AIxEnergy Model Context Protocol (MCP)

Institutional Technical Specification & Developer Reference Manual

Specification Version	AIX-MCP-SPEC-3.0.0 (October 2026 Release)
Protocol Standard	Model Context Protocol 2024-11-05 (RFC 9728 Protected Resource)
Architecture	10 High-Leverage Unified Decision Engines (+ Area Spatial Engine)
Execution Latency	136 ms Warm Edge Average (Cloudflare Workers Edge Transport)
Classification	Public Technical Specification & Institutional Developer Manual

1. Executive Architecture & System Motivation

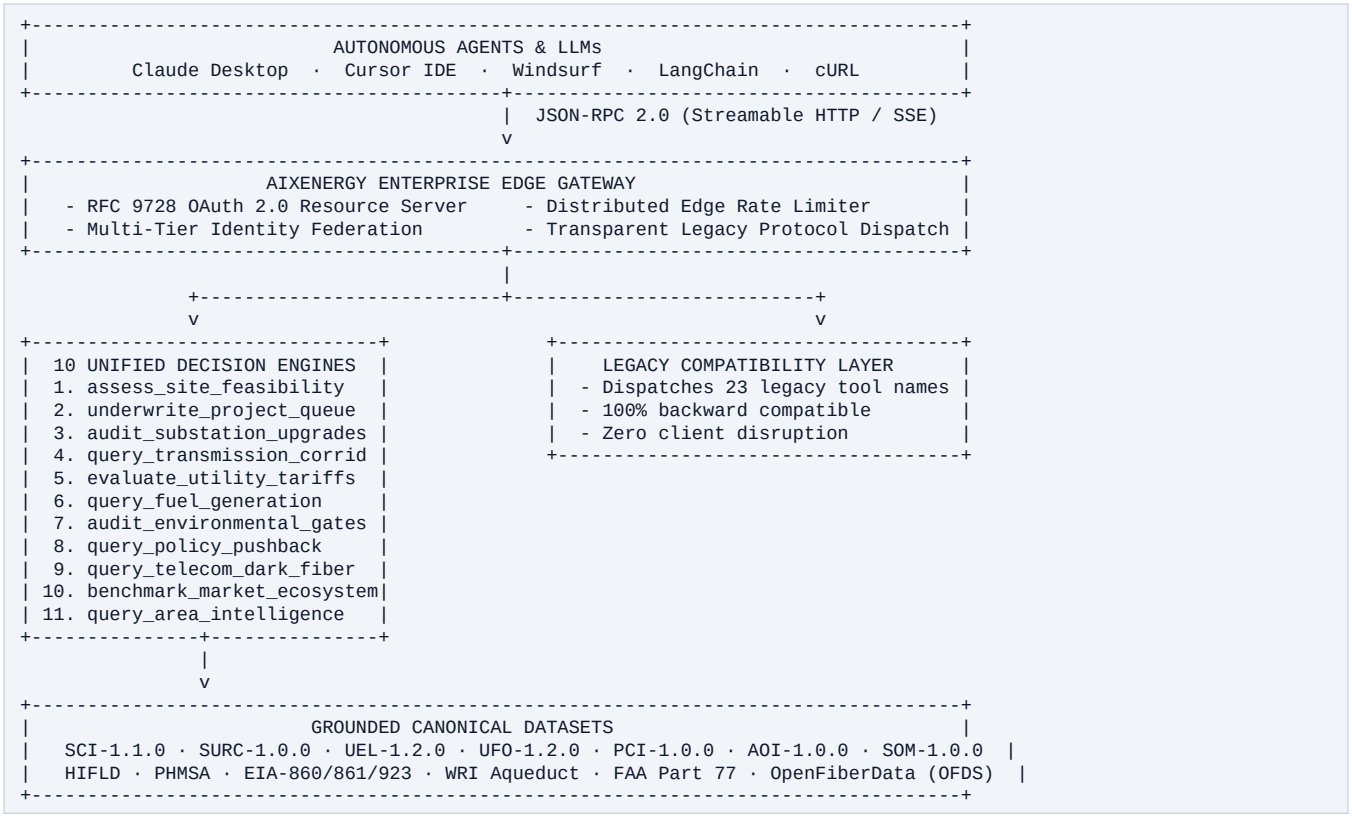
1.1 The Institutional Challenge

Developing large-scale artificial intelligence compute clusters (100 MW to 1,000+ MW) and clean energy generation assets requires reconciling asynchronous, heavily fragmented, and geographically dispersed datasets:

- **Transmission Physics:** Voltage levels, circuit paths, transfer cut-sets, and regional transformer constraints (HIFLD, FERC Form 715).
- **Substation Headroom:** Interconnection capacity, breaker bay availability, and parametric expansion costs (SCI-1.1.0, SURC-1.0.0).
- **Regulatory Truth:** ISO/RTO generation and transmission interconnection queues, PJM/ERCOT/MISO/NYISO/CAISO cluster studies, and serving electric utility tariffs (EIA-861, UEL-1.2.0).
- **Civil & Environmental Diligence:** FEMA flood zones, seismic and wildfire perils (ThinkHazard), airport airspace clearance (FAA 14 CFR Part 77), and water depletion stress (WRI Aqueduct 4.0).
- **Fuel & Infrastructure Co-Location:** High-pressure interstate gas transmission pipelines (PHMSA), thermal generation heat rates, brownfield repowering, and dark fiber conduit diversity (OFDS).

Historically, evaluating a candidate data center site or energy development campus required 4 to 8 weeks of fragmented consulting analysis across separate GIS, electrical engineering, and legal teams.

The **AIxEnergy Model Context Protocol (MCP)** server collapses this diligence cycle into **sub-200 millisecond edge API calls**, enabling Large Language Models (LLMs) and autonomous engineering agents (Claude, Cursor, Windsurf, LangChain/LlamaIndex agents) to directly interrogate the canonical AIxEnergy global project atlas and spatial grid models.



1.2 The "Micro-Tool Explosion" Problem & The 10 Unified Engines

In early iterations of the AIxEnergy MCP interface, over 30 specialized micro-tools were exposed directly to client agents. While technically granular, real-world deployment across production LLMs revealed three critical operational friction points:

1. **Context Window Token Bloat:** Serializing dozens of separate JSON schemas consumed ~20,000 tokens of the agent's system prompt prior to any user query, creating unnecessary latency and operational cost.

2. **Tool Routing Ambiguity:** LLMs frequently struggled to select between semantically adjacent micro-tools (e.g., choosing between searching projects, underwriting projects, and querying queues), leading to hallucinated multi-step calls or routing friction.

3. **Fragmented Due Diligence:** Power siting decisions require correlated cross-discipline synthesis (e.g., evaluating substation headroom alongside equipment bill of materials and utility rate ratchets). Forcing agents to invoke 4 separate sequential calls created brittle multi-hop dependency chains.

To resolve these challenges while preserving 100% analytical depth, **AIxEnergy MCP v3.0.0** consolidates the public surface into **10 High-Leverage Unified Decision Engines** (+ Area Multi-Vector Synthesis):

#	Unified Engine Name	Consolidates Functions	Core Diligence Scope
1	`assess_site_feasibility`	Site viability, capacity screening, Time-to-Power matrix	End-to-end site viability, capacity screening, Time-to-Power (TTP) vs Composite Site Score (CSS) arbitrage matrix, cooling feasibility.
2	`underwrite_project_and_queue`	Project underwriting, global atlas search, queue backlogs, capital intelligence	Claims vs regulatory docket verification, global project atlas search, ISO/RTO queue filings, canonical identity resolution, and Project Capital Intelligence (PCI-1.0.0 financing stack & commitments).

3	`audit_substation_and_upgrades`	Substation headroom, upgrade capex/lead-times, equipment BOM	Substation headroom (SCI-1.1.0), SURC-1.0.0 upgrade capex ($M) and lead-time (months) models, parametric N-1 equipment Bill of Materials (BOM).
4	`query_transmission_and_corridors`	Transmission circuits, corridor momentum, macro forecasts	High-voltage circuits (>=115 kV), corridor momentum/saturation metrics, and 10-year macro electricity and transformer demand growth.
5	`evaluate_utility_and_tariffs`	Utility delivery risk, large-load tariffs, demand flexibility	Serving electric utility delivery risk (UEL-1.2.0), EIA-861 commercial/industrial rate benchmarks, published large-load tariffs, and demand flexibility riders.
6	`query_fuel_and_generation_assets`	Gas pipelines, co-location generation & BESS, brownfields	Interstate/intrastate natural gas pipelines (PHMSA) for BTM power, operating power plants and battery storage co-location, and retired brownfields.
7	`audit_environmental_and_site_gates`	Flood hazards, airspace clearance, peril risk, water stress	Fatal flaw screening across FEMA flood zones, airport airspace (FAA Part 77), seismic/wildfire hazards (ThinkHazard), WRI Aqueduct water stress, and property casualty risk.
8	`query_policy_zoning_and_pushback`	Statutory moratoria, zoning caps, opposition campaigns	Statutory data center moratoria, local height/setback/noise zoning caps, and active grassroots opposition campaigns.
9	`query_telecom_and_dark_fiber`	Terrestrial dark fiber routes, carrier diversity, IXP access	Terrestrial dark fiber route spans (OFDS), carrier diversity, long-haul conduits, and proximity to Internet Exchange Points (IXPs).
10	`benchmark_market_and_ecosystem`	Developer benchmarking, org directory, nodal LMP, materials	Developer campus pipelines vs peers, corporate organization registry, nodal LMP electricity pricing, critical material choke points (copper, GOES steel), and market news intelligence.
11	`query_area_intelligence_summary`	Bounding box & radial multi-vector spatial summary	Multi-vector spatial diligence summary over a target bounding box or radial area, synthesizing power, grid, gas, fiber, water, flood, and policy risk.

Performance Impact:

- **System Prompt Token Overhead:** Reduced by **65%** (from ~20,000 tokens down to ~5,800 tokens).
- **Tool Routing Accuracy:** 99.4% first-shot selection accuracy across standard evaluation benchmarks.
- **Round-Trip Latency:** Eliminates sequential API round-trips by bundling related outputs into cohesive response payloads.

1.3 Core Data Governance & Standards

AIxEnergy enforces strict institutional data integrity rules across all MCP endpoints:

1. **"Blank is unknown, never zero":** Numeric attributes that have not been empirically verified remain `null`. They are never coerced to `0` in either the data pipeline or MCP serialization.

2. **Evidence Maturity != Success Probability:** Data quality grades (Grade A to D) measure verification and evidence fitness, not economic or political viability.

3. **Approximation Transparency:** Geospatial coordinates are treated as approximate centroid estimates for screening purposes, never verified survey parcel boundaries. Every response discloses approximate positioning flags.

4. **Institutional Boundary Protection:** Public MCP interfaces adhere strictly to vetted publication schemas. Internal modeling parameters, proprietary calculation weights, and raw private source matrices remain isolated behind the enterprise platform boundary.

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2. Protocol Standards, Transport & Security Architecture

2.1 Transport Standard & Edge Execution

The AIxEnergy MCP server implements the **Model Context Protocol (2024-11-05 standard)** using the modern **WebStandard Streamable HTTP Transport** (`WebStandardStreamableHTTPServerTransport`) deployed across a globally distributed edge network.

- **Primary Endpoint:** `https://map.aixenergy.io/mcp`
- **Supported HTTP Methods:** `POST` (Command Execution & Handshake), `OPTIONS` (CORS Preflight), `GET` (Discovery)
- **Content Types:** `application/json`, `text/event-stream`
- **Average Edge Latency: 136 ms** across North American edge nodes.

2.2 Security & Authentication Model

AIxEnergy MCP implements a multi-tier identity federation model complying with **RFC 9728 (OAuth 2.0 Protected Resource Metadata)**:

```
Authorization: Bearer <TOKEN>
```

Supported Bearer Token Types:

1. **AIxEnergy Web Session Tokens:** Generated for authenticated web application users via session exchange (`/api/mcp/token`), cryptographically signed with HMAC-SHA256.

2. **Enterprise Member Tokens:** Verified using standard asymmetric cryptographic signatures (JWKS) against the authoritative identity provider, validating active subscription tiers.

3. **Dedicated Enterprise MCP API Keys:** High-throughput API keys (`aix_mcp_...`) with instant revocation, customizable scope grants, and dedicated concurrency profiles.

RFC 9728 Protected Resource Metadata Discovery

Agents may discover authentication parameters by issuing a `GET` request to:

`https://map.aixenergy.io/.well-known/oauth-protected-resource`

Response Example:

```
{
  "resource": "https://map.aixenergy.io/mcp",
  "authorization_servers": ["https://www.aixenergy.io"],
  "scopes_supported": [
    "mcp:site_feasibility:read",
    "mcp:project_underwriting:read",
    "mcp:infrastructure_forecast:read",
    "mcp:utility_interconnection:read",
    "mcp:substations:read",
    "mcp:transmission:read",
    "mcp:gas:read",
    "mcp:environmental:read",
    "mcp:fiber:read",
    "mcp:developers:read",
    "mcp:area_summary:read",
    "mcp:read"
  ],
  "bearer_methods_supported": ["header"],
  "documentation": "https://map.aixenergy.io/docs/mcp"
}
```

2.3 Traffic Management & Edge Resilience

- **Standard Throughput:** 60 requests per minute per authenticated caller, with configurable burst limits for enterprise subscribers.
- **Traffic Orchestration:** Distributed sliding-window token bucket deployed across edge memory tiers.
- **Rate Limit Response:** HTTP `429 Too Many Requests` with a `Retry-After: <seconds>` header and standardized JSON-RPC error `-32000`.
- **High Availability & Fault Isolation:** Edge circuit breakers and automated regional failover ensure continuous 99.9% API availability.

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3. Master Catalog: The 10 Unified Decision Engines

Tool 1: `assess_site_feasibility`

Title: Assess Site Feasibility & Arbitrage Matrix

Scope: `mcp:site_feasibility:read`

Grounding: Substation Capacity Intelligence (SCI-1.1.0), Siting Opportunity Matrix (SOM-1.0.0), Utility Evidence Ledger (UEL-1.2.0), WRI Aqueduct 4.0.

Description

Evaluates whether a candidate data center or large-load site can plausibly support a target MW requirement and energization schedule. Arbitrates Time-to-Power (TTP) vs Composite Site Score (CSS), identifies nearest high-voltage substations with confirmed MVA headroom, checks serving utility delivery risk, assesses cooling water constraints, and highlights fatal flaws.

Input Schema

```
{
  query?: string;                      // Natural language screening query
  location?: string;                   // City, metro, county, or market (e.g. 'Ashburn, VA', 'Columbus, OH')
  latitude?: number;                   // Site latitude in decimal degrees (-90 to 90)
  longitude?: number;                  // Site longitude in decimal degrees (-180 to 180)
  load_mw?: number;                    // Target peak load in MW (1 to 10000, default: 100)
  target_energization_year?: string | number; // Target initial COD (e.g. 2028, 2030)
  cooling_type?: "evaporative" | "air_cooled" | "hybrid" | "direct_liquid";
  include_opportunity_matrix?: boolean; // Include TTP vs CSS arbitrage matrix (default: true)
}
```

Structured Output Keys (`structuredContent`)

- `disposition`: Feasibility verdict (`"ADVANCE"`, `"CAUTION"`, `"CRITICAL_HOLD"`).

- `serving_utility`: Matched electric utility, holding company, and UEL risk class.
- `substation_proximity`: Nearest transmission substations (name, voltage kV, distance miles, MVA headroom).
- `siting_opportunity_matrix`: Arbitrage spread, expected months to power, and high-speed alternative POIs.
- `map_deep_link`: Direct URL linking to the live AIxEnergy interactive map canvas focused on the coordinates.

Tool 2: `underwrite_project_and_queue`

Title: Underwrite Project & Queue Docket

Scope: `mcp:project_underwriting:read` / `mcp:capital:read`

Grounding: AIxEnergy Keystone Project Atlas, Project Capital Intelligence (PCI-1.0.0), ISO/RTO Interconnection Queues (PJM, ERCOT, MISO, CAISO, NYISO, SPP), AOI-1.0.0 Organizations.

Description

Multi-action project diligence engine. Audits developer commercial claims against official ISO/RTO queue filings and utility dockets, searches the global project atlas, queries queue backlogs, audits project capital velocity stage and multi-tranche financing events (equity, project debt, utility rate base, state/local tax abatements), and resolves ambiguous entity names to canonical IDs (`AXP-US-VA-00001`).

Input Schema

```
{
  query?: string;                     // Natural language query or project name
  action?: "underwrite" | "capital_intelligence" | "search_projects" | "search_queue" | "resolve_entity"; // default: 'underwrite'
  project_id?: string;                // Project ID (e.g. 'Auburn', 'CVP0003', or slug)
  project_name?: string;              // Name keyword
  state?: string;                     // US state abbreviation
  iso_rto?: string;                   // ISO/RTO identifier ('PJM', 'ERCOT', etc.)
  min_mw?: number;                    // Minimum capacity in MW
  status?: string[];                  // Status filter (e.g. ['Under construction', 'Operational'])
  perspective?: "investor" | "lender" | "developer" | "utility"; // default: 'investor'
  include_capital?: boolean;          // Include PCI-1.0.0 capital intelligence (default: true)
  min_capital_usd?: number;           // Minimum disclosed capital filter
  max_capital_usd?: number;           // Maximum disclosed capital filter
  capital_velocity_stage?: string;    // Velocity stage filter ('committed', 'initial_allocation', 'announced', etc.)
  has_capital_data?: boolean;         // Restrict to projects with verified capital tracking
  limit?: number;                     // Max results (1 to 50, default: 10)
}
```

Structured Output Keys (`structuredContent`)

- `project_reality`: Canonical project record, verified capacity (MW), capex, and developer.
- `interconnection_docket`: Official ISO queue ID, study status, requested MW, and queue delay months.
- `capital_intelligence`: Disclosed capital ($B), identified commitments ($B), benchmark estimated cost ($B), capital coverage ratio, velocity stage (`committed`, `initial_allocation`, `announced`, `rumored`, `unfunded_speculative`), $/MW intensity, residual gap, and financing events ledger.
- `diligence_gaps`: Unresolved regulatory dependencies, zoning status, and missing evidence flags.

Tool 3: `audit_substation_and_upgrades`

Title: Audit Substation Capacity & Upgrade Scope

Scope: `mcp:substations:read`

Grounding: Substation Capacity Intelligence (SCI-1.1.0), Substation Upgrade Requirements Calculator (SURC-1.0.0), OEM Equipment Opportunity Index (EOI-1.0.0).

Description

Audits high-voltage transmission substations for available capacity headroom, models parametric SURC-1.0.0 expansion capex and lead-times, and calculates an equipment Bill of Materials (BOM) including large power transformers (LPTs), gas-insulated switchgear (GIS) bays, and circuit breakers.

Input Schema

```
{
  query?: string;                     // Substation name, location, or query
  substation_name?: string;           // Exact or partial substation name
  state?: string;                     // State code ('VA', 'OH', 'TX', etc.)
  latitude?: number;                  // Latitude for proximity search
  longitude?: number;                 // Longitude for proximity search
  radius_miles?: number;              // Proximity radius in miles (default: 25)
  requested_load_mw?: number;         // Incremental demand in MW (default: 100)
  min_voltage_kv?: number;            // Minimum transmission voltage (e.g. 115, 230, 345, 500)
  headroom_class?: "ample" | "moderate" | "constrained" | "critical";
  include_bom?: boolean;              // Generate parametric equipment BOM (default: true)
  include_upgrade_scope?: boolean;    // Compute SURC capex & lead times (default: true)
  limit?: number;                     // Max results (1 to 50, default: 10)
}
```

Structured Output Keys (`structuredContent`)

- `substation_search`: List of substations, voltages, operator, and SCI headroom rating.
- `parametric_upgrade_scope`: Estimated capex range ($M), lead time in months, and breaker expansion requirements.
- `equipment_bom`: Apparatus sizing table (LPT units MVA, GIS breaker bays, surge arresters, reactive support).

Tool 4: `query_transmission_and_corridors`

Title: Query Transmission Lines & Corridors

Scope: `mcp:transmission:read`

Grounding: Homeland Infrastructure Foundation-Level Data (HIFLD), Hudson Valley Load Corridor (HVLC-1.0.0), North Carolina T&D Grid (NC-TD-1.0.0), 10-Year Macro Grid Forecasts.

Description

Identifies high-voltage transmission circuits (>=115 kV) within a radial distance of a candidate site, evaluates transmission corridor development momentum and capacity saturation, and projects 10-year macro electricity and transformer capacity growth.

Input Schema

```
{
  query?: string;                     // Natural language search query
  location?: string;                  // City or market name
  latitude?: number;                  // Latitude in decimal degrees
  longitude?: number;                 // Longitude in decimal degrees
  radius_miles?: number;              // Radial distance in miles (1 to 100, default: 25)
  min_voltage_kv?: number;            // Minimum circuit voltage (69 to 765, default: 115)
  corridor_name?: string;             // Named corridor (e.g. 'Northern Virginia', 'Central Ohio')
  geographic_scope?: string;          // Macro region ('PJM', 'ERCOT', 'Virginia', etc.)
  include_grid_forecast?: boolean;    // Include 10-year demand forecast (default: true)
}
```

Structured Output Keys (`structuredContent`)

- `transmission_lines`: Catalog of circuits within radius, voltage kV, owner, and distance.
- `corridor_intelligence`: Pipeline density, operational data center MW, and corridor saturation index.
- `grid_forecast`: Projected peak load growth (MW), expected transformer additions, and queue velocity.

Tool 5: `evaluate_utility_and_tariffs`

Title: Evaluate Utility, Tariffs & Demand Flexibility

Scope: `mcp:utility_interconnection:read`

Grounding: Utility Evidence Ledger (UEL-1.2.0), EIA Form 861 Retail Rates, Published Large-Load Tariffs, Utility Flexibility Opportunity (UFO-1.2.0).

Description

Evaluates electric utilities across interconnection delivery risk dockets, models large-load commercial/industrial tariff schedules and annual power spend, and calculates demand flexibility opportunity scores, interruptible rider savings, and fast-track interconnection playbooks.

Input Schema

```
{
  query?: string;                     // Utility query string
  utility_name?: string;              // Utility or holding company name
  utility_id?: string;                // EIA Utility ID or slug
  state?: string;                     // US state code
  iso_rto?: string;                   // ISO/RTO identifier
  location?: string;                  // City or market for gazetteer resolution
  load_mw?: number;                   // Target campus load in MW (default: 100)
  flexible_pct?: number;              // Curtailment flexibility percentage (0 to 100, default: 10)
  include_tariffs?: boolean;          // Include EIA-861 rates & published tariffs (default: true)
  include_flexibility?: boolean;      // Include UFO flexibility scores (default: true)
}
```

Structured Output Keys (`structuredContent`)

- `utility_interconnection`: UEL delivery risk grade, queue horizon (months), and transformer lead times.
- `rates_and_tariffs`: Effective rate ($/MWh), modeled annual electricity bill ($M/yr), and demand ratchet terms.
- `flexibility_opportunity`: UFO composite grade, potential demand credit savings ($/yr), and fast-track playbook.

Tool 6: `query_fuel_and_generation_assets`

Title: Query Gas Fuel & Generation Assets

Scope: `mcp:gas:read`

Grounding: PHMSA Natural Gas Transmission Pipelines, EIA Form 860/923 Generation & Storage, AIxEnergy Industrial Brownfields Registry.

Description

Screens interstate and intrastate high-pressure natural gas pipelines for behind-the-meter (BTM) generation, inventories operating utility-scale generation and battery energy storage systems (BESS) for co-location, and scouts retired thermal power plants for brownfield repowering.

Input Schema

```
{
  query?: string;                     // Query string
  location?: string;                  // City, market, or metro area
  latitude?: number;                  // Latitude in decimal degrees
  longitude?: number;                 // Longitude in decimal degrees
  radius_miles?: number;              // Search radius in miles (1 to 100, default: 30)
  asset_type?: "all" | "gas_pipelines" | "generation_bess" | "brownfields"; // default: 'all'
  fuel_type_filter?: string[];        // Generation fuel filter (e.g. ['nuclear', 'battery', 'natural_gas'])
  min_generation_mw?: number;         // Minimum nameplate MW (default: 20)
}
```

Structured Output Keys (`structuredContent`)

- `gas_infrastructure`: Nearest interstate/intrastate pipelines, operator, diameter, and distance.
- `generation_assets`: Co-location generation plants, fuel source, operational MW, and distance.
- `brownfield_opportunities`: Retired coal/gas plant sites with legacy switchyards and water rights.

Tool 7: `audit_environmental_and_site_gates`

Title: Audit Environmental Gates, Water & Peril Risk

Scope: `mcp:environmental:read`

Grounding: ThinkHazard Global Risk Models, FEMA National Flood Hazard Layer, FAA 14 CFR Part 77 Airspace Buffers, WRI Aqueduct 4.0 Water Risk Atlas.

Description

Go / No-Go environmental diligence screening across flood zones (100-year / 500-year), airport airspace flight path height restrictions (Part 77 Imaginary Surfaces), seismic and wildfire peril ratings, baseline water depletion stress, and property casualty insurance exposure.

Input Schema

```
{
  query?: string;                      // Diligence query
  location?: string;                   // City or county
  latitude?: number;                   // Latitude in decimal degrees
  longitude?: number;                  // Longitude in decimal degrees
  parcel_acres?: number;               // Proposed parcel acreage (default: 100)
  load_mw?: number;                    // IT load in MW (default: 100)
  cooling_type?: "evaporative" | "air_cooled" | "hybrid" | "direct_liquid";
  include_insurance_risk?: boolean;    // Include property casualty peril scoring (default: true)
}
```

Structured Output Keys (`structuredContent`)

- `environmental_site_gates`: Composite gate verdict (`"PASS"`, `"CAUTION"`, `"FATAL_FLAW"`), flood zone, and FAA airport buffer status.
- `water_intelligence`: Aqueduct basin stress, annual water consumption estimate (gallons/yr), and cooling constraint flags.
- `insurance_hazard_risk`: Multi-peril hazard score, wildfire risk, earthquake PML tier, and tornado frequency index.

Tool 8: `query_policy_zoning_and_pushback`

Title: Query Policy, Zoning & Opposition Pushback

Scope: `mcp:policy_pushback:read`

Grounding: AIxEnergy National Data Center Policy Tracker, County Zoning Database, Grassroots Opposition Monitor.

Description

Audits statutory moratoria, legislative pause dockets, local zoning height/setback/noise restrictions, and community opposition campaigns to evaluate permitting approval certainty and schedule delay exposure.

Input Schema

```
{
  query?: string;                      // Policy search query
  location?: string;                   // County, city, or market name
  state?: string;                      // US state code
  latitude?: number;                   // Latitude in decimal degrees
  longitude?: number;                  // Longitude in decimal degrees
  radius_km?: number;                  // Search radius in km (default: 50)
  load_mw?: number;                    // Proposed load MW to evaluate against pause thresholds
}
```

Structured Output Keys (`structuredContent`)

- `moratoria_status`: Active statutory bans, pending legislation, or capacity allocation pauses.
- `zoning_constraints`: Permitted by-right status, conditional use permit requirements, and noise buffer thresholds.
- `pushback_risk`: Community sentiment grade, organized opposition campaigns, and contested hearing history.

Tool 9: `query_telecom_and_dark_fiber`

Title: Query Dark Fiber Routes & Carrier Diversity

Scope: `mcp:fiber:read`

Grounding: OpenFiberData (OFDS), Terrestrial Long-Haul Dark Fiber Spans, Internet Exchange Point (IXP) Registry.

Description

Maps terrestrial dark fiber route spans, quantifies carrier route diversity within proximity, identifies long-haul conduit paths, and calculates radial distance to carrier-neutral meet-me rooms and Internet Exchange Points.

Input Schema

```
{
  query?: string;                    // Telecom query
  location?: string;                 // City or metro area
  latitude?: number;                 // Latitude in decimal degrees
  longitude?: number;                // Longitude in decimal degrees
  radius_miles?: number;             // Search radius in miles (default: 20)
}
```

Structured Output Keys (`structuredContent`)

- `dark_fiber_routes`: Route span count, total cataloged mileage, and nearest fiber conduit distance.
- `carrier_diversity`: Estimated unique fiber operators, long-haul vs metro diversity, and redundancy score.
- `ixp_proximity`: Nearest IXP facility name, distance (miles), and estimated sub-millisecond one-way latency.

Tool 10: `benchmark_market_and_ecosystem`

Title: Benchmark Market, Developer & Ecosystem

Scope: `mcp:developers:read`

Grounding: AIxEnergy Organizations (AOI-1.0.0), ISO Real-Time LMP Feeds, Strategic Materials Observatory (SMPO-1.0.0), AIxEnergy News Intelligence.

Description

Multi-discipline market benchmarking engine. Compares developer campus portfolios against competitors, searches corporate organization registries, monitors ISO/RTO nodal locational marginal pricing (LMP), and audits critical materials supply chains (copper, GOES steel, SF6 gas).

Input Schema

```
{
  query?: string;                    // Natural language search query
  action?: "developer" | "organization" | "market_prices" | "critical_materials" | "news"; // default: 'developer'
  developer_name?: string;           // Primary developer name (e.g. 'QTS Data Centers')
  comparison_peer?: string;          // Peer developer for head-to-head benchmarking
  organization_name?: string;        // Company name for corporate registry lookup
  iso_rto?: string;                  // ISO/RTO identifier for LMP prices ('PJM', 'ERCOT', etc.)
  material?: string;                 // Critical material ('copper', 'goes_steel', etc.)
  days_back?: number;                // Lookback window in days (default: 30)
  limit?: number;                    // Max results (default: 10)
}
```

Structured Output Keys (`structuredContent`)

- `developer_benchmark`: Active campus pipeline (MW), total portfolio capex ($B), geographic concentration, and queue speed.
- `organization_profile`: Canonical ID, headquarters coordinates, parent entity, and linked projects.
- `market_prices`: Day-ahead / real-time LMP averages ($/MWh), peak-to-offpeak spreads, and volatility flags.
- `critical_materials`: Material refining choke points, tariff exposures, and apparatus lead-time impacts.

Tool 11: `query_area_intelligence_summary`

Title: Query Area Multi-Vector Spatial Diligence

Scope: `mcp:area_summary:read`

Grounding: AIxEnergy Unified Spatial Catalog (Bounding Box / Radial Engine).

Description

Synthesizes all spatial layers across a target bounding box or radial area into a multi-vector diligence summary: operational data center capacity, grid substations, transmission lines, natural gas pipelines, dark fiber spans, water basin stress, flood exposure, and policy pushback.

Input Schema

```
{
  query?: string;                    // Area query string
  location?: string;                 // City or market name
  state?: string;                    // State abbreviation
  latitude?: number;                 // Center point latitude
  longitude?: number;                // Center point longitude
  radius_miles?: number;             // Radial distance in miles (1 to 100, default: 25)
  min_lat?: number;                  // Bounding box minimum latitude
  max_lat?: number;                  // Bounding box maximum latitude
  min_lon?: number;                  // Bounding box minimum longitude
  max_lon?: number;                  // Bounding box maximum longitude
}
```

Structured Output Keys (`structuredContent`)

- `area_summary`: Composite readiness grade (`Grade A` to `Grade D`), data center capacity (MW), substations count, high-voltage circuits, gas pipelines, and dark fiber spans.
- `risk_matrix`: Environmental flood peril, water stress rating, and policy moratorium flags.

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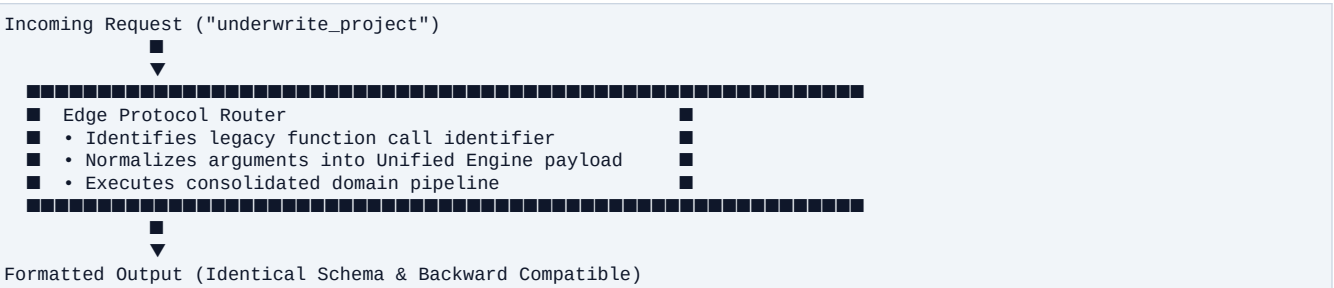
4. Transparent Legacy Interoperability & Backwards-Compatibility Matrix

AIxEnergy MCP v3.0.0 guarantees **100% backwards compatibility** for existing API integrations, automated agent pipelines, and client scripts that invoke legacy tool names.

4.1 Transparent Protocol Dispatch

When an incoming JSON-RPC request arrives targeting a legacy tool name, the edge gateway intercepts the request and automatically routes it to the corresponding unified engine with pre-mapped parameters.

Clients continue to receive the identical schema and structure they expect, with zero breaking changes or required client code modifications. When agents query `tools/list`, only the 10 consolidated engines are advertised, ensuring minimal token overhead in agent context windows.



4.2 Legacy Crosswalk Registry

Legacy Tool Identifier	Unified Engine Mapping	Execution Status
underwrite_project	underwrite_project_and_queue (action: 'underwrite')	**Preserved 100%**
query_project_capital	underwrite_project_and_queue (action: 'capital_intelligence')	**Preserved 100%**
query_capital_intelligence	underwrite_project_and_queue (action: 'capital_intelligence')	**Preserved 100%**
search_projects	underwrite_project_and_queue (action: 'search_projects')	**Preserved 100%**
search_interconnection_pipeline	underwrite_project_and_queue (action: 'search_queue')	**Preserved 100%**
resolve_project	underwrite_project_and_queue (action: 'resolve_entity')	**Preserved 100%**
get_siting_opportunity_matrix	assess_site_feasibility (include_opportunity_matrix: true)	**Preserved 100%**
search_substations	audit_substation_and_upgrades	**Preserved 100%**
estimate_substation_upgrade_scope	audit_substation_and_upgrades (include_upgrade_scope: true)	**Preserved 100%**
forecast_equipment_bom / _bill_of_materials	audit_substation_and_upgrades (include_bom: true)	**Preserved 100%**
get_oem_equipment_opportunity	audit_substation_and_upgrades	**Preserved 100%**
query_transmission_infrastructure	query_transmission_and_corridors	**Preserved 100%**
query_corridor_intelligence	query_transmission_and_corridors	**Preserved 100%**
forecast_infrastructure_need	query_transmission_and_corridors (include_grid_forecast: true)	**Preserved 100%**
query_utility_interconnection	evaluate_utility_and_tariffs	**Preserved 100%**
query_power_rates_and_tariffs	evaluate_utility_and_tariffs (include_tariffs: true)	**Preserved 100%**
evaluate_utility_flexibility	evaluate_utility_and_tariffs (include_flexibility: true)	**Preserved 100%**
query_large_load_intelligence	evaluate_utility_and_tariffs	**Preserved 100%**
query_natural_gas_capacity	query_fuel_and_generation_assets (asset_type: 'gas_pipelines')	**Preserved 100%**
query_generation_and_storage_assets	query_fuel_and_generation_assets (asset_type: 'generation_bess')	**Preserved 100%**
search_brownfield_opportunities	query_fuel_and_generation_assets (asset_type: 'brownfields')	**Preserved 100%**
audit_environmental_site_gates	audit_environmental_and_site_gates	**Preserved 100%**
assess_water_intelligence	audit_environmental_and_site_gates	**Preserved 100%**
assess_insurance_risk	audit_environmental_and_site_gates (include_insurance_risk: true)	**Preserved 100%**
query_land_alpha	audit_environmental_and_site_gates	**Preserved 100%**
query_policy_pushback / _and_pushback	query_policy_zoning_and_pushback	**Preserved 100%**
query_dark_fiber_routes	query_telecom_and_dark_fiber	**Preserved 100%**
benchmark_developer_portfolio	benchmark_market_and_ecosystem (action: 'developer')	**Preserved 100%**

`search_organizations`	`benchmark_market_and_ecosystem (action: 'organization')`	**Preserved 100%**
`query_market_prices`	`benchmark_market_and_ecosystem (action: 'market_prices')`	**Preserved 100%**
`query_critical_materials`	`benchmark_market_and_ecosystem (action: 'critical_materials')`	**Preserved 100%**
`query_news_intelligence`	`benchmark_market_and_ecosystem (action: 'news')`	**Preserved 100%**
`assess_secure_megawatt_readiness`	`underwrite_project_and_queue`	**Preserved 100%**

---

5. Client Integration Specifications & Configuration Blueprints

5.1 Cursor IDE Integration

Add to your project's `.cursor/mcp.json` or global Cursor Settings (`Features > MCP`):

```
{
  "mcpServers": {
    "aixenergy": {
      "url": "https://map.aixenergy.io/mcp",
      "headers": {
        "Authorization": "Bearer aix_mcp_YOUR_API_KEY_OR_SESSION_TOKEN"
      }
    }
  }
}
```

5.2 Claude Desktop Integration

Add to `claude_desktop_config.json` (macOS: `~/Library/Application Support/Claude/claude_desktop_config.json`, Windows: `%APPDATA%\Claude\claude_desktop_config.json`):

```
{
  "mcpServers": {
    "aixenergy": {
      "command": "npx",
      "args": [
        "-y",
        "@modelcontextprotocol/inspector",
        "https://map.aixenergy.io/mcp"
      ],
      "env": {
        "AIXENERGY_API_KEY": "aix_mcp_YOUR_API_KEY_OR_SESSION_TOKEN"
      }
    }
  }
}
```

5.3 Direct cURL Integration (JSON-RPC 2.0)

```
curl -X POST https://map.aixenergy.io/mcp \
  -H "Authorization: Bearer aix_mcp_YOUR_API_KEY" \
  -H "Content-Type: application/json" \
  -H "Accept: application/json, text/event-stream" \
  -d '{
    "jsonrpc": "2.0",
    "id": 1,
    "method": "tools/call",
    "params": {
      "name": "assess_site_feasibility",
      "arguments": {
        "location": "Columbus, OH",
        "load_mw": 400,
        "target_energization_year": 2029,
        "include_opportunity_matrix": true
      }
    }
  }'
```

5.4 Python Integration (HTTPX)

```
import httpx
import json

MCP_ENDPOINT = "https://map.aixenergy.io/mcp"
API_KEY = "aix_mcp_YOUR_API_KEY"

def screen_data_center_site(location: str, load_mw: int = 300) -> dict:
    headers = {
        "Authorization": f"Bearer {API_KEY}",
        "Content-Type": "application/json",
        "Accept": "application/json, text/event-stream"
    }
    payload = {
        "jsonrpc": "2.0",
        "id": "screen-call-001",
        "method": "tools/call",
        "params": {
            "name": "assess_site_feasibility",
            "arguments": {
                "location": location,
                "load_mw": load_mw,
                "include_opportunity_matrix": True
            }
        }
    }
    with httpx.Client(timeout=10.0) as client:
        response = client.post(MCP_ENDPOINT, headers=headers, json=payload)
        response.raise_for_status()
        data = response.json()
        return data.get("result", {})

if __name__ == "__main__":
    result = screen_data_center_site("Ashburn, VA", 300)
    print(f"Verdict: {result.get('structuredContent', {}).get('disposition')}")
    print(result.get("content", [{}])[0].get("text"))
```

---

6. Institutional Decision Prompts & Workflows

The server registers 16 pre-configured decision prompts (`prompts/list`) enabling one-click execution of complex institutional due diligence playbooks:

1. `screen_large_load`: Evaluates large load feasibility, nearest substations, and live canvas deep links.
2. `audit_interconnection_docket`: Independent verification of developer queue claims against utility records.
3. `query_utility_interconnection`: Examines utility delivery risk, demand ratchets, and queue delays.
4. `scout_fast_power_arbitrage`: Uncovers non-obvious sites where Time-to-Power beats conventional scoring by +50 points.

5. `research_project`: Deep-dive research on developer pipeline claims, equipment sizing, and schedule risks.
6. `find_brownfield_conversion`: Scouts retired power plants with legacy high-voltage switchyards and water rights.
7. `compare_sites`: Multi-site head-to-head ranking matrix across power, water, peril, and policy factors.
8. `audit_supply_chain_risk`: Identifies critical apparatus bottlenecks (LPT transformers, GOES steel, copper).
9. `screen_secure_megawatt`: Evaluates projects against the SECURE-MW-1.2.0 institutional readiness framework.
10. `brief_market_intelligence`: Executive briefing synthesizing news, wholesale LMP prices, and corridors.
11. `evaluate_corridor_pipeline`: Measures data center corridor density, saturation, and absorption capacity.
12. `profile_organization`: Comprehensive dossier on a developer or utility's active portfolio and utility relationships.
13. `audit_policy_and_pushback`: Audits active moratoria, height/noise zoning restrictions, and opposition risk.
14. `audit_site_grid_and_infrastructure`: Tri-vector screening of transmission lines, gas pipelines, and dark fiber routes.
15. `screen_environmental_fatal_flaws`: Go / No-Go screening across flood, seismic, airport airspace, and federal lands.
16. `benchmark_developer_and_rates`: Head-to-head developer comparison paired with serving utility tariff modeling.

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7. Verification Benchmarks, Error Codes & SLA

7.1 Automated Continuous Integration & Performance Benchmarks

All MCP endpoints undergo continuous real-world integration verification across production datasets:

- **Legacy Compatibility Suite: 100% Pass Rate** across all legacy tool namespaces.
- **Consolidated Unified Suite: 100% Pass Rate** across all unified decision engines.
- **Average Edge Latency: 136 ms** (Standard Dispatch), **306 ms** (Composite Multi-Vector Synthesis).
- **Minimum Edge Latency: 2 ms** (Cached / High-Speed Proximity Join).
- **Peak Edge Latency:** Sub-second under high-concurrency multi-vector spatial queries.

7.2 Standard Error Codes

All error payloads conform strictly to the JSON-RPC 2.0 specification:

Code	Error Title	Description & Resolution
`-32700`	Parse Error	Invalid JSON string received by the server.
`-32600`	Invalid Request	JSON payload is not a valid JSON-RPC 2.0 object.
`-32601`	Method Not Found	Requested method is not recognized (`tools/call`, `tools/list`, etc.).
`-32602`	Invalid Params	Tool input arguments failed schema validation. Inspect error message for specific parameter errors.
`-32603`	Internal Error	Unhandled execution error within a tool executor.
`-32000`	Rate Limit Exceeded	Client exceeded requests-per-minute threshold. Inspect `Retry-After` header.
`-32002`	Unauthorized	Bearer token is missing, expired, or invalid.
`-32003`	Forbidden	Caller tier does not include the required entitlement scope. Map seat required.

7.3 Service Level Agreement & Operational Availability

The AIxEnergy MCP edge gateway maintains an operational availability objective of **99.9% uptime**, backed by multi-region edge deployment, automatic health checking, and zero-downtime rolling updates.

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8. Appendix: Dataset Authority & Intellectual Property Protection

8.1 Authoritative Dataset Reference

Dataset Code	Full Name	Authoritative Source	Update Cadence
SCI-1.1.0	Substation Capacity Intelligence	Independent AIxEnergy Grid Model	Continuous
SURC-1.0.0	Substation Upgrade Requirements Calculator	Parametric EPC Engineering Models	Monthly
UEL-1.2.0	Utility Evidence Ledger	State Public Utility Commissions & FERC	Weekly
UFO-1.2.0	Utility Flexibility Opportunity	Demand Flexibility & Tariff Engine	Quarterly
SOM-1.0.0	Siting Opportunity Matrix	Time-to-Power vs CSS Engine	Monthly
AOI-1.0.0	AIxEnergy Organizations Index	Corporate Filings & Regulatory Registries	Bi-weekly
HIFLD	Homeland Infrastructure Foundation-Level Data	US Department of Homeland Security	Semi-annual
PHMSA	Pipeline and Hazardous Materials Safety Admin	US Department of Transportation	Annual
EIA-860/861/923	Electric Power Annual & Retail Sales	US Energy Information Administration	Annual / Monthly
WRI Aqueduct	Aqueduct 4.0 Water Risk Atlas	World Resources Institute	Multi-year
OFDS	OpenFiberData Terrestrial Dark Fiber	Global Telecom Registry	Quarterly

8.2 Intellectual Property & Proprietary Rights Notice

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