



Modeling and Simulation Driven Advancement in Emission Control Strategies for Future Regulations

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Outline

01 **Introduction to JM Aftertreatment System Modeling**

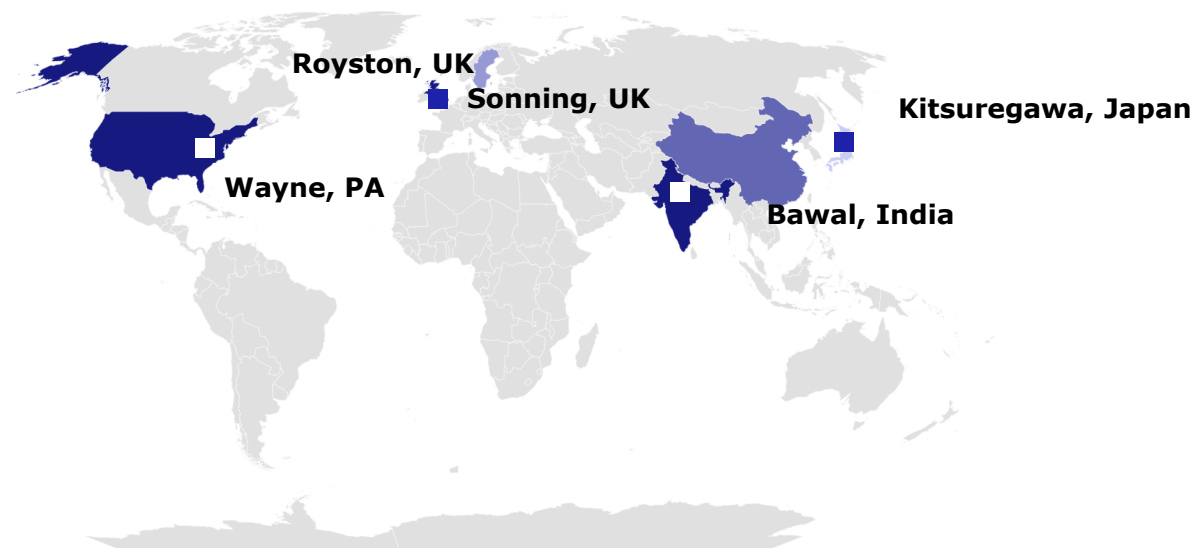
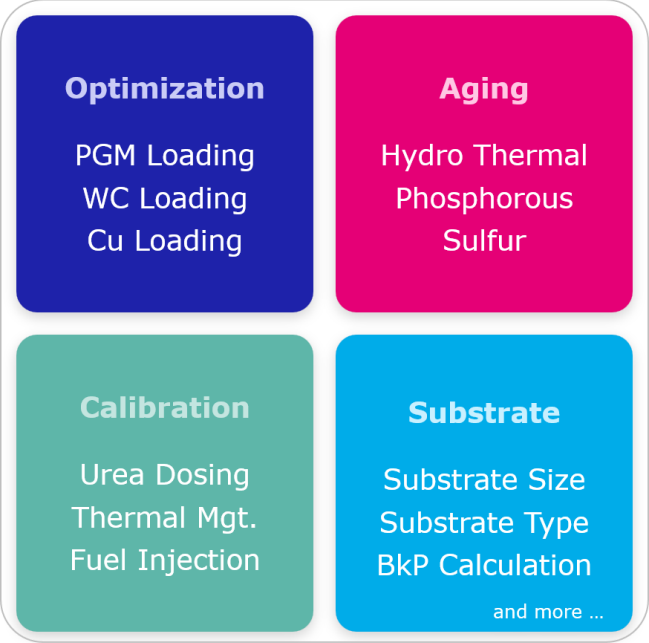
02 **Use of Models for Product Design/Optimization**

03 **Use of Models for System Design/Optimization**

04 **NS-VII and BS-VII examples**

Summary

Modeling at JM – Global Locations



- 35+ yrs. history of using simulation in Clean Air
- High fidelity kinetic models validated against engine data
- Use simulations to reduce the numbers of engine/vehicle tests, save time and cost

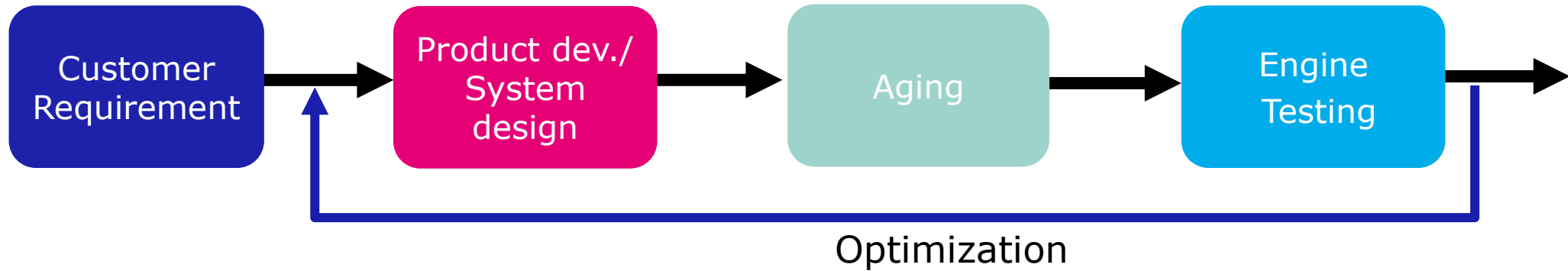
JM models for emission aftertreatment

CO/HC	PM	NOx	NH3	CO/HC/NOx
DOC	DPF	SCR	ASC	TWC
	CSF	LNT		
	GPF	PNA		
	SCRf®			

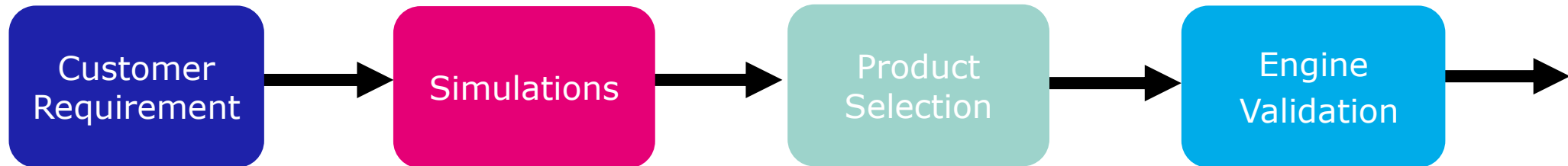
Modeling First Approach for Customer Focus Solutions

Replace prototype-intensive trial-and-error development with simulation-driven optimization to deliver faster, lower-cost, and customer-focused solutions

Conventional Approach

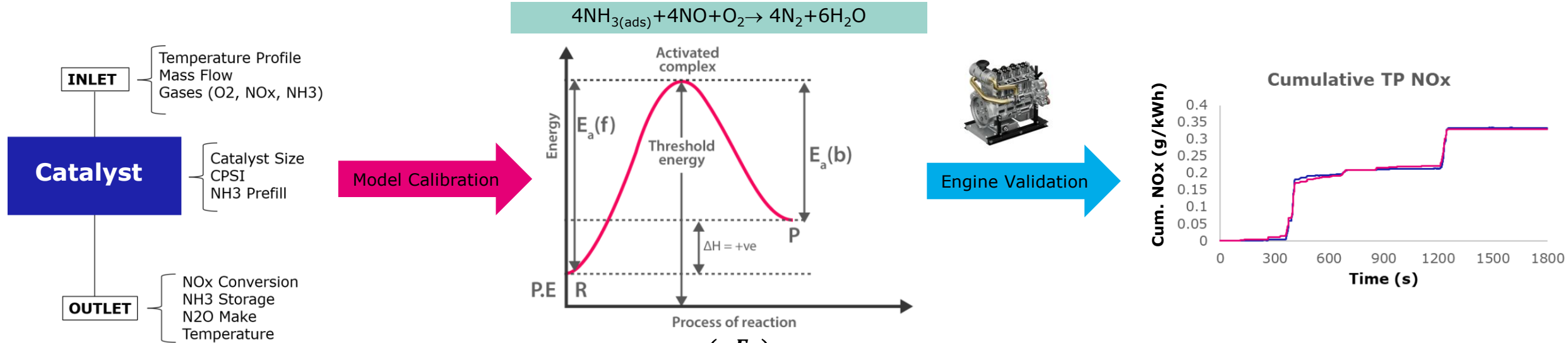


Modeling First Approach



Kinetic Model Development Approach

Model development follows same basic procedure for all technologies



$$rate = k \exp\left(\frac{-E_a}{RT}\right) \theta_{NH3} C_{NO} C_{O2}^{0.5}$$

Catalyst performance in reactor

- ✓ Temperature
- ✓ Concentration
- ✓ Flow rate
- ✓ Inhibition impacts

e.g., NH3 storage and oxidation, NOx reduction, N2O formation

Model calibration by tuning

- ✓ Arrhenius constant
- ✓ Reaction order
- ✓ Temperature dependence
- ✓ Inhibition factors
- ✓ Mass transfer

e.g., Standard SCR, Fast SCR, Slow SCR

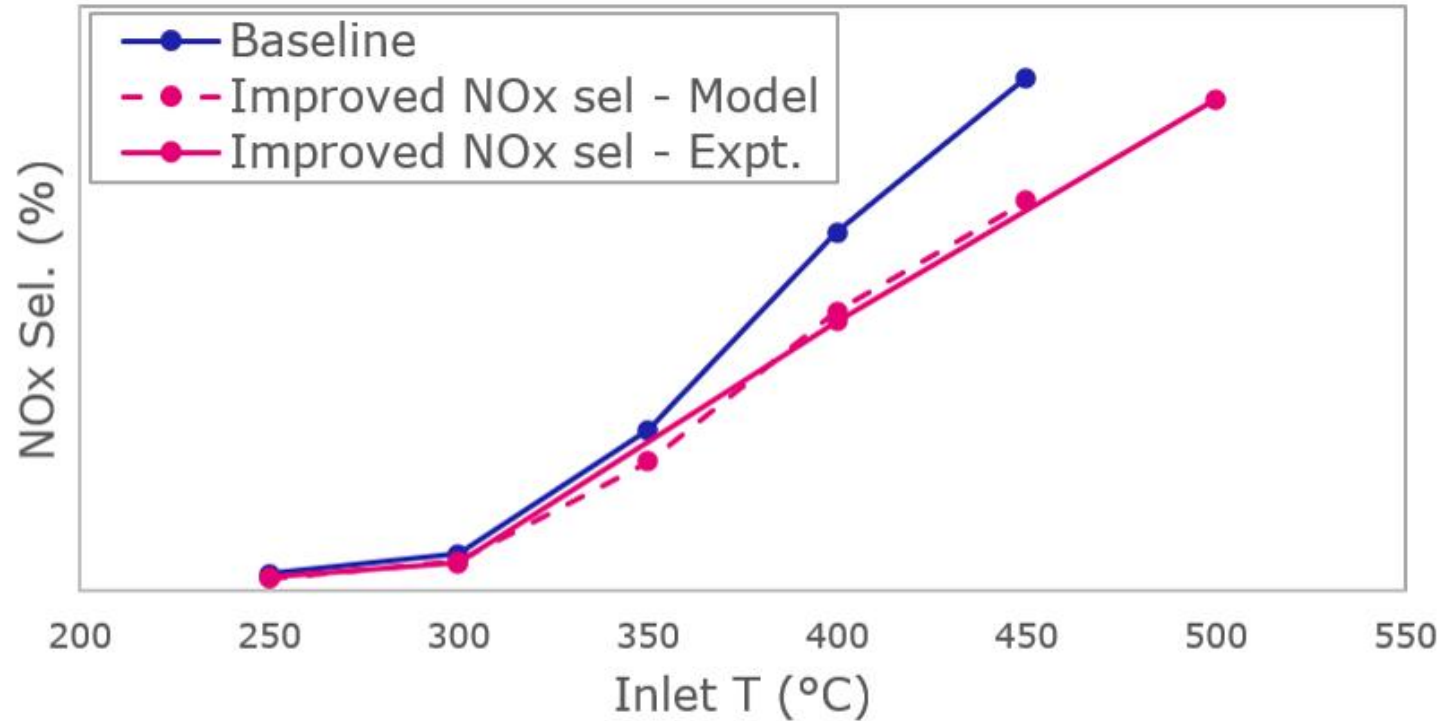
Validate model with engine test data.

- ✓ Model retuned if needed to incorporate engine impacts

e.g., Steady state, Transient (FTP, RMC, LLC, WHTC, WHSC)

Example of ASC Models Used For Customer Product Optimization

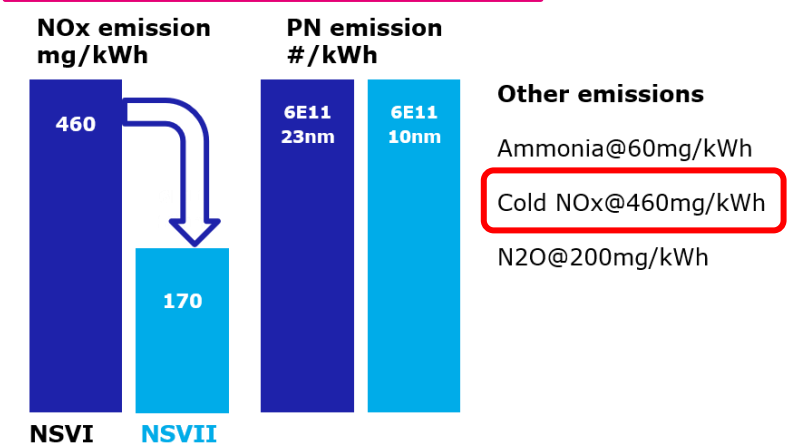
Model Led Optimization of ASC NOx Selectivity



- Modelling was used to optimize washcoat loading (WCL) and PGM.
- The predicted improvements were verified in reactor testing
- The modelling-based design approach reduced development cost and time significantly

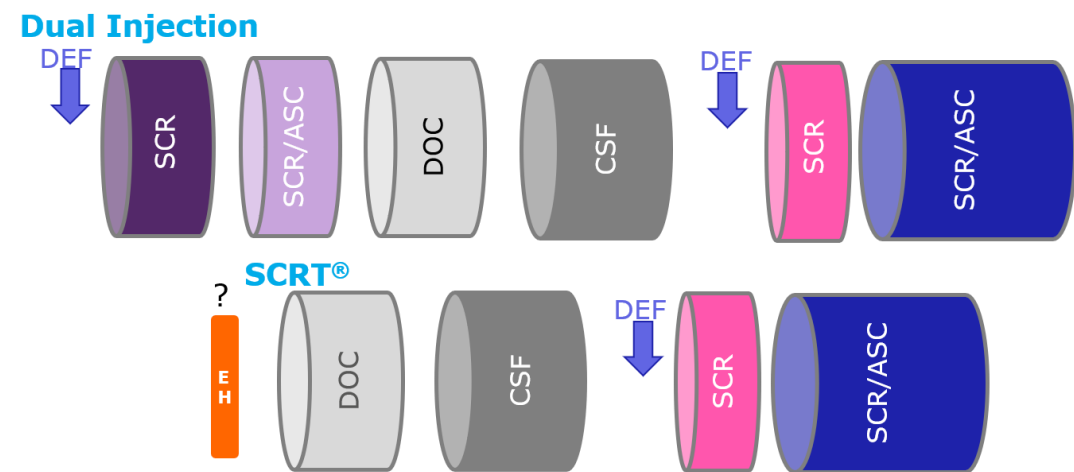
NS-VII HD Diesel Emission Limits And ATS Architecture to Meet

NS-VII Emission limits



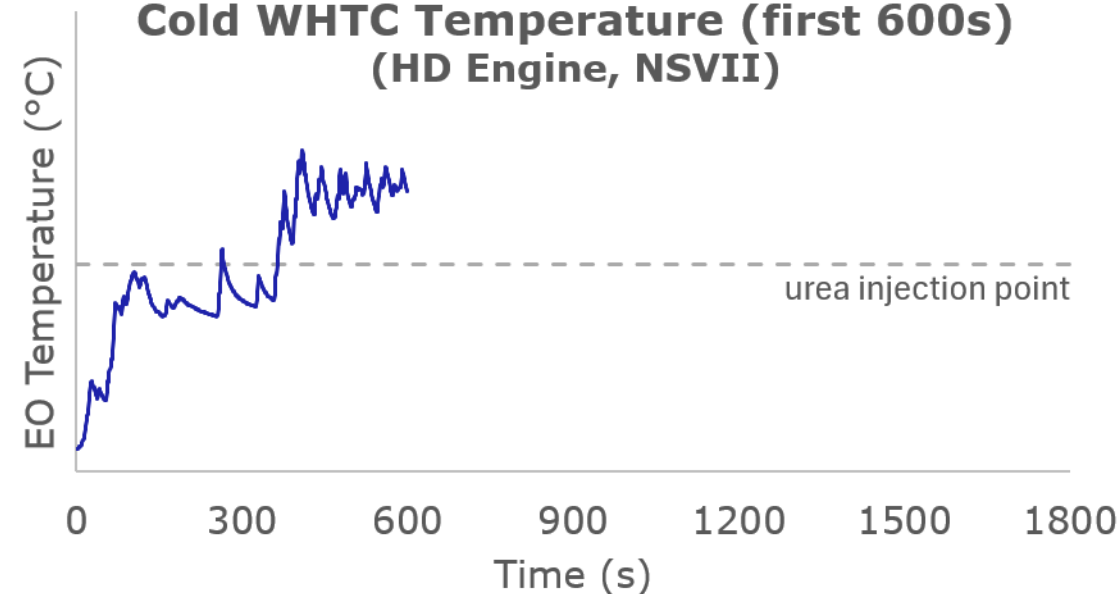
Challenges with NSVII HD

- ✓ Addition of cold NOx limit (specially at EUL)
- ✓ Addition of N2O (specially at Fresh)
- ✓ Strict emissions limits
- ✓ Stringent limits of PM/PN
- ✓ Stronger push towards dual dosing



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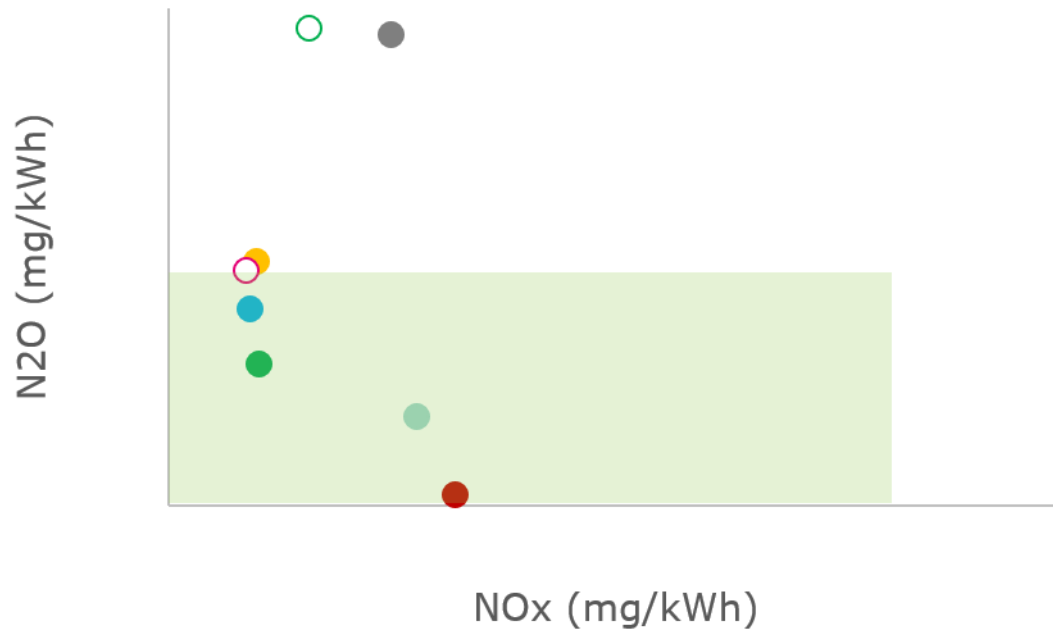
Cold WHTC Temperature (first 600s) (HD Engine, NSVII)



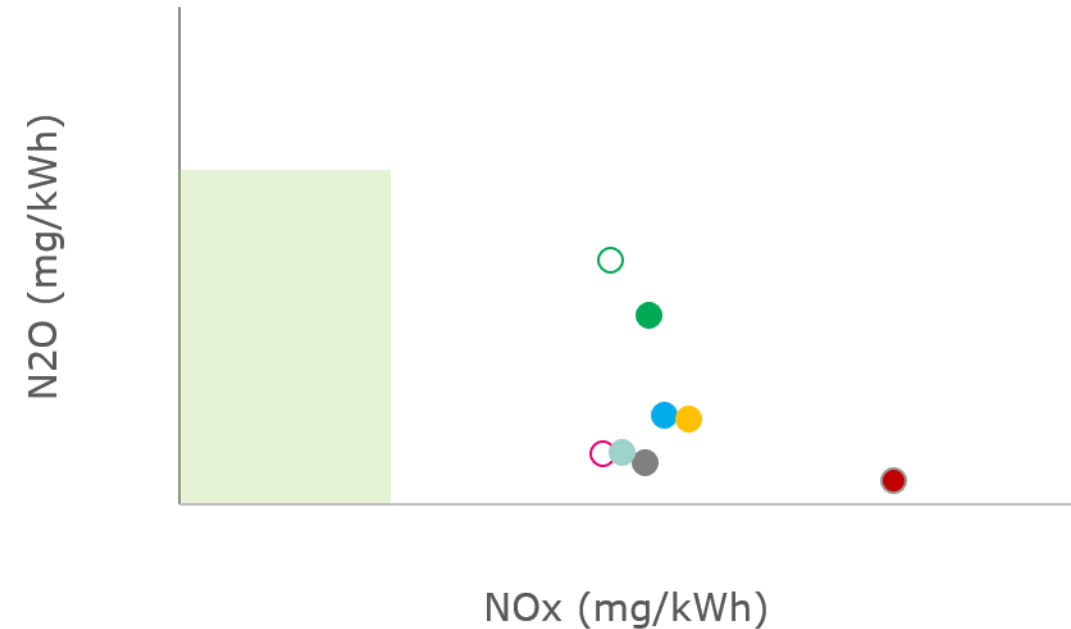
Modeling First Approach Allows Screening of Several Potential Systems

Simulation results demonstrate cold start emissions target be difficult to meet even with state-of-the-art system design if the engine out conditions are extremely unfavorable.

Weighted WHTC Emissions, Fresh



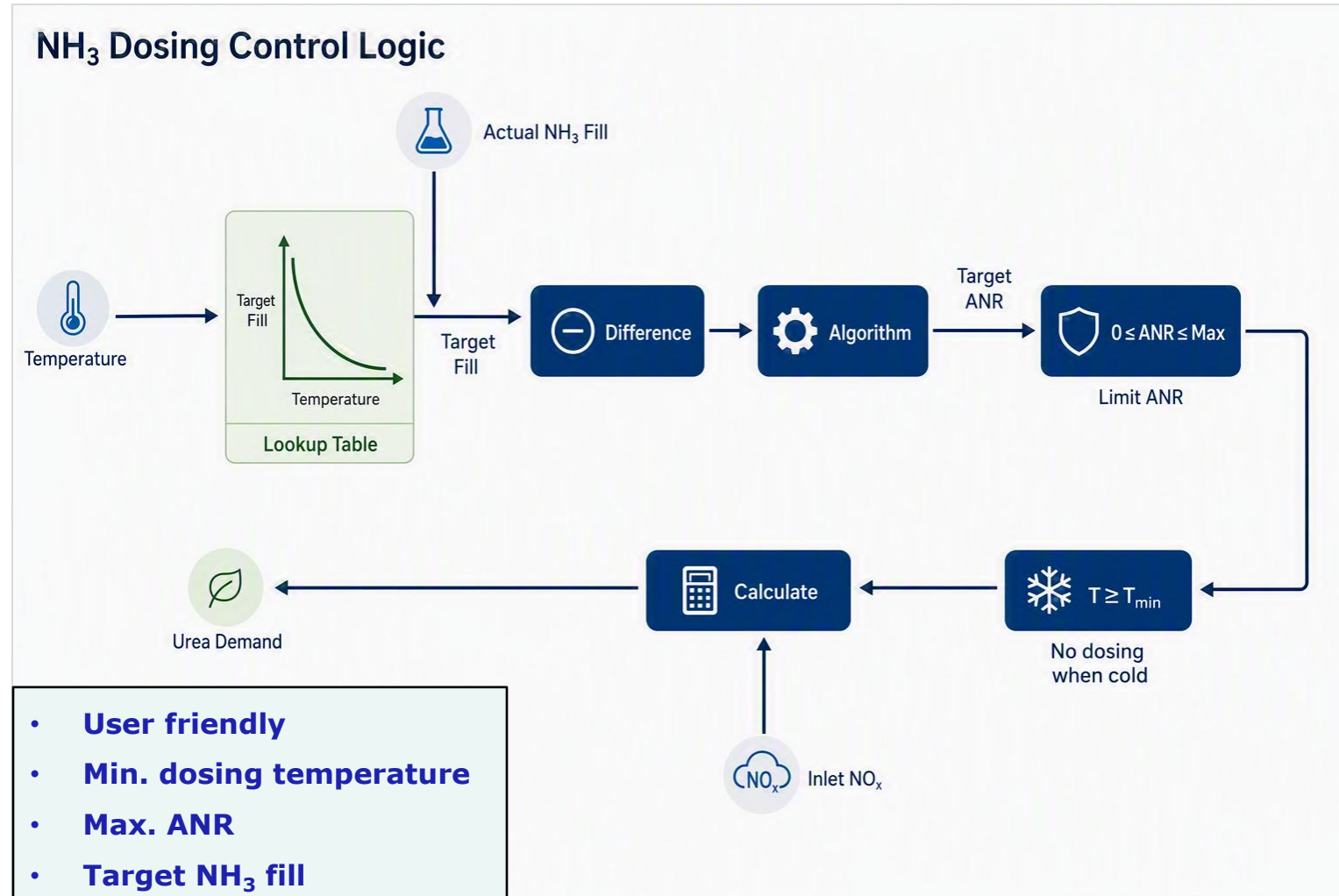
Cold WHTC Emissions, End of Life



- Simulation results demonstrate cold start emissions target be difficult to meet even with state-of-the-art system design if the engine out conditions are extremely unfavorable.
- Each circle represents a different system design.

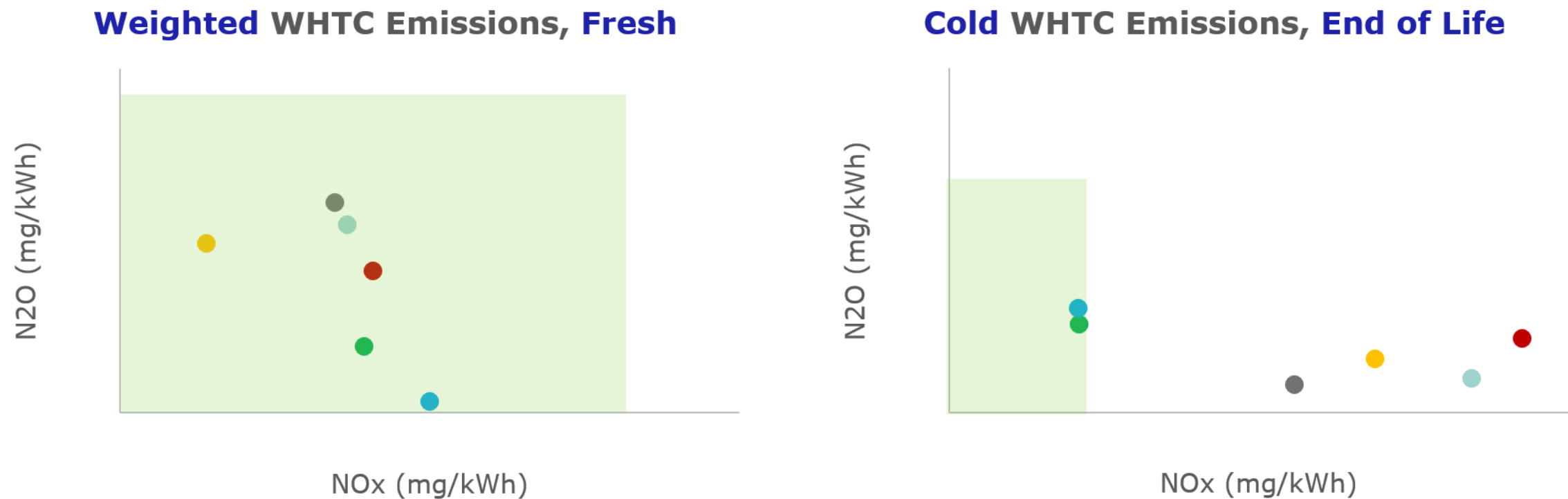
JM Tool for Urea Dosing Optimisation

Dynamically adjusts NH_3 dosing based on catalyst temperature at given conditions



Dosing Optimization Is Critical to Meet Regulation Targets

Provides improved NO_x conversion and reduced NH₃ slip compared with fixed ANR



System opt. = Component opt. + Dosing opt.

20+ designs, 200+ simulations

Overall resulted in test cost reduction and system design via simulation

Future Direction: Deep Learning to Accelerate Model Evaluation

Advantage of ML/AI tools for the advancement of the physics-based model

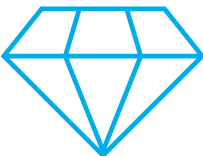
High level of maturity
(current efforts: Global Modelling team)

Future efforts

Motivation



Cost reduction:
simulations as
alternative to testing



Enhanced value proposition: give the customer a model as part of the “package”

Physical models

- Based on mass and heat balances
- Include reaction kinetics based on mechanistic understanding (require extensive domain expertise)
- Include thermodynamic limitations
- Solve lots of problems at the same time (e.g. SCAT, engine and vehicle testing)

Machine Learning models

- Usually based on random forest or neural network
- No physical grounding (domain expertise is less important)
- How can these calculations be sped up?

Hybrid ?
models

Summary

- Many solutions exist, but not all address the real problem. Effective outcomes require customer-specific solutions tailored to actual needs and use cases.
- Multiple simulations have been used to demonstrate how JM technology can be used to meet EPA27/Euro VII/BSVII/NSVII target regulations.
- The most challenging cycle has been the cold start cycle, such as WHTC, particularly reducing NOx to very low limits.
- Cycle analysis and simulations indicate that the temperature profile during cycle heat up, urea dosing, and EO NOx during cold segments are key factors in determining if a system can meet regulatory limits.

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