TENNECO

LEAN ENGINEERING: BEST PRACTICES

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AGENDA

- **Introduction**
- **Establish customer-defined value**
- **Front-load to thoroughly explore alternative solutions while there is maximum design space:**
  - Kentou (study) phase with set-based concurrent engineering applied at Tenneco
  - Case examples and results
- **Conclusions**

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LEAN PPD MODEL

1. Establish customer-defined value to separate value added from waste
2. Front-load

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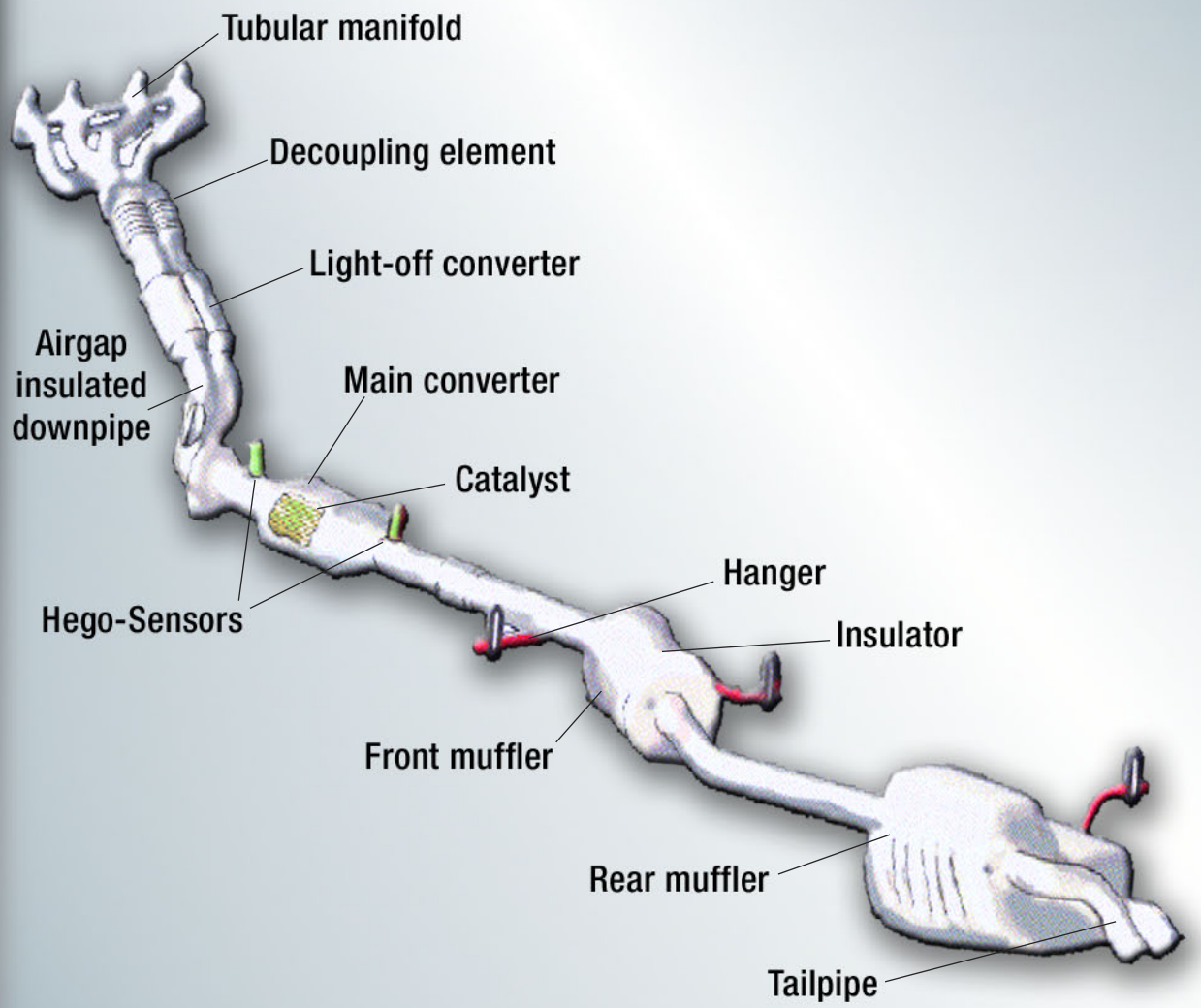
LEAN PD PRINCIPLE 1: ESTABLISH CUSTOMER VALUE

- **Evaluate the customer-defined value as accurately as possible**
  - Translation of the car objectives on the component level
  - Emotional connection with the end user
    - Example: Target definition for a sporty car

- **To meet this level of excellence, product development is composed of:**
  - Robust engineering based on skilled people and adequate tools
  - Strong product development process; optimized by using VSM in order to minimize waste
    - Example: Sound engineering procedure

TECHNICAL REQUIREMENTS OF AN EXHAUST SYSTEM: CUSTOMER VALUE



Customer Engineering Specifications

- **Power & Torque**
- **Back Pressure**
- **Acoustics**
  - Tailpipe Noise
  - Shell Noise
  - In-Cabin Noise
  - Subjective Noise
- **Emissions**
  - Light-Off
- **Durability**
  - Vibration
  - Corrosion
- **Heat Radiation**
- **Packaging**
- **Mounting**
- **Decoupling**
- **Materials**
- **Weight**
- **Cost**

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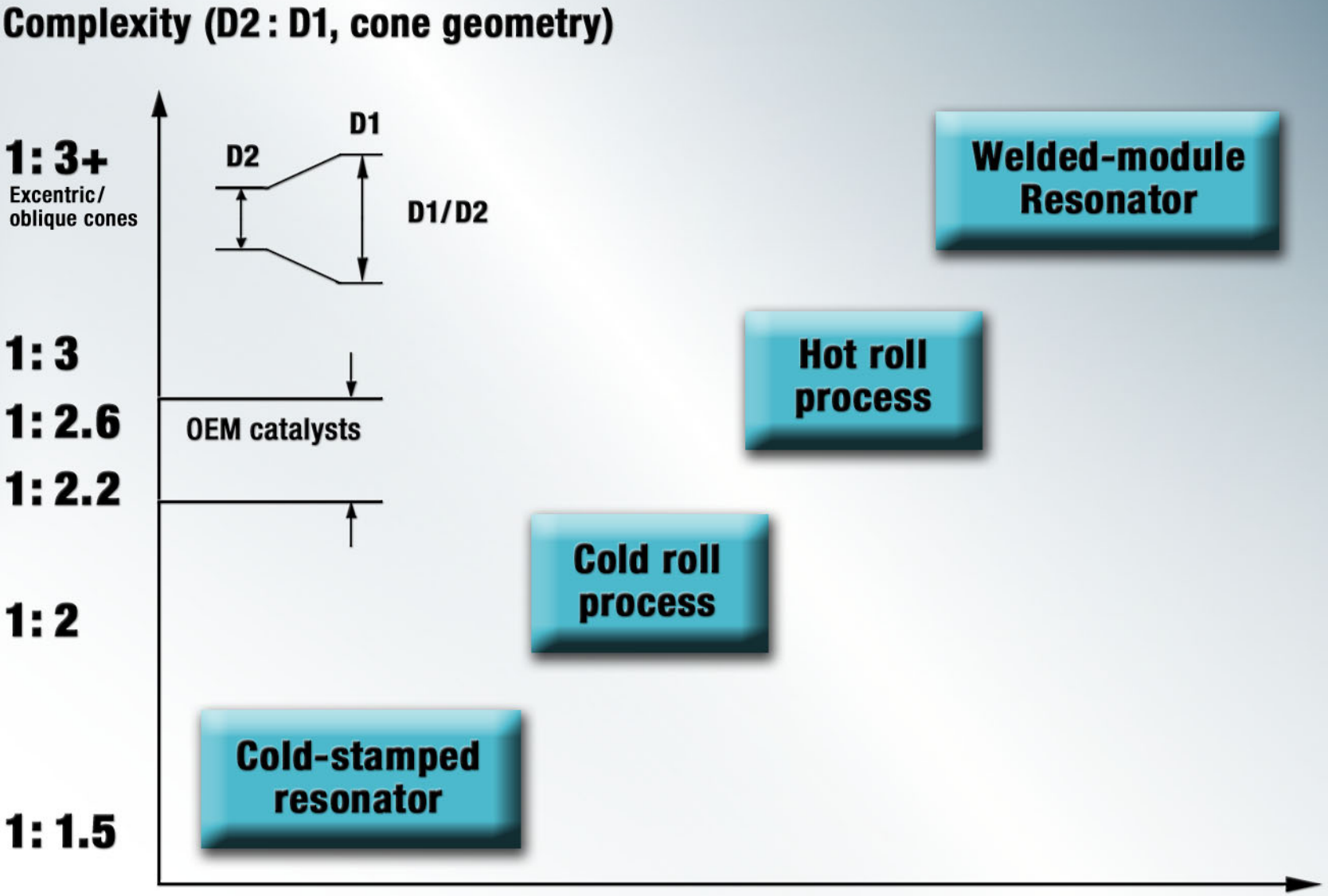
LEAN PD PRINCIPLE 2: FRONT-LOADING THE PD PROCESS TO EXPLORE ALTERNATIVES THOROUGHLY

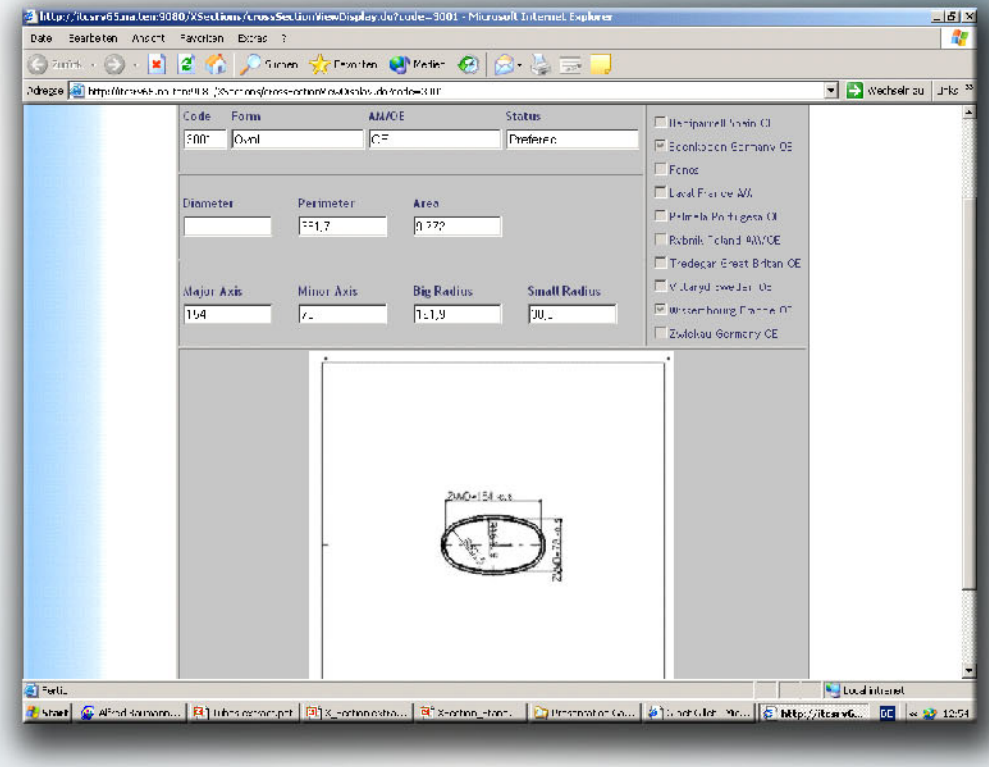
- **Front-loading is an effective method to isolate and minimize design and engineering variations early in the process by**
  - **Standardizing exhaust systems**
  - **Creating an early phase (Kentou) to explore alternative solutions**
    - Development cycle for an exhaust system
    - Advanced technology planning
    - Set based concurrent engineering
  - **Using checklists / guidelines, trade-off curves to accelerate the decision-making process**

COMPARISON OF RESONATOR MANUFACTURING PROCESSES

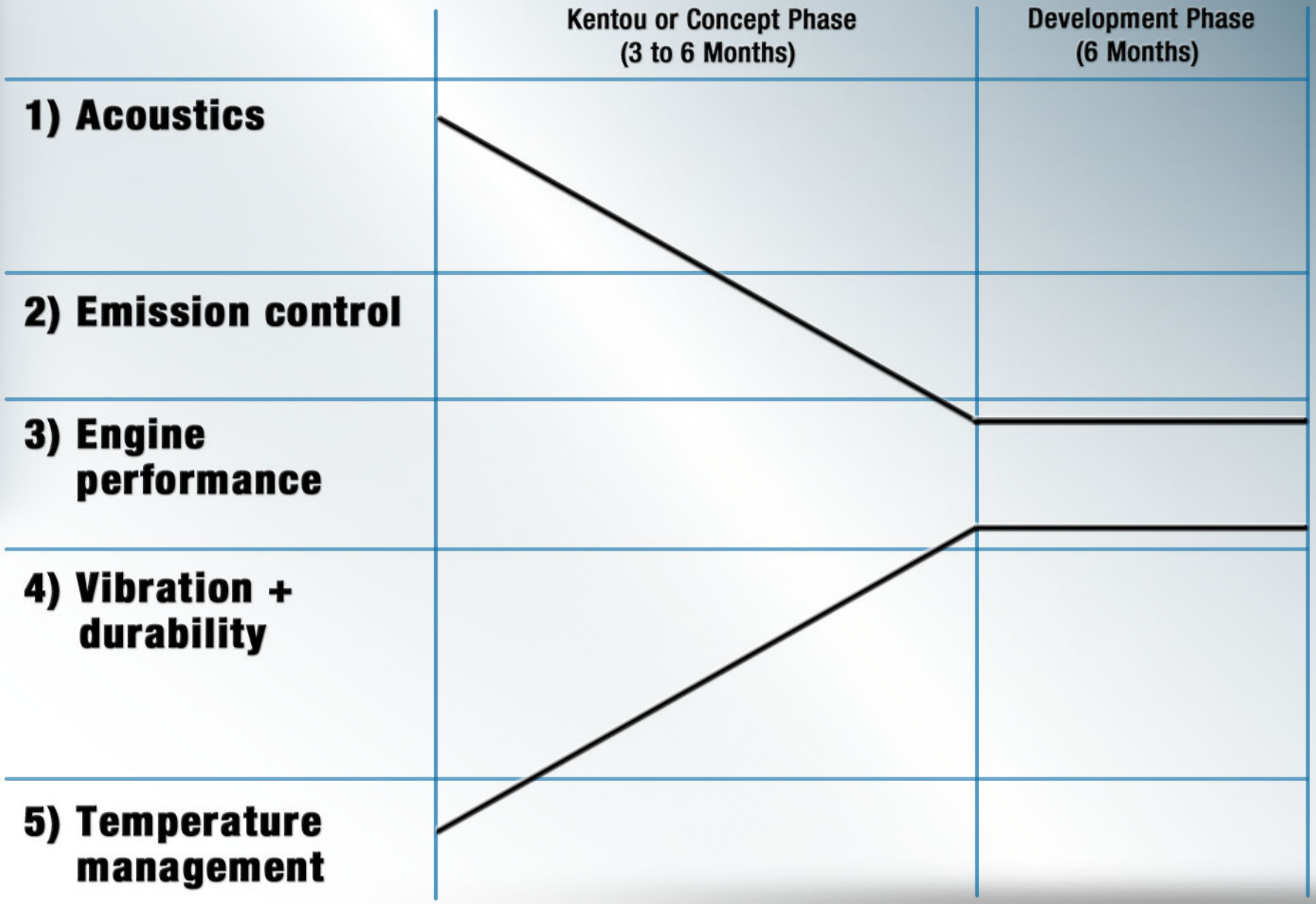


DATABASE: SPUN MUFFLER STANDARDIZATION

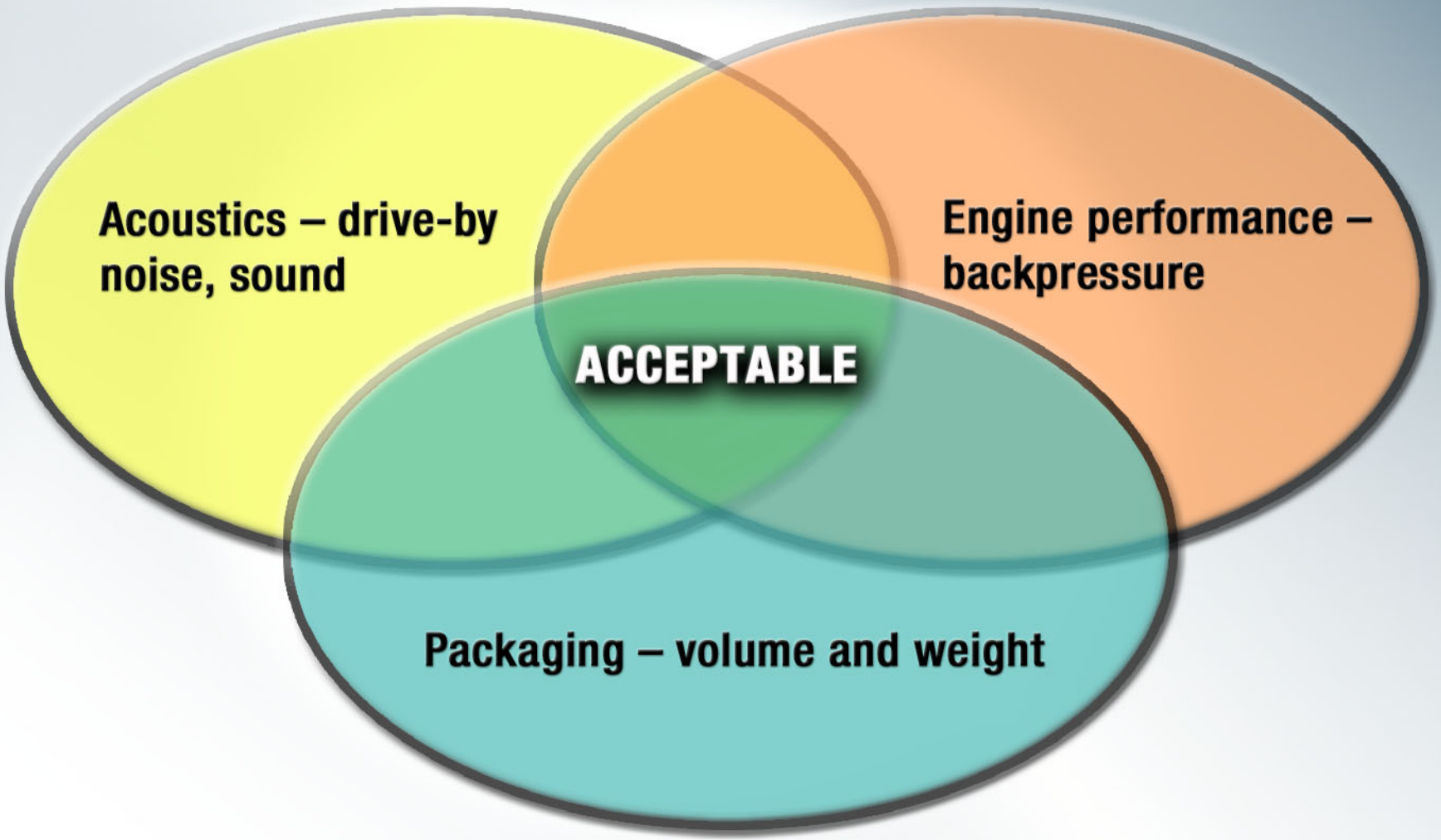
- Designer must first check database
- Deviation can be requested if necessary
- These simple processes and tools significantly reduce the variability during development phase



DEVELOPMENT CYCLE OF AN EXHAUST SYSTEM



DESIGN OPTIMIZATION TRADE-OFF

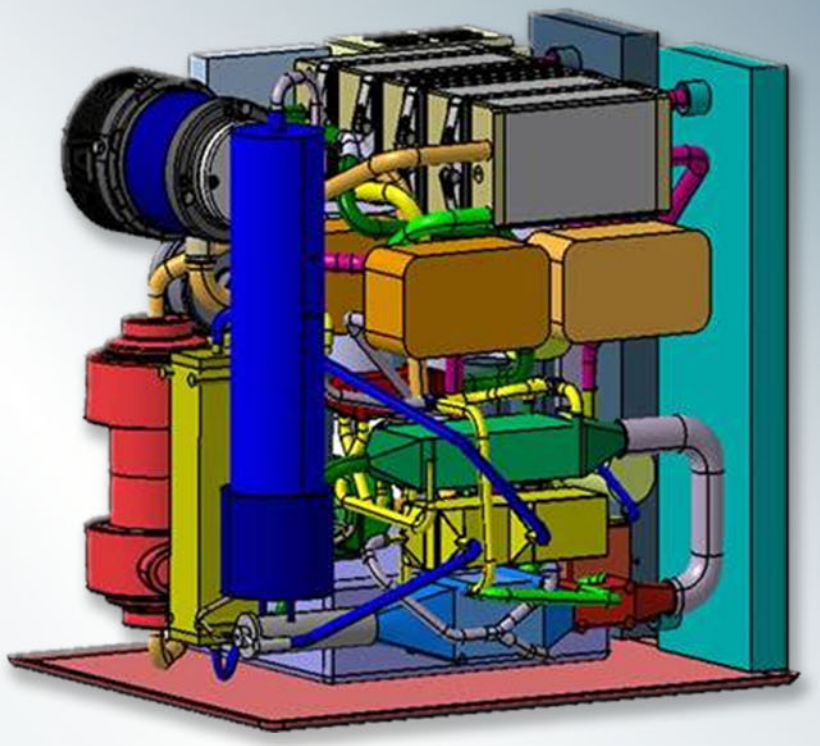


LEAN PRINCIPLE 2: FRONT-LOADING ADVANCED TECHNOLOGY PLANNING

- **Front-loading for innovative products coming from:**
  - **Internal research**
  - **Suppliers – new stainless steel development**
  - **Benchmark analysis**
  - **Innovation Process – TENPI Process**
  - **OEMs**
    - Tech days and audits
    - Common projects – e.g. fuel cell technology
  - **University network**
    - Technology transfer, integration of students in advanced engineering
- **New concepts selected, evaluated and validated separately**
- **Solutions on the shelf – SAM and low-cost, lightweight muffler**

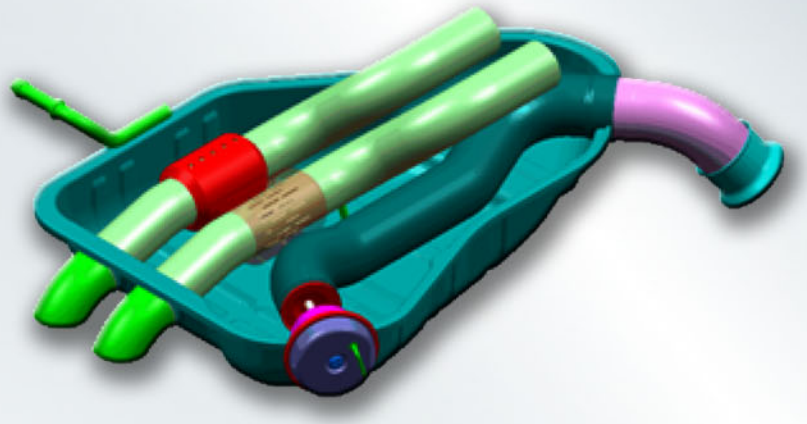
AUXILIARY POWER UNIT (APU) TENNECO CONTRIBUTION

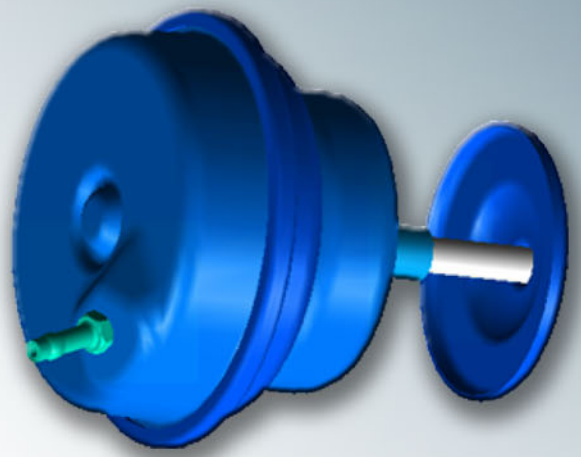
- **Layout study (together with Volvo & other partners)**
- **Virtual integration**
- **System layout refinement**
  - Pressure drop/heat loss
  - Thermal Insulation
  - Determining components – tubes, material, connectors, valves
  - Investigating spaceframe
- **Physical system integration**



Preliminary 3D CATIA model of Fuel Cell APU

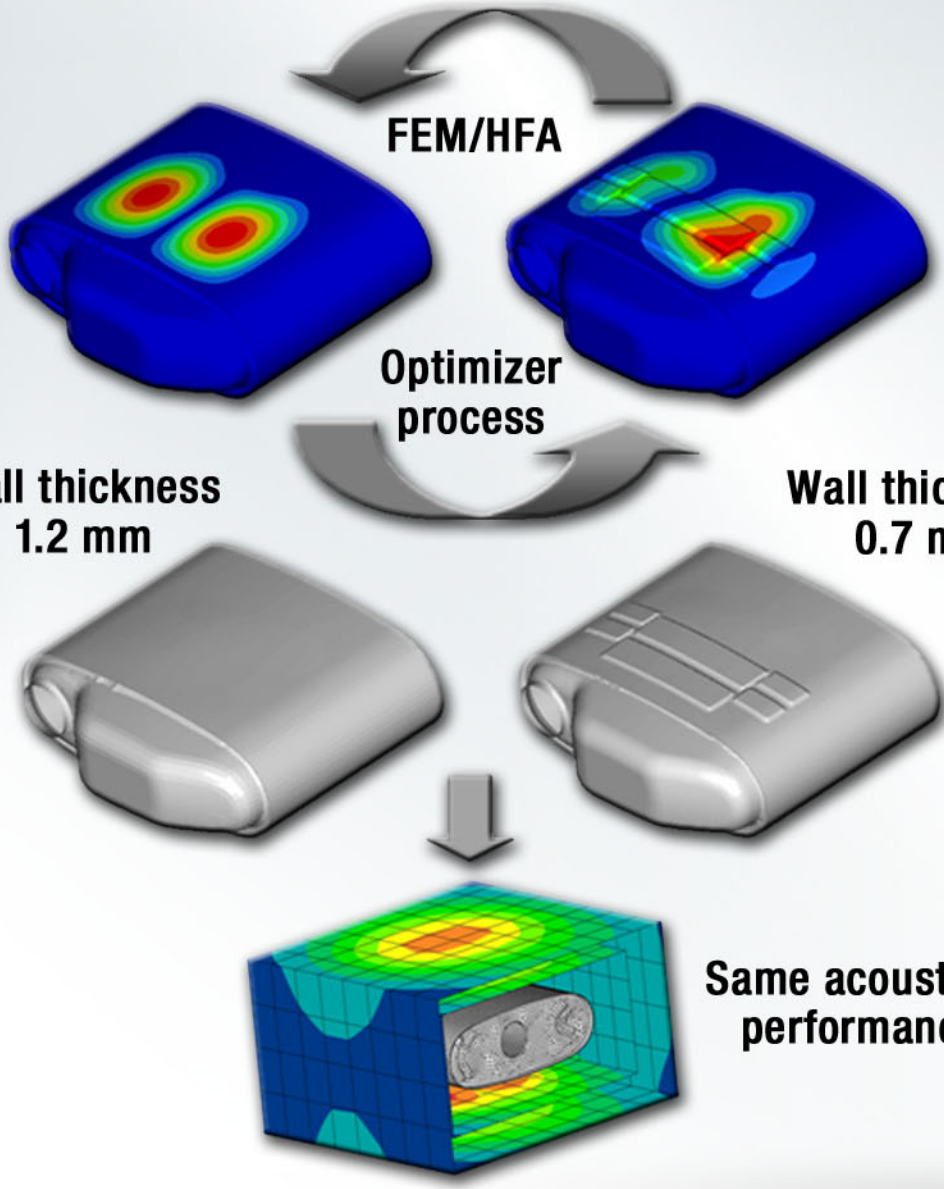
SEMI-ACTIVE MUFFLER (SAM): APPLICATION FOR PSA 407





- Proactive development
- Ready for application

LOW-COST, LIGHTWEIGHT MUFFLER



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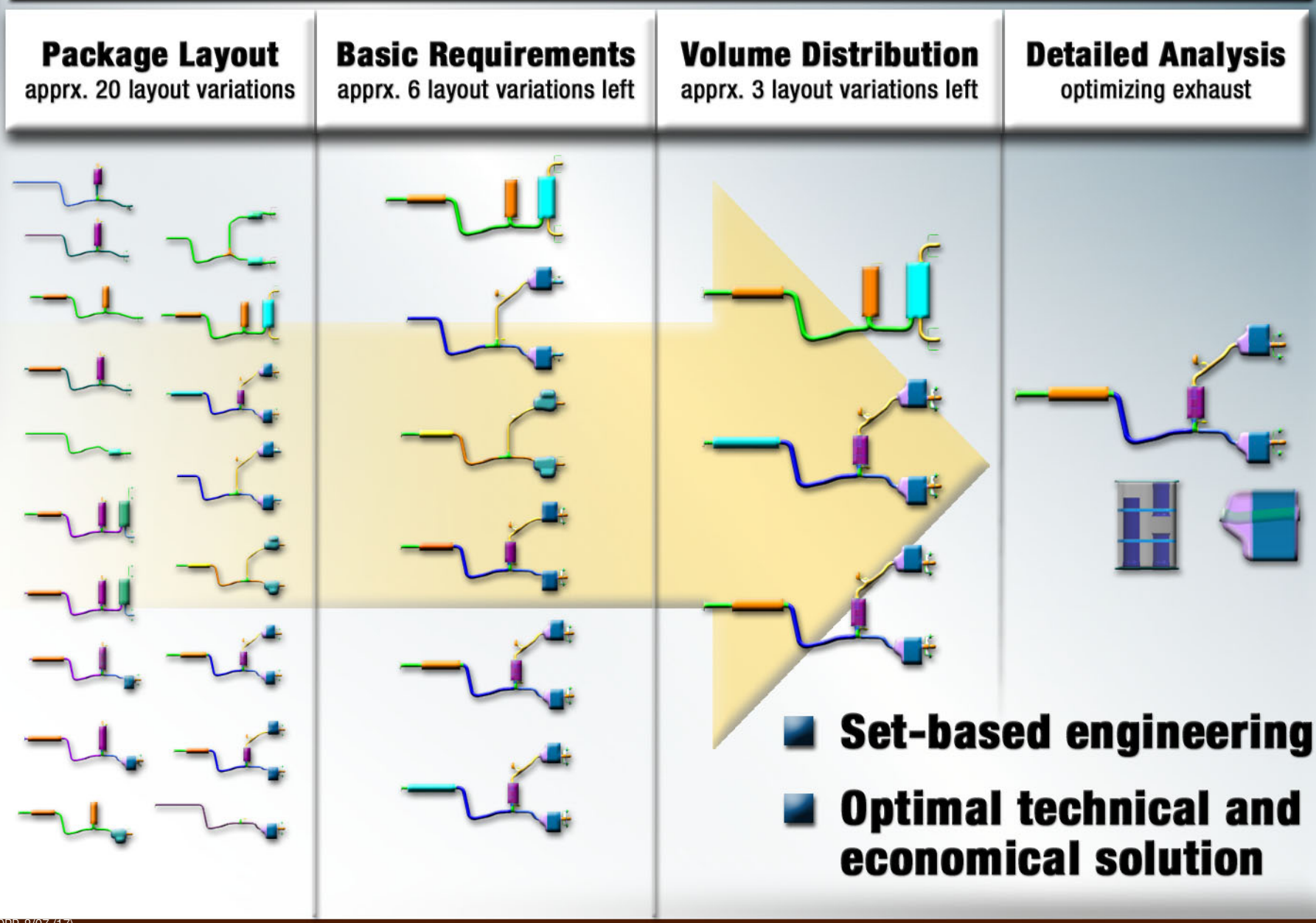
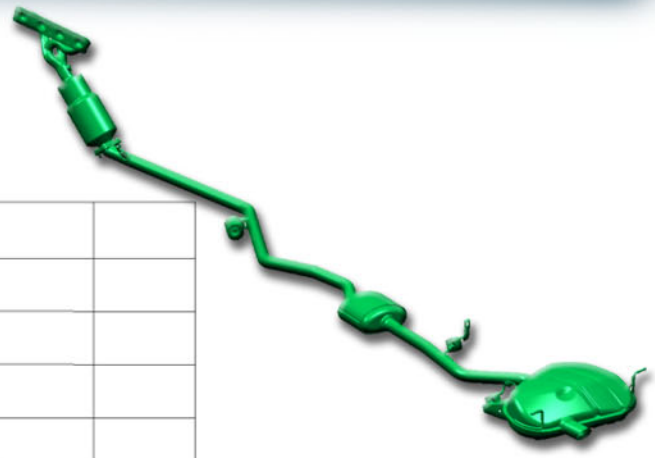
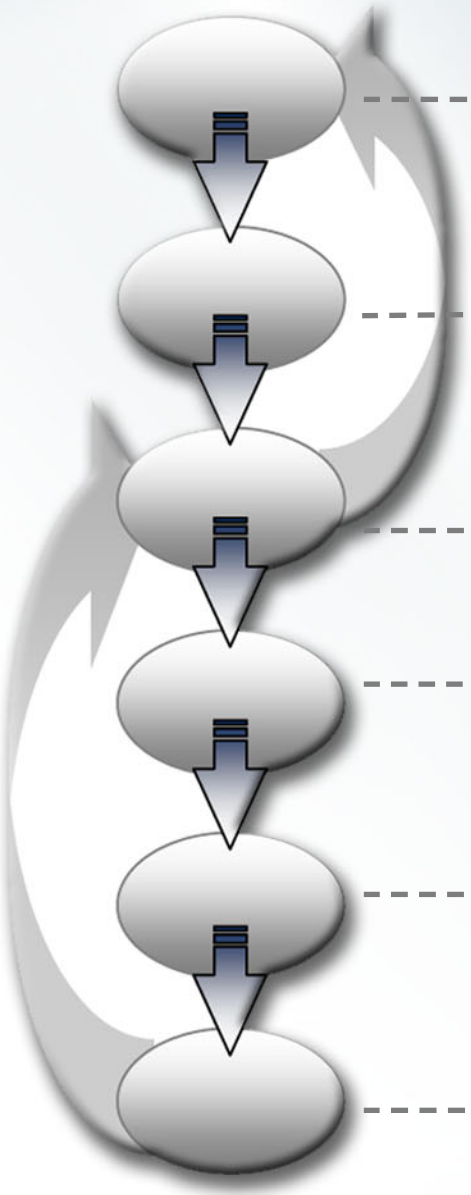
KENTOU PHASE: EXAMPLE FOR 2.0L TURBO GAS ENGINE



TRADE-OFF CURVES



SOUND ENGINEERING GUIDELINES



Step 1 ------- **Definition of sound target with customer**

Step 2 ------- **Binaural and harmonic analysis at listening lab**

Step 3 ------- **CAE-prediction – target reachable?**

Step 4 ------- **Building hardware**

Step 5 ------- **Validation of proposed exhaust designs on chassis dyno**

Step 6 ------- **Final validation together with customer**

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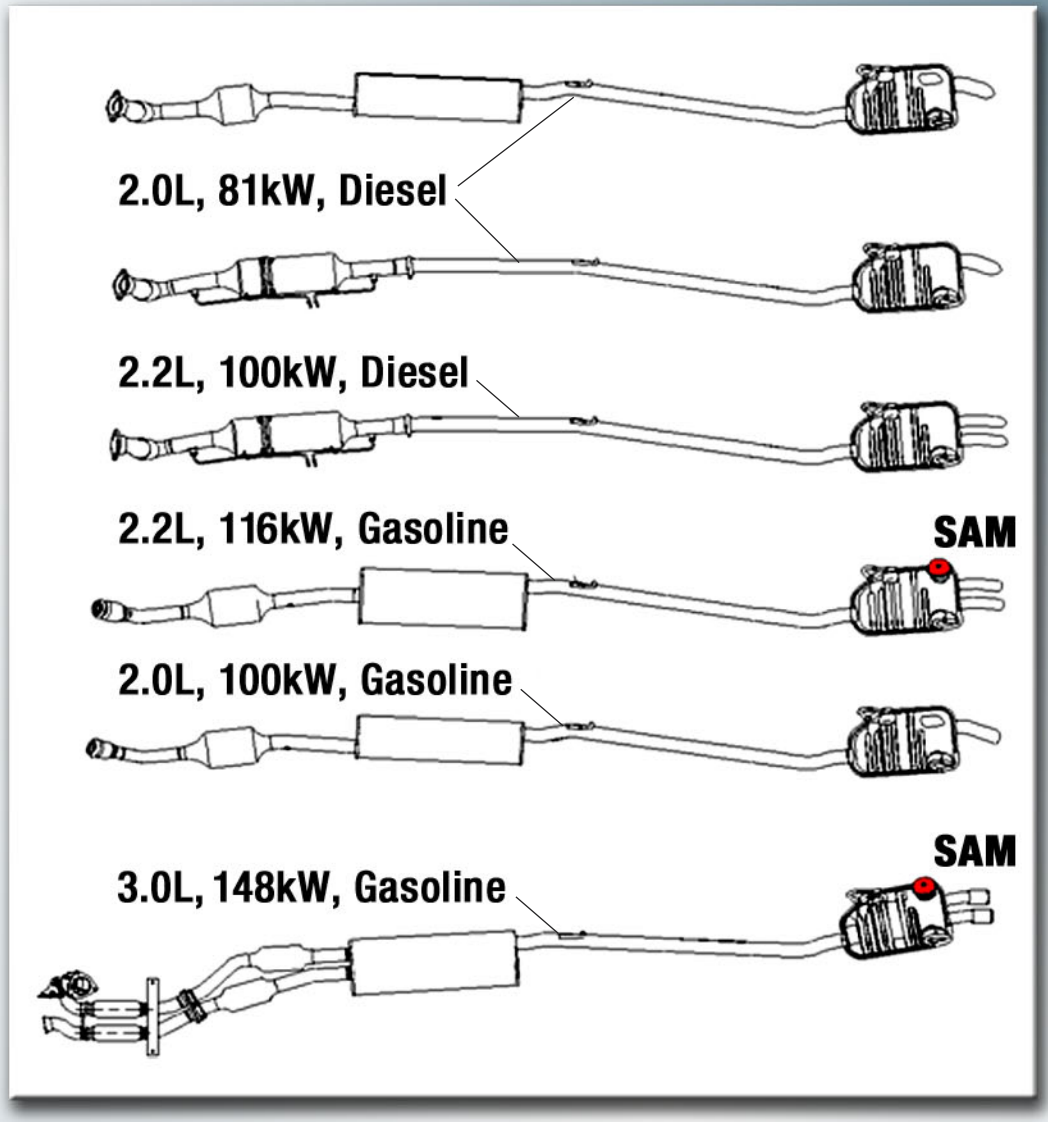
AFTER KENTOU, FOLLOW EXECUTION PHASE

- Kentou allows for isolating, treating and minimizing variability; therefore providing design solutions and improved focus on downstream task execution

- Results of Kentou phase: 2 cases
  - Standardized exhausts with SAM – PSA vans
  - Sporty exhaust system – BMW Series 1

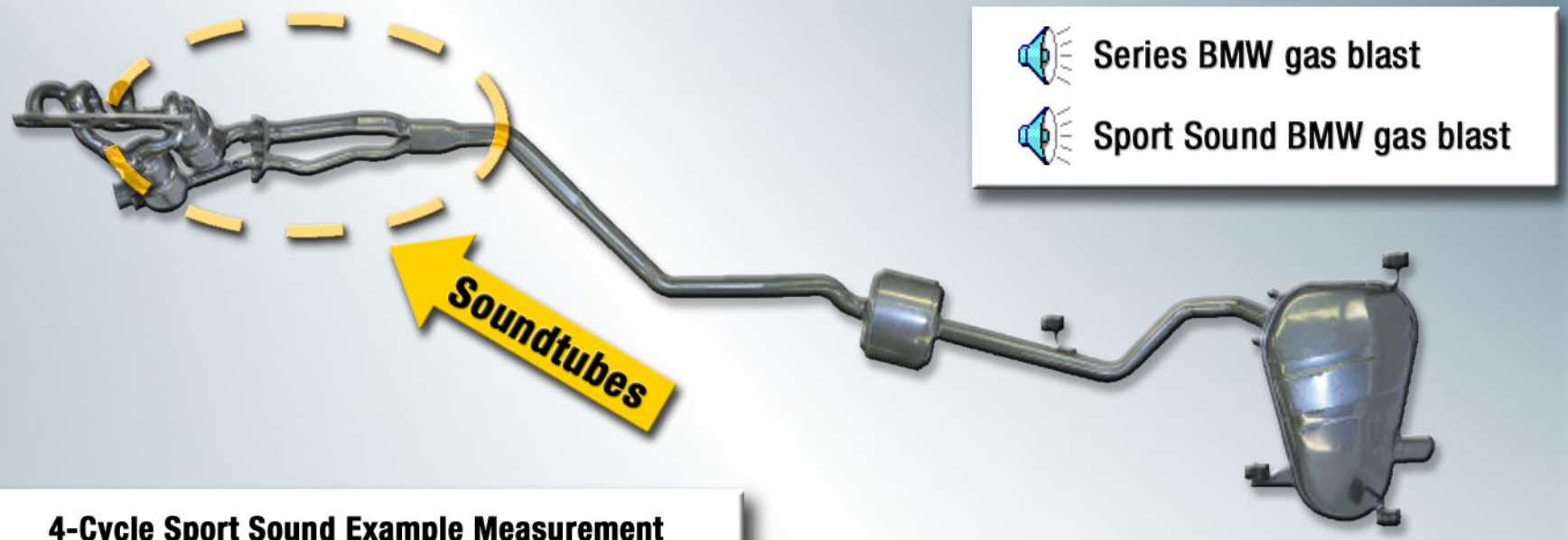
SAM: MID-UP STANDARDIZATION

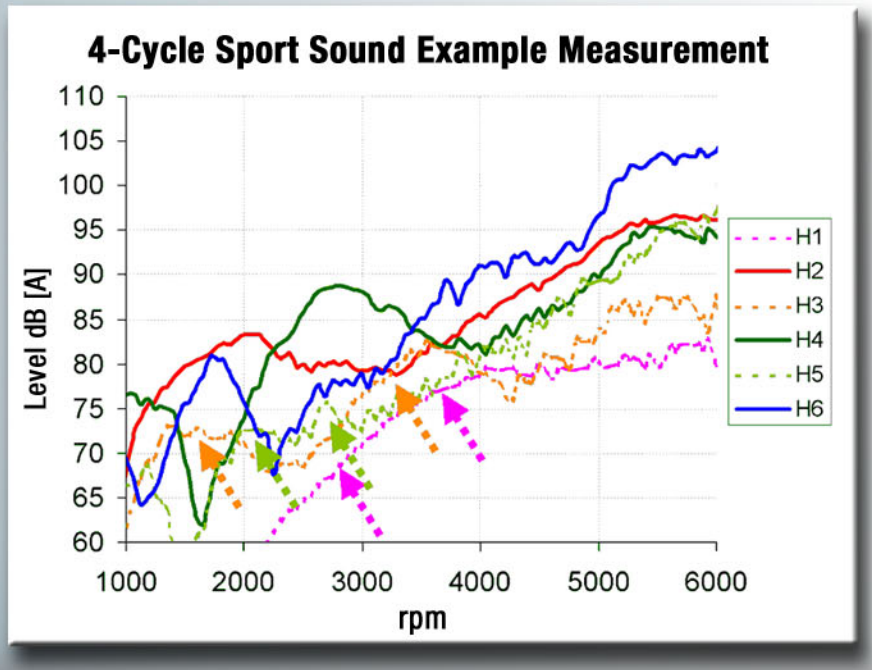
- Design standardized to one single rear muffler with SAM valve
- Significant savings on tooling costs, development efforts



SOUND ENGINEERING MEASUREMENT PROCEDURE

LAYOUT FOR 4-CYLINDER SOUND





- Sporty sound defined as rough sound
- Sound obtained with unsymmetrical downpipes
- Simulation with CAE and sound manipulation in sound labs
- Final validation on the chassis dyno

CONCLUSIONS

- **Tenneco as Lean company**
  - Kentou and set-based concurrent engineering – part of development process
  - Tenneco proactively pre-develops innovative products for customer applications
  - We are investing in people, resources to further improve:
    - Engineering processes
    - Skills, education
    - Quality of tools, technologies
- **Next steps**
  - Integration of external partners
    - OEM – concept phase
    - Suppliers
  - Integration of Tenneco India and China in Lean engineering process