

Humanoid Robots 2.0

The convergence moment?

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Advanced and humanoid robotics are core mitigation measures for the rising trend of labor scarcity

Labor scarcity and mitigation measures

Change of working-age population
(aged 15-64 years), 2025 to 2050 [%]



For German companies

>85%

of companies experience first effects from labor scarcity in their operations

~4 months

are required on average until vacant positions can be staffed

For manufacturing specifically

~45%

of manufacturing companies are already missing talents for their vacancies

~57%

of companies in metal-working report operational difficulties due to staffing shortages



Key levers against labor scarcity

Automation & Operations



Level of Automation
Operational excellence & efficiency
Process maturity & repeatability
Complexity & flexibilization
IT-systems & governance

Lights-out-operations as a key lever against labour scarcity

Organization & Talents



Talent acquisition
Talent management
Talent retention

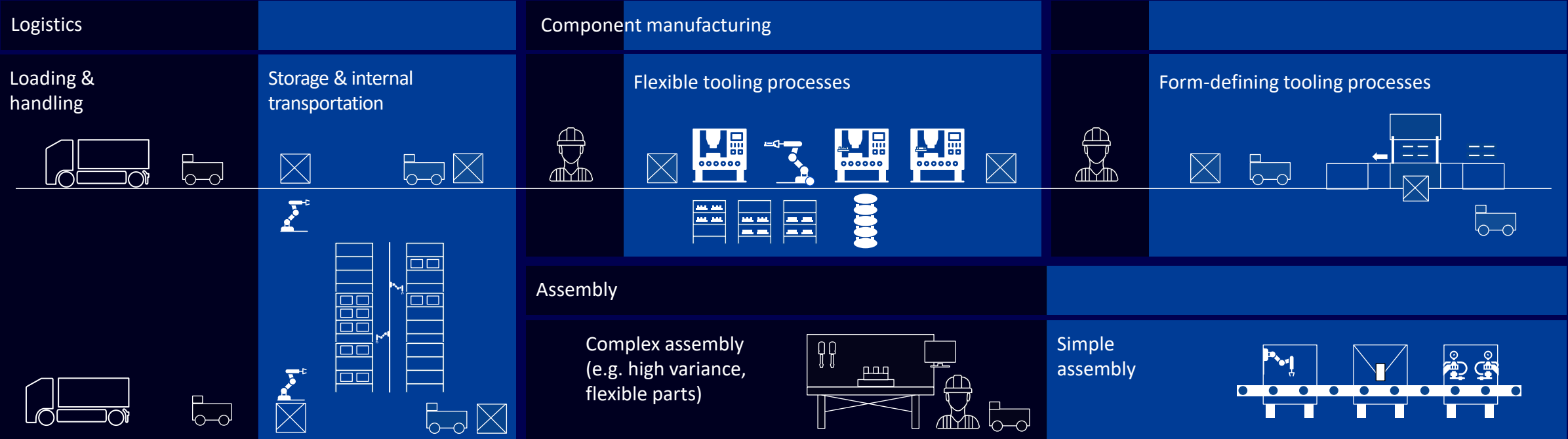
Value Chain & Business Models



Value and supply chain setup
Outsourcing potentials
and more...

With the right process design, significant portions of manufacturing plants can run fully autonomously – Material handling and assembly remain challenging

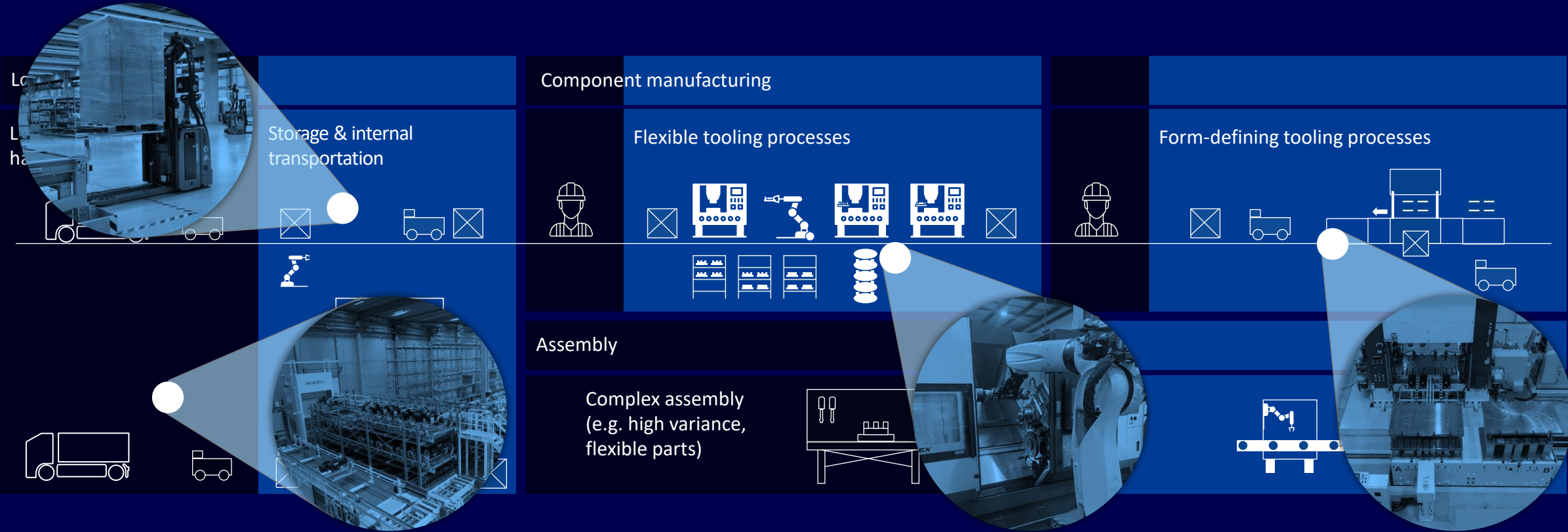
The current state of factory automation



Fully automated Highly manual

With the right process design, significant portions of manufacturing plants can run fully autonomously – Material handling and assembly remain challenging

The current state of factory automation



Material handling such as unpacking, picking of bulk goods and kitting remain challenging – Advanced robotics aims to reduce these automation gaps

Remaining automation challenges and potential solutions

Material handling challenges in today's manufacturing

Picking of bulk goods



Hanging parts onto a conveyor system



Kitting (e.g., picking of highly varying parts)



Unpacking of components



Fixing a workpiece on a jig



Manual assembly



Advanced robotics as a key lever



Ability to deal with process variance by adapting to the environment in real-time



Quick industrialization and flexible usage across tasks without significant programming and (re-)configuration effort



Ability to move and operate in all areas where humans can move and operate, e.g., not restricted by stairs and tight spaces, etc.



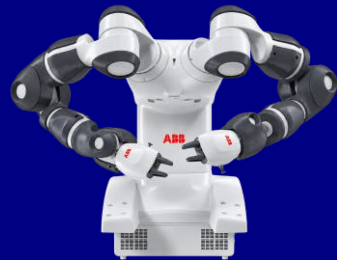
Figure AI 02 in BMW Spartanburg plant



Advanced robotics comes in different form factors and may even look like traditional robots – Their AI-enabled software stack is the key differentiator

Form factors of advanced robotics

Hardware



Stationary (multi-) arm-based industrial robot



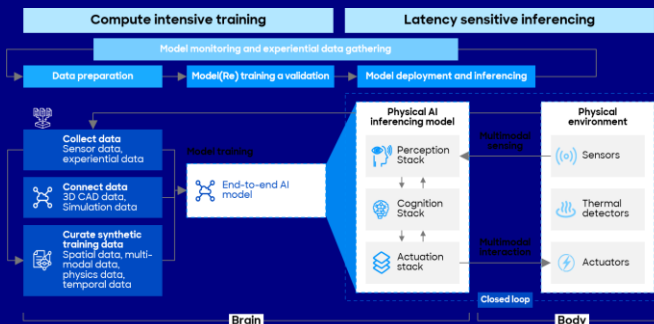
Mobile industrial-robot solution combining robot arm with AGV



Humanoid-shaped robot

Advanced robotics comes in different form factors – The optimal form factor depends on the specific use case

Software



- AI-enabled software stack that generated movement trajectories dynamically based on sensor input
- In contrast to traditional robotics, the humanoid can
 - deal with variance, e.g., different part positions or parts
 - leverage once learned capabilities between tasks
 - combine multiple capabilities to solve complex tasks

Independent of the form factor, all humanoids leverage a similar AI-enabled software stack

Advanced robotics is evolving along two paths: hybrid approaches for targeted use cases, and E2E policies for broader task generality

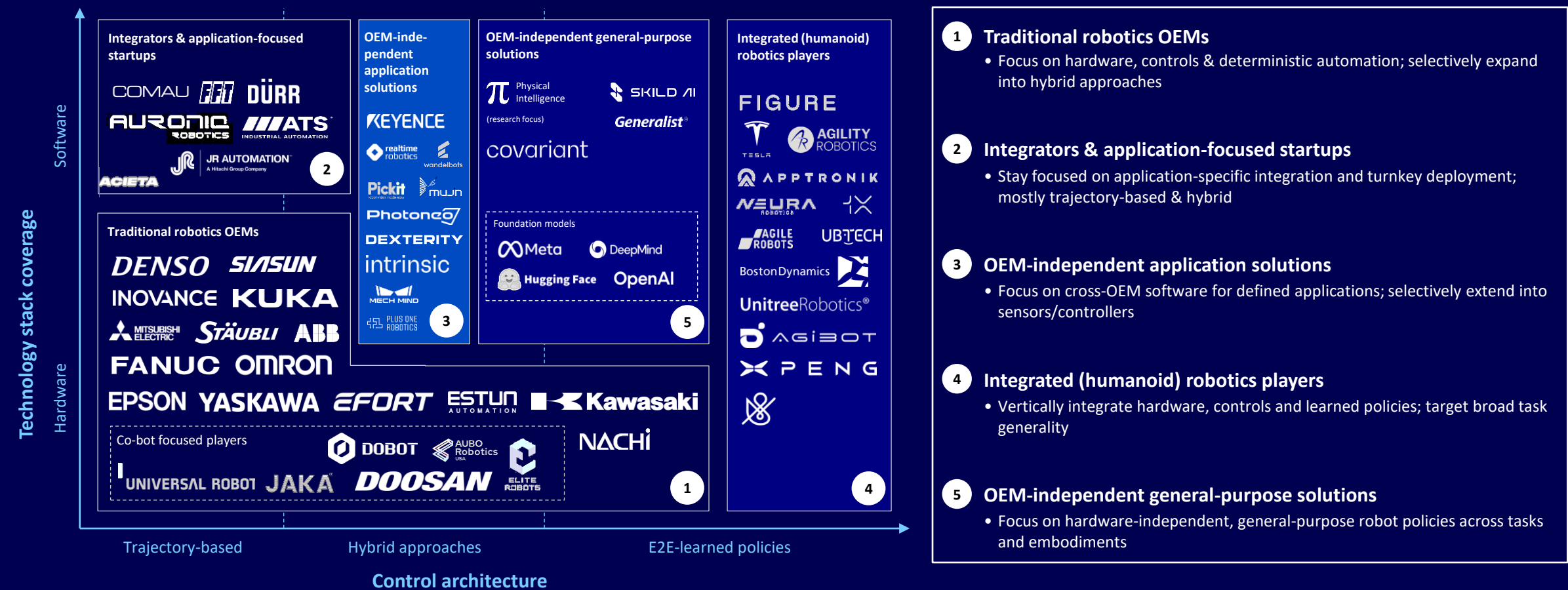
The advanced robotics software stack

	Traditional trajectory-based approach	Hybrid approaches	E2E-learned policies
Description	Execution of pre-programmed trajectories and robot programs	Perception identifies objects/states; classical planning and control generate robot motion	Learned policy maps multimodal observations (e.g., camera images, sensor signals) directly to robot actions / trajectory targets (e.g., coordinates)
Industrialization/ setup effort	• Application-specific programing of robot. • Every new use cases requires new programming	• Solution designed for specific application (e.g., bin picking) • Teaching of use case specifics, e.g., parts to be picked, often required	• Depending on training scope, solution generalizes across larger task family • At current stage, significant task-specific finetuning required
Use cases	• Automation in standardized and high-volume environments, e.g., – High volume assembly and pre-assembly – Material handling of standardized fixtures/containers	• Simple material handling use cases in non-standardized environments – Bin picking of bulk goods – Palletizing / de-palletizing of boxes – Picking of parts from/to shelves – Loading and unloading of machines	• Complex material handling tasks – Kitting of components – Handling of (semi-)flexible components • Coverage of broader task families, e.g., tending of different machines,

Providers focusing on E2E-learned policies are largely offering an integrated SW & HW solution – Cross-robotic OEM solutions are just emerging

The advanced robotics ecosystem

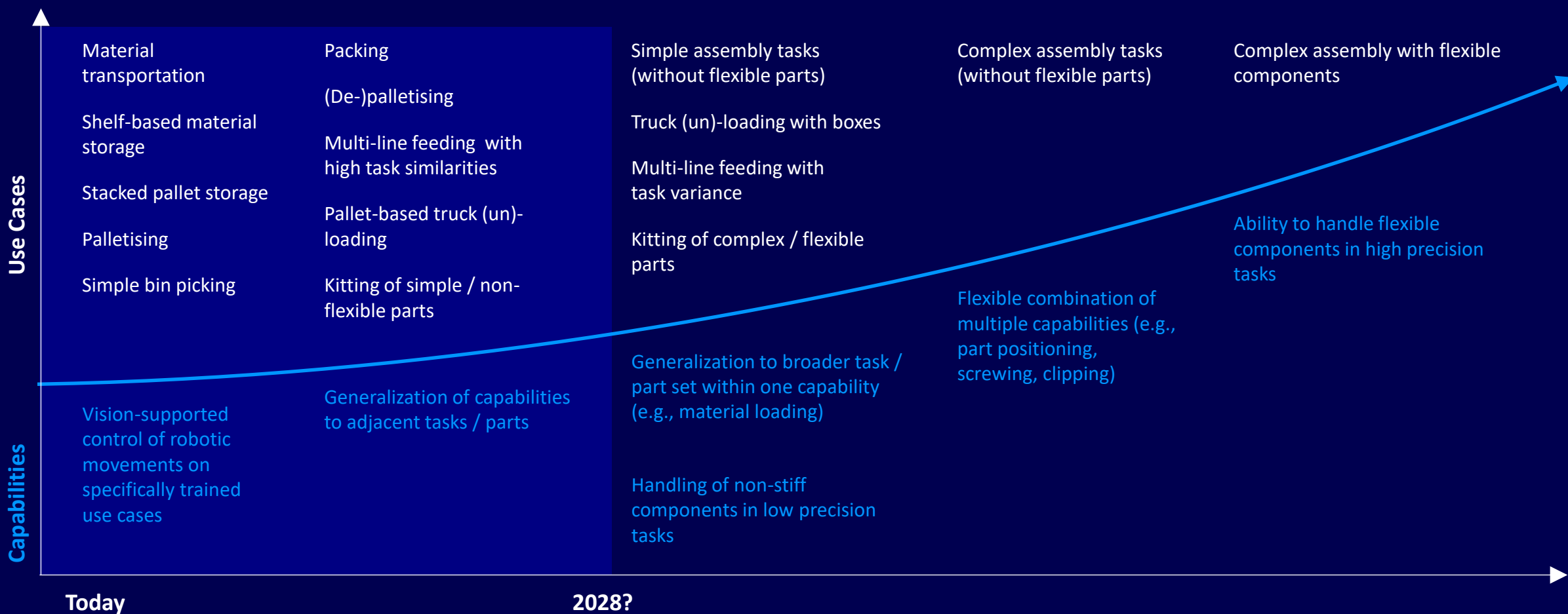
Selective players only



Note: Companies are allocated to clusters only; logo placement within a cluster does not indicate differences in portfolio focus.

Currently, both approaches lead to similar robotic capabilities as generalization of E2E policies across task families and to complex tasks not yet achieved

Estimated use cases and capabilities of advanced robotics



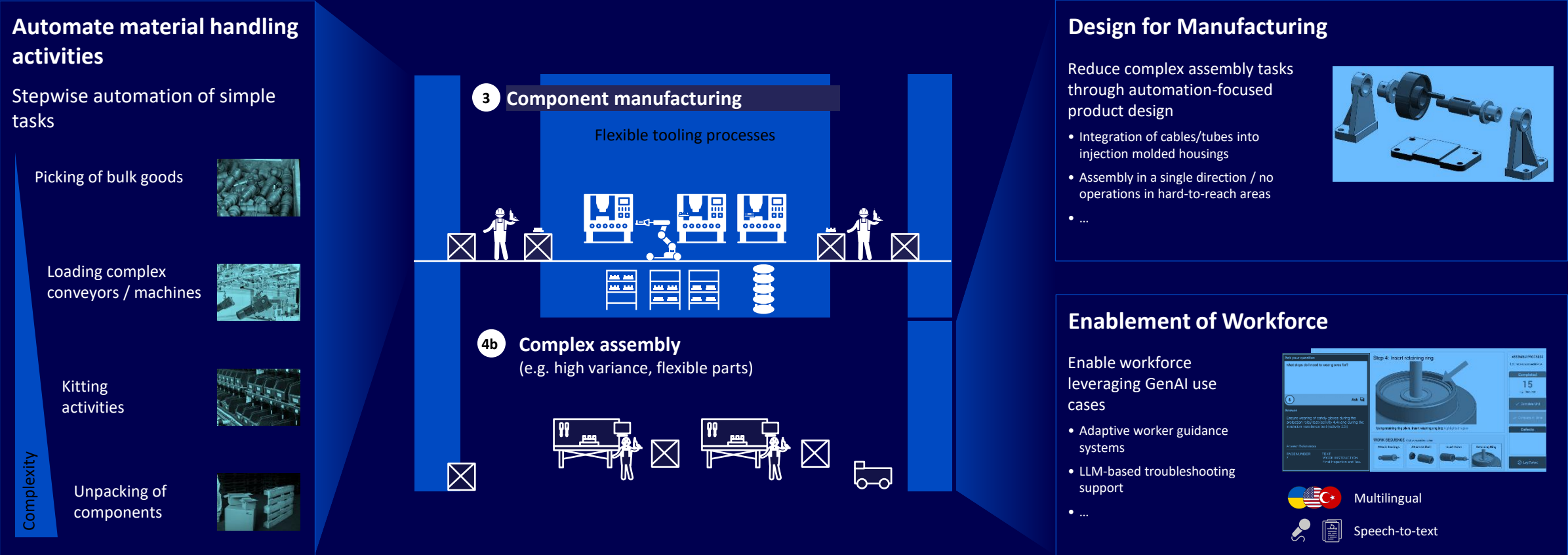
Humanoids leverage similar AI models as autonomous driving, but task complexity is significantly higher while training data availability is lower

Comparison of autonomous driving with humanoid robotics control problems

	Degrees of freedom	Degree of standardization	Data availability	Additional challenges with humanoid robotics
Autonomous driving 	LOW • 2 primary degree of freedom for control – Steering – Acceleration / braking	MEDIUM • Standardized road infrastructure • Common traffic rules and semantics • Various disturbances (e.g., light, weather, traffic, people)	HIGH • Large fleet of vehicles for data collection • Cheap passive collection	• No (regulatory) framework for risk evaluation in collaborative tasks • Risk of sharing proprietary process knowledge across competitors
Humanoid robotics 	HIGH • 20-50+ degrees of freedom – Legs – Arms – Torso – Hands (dep. on complexity)	LOW • Highly varied environments • Open-ended tasks and objects • Some ability to control environment (but at additional cost)	LOW • Limited large-scale robot interaction datasets • Data collection via teleoperation costly and difficult to scale	

Until humanoids have matured, companies need to focus on simple tasks – Design for Manufacturing and Workforce enablement remains key

Implications for manufacturers



To effectively leverage advanced robotics and humanoids, companies need to embed them into an holistic automation and AI roadmap

How to get started?

Use Case Roadmap

Short-term 1-2 years	Mid-term 3-5 years	Long-term 6-10 years
Use Case 1	Use Case 5	Use Case 7
Use Case 2	Use Case 6	Use Case 8
...		...
Solutions and technologies already available today	Technologies avail. but still immature – Dev. of ind. applications required	Technologies still in research, but already on the horizon

- Structured overview of key use cases providing most value-add / addressing core challenges
- Future-looking, i.e., also considering use cases that are enabled by future technological development
- Consideration of interdependencies between use cases

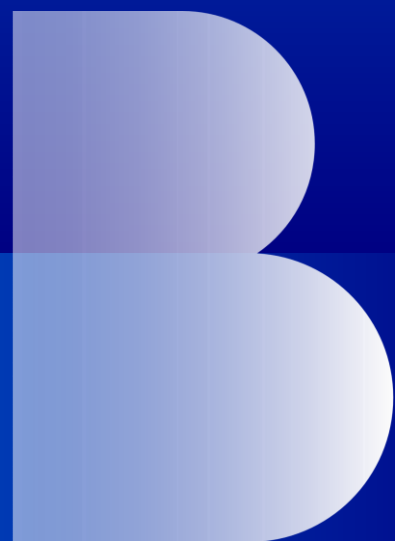
REQUIREMENTS

IT/OT system landscape & architecture

- Technology requirements of prioritized use cases including make-or-buy strategy
- Target IT/OT landscape considering platform approach to leverage synergies between use cases
- Transition roadmap from current to target IT/OT landscape (in alignment with use case roadmap)

Resources & Competencies

- Internal resource requirements, e.g., for own development or management of development projects
- Organizational structure to support implementation, e.g., central Center of Competence, and operating model



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