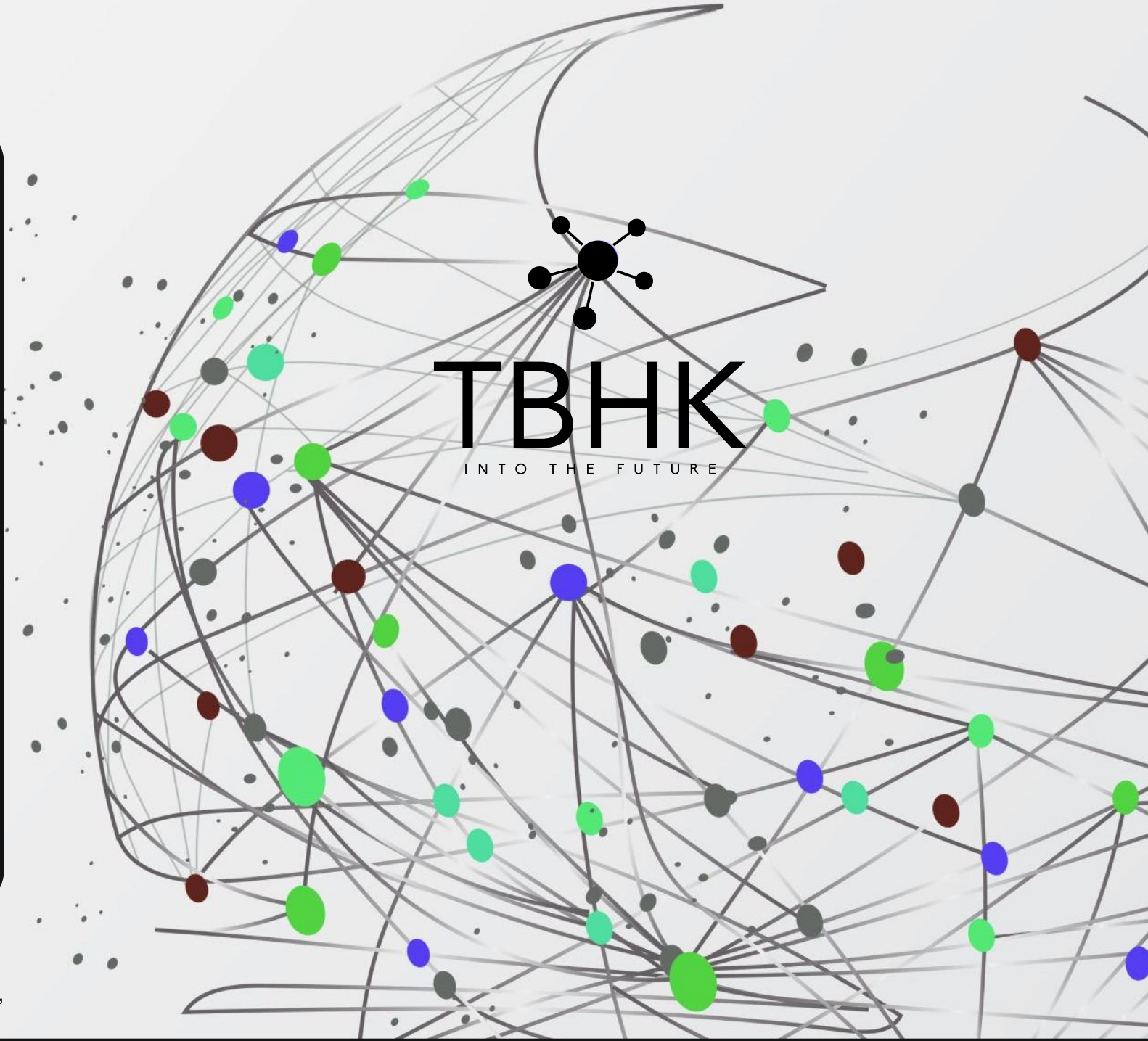
Semantic STEP

Bridging data standards for industrial interoperability



The Arrowhead fPVN project is supported by the Chips Joint Undertaking and its members, including the top-up funding by Finland, Denmark, Sweden, Spain, Italy, Rumania, Portugal, Hungary, and France

Context and Objectives

Why this talk and what you will take away

Proven Feasibility

Validated mapping choices show STEP-derived OWL integrates well with existing knowledge graphs.

Automation and Consistency

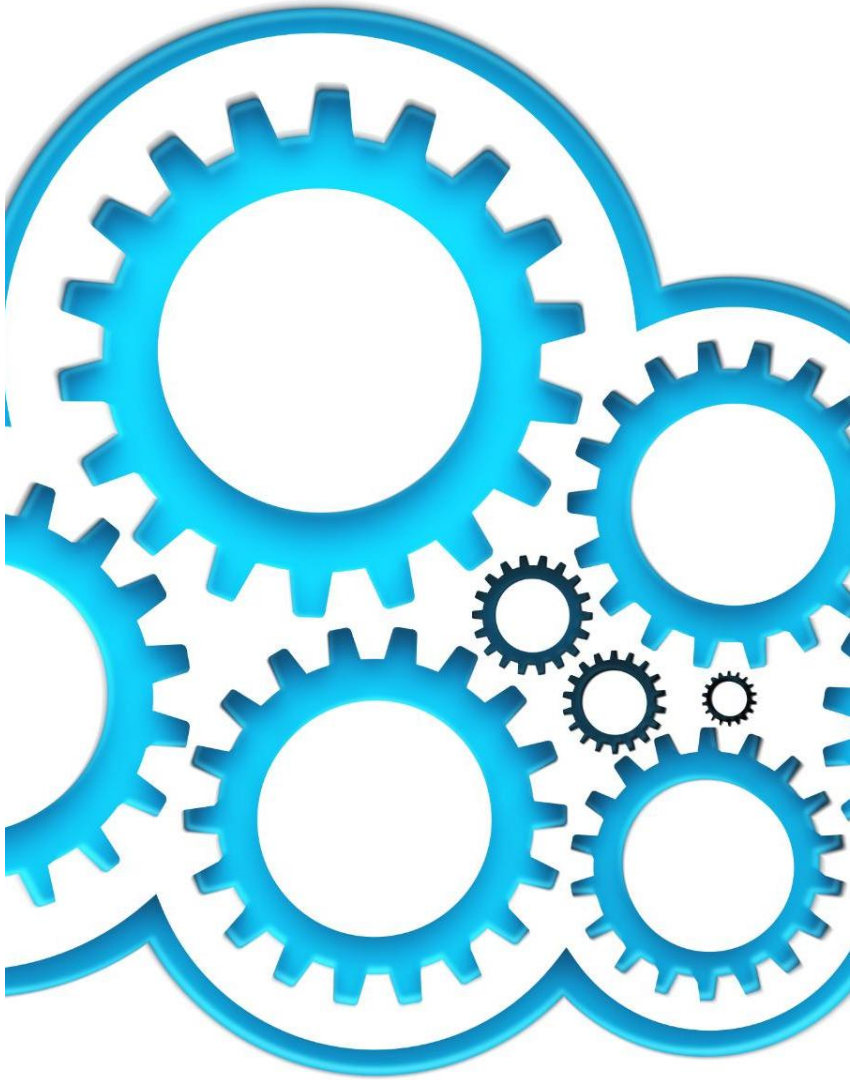
Transitioned from manual to repeatable transformation that preserves engineering semantics and handles complex types.

Intentional Alignment

Using Industrial Data Ontology connects STEP with other transformed engineering standards creating semantic continuity across lifecycle data.

ARROWHEAD
fPVN

History, Scope, and Global Impact of ISO/TC 184/SC 4



Establishment and Mandate

Founded in 1984, ISO/TC 184/SC 4 standardizes product data across entire lifecycles to enhance Industrial data interoperability.

STEP Standards Core

The STEP family (ISO 10303) enables neutral industrial data exchange independent of software systems, underpinning digital engineering.

Global Reach and Impact

With over 800 standards and broad international participation, SC 4 drives billions in economic benefits through improved interoperability.

Future Directions

SC 4 advances ontology-based interoperability, digital twins, and data-driven compliance to lead Industry 4.0 innovations.

ARROWHEAD
fPVN

Why STEP (ISO 10303) still matters – Example APs and lifecycle breadth

AP ID	NAME	WHY IT MATTERS
AP242	Managed Model-Based 3D Engineering	Unifies product structure, geometry, and configuration for CAD/PLM exchange & long-term archiving.
AP209	Multidisciplinary Analysis and Design	Relates CAD definitions to CAE/FEA models & results; preserves design-to-analysis traceability.
AP239	Product Life Cycle Support (PLCS)	Structures configuration baselines, maintenance, documents, and approvals across life.

The modernized STEP Core in SysML and why XMI matters

Harmonized SysML Core Model

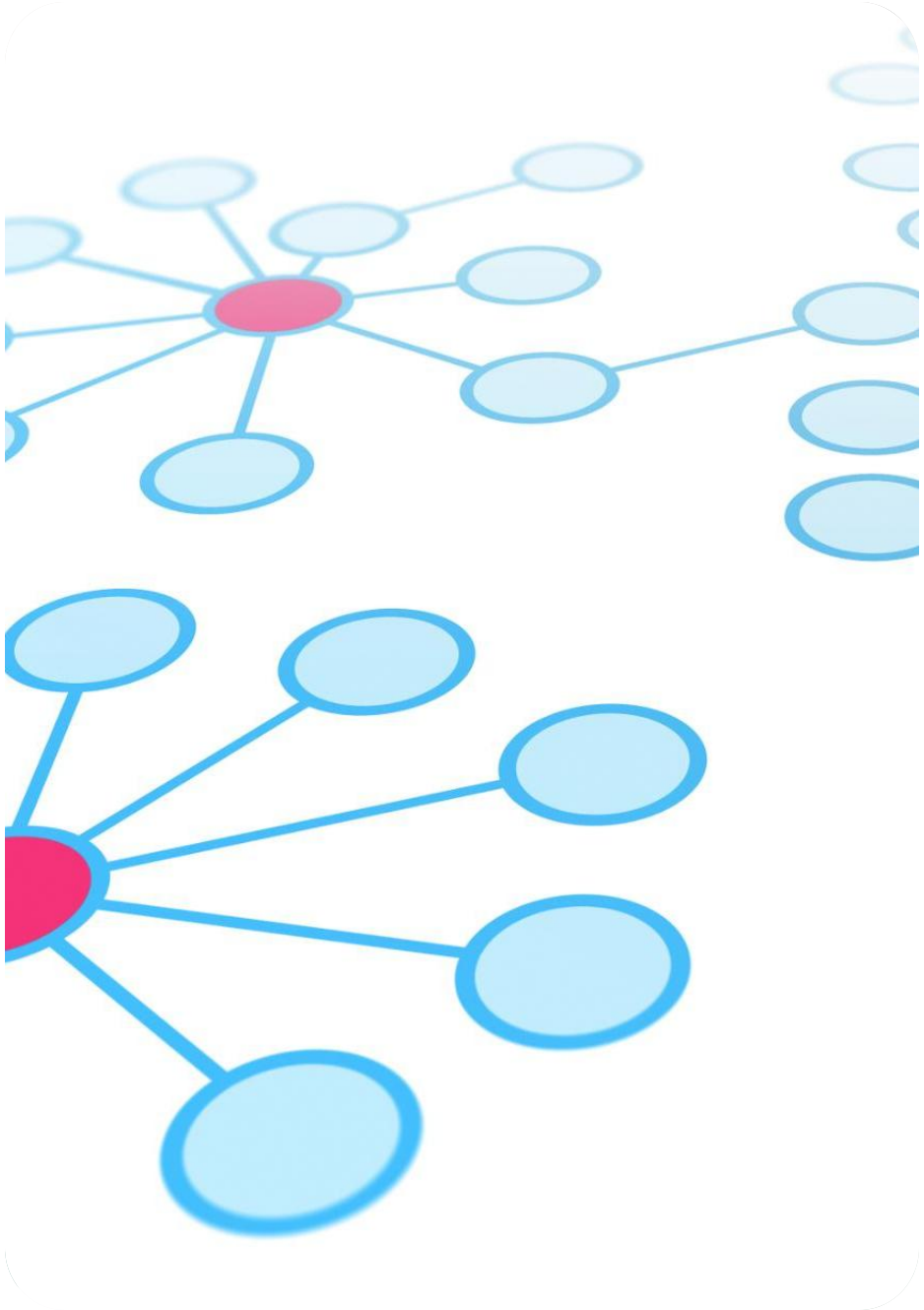
The STEP Core consolidates common semantics into a single SysML model reusable across multiple Application Protocols.

XMI Export Advantages

XMI export produces deterministic, parser-friendly artifacts with stable identifiers and structural consistency.

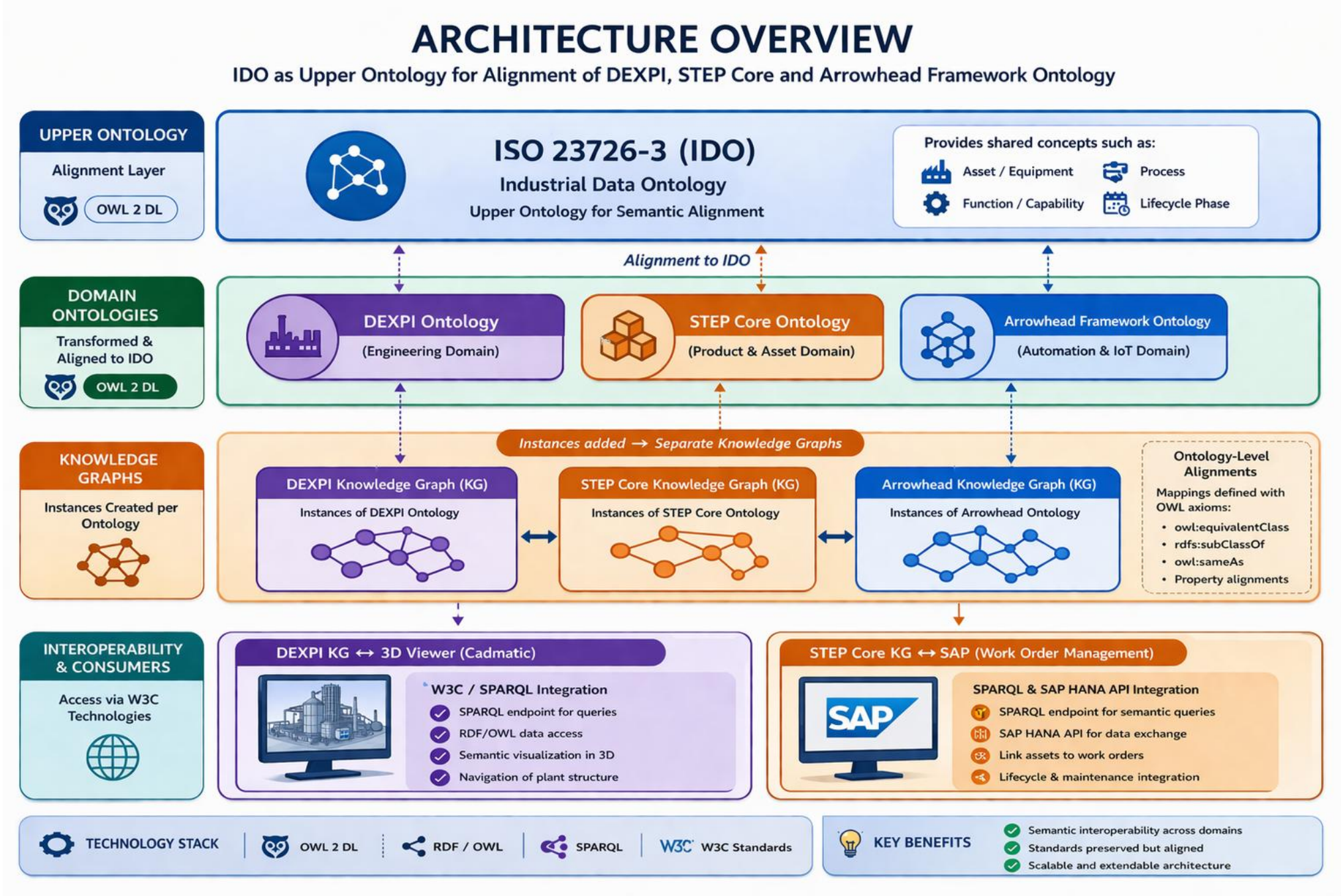
Rule-Driven Ontology Mapping

Mappings interpret model constructs into OWL 2 DL classes and axioms, supporting consistent semantic integration.



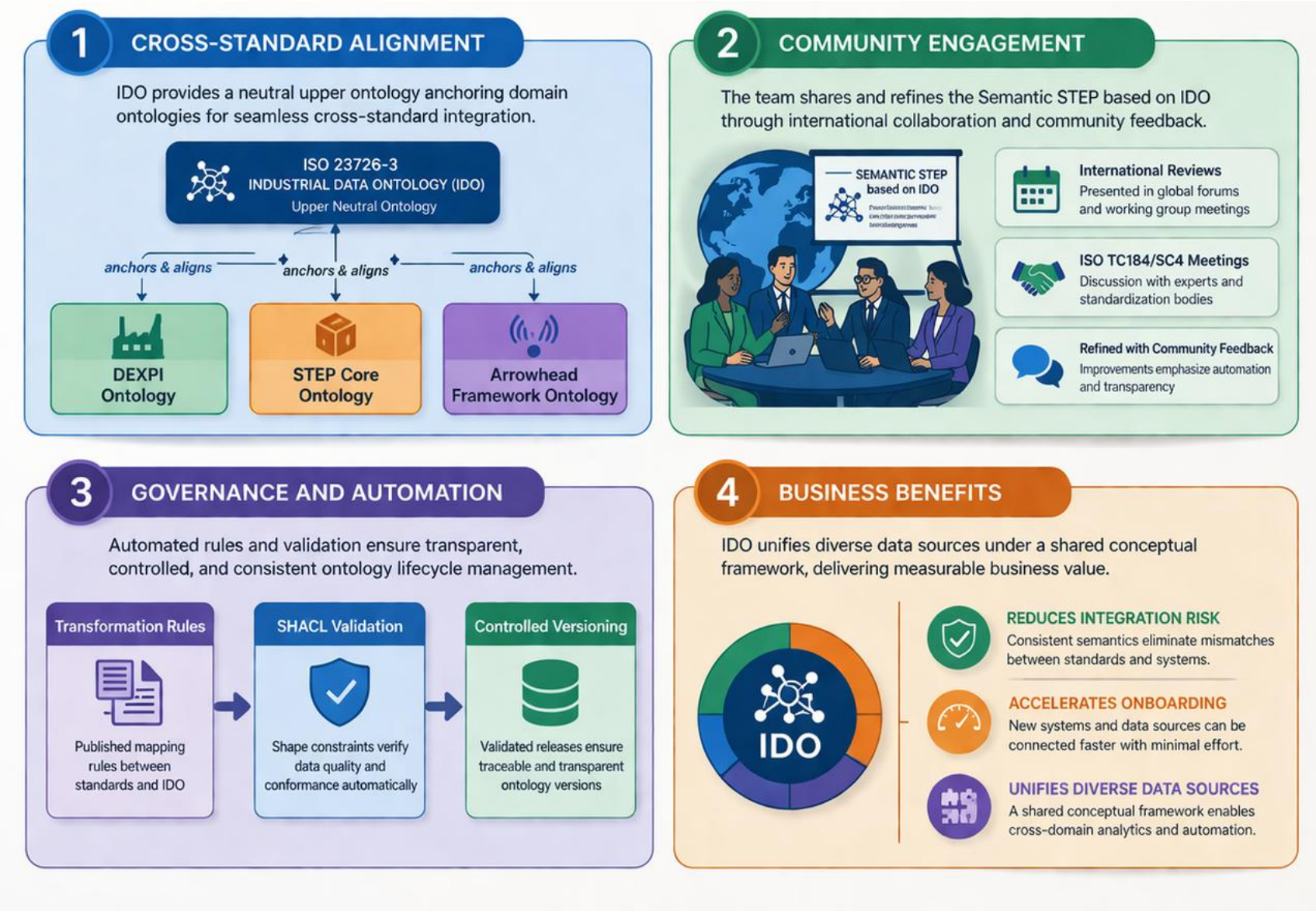
ARROWHEAD
fPVN

Semantic STEP and the applied architecture in the validation UC



ARROWHEAD
fPVN

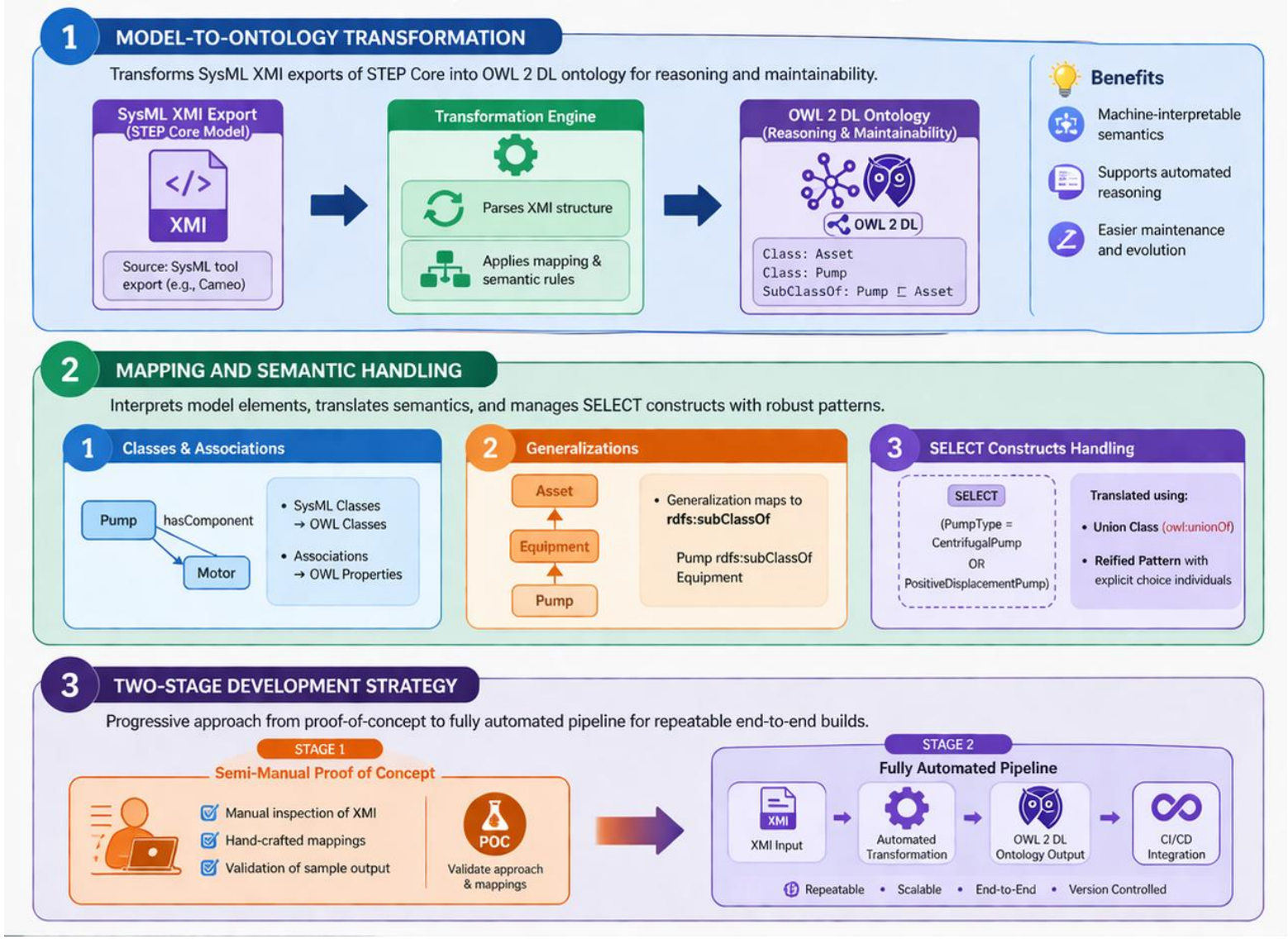
Collaboration touchpoints and the IDO (ISO 23726) strategy



ARROWHEAD
fPVN

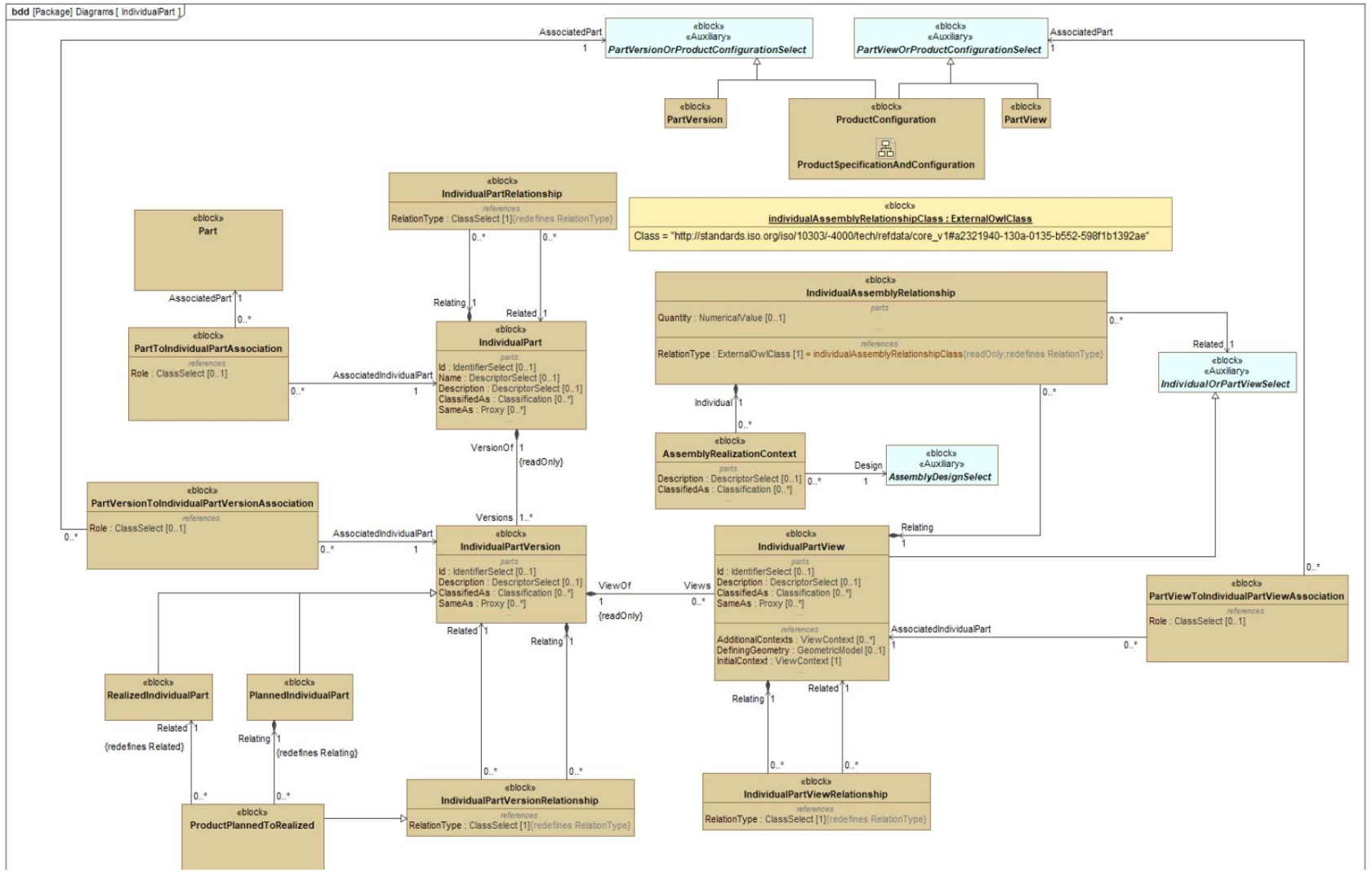
Methodology and POC

Model-to-ontology pipeline: STEP Core SysML XMI → OWL 2 DL



ARROWHEAD fPVN

Example on STEP Core modules - IndividualPart



ARROWHEAD fPVN

Cross-Standard Alignment and Integration

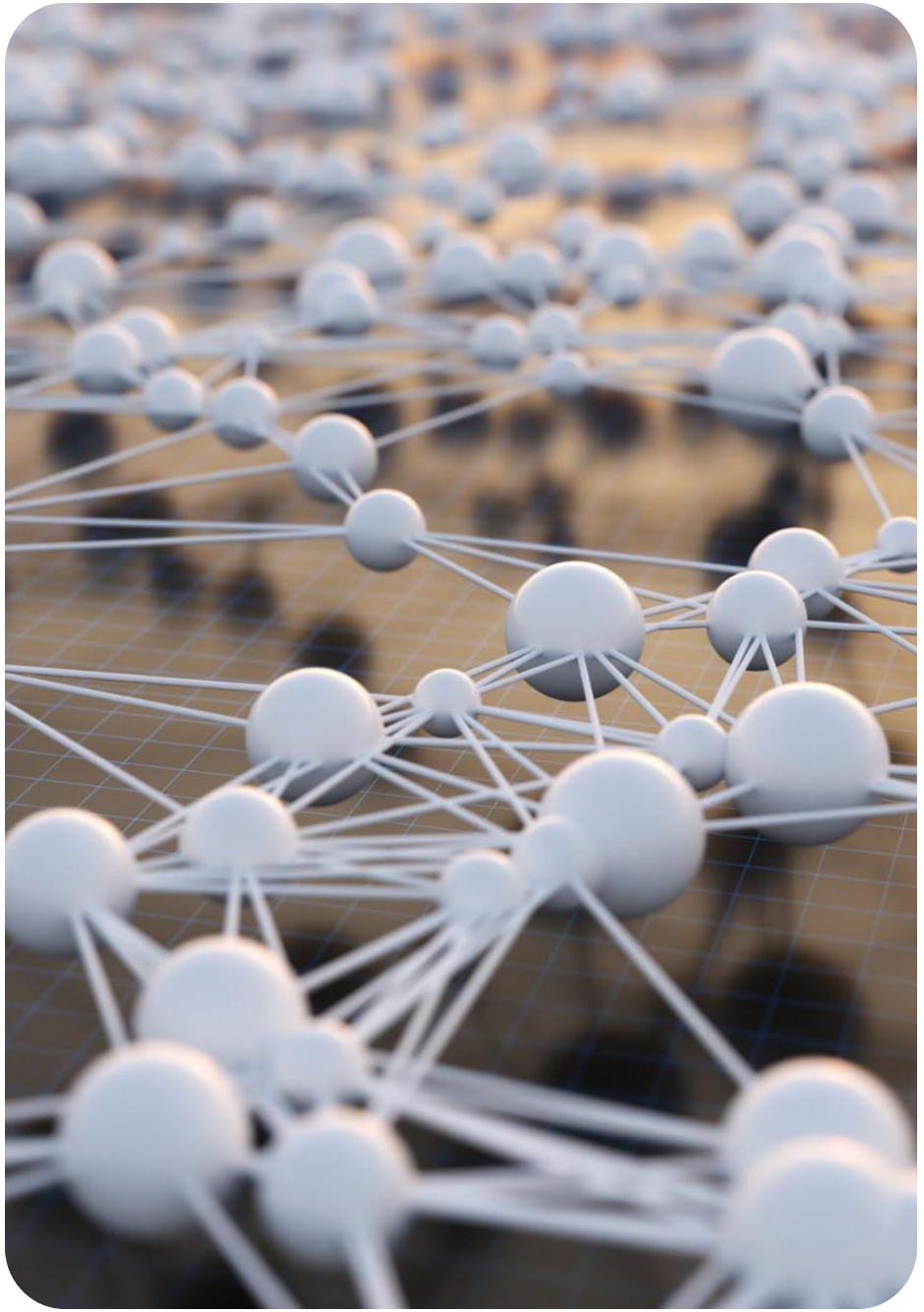
IDO as the alignment spine across STEP, DEXPI and Arrowhead

IDO as Harmonizing Ontology
IDO provides upper-level abstractions that harmonize multiple domain ontologies without losing their specificity.

Cross-Standard Querying
IDO enables efficient cross-standard queries across STEP, DEXPI, and Arrowhead frameworks by linking related data nodes.

Reduced Integration Complexity
Mapping each standard to IDO once reduces integration debt by avoiding multiple pairwise bridges.

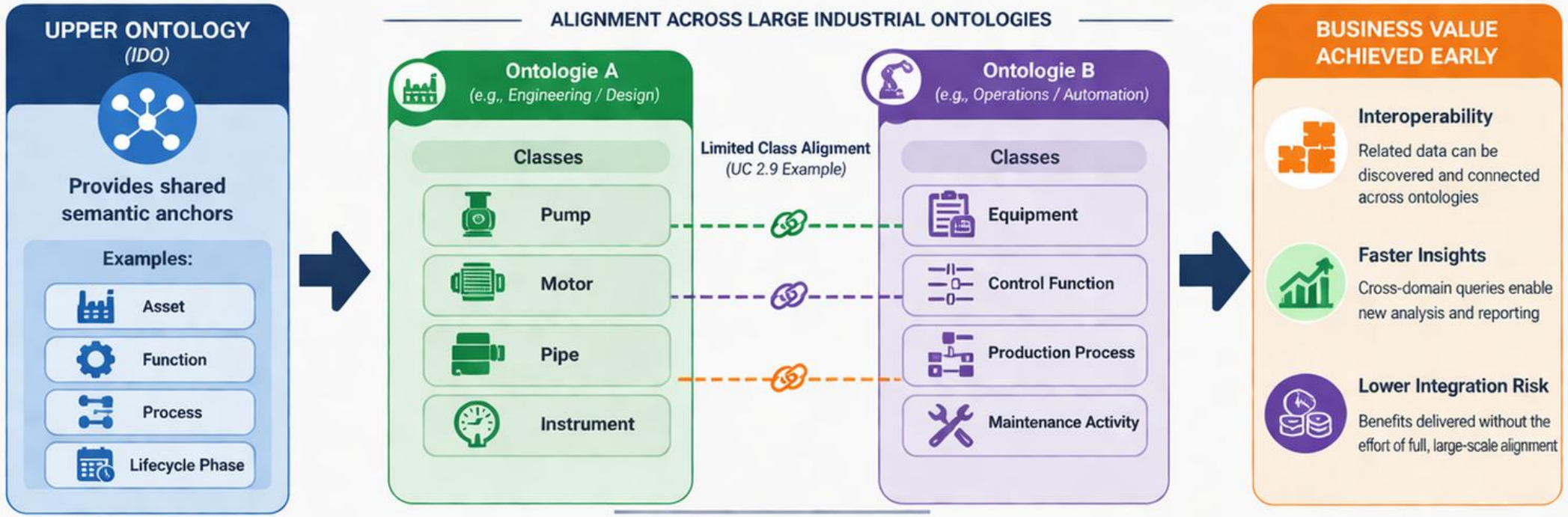
Simplified Governance and Onboarding
IDO supports documentation and governance through shared shapes, easing onboarding and stakeholder buy-in.

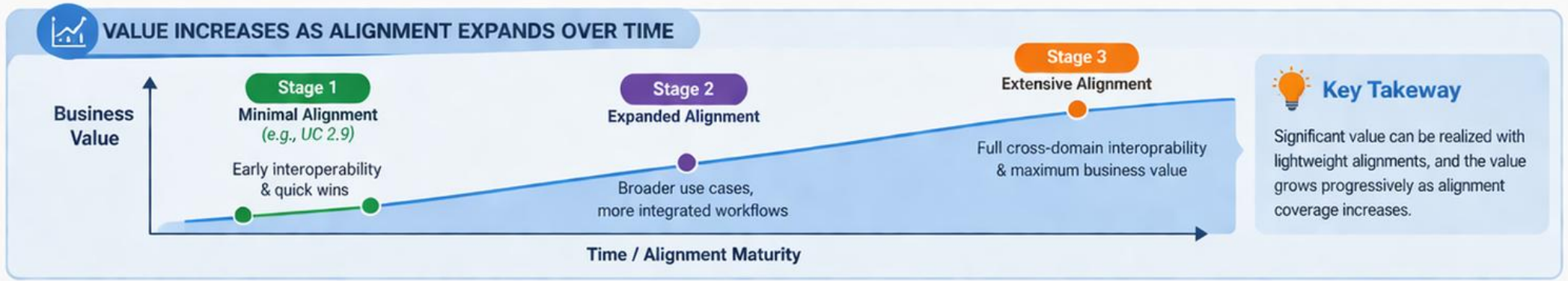


ARROWHEAD
fPVN

LIGHTWEIGHT ALIGNMENTS

The Upper Ontology approach enables alignment across large industrial ontologies.
In UC 2.9, limited class alignment already delivered significant interoperability and business value.
This shows that early benefits are achievable without large-scale alignment, with value increasing as alignment expands over time.





ARROWHEAD
fPVN

ONTOLOGY AND RUNTIME INTEGRATION

Connecting semantic ontologies with the Arrowhead runtime fabric for intelligent, secure cyber-physical operations

1 ONTOLOGY AND RUNTIME INTEGRATION

Connecting ontology layers to the Arrowhead runtime fabric enables seamless service registry and secure microservices interaction in cyber-physical systems.

ONTOLOGY LAYERS

- **IDO** — Upper Ontology
- **DEXPI Ontology** — Plant & Instrumentation
- **STEP Core Ontology** — Product & Asset
- **Arrowhead** — Framework Ontology

SECURE INTEGRATION

ARROWHEAD RUNTIME FABRIC

ARROWHEAD

- Service Registry
- System Orchestrator
- Authorization & Security

2 KNOWLEDGE-DRIVEN SERVICE DISCOVERY

Aligning Arrowhead services with IDO domain ontologies enables semantic discovery based on relationships to assets, documents, and analysis results.

SEMANTIC QUERY

Find services related to Pump with recent analysis results

```
PREFIX ido: <.../ido#>
PREFIX arrow: <.../arrowhead#>

SELECT ?service
WHREE {
  ?service arrow:providedFunction ?func .
  ?func ido:realizesAsset ?asset .
  ?asset a ido:Pump .
  ?analysis ido:aboutAsset ?asset ;
            a ido:AnalysisResult ;
           ido:hasTimestamp ?ts .
}
```

DISCOVERY RESULTS

- **Pump Monitoring Service** — Asset: Pump P-101
- **Maintenance Document Service** — Asset: Pump P-101
- **Vibration Analysis Service** — Analysis: Result #AR-556

3 OPERATIONAL DECISION SUPPORT

Integration reconciles system design, maintenance history, and real-time telemetry to provide a unified view for informed operational decisions.

DATA SOURCES

- **System Design** (DEXPI / STEP Core)
- **Maintenance History** (Work Orders & Events)
- **Real-Time Telemetry** (Arrowhead Services)

UNIFIED SEMANTIC VIEW

- **IDO-Aligned Knowledge Graph**

Pump P-101
360° operational context

DECISION SUPPORT

- **Anomaly Detection** — Telemetry vs. design limits
- **Maintenance Planning** — History + condition-based
- **Performance Optimization** — Data-driven insights

4 GOVERNANCE AND DEVOPS ALIGNMENT

Proven software practices ensure data quality, control, and trust through automated governance and DevOps pipelines.

DATA GOVERNANCE

- **Standards & Policies** — IDO modeling rules, naming, versioning guidelines
- **Quality & Validation** — Automated SHACL constraints ensure semantic consistency
- **Access & Security** — Controlled permissions and audit trails via Arrowhead

CI/CD AUTOMATION

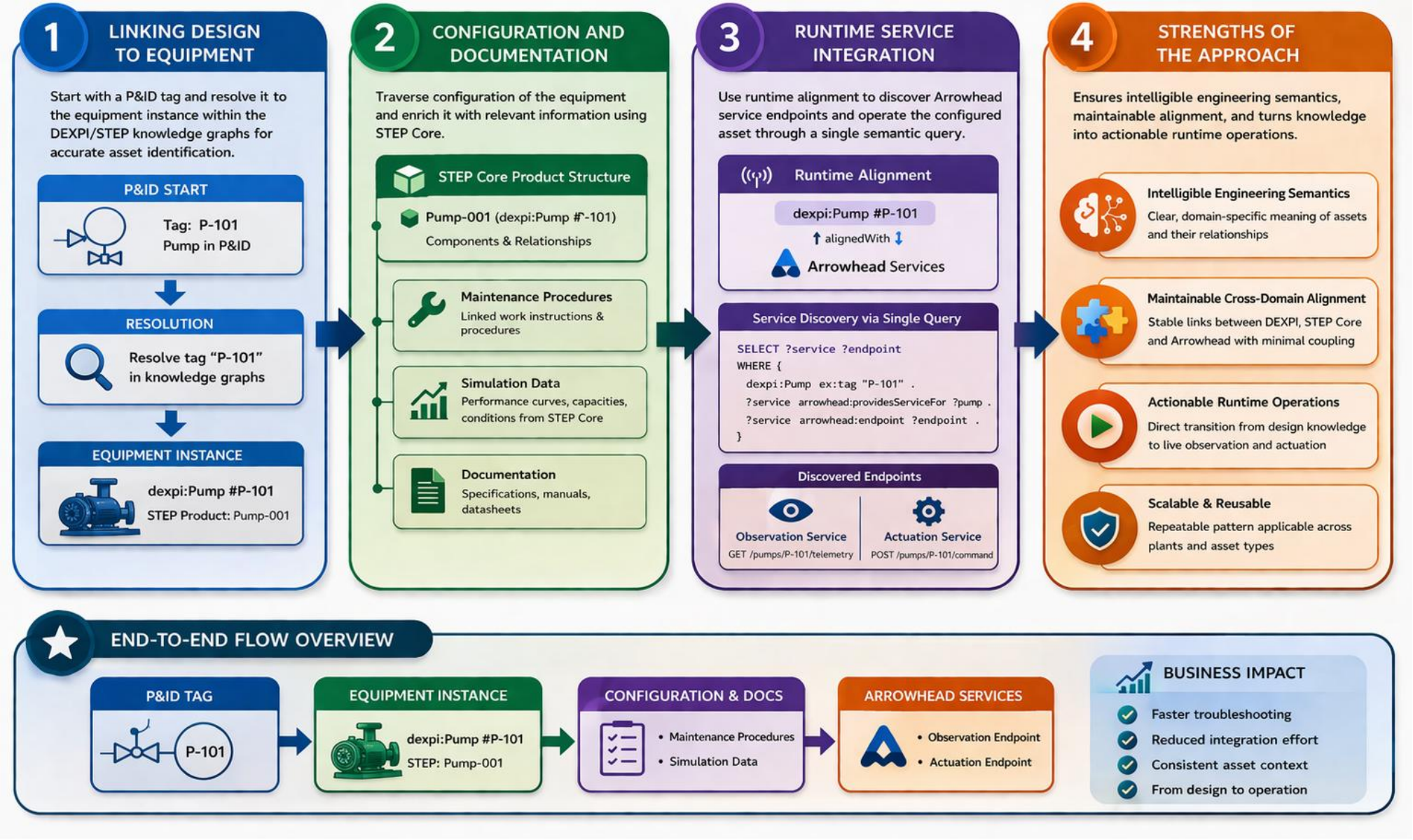
Code & Mapping Repository → Automated Build & Test → SHACL Validation → Deploy to Runtime

RESULT: TRUSTED & RELIABLE SEMANTIC DATA

- Consistent, high-quality data in production
- Faster delivery with controlled, repeatable releases

Demonstration, Roadmap and Risks

Proposed demo storyline: a single query across design, config and runtime

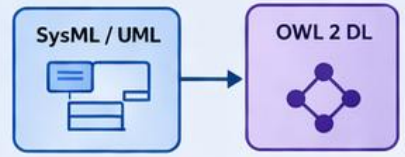


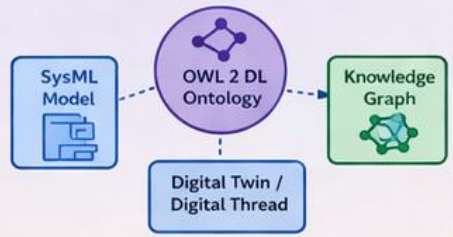
ARROWHEAD
fPVN

Proposed Further Work: Semantic Enablement of SysML/XMI with OWL 2 DL

Enable SysML-based standards to participate in the semantic web and digital thread.

HORIZON	KEY DELIVERABLES	KPIs
Now (0–6 months)	• Define SysML/UML → OWL 2 DL mapping profile (v1) • Identify semantic gaps in XMI serialization • Establish canonical RDF/OWL representation alongside XMI • Select pilot models for semantic translation	% of SysML constructs with OWL mapping # of pilot models translated to OWL Mapping profile published (committee draft)
3–6 months	• Build XMI → RDF/OWL 2 DL transformation pipeline • Introduce SHACL for constraint validation • Enable SPARQL querying over SysML-derived models • Validate model fidelity vs. XMI (semantic equivalence)	Transformation completeness (% elements preserved) SHACL coverage of constraints SPARQL query use cases validated; MVP stability
6–12 months	• Define semantic governance framework (URIs, versioning, modularization) • Publish ISO Technical Specification: – "SysML Models in OWL 2 DL" – "Constraint Validation using SHACL" • Define interoperability patterns with knowledge graphs and external ontologies (e.g., ISO 15926)	Query performance (latency, scalability) Interoperability success across tools and domains Adoption: # tools exporting OWL alongside XMI; release cadence





KEY MESSAGE

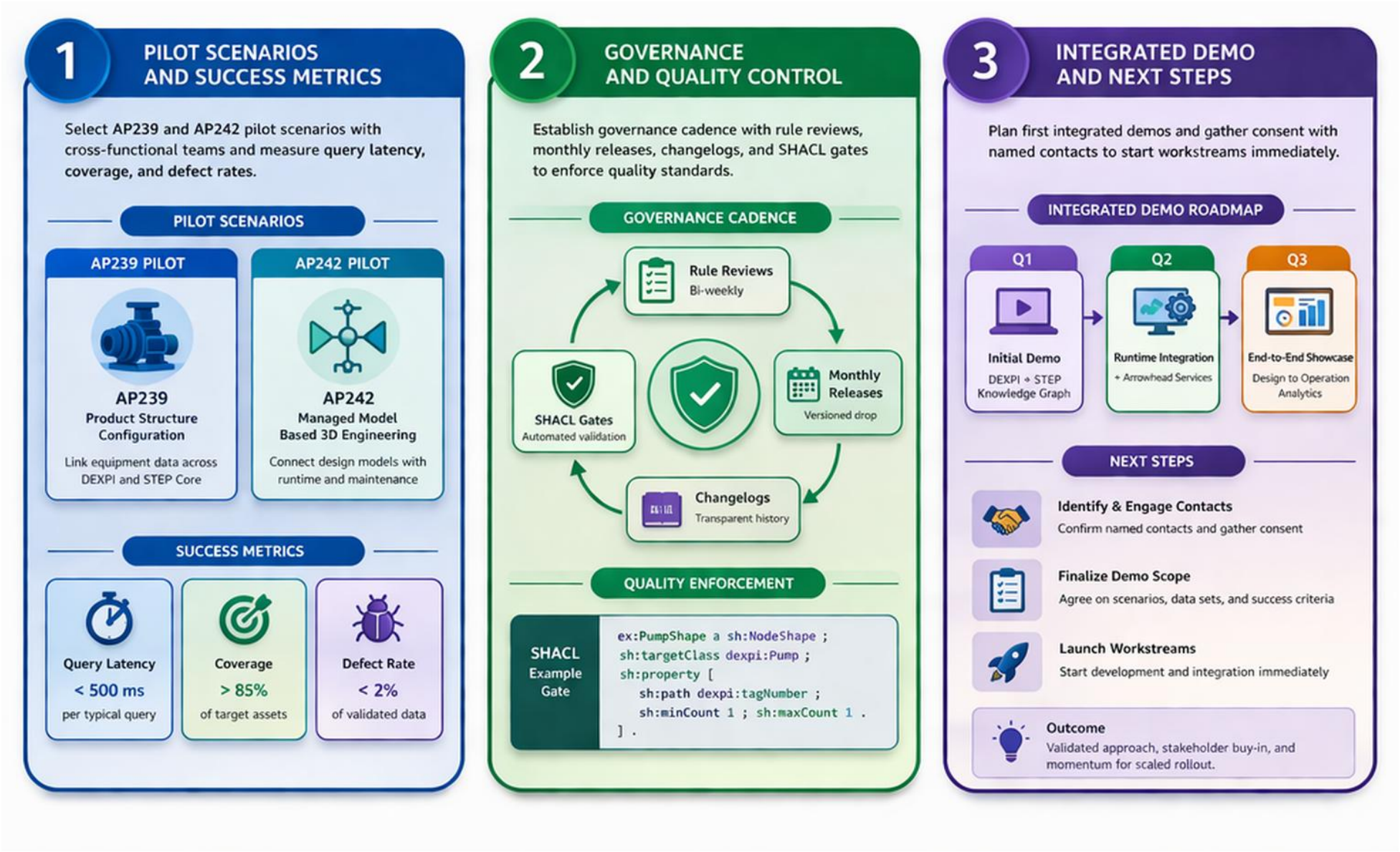
XMI is a syntax, not a semantic layer. By standardizing an OWL 2 DL representation of SysML models, we enable machine-understandable, interoperable engineering data across the digital thread.

STRATEGIC POSITIONING

"Standardize a semantic representation of SysML models in OWL 2 DL to complement XMI, enabling interoperable, machine-understandable engineering data across the digital thread."

ARROWHEAD fPVN

Proposed Further work: Implementation



ARROWHEAD
fPVN

TBHK
INTO THE FUTURE

Discussion