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Unlocking India’s Hydrokinetic Potential through Techno-Economic Analysis, Policy Insights and Pilot-Scale Feasibility

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***Abstract*— India possesses significant untapped hydrokinetic energy potential, with over 145,000 km of canals, major rivers, and hydropower tailraces capable of generating electricity from flowing water without the need for dams or significant head differences. The Central Electricity Authority (CEA) estimates this potential at approximately 92 GW, nearly twice the current large-hydro capacity. While international technologies such as GKinetic have achieved high Technology Readiness Levels, domestic developers like Maclec (Delhi) have implemented only small-scale pilot projects. The formal recognition of Surface Hydrokinetic Turbines (SHKT) under the hydro category by the CEA in November 2024 represents a critical step in clarifying regulatory pathways and enabling policy support. Nevertheless, challenges continue to remain which include seasonal flow variability, high sediment loads, limited national-level resource mapping and low investor confidence. The current study presents the first comprehensive synthesis of hydrokinetic resource potential, technology readiness, economic feasibility, and policy frameworks in India. It provides a structured roadmap for the large-scale deployment and mainstream adoption of SHKT technology.**

***Keywords*— Hydrokinetic Energy, Surface Hydrokinetic Turbines (SHKT), Canal-Based Renewable Power, Hydropower Tailraces, Techno-Economic Feasibility, India Renewable Energy Policy.**

I. INTRODUCTION

Till date Solar and wind power have been the main drivers of this growth. India's energy sector is changing rapidly as it tries to reach its goal of 500 GW of renewable capacity by 2030 and a net-zero pathway by 2070 (CEA, 2022 and PIB, 2024). As they are not always available, other renewable sources which can work all the time are required. One such opportunity is offered by hydrokinetic technology, which uses turbines to turn the kinetic energy of flowing water into electricity without the need for dams or head differences [5]. Hydrokinetic power is very important for India because of its unique situation. There are a lot of rivers that flow all year round and some that only flow during certain times of the year. There are also more than 145,000 km of canals and dozens of large hydropower plants with tailraces that let out controlled flows [8]. Unlike traditional hydropower, Hydrokinetic turbines can directly access this untapped resource which means that electricity can be made in a decentralised, modular, and environmentally friendly way.

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Pilot projects in the US, Canada, and Europe have shown that hydrokinetic systems can work technically [9]. India has made progress in recent years. The CEA's 2022 report [2] said that the theoretical hydrokinetic potential was 92 GW. International designs like GKinetic are at advanced TRLs, but domestic developers like Maclec (Delhi) and IMP Powers (Mumbai) have only done small-scale pilots. In November 2024, the CEA officially recognised Surface Hydrokinetic Turbines (SHKT) as part of the hydro category. This was a big step forward in policy [7].

II. EXPERIMENTAL METHODS AND MATERIALS

A. Canal Based Hydrokinetic Studies

Saini et al. (2021) in their study established a methodology aimed at evaluating the hydrokinetic potential within the Eastern Yamuna main canal.

This study provides a significant framework for assessing localised resources within the context of irrigation infrastructure in India.

B. Innovation in Turbine Design

Kumar (2016) has conducted a comprehensive review of Savonius-type hydrokinetic turbines, detailing performance parameters, efficiency factors, and their applicability to canals and rivers under Indian scenarios. Jayaram and Bavanish (2022) conducted simulation and experimental studies on Gorlov helical turbines, focussing on the optimisation of blade geometry (index of revolution) and validating performance in a river creek setting in India. The results indicated an output of approximately 1 W per unit (0.6 m).

C. National-Level Assessment and Technology Mapping

Final Report on SHK Turbines by CEA (2022) provides a thorough Canal Based Hydrokinetic Studies official assessment of India's hydrokinetic status, encompassing conceptual frameworks, technological classifications, site types (canals, rivers, tailraces), developer competencies, pilot structures, and commercial feasibility. The document presents essential data, including a theoretical potential of 92.2 GW and technology readiness levels (TRL 6–8) for Indian companies [2].

D. Discussion and Interpretation

The body of Indian literature regarding hydrokinetic technology is developing, yet remains constrained. Research conducted by Saini et al. (2021) and Jayaram & Bavanish (2022) emphasises interventions at the canal scale or turbine level. Kumar (2016) establishes the foundational performance parameters for a specific turbine type within the context of Indian hydrological conditions. The CEA Final Report (2022) is the sole comprehensive, centrally commissioned document that integrates resource potential, technology readiness, and commercial pathways.

Discrepancies observed are as follows:

- In India, there is no comprehensive, GIS-based resource mapping at the national level, unlike in other countries.
- There aren't many long-term field trials or operational data beyond small-scale assessments. There is not much integration between fields, like economic modelling, environmental impact assessment, and regulatory frameworks.
- There isn't much collaboration between academia and industry; most pilot studies are led by manufacturers and don't go through peer review.

III. HYDROKINETIC RESOURCE POTENTIAL IN INDIA

A. Scale of India's Water Infrastructure

The extensive hydrological network in India provides a crucial basis for substantial advancements in hydrokinetic energy development.

This encompasses the following:

- Canals where more than 145,000 km of channels are dedicated to irrigation and water delivery.
- Rivers and Tailraces where numerous regulated river systems and hydropower tailrace outlets present opportunities for turbine deployment, including those at the Koyna, Bhakra, and Nagarjuna Sagar projects.

In comparison, India's installed hydro power capacity serves as a significant resource for hydrokinetic integration.

B. Theoretical National Hydrokinetic Potential

The CEA's 2022 Final Report on SHK Turbine indicates a theoretical hydrokinetic energy potential of around 92 GW in India, which is nearly double the existing large hydro capacity. Nonetheless, the report also warns that this figure is preliminary, highlighting the necessity for thorough field validation and improved evaluations for accurate potential mapping.

C. Local-scale Canal Feasibility

A comprehensive modelling study of the Eastern Yamuna Main Canal evaluated the hydrokinetic potential within a specific localised segment.

The estimated capacity is approximately 26.48 MW, indicating significant energy potential even within specific canal reaches. This underscores that canal systems, when mapped and analysed systematically, can play a crucial role in localised energy generation.

To strengthen the techno-economic case, a few representative canals and tailraces were assessed using standard hydrokinetic power calculations.

$$P = \rho g Q H \eta$$

assuming a turbine efficiency of ~40%, water density $\rho = 1000\ kg/m^3$, and gravitational acceleration $g = 9.81\ m/sec^2$. The results are summarized in Table 1.

TABLE I: ESTIMATED HYDROKINETIC POTENTIAL AT SELECTED CANALS AND TAILRACES

Site	Flow Rate (m³/s)	Head (m)	Turbine Efficiency (%)	Estimated MW
Eastern Yamuna Canal	25	0.5	40	0.35
Indira Gandhi Main Canal	15	0.5	40	0.18
Koyna Tailrace	59	1.0	40	1.50
Bhakra Tailrace	51	1.0	40	1.20

Note: Estimated MW calculated as $P = \rho g Q H \eta$. These values represent potential for pilot-scale SHKT deployment.

These site-specific estimates highlight that even relatively small canal segments or regulated tailrace flows can support continuous, modular power generation. Integration of such quantitative assessments at this stage provides a practical basis for pilot selection, array sizing, and feasibility analysis and bridges the gap between theoretical potential and real-world deployment.

Quantitative Estimates of Hydrokinetic Potential

To provide a concrete perspective on India's hydrokinetic capacity, selected canals and tailraces have been evaluated based on available hydrological data, pilot studies, and theoretical extrapolations. Table 2 presents estimated capacities in MW for representative sites.

TABLE II: ESTIMATED HYDROKINETIC POTENTIAL IN SELECTED CANALS AND TAILRACES

Location	Estimated Potential (MW)	Notes
Eastern Yamuna Canal	26.48	Localized modeling study; potential for 904 turbine arrays under optimal flow conditions.
Malampuzha Canal, Kerala	~0.1	Pilot-scale demonstration highlighting feasibility in small irrigation canals.
Narmada Canal, Gujarat	~2.2	Indicative potential leveraging regulated flows; scalable integration feasible.
Tawa Reservoir Canal, Madhya Pradesh	13.5	Two units of 6.75 MW each; utilizes tailrace flows for energy generation.
General Canal Network	101.4	Aggregate potential estimated across 50,000 km of canals using theoretical extrapolation.

Even at localized scales, canal segments and regulated tailraces demonstrate significant potential for renewable electricity generation. These estimates complement the CEA's theoretical national hydrokinetic potential of ~92 GW thereby highlighting the scope for phased pilot projects, array-based deployments, and eventual commercial-scale integration. Even at localized scales, canal segments and regulated tailraces demonstrate significant potential for renewable electricity generation. These estimates complement the CEA's theoretical national hydrokinetic potential of ~92 GW, highlighting the scope for phased pilot projects, array-based deployments, and eventual commercial-scale integration.

D. Tailrace Integration Potential

Hydropower tailraces like those in Koyna offer significant potential for hydrokinetic deployment, thanks to their consistent and regulated flows. Although comprehensive estimates for hydrokinetic potential have not been released, the presence of established tailrace flows offers suitable locations for pilot integration.
Table 3 highlights significant Indian hydropower stations with tailraces that are promising candidates for hydrokinetic retrofits, considering their size, flow regulation, and nearby infrastructure.

TABLE III: INDIAN HYDROPOWER TAILRACES FOR HYDROKINETIC INTEGRATION

Hydropower station	Installed capacity (MW)	Tailrace suitability
Koyna (Maharashtra)	1956	Eastward side 2100 cusec discharge continuous
westward side discharge is also continuous		
Bhakra–Nangal (Himachal/ Punjab)	1325 (approx.)	Regulated tails into canals
Tehri (Uttarakhand)	1000 (Stage I)	Downstream controlled releases
Sardar Sarovar (Gujarat)	1450	Tailrace/canal integration potential
Indira Sagar (Madhya Pradesh)	1000	NHDC asset; downstream control; space for pilots
Nagarjuna Sagar (Telangana/Andhra)	816	Long regulated channels
Rihand (Uttar Pradesh)	300	Downstream regulation
Hirakud (Odisha)	347	Tailrace to the Mahanadi system

E. Gaps in National-Level Mapping

Even with the persuasive data, India remains without a thorough national-level GIS-based evaluation of hydrokinetic potential. Inspite of international efforts such as those by the U.S. Department of Energy and various European programs, India still considerably lacks a centralized database or comprehensive mapping initiative for its rivers, canals, or tailrace potentials. The focus continues to be on theoretical estimates and isolated channel studies.

IV. LANDSCAPE OF HYDROKINETIC TECHNOLOGY DEVELOPMENT IN INDIA

This section offers a comprehensive overview of the current landscape of hydrokinetic technology development in India, emphasising major domestic contributors, global standards, technology readiness levels, and design modifications suited to Indian conditions.

A. Major Indian Developers and Prototypes

Maclec Pvt. Ltd. (Delhi)

- Category: Surface Hydrokinetic Turbines (floating, zero-head units).
- Technical Capabilities: Demonstrated functionality in water flows as low as 0.5 m/s, with an anticipated operational lifespan of approximately 35 years, and environmentally friendly installation.
- CEA Engagement and Potential Impact: Maclec’s 2020 SHK turbine submission to CEA led to a panel review, showcasing India’s domestic manufacturing progress under ‘Make in India.’

IMP Powers (Mumbai)

- Offering 5 kW gearless axial-flow "Smart Hydro Kinetic Turbines."
- Maximum output achieved at water velocities ranging from 2.4 to 3.1 m/s.
  High Plant Load Factor (PLF): 75–85%, ideal for consistent base-load generation.
  Quick and flexible setup, expandable through arrays, suitable for grid, off-grid, and hybrid configurations.
- Illustrates the practical potential for deployment that is independent of site constraints, in harmony with India’s decentralised energy requirements.

International Players: GKinetic (Ireland)
Although GKinetic is not based in India, it has achieved globally advanced designs that have reached higher Technology Readiness Levels, establishing a performance benchmark for efforts within India. The 2021 presentation to the CEA showcased a comparative analysis and reflected strong interest in the technology.

B. Technology Readiness Levels (TRLs)

Domestic TRLs
Maclec’s SHK turbines are assessed to be at TRL 6–7, indicating that full-scale prototypes have been validated under operational conditions, although they have not yet undergone large-scale field deployment. IMP Powers is probably positioned within TRL 7–8, as operational pilots have demonstrated high PLFs, although they have not

yet been validated over prolonged periods.Assessment by Authorities: The CEA committee emphasized verifying performance claims through independent testing, especially given limited operational data and fluid dynamics complexities.

International Benchmark

GKinetic units appear to be at or nearing TRL 8 or higher, providing valuable reference points for Indian systems.

C. Design Considerations in Indian Conditions

Indian hydrokinetic projects face seasonal flow changes, monsoon debris and diverse water conditions.

Design perspective

Axial-flow turbines from IMP Powers offer compact design and efficient performance in moderate flows. Surface-floating designs, such as Maclec, offer advantages like reduced civil infrastructure requirements and simplified maintenance access. Considerations of Technical Compromises: CEA officials identified concerns, including heightened head loss in power channels and the limited efficiencies (approximately 40%) characteristic of SHK turbines, indicating that these turbines may be more appropriate for irrigation canals unless a redesign is undertaken.

D. Analytical summary

Indian developers have achieved significant progress in adapting hydrokinetic technologies to local contexts, moving from theoretical models to systems that are ready for pilot testing. Nevertheless, they are still in the demonstration phase (TRL 6–8)—an essential stage before commercialisation. Addressing challenges like performance verification, debris resilience, hydrodynamic impacts on current infrastructure, and seasonal variability requires structured field validation and collaboration across disciplines, including engineering, hydrology, and policy. International counterparts (e.g., GKinetic) emphasise the route to commercial readiness that Indian systems can adopt.

V. DEMONSTRATION PROJECTS

India has tested a number of hydrokinetic (HK) pilots that help with planning, operations, and scaling up. In Neyveli, Tamil Nadu, IMP Powers built a 20 kW canal-based installation (4×5 kW, axial-flow) that had a high PLF (>75%) and continued to work with the grid, generating more than 0.2 GWh of energy by 2021. IMP's pipeline also mentioned a 200 kW Bathinda (Punjab, PEDA) LOA and a 25 kW Kakkad (Kerala) pilot PO. Updates on public commissioning have been few and far between. THDC's Koteshwar downstream pilot in Uttarakhand showed 2×50 kW modules and a modular concept that could reach ~66 MW over ~21 km. A 2024 presentation went over the design, grid interface, and performance assessment plan. The developer's project pages say that Maclec's 50 kW Indira Gandhi Main Canal installation in Rajasthan is grid-synchronous. They also used Uttarakhand demos to learn how to mount, maintain, and collect data. [11-15].

Challenges in Scaling: Notable challenges include flow variability, sediment load, structural anchoring needs, and long-term durability—especially in high-flow or debris-laden riverine environments.

A. Integration of hydrokinetic with major hydropower in India

Large hydropower stations have controlled tailrace flows that are perfect for adding hydrokinetic energy. Integrating SHKT arrays into major Indian projects like Bhakra, Tehri, Koyna, and Nagarjuna Sagar can provide modular, 24-hour-a-day generation without the need for major civil works. Some possible benefits are more renewable energy capacity at existing sites, better local reliability through on-site auxiliary supply, lower transmission losses through behind-the-meter consumption, and shared operations and maintenance with current hydro operators. A first-order capacity screen using regulated tailrace discharges and conservative capture assumptions suggests that multi-MW opportunities may exist at long, regulated tailraces, while compact near-field zones can support tens to hundreds of kilowatts via modular arrays. Before buying, you need to do detailed ADCP surveys, CFD, and vendor power-curve matching to improve capacity and array layouts. [2, 7].

VI. TECHNO-ECONOMIC FEASIBILITY

A. Capital Cost Estimates

The Central Electricity Authority's 2022 review of small hydrokinetic turbines found that the reported capital costs vary widely. Maclec (domestic, with at least 50% local content) prices 1 MW-class arrays between ₹8 and

₹14.95 crore per MW. The low end is for a Bhakra Beas Management Board (BBMB) site that is fully indigenised, and the high end is for the Tanakpur canal. For smaller deployments, Maclec says it costs about ₹16 crore per MW. IMP Powers (a joint venture between a domestic and a foreign company with less than 50% local content) costs about ₹21.4 crore per MW. An imported option, GKinetic, has a 12 kW unit that costs about ₹24.7 lakh to build and about ₹55.5 lakh to buy. When installation and commissioning are not included, the cost per MW is about ₹46.25 crore. The CERC's standard capital cost range for traditional small hydro (SHP) is ₹7.8–11 crore per MW. In general, hydrokinetic options made in the US (Maclec, IMP) are much cheaper than systems made in other countries. However, the final costs depend on things like where they are built, civil works, grid interconnection, and site conditions.(2)

B. Estimated Electricity Tariffs

According to the CERC 2020 RE rules and the economic modelling in the 2022 CEA report, estimated generation tariff for SHKT (household) is between ₹2.6 and ₹3.0 per kWh, depending on CUF, capital cost, and O&M cost.

C. Economic Comparison

Table 4 compares capital costs per MW across small hydro, domestic SHK prototypes (Maclec, IMP), imported SHK (GKinetic), and conventional large hydro in India.

TABLE IV. CAPITAL COST PER MW

Technology	Capital Cost (₹ crore/MW)
Small Hydro Power (SHP)	7.8–11
Maclec SHK (Domestic)	8–15 (indigenized)
IMP SHK (Domestic)	~21.4
GKinetic SHK (Imported)	~46.25
Conventional Large Hydro (India)	70–200

VI. POLICY AND REGULATORY FRAMEWORK

A. Official Recognition by CEA (2024)

A significant advancement took place in November 2024, as the Central Electricity Authority (CEA) formally acknowledged Surface Hydrokinetic Turbine (SHKT) technology within the "Hydro" category. This acknowledgement was granted to encourage innovation and investigate alternative renewable technologies that are in harmony with India’s net-zero objectives and sustainable development aspirations. SHKTs were recognised for their effectiveness in delivering consistent, continuous power, particularly in areas with restricted grid connectivity, as well as their straightforward installation and affordability (generation cost ₹2–3 per unit).

B. Strategic Policy Implications

This official incorporation emphasises the Indian government’s willingness to incorporate SHKT into the larger energy framework. Important strategic implications are that SHKT can now be approached similarly to traditional hydro projects regarding approvals and standards, which streamlines project structuring and implementation. The policy promotes the utilisation of India's vast canal systems and hydropower tailraces for the implementation of SHKT. This acknowledgement is in harmony with India's commitments to achieving net-zero emissions and its efforts towards diversifying sustainable energy sources.

C. Policy Gaps & Required Enablers

In light of this achievement, it is essential to identify and address several gaps to ensure effective deployment: Unlike solar and wind, SHKT is not yet included under central schemes like RPOs (Renewable Purchase Obligations), viability gap funding, or state-level incentives. No established technical specifications or performance benchmarks compliant with BIS or CEA exist for SHKT systems. There is a deficiency in SHKT-specific mapping for canal and tailrace zones within the frameworks of national or state-level renewable energy planning.

D. Role of Key Agencies

- CEA: Mainly tasked with establishing standards, supervising pilot frameworks, and assessing eligibility within hydro sector initiatives.

- MNRE (Ministry of New & Renewable Energy): By incorporating SHKT into future research support, pilot schemes, and state incentive packages, it has the potential to play a critical role.
- State Utilities & DISCOMs: Potential enablers through RPO enforcement, grid connectivity facilitation, and local demonstration projects.
- R&D Institutions: Essential for the validation of SHKT performance in a variety of Indian hydrological settings, the development of technical specifications, and the use of GIS mapping tools and environmental assessments.

E. Strategic Recommendations

Table 5 outlines proposed policy actions for SHKT in India, covering regulation, standards, incentives, resource mapping, R&D, and pilot-to-scale deployment.

TABLE V: STRATAGIC RECOMMENDATION SUMMARY

Policy Area	Proposed Action
Regulatory Framework	Update small hydro/hydro policy to explicitly include SHKT projects.
Standards & Testing	Develop design, performance, and safety testing protocols via BIS & CEA.
Incentives	Tie SHKT deployment to RPO compliance and offer early-stage subsidies.
Resource Planning	Conduct national GIS mapping of canal and tailrace potential zones.
R&D Support	Launch SHKT collaborative research programs among government, academia, & industry.
Pilot to Scale	Encourage canal-tailrace hybrids and array-based field pilot deployments.

VIII. CHALLENGES AND BARRIERS

A. Technical Challenges

- Sediment and Debris Load: Erosion, clogging, and reduced turbine efficiency are frequently the result of high sediment concentrations in Indian rivers and canals, particularly during the monsoon. The safe and continuous operation of the system is further complicated by floating debris, such as vegetation.
- Flow Variability: Velocity profiles exhibit substantial discrepancies due to seasonal fluctuations. Natural rivers exhibit significant reductions in capacity utilisation during dry seasons, although canal flows are more tightly controlled.
- Anchoring and Structural Integrity: Robust anchoring is necessary for turbines that are installed in rivers or tailraces to withstand strong currents and floods. The absence of standardised anchoring solutions for Indian conditions continues to be a challenge.
- Efficiency Limits: Surface Hydrokinetic Turbines (SHKT) that are currently in use in India typically achieve conversion efficiencies of approximately 35–40%, which are lower than those of their hydro or wind counterparts. This affects investor confidence and the economy.

B. Economic and Financial Barriers

- High Capital Costs at Pilot Scale: Tariffs are anticipated to be as low as ₹2–3/kWh; however, the initial capital cost remains high (₹8–21 crore/MW for domestic systems and ₹46 crore/MW for imported units). In the absence of scale economies, projects are rendered unattractive to private investment.
- Limited Funding Mechanisms: SHKT is not currently supported by central schemes, viability gap funding, or state-level incentives, in contrast to solar and wind. The technology is unfamiliar to banks and financial institutions, resulting in restricted financing options.
- Revenue Risk: Investors perceive uncertainty in the actual output as a result of the absence of long-term operational datasets from Indian sites.

C. Policy and Institutional Barriers

- Absence of Standards: The procurement and deployment of SHKT devices are uncertain due to the absence of BIS/CEA standards for design, performance testing, and certification.
- Regulatory Delays: Although the recognition of CEA in 2024 was a significant development, the integration of CEA into Renewable Purchase Obligations (RPOs) and state renewable energy policies remains unfinished.
- Planning Gaps: Systematic project identification and planning have been hindered by the absence of national GIS-based resource mapping.

D. Social and Environmental Barriers

- Local Acceptance: Communities and irrigation authorities frequently express reluctance to permit experimental turbine installations in canals and rivers due to concerns regarding the potential disruption of irrigation flows or navigation.
- Environmental Concerns: Although the potential impacts on aquatic biodiversity and fish movement are generally less severe than those of conventional hydroelectric power, they necessitate meticulous monitoring. The scaling of SHKT is impeded by the absence of Environmental Impact Assessment (EIA) protocols.
- Awareness Gap: Policymakers, local utilities, and the general public are largely unaware of hydrokinetic technology. This results in a delay in the adoption of policies and the acquisition of stakeholder support.

IX. FUTURE ROADMAP FOR INDIA

A. National Resource Mapping and Assessment

The initial objective is to create a comprehensive GIS-based resource atlas for India's hydrokinetic potential, similar to the initiatives implemented by the U.S. Department of Energy and the European Marine Energy Centre. This mapping should encompass the following:

- Major river systems (Ganga, Brahmaputra, Godavari, Krishna, Narmada, Koyna, etc.)
- Canal networks (over 145,000 km of irrigation channels)
- Tailraces of large hydropower stations (Koyna, Bhakra, Tehri, Nagarjuna Sagar, etc.)

In order to generate accurate estimates of extractable capacity that surpass the CEA's theoretical figure of 92 GW, this evaluation must include seasonal flow data, sediment loads, and velocity-duration curves.

B. Structured Pilot Programs

India should adopt a phased pilot program led by MNRE, CEA, and state utilities:

- Phase 1 (Short-Term, 2025–2027): Deploy small-scale pilots (5–50 kW) in controlled canal/tailrace environments (e.g., Indira Gandhi Main Canal, Koyna tailrace). Concentrate on anchoring solutions and debris-handling designs.
- Phase 2 (Medium-Term, 2027–2032): In large canals and downstream regulated rivers (e.g., Bhakra tailrace, Yamuna canals), scale up to array-based demonstrations (0.5–5 MW). Gather data on operations and maintenance (O&M) and long-term performance.
- Phase 3 (Long-Term, 2032 onwards): Supported by tariffs, Renewable Purchase Obligations (RPOs), and private investment, integrate commercial-scale arrays (>10 MW) with grid interconnections.

C. Policy and Regulatory Mainstreaming

- Inclusion in RPO Targets: SHKT-generated electricity should be counted towards state DISCOM renewable obligations.
- Standardization: BIS and CEA should develop design and performance standards, certification protocols, and environmental impact guidelines.
- Financial Incentives: Similar to solar’s early years, SHKTs may require viability gap funding, capital subsidies, or concessional loans to improve bankability.
- Hybrid Integration: Promote canal-top solar + SHKT hybrids to maximize energy density from existing water infrastructure.

D. R&D and Institutional Support

A dedicated Hydrokinetic R&D Consortium should be created, involving IITs (Roorkee, Delhi, Madras), CWPRS Pune, and state hydropower utilities. Areas of focus:

- Turbine optimization for low-velocity flows (0.5–2.5 m/s)
- Debris and sediment mitigation techniques
- Anchoring systems and floating platforms
- Control systems and IoT-enabled monitoring for remote operation
- Environmental and socio-economic impact studies

E. Commercialization and Scaling

- Indigenous Manufacturing: Strengthen “Make in India” initiatives to reduce costs below ₹8 crore/MW and bring LCOE consistently within ₹2.0–2.5 per kWh.

- Private Sector Participation: Encourage partnerships between turbine developers (Maclec, IMP Powers) and EPC contractors to deliver turnkey SHKT projects.
- Export Potential: Position India as a hub for hydrokinetic turbine manufacturing, exporting to South Asia, Africa, and other emerging markets with large canal/river systems.

F. Alignment with National Targets

By systematically pursuing this roadmap, SHKT could contribute:

- 1–2 GW by 2032 through canal and tailrace deployments
- 10+ GW by 2040 with array-based scaling
- 25–30 GW by 2070, making a meaningful contribution to India's net-zero goal.

The proposed roadmap fills the gap between promising pilots and actual use in business. India can make SHKT technology a regular part of its renewable energy portfolio by focusing on resource mapping, structured pilots, regulatory inclusion, and indigenous manufacturing. Hydrokinetics could become a niche but scalable renewable energy source in India if its tariffs are competitive with those of solar and wind power, and it has the unique advantage of being able to generate power all the time.

X. CONCLUSION

Hydrokinetic technology offers a promising avenue to diversify and strengthen India's renewable energy portfolio, particularly by harnessing the untapped potential of canals and hydropower tailraces. With a theoretical national potential of ~92 GW as estimated by the CEA (2022), pilot initiatives—such as IMP Powers' 5 kW canal installations, Maclec's SHKT units, and downstream Koteshwar HEP demonstrations—have validated the technical feasibility under Indian conditions, though large-scale operational validation remains essential.

The CEA's 2024 recognition of Surface Hydrokinetic Turbines (SHKT) within the hydro category provides regulatory clarity and a pathway for mainstream adoption. Economic assessments suggest that domestically developed SHKT systems can deliver continuous, cost-competitive power at ₹2.6–3.0/kWh which makes them a viable complement to solar and wind energy. A few key challenges are seasonal flow variability, sediment management, limited long-term field data and the lack of comprehensive national mapping. These challenges must be addressed with the aid of structured pilot programs, indigenous manufacturing, standardization, and integration into Renewable Purchase Obligations. With the adoption of a coordinated roadmap combining resource mapping, phased pilot deployments, array-based scaling, and commercialization, SHKT has the potential to contribute multi-gigawatt capacity by 2040. This can in turn position India as a global leader in this emerging, scalable renewable sector and advancing the nation toward its net-zero 2070 vision.

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