **which is precisely why 80% of AI projects fail to deliver value.**

Conclusion

Every company in our industry wants AI agents. The vision of autonomous systems that optimise operations and unlock margin is achievable — but only when built on the right foundation. That foundation is data readiness. **It represents roughly 80% of the work, yet receives barely 5% of the budget.** Closing this gap is not a technology problem; it is a leadership problem. The AI agents will come, the models will keep getting better. But the enterprises that win will be those that got their fundamentals right first.

Mr. Partha Ray - From hands-on plant floor engineer to multi-country P&L head to Intrapreneur to finally, Entrepreneur - Founder of dDriven Solutions Pte Ltd / dDriven Data Sciences & Analytics Pvt Ltd. - Partha Ray, a technology leader with over 30 years of deep expertise in industrial automation, IT/OT convergence, and enterprise intelligence and analytics. Partha previously served as Vice President – Asia at Siemens (Singapore), where he conceptualised and scaled their enterprise intelligence and analytics business across the Asia-Pacific region — a testament to both his entrepreneurial drive and enterprise-grade execution capability. dDriven is a technology company with a proven track record of delivering enterprise-grade AI/ML transformation projects in India and internationally.

5 Questions Every CEO Must Ask

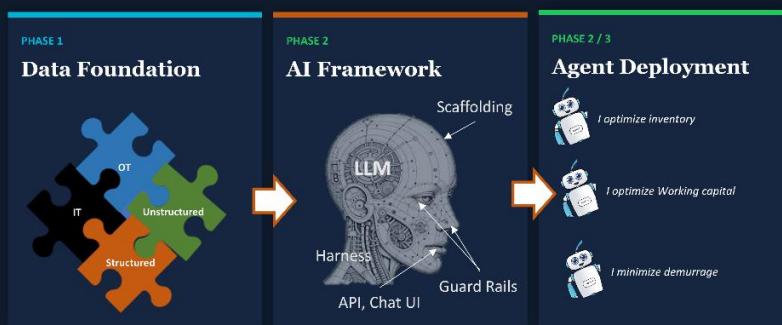
Before spending another dollar on AI agents

- 1** Can our AI agent access ALL the data it needs — OT and IT — in real / Right time time?
Furnace temperature every minute, inventory every 30 minutes, dispatches every shift, sales, payable, receivables daily, etc.
- 2** Data homogenized, harmonized and contextualized — or are we feeding raw chaos into a sophisticated model?
Garbage in, hallucination out.
- 3** Do we have a unified data layer, or are we asking agents to navigate 15 disconnected systems?
Agents do not navigate through politics between departments.
- 4** What percentage of our AI budget goes to data readiness vs. model development?
If it's less than 50%, you're building on sand.
- 5** Can we measure what our AI agent actually changed in operations — in dollars?
If you can't measure it, you're running an experiment, not a business — compare trend of your KPIs before and after, calculate impact, or ask the Agent to do it.

Partha Ray | CEO & Founder, dDriven

The Fundamental (i.e., Data) -First Playbook

What the 20% who succeed actually do differently:



AI does not work in vacuum, just like your most brilliant engineer cannot work without a PC, access to DCS PFD, LIMS results, SOP, etc.

Very simple and approximate metaphors are used for explanation purposes only

Partha Ray | CEO & Founder, dDriven

Transnational Deep-Water Gas Pipelines: A Strategic imperative for Viksit Bharat



Pankhuri Goyal

Federation of Indian Petroleum Industry

As India targets "Viksit Bharat" by 2047, securing an uninterrupted, affordable, and clean energy supply is paramount. To honour its climate commitments while sustaining rapid GDP growth, the Government of India aims to increase the share of natural gas in its primary energy mix. This expansion is driven by escalating demand in the City Gas Distribution (CGD), fertilizer, and power sectors. However, stagnant domestic production has forced reliance on volatile and imported Liquefied Natural Gas (LNG). This article evaluates the strategic significance of deep-water transnational pipelines—specifically bypassing traditional geopolitical chokepoints like the Strait of Hormuz and acting as an alternative to RLNG, while analysing the critical challenges to its development.

Introduction & The Demand-Supply Paradox

India's transition toward a sustainable, low-carbon economy relies heavily on natural gas as a critical bridge fuel, which emits roughly 35% less carbon than coal according to the IEA's "Global Methane Tracker 2025" report. It is highly versatile—serving as an efficient energy source for industries, cooking, transportation, and electricity generation, while also acting as a vital feedstock for fertilizer production. Furthermore, its seamless compatibility and ease of conversion with emerging alternative fuels make it uniquely suited to bridge the gap toward a sustainable energy future.

However, because domestic production remains structurally constrained, India is forced to import over half of its natural gas as maritime LNG. Despite developing a robust network of eight major regasification terminals with a combined capacity exceeding 52 MT per year, this physical infrastructure cannot shield the economy from the volatile spot market or maritime vulnerabilities, particularly the recent disruptions in the strategic Strait of Hormuz chokepoint. Any instability in these shipping corridors directly threatens India's macroeconomic landscape through sudden price hikes, cargo delays, and industrial inflation. Consequently, diversifying India's energy architecture via deep-sea transnational pipelines from the Middle East emerges as a vital strategic necessity, providing the long-term price stability, supply continuity, and geographic risk mitigation required to sustain national industrial competitiveness.

Middle East-India Deepwater Pipeline (MEIDP): Oman - India Transnational gas Pipeline

The proposed Oman - India transnational pipeline represents a strategically important concept in India's long-term energy security architecture. The project

broadly envisions an undersea deep-water natural gas pipeline connecting Oman to India through the Arabian Sea, potentially bypassing some of the geopolitical and maritime vulnerabilities associated with conventional LNG shipping routes.

The Middle East-India Deepwater Pipeline (MEIDP) combines a tariff-based, open-access commercial model with advanced deep-sea engineering to deliver a secure natural gas supply route to India. With a designed throughput of approximately 31 MMSCMD, this infrastructure could be a boon for India's energy security.

Benefits of the MEIDP to India

The Middle East-India Deepwater Pipeline (MEIDP) serves as a strategic energy corridor, offering four critical advantages to India's energy landscape:

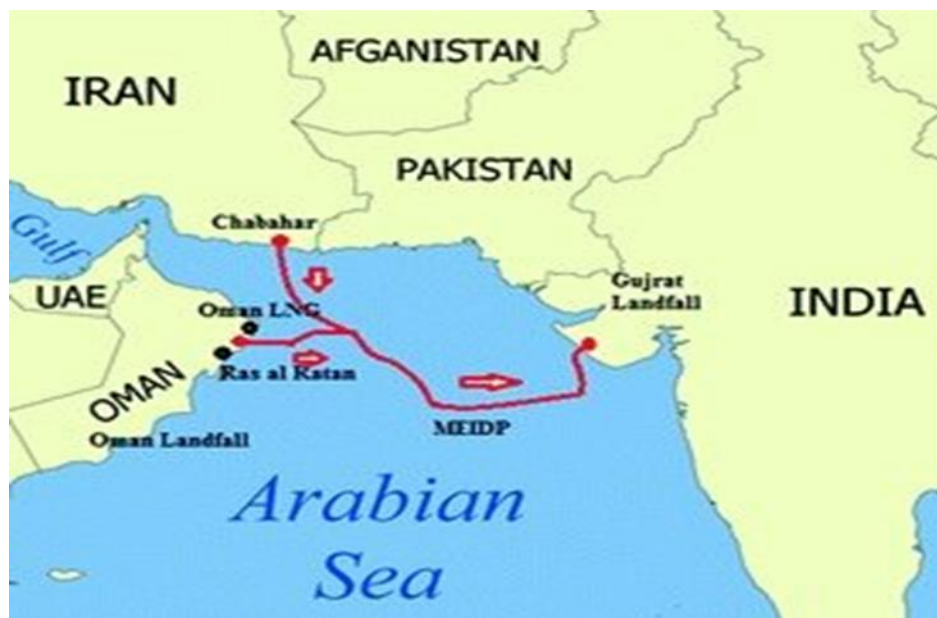
- **Revitalizing Gas-Based Power Generation**

Gas-based power plants in India have historically operated at low utilization levels due to high RLNG prices and inadequate domestic gas availability. MEIDP provides the affordable volume needed to bridge this deficit and restore dormant power capacity.

- **Lower Landfall Gas Prices**

By bypassing expensive shipping, regasification processes, and volatile transit routes like the Strait of Hormuz, MEIDP will deliver cheaper gas directly to Gujarat. These lower input costs shield consumers from global LNG price spikes and stimulate demand in price-sensitive sectors, thereby creating a demand-pull effect.

Figure: - Oman – India Under sea pipeline



Source- Indian Infra Report

- **Sustaining the CGD Growth Trajectory**

According to PNGRB, with CGD demand projected to grow at a 15% CAGR (from 36.9 MMSCMD in 2024 to 87.1 MMSCMD by 2030), stagnant domestic production forces an unsustainable reliance on costly RLNG. MEIDP provides the affordable, baseload gas vital to keeping the expanding CGD ecosystem economically viable.

- **Enabling Greenfield Projects**

Major industries (fertilizers, petrochemicals) require stable, 15–20-year feedstock pricing to secure investment bankability. MEIDP's long-term contracted volumes provide this certainty, unlocking capital for new domestic manufacturing plants aligned with India's growth and manufacturing visions.

Strategic Significance of Transnational Pipelines for India

- **Long-Term Strategic Interdependence thus ensuring energy security**

Transnational cross-border gas pipelines represent a critical mechanism for long-term strategic interdependence, offering far greater energy security, price stability, and supply predictability than volatile maritime LNG imports. By locking supplier and consumer nations into multi-decadal diplomatic partnerships, fixed pipeline infrastructure inherently minimizes geopolitical risks. A prime example of this dynamic is the Central Asia–China Gas Pipeline, which transports over 40 bcm of natural gas

annually from Turkmenistan and Uzbekistan to fulfil roughly 19% of China's domestic consumption. This pipeline successfully diversified China's energy imports away from maritime chokepoints like the Strait of Malacca, while simultaneously providing Central Asian states with reliable, non-Russian revenue streams and deepening regional diplomatic ties.

For India, similar transnational pipeline arrangements could strengthen long-term energy security by ensuring stable gas supplies, diversifying import routes, and reducing exposure to volatile global LNG markets and maritime disruptions.

- **Reduce exposure to LNG spot market volatility**

The post-2022 global gas crisis highlighted the risks of excessive dependence on LNG spot markets. Following disruptions in Russian gas supplies to Europe after the Russia–Ukraine War, European countries sharply increased LNG imports, causing global spot LNG prices to surge and severely affecting import-dependent Asian economies with inflated freight, soaring insurance premiums, and procurement uncertainty.

For India, which relies heavily on Gulf-derived LNG, these maritime disruptions directly threatened the financial viability of key sectors like fertilizers, petrochemicals, glass manufacturing, and City Gas Distribution

(CGD). As India aggressively pushes to increase natural gas, long-term transnational pipeline projects, such as the MEIDP, offer a vital strategic alternative. By utilizing dedicated subsea infrastructure governed by stable, long-term contractual frameworks, pipelines effectively insulate the domestic economy from seafaring chokepoint vulnerabilities and spot-market shocks, establishing a predictable and resilient long-term energy architecture.

- **Strategic Relevance for India's Industrial Competitiveness**

Securing a reliable and affordable supply of natural gas via transnational pipelines is a critical driver of India's macroeconomic stability and industrial competitiveness. By reducing input-cost volatility, stable pipeline-based imports shield key sectors—including fertilizers, petrochemicals, refining, steel, ceramics, and heavy manufacturing—from global energy shocks. This pricing predictability enhances long-term corporate planning and boosts export competitiveness, while directly easing the government's fiscal burden by lowering domestic fertilizer subsidies.

It would also open new opportunities for gas-based industries, city gas networks, hydrogen blending and future clean energy transitions. In this context, transnational pipelines are not merely energy infrastructure assets but potential enablers of long-term industrial growth, energy transition, and economic resilience.

- **Strait of Hormuz and the relevance of MEIDP**

The Strait of Hormuz is one of the world's critical maritime chokepoints, facilitating the transit of approximately 20% of global petroleum and one-fifth of the world's liquefied natural gas (LNG). The Strait of Hormuz is currently embroiled in its most severe supply crisis in history. Following the outbreak of the US-Israel conflict with Iran, shipping traffic through this vital chokepoint has collapsed by over 90% due to military blockades, drone strikes on commercial vessels, leaving hundreds of ships stranded and choking global oil and LNG flows.

The severe disruption of the Strait of Hormuz has triggered an acute natural gas crisis for India, driving Asian spot LNG prices up by 90% and forcing a costly restructuring of energy basket. Because India used to get most of its natural gas from Qatar through this shipping route, the current blockade has caused major supply shortages. This severe price shock heavily exacerbates India's fiscal deficit causing the Indian rupee to plummet to record lows and

heavily draining foreign exchange reserves as import bills skyrocket. To mitigate this unprecedented vulnerability, India has been forced to aggressively ration domestic gas, and reroute crude supplies via non-Hormuz pathways. This underscores the urgent economic case for the Middle East-India Deepwater Pipeline (MEIDP). By bypassing the volatile waterway entirely through a 2,000-kilometer undersea route from Oman directly to the coast of Gujarat at water depths somewhere up to 3,450 meters, the MEIDP offers India a secure, cost-competitive energy corridor.

- **Potential Integration with Regional Energy Corridors**

Cross-border energy infrastructure can complement emerging regional connectivity initiatives by integrating energy trade with transport, logistics, manufacturing, and industrial development. For example, China integrated the Central Asia-China Gas Pipeline network with transport and industrial connectivity under the Belt and Road Initiative. Beyond securing gas supplies, the corridor boosted regional trade, infrastructure investment, and industrial cooperation between China and Central Asian economies.

For India, transnational pipelines could complement regional integration frameworks. It could support the development of petrochemical hubs, fertilizer plants, industrial clusters, and logistics corridors alongside transport infrastructure, thereby strengthening regional economic integration and long-term industrial growth.

Economic Aspects of Transnational Gas pipelines vis-a-vis LNG imports

The feasibility of a transnational subsea pipeline depends heavily on economics, seabed depth, route complexity, geopolitical stability, and long-term supply security. While subsea pipelines involve very high upfront capital expenditure, they become strategically viable when LNG imports become substantially more expensive, volatile, or operationally constrained due to geopolitical disruptions, maritime insecurity, or supply-chain bottlenecks.

The cost of subsea pipelines increases sharply with:

- Ultra-deep-water construction requirements
- Seismic and seabed terrain complexity
- Compression and maintenance infrastructure
- Long-distance offshore engineering challenges
- Corrosion protection and operational safety systems

However, despite these costs, pipeline infrastructure can become economically attractive over the long term because transnational pipeline gas generally offers:

- Lower transportation costs per unit after commissioning
- Stable long-term pricing mechanisms linked to contractual agreements
- Reduced exposure to spot LNG volatility
- Limited dependence on shipping availability, freight rates, and tanker disruptions
- Reduced regasification and liquefaction costs compared to LNG supply chains

According to PNGRB, considering, Liquefaction, Transportation & Re-gasification costs of R- LNG, which is about USD 4.5-5/ mmbtu, gas from MEIDP pipeline would be cheaper by USD 2.0–2.5/mmbtu.

Middle East as a Long-Term Gas Source for India

Given the enormous capital intensity of subsea pipelines, it becomes essential to connect India only with countries possessing sufficiently large and commercially sustainable gas reserves capable of ensuring reliable multi-decade supply commitments. Therefore, India's potential transnational pipeline partnerships must necessarily focus on countries possessing:

- Large proven natural gas reserves
- Stable long-term production potential
- Export-oriented energy infrastructure
- Geographical proximity to India
- Relatively reliable geopolitical and diplomatic relationships

Immense Reserve Capacity: Leading producers such as Qatar, Saudi Arabia, the UAE, and Oman command a massive share of global natural gas reserves, backed by highly developed, export-oriented infrastructure capable of securing multi-decade supply commitments.

Optimal Geographical Proximity: Located significantly closer to India's western coastline than suppliers in Africa, Europe, or the Americas, the Gulf region offers shorter transit distances. This proximity directly improves project economics by lowering operational costs and reducing transit energy losses.

Deep Strategic Alignment: The Gulf region already forms the backbone of India's crude oil and LNG imports. Transitioning from transactional maritime trade to permanent subsea pipeline connectivity would deepen this existing commercial cooperation into long-term, structural interdependence between India and West Asian energy majors.

Challenges in the Development of Transnational Gas Pipelines

Transnational gas pipeline projects are inherently complex undertakings that face multifaceted challenges spanning political, financial, technical, and legal domains.

- **Geopolitical and Security Considerations:** These remain a primary constraint, as proposed routes frequently traverse regions characterized by political volatility and security concerns. The involvement of countries with histories of instability introduces significant operational risk, compromising the long-term security of energy supply and infrastructure integrity.
- **Regulatory Challenge:** A fundamental challenge to transnational gas pipelines is the need for effective, stable, and fair domestic regulation in every participating country. The viability of such project rests on the presence of an independent regulator that is legally and organizationally distinct from participating governments and utilities, with a clearly defined mandate, and ensure transparent and efficient procedures.
- **Financial Structuring:** This includes capital-intensive nature of deep-sea and cross-border infrastructure. Mobilizing investment requires government assurances on long-term tariff frameworks, guaranteed offtake commitments, and contractual stability.
- **Commercial Sustainability:** This is contingent upon robust market fundamentals, including well-defined tariff structures, and stable projections of long-term demand growth.
- **Engineering and Technological Demands:** These are amplified in deep-sea contexts, necessitating advanced solutions for high-pressure operations, corrosion mitigation in marine environments, real-time monitoring systems to ensure asset integrity & environmental safety.
- **Legal Coordination:** Legal coordination across multiple jurisdictions presents further complexity. Harmonization of environmental standards, transit fee regimes, taxation policies is essential.

Risk assessment of the MEIDP

The MEIDP carries risk dimensions that require structured mitigation-

- **Construction & Engineering:** Traversing 3,000–3,500m depths exposes the pipeline to seabed instability, landslides, tectonic activity, extreme hydrostatic pressure, thermal cycling, and saline-induced material fatigue.

- **Operations & Maintenance:** Limited subsea access complicates leak detection, rupture response, and routine inspection.
- **Environmental:** Arabian Sea cyclones, storm surges, seismic events, potential methane leakage pose ecological threats.
- **Capex Overruns:** Offshore projects face cost escalations often due to time overruns and unforeseen technical challenges.
- **Currency & Payment Risks:** Fluctuations in currencies of participating nations can destabilize revenues.
- **Regional Dependencies:** Success depends on alignment between participating countries.

Risk Mitigation Strategies- To effectively de-risk the project across technical, financial, and geopolitical dimensions, the following mitigation framework may be considered:

- **Technical & Environmental Resilience:** Conduct detailed geotechnical surveys to ensure slope and seismic stability. Implement robust Environmental Impact Assessments (EIAs), utilize cyclone-resilient designs etc to manage environmental risks.
- **Commercial & Structural De-risking:** Deploy modular EPC (Engineering, Procurement, and Construction) contracts to control execution timelines. Financial viability is secured through long-term take-or-pay agreements featuring flexible pricing formulas linked to global benchmarks like Brent, Henry Hub, and JKM.
- **Financial & Currency Safeguards:** Structuring transactions in USD/EUR, utilizing targeted currency hedging, implementing secure escrow mechanisms to guarantee payment security.
- **Geopolitical & Sovereign Alignment:** Leverage deeply anchored bilateral ties, particularly India's strong trade, defense, and energy partnerships with Oman and the UAE. Securing anchor investments from National Oil Companies (NOCs) and global gas majors provides vital sovereign backing to de-risk project execution.

Conclusion

In conclusion, as India pursues its macroeconomic goal of increasing the share of natural gas in its primary energy mix, the structural limitations of relying solely on maritime LNG imports become glaringly evident. Thus, in order to become Viksit Bharat by 2047, requires a massive, uninterrupted volume of baseload gas that simply cannot be sustained by a highly volatile, choke-point-dependent, and expensive seaborne spot market. Transnational subsea pipelines, such as the Middle East-India Deepwater Pipeline (MEIDP), emerge as a critical strategic imperative to bridge this gap. By establishing a direct, permanent energy corridor that provides high molecular efficiency, lower per-unit transportation costs, sustainable long-term supply and long-term price predictability, these cross-border pipelines offer the structural stability needed to fuel India's industrial growth, and anchor its transition toward a cleaner energy future.

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Pankhuri Goyal, Deputy Director (Economic Research), Federation of Indian Petroleum Industry

Evolving Tax Processes under the Income-tax Act, 2025: Key Changes and Transitional Alignment



Neetu Vinayek

Ernst & Young LLP

A. Backdrop

The enactment of the Income-tax Act, 2025 ('ITA 2025') represents a significant milestone in India's tax landscape, reflecting a calibrated evolution of the statutory framework rather than a fundamental shift in underlying tax policy. The new law seeks to modernise and rationalise the legislative architecture by simplifying language, reorganising provisions, and improving structural coherence, while retaining the core principles embedded in the Income-tax Act, 1961 ('ITA 1961').

Alongside these developments, the transitional framework plays a supporting role in ensuring continuity of rights, obligations, and ongoing proceedings across the two regimes. Accordingly, an understanding of both the key provisions driving process-level changes and the transitional alignment mechanism becomes essential for taxpayers to navigate the evolved statutory framework in an efficient and consistent manner.



Hiten Sutar

B. Key provisions resulting in process-level changes

While the ITA 2025 broadly retains the substantive framework of the ITA 1961, these changes, though not always altering the underlying tax position, necessitate a shift in the manner in which provisions are interpreted, applied, and administered. In this context, the subsequent paragraphs focus on key provisions where such changes translate into practical implications, requiring taxpayers to realign their processes to ensure seamless compliance under the revised statutory framework



Archana Karnani

I. Presumptive taxation for Oil & Gas service providers

Section 44BB of ITA 1961 provided a presumptive taxation regime for non-residents engaged in providing services or facilities, or supplying plant and machinery on hire, in connection with the prospecting for, or extraction or production of, mineral oils, resulting in an effective tax rate of 3.822% on gross receipts. Under the ITA 1961 framework, while taxpayers opting for this regime were not permitted to set off unabsorbed depreciation or brought forward business losses, certain deductions from total income could still be claimed.

Under ITA 2025, Section 61 deals with the corresponding provision which prohibits set-off of any losses including the claim of any deduction or allowance against income computed on a presumptive basis. As a result, deductions that were otherwise permissible under the earlier framework are no longer available under the ITA 2025.

The below illustration explains the difference under both the provisions:

Non-resident	Branch office	Project office*	ITA 1961
Business income	(500)	600	100
Set off of current year business loss was allowed hence no carried forward of business loss			-

Non-resident	Branch office	Project office*	ITA 2025
Business income	(500)	600	600
Carry forward of business loss			(500)

* Opted for presumptive taxation



Viral Mundada

Separately, since the new provision restricts claim of any deduction, even donations made would not be eligible for a deduction. Thus, the presumptive regime is intentionally narrowed to disallow deductions and loss set-offs given its estimation-based approach to income.

II. PAN application for Foreign Companies

Under the Income-tax Rules, 2026 ('ITR 2026'), entities incorporated or formed outside India are required to apply for PAN in Form 96 (erstwhile Form 49AA in ITR 1962).

From a compliance perspective, the revised Form 96 introduces certain mandatory disclosure requirements that were not required in the earlier framework.

- Details of Representative Assessee ('RA') or Authorised Representative ('AR') having Indian address
- Such RA or AR is required to furnish their PAN or Aadhar
- Quoting of the Tax Identification Number ('TIN')

However, in case of Foreign Portfolio Investors ('FPIs') certain relaxations have been provided such as the liability of the Authorised Signatory ('AS') mentioned in the RA/AR field is limited solely to the purpose of PAN application, where the PAN, Aadhar or Passport Number of the AS is not available, FPI registration number can be provided.

The requirement to appoint an AR/RA in India may create practical challenges for foreign entities that do not have an established presence or personnel in India. The need to obtain representative documentation, capture personal identifiers, and execute powers of attorney adds further compliance layers, thereby increasing administrative effort and timelines. Groups setting up new entities may therefore need to evaluate PAN-related documentation at the outset. Where required, they may consider appointing an authorised representative in India to facilitate smoother compliance.

III. Mandatory filing of Form 41 (erstwhile Form 10F) to claim treaty benefits

Under the ITA 1961, for claiming treaty benefits, Tax Residency Certificate ('TRC') and form 10F is required to be furnished to the deductor however, filing of form 10F was not mandatory where details such as status, nationality or country of incorporation, TIN, period of residential status, and address outside India were duly captured in the TRC.

However, under the ITR 2026, Form 41 (in place of Form 10F) has been made mandatory in all cases. Form 41 is required to be filed electronically once per tax year. This form captures prescribed details such as name, address, tax year, status, country of tax residency, TIN and TRC. Further, the 'communication address in India' is specifically requested however, providing these details is not mandatory. Considering filing of Form 41 is mandatory, this new Form has increased the compliance burden on the assessee and any omission or inconsistency may lead to denial of treaty benefit.

IV. Foreign Tax Credit Form 44 (erstwhile Form 67 in ITR 1962)

While the underlying provisions governing the allowability of foreign tax credit has remain unchanged, the reporting and documentation framework has undergone refinement under the ITR 2026 through the introduction of new prescribed forms.

Form 44

Form 44 is required to be furnished for claiming credit of foreign taxes paid. In cases where a refund of foreign tax arises due to revision of return, carry backward of losses, or any other reason and credit in respect of such taxes has already been claimed - Form 44 is required to be filed.

Key changes relating to Form 44 are as follows:

- Verification by an accountant where the taxpayer is a company or where the foreign tax paid outside India for a tax year is INR 100,000 or more.
- Form 44 is required to be furnished within 12 months from the end of the relevant tax year in which the corresponding income is offered to tax. In the case of an updated return, the form is required to be furnished on or before the date of filing such updated return.

Form 45

Represents an additional compliance requirement aimed at addressing situations involving post-facto adjustments, particularly where credit could not be claimed earlier due to pending disputes.

This form is required to be furnished where foreign tax credit could not be claimed earlier on account of the pendency of a dispute and is subsequently claimed upon settlement. Consistent with the approach adopted for Form 44, verification by an accountant is mandated in specified cases. The Form 45 is required to be filed within six months in which the dispute is finally settled.

Whilst the new forms are more logical and improves transparency, taxpayer must adopt correct disclosure practice as non-compliance can impact the eligibility for tax credit.

Associate Enterprises for Transfer Pricing applicability – Simplification or Expansion

Under ITA 1961, the definition of Associated Enterprise ('AE') operated through a two-tier framework. The primary condition was based on participation in management, control, or capital, while the secondary layer set out 13 deeming tests, including shareholding, loan dependency, and supply dependency. In effect, taxpayers were required to examine both layers together before concluding that two entities qualified as AEs.

ITA 2025 replaces this position with a single integrated provision rather than a two-tier definition. Under the revised framework, an entity may be regarded as an AE if any one of the prescribed conditions is met, whether through participation in management, control, or capital, or through the satisfaction of a deeming condition.

Another important change relates to the period for which AE status may apply. Under the ITA 1961, if a deeming condition was satisfied at any time during the year, the entities could be treated as AEs for the entire year. However, under ITA 2025, the expression "at any time during the year" has been retained only in the context of shareholding carrying 26 percent voting power.

This change warrants a fresh review of existing structures and transactions. Given the wider scope of the revised AE definition, transactions that may previously have fallen outside the transfer pricing net could now require closer evaluation.

VI. Changes in Transfer Pricing reporting

While the foundational transfer pricing framework remains unchanged, the reporting requirements (Form 48 erstwhile Form 3CEB) have undergone refinement, particularly in relation to the format and depth of disclosures. The revised framework introduces greater granularity and standardisation in reporting, with specific emphasis on transaction-level disclosures and documentation.

Key changes are summarised below:

- ***APA coverage***

Disclosure of transactions covered under APA, including the date of agreement, acknowledgement number, nature of transactions covered under APA and amounts covered under APA.

- The revised form prescribes 18 categories of international transactions and 5 categories of specified domestic transactions for selection. It also provides a structured format to disclose additional details for each category. For instance, in the case of royalty transactions, specific details such as date of agreement, rate, and amount of royalty are required to be disclosed in a prescribed format.

- ***Determination of Arm's Length Price***

The revised reporting in table no. 11 mandates disclosure of the most appropriate method adopted and the outcome of the transfer pricing analysis, along with additional particulars such as the number of comparables considered and the applicable arithmetic mean or range, as determined under the prescribed framework.

In effect, while these changes enhance the comprehensiveness and transparency of transfer pricing reporting, they also result in an increased level of detail and documentation, necessitating a more structured approach to compliance.

VII. Lower deduction certificate

Any person seeking a certificate for no deduction of tax, or for deduction or collection at a lower rate, is required to apply in Form 128, which has replaced the earlier Form 13 and is to be filed electronically.

Some of the key changes under the new framework are as follows:

- The new form requires details of returns filed for the preceding four tax years, including the tax year, acknowledgement number, date of filing, taxable income and tax liability and in case the return of any of the preceding four tax years are not filed, computation of total income of that year.
- The new framework introduces the concept of a Child Certificate. Where the relevant deductor details are not available at the time of application, the request may be made through Annexure II. In such cases, the certificate may first be issued in the applicant's own name. Once the relevant details become available, separate Child Certificates may be generated with the details of the deductor and the amount of income covered.

This appears intended to improve tracking of certificate usage and to help ensure that the overall approved amount is allocated in a controlled manner across multiple deductors. Annexure II is specifically intended for cases where the number of withholding counterparties is likely to exceed 100 or their details are not available when the application is made.

C. Transitional provisions

The transitional framework under ITA 2025 is anchored in the repeal and savings provisions, which ensure continuity of tax positions without disrupting the existing legal and procedural framework.

- **Foundational continuity and legal stability**

The repeal of the ITA 1961 does not affect actions already taken under it. Any orders passed, rights granted, or obligations created under the earlier law (viz. carry forward of credits, losses, etc.) will continue to remain valid and enforceable. Taxpayers' rights and liabilities are preserved, and there is no reopening of settled matters merely due to the change in law.

Further, approvals, exemptions, agreements, and notifications issued under the ITA 1961 will continue to remain in force, to the extent they are consistent with the ITA 2025, ensuring continuity without the need for fresh approvals.

- **Continuity of proceedings and adjudication of earlier years**

All proceedings relating to prior tax years - whether ongoing or initiated after 01 April 2026 - continue to be governed by the regime under ITA 1961, ensuring consistency in assessments, reassessments, penalty proceedings, and appellate processes. Further, all matters pending before tax authorities, appellate forums, or courts shall continue seamlessly under the ITA 1961. The repeal does not interrupt or alter the course of such proceedings.

- **Time limits for appeals and applications**

Where the period prescribed under ITA 1961 for filing an application, appeal, reference, or revision has expired on or before 01 April 2026, such rights are not revived merely by reason of the repeal. The transition does not reopen time-barred remedies. In other words, if the deadline to file an appeal expired before 1 April 2026, the taxpayer cannot file it later under the new law—the lapsed right is not revived.

For example, if assessment order for AY 2023–24 is passed on 15 March 2026 under the ITA 1961. Taxpayer files an appeal before the CIT(A) on 10 May 2026. Since the appeal pertains to prior years, the appeal proceedings would be governed under ITA 1961.

- **Treatment of interest on refunds and defaults**

For proceedings relating to tax years before 1 April 2026, the provisions on interest for refunds and defaults will continue to be governed by the ITA 1961, even where a refund becomes due or interest on default arises on or after 01 April 2026, subject to the applicable rates under the ITA 2025. For example, if a refund relates to FY 2024–25 and is granted on 15 June 2026, the interest will be calculated based on the provisions of the ITA 1961, but the rate of interest will be as per the ITA 2025.

- **Recovery of outstanding dues**

Any sum payable in relation to tax years governed by the ITA 1961 remains recoverable notwithstanding the repeal. Recovery proceedings may be continued or initiated without prejudice to actions already undertaken.

Accordingly, the transitional provisions ensures that each tax year is administered consistently under the applicable law and its corresponding procedural framework.

D. Conclusion

ITA 2025 reflects a considered evolution of the existing tax framework, where the emphasis extends beyond preservation of substantive principles to the manner in which such principles are structured, applied, and administered within a more streamlined statutory environment. While the core tax position in many areas continues to align with ITA 1961, the rearticulation of provisions and the accompanying refinements in compliance frameworks result in tangible processlevel implications that warrant careful evaluation.

A proactive and well-calibrated approach to these changes will be critical in achieving seamless compliance and in realising the intended objectives of clarity, certainty, and administrative efficiency under the evolving tax framework.

The information contained herein is of a general nature and is not intended to address the circumstances of any particular individual or entity. The views and opinions expressed herein are those of the author.

This appears intended to improve tracking of certificate usage and to help ensure that the overall approved amount is allocated in a controlled manner across multiple deductors. Annexure II is specifically intended for cases where the number of withholding counterparties is likely to exceed 100 or their details are not available when the application is made.

C. Transitional provisions

The transitional framework under ITA 2025 is anchored in the repeal and savings provisions, which ensure continuity of tax positions without disrupting the existing legal and procedural framework.

- **Foundational continuity and legal stability**

The repeal of the ITA 1961 does not affect actions already taken under it. Any orders passed, rights granted, or obligations created under the earlier law (viz. carry forward of credits, losses, etc.) will continue to remain valid and enforceable. Taxpayers' rights and liabilities are preserved, and there is no reopening of settled matters merely due to the change in law.

Further, approvals, exemptions, agreements, and notifications issued under the ITA 1961 will continue to remain in force, to the extent they are consistent with the ITA 2025, ensuring continuity without the need for fresh approvals.

- **Continuity of proceedings and adjudication of earlier years**

All proceedings relating to prior tax years - whether ongoing or initiated after 01 April 2026 - continue to be governed by the regime under ITA 1961, ensuring consistency in assessments, reassessments, penalty proceedings, and appellate processes. Further, all matters pending before tax authorities, appellate forums, or courts shall continue seamlessly under the ITA 1961. The repeal does not interrupt or alter the course of such proceedings.

- **Time limits for appeals and applications**

Where the period prescribed under ITA 1961 for filing an application, appeal, reference, or revision has expired on or before 01 April 2026, such rights are not revived merely by reason of the repeal. The transition does not reopen time-barred remedies. In other words, if the deadline to file an appeal expired before 1 April 2026, the taxpayer cannot file it later under the new law—the lapsed right is not revived.

For example, if assessment order for AY 2023–24 is passed on 15 March 2026 under the ITA 1961. Taxpayer files an appeal before the CIT(A) on 10 May 2026. Since the appeal pertains to prior years, the appeal proceedings would be governed under ITA 1961.

- **Treatment of interest on refunds and defaults**

For proceedings relating to tax years before 1 April 2026, the provisions on interest for refunds and defaults will continue to be governed by the ITA 1961, even where a refund becomes due or interest on default arises on or after 01 April 2026, subject to the applicable rates under the ITA 2025. For example, if a refund relates to FY 2024–25 and is granted on 15 June 2026, the interest will be calculated based on the provisions of the ITA 1961, but the rate of interest will be as per the ITA 2025.

- **Recovery of outstanding dues**

Any sum payable in relation to tax years governed by the ITA 1961 remains recoverable notwithstanding the repeal. Recovery proceedings may be continued or initiated without prejudice to actions already undertaken.

Accordingly, the transitional provisions ensures that each tax year is administered consistently under the applicable law and its corresponding procedural framework.

D. Conclusion

ITA 2025 reflects a considered evolution of the existing tax framework, where the emphasis extends beyond preservation of substantive principles to the manner in which such principles are structured, applied, and administered within a more streamlined statutory environment. While the core tax position in many areas continues to align with ITA 1961, the rearticulation of provisions and the accompanying refinements in compliance frameworks result in tangible processlevel implications that warrant careful evaluation.

A proactive and well-calibrated approach to these changes will be critical in achieving seamless compliance and in realising the intended objectives of clarity, certainty, and administrative efficiency under the evolving tax framework.

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Startup Section

Empowering Rural Livelihoods: The Decarbonization Journey of AgriVijay

Executive Summary: India's First Agri-Climate Green Energy Marketplace

Deploying decentralized renewable energy at the intersection of agriculture and climate tech is a critical driver for sustainable rural development in India. Traditional smallholder farming remains heavily dependent on volatile, carbon-intensive fossil fuels and biomass for daily operations, incurring substantial energy expenses. To bridge this gap, AgriVijay (Renewagri Om Ecommerce Private Limited) was co-founded in June 2020 by Shobha Chanchlani and Vimal Panjwani in Pune, Maharashtra. Operating as India's first curated marketplace for agri-climate and renewable energy solutions, the social enterprise replaces diesel, firewood, and chemical-heavy farming with clean-tech alternatives.

AgriVijay sets itself apart with a specialized "Energy Advisory" recommendation framework. Rather than executing standard transactions, local franchise owners and field representatives evaluate a farmer's land size, waste availability, and specific energy requirements before recommending tailored, budget-friendly technologies. To build trust, AgriVijay supports its digital platform and AI-enabled WhatsApp chatbot with local-language call centers and a physical retail franchise network called "AgriVijay Renewable Energy Stores". This "phygital" model bridges the rural technology gap by pairing delivery with reliable after-sales service and long-term warranties.



The graphic features the AgriVijay logo with the tagline "Empowering Farmers for Tomorrow". It includes logos for Startup India, Azadi Ka Amrit Mahotsav, NITI Aayog, AIMA, and G20. On the left, a photo of an offline store is shown with the text "Our Offline & Online (AI Based) Renewable Energy Store". In the center, a QR code and a smartphone displaying the AgriVijay app are shown. On the right, a computer monitor displays the AgriVijay website with various product offerings: Solar Inverter, Solar Sprayer, Solar Hydroponics, Solar Dryer, Solar Refrigerator, Organic Products, Electric Brush Cutter, Floating Biogas digester, Floating Biogas digester, Electric Tractor, Drone, and Soil Testing Machine. Below the monitor, it says "Our Product Offerings - Solar, Biogas, Green Energy - Electric". At the bottom, it says "Follow us on:" with social media icons and the website "www.agrivijay.com".

Operational Milestones and the Impact of the Avinya Platform

AgriVijay's growth accelerated after its participation in the Avinya 2025 Energy Startup Challenge. Organized by the Ministry of Petroleum and Natural Gas (MoPNG), the Oil and Natural Gas Corporation (ONGC), and the Federation of Indian Petroleum Industry (FIPI), the national challenge was designed to support low-carbon, sustainable business models. Securing the position of second runner-up from a national pool of 173 enterprise applications, AgriVijay was officially honoured in February 2025, by Union Minister Shri Hardeep Singh Puri.

The Avinya platform provided several key opportunities for the enterprise:

- **Global Exposure:** The startup was given dedicated exhibition space in the startup pavilion at India Energy Week (IEW) 2025 in New Delhi, presenting its solutions to over 70,000 energy professionals from 120 countries.
- **Policy Visibility:** Following this recognition, CEO Vimal Panjwani presented the company's rural decentralized energy model as a panelist at the NITI State Workshops & Conclave in Uttarakhand.

- **Institutional Trust:** Prior to the challenge, building partnerships with large organizations required lengthy verification cycles. Winning a national energy competition validated AgriVijay's business-to-business-to-consumer (B2B2C) model. The startup has since established partnerships with the United Nations Development Programme (UNDP), the JSW Foundation, the SELCO Foundation, BAIF, and the Grameen Foundation, implementing clean energy initiatives across rural communities.

Commercial Engagements with PSUs and Next-Generation Agrivoltaics

A key driver of AgriVijay's strategic evolution is its increasing commercial collaboration with public sector undertakings (PSUs) and government bodies to execute specialized clean-tech deployments:

- **NTPC Limited:** AgriVijay successfully commissioned Solar Submersible Pumping System in Aurangabad, Bihar, demonstrating how centralized energy entities can integrate off-grid water security solutions.
- **Hindustan Petroleum Corporation Limited (HPCL):** The company collaborates with HPCL for Supply & Commissioning of Solar Panels at Chennai New Terminal, Tamil Nadu.
- **Rajasthan Electronics & Instruments Limited (REIL):** AgriVijay works alongside REIL for the Supply & Commissioning of Solar Water Pumps.
- **Ministry of Ports, Shipping, and Waterways (MoPSW):** The startup coordinates clean energy and solar-powered solutions for coastal communities and green terminal projects, aligned with national maritime decarbonization initiatives.

In a milestone step for climate-smart agriculture, AgriVijay has partnered with German agrivoltaics pioneer **Next2Sun AG** and Wattkraft India. This strategic alliance introduces Next2Sun's innovative vertical bifacial solar panels to the Indian market. Unlike conventional flat solar arrays that displace farmland, the vertical setup preserves over 90% of land usability, allowing crops to grow unimpeded between the panel rows while generating solar energy from both sides of the vertical bifacial systems.



The partners are currently establishing a dedicated **Special Purpose Vehicle (SPV)** to deploy their first 100 kWp to 500 kWp agrivoltaic pilot projects under the central government's PM-KUSUM Component A scheme, combining clean energy production with active farming.

Financial Growth, Capital Efficiency, and Regional Expansion

AgriVijay has built a financially self-sustaining business model, balancing commercial scaling with its social impact mission. Total capital raised since its inception in 2020 stands at INR 2.47 Crore, reflecting a strong focus on capital efficiency.

The company is growing on year-on-year (YoY) growth rate of 105%. This growth rate helped the startup achieve absolute financial profitability in the fiscal year 2024–25, with annual revenues crossing INR 5 Crore. In late 2025, the company completed structured exits for early-stage investors. AIC JKLU (the incubation arm of JK Lakshmipat University, supported by NITI Aayog) and early angel investor Sanvali Kaushik, both of whom backed the startup in 2022, exited their positions with returns of up to 400%. This exit shows that rural-focused, climate-tech social enterprises can deliver strong financial returns while remaining committed to grassroots environmental and social goals.

The exits were completed alongside the onboarding of new strategic investors, including ABIF IIT Kharagpur (under the MeitY Samridh Accelerator Program) and veteran banker Joginder Singh Shekhawat (Deputy General Manager, ICICI Bank), who bring extensive corporate finance and banking experience. This capital-efficient growth supported the expansion of AgriVijay's physical retail footprint, scaling to 101 active franchised stores across Maharashtra, Rajasthan, Uttar Pradesh, Telangana, and Andhra Pradesh. Today, the startup has established an operational presence across 22 States & Union Territories, 139 districts, and over 910 rural villages.



Grassroots Impact, Awards, and the Global 2030 Roadmap

AgriVijay is transitioning from a curated marketplace into a full-stack green energy and financial services platform for rural communities. This approach has brought national and international recognition, highlighted recently by the startup being named the **Winner of the Outlook Planet C3 Summit & Awards 2026** under the "Using Clean Energy" Category. The enterprise also won the prestigious **Dr. BML Munjal Social Impact Award 2026** for "Outstanding Effort Towards Promoting Sustainability," presented in the esteemed presence of Shri Rahul Munjal (Founder & Chairman of Hero Future Energies). Additionally, AgriVijay has been named one of the top finalists in the 'Rural Impact Leader' category at the Sankalp Bharat Awards, the SolarX challenge by the International Solar Alliance, and the NASSCOM SME Inspire Award.

The grassroots socio-environmental impact achieved to date includes:

- **Carbon Mitigation:** Over 1,52,320+ tonnes of CO₂ and greenhouse gas emissions mitigated across the 40,342+ families served.
- **Firewood Preservation:** Over 5,04,720+ kg of firewood saved, reducing deforestation pressures and domestic indoor air pollution.
- **Economic Value:** Over INR 4.36 Crore in cumulative savings generated for rural households, allowing for reinvestment in education and farm assets.
- **Job Creation:** 560+ green jobs created, offering localized incomes for franchise store owners and technical installers.
- **Resource Circulation:** Over 15,88,500+ kg of animal and organic waste treated, producing 31.77.000+ Liters of bio-slurry to help restore organic soil health.

The company's long-term growth roadmap is defined by its 2030 vision:

- **Fundraising and Capital Injection:** To fund its rapid domestic scaling and international market entry, AgriVijay is actively looking to raise its **Pre-Series A investment round** and is currently holding positive, advanced conversations with prominent impact investors and venture capital firms.
- **Global Footprint:** Backed by this growth capital, the enterprise is planning its international foray into emerging markets across **Africa** (specifically target countries such as Mauritius and Kenya) and **South East Asia**, adapting the "phygital" marketplace store model to assist smallholders globally.
- **Retail and Farmer Expansion:** Scaling the network to 10,000 village-level stores, and eventually targeting 1 Lakh (100,000) stores/kiosks to onboard 10 Lakh (1 million) rural households as active clean energy producers and consumers.
- **Decarbonization:** Mitigating over 10 Lakh (1 million) tonnes of greenhouse gas emissions by 2030, contributing directly to global net-zero commitments.
- **Financial Integration:** Collaborating with Kisan Credit Card (KCC) networks and micro-finance institutions to offer low-interest financing directly through its digital platforms.



*AgriVijay Founders
Vimal Panjwani and Shobha Chanchlani*

By combining physical retail networks, localized energy advisory services, and digital financial solutions, the platform establishes a sustainable, scalable model for driving clean energy transitions, supporting rural livelihoods, and building climate resilience across the Global South.

From Innovation to Industrial Impact: UrjanovaC's Growth Journey After Winning the Prestigious Avinya'25 Energy Startup Challenge

From Recognition to Commercialization

The transition to a low-carbon economy requires technologies that are not only innovative but also scalable, economically viable, and deployable under real industrial conditions. UrjanovaC was founded with this vision — to develop breakthrough carbon capture, utilization, and storage (CCUS) technologies that enable industries to significantly reduce greenhouse gas emissions while creating economic value from captured carbon dioxide.

UrjanovaC's patented carbon capture and utilization platform provides industries with a sustainable, cost-effective pathway to decarbonization by converting captured CO₂ into valuable products, enabling emissions reductions without disrupting existing industrial operations. The technology simultaneously supports ESG objectives, carbon credit generation, and long-term sustainability commitments.

A defining milestone in the company's journey came with its recognition as the Winner of the Avinya'25 Energy Startup Challenge. More than an award, Avinya became a catalyst for accelerating commercialization, strengthening industry credibility, and expanding access to strategic stakeholders across India's clean energy ecosystem. Since March 2025, UrjanovaC has made significant progress in technology validation, industrial partnerships, pilot deployments, and business expansion, positioning itself among India's emerging climate-tech innovators.



Accelerating Technology and Commercial Readiness

Over the past year, UrjanovaC has rapidly advanced its proprietary CCUS technology from laboratory research to industrial deployment. The company received TRL-6 validation from BPCL and Forbes Marshall, confirming its industrial readiness, and commissioned a 3 TPD integrated carbon capture and conversion pilot plant at IIT Bombay, inaugurated by Shri Dharmendra Pradhan, Hon'ble Minister of Education. UrjanovaC is now progressing toward commercial deployment through pilot and demonstration projects with leading industrial partners, including BPCL, Godawari Power & Ispat Limited (HIRA Group), and Coal India Limited.

More recently, UrjanovaC had the distinct privilege of representing India at the Bharat Innovates and VivaTech conferences in France, among the world's leading innovation and technology platforms. During these prestigious events, the company showcased its breakthrough carbon technology to the Hon'ble Prime Minister of India, Shri Narendra Modi, and the Hon'ble President of France, Emmanuel Macron, both of whom expressed strong appreciation for the innovation and its potential contribution to industrial decarbonization and global climate action.

Building a Strong Industrial Ecosystem

UrjanovaC has significantly expanded its strategic partnership ecosystem to accelerate industrial decarbonization. The company has established engineering and EPC collaborations with leading firms such as Abhitech Energycon, Ingenero Technologies, Technip Energies, TOPSE, BALIEF, and Texol, while technology partnerships with the National Centre of Excellence in Carbon Capture & Utilization and Sprih Pvt. Ltd. continue to advance its CCUS platform. Strategic engagements with industry leaders including ArcelorMittal, ONGC, Forbes Marshall, SAIL, and Dalmia have further strengthened commercialization opportunities. Simultaneously, UrjanovaC has expanded its multidisciplinary team and enhanced its capabilities in carbon capture, process engineering, and industrial project execution.

The Transformational Impact of the Avinya Platform

Participation in the Avinya'25 Energy Startup Challenge significantly enhanced UrjanovaC's visibility, credibility, and commercial momentum. The recognition strengthened engagement with industrial customers, investors, policymakers, and technology partners, leading to new pilot deployment opportunities and strategic collaborations across multiple sectors. It also expanded access to India's deep-tech and climate innovation ecosystem, supporting the company's commercialization journey. Building on this momentum, UrjanovaC was selected by the Ministry of Education under Bharat Innovates 2026 to represent India in France and was internationally recognized as a "Deep Tech Pioneer" by Hello Tomorrow, further strengthening its global profile.

Business Growth and the Road Ahead

Since Avinya'25, UrjanovaC has evolved from a research-driven startup into a commercialization-focused climate-tech company with a growing pipeline of industrial projects, strengthened engineering partnerships, and enhanced execution capabilities. Today, the company operates at TRL 6–7, supported by validated pilot infrastructure and active industrial collaborations. Going forward, UrjanovaC aims to deploy commercial CCUS systems across hard-to-abate industries, expand internationally through strategic partnerships, and develop scalable carbon management solutions that contribute to India's net-zero ambitions. The Avinya platform has been instrumental in accelerating this journey from innovation to industrial impact.

FIPI Student Chapters

Osmania University FIPI Student Chapter

Earth Day Celebrations – 2026

Department of Geophysics, FIPI Osmania University Student Chapter

The Department of Geophysics, Osmania University, in collaboration with the student chapters of AEG, IGU, SEG, and FIPI, and the Centre of Exploration Geophysics, celebrated Earth Day 2026 on 22nd April 2026 under the global theme “**Our Power, Our Planet.**” The programme began with a tree plantation drive involving dignitaries, faculty members, and students, highlighting their commitment to environmental conservation



The event was presided over by Prof. B. Veeraiah, Head, Department of Geophysics. Chief Guest Prof. Kumar Molugaram, Vice Chancellor, Osmania University, emphasized the need to strengthen basic sciences alongside technological advancement and highlighted the importance of quality education, research, innovation, and infrastructure in achieving sustainable development. He also discussed major environmental challenges such as climate change, biodiversity loss, pollution, deforestation, and resource depletion.

Guest of Honour Shri N. Jyothi Kumar, Regional Director, CGWB (Southern Region), underscored the significance of geophysics in groundwater exploration and sustainable water management, while noting that artificial intelligence would complement geoscientific expertise. Prof. M. Vijjulatha, Principal, University College of Science, stressed the need for collective action to restore ecological balance.

The event was also graced by Dr. Abhey Ram Bansal, Chief Scientist & Hon. Secretary, IGU, Hyderabad, Dr. B. Narsimha Rao, Secretary, AEG Hyderabad, Prof. B. Srinivas, FIPI Coordinator & Head, Department of Applied Geochemistry, Dr. G. Udaya Laxmi, Associate Professor & Chairperson, BOS in Geophysics.

This event concluded with a strong message promoting scientific awareness, environmental responsibility, and sustainable practices.

Rajiv Gandhi Institute of Petroleum Technology (RGIPT) – FIPI Student Chapter

FIPI ELEVATE – Executive Recruitment Drive

FIPI-ELEVATE was an executive recruitment drive organized by the FIPI RGIPT Student Chapter to induct motivated and talented students into its executive team. The interview assessed candidates' communication, leadership, teamwork, and commitment to the chapter's activities. Conducted in a professional and interactive manner, the initiative successfully identified dedicated students who will contribute to organizing technical, professional, and student-centric events, strengthening the chapter and supporting its long-term vision and growth.



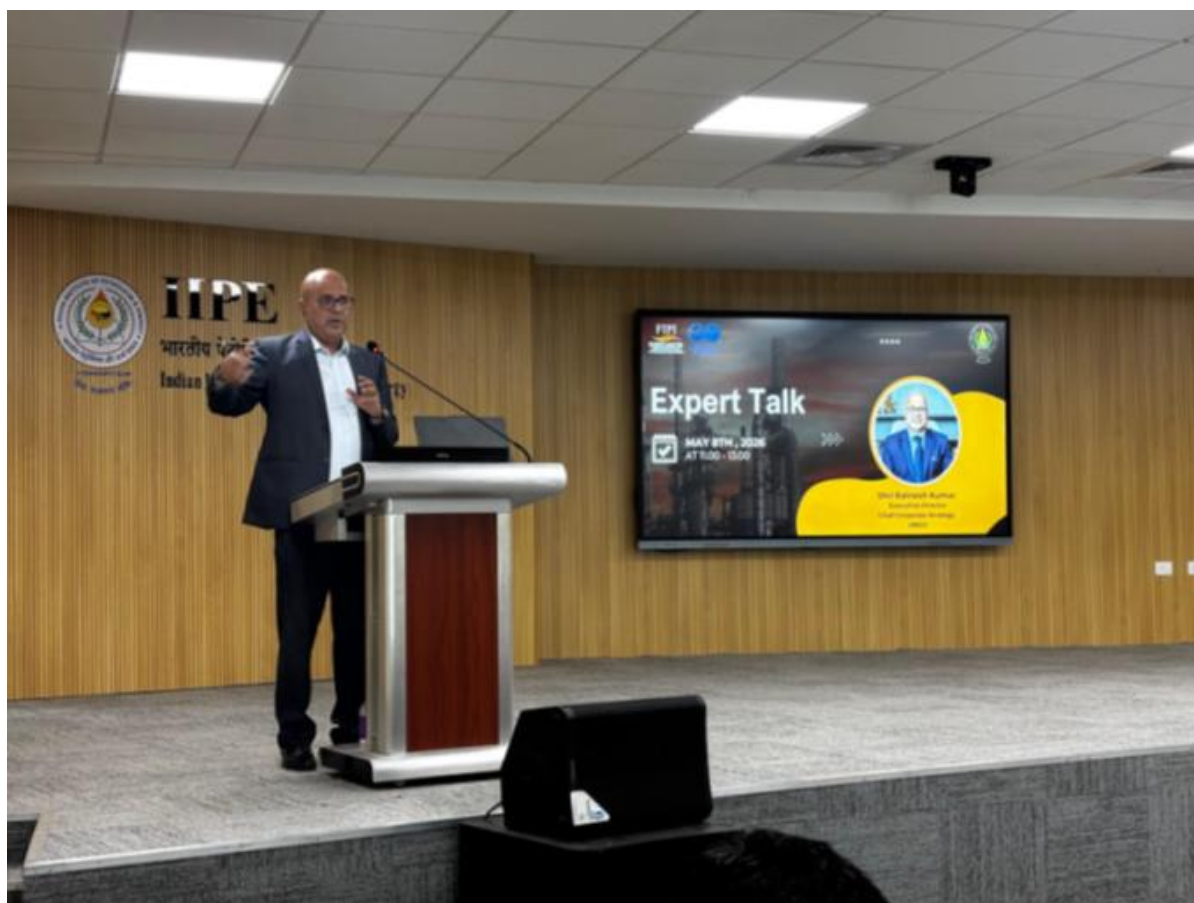
DESIGNING WORKSHOP

The Designing Workshop was organized collaboratively by the FIPI, AAPG, SEG, and EAGE RGIPT Student Chapters with the objective of introducing students to the fundamentals of graphic design and visual communication. The workshop provided participants with hands-on exposure to modern designing tools and techniques used for creating posters, social media content, presentations, and promotional materials. During the session, participants learned key design principles, including layout, typography, colour combinations, and content organisation. Live demonstrations and practical activities enabled students to apply these concepts and enhance their creative skills. The workshop encouraged innovation, teamwork, and effective communication through design.



Indian Institute of Petroleum and Energy (IIPE) FIPI Student Chapter

Following the inauguration of the HPHT facility, an expert talk was organized by IIPE FIPI Student Chapter on 8th May 2026. The talk was delivered by Shri Ratnesh Kumar Executive Director, Chief Corporate Strategy, ONGC. He shared valuable insights into the energy industry, emerging technological advancements, career opportunities, and the significance of industry– academia collaboration. Shri Sachin Bodge, General Manager (HR), ONGC also addressed the audience and shared his perspectives. The interactive session offered students and faculty practical insights into research, innovation, and skill development, highlighting the competencies required to thrive in the evolving energy sector.



Dibrugarh University FIPI Student Chapter

I. Innovation:

A Process for Remediation of Crude-oil Contaminated Water Using a Plant-based Adsorbent Derived from Water Hyacinth (*Eichhornia Crassipes*)

Inventors: Ipsita Deka, Isfaquul Alam, Junayed Khan, Kasturi Bonia, Dr. Chayanika Borah and Joyshree Barman
The invention presents an innovative, eco-friendly, and sustainable process for the remediation of crude oil-contaminated water using a plant-based adsorbent developed from *Eichhornia crassipes* (water hyacinth), an abundant aquatic weed. The process transforms this invasive plant into a value-added biosorbent capable of efficiently removing crude oil from water bodies, thereby addressing both environmental pollution and biomass management.

The methodology begins with the collection and pre-processing of water hyacinth biomass. The stems and leaves are carefully separated, thoroughly washed with distilled water to remove dirt and impurities, followed by acetone washing to eliminate surface oils and organic contaminants. The cleaned biomass then undergoes multi-stage drying to ensure complete removal of moisture, which enhances the effectiveness of subsequent treatment.

To improve the adsorption performance, the dried biomass is chemically activated by immersing it in a 0.5% aqueous hydrochloric acid (HCl) solution for three hours at room temperature. This acid treatment increases the surface porosity and exposes additional active adsorption sites, thereby significantly enhancing the material's oil sorption capacity. After treatment, the biomass is neutralized, dried at 80°C, finely ground, and sieved to obtain a uniform 25-mesh particle size, ensuring consistency and efficient performance during application.

The prepared adsorbent is then applied directly to the surface of crude oil-contaminated water, where it rapidly absorbs floating oil due to its porous structure and buoyant nature. Experimental evaluation demonstrated an Oil Sorption Capacity (OSC) of at least 5.5 g of oil per gram of stem-derived adsorbent and 6.0 g of oil per gram of leaf-derived adsorbent within 120 minutes, indicating excellent adsorption efficiency.

Overall, the invention offers a simple, low-cost, biodegradable, and highly effective solution for oil spill remediation. By utilizing an easily available invasive plant species as a raw material, the process not only provides an environmentally sustainable approach to treating oil-contaminated water but also contributes to the beneficial utilization of water hyacinth, promoting waste-to-resource conversion and supporting environmentally responsible oil spill management practices.

II Industrial Visits:

A. An industrial visit for the 4th-semester B.Tech. Petroleum Engineering students to the Water Supply Station (WSS) and Air Liquefaction Plant (ALP) located within the Oil Gathering Pumping Station (OGPS) complex of Oil India Limited (OIL) in Duliajan was organized on 7th May, 2026. Students gained practical exposure to surface production facilities through demonstrations of the Coiled Tubing Unit (CTU), production operations, and Sucker Rod Pump (SRP) systems. Expert interactions with OIL professionals enhanced their understanding of hydrocarbon production, well intervention, and artificial lift technologies, effectively bridging classroom learning with real-world industry practices.



B. As a part of Project SHARE (Strategic Handholding for Industry-Academia Relationship and Engagement), and in collaboration with FIPI Dibrugarh University Student Chapter, a one-day industrial visit to the Well Logging Department of Oil India Ltd, Duliajan was organized on 28th April 2026 for M. Tech 2nd Semester Students of the Department of Petroleum Technology. The visit provided hands-on exposure to open- and cased-hole logging operations, wireline tools, production logging, and advanced interpretation software. Interactions with OIL experts strengthened students' understanding of reservoir characterization, well integrity, and data interpretation, effectively connecting academic learning with real-world petroleum exploration and production practices.



Events

Global Energy Leadership Dialogue - Energy Security Rewritten

S&P Global Energy and the Federation of Indian Petroleum Industry (FIPI) strengthened their strategic engagement at the FIPI-S&P Global Energy Leadership Talk Series 2026, convened under the theme "Energy Security Rewritten". Held on 24 June 2026 at Hyatt Regency, New Delhi, the closed-door dialogue brought together senior government stakeholders, FIPI leadership, and chairmen, directors, CEOs and board-level executives from 26 leading oil and gas companies for a focused discussion on the future of India's energy security.



Dr. Neeraj Mittal, Secretary, Ministry of Petroleum & Natural Gas, addressed the gathering, setting the context for the strategic importance of energy security for India's growth and resilience. He also inaugurated the Talk Series that FIPI and S&P Global jointly convened.



FIPI leadership was represented by Shri A S Sahney, Chairman, FIPI and Chairman, Indian Oil; Shri Arun Kumar Singh, Vice Chairman, FIPI and Chairman & CEO, ONGC; Shri Sarthak Behuria, Co-Chairman, FIPI and Chairman, Jio-BP Mobility; and Shri V Satish Kumar, Director General, FIPI.

S&P Global Energy experts led an intelligence-driven agenda focused on market disruption, chokepoint risks, supply-chain resilience and the changing dimensions of energy security. Abhishek Tomar, Head of Data and Energy OPCO Leader, anchored the session and framed energy security as a strategic leadership issue requiring deeper data, sharper foresight and stronger preparedness.



Shri Abhishek Tomar, Head of Data and Energy OPCO Leader anchored the session



Jim Burkhard, Vice President and Global Head of Oil Markets and Mobility, S&P Global shared perspectives on geopolitical disruption and its cascading impact across global energy systems.

This was followed by a series of key sessions focused on navigating volatile global energy markets, trade flows, energy transition, and the supply chain.

The dialogue provided participants with valuable perspectives on evolving global energy markets, emerging geopolitical and market risks, and their potential implications for India's energy sector. It enabled senior industry leaders to obtain insights that could support more informed strategic thinking and decision-making in an increasingly interconnected and uncertain global energy environment.

Webinar on Recent Judicial Developments in International and Corporate Taxation

The Federation of Indian Petroleum Industry (FIPI) in association with KPMG in India organized a webinar on **Recent Judicial Developments in International and Corporate Taxation** on 15th June, 2026. This webinar aimed to provide an overview of recent landmark rulings across Indian courts and tribunals, highlighting emerging principles in Permanent Establishment (PE), treaty interpretation, cross-border financing, and corporate taxation. These rulings reflect judicial approach towards expanding taxability where economic presence and control exist, protecting taxpayers via DTAA safeguards, clarifying treatment of modern financial instruments and corporate transactions. The webinar was appreciated by one and all and was attended by 60 professionals working across the oil and gas value chain.



Mr. Vivekanand, Director (Finance, Taxation & Legal), FIPI began the session with the opening remarks. He said that this is the first time that FIPI is organizing a webinar focused specifically on recent judicial tax decisions. He said that while we have regularly conducted sessions on changes in tax laws and rules, judicial pronouncements are equally important as they significantly influence tax positions and business decisions. He said that, in day-to-day operations, important judicial rulings may sometimes go unnoticed, even though they can have a substantial impact on tax planning, tax savings, compliance obligations, and potential tax exposures. He further said that the topic of webinar is particularly relevant as many FIPI member companies have expanded their global presence and are engaged in cross-border operations. The session covers important judicial decisions relating to international taxation, permanent establishment (PE), double taxation avoidance agreements (DTAAs), corporate guarantees, and other key tax issues. Understanding these rulings will help organizations make informed decisions, assess tax risks more effectively, and structure their transactions in a tax-efficient and compliant manner.

Mr. Himanshu Sikka, Partner, Indirect Tax and Tax Incentives Practice at KPMG India highlighted, that the subject of webinar is highly relevant in the current business environment. Recent judicial pronouncements in international taxation are reshaping the landscape of tax certainty, dispute resolution, and cross-border investment structures. He said that these rulings have significant implications for how businesses manage tax risks, interpret treaty provisions, and structure their global operations.

Ms. Nidhi Kansal, Partner in B S R & Co LLP and Ms. Nidhi Bansal, Associate Director in B B S R & Associates LLP then discussed about the five significant recent tax rulings and their implications for multinational companies, cross-border transactions, financing structures, and treaty benefits.

1. Supreme Court Decision – Hyatt International (Permanent Establishment)

The Court examined whether Hyatt UAE had a Permanent Establishment (PE) in India. Although the UAE entity claimed that it only provided strategic oversight services and did not have a fixed place of business in India, the tax authorities noted frequent visits by expatriate employees, significant involvement in hotel operations, and a revenue-linked remuneration model. Based on the overall facts, the Supreme Court held that Hyatt UAE effectively exercised operational control and had a Fixed Place PE in India. The Hyatt International ruling shows that tax authorities and courts will focus on the actual conduct of business rather than contractual wording. Although Hyatt UAE claimed that it only provided strategic oversight, frequent visits by its employees, operational involvement, and revenue-linked compensation led the Supreme Court to conclude that it had a Permanent Establishment (PE) in India. For oil and gas companies with cross-border operations, the ruling highlights the need to clearly separate advisory functions from operational control, maintain strong documentation, and carefully manage employee activities and group support arrangements.

2. Chennai Tribunal – Vestas Wind Technology (Section 94B)

The Chennai Tribunal's decision in the Vestas Wind Technology case deals with the applicability of Section 94B and the protection available under the Non-Discrimination Clause of the India-Denmark DTAA. Section 94B restricts the deduction of interest paid on loans from non-resident associated enterprises to 30% of EBITDA, with the excess interest being disallowed and carried forward for up to eight years. The Chennai Tribunal held that Section 94B interest disallowance cannot apply where it violates the Non-Discrimination Clause of the India-Denmark DTAA. Since interest paid to non-residents was being treated less favourably than interest paid to residents, the Tribunal deleted the entire disallowance. Therefore, it was mentioned that companies with ECBs from countries having similar Treaty provisions should explore relief from Section 94B disallowances and potentially reduce their tax burden.

3. Delhi High Court – Globe Capital Market (Section 56(2)(x))

The Delhi High Court held that when a company buys back its own shares at a price lower than Fair Market Value (FMV), the difference between FMV and the buyback price cannot be taxed under Section 56(2)(x). The Court ruled that a buyback is essentially a reduction of share capital, not an acquisition of property, because the shares are extinguished and cease to exist after the buyback. Thus, it was mentioned that companies can undertake buybacks below FMV without attracting tax under Section 56(2)(x), providing strategic restructuring transactions.

4. Corporate Guarantee Cases (Johnson Matthey & Kia Corporation)

These cases deal with the taxability of guarantee fees charged by foreign parent companies to their Indian subsidiaries for providing corporate guarantees on loans.

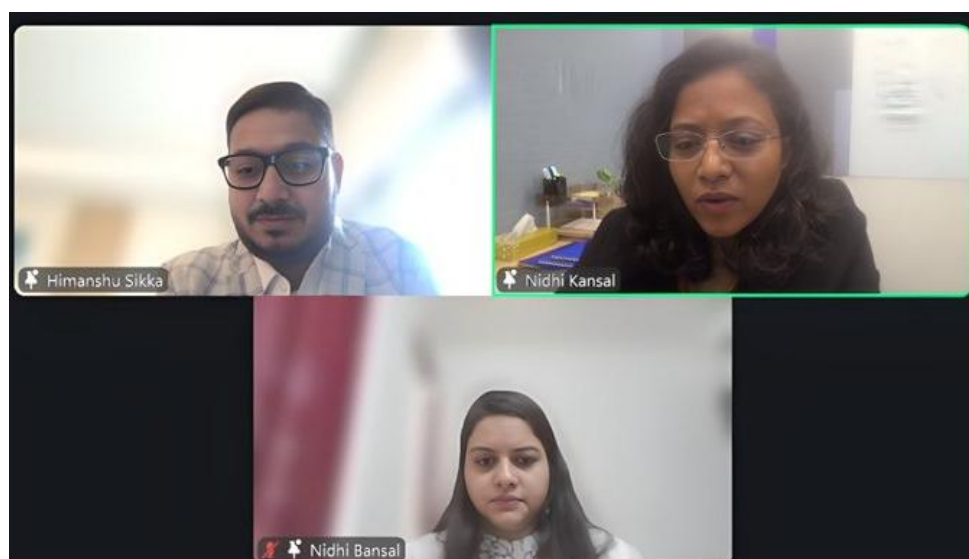
In Johnson Matthey (UK), the Supreme Court held that guarantee fees are not interest income and are taxable as "Other Income" under the India-UK DTAA. Since the underlying loan was used in India, the income was considered to arise in India and was therefore taxable in India.

In Kia Corporation (South Korea), the Bangalore Tribunal held that under the India-Korea DTAA, the "Other Income" article grants taxation rights only to the country of residence. Therefore, the guarantee fees was not taxable in India.

5. Supreme Court – Tiger Global

The Tiger Global case dealt with the availability of capital gains exemption under the India-Mauritius DTAA. The Supreme Court denied treaty benefits, holding that tax authorities can look beyond the structure of a transaction and examine whether it was designed primarily for tax avoidance. The most significant takeaway is that a Tax Residency Certificate (TRC) alone is no longer sufficient to claim treaty benefits. Tax authorities can examine the commercial substance, purpose, and economic activities of the entity claiming treaty protection.

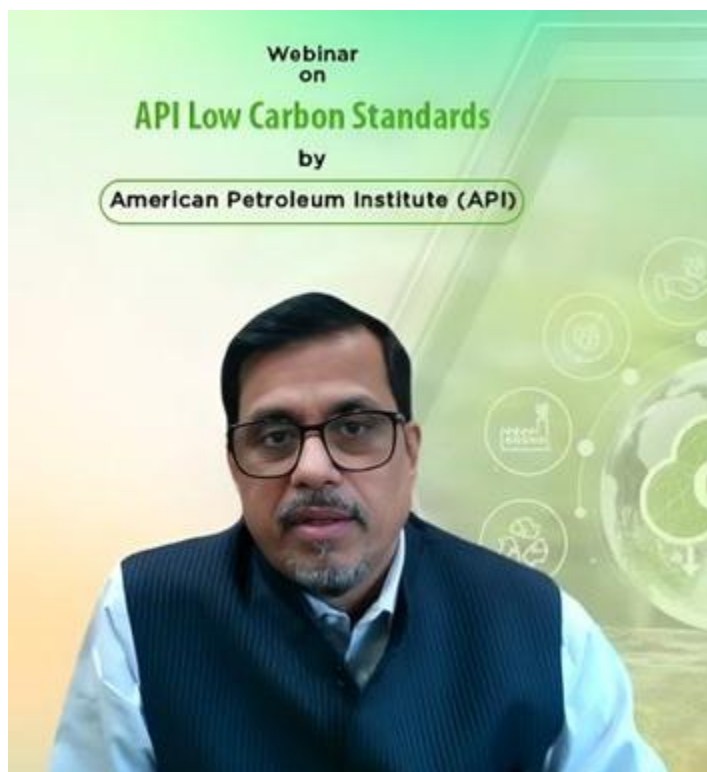
Lastly, Mr. Vivekanand gave the closing remarks and thanked the KPMG team for sharing these important judicial developments. He said that the decisions discussed have significant implications for companies, particularly in relation to cross-border transactions, support arrangements with foreign partners and joint ventures, treaty benefits, and financing structures. He also thanked all participants for their active participation.



During the webinar, eminent speakers Mr. Himanshu Sikka, Partner, KPMG India; Ms. Nidhi Kansal, Partner, B S R & Co. LLP; and Ms. Nidhi Bansal, Associate Director, B S R & Co. LLP delivered an insightful and comprehensive presentation on the evolving landscape of international and corporate taxation.

Webinar on API Low Carbon Standards

The Federation of Indian Petroleum Industry (FIPI), in association with the American Petroleum Institute (API), organized a webinar on 'API Low Carbon Standards' on June 12, 2026. The technical session was inaugurated by Mr. Deb Adhikari, Director (E&P), FIPI and API was represented by Mr. Ralph Samaha, Chief Representative, Middle East, Africa and India. The webinar provided an overview of API's ongoing standards development efforts across key low-carbon technologies.



In his opening remarks, Mr. Deb Adhikari, highlighted that nations, industries and consumers are increasingly seeking meaningful pathways to meet growing energy needs while also addressing the challenge of climate change. He emphasized that achieving this elusive balance requires not only technological innovation and investment, but also robust standards and frameworks that enable consistent measurement, reporting, and verification of emissions and decarbonization efforts. As companies around the world pursue decarbonization he highlighted the critical role of API standards in creating a common language for the entire energy ecosystem, promoting transparency, enhancing credibility, facilitating benchmarking, and supporting informed decision-making.

Mr. Adhikari underscored that the energy transition project presents both opportunities and responsibilities for India. As one of the world's fastest-growing major economies, India must continue to ensure energy security and

affordability while advancing its climate commitments and sustainability objectives. He also stated that the petroleum and natural gas industry will continue to play an important role in the energy mix for the foreseeable future, even as it works towards reducing its carbon footprint through improved efficiency, emissions management, carbon capture technologies, low-carbon fuels, and other innovative solutions.

Presentation on API Low Carbon Standards

Mr. Ralph Samaha began his presentation by highlighting API's offerings in standards development, certification programs, training, auditing, personnel qualification, publications, and a range of other initiatives that help improve safety, quality, and operational performance across the energy value chain.

Mr. Samaha emphasized that standards play a critical role in supporting the scaling and adoption of low carbon technologies by creating consistency, building confidence among investors and operators, supporting international collaboration, and accelerating the deployment of new technologies. He stated that API's low carbon standards initiatives are intended to help the industry deploy emerging technologies with the same level of safety, reliability, and consistency that API standards have historically brought to conventional oil and gas.

Recognizing the growing need for industry alignment around emerging technologies, API's Global Industry Services (GIS) Division established its Low Carbon Standards team vertical. He explained that API undertakes pre-standardization activities, including research and gap analyses, while also updating existing standards to incorporate low-carbon technologies. These efforts are focused on five key areas: Carbon Capture, Utilization and Storage (CCUS), hydrogen, greenhouse gas abatement, life cycle assessment, and renewables—mostly geothermal.

Mr. Samaha He explained that CCUS involves capturing carbon dioxide from industrial facilities or directly from the atmosphere, followed by compression, transportation, utilization and/or permanent storage. He also noted that large-scale CCUS deployment requires clear guidance on transportation infrastructure, materials, well integrity, measurement, monitoring and long-term reliability. API is therefore reviewing existing standards and identifying areas where updates or additional guidance may be required for CO₂ service conditions.



Mr. Samaha further explained that captured CO₂ can be used in several applications, including enhanced oil recovery, building materials, chemical synthesis, fuels and food and beverage products. However, he clarified that utilization alone may not absorb all captured emissions, making long-term geological storage an important pathway. He also highlighted that different carbon capture methods produce CO₂ streams with varying compositions and impurities, which can affect material selection, transportation, storage and system performance. This reinforces the need for common technical frameworks across the CCUS value chain.

On hydrogen, Mr. Samaha stated that while hydrogen is often viewed as a new energy solution, the oil and gas industry has been producing, transporting, storing and using hydrogen for decades, particularly in refining and petrochemical operations. He discussed key production pathways such as steam methane reforming, coal gasification and electrolysis, noting that the carbon intensity of hydrogen depends on the method of production and the source of energy used.

He also highlighted API's work in updating existing standards to support hydrogen applications. He referred to API Spec 6D, which has been updated to include hydrogen gas service for pipeline valves, and API Spec 5L, which supports line pipe manufacturing and is being expanded for emerging applications such as CO₂ and hydrogen transportation. API is also exploring further work in areas such as hydrogen leak detection, above-ground storage and underground geological storage.

Mr. Samaha also discussed geothermal energy as an area where oil and gas expertise can be effectively applied. He stated that geothermal projects rely significantly on drilling, well design and subsurface knowledge, which are areas where the oil and gas industry has extensive experience. He mentioned that while several existing API standards may already be relevant for geothermal operations, some may require updates to address geothermal-specific operating conditions, including higher temperature environments.

In the context of offshore wind, Mr. Samaha highlighted that API is helping transfer offshore oil and gas experience to the offshore wind sector, especially in areas such as asset integrity, workforce safety, risk management, environmental protection and offshore operations. He referred to API Recommended Practice 75, which provides a Safety and Environmental Management System framework, and API Recommended Practice 75W, which adapts this framework for offshore wind operations. This reflects API's approach of leveraging proven standards and modifying them to meet the requirements of emerging low-carbon sectors.

In conclusion, Mr. Samaha stated that while technologies such as CCUS, hydrogen, geothermal energy and offshore wind differ in application, they share a common requirement for standards that support safety, reliability, interoperability and scalability. He emphasized that innovation will drive the deployment of low carbon technologies, but standards, operational experience and industry collaboration are essential to enable these technologies to be deployed safely and at scale.

Mr. Samaha then conducted the Q&A session, addressing the various queries raised by participants and sharing his views and insights on the topics discussed. In closing, FIPI complimented the API team for the informative and comprehensive presentation and thanked the participants from the student chapters and the energy industry for their active and engaging participation throughout the event.

Member Organizations

S.No	Organization	Name	Designation
1	Adani Welspun Exploration Ltd.	Mr. Arvind Hareendran	Sr. Vice-President (Exploration)
2	AGP City Gas Pvt. Ltd.	Mr. Abhilesh Gupta	CEO & MD
3	Arham Oil Gas Products and Services Pvt. Ltd.	Mr. Tapas Baldia	Director
4	ASAP Fluids Pvt. Ltd.	Mr. Vivek Gupta	Managing Director
5	Axens India (P) Ltd.	Mr. Siddhartha Saha	Managing Director
6	Baker Hughes, A GE Company	Mr. Neeraj Sethi	Country Leader
7	Bharat Petroleum Corporation Ltd.	Mr. Sanjay Khanna	Chairman & Managing Director
8	Bliss Anand Pvt. Limited	Mr. Vikas Anand	Managing Director
9	BP Exploration (Alpha) Ltd	Mr. Kartikeya Dube	Head of Country, bp India
10	Cairn Oil & Gas, Vedanta Ltd	Mr. Biswanath Ghosh	Director (Technical Excellence & Growth)
11	Central U.P. Gas Ltd.	Mr. Rajib Lochan Pal	Managing Director
12	Chandigarh University	Mr. Satnam Singh Sandhu	Chancellor
13	Chennai Petroleum Corporation Ltd.	Mr. H. Shankar	Managing Director
14	CSIR- Indian Institute of Petroleum	Dr Harender Singh Bisht	Director
15	dDriven Data Sciences & Analytics Pvt Ltd	Mr. Partha Ray	Founder & CEO
16	Decom North Sea	Mr. Will Rowley	Interim Managing Director
17	Dynamic Drilling & Services Pvt. Ltd.	Mr. S.M. Malhotra	President
18	Engineers India Ltd.	Mr. Atul Gupta	Chairman & Managing Director Additional Charge of Director (Commercial)
19	Ernst & Young LLP	Mr. Rajiv Memani	Country Manager & Partner
20	ExxonMobil Gas (India) Pvt. Ltd.	Mr. Matthew Chandler	Managing Director
21	FMC Technologies India Pvt. Ltd.	Mr. Arjun Kumar Rumalla	Managing Director
22	GAIL (India) Ltd.	Mr. Deepak Gupta	Chairman & Managing Director and Director (Projects)
23	GSPC LNG Ltd.	Mr. Sanjay Sengupta	Chief Executive Officer
24	Goa Natural Gas Private Limited	Ms. Barathy S	Chief Executive Officer
25	Hindustan Petroleum Corporation Ltd.	Mr. Vikas Kaushal	Chairman & Managing Director
26	HPCL Mittal Energy Ltd.	Mr. Prabh Das	Managing Director & CEO
27	IIT (ISM) Dhanbad	Prof. Sukumar Mishra	Director
28	IMC Ltd.	Mr. A. Mallesh Rao	Managing Director
29	Indian Gas Exchange Ltd.	Mr. Rajesh Kumar Mediratta	Managing Director & CEO
30	Indian Oil Corporation Ltd.	Mr. A S Sahney	Chairman
31	Indian Strategic Petroleum Reserves Ltd.	Mr. Atul Gupta	CEO & MD (Addl. Charge)
32	IndianOil Adani Ventures Ltd.	Mr. Anubhav Jain	Managing Director
33	Indradhanush Gas Grid Ltd.	Mr. Subrata Das	Chief Executive Officer
34	Indraprastha Gas Ltd.	Mr. Kumar Shanker	Managing Director
35	International Association of Drilling Contractors: IADC	Mr. Jason McFarland	President
36	International Gas Union	Mr. Milton Catelin	Secretary General

Member Organizations

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39	Lanzatech Pvt. Ltd.	Dr. Jennifer Holmgren	Chief Executive Officer
40	Larsen & Toubro Ltd.	Mr. S.N. Subrahmanyam	CEO & Managing Director
41	Lummus Technology LLC	Mr. Leon de Bruyn	President & Chief Executive Officer
42	Mangalore Refinery & Petrochemicals Ltd.	Mr. M Shyamprasad Kamath	Managing Director & CEO
43	Marine Solutionz Ship Management Private Limited	Mr. Sumit Kumar	Director
44	MIT World Peace University Pune	Mr. Rahul V. Karad	Executive President
45	Multi Commodity Exchange of India Ltd.	Ms. Ruchi Shukla	Head Energy
46	Nayara Energy Ltd.	Mr. Prasad K. Panicker	Executive Chairman
47	Numaligarh Refinery Ltd.	Mr. Bhaskar Jyoti Phukan	Managing Director
48	Oil and Natural Gas Corporation Ltd.	Mr. Arun Kumar Singh	Chairman & CEO
49	Oil India Ltd.	Dr. Ranjit Rath	Chairman & Managing Director
50	Petronet LNG Ltd.	Mr. Akshay Kumar Singh	Managing Director & CEO
51	Petronet MHB Ltd.	Mr. Pankaj Kumar Meena	Managing Director
52	Pipeline Infrastructure Ltd.	Mr. Akhil Mehrotra	Chief Executive Officer
53	Rajiv Gandhi Institute of Petroleum Technology	Prof. Harish Hirani	Director
54	Reliance BP Mobility Ltd.	Mr. Akshay Wadhwa	Chief Executive Officer
55	Reliance Industries Ltd.	Mr. Mukesh Ambani	Chairman & Managing Director
56	S&P Global Commodity Insights	Mr. Anupam Bagri	President
57	Seros Energy Private Limited	Mr. Devashish Marwah	CEO (Seros Well Services)
58	Shell Companies in India	Mr. Noor Khan	Director and Head – Government Relations, Policy and Advocacy
59	Siemens Ltd.	Mr. Guilherme Vieira De Mendonca	CEO (Siemens Energy - India)
60	SK Oilfield Equipment Company Pvt. Ltd.	Mr. Manav Kanwar	Managing Director
61	SLB	Mr. Lalit Aggarwal	Managing Director
62	SNF Flopam India Pvt. Ltd.	Mr. Shital Khot	Chairman & Managing Director
63	South Asia Gas Enterprise Pvt. Ltd.	Mr. Subodh Kumar Jain	Director
64	Sun Petrochemicals Pvt. Ltd.	Mr. Padam Singh	President
65	THINK Gas Distribution Pvt. Ltd.	Mr. Abhilesh Gupta	Managing Director & CEO
66	Topsoe India Private Limited	Mr. Alok Verma	Managing Director
67	TotalEnergies Gas and Power Projects India Pvt. Ltd.	Dr. Sangkaran Ratnam	Country Chair
68	University of Petroleum & Energy Studies	Dr. Ram Sharma	Vice-Chancellor
69	VCS Quality Services Pvt. Ltd.	Mr. Shaker Vayuvegula	Director
70	World Biogas Association	Ms. Charlotte Morton OBE	Chief Executive
71	World LP Gas Association	Mr. James Rockall	CEO & Managing Director

As on 21st August 2026



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