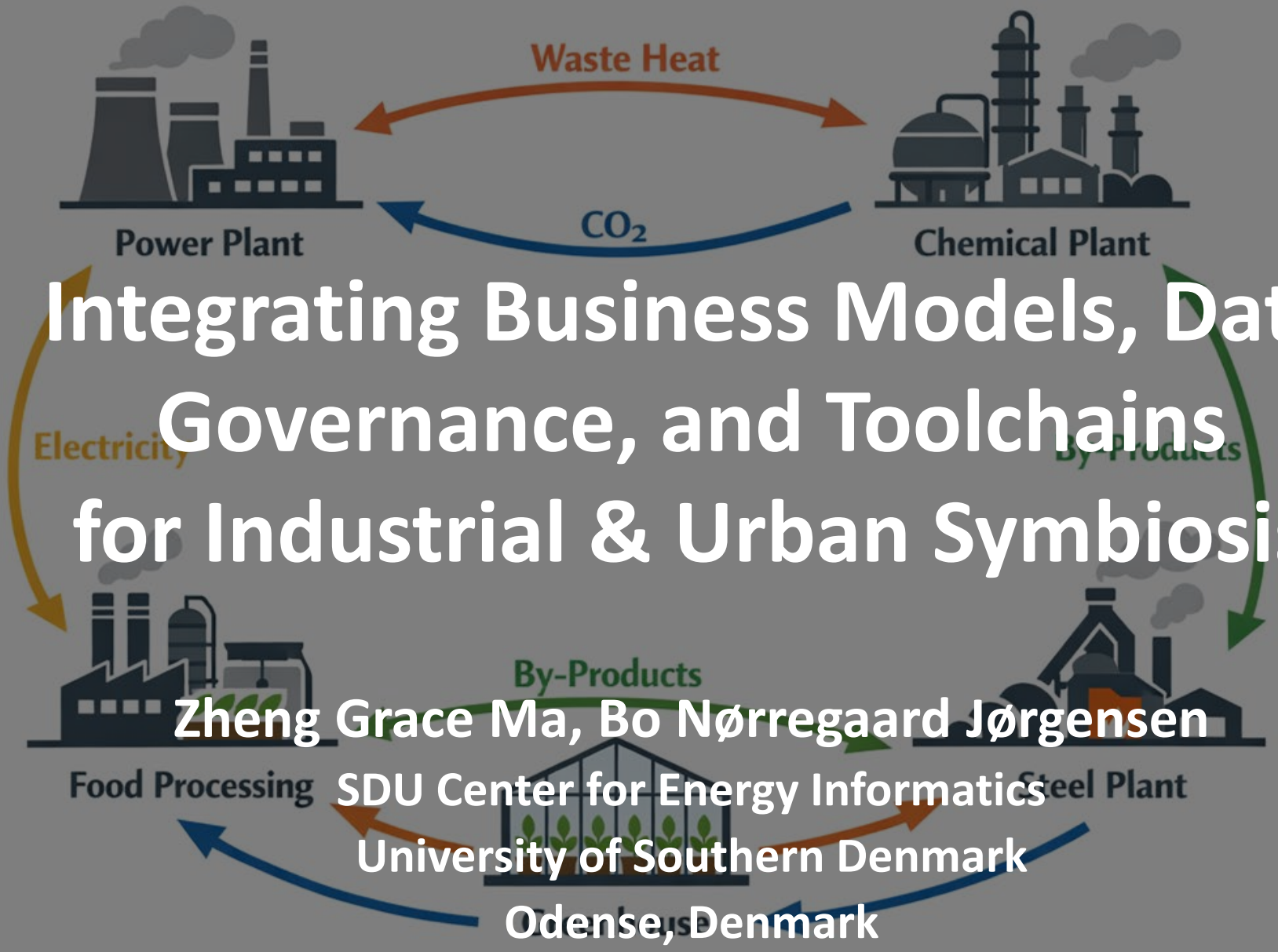

Integrating Business Models, Data Governance, and Toolchains for Industrial & Urban Symbiosis

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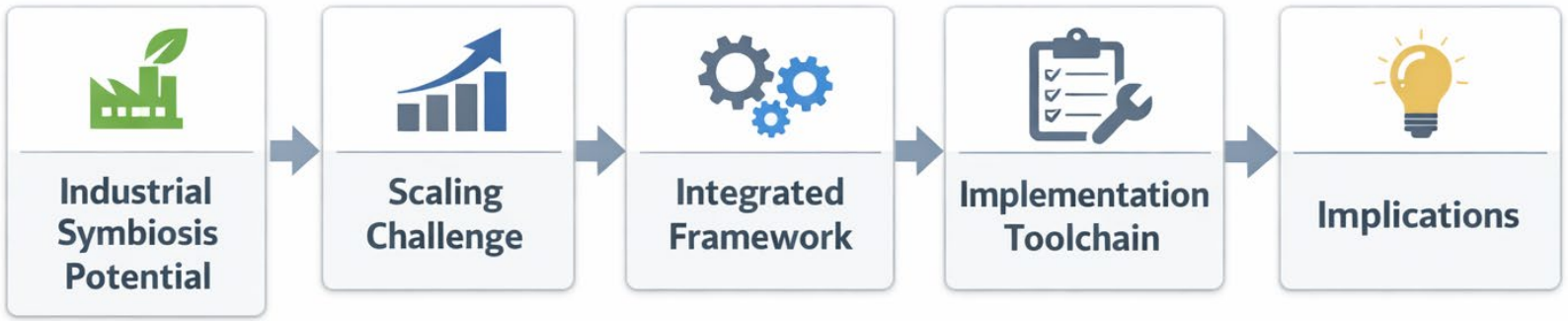
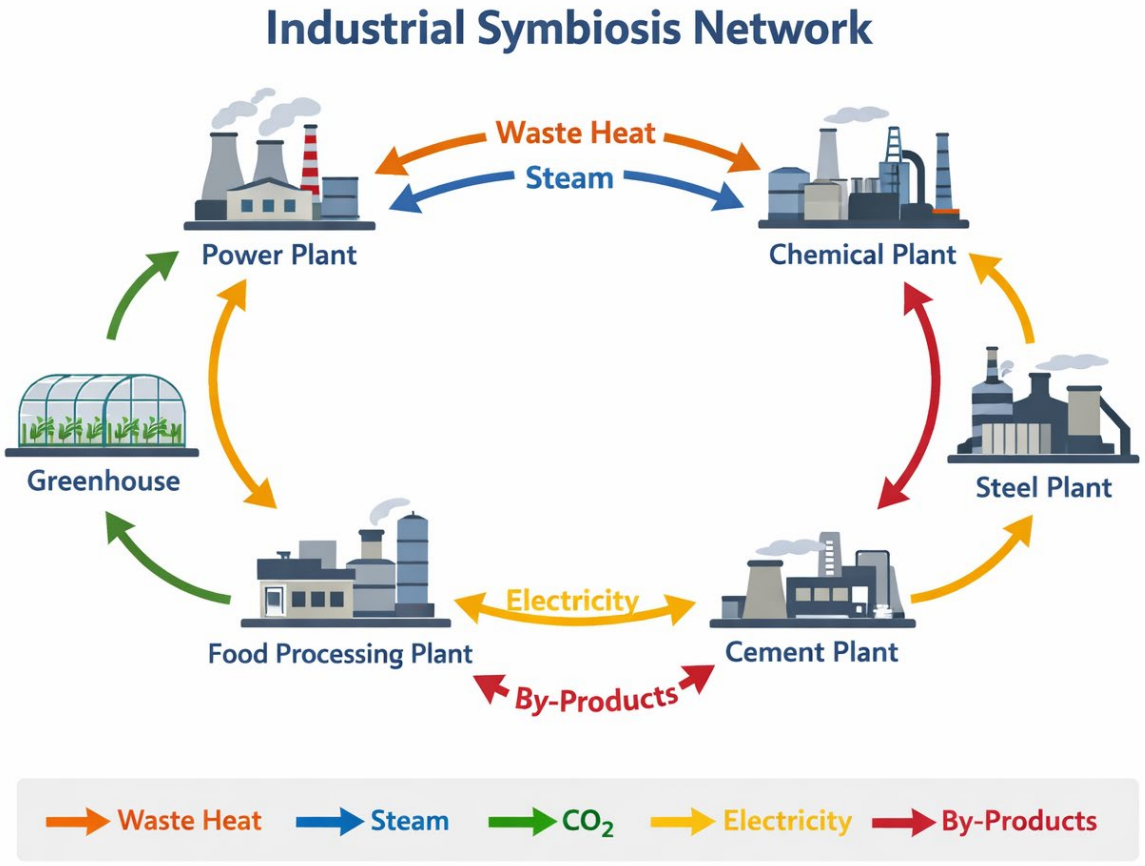


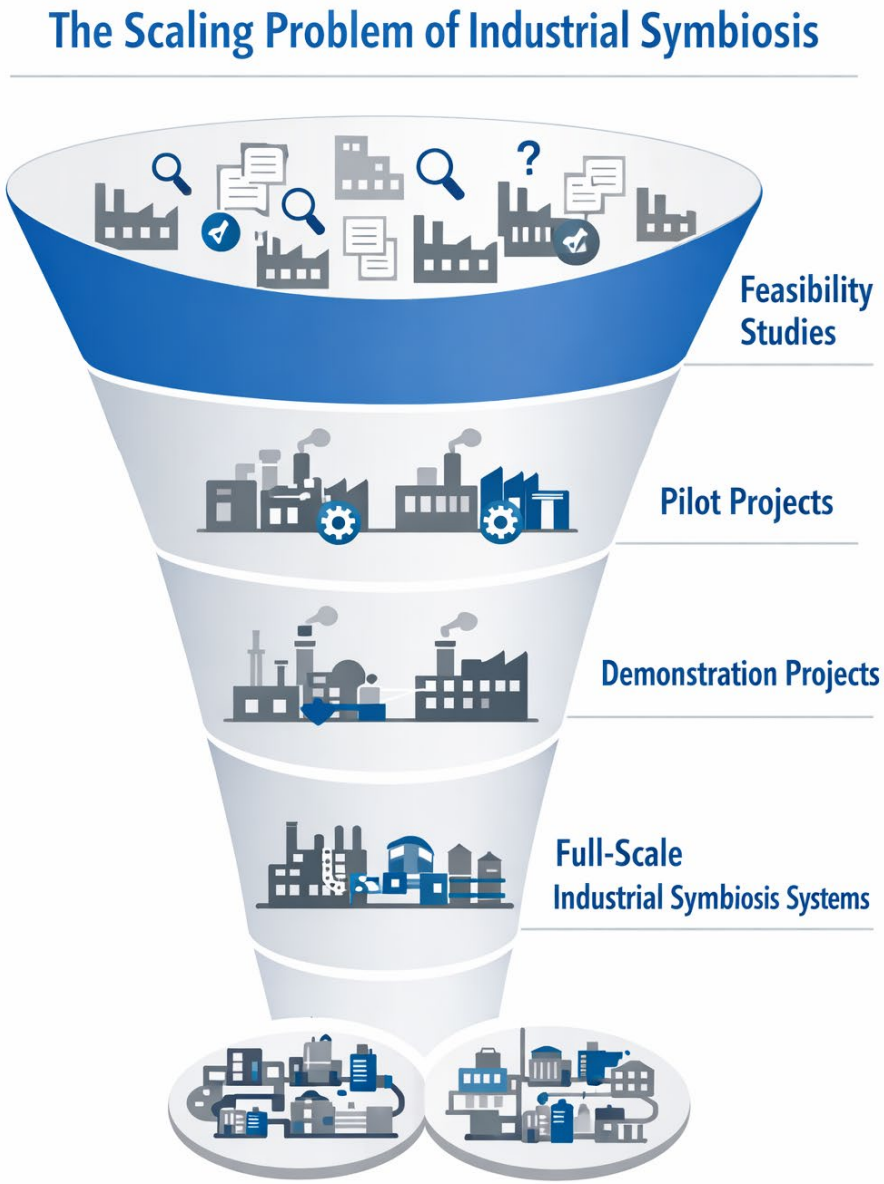
Conference Agenda

Industrial Symbiosis: A Key Pathway for Industrial Decarbonization

Industrial Symbiosis Creates Three Types of Value

- **Environmental value**
  - lower emissions
  - reduced waste
- **Economic value**
  - cost savings
  - new revenue from by-products
- **System value**
  - improved resilience of industrial ecosystems
- Examples: Kalundborg Symbiosis, eco-industrial parks





The Industrial Symbiosis Scaling Paradox

Industrial symbiosis is widely promoted for **decarbonization and circular economy**

Yet:

- Most projects remain **small-scale pilots**
- Many feasibility studies **never reach implementation**
- Industrial symbiosis **rarely scales across industrial parks**

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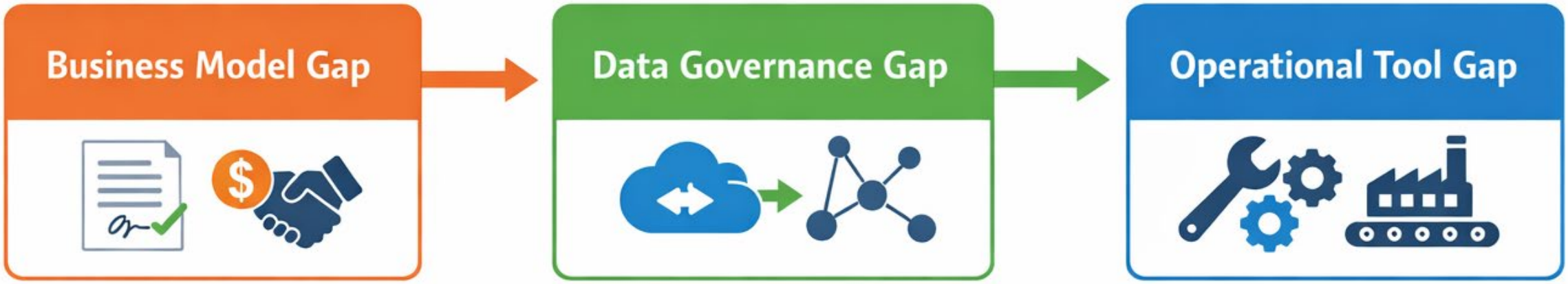
Three Systemic Gaps Prevent Industrial Symbiosis Scaling



unclear roles, incentives, and value allocation

limited interoperability and secure data sharing

analytical tools rarely integrated into real operations

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Research Gap: Fragmented Perspectives

Research on industrial symbiosis is **fragmented across domains:**

- **Industrial symbiosis studies**
  focus on resource exchanges and industrial networks
- **Engineering and optimization studies**
  focus on modeling and analytical tools
- **Policy studies**
  focus on governance and circular economy strategies
- **Missing:**
  an integrated approach connecting **business models, data governance, and operational toolchains**

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Research Objective

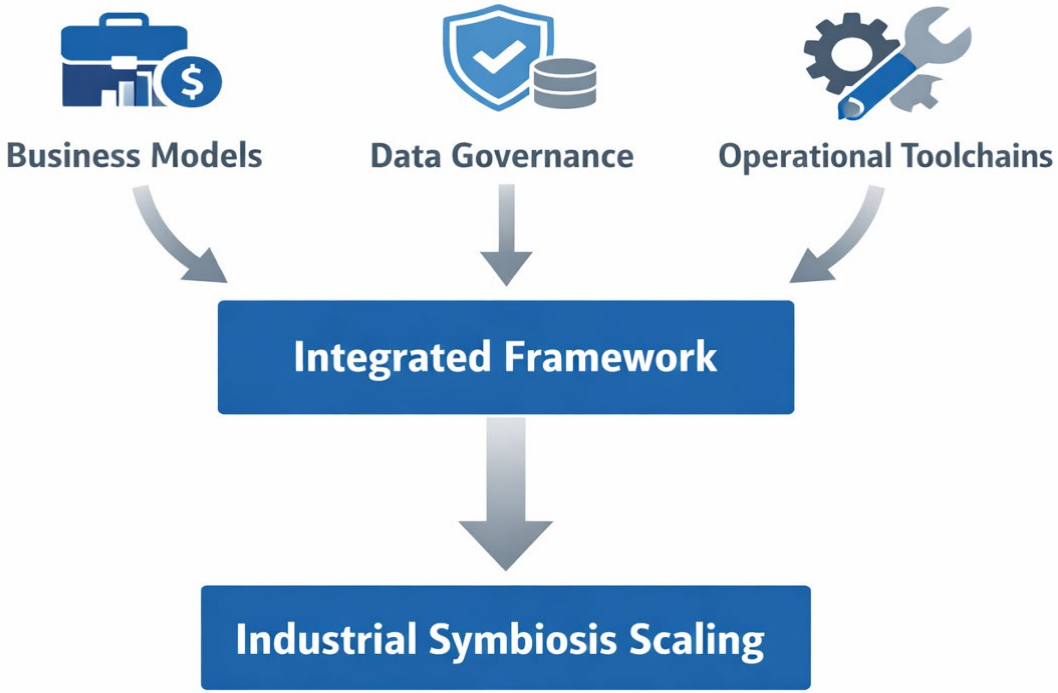
- **Goal**

  Develop an integrated framework to enable **large-scale deployment of industrial symbiosis**

- **Focus**

  Integration of:

  - business models
  - data governance
  - operational toolchains



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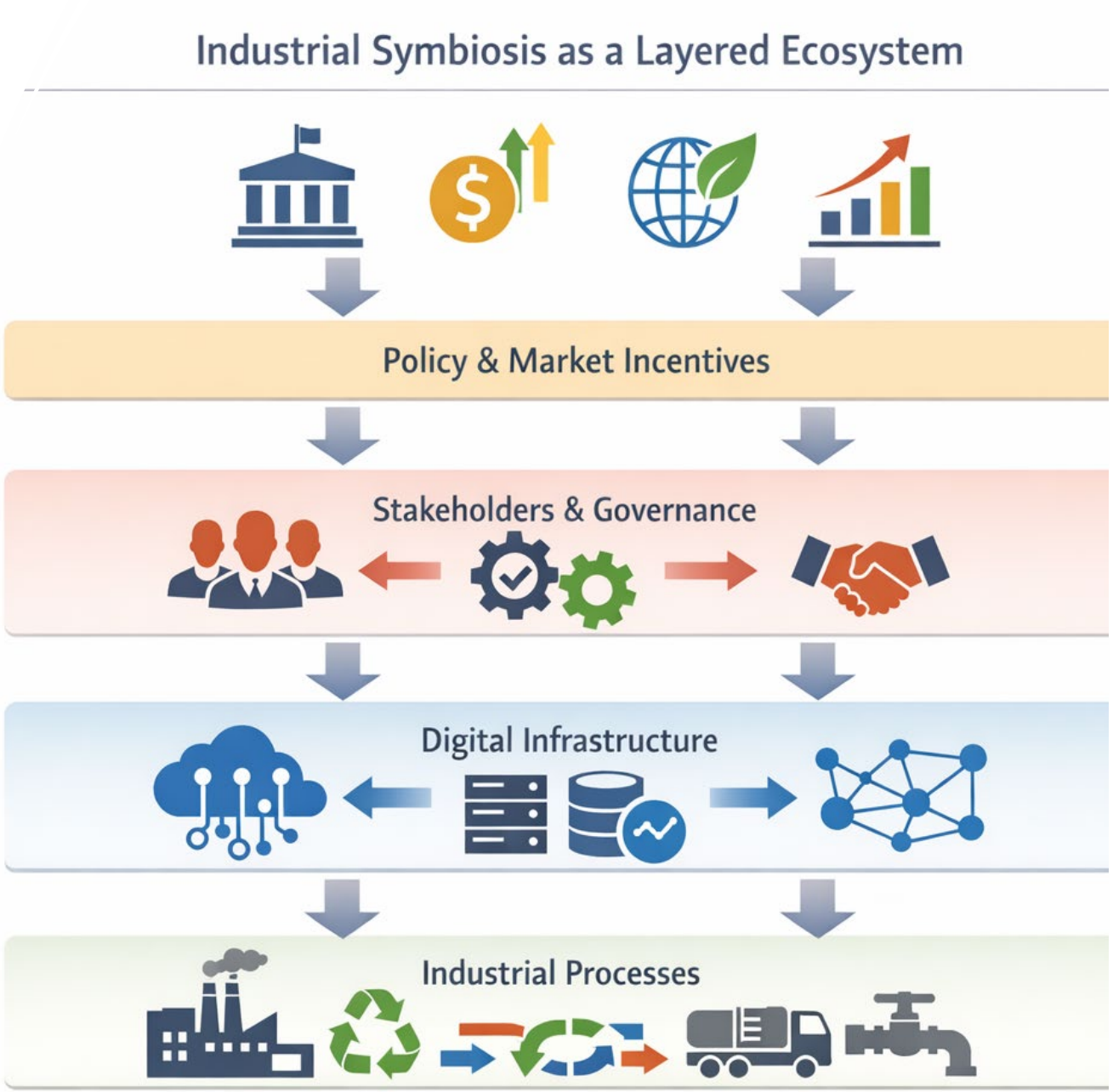
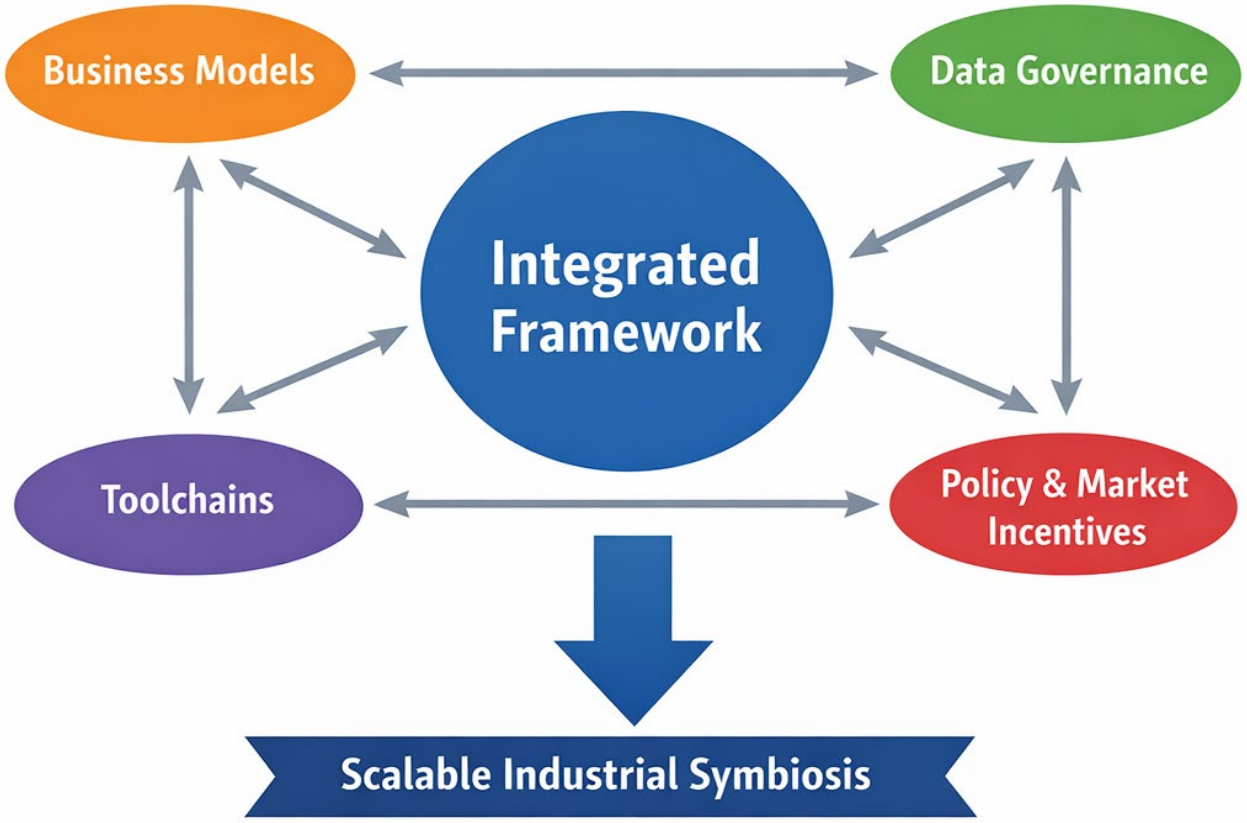
Industrial Symbiosis as Ecosystem

Industrial symbiosis depends on the interaction of:

- **Industrial layer**
  resource and energy exchanges betwe companies
- **Digital layer**
  data infrastructure and analytical tools
- **Governance layer**
  stakeholder collaboration and agreements
- **Policy layer**
  regulations and market incentives



Integrated Framework for Scaling Industrial Symbiosis



Scaling industrial symbiosis requires integration of:

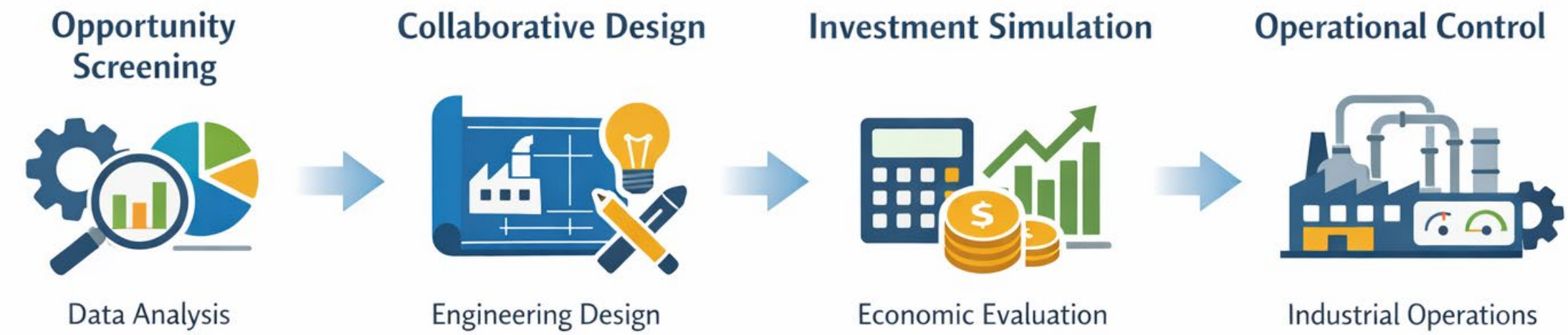
- **Business models**
- **Data governance**
- **Operational toolchains**

Enabled by:

- stakeholder collaboration
- policy and market incentives

Operational Toolchain for Industrial Symbiosis

Industrial symbiosis implementation typically follows four stages:



identify potential resource exchanges

evaluate technical and organizational feasibility

analyze economic and environmental impacts

manage and optimize real industrial exchanges

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Industrial Symbiosis Toolchain

Tool examples:	GIS, Sankey diagrams	System dynamics, stakeholder workshops	MILP optimization, Aspen Plus	Digital twins, MPC

Implications for Scaling Industrial Symbiosis

- **Industry**
  - improve energy and material efficiency across industrial parks
  - support large-scale industrial decarbonization
- **Policy**
  - establish interoperable data-sharing frameworks
  - create incentives for cross-company collaboration
- **Research**
  - integrate digital tools with industrial ecosystems
  - advance AI-enabled optimization and decision support

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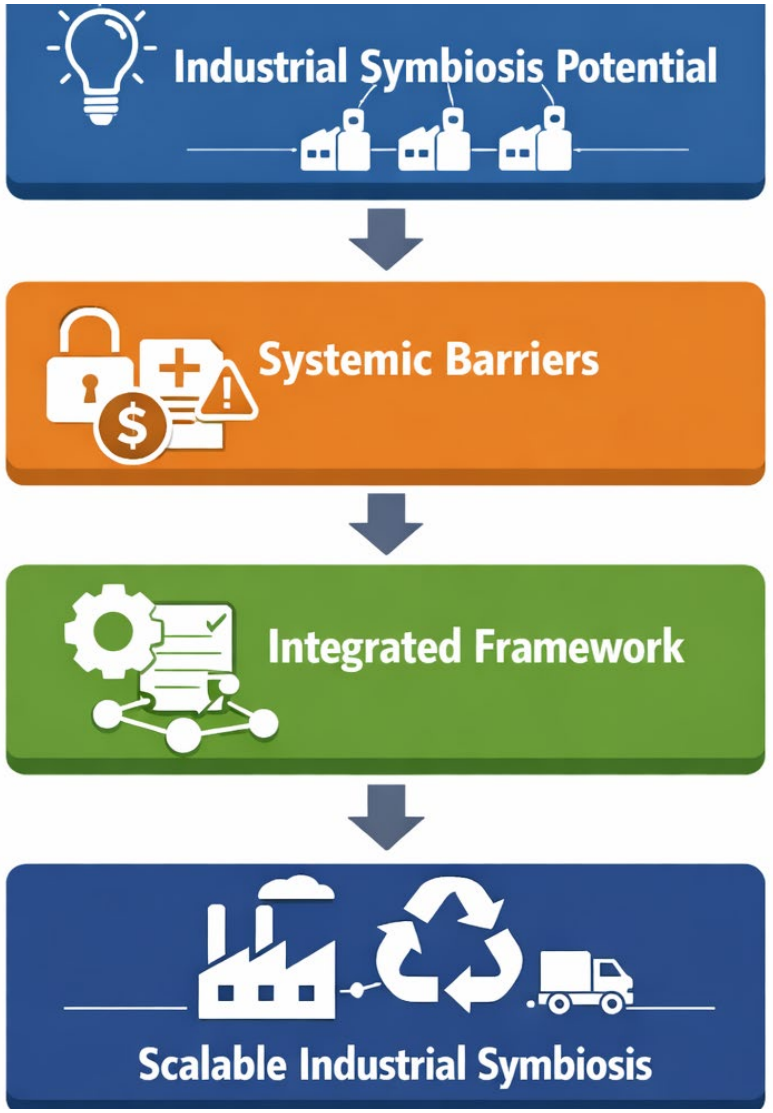
Key Takeaways

- Industrial symbiosis offers major opportunities for resource efficiency and decarbonization
- Scaling requires integration of business models, data governance, and toolchains
- Industrial symbiosis must evolve from pilot projects to coordinated ecosystems

Transformation Pathway for Scaling Industrial Symbiosis



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