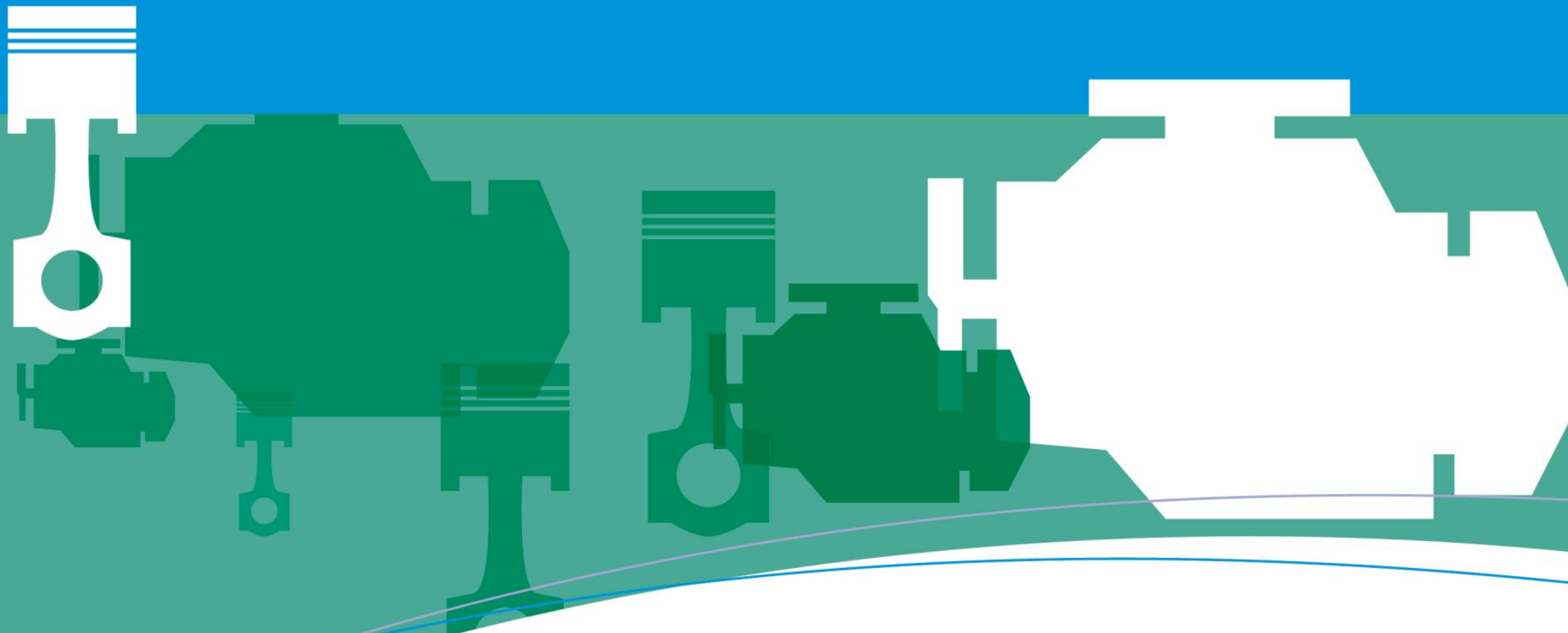
Performance you can rely on.

Crankcase Lubricant Formulation



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Agenda

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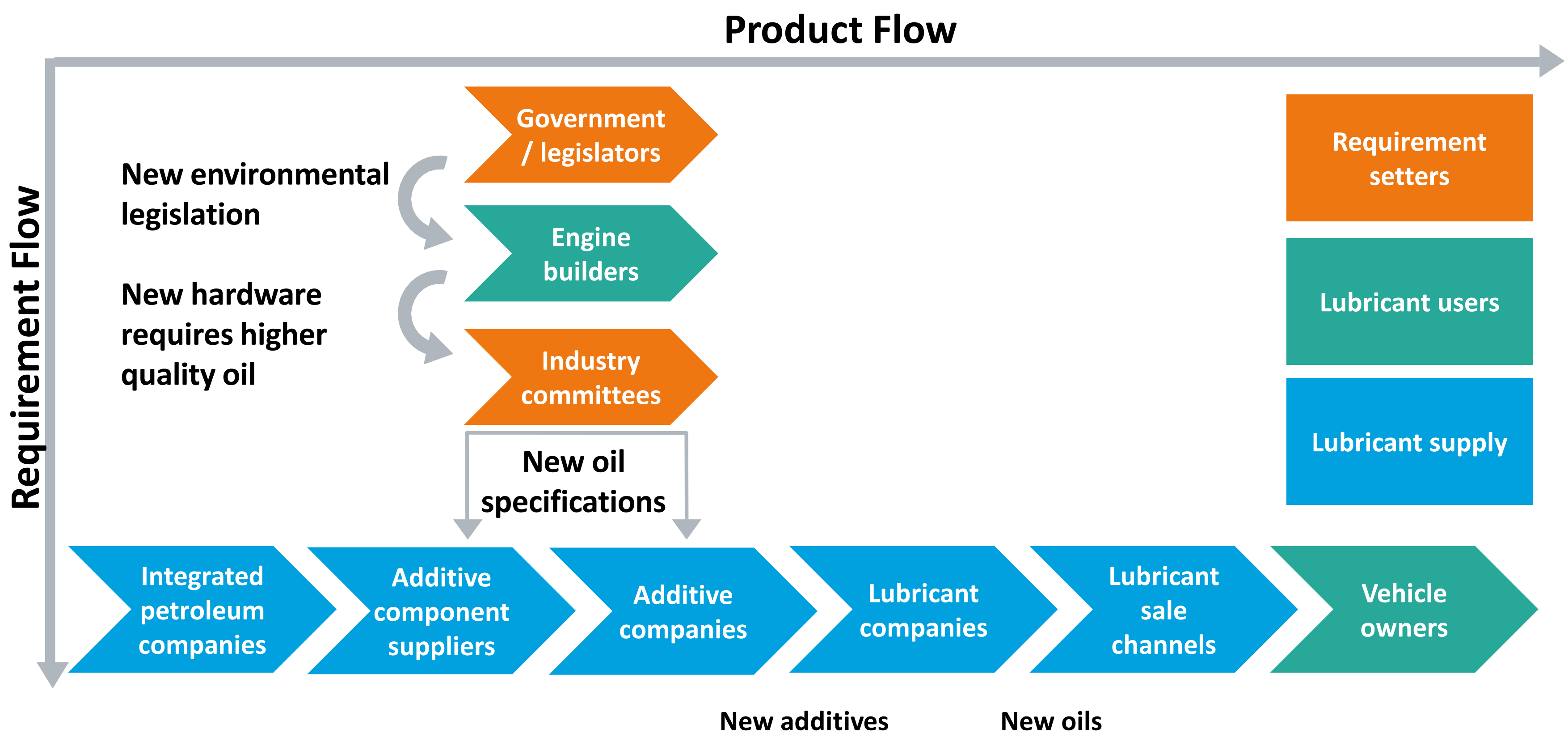
Oil and Additive Industry Value Chain

New requirements drive innovations by engine manufacturers and the lubricant industry for the consumer



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Industry Organisations

	Additive	Oil	Engine	Testing
Europe	ATC • *Lubricant and Fuel Additives* • *Code of Practice for CEC tests*	ATIEL • *Code of Practice for ACEA Engines oils* • *Technical issues related to lubricant industry in Europe*	ACEA • *Light and Heavy Duty* • *Issues ACEA Sequences*	CEC • *Extensively used in Europe* • *Board inc. ATC, ATIEL and ACEA* IP • *Oil analysis test methods* GFC • *Bench tests for French industry*
North America	ACC • *Petroleum Additive Panel (PAP)* • *Code of Practice for ASTM tests*	API • *All aspects of N.A. oil and gas industry* • *EOLCS for Engine Lubricants* • *Issues API S, C, & F* • *Donut and Starburst* ILMA *Trade organisation for smaller oil companies in NA*	EMA • *Mainly HD* AAM • *Car and Light Duty* ILSAC • *Own Spec based on API*	ATSM • *Engine and Analytical tests*
Asia Pacific - China	CLSAC • *Chinese Lubricant Standards Alliance Committee*			CTMC • *China Test Monitoring Centre*
Asia Pacific – Japan		PAJ • *Develops lubes specifications*	JAMA • *Light, HD and Motorcycle* • *Develops Lubes Spec*	JASO • *Japanese Tests* JPI • *Bench and Analytical tests*
Asia Pacific - India	BIS • *Bureau of Indian Standards*			

ACEA EXTENDED WORKING GROUP – CONSULTS WITH ATC AND ATIEL

NA – SPEC SETTING

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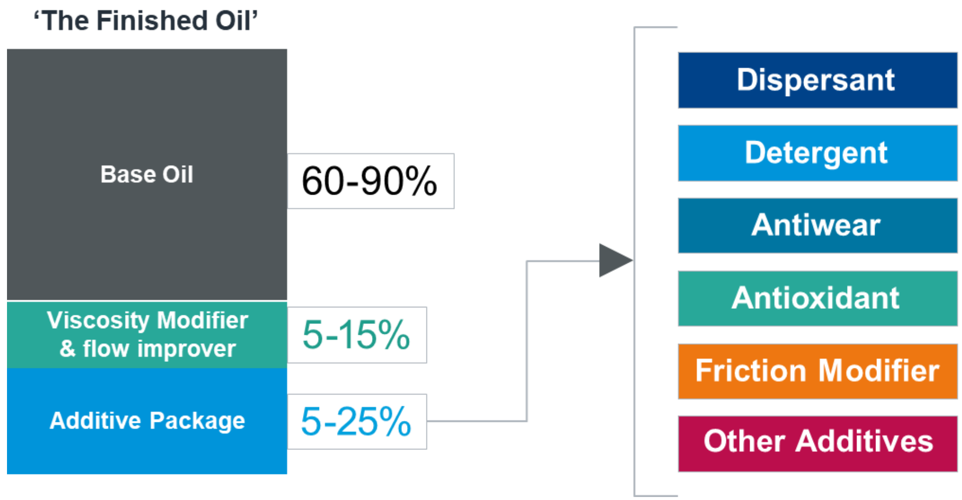
Developing a New Lubricant Formulation

Oil must meet performance targets:

- Engine test
- Bench test

Each **test requirement** typically demands something **different from lubricant performance**

Product **approvals**



Key is balancing the additives and other constituents for the application

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Example of a formulation problem

Suppose that, in a formulation development*

- We need to pass three tests: **Test 1, Test 2, Test 3**
- For this particular product type, we traditionally use only two additive components: Alpha and Beta
- In scoping work we can identify combinations of Alpha and Beta that can pass **Test 1** and **Test 2** together
  - However none of these combinations can pass **Test 3** and this is a major issue for the project
- This is illustrated in a plot in the next slide

*(This example is highly idealised in order better to illustrate principles of formulation)

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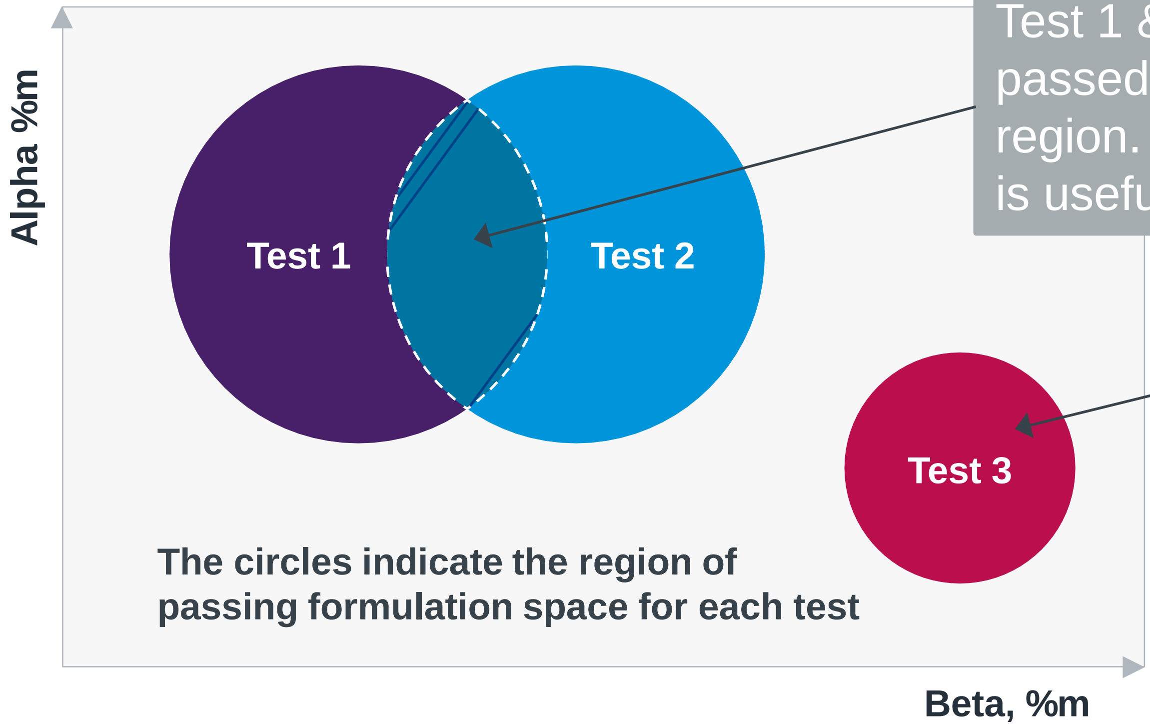
Example of a formulation problem

Plot of the passing regions of "Formulation Space" for each test. Using components Alpha and Beta



Test 1 & Test 2 can be passed together, in this region. This overlap region is usefully large

Test 3 can be passed, but not with a formulation that passes the other tests,

There is no formulation above that can pass all three tests together. This is a problem for this project.

How can lubricant formulation be used to overcome performance challenges?

Later, in the same development

- A colleague has discovered that the response of Test 3 to Alpha and Beta can be altered beneficially by adding 1% of a new component, Gamma, to the system
- We therefore add 1% of Gamma to the system and re-explore the formulation space of each test across differing treat rates of Alpha and Beta
- We see what happens in this case, in the next slide

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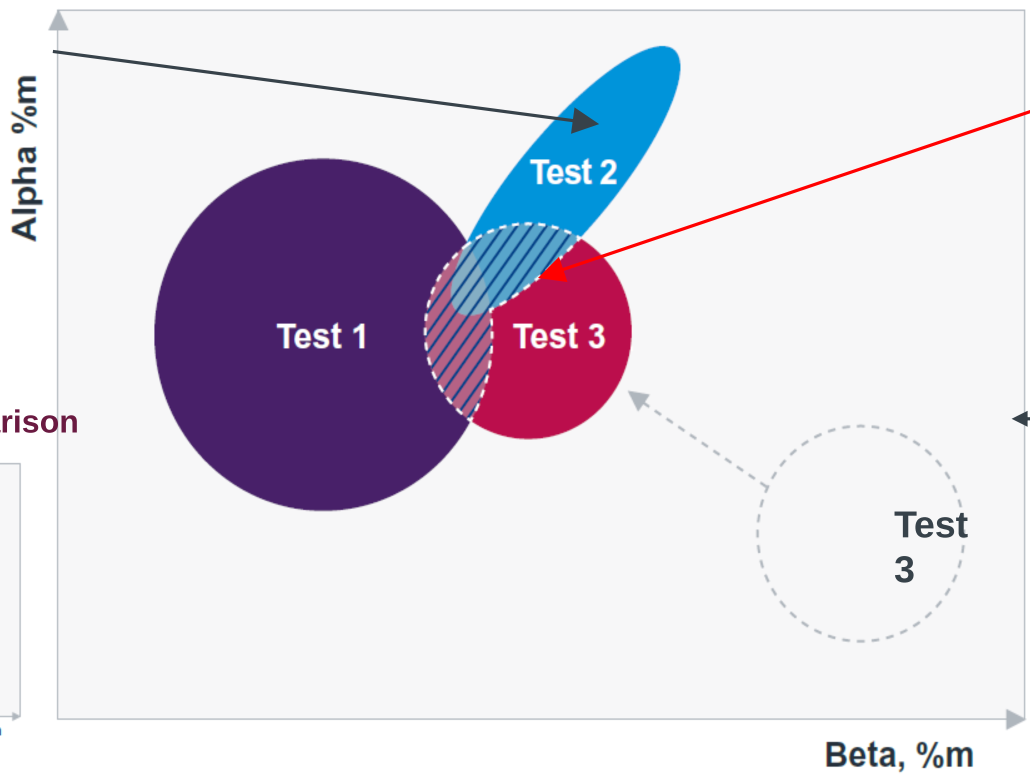
How can lubricant formulation be used to overcome performance challenges?

Plot of the passing regions of "Formulation Space" for each test.
Using components Alpha, Beta, with 1%m Gamma

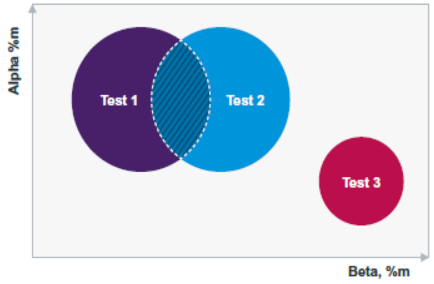
3. However, the use of Gamma has also changed the response shape of Test 2



2. A region of formulation space can pass all three tests

1. The passing region of Test 3 has now moved to a more useful place

Previous case, for comparison



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Formulation Problem

Example - conclusions

Concept of formulation balance

- Demonstrates how addition of a component can have a positive effect on one test but also a negative effect on another
- Very common occurrence in crankcase formulations and the skill of the formulator is to set an appropriate balance between all the various opposing effects
- In a development project where there can be 50 tests and 10 or more additive components, the task of achieving balance is not always straightforward

Formulation Balance

Examples

Potential Positive Effects	Additive	Potential Negative Effects
Soot induced oil thickening, Sludge control	Dispersant Mixture	Fuel economy, Fluoroelastomer seals
Acid control Piston cleanliness Anti-rust	Overbased Detergent Mixture	Particulate filter blocking Wear Oil haze
Fuel economy	Organic Friction Modifier	Package instability Oil haze
Film thickness (viscosity contribution) Fuel economy	Viscosity Modifier	Viscosity loss on shear Piston cleanliness

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Formulation Aspects

Base stock

Viscometrics

- Tailored to meet SAE grade
- Deliver low temperature properties

Volatility

- Key to control evaporation
- Lower W-grades have higher volatilities for a given base stock type
  - 0W-30 >5W-30
- Reduction with low volatility base stock types
  - PAO (expensive)

Engine and bench test performance

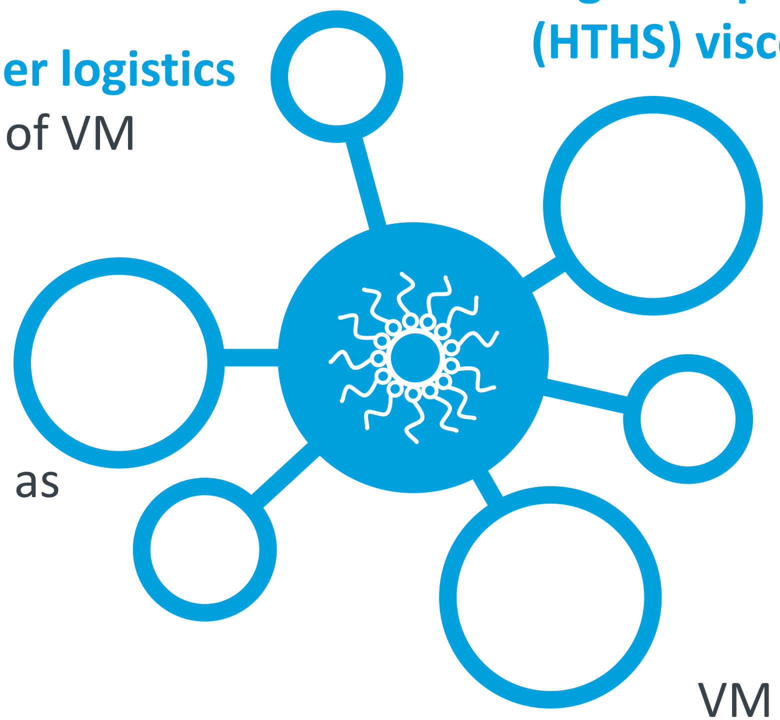
- Higher quality base stocks can deliver improved:
  - Oxidation stability
  - Cleanliness

Formulation Aspects

Viscosity modifier

Sufficient contribution to **High Temperature High Shear (HTHS) viscosity** SAE grade

Often, **customer logistics** impact choice of VM



Impacts **engine performance** such as **cleanliness** and **fuel economy**

Shear stability within specification limits

VM choice can affect wax in **cold temperatures**

VM diluent oil contributes to finished oil **volatility**

Formulation Aspects

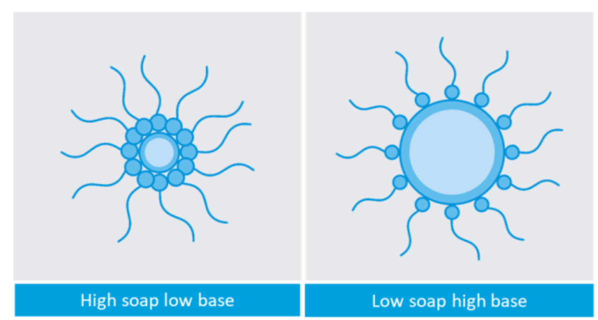
Detergent systems

Detergent role

- **Neutralise** acidic species
- Minimise high temperature **engine deposits**
- Provide supplementary **anti-oxidant** properties

Key considerations

- **Detergent type**
- **TBN limits**
- **Ash contribution**
- **Stability**



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Formulation Aspects

Dispersant systems

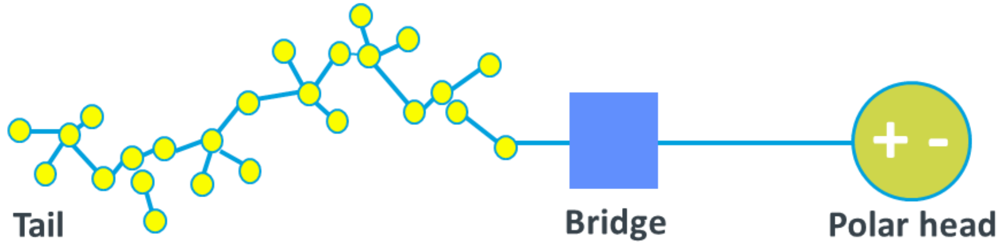
Levels and types of dispersant in the formulation are chosen to provide a balance of properties:

Positive attributes

- Control of soot-induced oil thickening
- Black sludge control
- Piston and engine cleanliness in key tests

Other aspects for consideration

- Viscosity at cold temperatures
- Fluoroelastomer performance
- Fuel economy



Formulation Aspects

Other components

Anti-oxidant and Anti-wear

- **Anti-oxidants** aminic and phenolic additives commonly used
  - Treat minimised due to cost
  - **Other components** also have anti-oxidant properties
- **ZDDP's** highly effective anti-wear and anti-oxidant additives
  - Phosphorus and Sulphur limits common to protect after treatment systems

Other additives

- **Friction modifiers** may be organic or contain metal
  - Anti-wear performance may be affected by the addition of surface active components
- Others include
  - **Corrosion inhibitors**
  - **Anti-foam**
  - **Demulsifiers**
  - **Seals fixes**
  - **Pour point depressants**

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Formulation Aspects

Stability / harms

Once formulation is defined, essential to check that package and oil are stable and assess 'no-harms' of the additive combination

Stability

- Haze or formation of visible layers early indicators of **instability**
- Detergent overbased material can **form sediment**
- Friction modifiers can induce **stability issues**

Harms testing

- Early lab testing for **unexpected effects** recommended
- As a minimum this will include seals, foaming and corrosion tests

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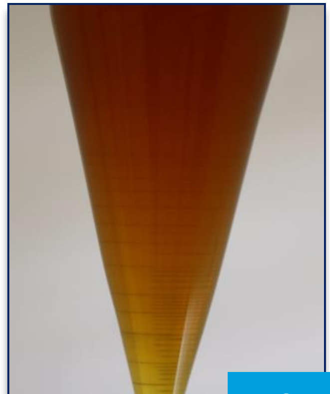
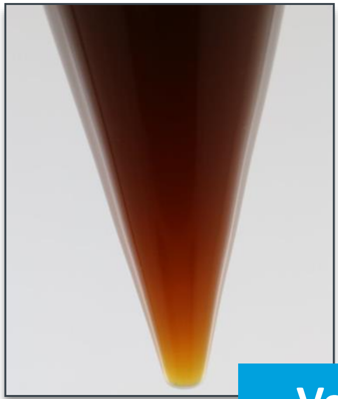
Oil Appearance

Clear and bright



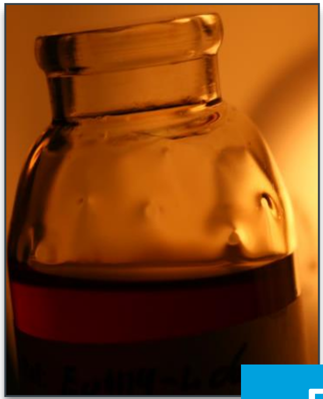
Slightly hazy



Very hazy

Sediment

Phase separation



Fish eyes

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Formulation for Key Engine Tests

Some examples of engine tests in current ACEA and API specifications and the key oil properties that they probe are listed below

Passenger Car Motor Oil

Property	Relevant test
Black sludge	M271SL, Seq. VH
Soot induced oil thickening	DV6
Piston cleanliness, ring sticking	VW TDI, EP6
Oxidative oil thickening	Seq. IIIH
Valve train wear	OM646LA, Seq. IIIH, Seq. IVB
Fuel economy	M111FE, Seq. VIE
Bearing corrosion	Seq. VIII

Heavy-duty Diesel Oil

Property	Relevant test
Soot induced oil thickening	Mack T8E, Mack T-11
Filter plugging	Cummins ISM
Piston cleanliness, ring sticking	OM501LA, Cat C13, Cat 1N
Valve train wear	Cummins ISM, Cummins ISB, RFWT, OM646LA
Ring/liner wear	OM501LA, Mack T12
Aeration	EOAT, COAT
Oxidative oil thickening	Volvo T-13
Bearing corrosion	Mack T12

Further testing requirements, not listed here, may include OEM requirements, either in-house OEM engine tests or OEM field trials

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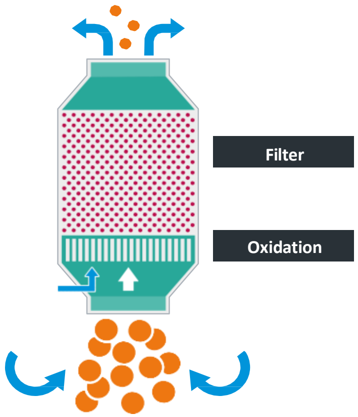
Demands on the Lubricant Continue to Evolve

As engine design and operation evolve, so too do the challenges faced by the lubricant



Recent examples include:

After-treatment compatibility

Fuel economy improvement

Low speed pre-ignition

Electrification

In some cases existing lubricant technologies meet changing demands. However, new generation engines can drive the development of new lubricant formulations

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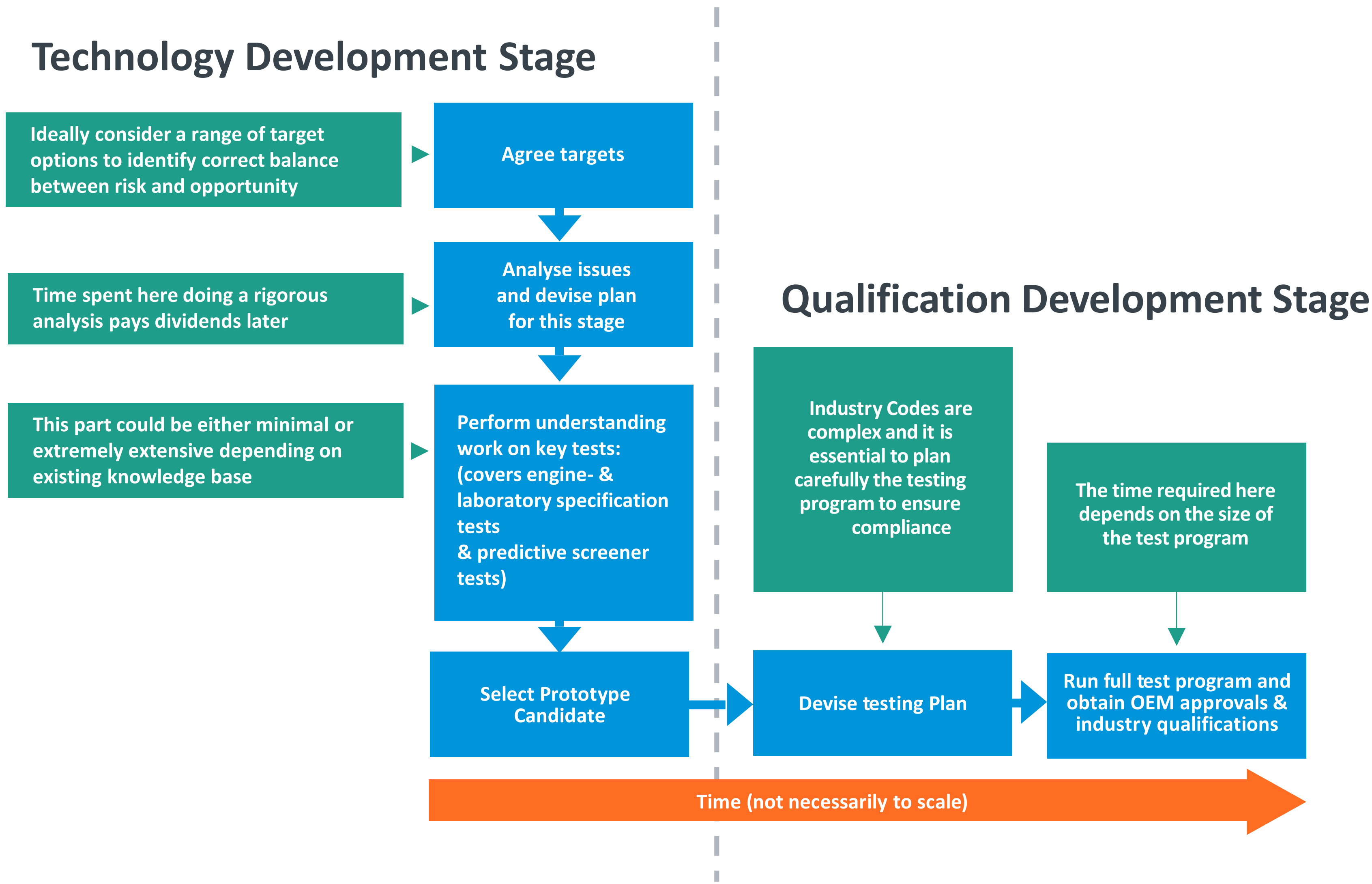
Product Development Program Stages



Product Development Program

Time and cost

European Automobile Manufacturers Association

Lower-end complexity and challenge

Single ACEA specification added to existing product

Assume no technology development work

- Testing cost (= once-through costs): **400k USD**
- Elapsed time to complete: **2-3 months**

Higher-end complexity and challenge

Product to meet combinations of OEM specifications with extensive testing requirements

Assume considerable technology development work

- Total project cost: **> 5 million USD**
- Elapsed time to complete: **> 3 years**

Codes of Practice Framework

Codes of practice
- Assures the quality of the tested product

Principles include
- All test work should be visible to the customer
- Any read-across of results should not compromise the quality of the product

- Represent both European and North American Additive companies with own Codes of Practice
- Allowable changes to the additive package and constituent components, plus changes to viscosity modifiers

- Equivalent Codes of Practice from Oil Marketer perspective
- Include guidelines for base oil interchange (BOI) and viscosity grade read across (VGRA)
- Other aspects such as data reporting and (for API) licensing

Summary

Crankcase formulation: what’s it all about?

- Satisfying huge number technical requirements which often oppose each other
- Recognising concept of formulation balance
- Understanding positive and negative impacts of the individual components
- Planning very carefully the technology development scoping work as well as the detail of the qualification test work
- Investing potentially very large engine test budgets where programs are complex and technically challenging
- Adhering to industry codes of practice

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