BRIEF · PHYSICS-INFORMED INDUSTRIAL AI

Wellhead: industrial AI for *upstream operations.*

Pure-ML approaches failed in upstream because reservoir engineers reject any output without a physical mechanism. Wellhead is physics-informed by construction, edge-deployed by default, with regulator-ready ESG signing built in. The runtime survives 30+ days disconnected; cross-operator learning happens on aggregated gradients, never raw telemetry.

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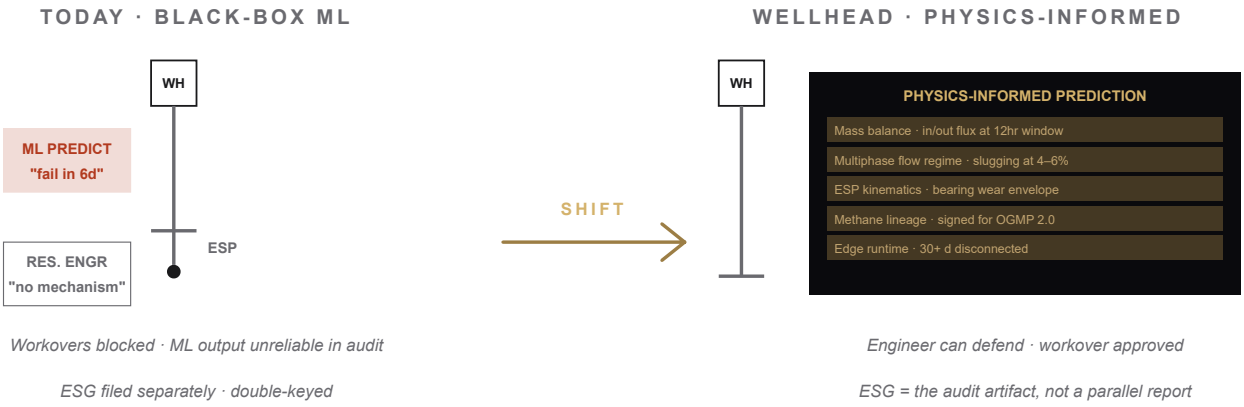
Targets Aramco · ExxonMobil · Shell · Occidental

The Problem

1.2M producing wells globally; unplanned downtime runs $38–88M per facility per year offshore, and industry-wide benchmarks put the aggregate cost in the tens of billions. The 2018–2023 pure-ML wave lost: reservoir engineers don't approve workovers on outputs they can't mechanistically defend. Concurrently, **methane regulation hit calendar deadlines** (EPA NSPS OOOOb/c, EU Methane Reg, OGMP 2.0) requiring operator-signed lineage on emissions. Operators currently file separately. The disconnect between operational AI and regulator-grade ESG is the gap.

FIGURE 1 · PREDICTIVE SHIFT



Today (left): pure-ML prediction is rejected by reservoir engineers because they can't trace the mechanism. Wellhead (right): every prediction surfaces a defensible mechanism (mass balance, flow regime, equipment kinematics) plus a signed methane-lineage record that is the regulator filing.

Why this matters now

Three forces converge: **methane regs hit calendar deadlines** (NSPS OOOOb/c on new and modified US sources, EU Methane Reg on importers, and OGMP 2.0 whose voluntary membership now covers about 42% of global oil and gas production), **ESP installed base aged into failure window** (2014–18 bulge now at years 8–12), and **physics-informed ML cleared a 2024 deployability inflection**. The first vendor combining them wins the brownfield.

Sizing the prize

Bottom-up: **1.2M wells × $80K / well / yr addressable = $96B / yr TAM** (Wood Mac + Rystad). Realistic capture: **$8–14B / yr** at vendor-share. ESG signing adds a fixed compliance line. Wedge: ESP failure prediction at *one* major's brownfield, where downtime reduction shows up cleanest in audit.

Sources: Wood Mackenzie (2024–25); Rystad Energy (2024–25); EPA NSPS OOOOb/c final rule (2024); EU Methane Regulation (2024); OGMP 2.0 / UNEP (2025). Per-well TAM is modeled bottom-up against 5 operator-CTO interviews.

UPSTREAM AI TAM
$96B / yr
1.2M wells × $80K avg

REALISTIC CAPTURE
$8–14B / yr
Vendor-share economics

Strategic insight

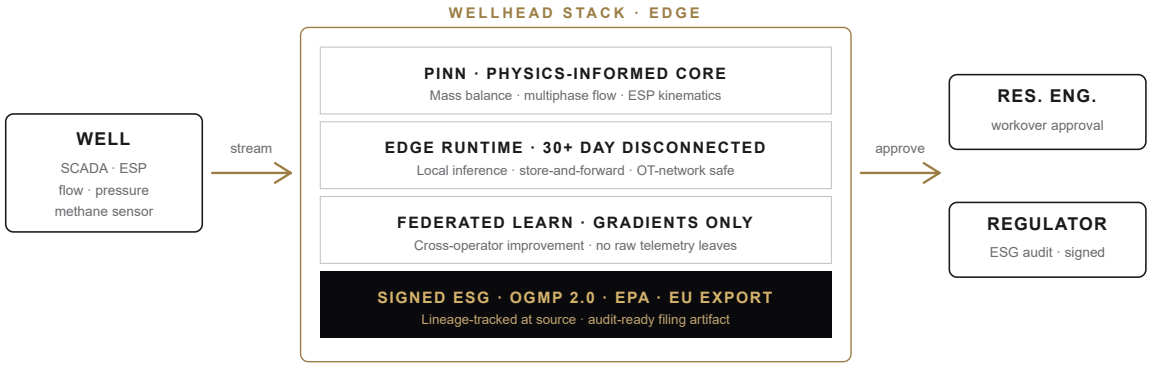
The reservoir engineer is the user; procurement is the buyer; the regulator is the auditor. **All three need a mechanism, not a number.** PINNs hit a 2024 inflection: stable enough to ship, novel enough to differentiate. Bundling PINN prediction with regulator-ready ESG signing collapses two procurements into one and makes compliance a co-buyer.

The defensibility compounds two ways. Federated learning lets every operator's deployment sharpen the shared model without exposing raw telemetry, so prediction quality widens with each asset added, an edge a single-operator pilot cannot match. And once filings run through signed lineage, switching costs turn regulatory rather than technical: the audit trail an operator hands the EPA is the one the runtime produced, so ripping out the predictor means re-validating the compliance record.

> **THE UNLOCK**
> Every prediction emits a defensible mechanism (mass balance, flow regime, ESP kinematics). Edge runtime survives 30+ days disconnected. ESG measurements are signed at source, exportable in OOOOb/c / EU Methane / OGMP 2.0 formats. Cross-operator learning is federated gradients only, never raw telemetry.

Architecture · Edge runtime + federated learning

FIGURE 2 · SYSTEM ARCHITECTURE



Telemetry stays at the asset; PINN core runs at the edge with 30+ day disconnected operation; cross-operator learning happens via federated gradients (raw telemetry never leaves); ESG measurements are signed in the same runtime that did the prediction: same record, two consumers.

> **WORKED EXAMPLE · 280-WELL BROWNFIELD, GOM, ESPS IN YEARS 8–12**
> Pre-deployment baseline: **14% unplanned downtime / quarter**. Wellhead PINN flags 8 ESPs at > 70% bearing-wear envelope; engineer accepts 6, defers 2. Workovers staged into next maintenance window. Q1 result: **downtime 9.2%** (audited against pre-baseline), **$28M / quarter saved** (operator-attested). OGMP 2.0 Level 4–5 reporting submitted on time, Gold-Standard pathway maintained.

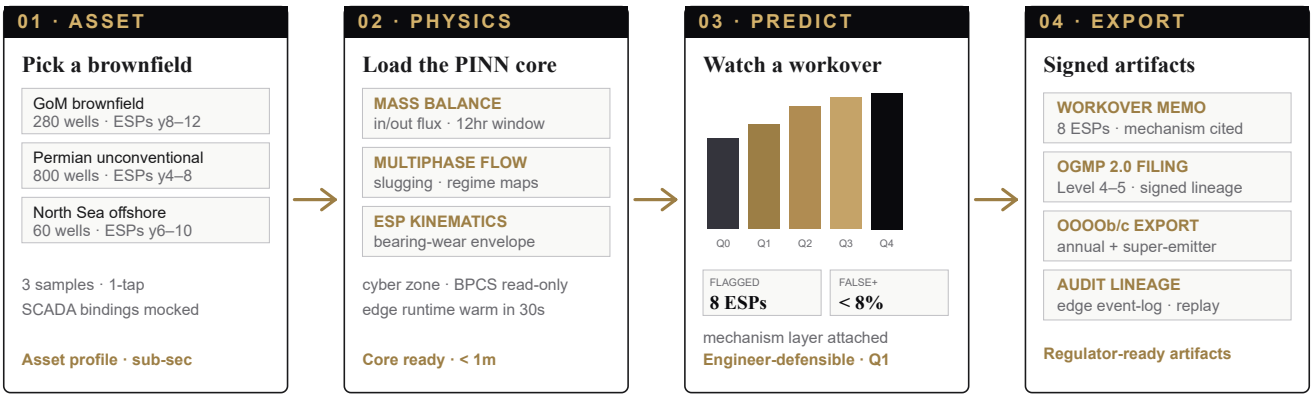
Sequenced GTM

PHASE	CUSTOMER WEDGE	FORCING-FUNCTION WORKLOAD	PROOF POINT
Wedge M0–9	1 major operator's brownfield asset · ESP failure prediction	Aging-ESP failure-rate spike + EPA OOOOb/c annual filing + super-emitter response window	25%+ downtime reduction · OGMP 2.0 filed clean
Beachhead M9–24	3 majors, multi-asset rollout, GoM + Permian + North Sea	Cross-asset standardization on a single edge runtime	4,000 wells · federated learning gains measured
NOC M24+	National oil companies (Aramco, Petrobras, ADNOC)	Sovereign data residency + national-scale ESG filings	2 NOCs signed · 40% of revenue from sovereign tier

Prototype walkthrough

An interactive edge-runtime simulator runs the operator-side view end to end: pick a brownfield asset, load the physics-informed core against a cyber zone, watch a PINN prediction build with its mechanism layer (mass balance · multiphase flow · ESP kinematics) and emit an engineer-defensible workover recommendation, then export the artifacts the engagement contracts against. Built to demonstrate that **physics-informed prediction**, **edge-resident inference**, and **regulator-grade ESG signing** are concrete outputs, not language in a deck.

FIGURE 3 · EDGE-RUNTIME SIMULATOR, FOUR INTERACTIVE STEPS



Schematic of the live UI; all four steps are interactive in the demo. Pick an asset, load the physics, watch the prediction with its mechanism layer, export signed artifacts.

What the prototype proves, and what it doesn't yet

Proven on the prototype

- PINN flags ESPs above the bearing-wear envelope with mechanism citations the reservoir engineer can defend
- Edge runtime simulates 30+ days disconnected; predictions store-and-forward with no quality loss
- OGMP 2.0 Level 4–5 export and OOOOb/c annual filing both render with signed lineage
- Federated gradient round across 5 simulated peer operators; no raw telemetry leaves the asset
- Workover memo and OGMP filing render from one event log, so the prediction and the regulator artifact never diverge

Out of scope, by design

- SCADA + ESP telemetry is mocked; live ingest is brownfield M0–3 work on real assets
- IEC 62443-3-3 SL2 certification is a real third-party audit, not simulated in the prototype
- NOC sovereign-cluster variant requires production deployment with operator-controlled key custody
- Per-asset PINN training on customer-specific physics constants is post-engagement work
- Multi-year PINN drift monitoring and re-calibration cadence are scoped in the engagement, not the prototype

THREE PATHS TO TRY IN THE LIVE DEMO

ESP failure prediction at a GoM brownfield: 280 wells, 14% baseline downtime → PINN flags 8 ESPs at > 70% bearing-wear; engineer accepts 6, defers 2; workover memo + OGMP filing drafted.

OGMP 2.0 quarterly methane filing: Level 4–5 schema render with signed lineage; OOOOb/c annual filing produced from the same event log without re-measurement.

Federated gradient sync across a 3-operator consortium: aggregated gradient round completes; raw telemetry remains at the asset; cross-operator prediction-quality lift measured against the held-out cohort.

Metrics that matter

LAYER	METRIC	Y1 TARGET	WHY IT MATTERS
North-star	Unplanned downtime hrs / asset / quarter	−25% vs pre-deploy	Audited against operator-attested baseline
Quality	False-positive rate on workover predictions	< 8%	Above this, engineers stop running the queue
ESG	OGMP 2.0 / OOOOb/c filings accepted clean	100%	Below this, compliance team rolls back
Resilience	Edge runtime disconnected operation	> 30 days	Offshore + remote uptime constraint
Liquidity	Wells under runtime (paying)	1,200+ by Y1	Federated learning gains require well count
Business	Net revenue retention (well-expansion)	> 130%	Lands at brownfield, expands to greenfield

Risks & mitigations

HIGH **PINN model drift on novel reservoir / equipment classes (deepwater, sour gas).**

Mitigation: per-asset model with explicit physics constraints; novel-class flagging triggers conservative-mode (predicts only on the kinematic envelopes that match training distribution); reservoir-engineer team validates each new class before unlock. Federated learning helps but never overrides physics.

HIGH **OT cybersecurity: edge runtime touches an operations-network process control system.**

Mitigation: read-only on PCN; outbound store-and-forward only over a unidirectional gateway; certified to IEC 62443-3-3 SL2 before customer 1. Independent third-party penetration test on a contractually-required cadence.

MED **Operator data sovereignty: NOCs prohibit cross-operator gradient sharing.**

Mitigation: federated learning is opt-in per asset; sovereign tier customers run a private-cluster variant where gradients never leave operator borders. Feature parity preserved; only the cross-operator improvement rate differs.

MED **Regulatory format drift: OGMP 2.0 / EPA / EU schemas change mid-deployment.**

Mitigation: ESG export is schema-versioned; lossless event store at the edge means re-export against a new schema is a software upgrade, not a re-measurement. 90-day SLA on new format support.

30 / 60 / 90, first quarter sprint plan

30 DAYS

PINN core + edge runtime v0

- Mass balance + multiphase flow + ESP kinematics models
- Edge runtime · 30-day disconnected proof
- 1 design-partner brownfield asset (40 wells)

60 DAYS

ESG signing + OT cyber cert

- OGMP 2.0 / EPA / EU export adapters · signed lineage
- IEC 62443-3-3 SL2 cert · pen-test pass
- 2nd design partner · 280 wells live

90 DAYS

Federated learn + audit baseline

- Cross-operator gradient sharing live
- Q1 audited downtime read · 25% target
- 3rd operator signed · 1,200 wells under runtime

DECISION ASKED

Authorize a 90-day brownfield pilot sprint with a ten-person team (PM, three ML/PINN engineers, two systems/edge engineers, OT-cyber lead, reservoir-engineer SME, ESG/regulatory counsel, customer success) and a budget of **$5.6M**. Success: 1,200 wells under runtime, 25% audited downtime reduction, 100% clean OGMP 2.0 filings, false-positive < 8%, NRR clearing 130%.