

Advanced Internal Combustion Engines Workstream Conclusions & Consensus Roadmap

September 2013

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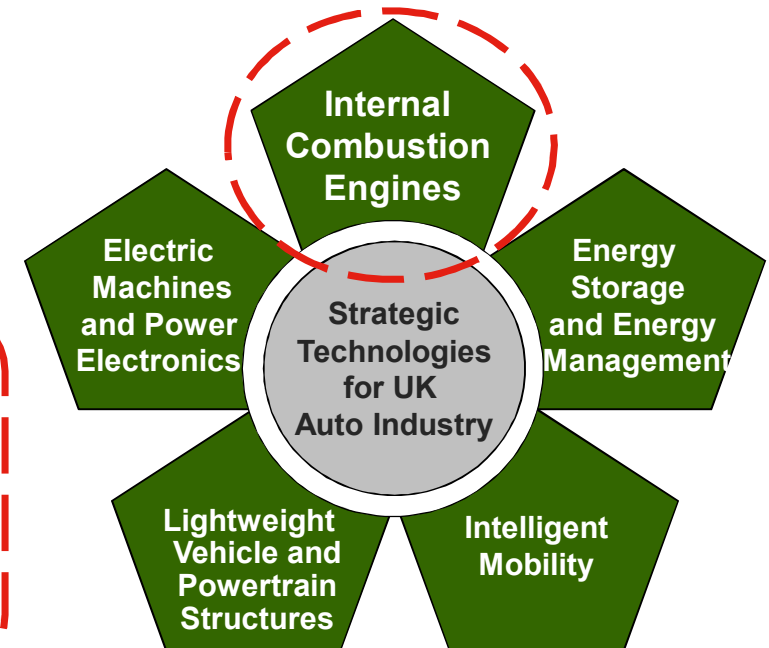
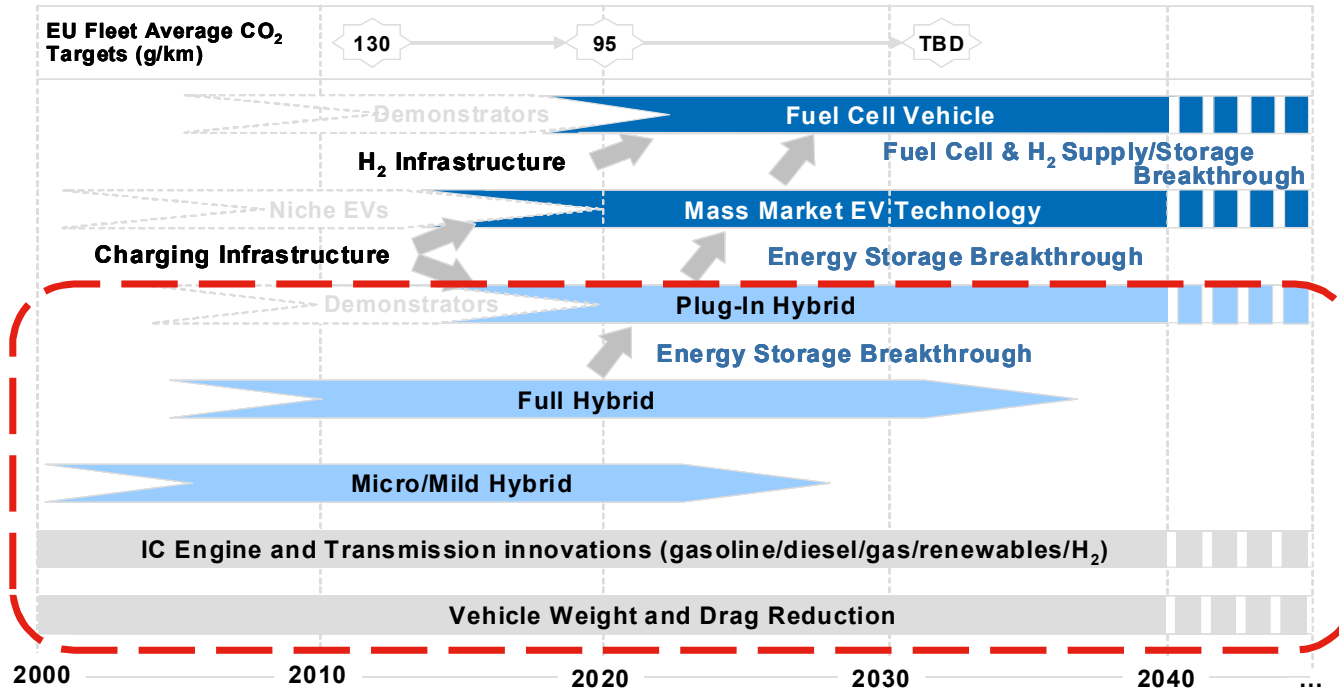
Low Carbon Vehicle Event 2013
Millbrook Proving Ground

The UK's Premier Low Carbon Vehicle (Technology Showcasing & Networking) Event

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- Team Members, Objectives
- Challenges & Opportunities
- Technology Options & Consensus Roadmap
- Key Messages, Recommendations & Future Plan

Advanced Internal Combustion Engines vital for vehicle CO₂ are a key feature of the consensus roadmap & core UK focus area



Advanced high efficiency Internal Combustion Engines key feature of roadmap & UK focus area

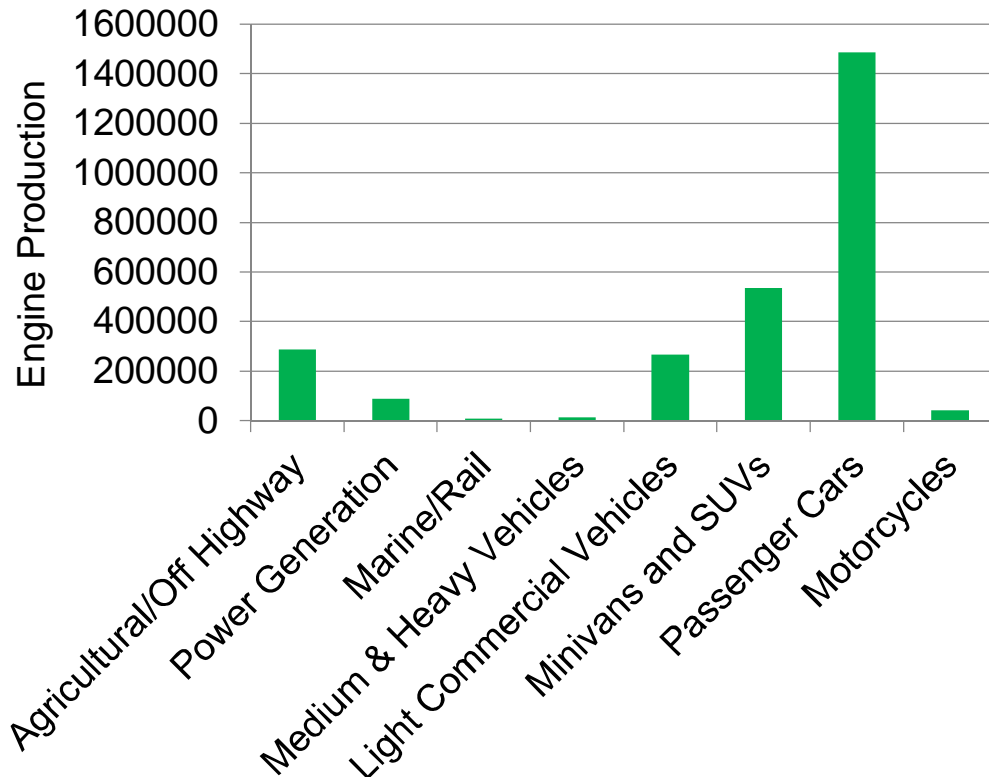
- Most effective short term route to CO₂ reduction.
- UK has all the elements of the supply chain from research to mass production.
- Companies with a fundamental expertise in combustion technology, active fuels and lubricants companies and expertise in motorsport engine technology.
- Opportunity is to grow Tier1 supplier capability & presence

UK is a leader in the manufacture of Advanced Internal Combustion Engines – High Value Exports in passenger car & off-highway products



Internal Combustion Engines important for Economy

- UK produces ~ 2.7* million engines/year
- Associated value to UK is ~£7bn
- Majority of engines made in UK exported



UK ICE Characterised by:

- **Leading University/Industry Partnerships**
 - Around £36m over 3 yrs invested in ICE research
 - Internationally leading University research teams
 - “ Turbomachinery and boosting
 - “ Advanced clean/high efficiency combustion
- **Product Development & Manufacture**
 - High efficiency downsized boosted engines
 - Leading construction & off-highway engines
 - World beating high performance engines



Ford 1.0l
Ecoboost



BMW-PSA
1.6-litre turbo



McLaren
12C M838T

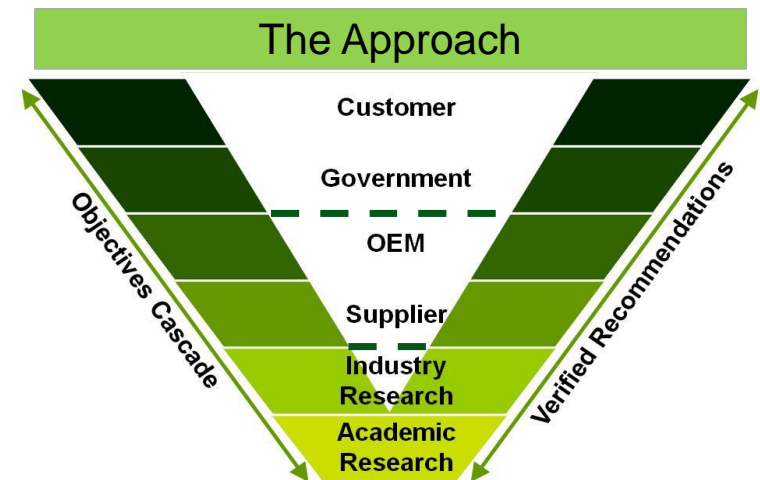
3 of 8 International Award winning engines in 2013 made in UK
Award winning engines also a key feature of Off-Highway sector

Broad multi-sector team created to develop Internal Combustion Engine Technology Strategy with an objective to grow UK value & capability



- Objective . To create a UK Internal Combustion Engine strategy that defines a consensus industry view on what needs to be done to grow the UK capability in technology, infrastructure and market development

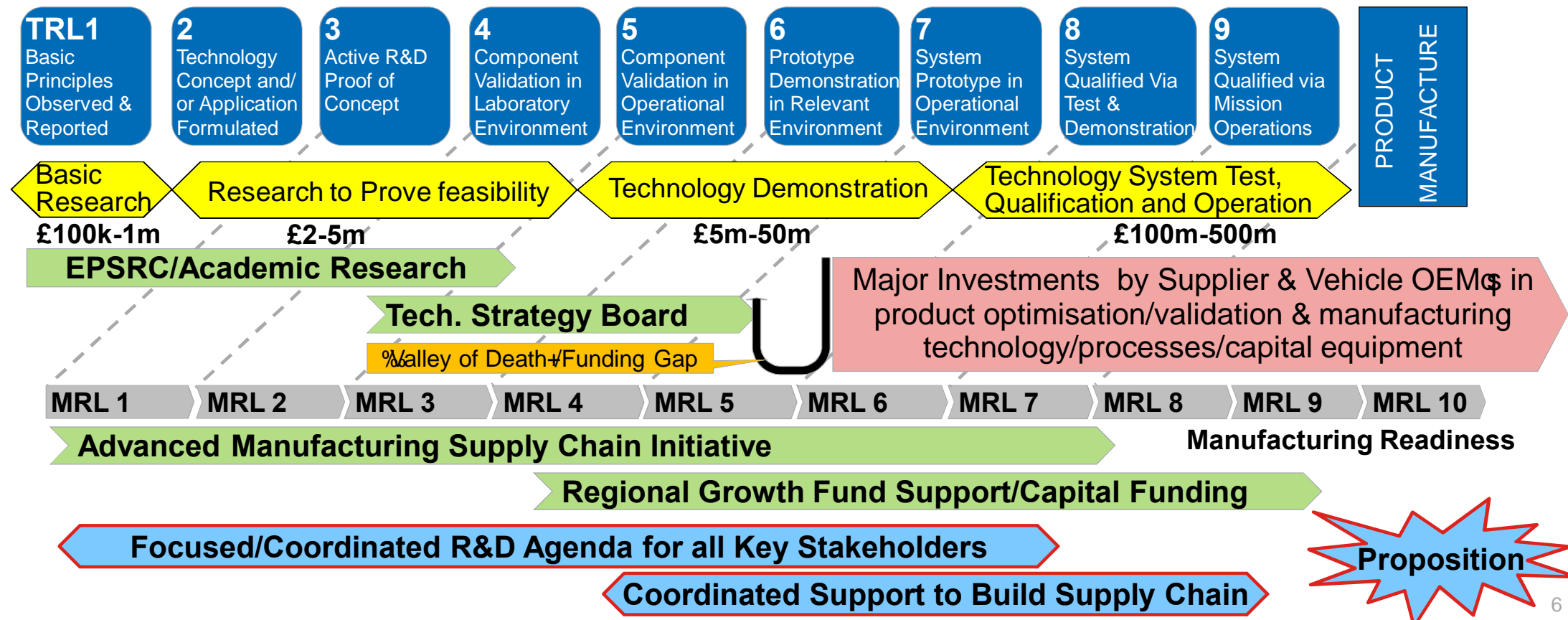
The Team & Group Leaders*			
Neville Jackson	Ricardo (Chair)	David Skipp*	Ford (Co-ordinator)
Richard Banks*	BMW	Steve Richardson*	Jaguar LandRover
John Turton	Nissan	Steve Faulkner	Caterpillar
Jamie Turner	Lotus	Brian Gush	Bentley
Martyn Hawley	SAIC	Colin Garner	Loughborough Univ.
Colin Loud	JCB	Pierre French	Cummins Turbo Tech
Dave Yuill	BIS	Richard Hall	Schaeffler
Marco Warth	Mahle	John Laughlin	Tech. Strategy Board
John Kell	UKTI	Ian Bacon	SMMT



- Focus on Passenger Car, Commercial Vehicle and Off Road Equipment
- Canvas & Consolidate data & points of view from key stakeholders
- Input from survey of Academic Research Capability/Activities and TSB Automotive Capability Study
- Develop ICE and related Technology Roadmap to highlight key future focus areas
- Outline likely Mobility transition pathways comparing ICE with other technologies
- Propose ICE opportunities/enablers for wealth generation & CO₂ reduction via investment & training

UK Innovation Chain has key strengths but we need to coordinate & focus R&D agendas & build capable supply chains in added value systems

- UK has significant design & manufacturing capability, largely dominated by assembly
 - Many of the high added value, fuelling, control and electrical systems imported from overseas
- UK strong academic & vehicle OEM R&D capability, less homogenously strong R&D capability in supply chain
- Support Structures for TRL 1-5 but many technologies fail to reach TRL 6-9:



Future key technologies identified to improve ICE efficiency supported by enabling technologies – Focus areas defined via impact & UK benefit

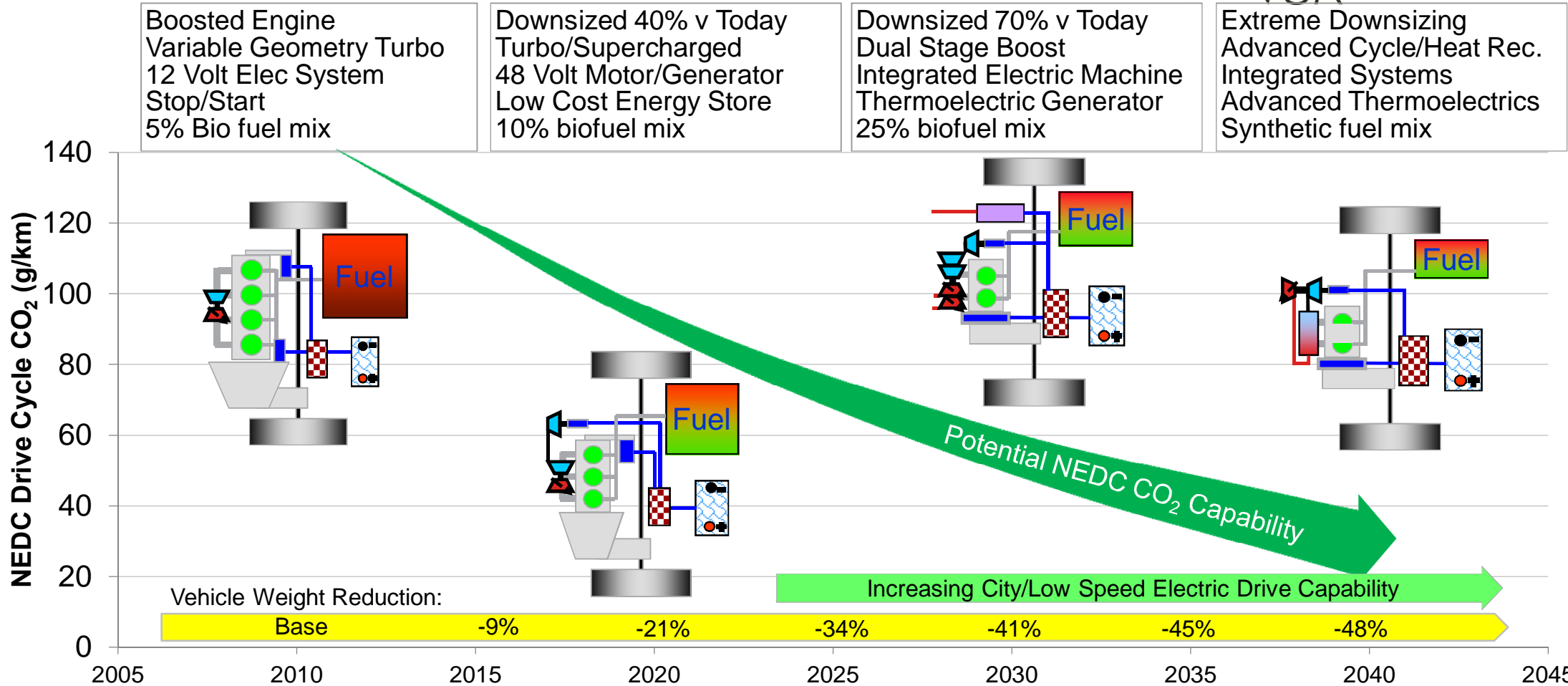


- Future technologies categorised into improved thermal efficiency, improved system efficiency, enabling technologies and carbon reduction for fuels/production

Thermal Efficiency	System Efficiency	Enabling Technologies	Carbon Reduction
Reduced Comb. Heat Losses	Downsizing & Boosting	Charge Thermal Management	1 st Gen Biofuels (Crop Based)
Fuel Injection Optimisation (CI)	Lower Mech. Friction	Flexible/Fast Response Boost	2 nd Gen Biofuels (Waste Re-use)
High Efficiency Combustion	Thermoelectric Generators	Thermal Energy Storage	3 rd Gen Biofuels (Biotech)
Improved boost Eff/operating range	Electrification or Energy Recovery	Flexible Valve Trains	CNG/Biogas
Mechanical/Elec Turbocompound	Variable Power Ancillaries	Pm & NOx Emissions Control	Liquified Natural Gas
Organic Rankine Cycles	Low Inertia Fast Warmup	Advanced Control Approaches	Re-cycling & Re-manufacturing
Adv. Regen or Split Cycle	Downspeeding	Advanced/New Materials	

- Potential UK R&D focus areas identified via UK TSB capability study, Impact & likely UK benefits
- Further detailed analysis required to define priorities

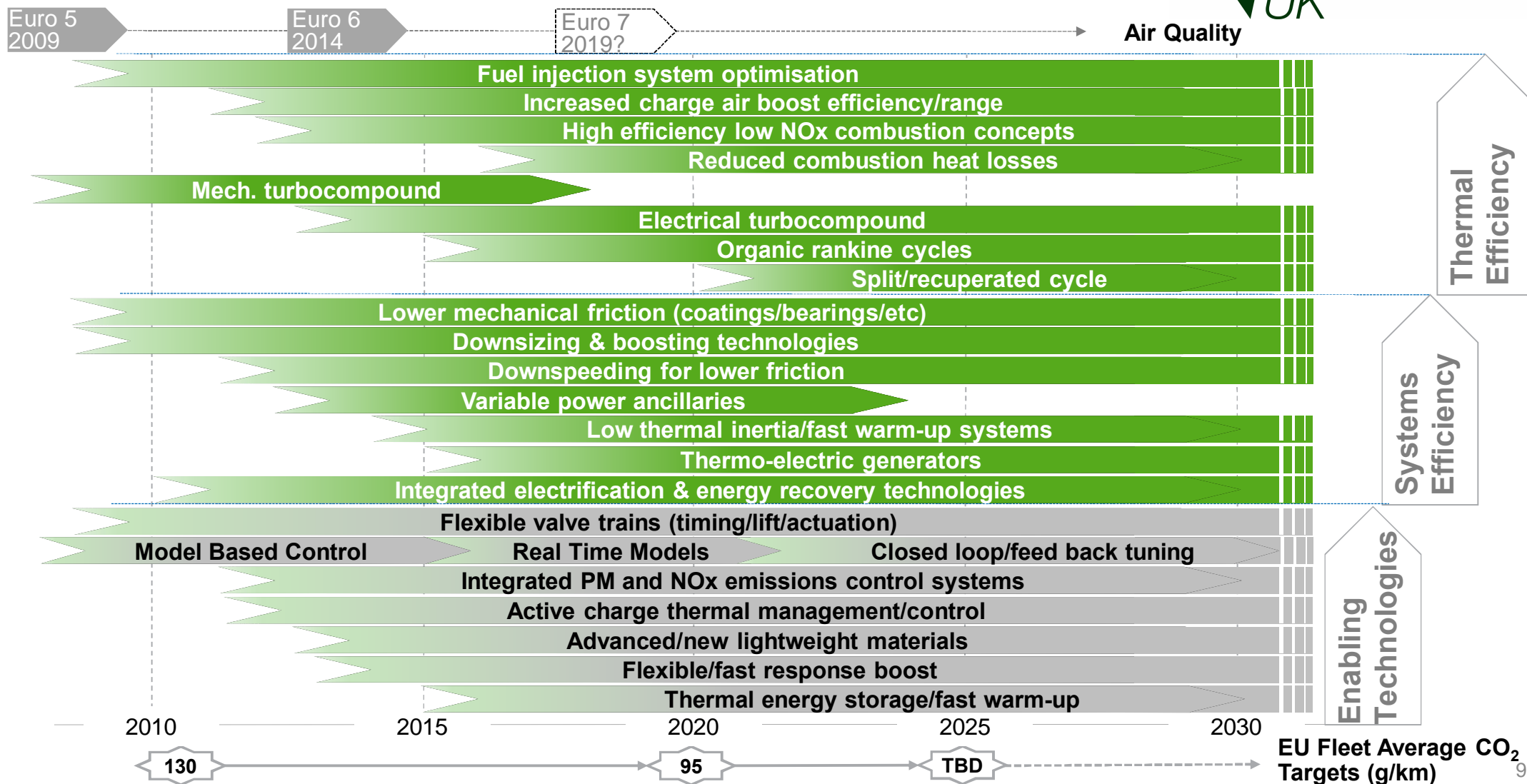
Many pathways to improve pass car powertrains – Example: downsizing/electrification/heat recovery combination could achieve 30 g/km CO₂



ICE/System efficiency improvements & low carbon fuels could deliver ~ 30 g/km CO₂ by 2040

ICE based systems competitive with EVs on life cycle carbon basis

ICE roadmap defines role & phasing for future technologies to meet future regulatory and commercial needs – similarities between On & Off Highway



The ICE will be a core feature of low CO₂ propulsion systems for decades Collaborative investment in supply chains could deliver £2b/year to UK



Key Messages:

- ICE research, development & manufacture is a **UK strength**, providing significant benefit to the UK economy
- Detailed analysis shows that the Internal Combustion Engine, operating on low carbon fuels, with varying degrees of electrification, is the most logical route to future on & off highway regulatory & commercial needs
- Increased global demand for low carbon propulsion systems offers an opportunity for the UK to grow a supply chain for added value systems through investment in skills, capabilities & advanced manufacturing technology

Recommendations:

- Improved coordination of **R&D agendas** via an Auto Council advisory group to connect our academic & industrial base in propulsion systems & research to manufacture, supporting high value low CO₂ propulsion technologies
- Stable, long-term policy required by Government to encourage collaboration and focused investment across fuel supply and ICE/vehicle industries, and to bring these **new low carbon sustainable fuels** to market
- Support development of **advanced manufacturing supply chains** to deliver **added value low carbon systems** for the next generation of on & off highway powerplants rather than purchasing these from outside the UK

Core Proposition:

- An investment of £1bn over 10 years in a co-ordinated collaborative program is recommended to grow a **demand led** supply chain for low carbon added value automotive propulsion systems establishing global leadership for UK 'research to manufacture' capability & skills. This could deliver £2b/year to the UK