Transforming the Software Development Paradigm to Meet Unique Needs of Our Industry and Customers

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Global Dynamic Systems and Controls

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Agenda

- Who we are: Cummins history and key data
- The Industry Background: Key enablers for AUTOSAR based architecture
- Cummins Approach:
  - High level overview of C-SAR
  - Model-based development and virtual validation

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Our history

For more than 100 years, we have defined ourselves by our unwavering values and our promise of innovation and dependability. In the next 100, we will continue to challenge the impossible. Here's a look at some highlights from our past 100 years:

1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020

1919

Clessie Cummins creates the Cummins Engine Company based in Columbus, Indiana (U.S.A). William G. Irwin, who employed Cummins as a driver, supplies nearly all of the $50,000 in startup capital.

1929

Cummins takes Irwin for a ride in a used Packard limousine that he equipped with a diesel engine on Christmas Day, convincing Irwin of the engine's potential. Irwin invests a much-needed infusion of cash.

1932

Cummins barnstorms across the country, demonstrating the power and fuel efficiency of the diesel engine in his Coast to Coast Cummins Diesel Test Bus.

1937

Cummins earns its first profit.

1944

Miller becomes Executive Vice President of Cummins.

1951

Miller becomes Chairman of the Cummins Board.

1962

Cummins begins operations in India, first as a joint venture with one plant in Pune.

1975

Cummins enters China as part of a deal involving heavy construction equipment with Cummins engines.

1986

Cummins purchases 86 percent of the Onan Corporation in Minneapolis, Minnesota (USA), which would become the basis for its Power Generation Business.

2000

Cummins Engine Company becomes Cummins Inc. to acknowledge it is also a leader in global markets including filtration and power generation.

2017

Cummins redefines Our Story including the Mission and Values around its Vision of "**Making people's lives better by powering a more prosperous world.**"

2019

Cummins celebrates 100-year anniversary.

Powering a more prosperous world in 2020

190

Countries & territories*

57,825

Global employees

1.3M

Engines built in 2020**

9,000

Cummins certified dealer locations

$903M

Invested in research & technology in 2020

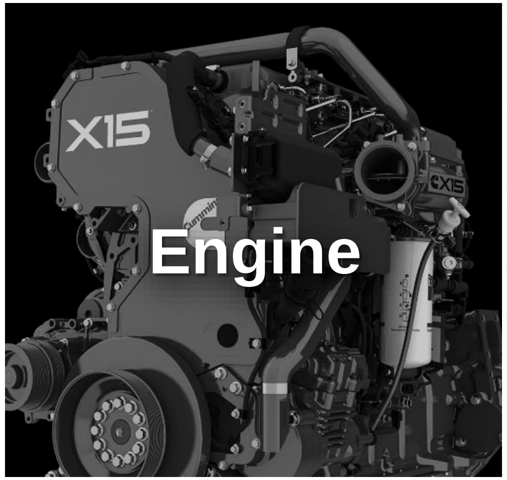
102

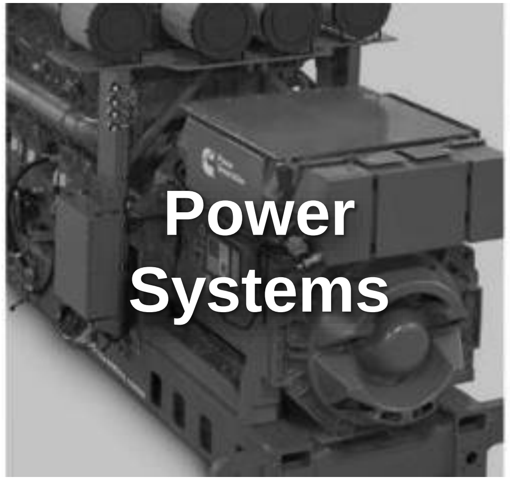
Years of industry leadership

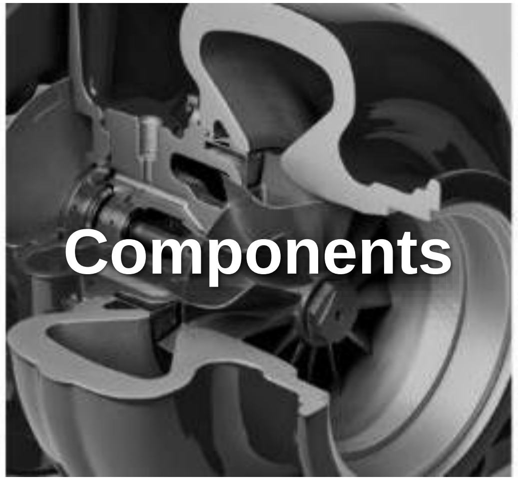
**Approximation of countries and territories with Cummins service*
***This includes engines from both our custodial plants and unconsolidated joint ventures.*
As published in the 2020 10K found on cummins.com

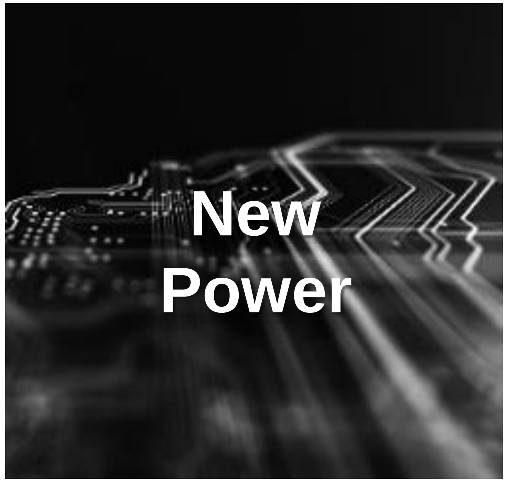
Five operating segments

Cummins has a 102-year-long track record of delivering leading power solutions. As we look ahead, we know our industries and markets will continue to change, and we are committed to bringing our customers the right technology at the right time.









We serve many markets and applications

- Heavy-duty Truck
- Medium-duty Truck
- Bus
- Construction
- Oil & Gas
- Fire & Emergency
- Power Generation
- Electrolysis
- Marine
- Mining
- Light-duty Automotive & Recreational Vehicle
- Defense
- Agriculture
- Rail

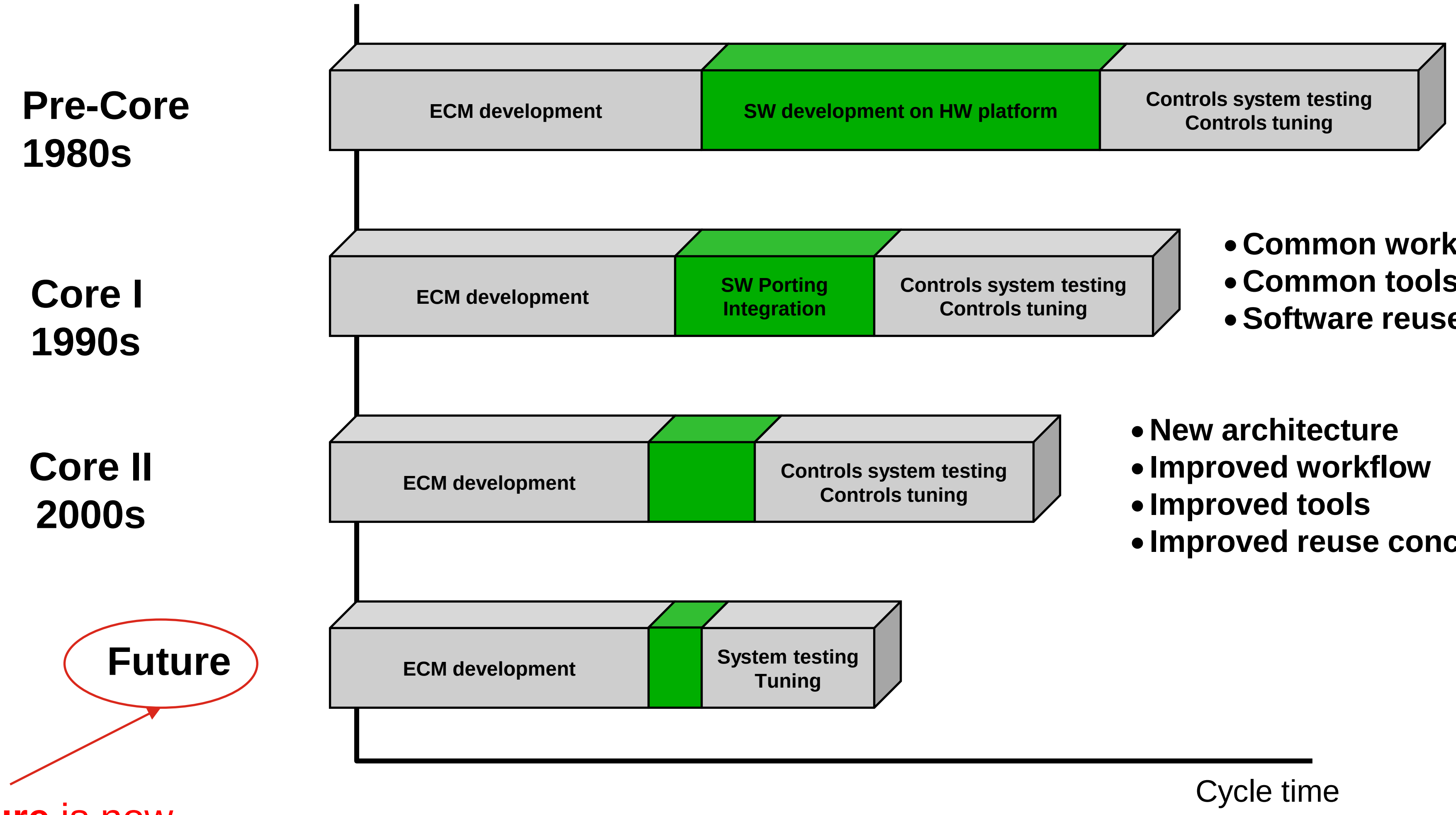
This is not an exhaustive display of Cummins-powered markets. Please refer to cummins.com for the most updated product information.

Global partnerships

Companies listed on this slide reflect a view of top customers globally but is not an exhaustive list of global partnerships. Companies are listed in no particular order.

Controls Software and Platform evolution at Cummins

Reducing cycle time, Improving Quality, Increased Reuse



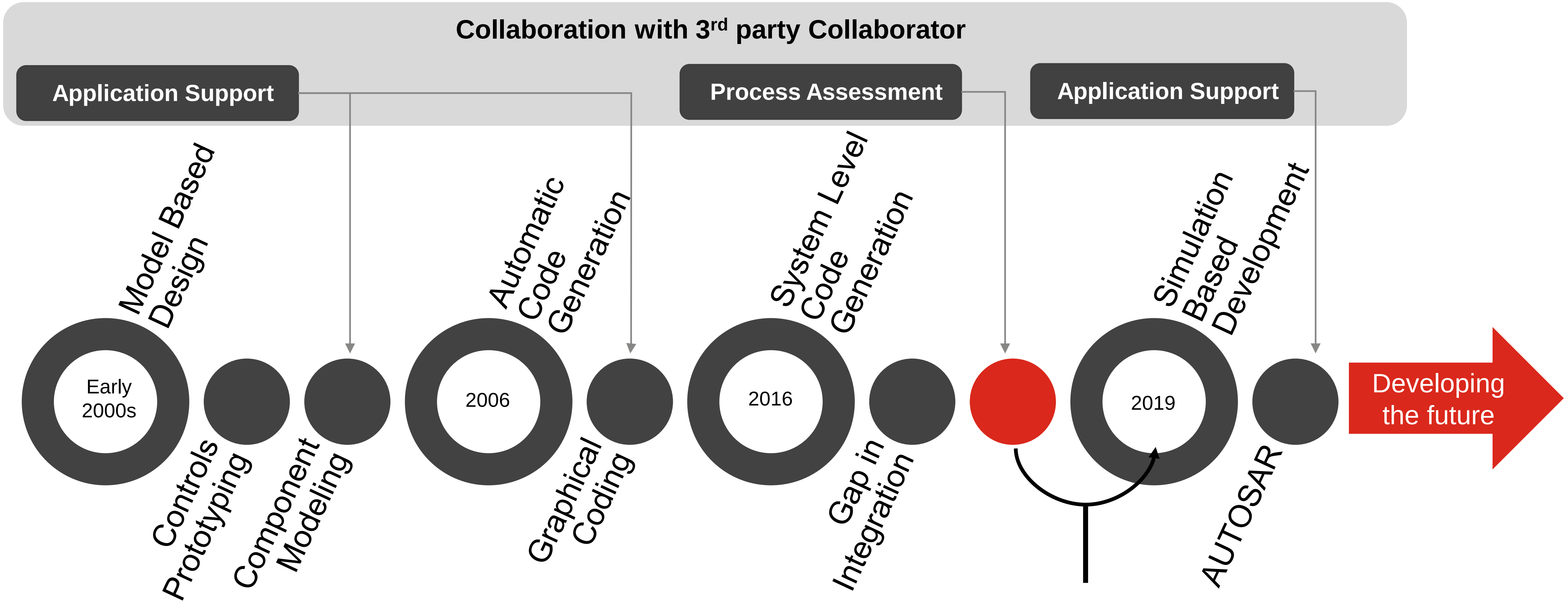
- **Common workflow**
- **Common tools**
- **Software reuse**

- **New architecture**
- **Improved workflow**
- **Improved tools**
- **Improved reuse concept**

The **Future** is now

Cycle time = f(Reuse, quality, portability, flexibility, integratibility, complexity, …)

Model-Based Design at Cummins



Simulation drives ROI of Model-Based Design

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“Our industry is in a transition. Technology, regulations and customer expectations are changing rapidly, requiring our teams to innovate so they can deliver the value our customers expect.”

Vice President and Chief Technical Officer Jim Fier

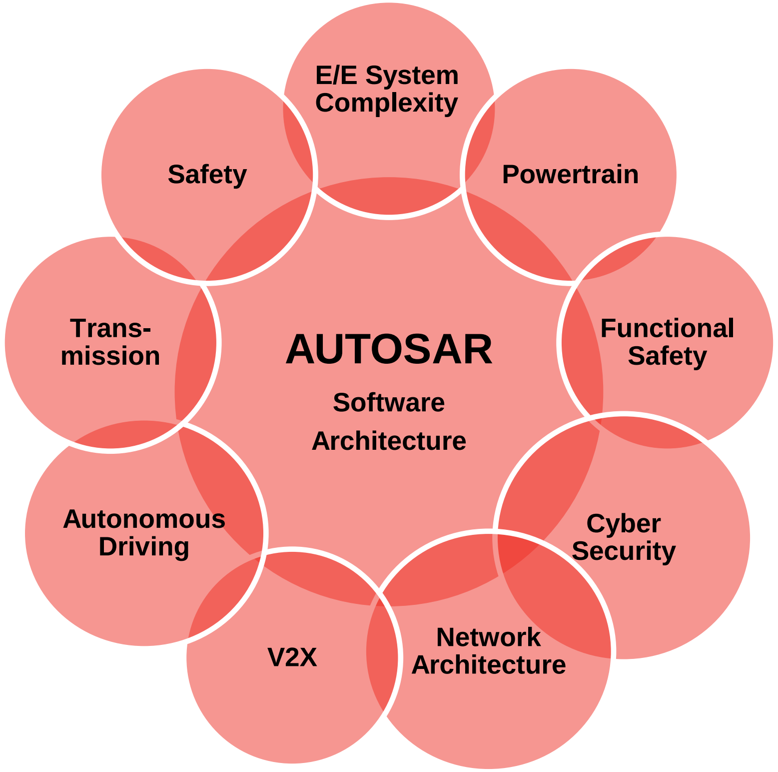
Industry Trends

Safety
• ISO 26262 • SQA • CMMI • ASPICE

(Cyber) Security
• Ethernet, CAN FD • Gateway compliance • Industry development practices • Regulations • Newer SAE standards for OBD Port

Integration
• OEM tools support • Industry protocols • OEM protocols • AUTOSAR

1. How can Cummins best position itself in times when OEMs are driving vertical integration to meet the market demands?
2. Are our electronics and digital architectures and plans in place to meet the future needs?



System Design Options Evaluation

Needs of customers translated into product needs and potential solutions

Customer Needs	Product Needs	Solutions
Increasingly demanding product requirements (fuel economy, performance, emissions)	Physics model-based controls Machine learning Greater ECM processing power	▪ Expand hardware capacity with distributed modules ▪ New hardware technologies for safety and security. ▪ Leveraging System Simulation for feature design.

System Design Options Evaluation

Needs of customers translated into product needs and potential solutions

Customer Needs	Product Needs	Solutions
Increasing machine integration needs and changing powertrain technology portfolio	Module-agnostic software residence	▪ Adopt off-the-shelf industry standard OS for increased compatibility and interoperability.
	Open vs. closed optionality	▪ A mix of Classic AUTOSAR and Adaptive AUTOSAR based on application needs.
	Flexibility in scope of controls	

System Design Options Evaluation

Needs of customers translated into product needs and potential solutions

Customer Needs	Product Needs	Solutions
Faster software release and update time	More modular software architecture Component-level test capability Faster end-to-end processes	▪ Design modular S/W architecture. ▪ Redesign controls processes to better balance quality and speed from end-to-end. ▪ Leveraging System Simulation for virtual validation.

Implement These Changes under One Initiative: C-SAR

AUTOSAR and Model-Based **Processes** to enable Agile Development

Tools that are commercially available and based on industry standards

Infrastructure to support ISO26262/CMMI/ASPICE, Cybersecurity and industry expectations

Transition to AUTOSAR-based **Architecture** using model-based principles

C-SAR Drives Changes in Many Functional Areas

Development process and tools

Define optimal end to end development process and tools for model centric controls development while ensuring AUTOSAR, Functional Safety and Cybersecurity compliance

Controls Architecture

Establish a multi-platform architecture capable of supporting future Cummins products

POC & Implementation

Define and implement a plan to demonstrate the “next gen” concept as well as the initial delivery to application teams

Diagnostics

Deliver an architecture and a plan to transition Cummins proprietary diagnostics approach into the AUTOSAR implementation

Machine Communication Protocols

Deliver an architecture and a plan to transition Cummins communications protocols to the AUTOSAR implementation

Electronic Tools Infrastructure

Re-architect the existing tool interfaces and related infrastructure and tools. Includes replacing proprietary protocols with UDS and XCP, adding ethernet, security updates, support for non-CMI devices.

Simulation Ecosystem

Deliver an embedded controls validation environment that enables simulation processes for the Next Generation Controls.

Strategy and Planning

Define overall direction and ensure alignment of resources. Responsible for the overall schedule and priorities.

Plant Modeling and Simulation

Deliver requirements to Next Gen design in order to enable efficient PureSim plant modeling and system simulation capability

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A Clean-Sheet Multi-platform Architecture

Model Centric, Distributed Computing, Standard-Based, Off-the-Shelf Tools

AUTOSAR & Model-Based Design

Agile Development

Application Authoring

BSW Configuration

AUTOSAR BSW & MCAL

Modeling in Simulink

Top-Down Workflow

Multi-Platform Architecture

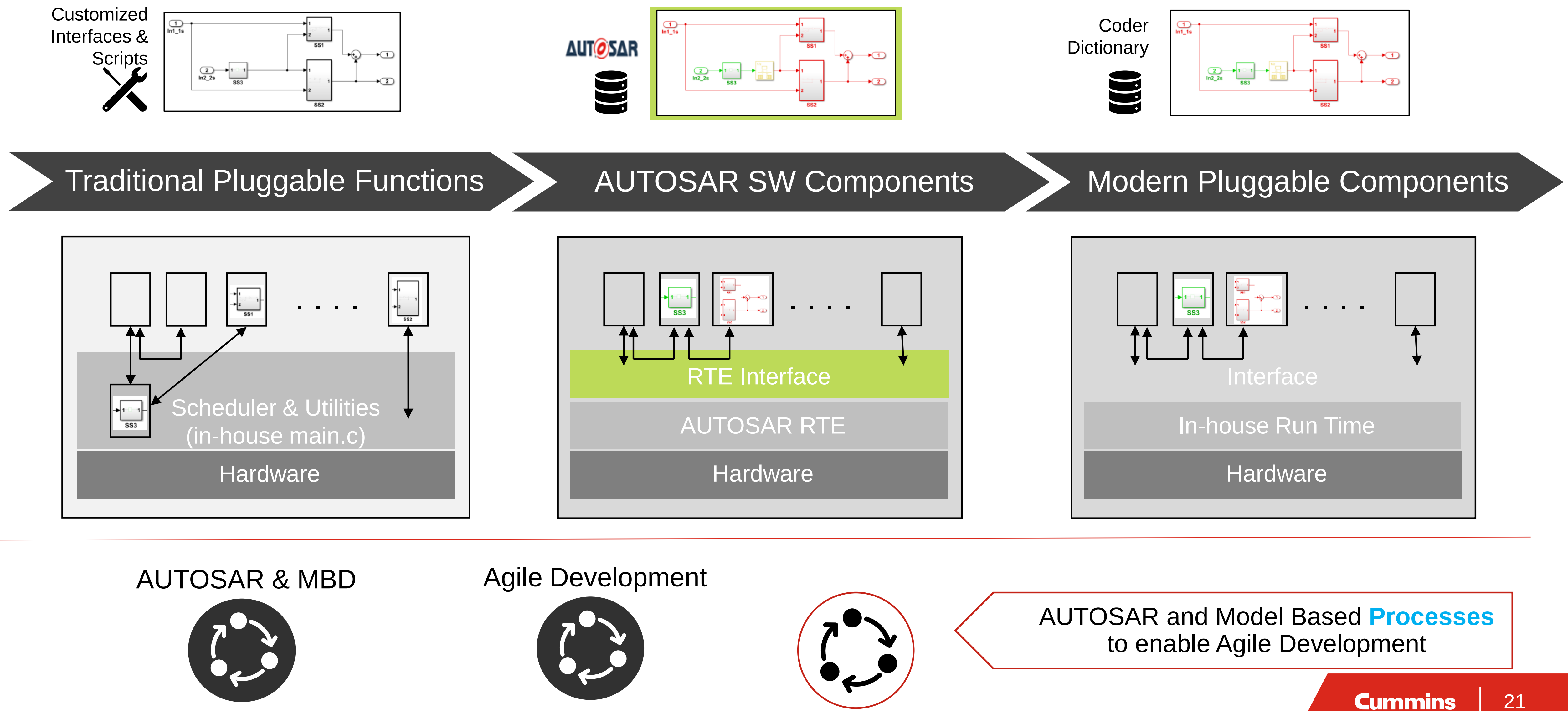
AUTOSAR and Model Based **Processes** to enable Agile Development

Tools that are commercially available and based on industry standards

Infrastructure to support ISO26262/CMMI/ASPICE, Cybersecurity and industry expectations

Transition to AUTOSAR-based **Architecture** using MBD principles

Enable Agile Development
with AUTOSAR and Model Based Processes

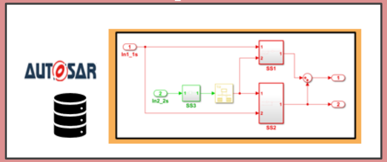


Leverage Synergy Across

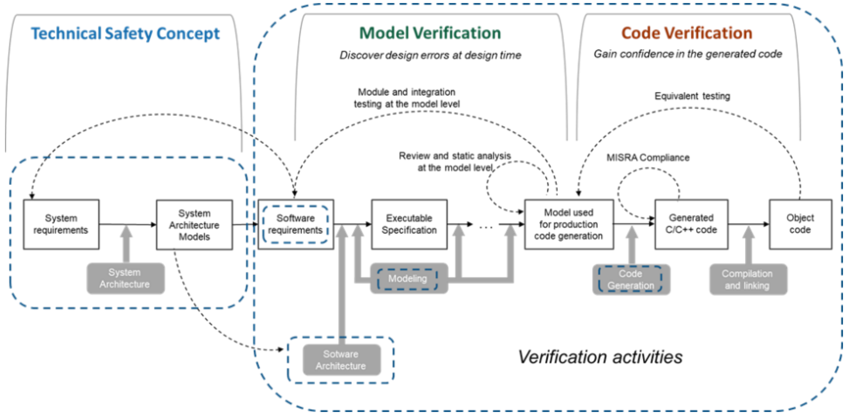
AUTOSAR, ISO 26262, Model-Based Design

Table 3 – Principles for Software Architectural Design	
1a	Appropriate hierarchical structure of the software components
1b	Restricted size and complexity of software components
1c	Restricted size of interfaces
1d	Strong cohesion within each software component
1e	Loose coupling between software components
1f	Appropriate scheduling properties
1g	Restricted use of interrupts
1h	Appropriate spatial isolation of the software components
1i	Appropriate management of shared resourcese

(AUTOSAR ASW) Component



ISO 26262 Reference Workflow



Right-Sizing Components

- "Restrict size…" of components
- De-couple components
- "Isolation" and partitioning

Unit-Based Testing

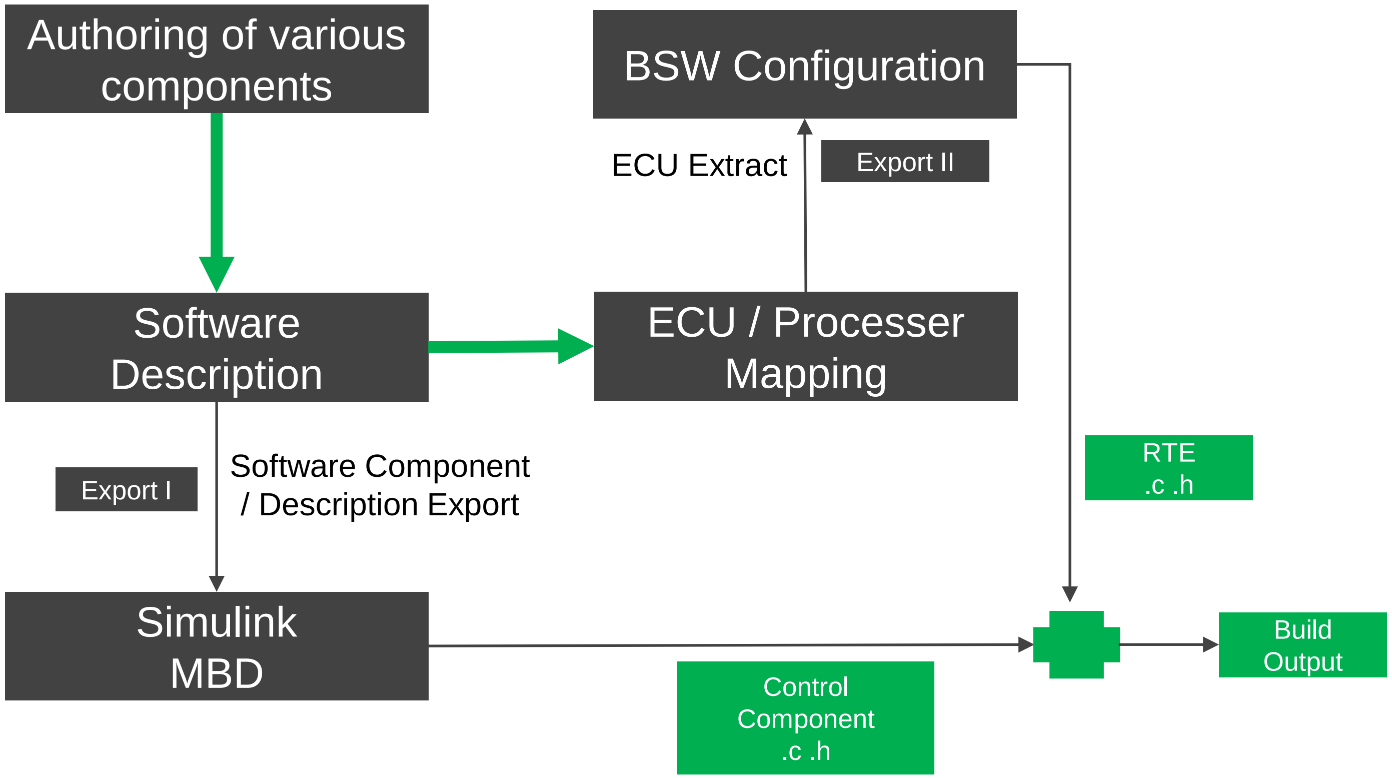
- Back-to-back MIL/SIL/PIL
- Model = Design
- Maximize Testing at Unit Level

AUTOSAR BSW & MCAL

Modeling in Simulink

Infrastructure to support ISO26262/CMMI/ASPICE, Cybersecurity and industry expectations

Implement Top-Down Workflow: Architecture - Design – Code



Authoring – Top Down

Define Architecture

1. Application Software Components, Internal Behavior
2. Software Component interaction
   - Application to Application
   - Application to BSW

Downstream Export I - Simulink MBD:

Application SWC/Component import

1. Implement Controls based on software description
2. Individual component Simulation
3. Auto generation of Production code

Downstream Export II – BSW Configuration:

ECU Extract Import

1. Task Mapping
2. BSW configuration/consideration
3. RTE Generation

Top-Down Workflow

Multi-Platform Architecture

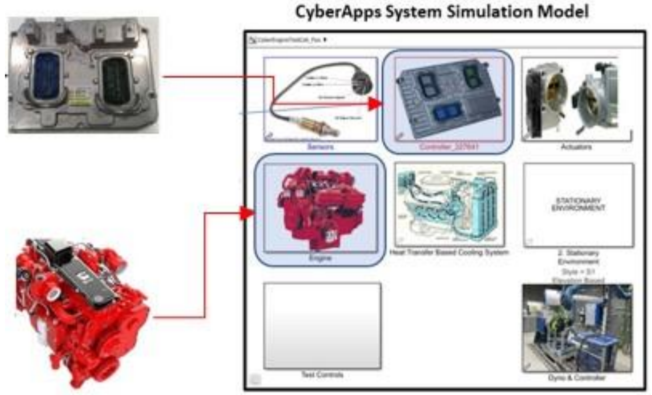
Transition to AUTOSAR-based **Architecture** using MBD principles

Connect Software Workflow with System Simulation

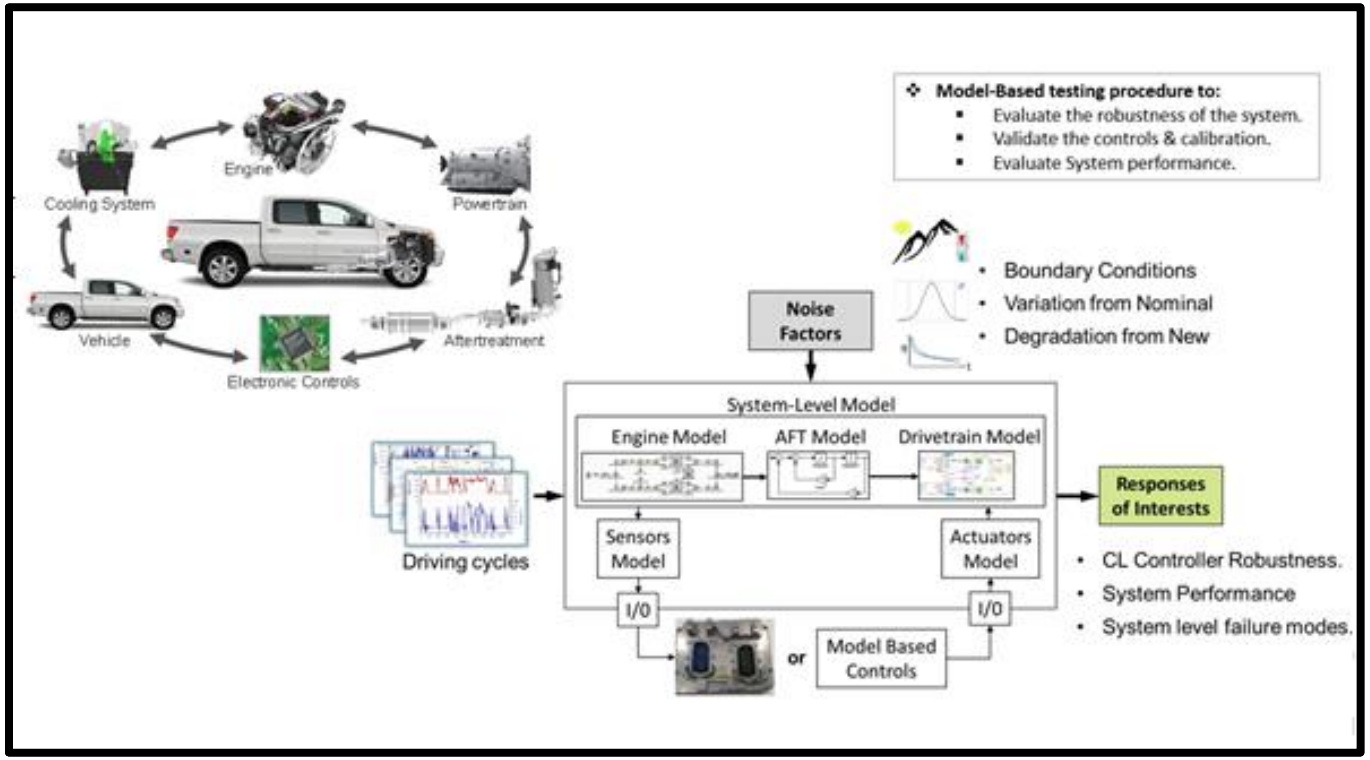
Seamless integration of controller models and plant models to enable efficient pure simulation plant modeling and system simulation capability.

Integration of ECU and Plant Models → *Allows us to fully Reach this!*

Simulink System Level Controller Model



GT Power, AVL Boost Simulation Capable Plant Models



Enabling an efficient and robust system simulation capability utilizing Model-Based Design and C-SAR will allow us to fully realize our total system simulation concept.

Next steps

- Process refinement
  - Reuse and product line
  - Agile methodologies
  - CI/CD
- Application software creation
  - Content migration, new content creation
  - Functional safety compliance


Cummins