"China's path to Net Zero CO_2 and the role of Hybrids in that path"

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Changan UK R&D Centre Ltd | March 2022

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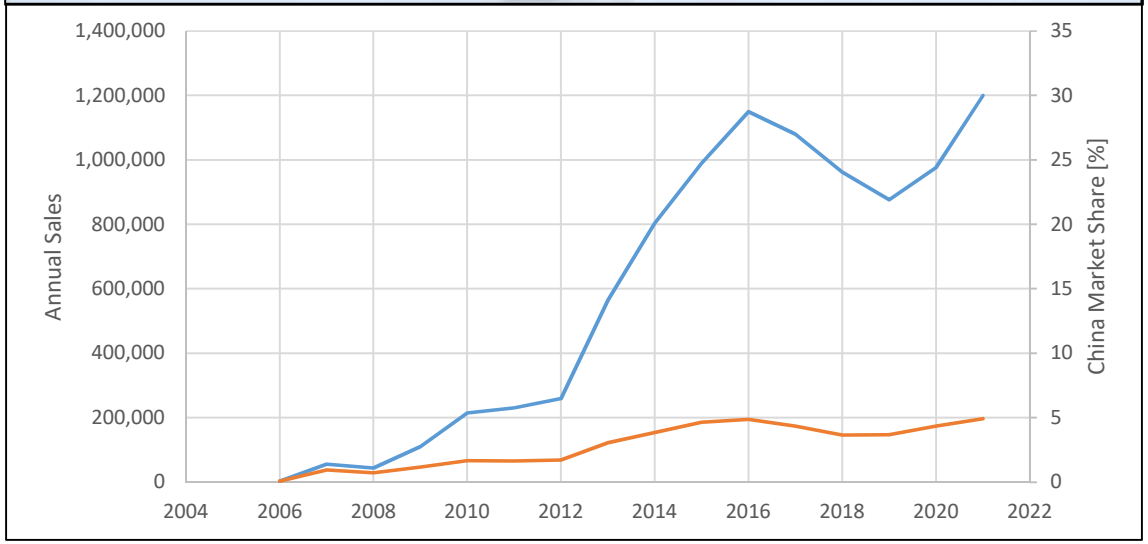
Overview of Changan Auto

- Changan Auto is one of the 4 largest OEM's in China
- 2021 sales were 2.3 million
  - 0.6 million Joint Venture cars (Ford & Mazda)
  - 0.5 million Commercial Vehicles
  - 1.2 million Passenger Cars (PC)

- 1862 Established
- 1958 Military vehicle production
- 1984 1st vehicle sales, licenced Suzuki mini-van
- 2006 1st Own Brand PC Car sales
- 2016 Own Brand PC sales exceed 1.0 million
- 2021 Own Brand PC sales exceed 1.2 million
  - Exports at ~10% of China sales having grown steadily



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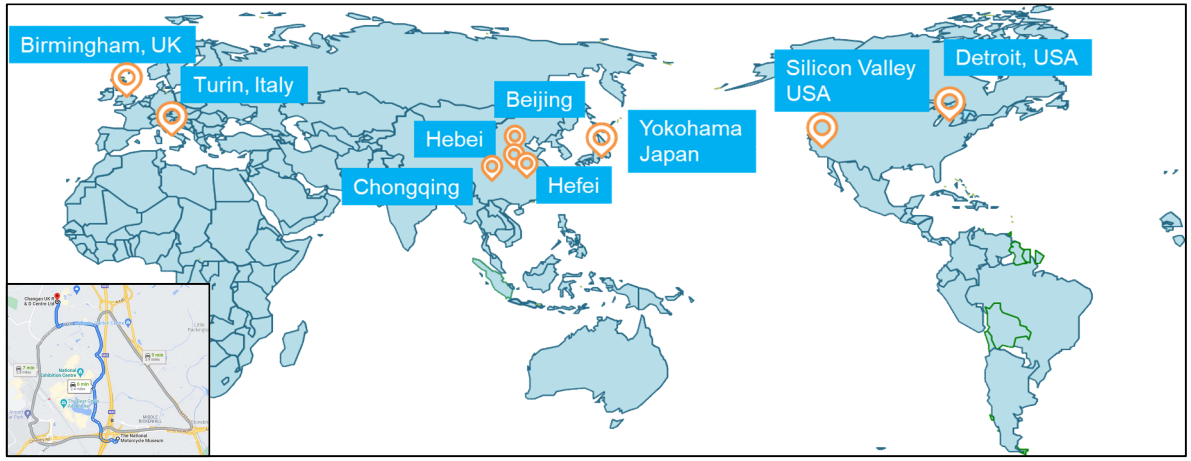
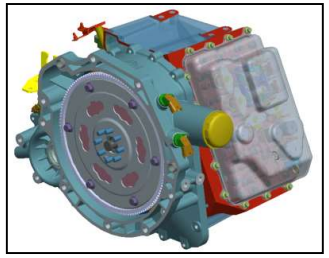
Overview of Changan UK (CAUK)

- Established in 2010 in Nottingham as the 3rd of 5 Overseas Technical Centres
- Moved to Birmingham Business Park (2.6 miles away) in 2015
- Focused on Research, Design & Development of High Efficiency Powertrains; Gasoline Engines, DCT Transmissions, Hybrid systems & their Integration and Application
- Typical lead projects in the early stages of concept design and validation and then transfer lead to China for introduction into production
- Around 90% of current PC production uses an engine lead from CAUK as well as approx 50% of automatic transmission volume (conventional and P2 Hybrid)





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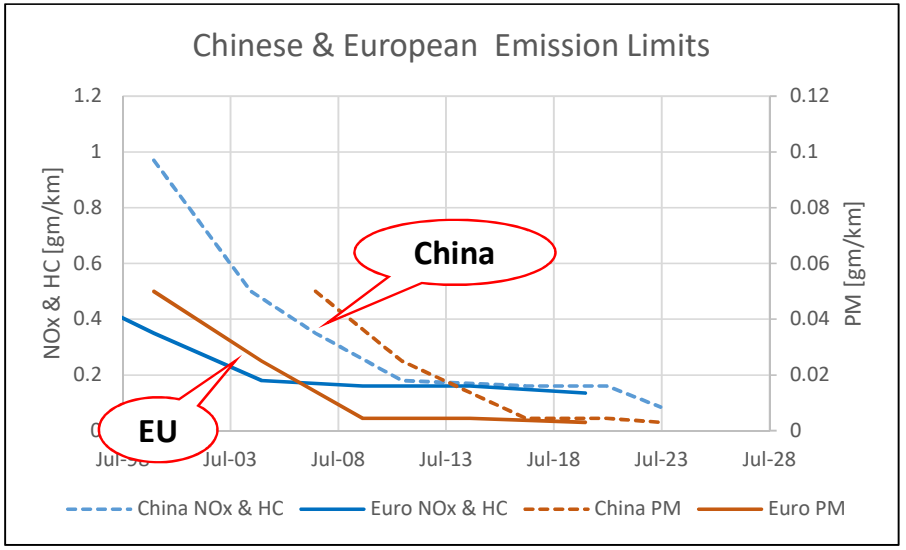
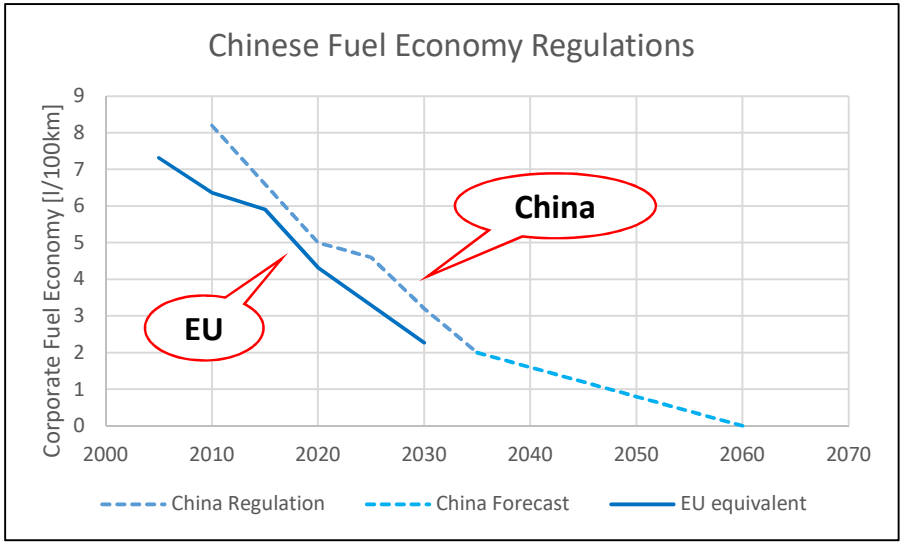
Chinese Fuel Economy & Emissions Regulations

- Chinese emission regulations have in the past largely followed the EU regulations whilst lagging in time but by increasing shorter periods of time
- In China 6, additional pollutants were added to the regulations in addition to the EU standards
- Regulations have been regulatory introduced in major cities in advance of national adoption by 1~3 years
- China 7 is anticipated in the mid to late 2020's and will further tighten the limits

- Fuel economy regulations have been introduced in the 2010's
- The regulations are quite complex covering both individual model fuel economy and Corporate Fleet Average
- A 4 fold reduction in fuel economy is required from 2010 to 2035
- This will drive the widespread adoption of Electrified vehicles, both Plug-in and non plug-in hybrids





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Chinese Fuel Availability – Past, Present and Future

- In the past China suffered with poor fuel quality
- This has now largely been resolved and the sulphur content of 10ppm is similar to other major countries
- China had issued an E10 mandate in 2017 which was being rolled out on a regional basis
- In 2020 it was suspended in 2020 due a lack of capacity to manufacture ethanol without risking food shortages. It is unclear when this may be resumed
- Methanol is widely used on a regional basis (coal mining areas) with M100, M85, M25 and M15 blends but this is not a National policy but a local activity
- There is no National policy at this time on Synthetic fuels and no apparent debate on this either
- Hydrogen is being promoted strongly at the National level although implementation is expected to be rolled out on a regional basis and meeting 20% of National energy needs – how much will be used in road transport and in passenger car is not yet clear

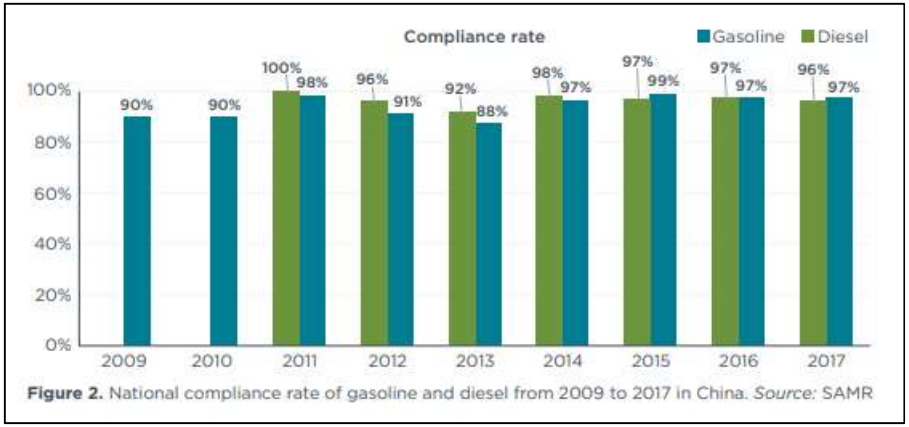
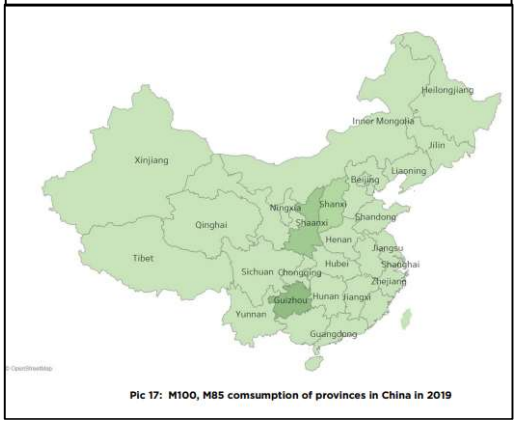


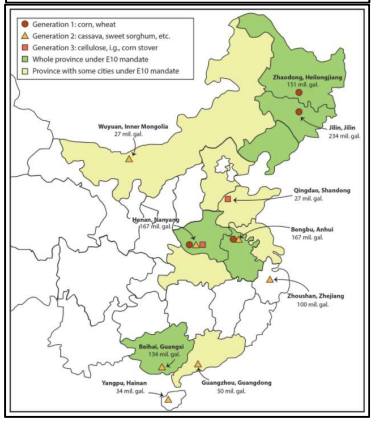
Figure 2. National compliance rate of gasoline and diesel from 2009 to 2017 in China. *Source:* SAMR

Methanol usage



Pic 17: M100, M85 comsumption of provinces in China in 2019

Ethanol usage



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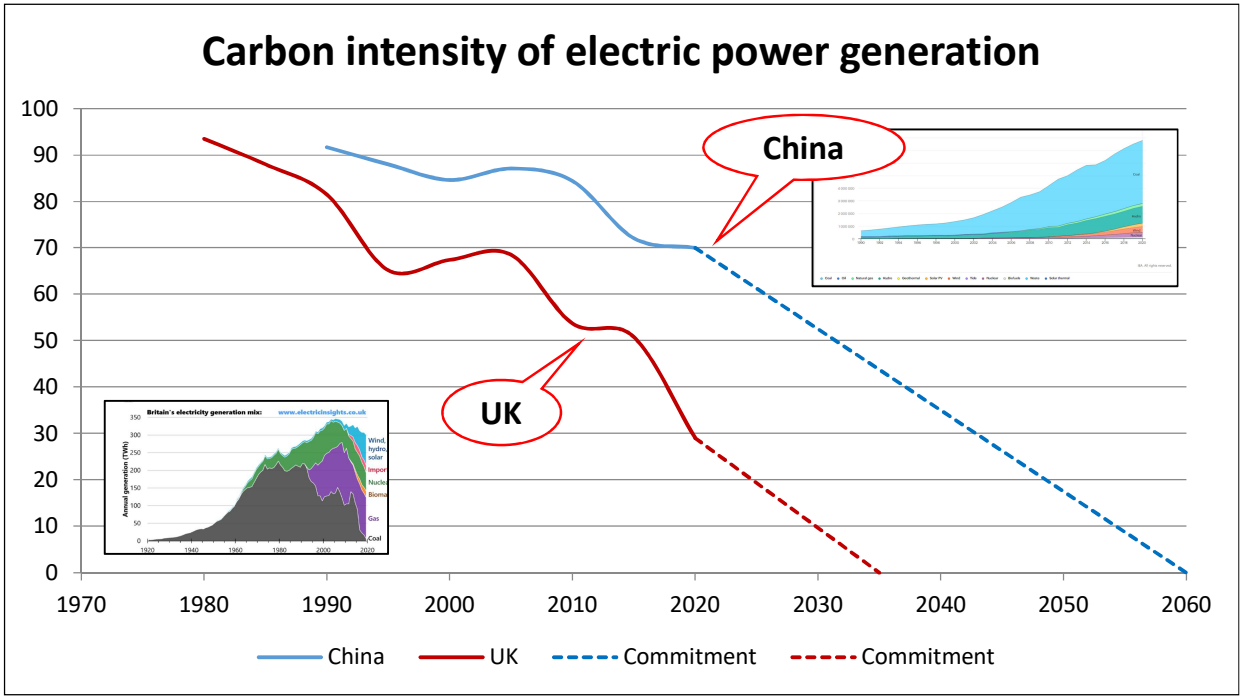
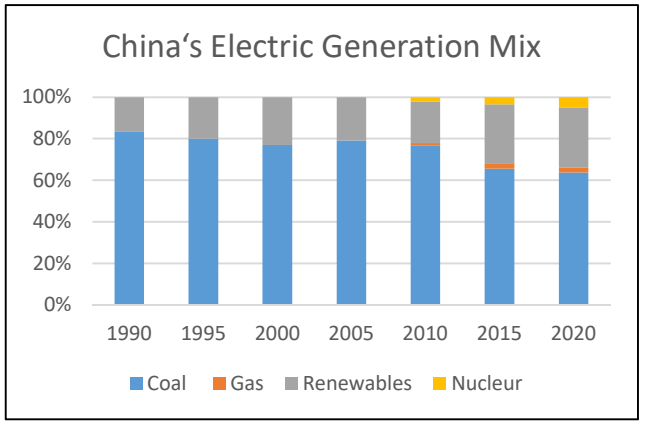
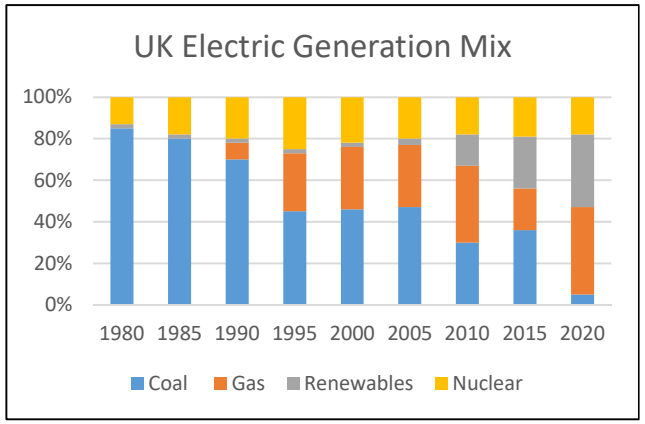
Chinese Electrical Power Generation

- Both the UK and China have committed to “Zero Carbon” electricity generation, in 2035 and 2060 respectively
- Since 1990 China’s electricity generation has increased 10 fold and moved from 80% to 60% coal with the remainder mainly renewables
- Since 1980 the UK has moved from 80% to less than 5% coal, initially with substituting gas but more recently with renewables
- Today’s carbon intensity of electric generation in China is equivalent to the UK in around 1995
- It is like to take 20 years before China can reach the UK’s current level







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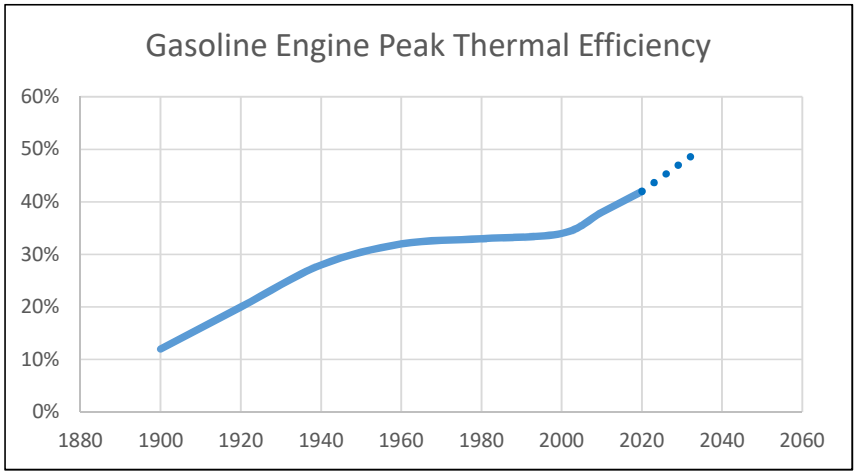
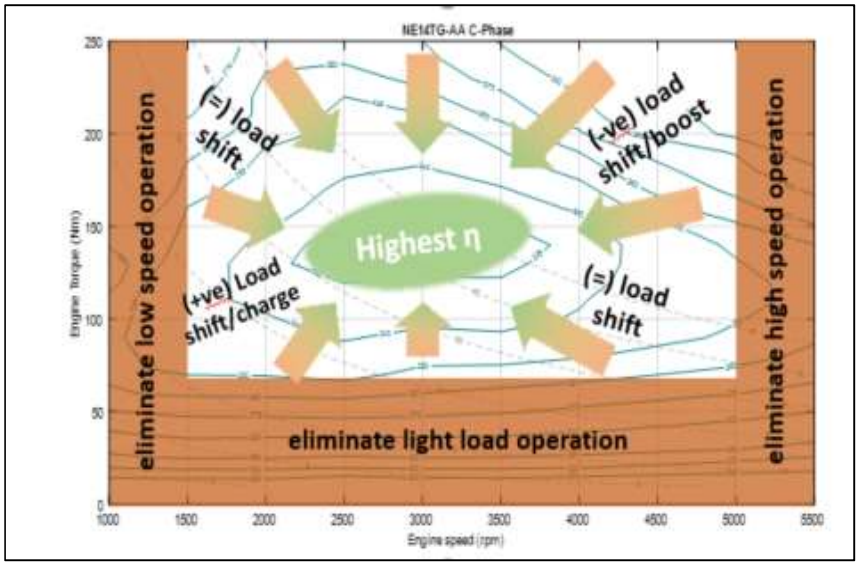
Optimising engine efficiency for Hybrid applications

- Gasoline ICE are generally reported as around 20~30% efficient. This was true for around 40 years but significant advances have been made in recent years with many engines now exceeding 40%
- These advances in peak efficiency of gasoline engines have been the result of three factors
  - **Added technology**
  - **Improved materials and development methodologies**
  - **Changed operating range in hybrid applications**
- The reduced operating range coupled with hybridisation dramatically affects the distribution of power usage
  - **The engine more of the time at high efficiency values; in excess of 90% of time over 33% TE compared to ~40% in a conventional car**
  - **The design of the engine can be optimised for higher power efficiency (higher CR, lower friction..) increasing the peak efficiency potential**





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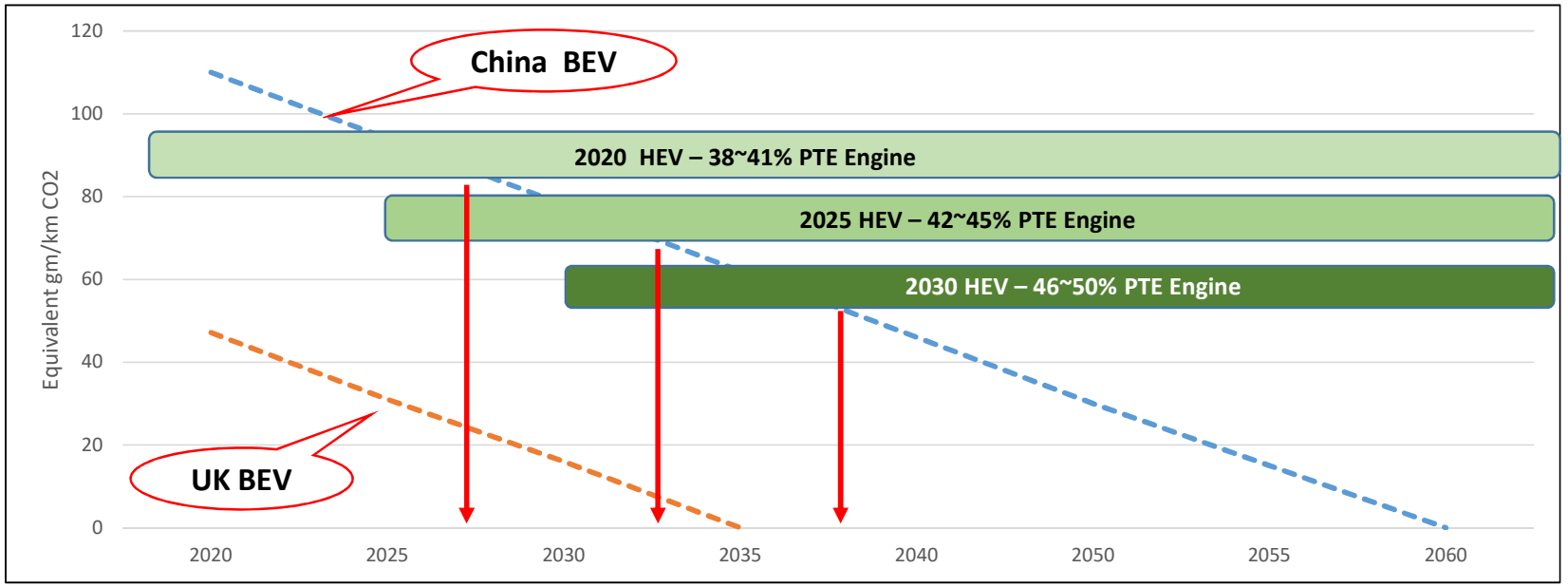
Net CO_2 of BEV's and Hybrids in use (excluding battery embedded CO_2)



Note 1) – PHEV's exist in a "state" between HEV and BEV and their merit is highly dependent on owner behaviour, patterns of charging and journey durations

Note 2) – A C segment vehicle is assumed in this analysis

- In China, current Hybrid emits 20~25% less than a BEV
- BEV's are important in cities for air quality reasons
- Improvements to the efficiency of Hybrids can extend this date towards 2040 if we can achieve over 50% efficiency from the Internal Combustion Engine with its related systems
- **Continued use of Hybrid's and the development of higher efficiency engines is suitable for China based on the expected carbon intensity of electricity generation**

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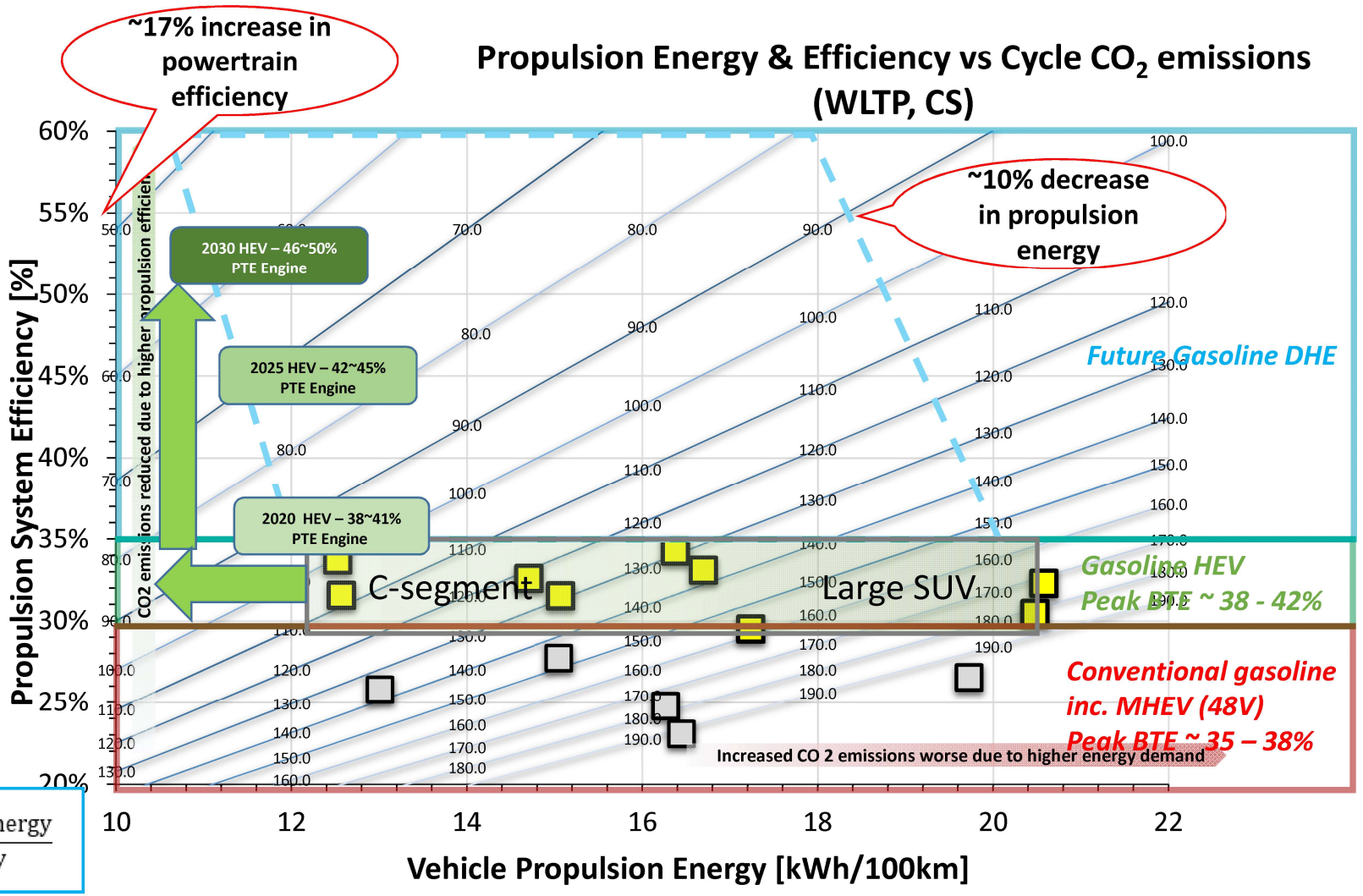
Propulsion efficiency vs propulsion energy

- Propulsion energy
  - Defined by vehicle mass and loss coefficients.
  - Integration of positive power flow to the wheels
  - Excludes driveline system losses and kinetic energy (after RL) during braking – both considered within 'propulsion efficiency'
    - Weight reduction
    - Improved aerodynamics
      - Including frontal area
    - Reduced rolling resistance
      - Tyres
      - Brakes
      - Bearings
- Propulsion efficiency
  - Warm up effects
  - Operating area and efficiency of engine
  - Ability to recuperate.

$$\text{Propulsion Efficiency} = \frac{\text{Vehicle Propulsion Energy}}{\text{Total Fuel Energy}}$$



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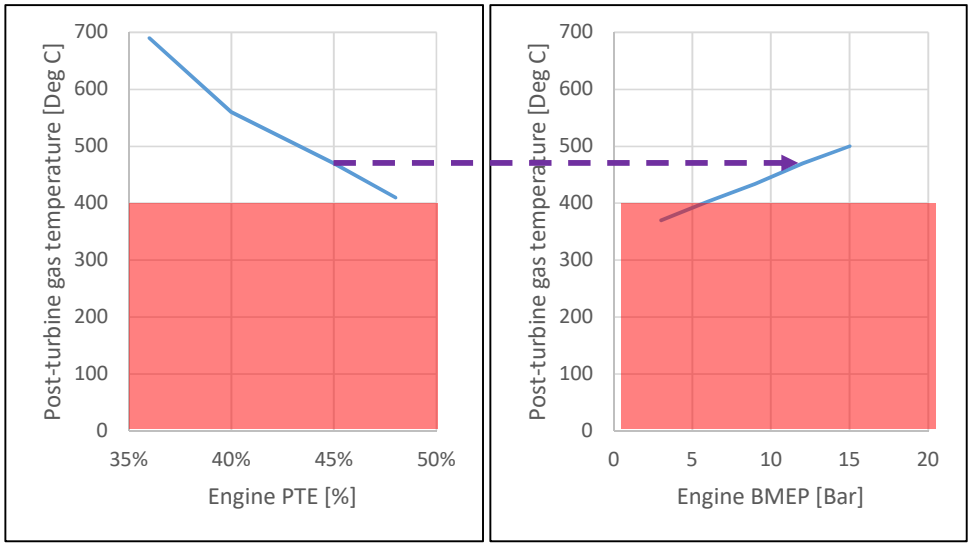
Emissions controls for very high efficiency hybrids

- There are two fundamental approaches that seem plausible for the after-treatment of the highest efficiency hybrids
  - **Lambda 1 operation with a 3-way catalyst**
  - **Lean operation with lean after-treatment**
- Both in principle readily applied, using experience either from gasoline vehicles or diesel vehicles however it is certain that adaption will be required
- Lambda 1 operation – PGM/wash coat formulations will need adjusting as the low exhaust temperatures will make achieving high conversion efficiencies very difficult without change
- Lambda > 1 operation – the PGM formulation will need adjusting for different HC species
- Conventional catalyst heating will be feasible with degraded combustion efficiency (as conventional engines) but there is a good case for high voltage electric catalyst heating if the engine peak efficiency is high enough to enable pre-heating of the catalyst without a fuel economy penalty



Conventional Catalyst Heating; use of fuel energy

10% Brake Work
27% Catalyst Heating
37% Net Efficiency

Electric Catalyst Heating

45% BTE
92% Generation Efficiency
96% Battery discharge Eff'y
40% Net Efficiency

Image c/o Vitesco

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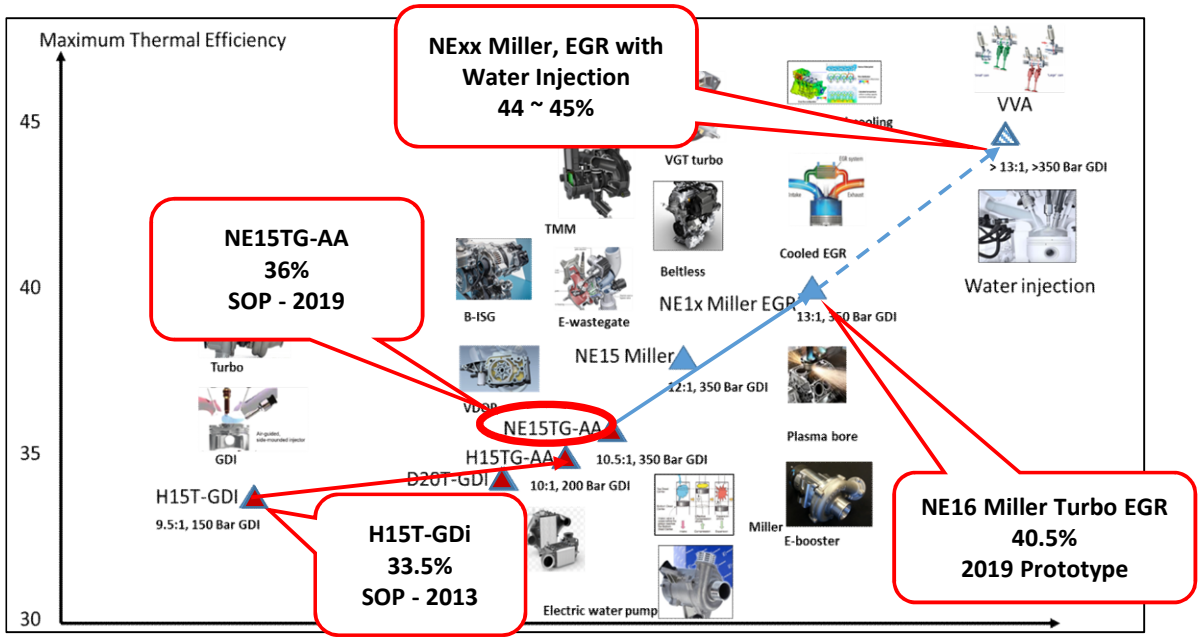
Changan Development Status – FPC 2019



- At the FPC in 2019 we introduced the new Changan engine family, the NE1
- At that time our achievements with this engine were
  - 36% PTE in production
  - 40.5% PTE – in prototype
- We also had a development plan and a roadmap in order to strive to achieve 45% PTE

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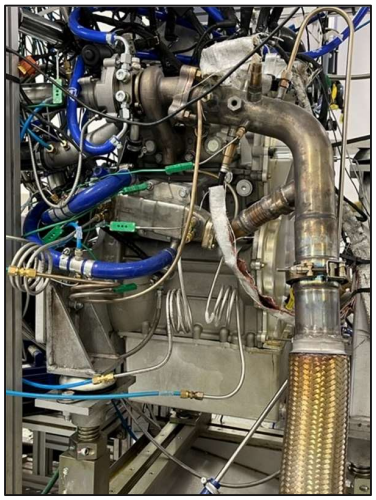
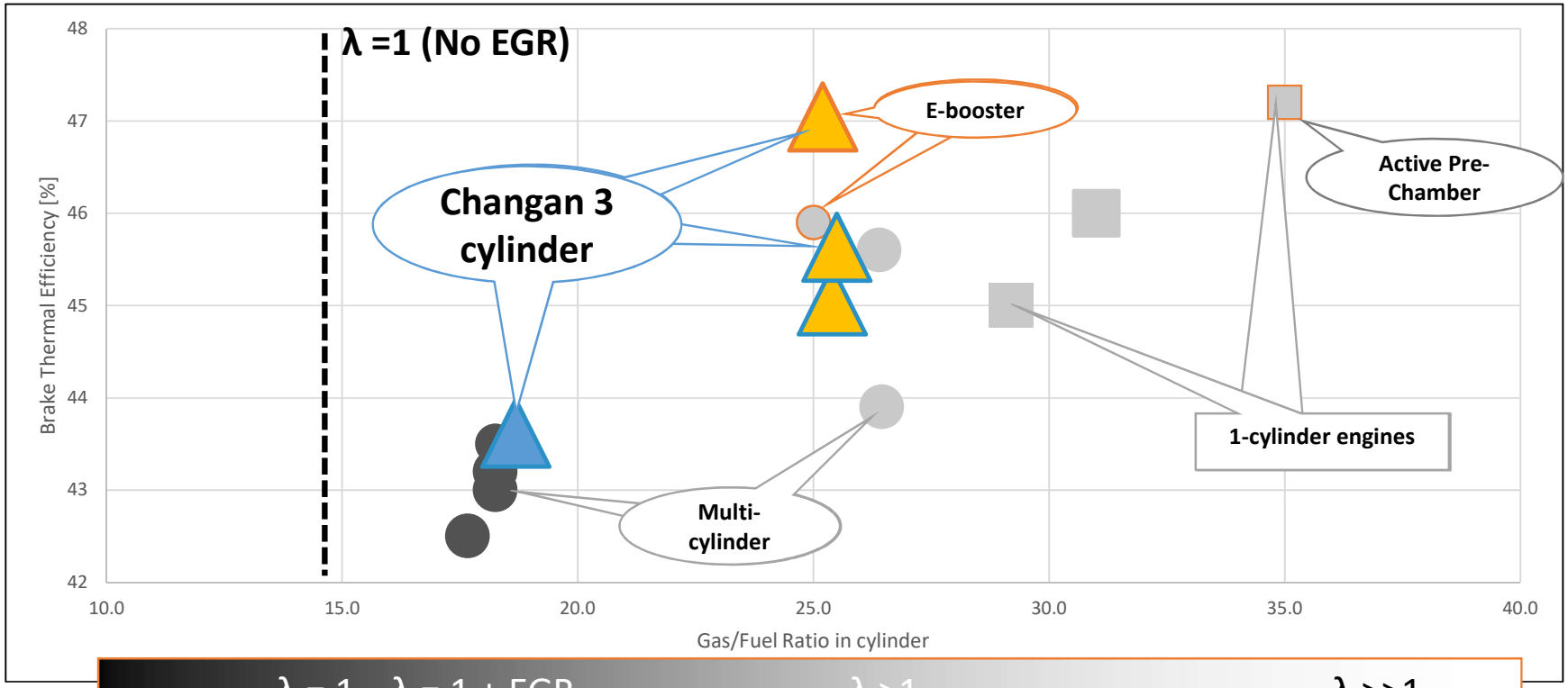
Changan Development Status – Peak Thermal Efficiency – FPC 2022



Other OEM
- Toyota
- Nissan
- Honda
- Hyundai
- Geely



λ = 1 | λ = 1 + EGR | λ >1 | λ >>1

Lean Aftertreatment requirement

Changan has achieved to date

- **Over 43.5% - Lambda 1 w. EGR & 92 RON fuel**
- **Over 45 % - Lean & 92RON fuel**
- **Over 45.5% - Lean & 100RON fuel**
- **Over 47 % - Lean, 100RON with an e-Booster (as a reference, without energy compensation)**

3 cyl 1.5l engine fitted with an exhaust driven turbocharger

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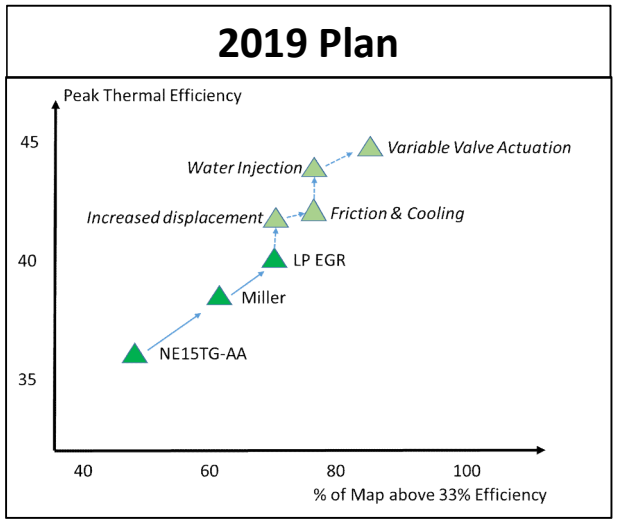
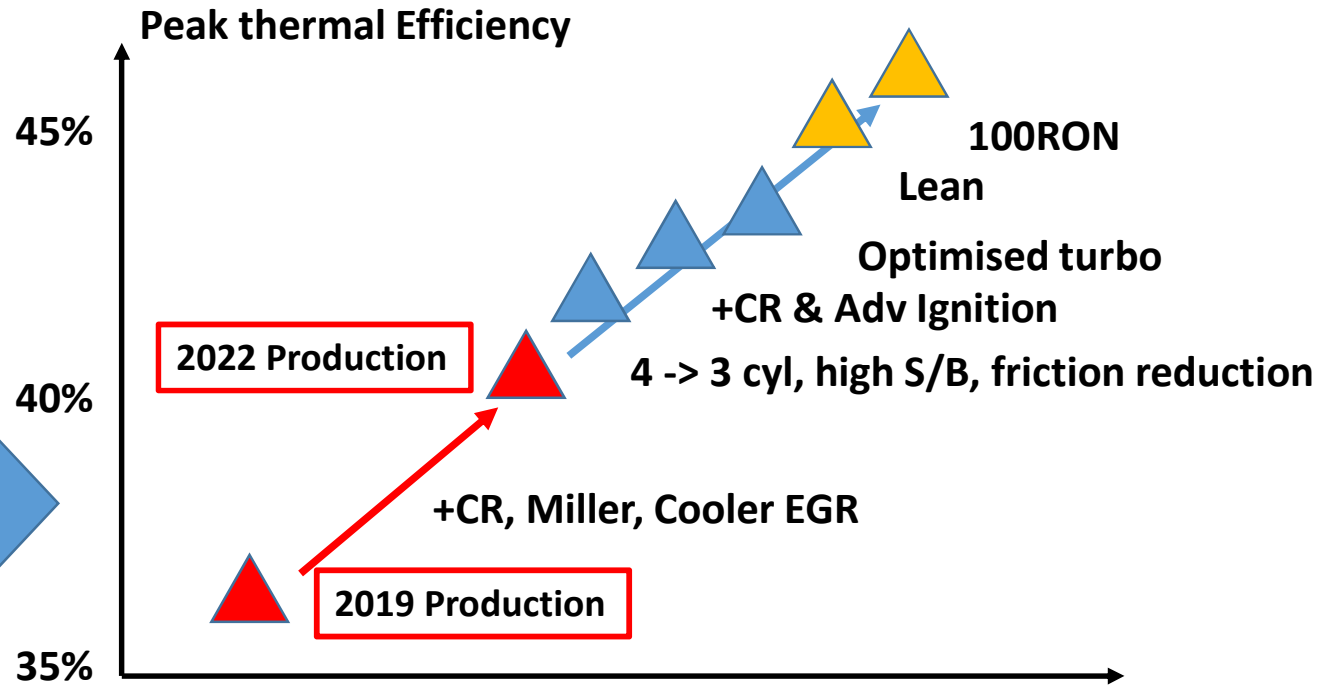
Technology to achieve 45%



2022 Actual



- Our "road to over 45%" proved to be different to that which we expected; VVA and Water Injection investigated but not used
- There was "no silver bullet" and the achievement was due an accumulation of small improvements and ensuring synergy between all the systems of the engine
- The result is both a high peak of 45% and the entire map used in a Series Hybrid above 38%

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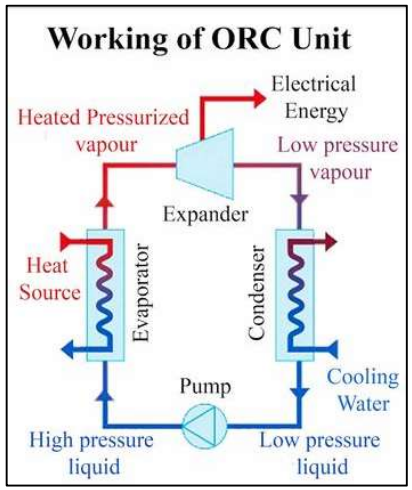
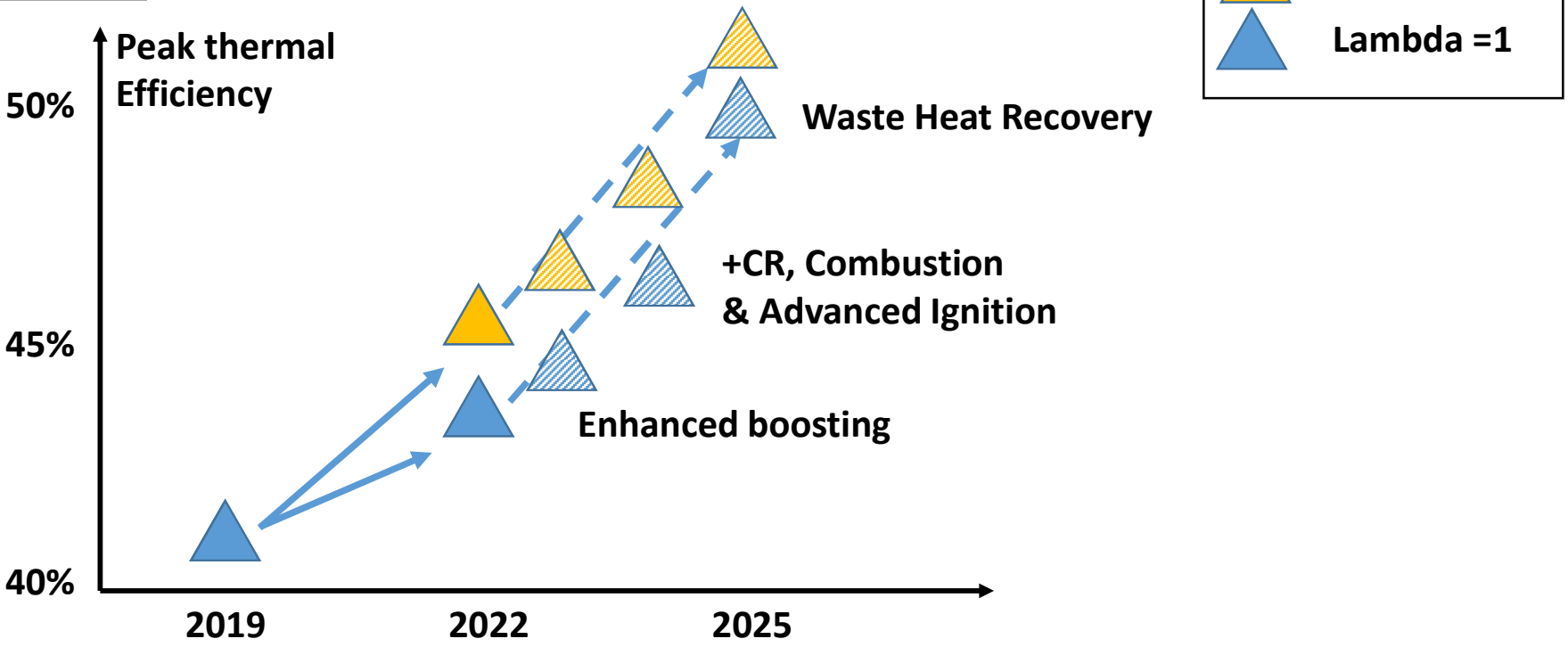
Roadmap to exceed 50%





- Next target is to exceed 50%
- This will be achieved through continuing our current path in order to achieve
  - Lambda 1 45~46%
  - Lambda > 1 46~48%
- Augmented with Waste Heat Recovery to add 3~5% to allow us to exceed 50% PTE

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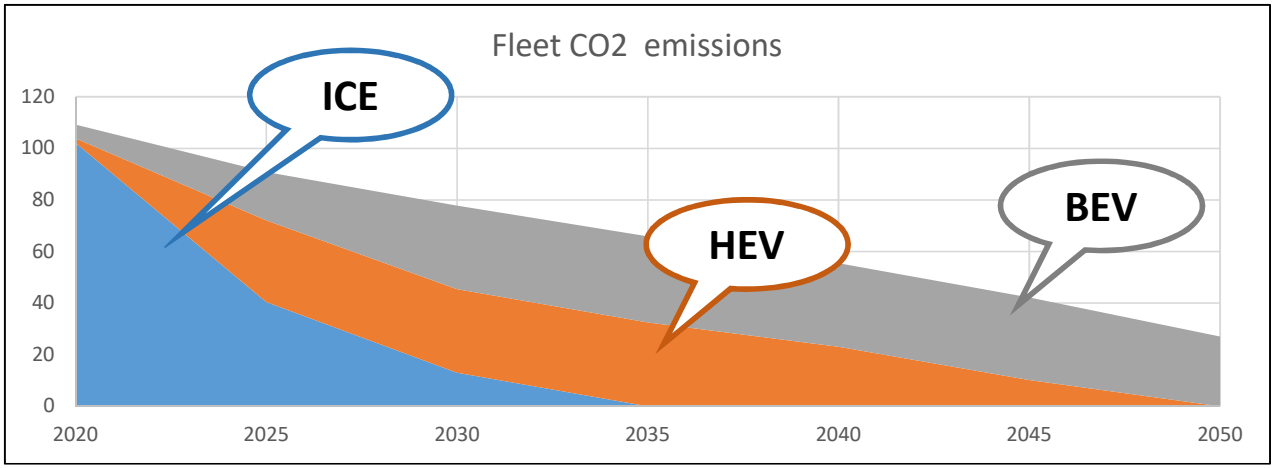
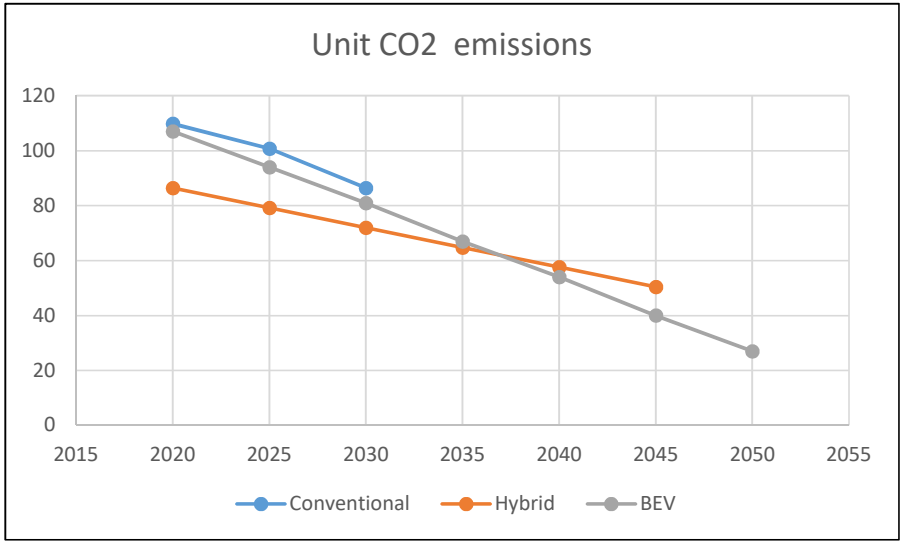
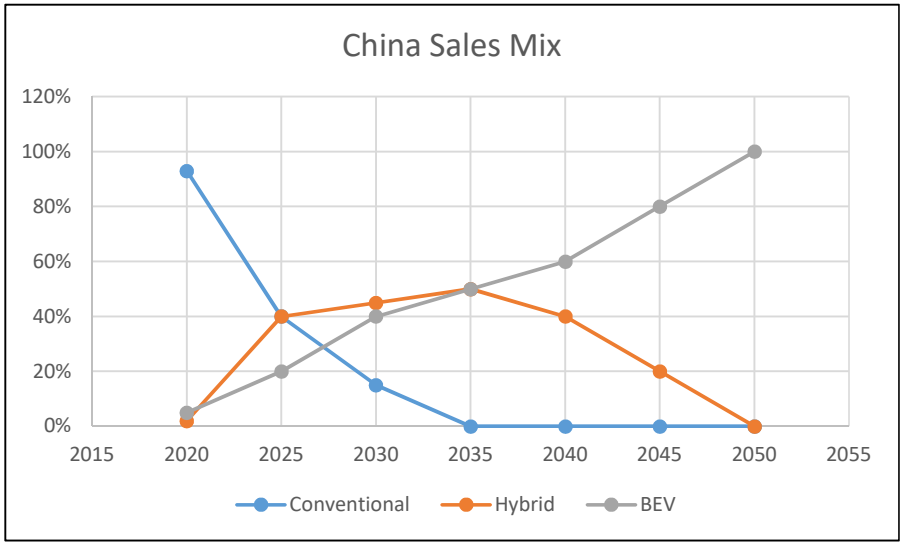
Overall Sales Mix and CO2 emissions





- Changan will move to a blend of HEV's and BEV's to reduce its Fleet CO_2 emissions progressively
- Until around 2040 HEV's offer lower CO_2 emissions whilst BEV's offer zero tailpipe noxious emissions
- Beyond 2040 a mix of BEV, H_2 Fuel Cell and H_2 ICE is possible to meet the market needs



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Summary

- When seeking to reduce global carbon emissions, the appropriateness of Electrified Powertrain technologies has to be considered in the context of the Electrical Power generation in the market under consideration
- Due to the relatively high carbon intensity of China's current power generation, even with continued action to "de-carbon" it is highly likely that gasoline Hybrids will result in lower net carbon emissions than Battery Electric Vehicles in China for the next 15 to 20 years
- Changan is investing heavily to improve the efficiency of its hybrid vehicles in all areas in addition to the engine improvements shown
- In the past 8 years Changan has improved the peak efficiency of it's production engines from 34% to 41%
- In the past 5 year Changan UK has improved the peak efficiency of its prototype engines from 37% to 47%
- In the next 2~3 years Changan UK plans to increase the prototype peak efficiency to in excess of 50%
- Hydrogen is being investigated as an alternate "net zero" fuel for Changan's Powertrains for use beyond 2040 for applications where a BEV is not ideal


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