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Société d'Automatique, de Génie Industriel & de Productique




Un cadre de modélisation de jumeau numérique de substitution basé sur l'IA pour une ligne de production durable de batteries lithium-ion

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Date: **12 June, 2026**

The BATTwin project has received funding from the European Climate, Infrastructure and Environment Executive Agency under grant agreement No. 101137954

Agenda

1) Batteries: Importance and Production
2) Simulated production line
3) Surrogate modelling
4) Integration and Application
5) Conclusions and Perspectives

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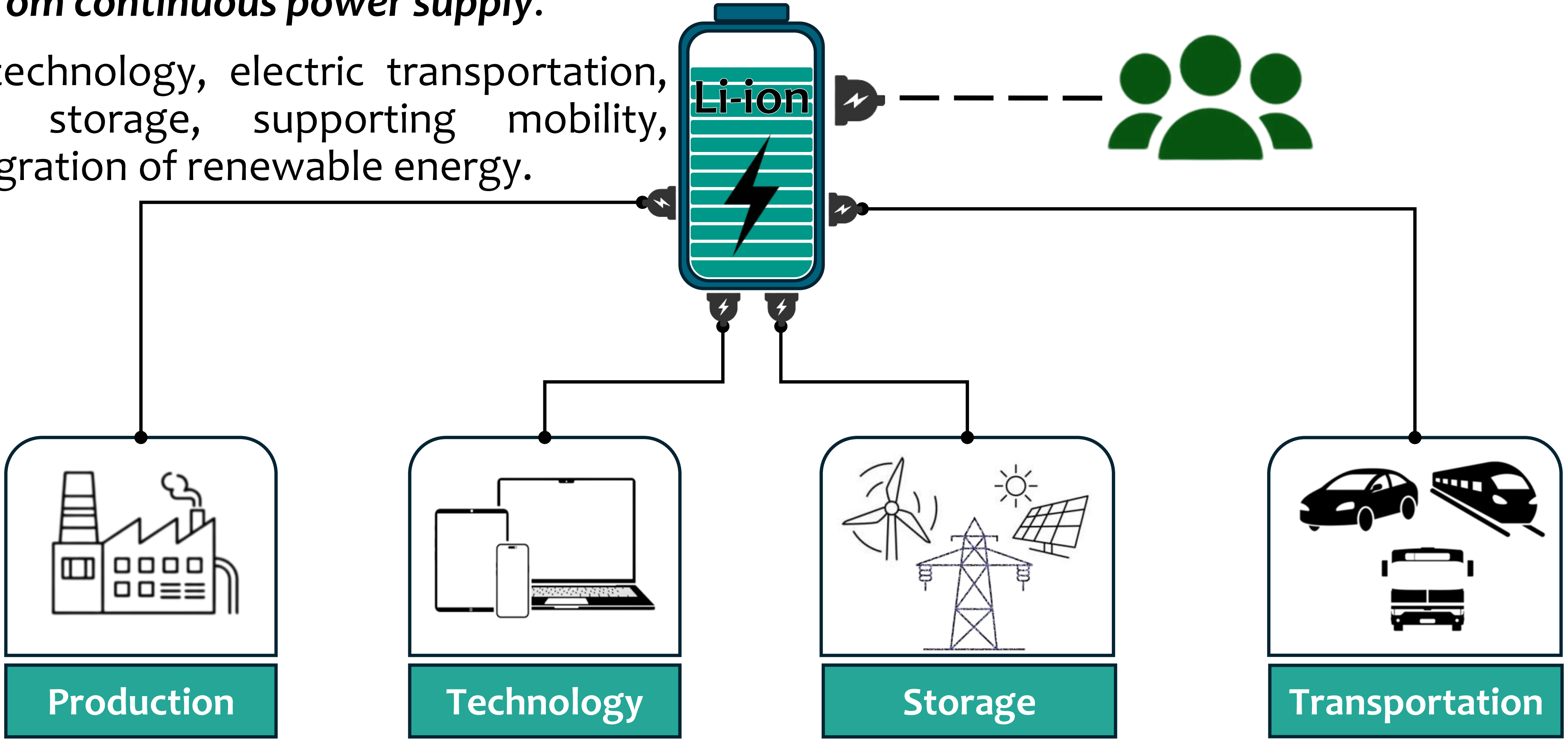
Batteries: Importance and Production

Batteries are essential because they ***store energy*** and ***provide independence from continuous power supply***.

They enable modern technology, electric transportation, and reliable energy storage, supporting mobility, autonomy, and the integration of renewable energy.



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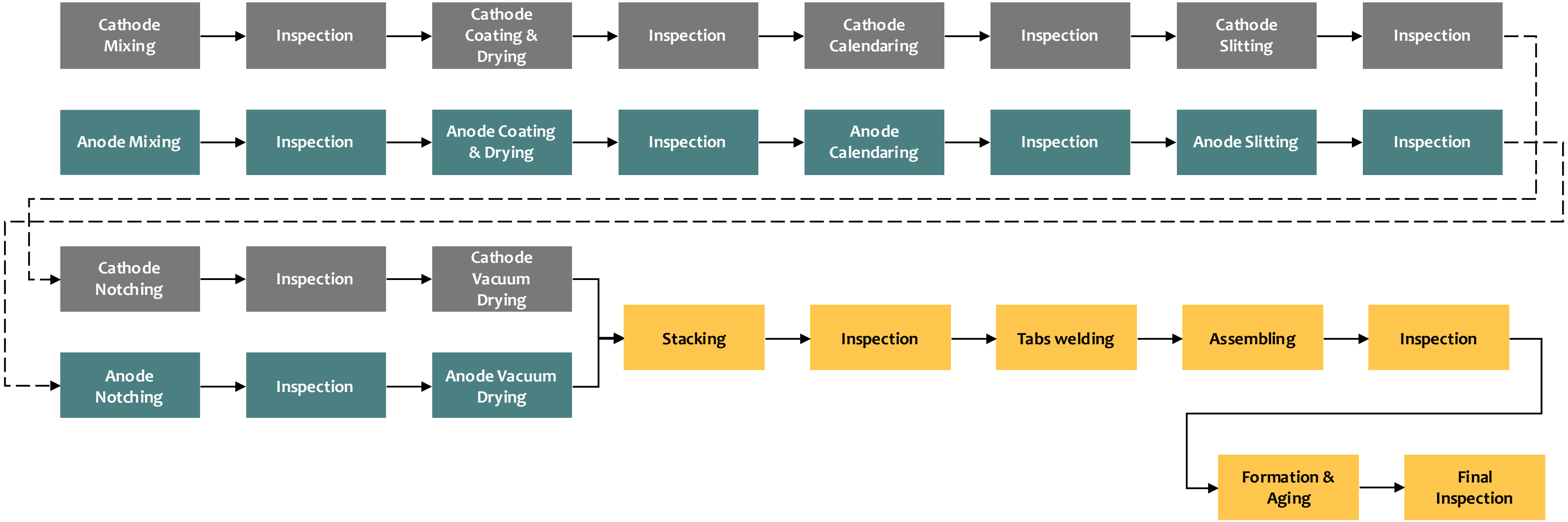
Batteries: Importance and Production

Lithium-ion battery production involves coating and processing ***cathode and anode materials, assembling them with a separator into cells, filling with electrolyte***, and ***forming the cells*** through controlled charging to activate electrochemical performance.



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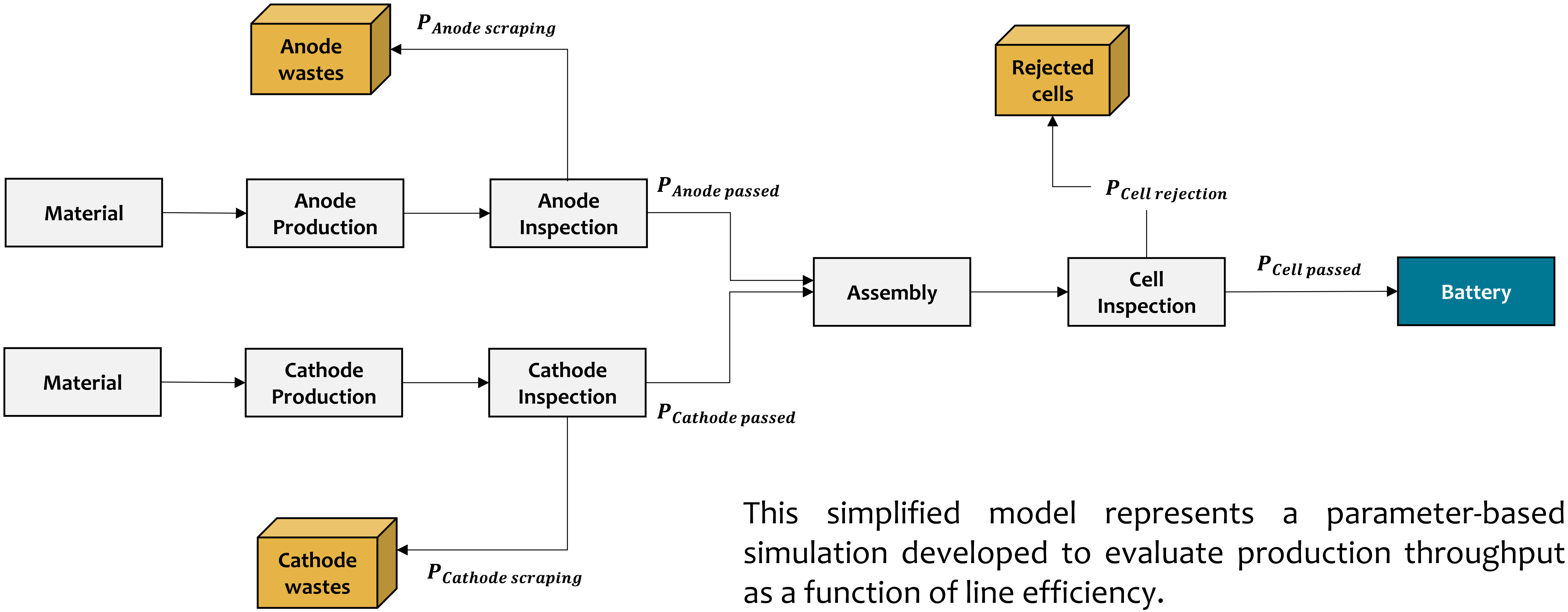
Simplified Battery Line



This simplified model represents a parameter-based simulation developed to evaluate production throughput as a function of line efficiency.

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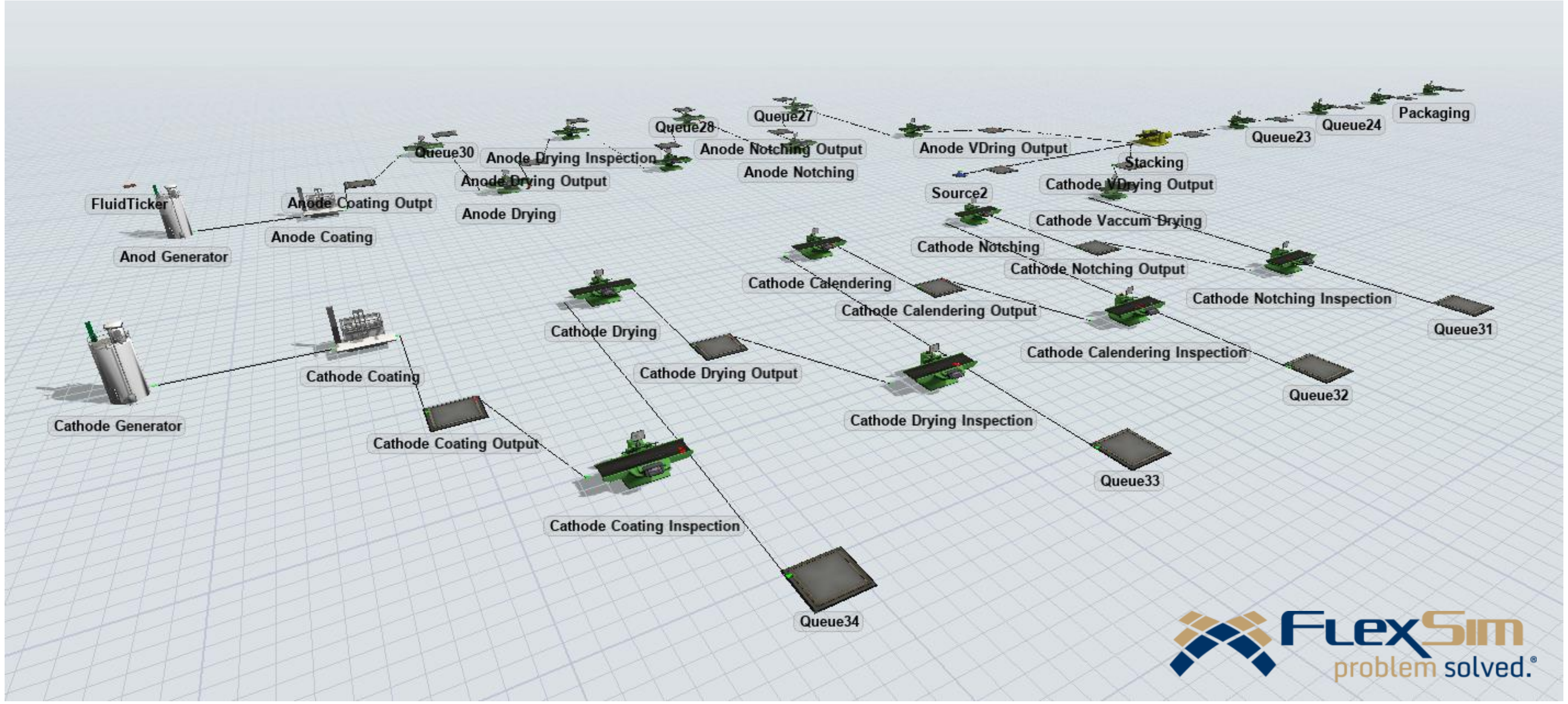
Simulated Battery Line

This figure illustrates the simulated battery line in FlexSim based on the proposed parametric model.



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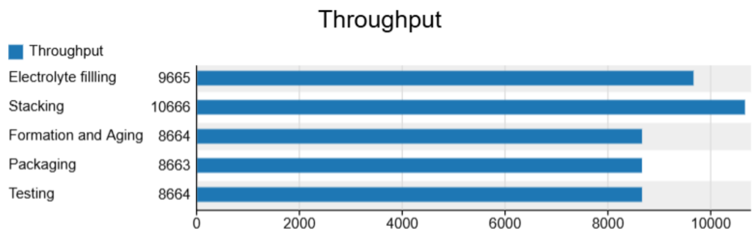
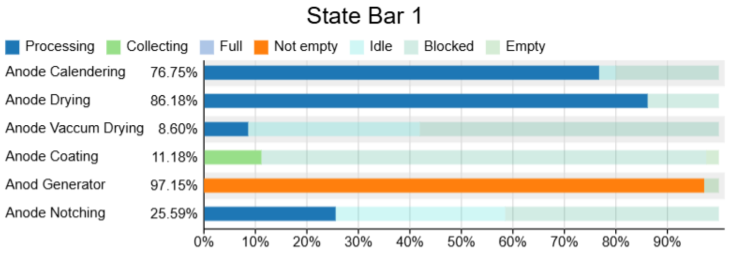
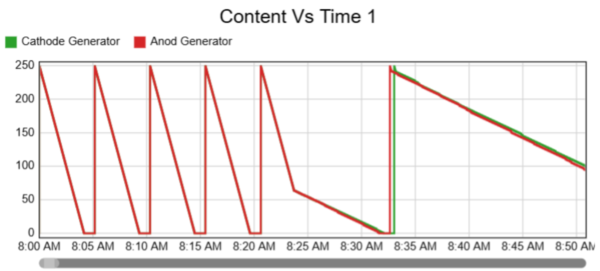
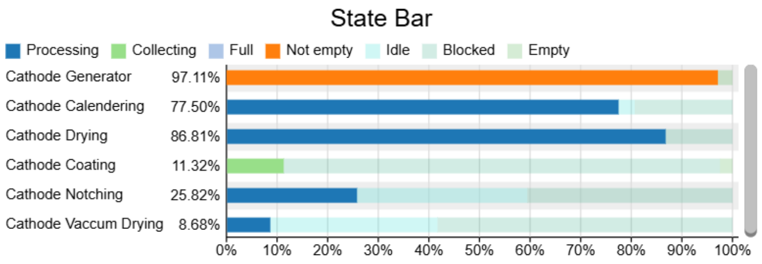
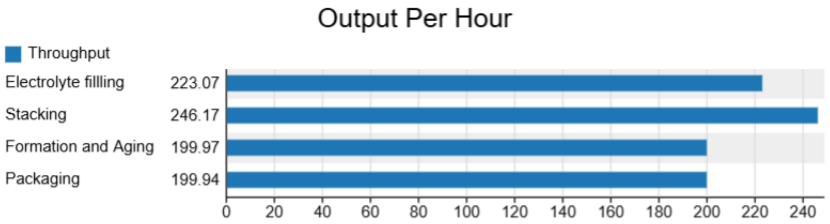
Simulation outputs

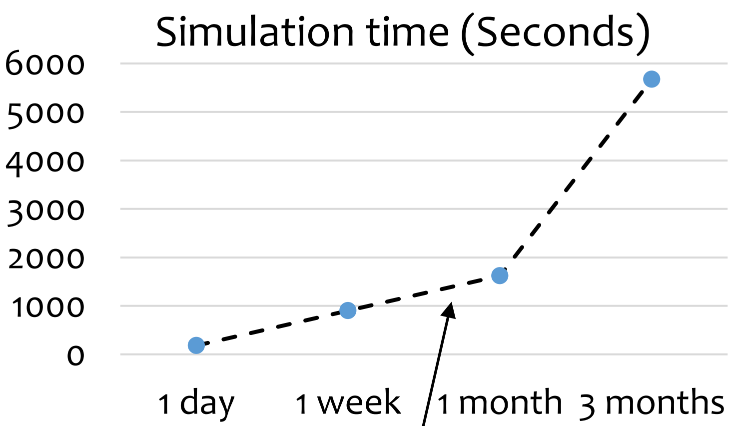












Simulation runtime for variety of production periods

Reason of the study. What can be done ?

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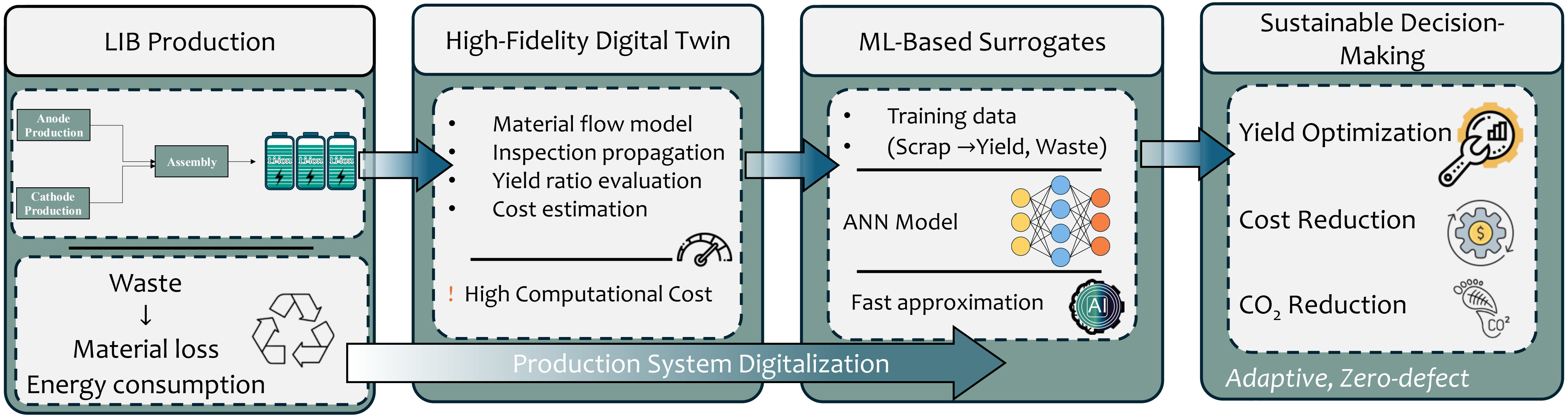
Scientific questions

- **Deployment** - ***How*** can AI-based surrogate models be ***integrated into decision-making*** frameworks to guide manufacturing decisions?
- **Purpose** - ***What*** computational efficiency gains are ***achieved*** by embedding surrogate models within optimization frameworks?



CIRP ICME '26 Conference

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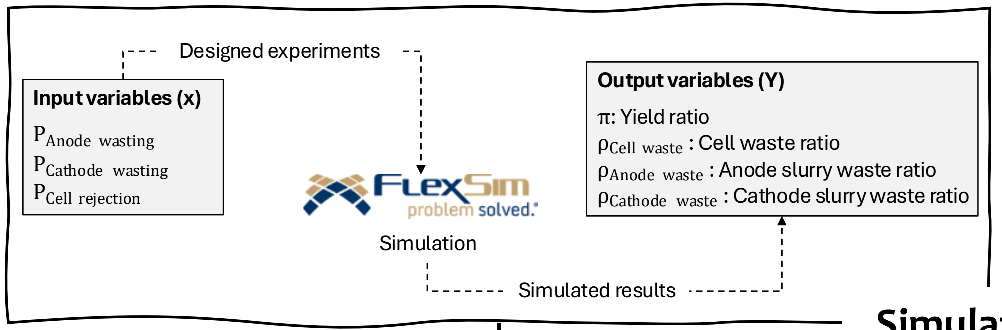
Surrogate modelling

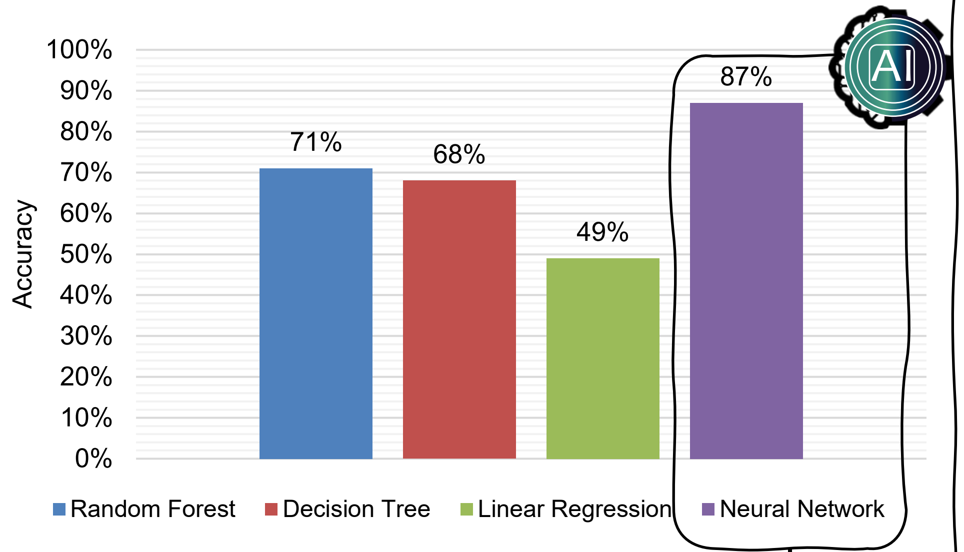
A surrogate model is a fast, ***learned approximation*** of a costly or ***complex model***, used to enable efficient optimization, learning, or decision-making.



Simulation

ScenarioID	Anode wasting rate	Cathode wasting rate	Cell rejection rate	Output ratio	Cell waste ratio	Anode slury waste ratio	Cathode slury waste ratio
6515	27	5	7	29.33%	0.00%	44.81%	8.57%
6516	2	9	10	64.07%	3.44%	2.58%	13.23%
6517	12	13	12	55.48%	3.75%	17.86%	13.32%
6518	22	17	15	40.14%	3.49%	11.15%	10.28%
6519	5	22	18	40.96%	4.37%	8.94%	2.62%
6520	15	26	21	25.37%	3.01%	10.79%	45.93%
6521	25	1	23	30.92%	4.03%	30.44%	2.15%
6522	9	5	26	65.50%	9.09%	1.27%	6.76%
6523	19	9	29	38.09%	5.57%	31.52%	7.74%

DOE



$$Outputs = \boxed{\hat{f}}\ (Inputs)$$

Surrogate

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Integration

Optimization model

Objective:
Finding the best combination of machines for investment and allocation

Multi-objective function: ***Cost, CO_2, Yield Loss***

Decision variables vector: technologies' nominal efficiencies

$$F\ (\mathrm{X}):\ [\mathrm{Min}\ Cost(\mathrm{X}), \mathrm{Min}\ CO_2(\mathrm{X}), \mathrm{Min}\ Loss(\mathrm{X})]$$

Subject to

$$Cost = Cost_{a\ good\ cell}(\pi) + Cost_{processing\ a\ cell}(\rho_{\text{Cell waste}}) + Cost_{Processing\ Anode}(\rho_{\text{Anode waste}}) + Cost_{Processing\ Cathode}(\rho_{\text{Cathode waste}})$$

$$\mathrm{CO}_2 = CO_{2\,a\ good\ cell}(\pi) + CO_{2\,Anode}(\rho_{\text{Anode waste}}) + CO_{2\,Cathode}(\rho_{\text{Cathode waste}}) + CO_{2\,Production}(\rho_{\text{Cell waste}})$$

$$\mathrm{Loss} = 1 - \pi$$

$$\underbrace{[\pi, \rho_{Cell\ waste}, \rho_{Anode\ waste}, \rho_{Cathode\ waste}]}_{KPIs} = \underbrace{\hat{f}}_{Surrogate\ (Simulation\ represantative)} \underbrace{(P_{Anode\ wasting}, P_{Cathode\ wasting}, P_{Cell\ rejection})}_{X:\ Variables}$$

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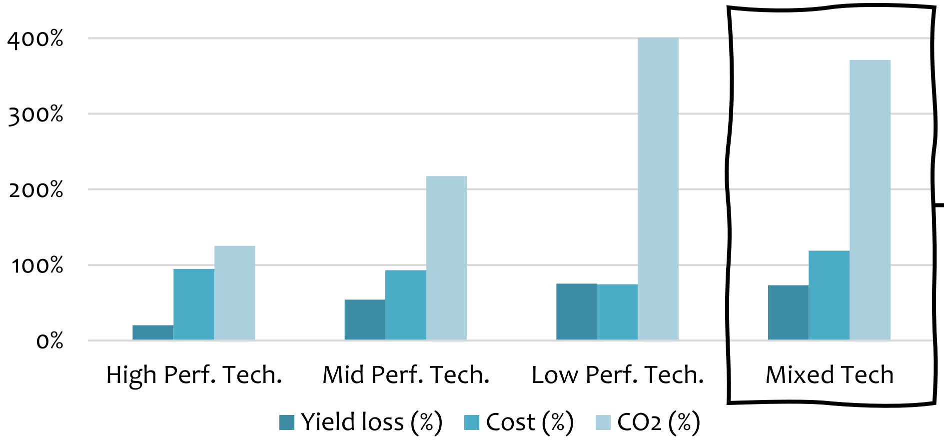
Application

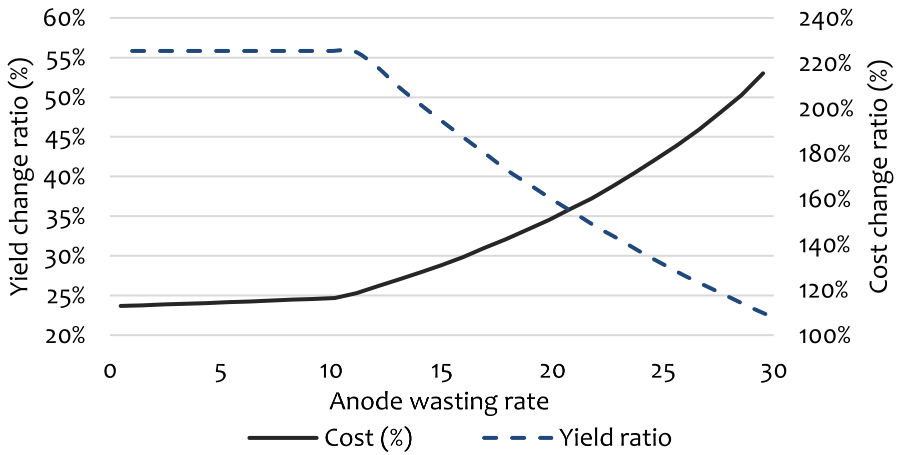
Table2. Exemplary production lines and associated performances

Scenario	Performance (%)		
	$P_{Anode\ wasting}$	$P_{Cathode\ wasting}$	$P_{Cell\ rejection}$
High Perf. Tech.	5	5	2
Mid Perf. Tech.	15	15	12
Low Perf. Tech.	25	25	22
Mixed Tech	25	10	15

Table 3. Adapted process related energy and CO2 emissions for 1day production in France [1,2]

Process	Nominal process power [kW]		Emitted CO_2 [kg/kWh]	
	Electricity	Gas	Electricity	Gas
Anode	205	1035	260.8	5117
Cathode	205	1035	260.8	5117
Cell	1848	978	2350.7	4835.2





The Impact of Technological Incompatibility:
Assume the performance of the Cathode (10%) and Assembly (15%) lines remains constant, while the performance of the Anode line degrades over time (0% - 30%).

[1] F. Degen, M. Schütte, Life cycle assessment of the energy consumption and GHG emissions of state-of-the-art automotive battery cell production. J. Clean. Prod., 2022.
[2] I. IEA, Net zero roadmap: a global pathway to keep the 1.5° C goal in reach. International Energy Agency Report, 2023.

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Conclusions and Perspectives

Conclusion

The critical advantage of the surrogate-assisted framework lies in its drastic reduction of computation time.

Perspectives

1) Circular and sustainable production

Introducing ***scenarios*** such as Reusing, Recycling and Repairing.

2) Surrogate-assisted reinforcement learning

Surrogate models accelerate the training process by providing rapid, synthetic rewards, allowing reinforcement learning agents to learn efficiently.

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Flexible and scalable digital-twin platform for enhanced production efficiency and yield in battery cell production lines

Thank you!

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