

His Worship the Mayor
Councillors
CITY OF MARION

NOTICE OF INFRASTRUCTURE AND STRATEGY COMMITTEE MEETING

Council Chamber, Council Administration Centre
245 Sturt Road, Sturt

Tuesday, 05 November 2019 at 06:30 PM

The CEO hereby gives Notice pursuant to the provisions under Section 83 of the Local Government Act 1999 that a Infrastructure and Strategy Committee meeting will be held.

A copy of the Agenda for this meeting is attached in accordance with Section 83 of the Act.

Meetings of the Council are open to the public and interested members of this community are welcome to attend. Access to the Council Chamber is via the main entrance to the Administration Centre on Sturt Road, Sturt.



Adrian Skull
Chief Executive Officer



TABLE OF CONTENTS

OPEN MEETING	3
KAURNA ACKNOWLEDGEMENT	3
ELECTED MEMBER'S DECLARATION (if any)	3
CONFIRMATION OF MINUTES	3
Confirmation of the minutes for the Infrastructure and Strategy Committee	3
Meeting held on 1 October 2019	
BUSINESS ARISING	11
Business Arising Statement - Action Items	11
CONFIDENTIAL ITEMS - Nil	15
REPORTS FOR DISCUSSION	15
Climate Risk and Governance	15
Strategic Review of Customer Experience Plan	24
Community Courts	32
REPORTS FOR NOTING	55
Acquisition of Land and CEO Delegation to Purchase Land of a Strategic Nature	55
City Property Strategic Asset Management Plan	59
WORKSHOP / PRESENTATION ITEMS	64
Autonomous vehicle trial experience	64
OTHER BUSINESS	201
MEETING CLOSURE	201

OPEN MEETING**KAURNA ACKNOWLEDGEMENT**

We acknowledge the Kaurna people, the traditional custodians of this land and pay our respects to their elders past and present.

ELECTED MEMBER'S DECLARATION (if any)**CONFIRMATION OF MINUTES****Confirmation of the minutes for the Infrastructure and Strategy Committee Meeting held on 1 October 2019**

Originating Officer Governance Officer - Angela Porter

Corporate Manager Manager Corporate Governance - Kate McKenzie

Report Reference: ISC191105R01

RECOMMENDATION:

That the minutes of the Infrastructure and Strategy Committee Meeting held on 1 October 2019 be taken as read and confirmed.

ATTACHMENTS:

#	Attachment	Type
1	ISC191001 - Final Minutes	PDF File



**MINUTES OF THE ISC191001 - INFRASTRUCTURE AND STRATEGY COMMITTEE
MEETING - 1 October 2019**

Tuesday, 01 October 2019 at 06:30 PM

Council Administration Centre, 245 Sturt Road, Sturt



PRESENT :

Mayor - Kris Hanna, Councillor - Matthew Shilling, Councillor - Tim Gard, Councillor - Bruce Hull

In Attendance:

Chief Executive Officer - Adrian Skull
General Manager Corporate Services - Sorana Dinmore
General Manager City Services - Tony Lines
General Manager City Development - Ilia Houridis
Manager Engineering & Field Services - Mathew Allen
Acting Manager Innovation & Strategy - Cass Gannon
Acting Manager City Property - Clare Benn
Unit Manager Sport & Recreation Facilities - James O'Hanlon
Acting Unit Manager Open Space and Recreation Planning – Renee Pitcher
Strategy Leader - Elaine Delgado
Smart Cities Project Officer - Georgie Johnston

Councillor Jason Veliskou
Councillor Raelene Telfer
Councillor Maggie Duncan

OPEN MEETING

In the absence of the Chair, the Chief Executive Officer opened the meeting at 6.36 pm on Tuesday, 1 October 2019.

Nominations for Chair

In the absence of the Chair the Chief Executive Officer called for nominations for a chair to preside over the meeting. The following nominations were received:

- Councillor Shilling

Moved Councillor Hull

Seconded Councillor Gard

That Councillor Shilling be nominated to preside over the meeting.

Carried

KAURNA ACKNOWLEDGEMENT

We acknowledge the Kaurna people, the traditional custodians of this land and pay our respects to their elders past and present.

ELECTED MEMBER'S DECLARATION (if any)

CONFIRMATION OF MINUTES

Confirmation of the minutes for the Infrastructure and Strategy Committee Meeting held on 4 June 2019 and 2 July 2019

Report Reference: ISC191001R01

Moved Councillor - Tim Gard Seconded Mayor - Kris Hanna

That the minutes of the Infrastructure and Strategy Committee Meeting held on 4 June 2019 and 2 July 2019 be taken as read and confirmed.

Carried Unanimously

BUSINESS ARISING

Review of the Business Arising from previous meetings of the Infrastructure and Strategy Committee Meetings

Business Arising Statement - Action Items

Subject

Report Reference ISC191001R02

Moved Mayor - Kris Hanna Seconded Councillor - Tim Gard

That the Infrastructure and Strategy Committee:

1. Notes the business arising statement, meeting schedule and upcoming items.

Carried Unanimously

WORKSHOP / PRESENTATION ITEMS

South Australian Productivity Commission

Report Reference GC191001R03

The Chief Executive Officer presented a summary of the collaboration achievements of the City of Marion, City of Charles Sturt and City of Port Adelaide Enfield that have been highlighted in the draft report on the South Australian Productivity Commission (SAPC) Inquiry into Local Government Costs and Efficiency.

6:40 pm Mayor Hanna left the meeting. Quorum was lost however the committee agreed to continue with the presentation and discussion.

Following the presentation, the discussion points are noted below:

- would like to see more done to dissect the business ie ways of cutting costs
- real enthusiasm between the councils for collaboration
- opportunities in the future
 - integrated IT systems
 - planning and development reform
 - utilities optimisation - potential for substantial savings
 - civil construction incl asset management - review starting this month
 - fleet management - better utilisation of fleet

7:15 pm Mayor Hanna returned to the meeting. Quorum resumed.

- neighbouring council's may be open to collaboration in future as savings realised by the Cities of Marion, Charles Sturt & Port Adelaide Enfield.

CONFIDENTIAL ITEMS - Nil

REPORTS FOR DISCUSSION

City Transport and Moveability Plan

Report Reference ISC191001R04

The Manager Engineering & Field Services and Strategy Leader gave a presentation on the City Transport and Moveability Plan that is being developed to meet the requirements of Council's Business Plan 2019-2023.

The following discussion points were noted:

- development of the plan is in the initial stages
- it is important the plan considers transport needs within the broader regional context and potential increase in use of electric and autonomous vehicles
- Beames Scooters have contacted Council to query the potential to supply scooters for public use which requires Ministerial approval. Potential impacts on safety and visual amenity were raised.
- basis of plan should be what people need to move around the City of Marion
- Community feedback on issues relating to travel could be sought to inform the plan
- back to basics / awareness of ageing population - focus on trip hazards on footpaths, overhanging trees, potholes, access for prams / gophers / walkers

Action: Topic to be added to the Elected Member Forum in February 2020.

Moved Councillor - Tim Gard Seconded Councillor - Bruce Hull

That the Infrastructure and Strategy Committee:

1. Note the report.
2. Provide input into the project's opportunities, challenges and scope.
3. Provide feedback on the development of a Transport and Moveability policy and plan.

Carried

Seaview High School Sports Facilities Partnership

Report Reference ISC191001R05

Prior to the commencement of this item, there was a brief discussion between Councillor Hull and Councillor Shilling regarding perceived conflict of interest. It was decided Councillor Hull would stay in the meeting to keep quorum but would not have any discussion on the matter and could vote as it is not a decision making committee.

The Acting Manager City Property and the Unit Manager Sport & Recreation Facilities discussed the possible options for a multi-purpose facility at Seaview High School.

The following discussion points were noted:

- oval heavily used and not possible to expand capacity further
- concerns around building a community asset that would have limited community use (unavailable during school hours), with a potential lack of control over the facility management
- Council would have full control over community assets on Tarnham Road site
- Management model not formalized
- Council to be presented with a range of options and indicative costings. May need to rescind previous Council decision.

Moved Mayor - Kris Hanna Seconded Councillor - Tim Gard

That the Infrastructure and Strategy Committee:

1. Notes the report.
2. Provides feedback on the range of options to progress this initiative.
3. Notes a report will be presented to Council on a preferred range of option(s) to progress.

Carried

REPORTS FOR NOTING

Oaklands Smart Precinct Project - Update

Report Reference ISC191001R06

The Acting Manager Innovation & Strategy and Smart Cities Project Officer provided an update on the Oaklands Smart Precinct Project. The following discussion points were noted:

- A letter has been sent to Minister Knoll regarding the opportunity add smart infrastructure to the DPTI carparking at Oaklands Station.
- Potential to include smart drinking water fountains in the project design following discussions with SA Water.
- Detailed design for the precinct is underway which will assist members with understanding the project.

Moved Mayor - Kris Hanna Seconded Councillor - Tim Gard
That the Infrastructure and Strategy Committee:

1. Notes the Oaklands Smart Precinct Project progress report (Appendix 1).

Carried Unanimously

Capital Construction Program - Update

Report Reference ISC191001R07

The General Manager City Services provided an overview of the quarterly capital construction progress. The following discussion points were noted:

- working on 4 designs including revised streetscape program
- carryover streetscaping / LED street lights expected to be completed by the end of the year
- resourcing impacted the completion of some works.

Moved Councillor - Tim Gard Seconded Councillor - Bruce Hull
That the Infrastructure and Strategy Committee:

1. Notes the report.

Carried Unanimously

Review of Use of Economic Statement

Report Reference ISC191001R09

Moved Mayor - Kris Hanna Seconded Councillor - Tim Gard

That the Infrastructure and Strategy Committee:

1. Notes this report
2. Notes that no future Economic Statements will be produced

Carried Unanimously

Report Reference ISC191001R08

Corporate Information and Communication Technology Update

The General Manager Corporate Services provided an update on the progress of the corporate information and communication technology projects. The following discussion points were noted:

- encouraged by all the work that has been done to date
- focus is on what we can do better particularly with our customers (internal & external) and achieving planned outcomes.

Moved Mayor - Kris Hanna Seconded Councillor - Tim Gard

That the Infrastructure and Strategy Committee:

1. Notes the update on the Corporate ICT Function, next steps and priority projects for the 19/20 financial year

Carried Unanimously

OTHER BUSINESS - NIL

MEETING CLOSURE

The meeting shall conclude on or before 9.30pm unless there is a specific motion adopted at the meeting to continue beyond that time.

MEETING CLOSURE - Meeting Declared Closed at 09:24 PM

CONFIRMED THIS 5TH DAY OF NOVEMBER 2019

.....
CHAIRPERSON

BUSINESS ARISING

Review of the Business Arising from previous meetings of the Infrastructure and Strategy Committee Meetings

Business Arising Statement - Action Items

Originating Officer	Executive Assistant to General Manager Corporate Services - Louise Herdegen
Corporate Manager	Manager Innovation and Strategy - Fiona Harvey
General Manager	General Manager City Development - Ilia Houridis
Report Reference	ISC191105R02

REPORT OBJECTIVE

The purpose of this report is to review the business arising from previous meetings of the Infrastructure and Strategy Committee meetings, the meeting schedule and upcoming items.

RECOMMENDATION

That the Infrastructure and Strategy Committee:

- 1. Notes the business arising statement, meeting schedule and upcoming items.**

Attachment

#	Attachment	Type
1	Business Arising & Forward Agenda - NOV19	PDF File

CITY OF MARION
BUSINESS ARISING FROM THE INFRASTRUCTURE AND STRATEGY COMMITTEE MEETINGS

APPENDIX 1
AS AT 5 NOVEMBER 2019



	Date of Meeting	Item		Responsible	Due Date	Status	Completed / Revised Due Date
1.	5 March 2019	ISC190305R04	Marino Hall – Update on Development Options <ul style="list-style-type: none"> Redevelopment opportunity comes into the City Property Strategic Asset Management Plan. 	Karen Cocks / Greg Salmon	30 June 2019	Marino Hall Community Engagement Plan being developed to understand community wishes for the site as a first step. Community engagement planned for October-December. Report to be presented to the Committee in February	Completed
2.	1 October 2019	ISC191001R04	City Transport and Moveability Plan			Added to the schedule of items for the Elected Member Forum on 4/2/2020	Completed
3.	1 October 2019		Was underground conduit for Electric Vehicle charging installed at Marion Outdoor Pool in conjunction with recent carpark works? (Councillor Hull)	Clare Benn	5 November 2019	EV charging station was not included at the Marion Outdoor Pool Stage 2 project. However, it is possible to install this in the future when required.	Completed

* Completed items to be removed are shaded

Meeting Schedule 2019



5 February	6.30 – 9.30
5 March	6.30 – 9.30
2 April	6.30 – 9.30
7 May	6.30 – 9.30
4 June	6.30 – 9.30
2 July	6.30 – 9.30
6 August	6.30 – 9.30
3 September	6.30 – 9.30
1 October	6.30 – 9.30
5 November	6.30 – 9.30
3 December	6:30 – 9:30

Committee Membership

- Membership – 5 Elected Members + 1 Expert Member
- Quorum - 4 Committee Members

Presiding Member – Luke Hutchinson

Expert Member – Christian Reynolds

Members

- Ian Crossland
- Tim Gard
- Bruce Hull
- Matthew Shilling

Infrastructure & Strategy Committee

Meeting Schedule 2019

Infrastructure & Strategy Committee		Date: Tuesday, 3 December Time: 6.30pm – 9.30pm				Venue: Chamber
Topic	Description	Presentation / Workshop	Duration	External Attendees	Staff Responsible	
Strategic Discussion – The value of Data					Fiona Harvey	
Guest Speaker (Options- TBC)	Peter Worthington Eyre – Chief Data Officer SA Government Aron Hausler – NVI Nick Faulkner – Adelaide University					
Oaklands Smart Precinct	Detailed designs and project update prior to tendering				G Johnson / G Salmon	

CONFIDENTIAL ITEMS - Nil

REPORTS FOR DISCUSSION

Climate Risk and Governance

Originating Officer	Environmental Sustainability Manager - Ann Gibbons
Corporate Manager	Manager Innovation and Strategy - Fiona Harvey
General Manager	General Manager City Development - Ilia Houridis
Report Reference	ISC191105R03

REPORT OBJECTIVE

The purpose of this report is to provide an update on a Climate Risk Governance review recently completed by the City of Marion, propose a number of short-term priority actions, and to discuss next steps.

EXECUTIVE SUMMARY

The City of Marion was one of four South Australian Councils to complete a pilot climate change adaptation governance assessment along with the City of Onkaparinga, Adelaide Hills Council and the District Council of Mt Barker.

The assessment was completed by consultants Climate Planning and Seed Consulting during April and May 2019 and included an online staff survey, a review of publicly available corporate documents, and face-to-face meetings with management and key operational staff.

The results of the assessment were presented in a joint staff workshop with the City of Onkaparinga in August 2019. The assessment found that climate change has been considered in all of the ten key governance indicators placing the City of Marion as the leader in Australia, compared to the 200 councils that have been assessed to date.

A number of short-term priority actions have been identified to further embed climate change considerations in Council's governance arrangements. Longer-term actions will be identified over the coming months in consultation with relevant teams within Council and with our regional local government partners.

An Elected Member briefing and workshop is being planned for early in 2020. It is proposed that this event be held jointly with other southern Adelaide councils that have also completed the assessment to enable shared learning and collaboration.

RECOMMENDATION

That the Infrastructure and Strategy Committee:

- 1. Notes this update on the Climate Risk and Governance Project;**
- 2. Supports the following priority City of Marion actions to be included in the regional response planning:**
 - Inclusion of climate change risk in Asset Management Plans as they are reviewed and updated;**

- **Review of the Climate Change Policy to include consideration of an emissions reduction target for Council;**
 - **Greater recognition of climate change in Council's emergency management planning documents, systems and processes;**
 - **Advocacy to the South Australian Government for greater recognition of climate change in planning policy.**
3. **Note that further Elected Member engagement and input on this matter will be sought at a joint briefing to be held in 2020 with other councils that have also completed the assessment.**

GENERAL ANALYSIS

Valuing Nature:	It is a key priority in the City of Marion Strategic Plan 2019 - 2029 to "plan for and respond to extreme weather events through our services and urban form, managing infrastructure issues associated with flooding and stormwater".
Risk Management:	Councils are now facing unprecedented legal liabilities and financial risks if they fail to address obligations arising from climate change.
Legal / Legislative / Policy:	City of Marion Climate Change Policy

DISCUSSION

Councils that fail to mitigate, manage and disclose climate risks in their governance and decision making will expose themselves to legal liabilities, including potentially breaching fiduciary duties. With climate risks now occupying the minds of mainstream investors, those not addressing climate risks will increasingly struggle to access affordable finance and insurance.

To better understand and prepare for these risks, consultants Climate Planning and Seed Consulting were engaged by the City of Marion, the City of Onkaparinga, Adelaide Hills Council and the District Council of Mt Barker to undertake a climate risk and governance assessment of their respective council operations using Climate Planning's "Informed.CityTM" climate risk governance assessment process. The assessment is not intended to measure 'on-ground' climate action but rather to identify documented climate risk governance arrangements in order to establish if there are gaps that may expose councils to legal or financial liability. It has been completed by 200 councils in eastern seaboard states, however these are the first South Australian councils to complete the assessment.

This project forms part of Council's response to climate change being delivered via the regional Resilient South program with partners the Cities of Onkaparinga, Holdfast Bay and Mitcham. Adelaide Hills and Mt Barker are part of the Resilient Hills and Coasts regional approach to climate change. A summary of this pilot is provided in Attachment 1. The remaining six councils in the two regions are looking to complete the assessment during 2019/20.

1. Summary of Climate Risk Governance Assessment

The **first stage** of the assessment involved a review of a range of publicly available corporate and strategic documents to explore how climate change is being considered against the ten quantitative governance indicators.

The document review found that the City of Marion has considerable inclusion of climate change in its formal governance documents. A highlight of the review was recognition of the City of Marion's leading approach to corporate risk governance and, in particular, the public disclosure of the corporate risk register via the Finance and Audit Committee.

The **second stage** of the assessment involved an online survey to gain insights of staff members' understanding of climate change impacts, their department's capacity to adapt, and their perceived barriers and enablers to improved consideration of climate change in Council decision-making. 120 staff members from across all council departments responded to the survey conducted during April 2019.

Key findings from the Marion staff survey include:

- 85% of respondents have some level of understanding of climate impacts and adaptation
- 59% believe that climate change is impacting on Council's operations and procedures now
- 58% identified limited assigned funding as a barrier hindering Council's ability to plan for climate change
- 61% believe that statutory planning support is very helpful in adapting to climate change impacts
- 31% of respondents believe that the City of Marion is prepared for responding to climate change impacts while 35% believe Council is NOT prepared at all.
- 43% recognised that effective risk management practices would better enable the City of Marion to plan for climate change

The **third stage** of the assessment involved face-to-face interviews to better understand the issues, barriers and enablers for embedding consideration of climate change in decision-making for the City of Marion. On Tuesday 30 April 2019, 39 staff from across the organisation, including all of the Senior Leadership Team, were interviewed in small groups based on relevant themes (e.g. finance and procurement, strategy and land use planning, etc.).

The interviews found that staff could readily identify key physical climate risks to the various organisational functions along with clear corporate strategic drivers for decision making. A consistent understanding of climate change risks from officer to senior executive level was also identified.

As the assessment found that climate change is being considered in all of the ten key governance indicators (refer to Attachment 2), the City of Marion is placed as a leader in Australia compared with the 200 councils that have been assessed. That said, there remain significant gaps associated with asset, financial and emergency management that require further attention.

In August 2019 around 80 staff from the Cities of Marion and Onkaparinga came together for a debrief on the climate risk and governance assessment, share success stories, and identify action opportunities. Since then a number of work areas have proactively sought to incorporate consideration of climate risk into their documents, systems and processes in response to the assessment findings eg climate risk analysis included in the recently adopted Asset Management Strategy, and the asset management plans which are currently in review.

The 'Climate Change Adaptation Governance Assessment Report for the City of Marion' is provided in Attachment 2.

7. Next Steps

The assessment recommendations are being reviewed and a planned approach to implementation is being prepared. For the City of Marion to have an improved climate change adaptation governance score and a better understanding of the issues, a detailed climate change risk assessment of Council's operations and assets will be required. Understanding the changing climate risk exposure and its effect on useful lifespan and depreciation models, is a priority. The report also recommends that a greenhouse gas emissions reduction target is set by Council, and suggests 'carbon neutral by 2050' as a minimum, which was recently discussed at the 29 October Elected Member Forum as part of discussions concerning climate initiatives.

The following actions are identified as short-term priorities for the City of Marion, some of which are already progressing:

- Inclusion of climate change risk in Asset Management Plans as they are reviewed and updated;

- Review the City of Marion Climate Change Policy to include consideration of an emissions reduction target for Council (next review due in 2020);
- Include greater recognition of climate change in Council's emergency management planning;
- Advocate to the South Australian Government for greater recognition of climate change in planning policy.

Medium and longer-term actions will be identified over the coming months in consultation with key work areas and with our regional local government partners.

To strengthen our regional climate response in southern Adelaide, a joint briefing and workshop for Elected Members from the City of Marion and other southern Adelaide councils that have completed the assessment is planned for sometime in 2020. This session will provide more in-depth information on the financial, legal and insurance risks of climate change for local government and an opportunity for peer learning and collaboration.

Attachment

#	Attachment	Type
1	Climate Risk Governance Assessment - Summary report	PDF File
2	Climate Change Adaptation Governance Assessment Report for Marion - July 2019	PDF File

Climate Risk Governance Assessment

South Australian Pilot of the Informed.City Tool

September 2019

Background

There is growing recognition of the need for councils to manage their exposure to climate related legal and financial risks. In response, four partner councils from Resilient South and Resilient Hills & Coasts – Adelaide Hills, Mt Barker, Marion and Onkaparinga – participated in the first South Australian pilot of Climate Planning's Informed.City™ climate risk governance assessment process.

On Monday 19 August 2019, the pilot Councils came together across two workshops to hear results and jointly identify next steps.

This document provides a short summary of results and next steps. More detailed results can be accessed in the reports provided to each participating council.

Methodology

The assessment is not intended to measure 'on-ground' climate action but rather to identify documented climate risk governance arrangements in order to establish if there are gaps that may expose councils to legal or financial liability. Assessments drew upon information gathered via:

- Desktop review of publicly available council documents
- Online survey with council staff
- In-depth group interviews with council staff

Councils were assessed against ten quantitative and seven qualitative key performance indicators, and specific recommendations were provided to each Council about how to lift performance against each indicator. Should a Council elect to advance even further, the appendices of the council reports provide further advice.

Councils can choose to repeat the assessment bi-annually to monitor progress and build accountability and transparency over time.

Results Snapshot

All four Councils were ranked among the top performing in Australia. Marion Council was ranked number one, Onkaparinga in the top five, and Adelaide Hills and Mount Barker were in the tenth percentile for small Councils.

Consultant, Donovan Burton, noted that the consistently high performance of the cohort was in large part due to the Regional Climate Partnerships. These partnerships enabled sharing of information, tools and resources, peer to peer learning, consistency and joint development of best practice approaches.

The assessments indicated that while there are sound foundations for effective climate risk governance, notable gaps leave partner councils exposed to legal and financial liabilities. Councils can address these gaps to a reasonable level by systematically and incrementally following the recommendations laid out in their report.

Next Steps

Some key opportunities were raised – both in the assessment reports and in the workshops – for participating Councils to improve their climate risk governance immediately. Highlights are listed below, but each Council can undertake a more detailed review of their assessment report.

Meanwhile, there has been substantial interest from other Councils to undertake the assessment. As more South Australian councils undertake the assessment, more opportunities to share successful approaches will be highlighted, supporting a community of practice approach.

Individual Council opportunities

- Councils must undertake a comprehensive review of their **Strategic Plan, Infrastructure and Asset Management Plan** and **Long-term Financial Plan** within two years of each general election. This provides an ideal opportunity to embed climate risk governance into these strategic documents. The Assessment Reports provide specific advice on how to lift performance in each of these (Indicators 1, 2 & 4), as well as specific advice on how to advance further.
- **Asset Management** came up strongly in the workshop ideas and as a performance gap in the assessment for all councils. Understanding the changing climate risk exposure and its effect on useful lifespan and depreciation models, is a priority.
- Establish a **Climate Risk Committee or Working Group** (similar to WHS committee) – or task an existing committee or working group – to review the report recommendations and workshop ideas, and systematically take all reasonable actions across the responsible areas within council.
- Add 'Climate Risk' as a heading to **Council Report** template (or add to guidance under 'Risk').
- Engage in the LGA's **Council Ready** program to embed climate risk governance in emergency management (Indicator 6), including adopting the **Council Emergency Management Model Policy**.
- Consider **publicly disclosing high-level climate risks**, in a Corporate Risk Report
- **Brief Elected Members** on climate risks for Councils.

Regional and sector-wide opportunities

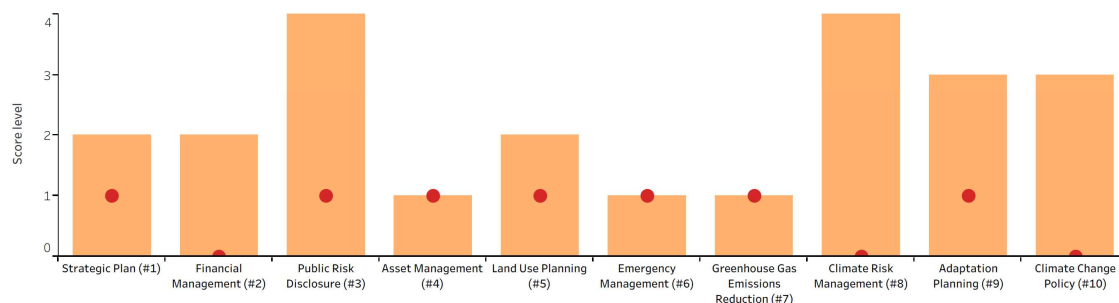
- **Sharing information, knowledge, tools and case studies** came up strongly in the staff survey as a preferred support mechanism.
 - DEW has funded a one-year trial of a **Central Coordination function** across the Regional Climate Partnerships, with one of its main aims being to improve knowledge sharing.
- Continue to engage in and resource the **Regional Climate Partnerships**, a proven effective model for sharing knowledge, tools and approaches, building staff capability, and maintaining momentum of change within Council business.
 - Advocacy to State Government to commit to extending these partnerships with Local Government has commenced.
- A future **knowledge sharing and showcasing event**, for all Councils seeking to improve their climate risk governance.
 - This has been mooted by Resilient South and Resilient Hills & Coasts.
- Ask LGA to draft a **Council Climate Risk Model Policy**.
 - See Kingsborough Council for a model.
- Ask LGA to provide an **Open Data Policy** or legal advice on public disclosure of Corporate Risk Registers and Hazard Mapping
 - Aspects of this have been initiated with the LGA.
- Advocate to State Government for **climate risks to be considered in planning system**, and for hazard maps in overlays to be current and comprehensive.
 - Some Regions and Councils have advocated on the Planning Reforms, and Central Coordinator advocacy on hazard mapping has commenced.
- Consider establishing a Southern **Climate Innovation Hub**.

Summary of Council Performance Against Quantitative Indicators

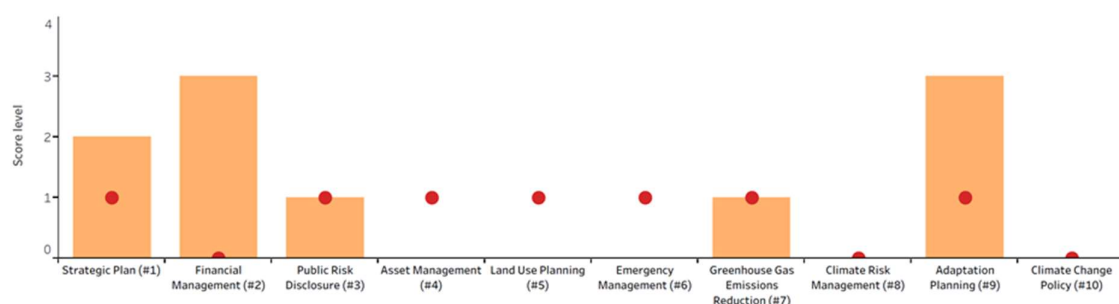
Orange bars are Council score, red dots are the average for all Informed.City Councils (200+)

0 = None, 1 = Basic, 2 = Intermediate, 3 = High, 4 = Advanced

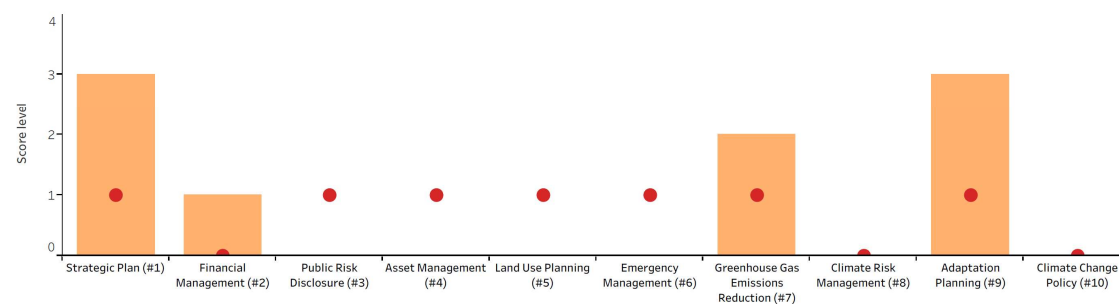
City of Marion



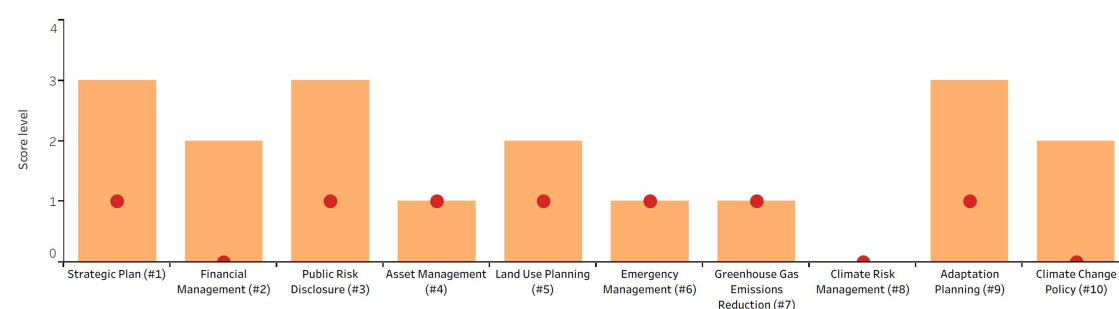
South Australian Council 1



South Australian Council 2



South Australian Council 3



Summary of Survey Findings

As part of the assessment, 301 staff across Adelaide Hills, Marion, Mount Barker and Onkaparinga Councils participated in an online survey. The survey sought to understand each Council's understanding of climate change impacts, and their capacity to adapt. Key findings, averaged across the four surveyed Councils, are listed below. Council-specific results are available in the reports.

Interesting points

- 5% say their department uses climate change risk assessments to **inform decision-making**.
- 37% believe climate change is an **important** issue that needs attention **now**.
- Over 50% believe climate change is impacting Council's operations and procedures **now**.
- One third believe their Council is **fairly** prepared for responding to climate change impacts.
- One third get their information on climate impacts from someone in Council.
- 21% of staff have climate change adaptation training.

Top 3 enablers contributing to Councils' ability to plan for climate change

- Good understanding of climate change (69% of staff nominated this)
- Senior management support (67%)
- Understanding the costs/benefits of climate adaptation actions (61%)

Top 3 barriers hindering Councils' ability to plan for climate change

- Limited assigned funding (62%)
- Uncertainty of the role of local government (51%)
- Confusing/changing policy at different levels of government (46%)

Top 3 types of information that would help me incorporate climate change into my job

- Knowing what to actually do (68%)
- The anticipated impacts for my department (56%)
- Understanding what other Councils are doing (51%)

Top 3 preferences of support for adapting to climate change impacts

- Specific ongoing resource allocation for climate adaptation projects (75% of staff ranked this 'very helpful')
- Provision of consistent, high quality information, knowledge and tools (74%)
- Case studies in effective adaptation planning, strategies and implementation (69%)

Strategic Review of Customer Experience Plan

Originating Officer	Manager Customer Experience - Karen Cocks
Corporate Manager	Manager Customer Experience - Karen Cocks
General Manager	General Manager City Services - Tony Lines
Report Reference	ISC191105R04

REPORT OBJECTIVE

To share the City of Marion Customer Experience Plan with the Infrastructure and Strategy Committee for discussion and strategic review.

EXECUTIVE SUMMARY

Customer experience was introduced to the City of Marion in 2017, to provide a strategic focus on customers and the experience that is provided when requesting service. 'The Year of The Customer' was the beginning of the customer focus transformation, including the introduction of a Customer Experience Charter.

A Customer Experience Plan has since been developed, which consists of the following elements:

- Defines the process of Customer experience.
- Long term aspirational goals: Single View of the Customer, End to End Customer Experience and Culture Shift.
- Split into three pillars: Service Delivery, Voice of the Customer, Culture.

The first Customer Experience Plan focused on assessing the current state of Customer Experience and then completing projects to lay the foundation for future enhancements.

The current Customer Experience Plan focuses on embedding the principles of Customer Experience.

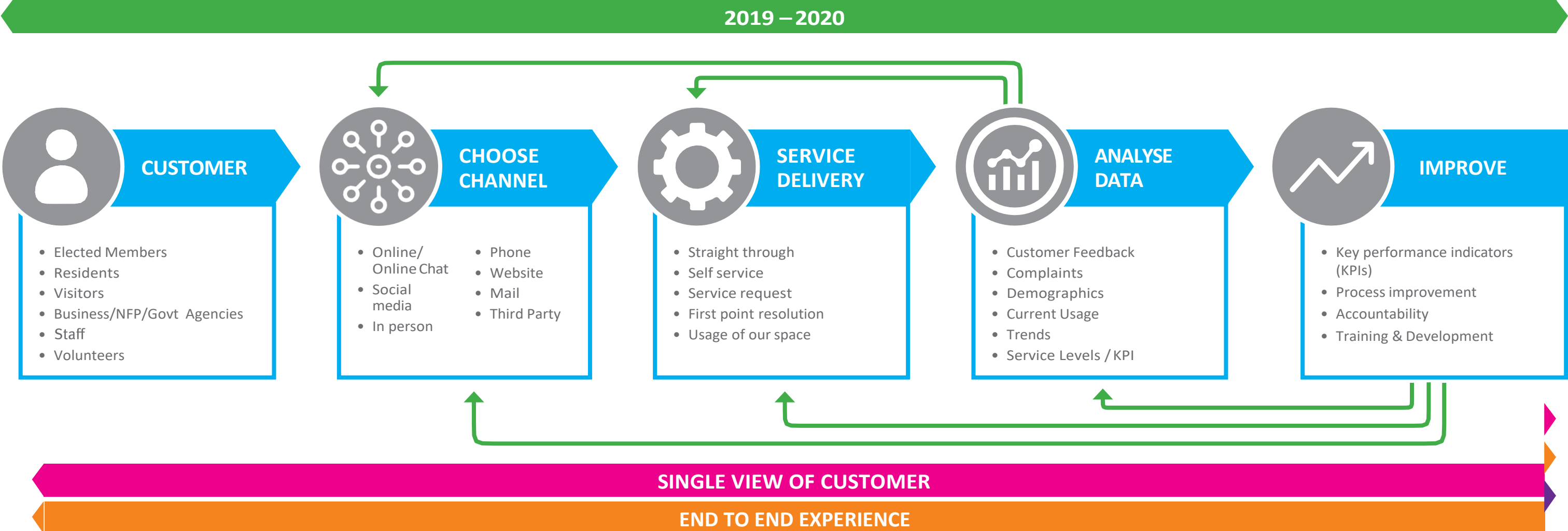
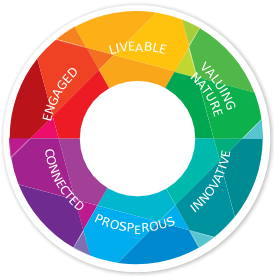
Engaged:	Provide Voice of the Customer analysis to guide decision making
Innovation:	Supporting digital solutions for Customer Experience
Organisational Excellence:	Developing organisational capabilities in Customer Experience consistently deliver exceptional outcomes to the community

Attachment

#	Attachment	Type
1	Customer Experience 19_20 Plan	PDF File
2	Customer Experience 3 year roadmap	PDF File
3	Customer Experience Plan achievements	PDF File

CUSTOMER EXPERIENCE

FUTURE OF MARION



2019 - 2020 PLAN	SERVICE DELIVERY Delivering the right service to the right customer through the channel of choice	VOICE OF THE CUSTOMER Listening to our Customers	CULTURE Inbuilt desire to achieve a positive response for all customers through all channels
	<ul style="list-style-type: none">• Improve written communication• Improve our technology to support future initiatives• Customer Experience reporting• Special Event Permit• Closing the Loop - Phase 2	<ul style="list-style-type: none">• Moments of truth - Customer Satisfaction• Complaint Handling Review• Customer Journey Mapping• First Call Resolution (FCR)• Social Media Strategy	<ul style="list-style-type: none">• Leadership Development• Training• Customer Insight Forums

Attachment 1

Customer Experience Team Vision: *We listen to our community to provide insights to help our people improve our residents' quality of life.*

City of Marion: Customer Experience 2019/20

The City of Marion is committed to improving our residents' quality of life – continuously, smartly and efficiently – today and into the future. This plan is the third Customer Experience Plan for the City of Marion, and builds on the foundation that has been built.

What is Customer Experience?

Customer Experience is the thoughts and feelings that customers have when interacting with our organisation. An interaction can be face-to-face, digital, by telephone, or through the delivery of a service e.g. playground or footpath.

Background

Customer Experience began in January 2017 with 'The Year of the Customer'. Milestones have included the introduction of a Customer Charter, creation of the Customer Experience Department and the appointment of a Customer Experience Manager. This has been supported by whole-of-organisation customer service training to improve the quality of service we deliver to our community.

2018/19 focused on building the foundation for Customer Experience initiatives which included transforming our Administration Centre to a Customer Service Hub, upgrading telephony systems to ensure reliable systems, providing feedback to customers through Closing the Loop and built a Customer Satisfaction feedback process. We also now have metrics for Customer Service including quality framework and core KPI's. We have successfully built our foundation.

We have also created the vision for a 'Single View of Customer' for the City of Marion, and built this into the IT application strategy. This will be a dominant feature of the 2020/21 Customer Experience Plan.

Our Customer Experience Plan for 2019/20

The focus for 2019/20 is on improving our 'Voice of the Customer' and feeding this into our 'Service Delivery'. We will develop individual customer experience initiatives at department level, and support the delivery of these plans with the development of Customer Insight Forums. Whilst enhancing Closing the Loop we will shift organisational focus to 'Positive First Response'.

During 2018/19, we invited KPMG in to audit Customer Experience, and their findings have been incorporated into this plan, along with the Metrics that Matter project deliverables and current Customer Satisfaction Data.

Attachment 1

Service Delivery – Delivering the right service to the right customer through the channel of choice

Goal	Initiative	Project Reporting method
Improve written communication	<p>We need to enhance our written communication to make it more engaging for our customers to improve positive first response.</p> <ol style="list-style-type: none"> 1. Reviewing current standards of letter writing. 2. Develop new written communication standards that are personal, engaging and informative. 3. Provide training to teams on writing. 	CAMMS project
Improve our Technology to support future initiatives	<p>Technology enhancements have been identified to support the development of the future customer experience strategy.</p> <ol style="list-style-type: none"> 1. Allow customers to generate customer requests for the most common category types, reducing call volume. 2. Continue Single View of the Customer initiative by developing user stories for the City of Marion (this has been postponed by 1 year due to IT application strategy). 	Monthly Customer Experience Report
Customer Experience Reporting	<p>Improve the customer experience KPI's to 100% achievement.</p> <ol style="list-style-type: none"> 1. Individual KPI's to be met by all team members. 2. Introduction of 2 additional KPI's – Time to answer and First Call Resolution. 	Monthly Customer Experience Report
Special Event Permit	<p>The special event permit process is complex and difficult for our customers. We need to improve this process, and reduce the amount of effort required by customers to access a special event permit.</p>	CAMMS project
Closing the Loop – Phase 2	<p>We will enhance CTL to include additional requests for service that use RAMMS.</p> <p>We will personalise the e-mail further, providing even more information to customers on their request for service.</p>	CAMMS project

Attachment 1

Voice of the Customer - Listening to our Customers

Goal	Initiative	Project reporting method
Moments of truth – Customer Satisfaction	What really matters for our customers? Through our Customer Satisfaction results we need to identify the requests for service that matter the most, the ‘Moments of truth’ for our customers. We will align service levels for these ‘moments of truth’ to ensure they meet customer expectations.	CAMMS project KPMG audit action
Complaint Handling Review	We have improved complaint handling by centralising some complaints and developed specific reporting. We now need to do a complete review of the complaints handling process to match CoM to best practice. <ol style="list-style-type: none"> 1. Complete a review on how complaints are being managed across departments. 2. Create a process on managing complaints that meets SOCAP guidelines. 3. Implement new process. 	CAMMS project
Customer Journey Mapping	2018/19 we piloted ‘Customer Journey Mapping’ with Finance, Volunteering and Planning. We will now develop a toolkit for the City of Marion to continue to map the customer’s journey through our organisation, focusing on our highest requests for service.	CAMMS project
First Call Resolution(FCR)	In 2018/19 we started our FCR program of work within Development & Regulatory Services and Finance. We have seen a significant improvement in the FCR rate. This work needs to continue. We will align FCR with the roll out of Customer Satisfaction measures and continue with the project.	Monthly Customer Experience Report
Social Media Strategy	Define and implement a social media strategy.	CAMMS project Annual Business Plan

Attachment 1

Culture - Inbuilt desire to achieve a positive first response for all customers through all channels

Goal	Initiative	Alignment & Measure
Leadership Development	<p>We will continue the development of our Customer Focused leaders with the following actions.</p> <ol style="list-style-type: none"> 1. Provide the organisation with relevant Customer Experience articles quarterly – with the focus on ‘Single View of the Customer’ benefits. 2. Incorporate Customer Experience into LEAD, LEAD-ON and LEAD in FIELD training. 	Customer Experience - Monthly Report
Training	<p>Our focus is to enhance ‘Positive first response’ through mindset and language changes in all communications.</p> <ol style="list-style-type: none"> 1. Deliver organisation wide ‘positive first response’ customer experience training. 2. Deliver Contact Centre training – Call control and Engagement. 3. Continue Customer Experience training as part of orientation. 	CAMMS project
Customer Insight Forums	<p>We will create a quarterly ‘Customer Insight Forum’ at department level.</p> <ol style="list-style-type: none"> 1. Customer Satisfaction Results. 2. Share stories on improvements to Customer Experience. 3. Review department Customer Experience Plan to focus on improvements. 4. Share relevant phone calls / feedback based on our service delivery. 	CAMMS project

17

18

19

20

AWARENESS

Customer Experience
Charter
Department Manager

Prepare the organisation to be customer focused
Introduced - the concept of customer experience

BUILD THE FOUNDATION

New customer hub
Telephony upgrade
KPI/customer service reporting
KPMG audit
Built single view customer vision
Closing the loop
Customer satisfaction

We had to build the tools to be able to deliver customer experience

EMBED THE PRINCIPLES

Deliver customer satisfaction
Align SLA to customer satisfaction results
First call resolution
Define “moment of truth” for our customers & deliver them well
Positive first response training
Map the customer journey eliminate the pain points

We are now able to measure and improve customer experience across CoM
Set up organisation for single view of customer

SINGLE VIEW Customer Experience

WE ARE HERE

We had to learn the difference between customer service and customer experience.

ACHIEVEMENTS

Customer Experience Plan
2018-19



Highlights of 2018/19 Customer Experience Plan

BEFORE VS. AFTER

Closing the loop when Customer Request Service



Kept customers informed with what is happening to their service

New initiative
Jun 19:
50 types of services included
981 message via Email
956 via SMS

Technology enhancements



PABX upgrade

Outdated telephony system with service disruptions

Upgraded and stable PABX system and telephony reporting platform



CRM scope options

Limited understanding about CRM for CoM

CRM scoping for CoM providing options to ELT and council



Digital sign in for visitors

New Initiative:
iPad based digital sign in at Admin Customer Service

Customer Experience Reporting



Reporting and performance metrics

Minimal reporting and performance metrics

AHT reduced by 2%
Transfer rate decreased by 4%
Compliance to Logout book
Improved Quality of calls

Improving Physical appearance of customer center



Admin Foyer Upgrade

Old look
Separate desk for development services

Refurbished Foyer
Combined desk CS & DS
Self-serve kiosk

Customer Satisfaction Measures



Voice of the Customer

No direct KPI for CX

Developed process to measure direct KPIs to Customer Experience

First Call Resolution



Empowered team to resolve request in first contact

Jan 2019
Event Rate = 58%
First call resolution rate = 27 %

Jun 2019:
Event Rate = 37%
First call resolution rate = 46%

Communication



GSM
Marion Muse

Revival of GSM structures to improve relevance and engagement

ACHIEVEMENTS

1.9K

Customer request was closed from August 18 to June 19



Stable & upgraded PABX system



CRM vision development



Convenience for customers



Monthly CX Dashboard
Individual KPI
Quality assessment tool developed



Improved Physical Customer Experience



CSAT for 5 months
90% satisfied in June 19



First Call Resolution

Community Courts

Originating Officer	Community Facilities Planner - Sean O'Brien
Corporate Manager	Acting Manager City Property - Clare Benn
General Manager	General Manager City Development - Ilia Houridis
Report Reference	ISC191105R05

REPORT OBJECTIVE

The objective of this report is to provide an update on the capital works program for tennis and netball facilities and a discussion on the supply and access to community courts provided across the City of Marion.

EXECUTIVE SUMMARY

Hamilton Park Reserve Community Courts (GC191022R16) was discussed at General Council on 22 October 2019. The item was deferred to the Infrastructure & Strategy Committee for placement in the Tennis and Netball Facilities Review Table.

The Tennis and Netball review and endorsed capital works program (GC280217R06) aimed to work collaboratively with clubs and the community to identify opportunities to improve ageing facilities and to consolidate or remove courts where they were considered surplus to community needs. A key driver for the program was to address the over supply of tennis courts and under supply of netball courts.

All works scheduled for 2017/18 and 2018/19 of the 3 year works project have been completed. The Tarnham Road courts are the sole project for year 3 of the program with the Nannagai Courts and associated works now being included as part of the Nannagai Precinct Plan.

Works to courts at Mitchell Park Sports & Community Club, McConnell Reserve and Weaver Street require further planning and engagement with the community before an outcome can be reached.

The net result of the tennis and netball capital works program to date is a reduction of 97 to 73 courts in total. This includes 43 tennis courts, 13 netball courts and 17 multiuse courts.

An objective of the tennis and netball review and subsequent facility improvements was to open up and enable wider community use. This objective has largely been met although access across the City of Marion falls into 2 categories:

- Courts are open for general community use any time 7 days a week free of charge.
- Clubs that are leased to tennis clubs who are required to have 2 courts available for community use which is achieved by either a Book A Court entry system or whereby public can access the courts through arrangement with the club at a nominated fee.

This report highlights some of the advantages gained from the works to date whilst providing updates on findings that have emerged since the initial review in the area of court provisions within the Marion boundaries.

RECOMMENDATION

The Infrastructure & Strategy Committee:

1. Notes the report.

2. Provides feedback on the potential provision of a new court at Hamilton Reserve.

DISCUSSION

Background

Through multiple Council reports in 2016 and 2017, Council considered a comprehensive review of its stock of tennis and netball facilities. The review included extensive desktop reviews, site reviews, condition audits as well as consultation with clubs, residents, Netball SA and Tennis SA.

The tennis and netball review formed a strategic approach to address a number of key issues that were identified.

Key issues identified include:

- An over-supply of tennis courts and under-supply of netball court facilities across the City.
- Changes in the demographics of the Marion population which has resulted in changes to the number and the size of clubs participating in local competitions.
- The city had created more assets than is sustainable in some areas whilst gaps were apparent in others.
- The standards of courts varied significantly and many clubs had been grappling with maintenance of courts which is often beyond their financial capacity.
- A majority of the courts used by clubs were generally locked and did not allow community access.

These issues drove the need to consider changes to the supply and quality of tennis and netball courts available across the City.

The rationale for change at each tennis & netball site in February 2017 is provided as Appendix 1 - Rationale of Change.

A summary of the outcomes of the endorsed capital works program undertaken over the past 2 years is provided as Appendix 2 - Summary of Courts.

Discussion

As part of the tennis and netball review Council adopted the following vision:

Stronger clubs, which have well managed good quality facilities and improved community access.

This vision was underpinned by the following principles:

- **Accessibility:** The venue is physically and economically accessible including to the public. The venue provides an adequate distribution and mix of programs and services.
- **Sustainability:** Financially viable in to the future. The venue/club implements an asset replacement plan, derives its funds from a range of activities and puts aside operational surpluses annually. The clubhouse and courts are maintained creating a safe and welcoming facility.
- **Community benefit:** Demonstrated by the club's ability to provide value to the community through inclusive practices, including to non-club members. This is achieved through increased participation pathways, and opportunities for community to achieve an active lifestyle and social benefits.
- **Accountability:** The club and its operations are sustainable. Operational responsibilities of the venue are clear and measures are in place to meet the targets. Obligations to stakeholders, including council, are met.

The open community courts considered in the tennis and netball capital works program were sites with existing courts only. Tennis and netball capital works program converted many tennis courts to netball or multi-use courts where there was poor supply. In other locations Council removed courts where they were considered surplus, demonstrated a duplication of nearby facilities or were at the end of their useful life. A key aim of the tennis and netball review was to reduce the number courts and did not propose the development of any new community court locations for use by sporting clubs.

While the provision for club courts has been programmed and carried out, Community Court provision, upgrade and maintenance is recommended to be captured and addressed within the Open Space Plan.

A draft Open Space Plan has been taken to Ward Briefings for feedback and will be considered further at a Forum in early 2019.

The Open Space Plan will provide a framework for Open Space upgrade and maintenance over a ten year period, including playgrounds, community courts and other open space treatments.

Mapping has been provided in Appendix 3 - Community Courts Mapping which shows the spread of Community Courts across the City of Marion.

Community Access to Courts

As part of Council's financial investment through the 3 year capital works program, it sought to ensure that the investment made was for the benefit of the whole community and not just the associated sporting clubs and sought clubs to open courts for wider community use. Club concerns regarding financial responsibility for potential damage incurred to their courts was addressed through a trialling of the Tennis Australia Book A Court (BAC) system at 3 sites.

The BAC system enables access to public via a designated gate that can only be accessed through the booking and logging of the user's details through an application available on any mobile device. Once booked the member of public is provided an access code which will open the gate and provide access. This system which has been trialled in the eastern states has seen a 98% drop in vandalism due to personal details being provided and stored as a condition of use. The clubs also have the option of charging a fee for access providing an additional income stream and leads for potential new members.

The BAC system will be trialled for 12 months at Warradale / Morphettville Park and Woodforde Reserve sites and have been funded by a grant from Tennis Australia. The remaining clubs that currently lock their gates and enable community use by appointment (picking up keys and paying a fee) would look to have the BAC system installed through a second round of funding if they do not wish to leave gates open for community use.

Several clubs which have multiple courts which split into courts groups have opted to leave gates open to one group of courts to meet this requirement and to date Council has received no notifications of vandalism or damage to the specialised court surfaces. Signage at these courts outlining permitted uses are in place to educate the wider community.

Sustainability Outcomes

The Tennis and Netball review proposed an amalgamation (in some instances) of some tennis & netball clubs into a single site or entity to increase utilisation and minimise duplication of assets. This outcome although met with intense resistance from the clubs involved has exceeded expectations. The Morphettville Park Netball club which occupied the end of life courts at Hamilton Reserve along with the struggling Ascot Park Tennis Club located at Weaver Street Reserve were amalgamated into the refurbished Woodforde Reserve site.

Both clubs, with assistance from council established a roster of usage and governance models suitable to both parties who now benefit from decreased operating costs due to cost sharing modelling and have gained members from each others membership bases and from the surrounding community of the relocated site.

The Ballara Park Tennis club was a small community tennis club located at the Ballara Park site. The courts were end of life - through the tennis & netball review it was proposed for the club to relocate to the nearby Sandery Avenue courts. Council through further discussion with both parties (and the promise of undertaking some minor Capital works) were able to facilitate an amalgamation of the Ballara Park club with the Stanley Street Community Club. By combining their membership base, together with financial and member resources, the amalgamation has resulted in a thriving community tennis club for the wider community.

Other clubs such as Warradale Park, Hallett Cove Beach & Morphettville Park Tennis Clubs have all cited growth and increased opportunities to grow their clubs through the provision of improved facilities.

Hamilton Park Reserve

Endorsed works at Hamilton Park Reserve, through the Tennis and Netball Review included demolition of the club rooms and 4 courts. This work was carried out in August 2019 with the club relocating to the refurbished Woodforde reserve site.

In 2018 the State Government granted \$180,000 to install an automated toilet at Hamilton Park Reserve. Extensive community consultation was undertaken to understand how the residents wanted the reserve to be developed in the future to ensure correct placement of the toilet.

Whilst the consultation articulated a clear desire for a community tennis court on site, Council's endorsed direction was to remove courts from the site due to poor condition, impacts of the gum trees on maintaining quality courts, duplication of nearby courts at Hazelmere and the relocation of the tenant clubs (GC280217R06). Hazelmere Reserve is located in close proximity (180 metres walking distance) providing 2 netball, 1 tennis and 1 multi-use courts. The consultation report for Hamilton Park Reserve can be found in Appendix 4 - Hamilton Park Reserve Engagement Findings.

Administration recommend a community court be built at Hamilton Park Reserve as:

- Community Consultation shows a clear desire for a court at Hamilton Park Reserve
- While there is a demolition site at the reserve, it will require fewer resources and time to build a community court
- Warradale has a low supply of open space and therefore, open space in this suburb should be developed to its potential.

Further provision, upgrades and maintenance of community courts through the City should be considered through the Open Space Plan and funded accordingly.

In respect of Hamilton Park Reserve, Council (GC191022R16) referred the item to the Infrastructure & Strategy Committee for further discussion regarding the proposed options:

That council:

- 1. Constructs a community tennis court at Hamilton Park Reserve, with facility for basketball and netball.*
 - 2. Fund \$136,000 for a bitumen community court at Hamilton Park Reserve through the unfunded initiatives program with an operating, maintenance and renewal cost of \$14,053 per annum.*
- OR*
- 3. Fund \$150,000 for an acrylic community court at Hamilton Park Reserve through the unfunded initiatives program with a operating, maintenance and renewal cost of \$15,500 per annum.*

Hallett Cove Netball Courts

Since the undertaking of the tennis & netball review the Hallett Cove Netball Club (Tigers) has undergone impressive growth on its 4 court facility which it shares with the Cove Netball Club (Lightning). The provision for an additional 2 courts to accommodate this growth has been included in the 2020/21 budget and forms part of Councils investigations into the future set up of the Cove Sports and Community Facility.

Community Courts

To understand the current condition of community courts, including tennis, netball and basketball, administration will undertake an audit of courts to ascertain the extent of future works and maintenance required. These needs can then be considered through the Open Space Plan. These courts are:

- Ballara Park Reserve
- George Street Reserve
- McConnell Avenue Reserve
- Weaver Street Reserve
- Edwardstown Memorial Oval
- Aldridge Avenue Reserve
- Mulcra Avenue Reserve
- Rajah Street Reserve
- Sandery Avenue Reserve
- Mitchell Park Oval

The need for new community courts should be considered on a City Wide basis through the Open Space Plan and developed in consultation with Elected Members.

Community Consultation will form part of the decision making for new and upgraded community courts.

Attachment

#	Attachment	Type
1	Appendix 1 - Rationale for Change	PDF File
2	Appendix 2 - Summary of Courts	PDF File
3	Appendix 3 - Community Courts Mapping	PDF File
4	Appendix 4 - Hamilton Park Reserve Engagement Findings	PDF File

Rationale for Change 2017

Tennis & Netball Sites

The tennis and netball review 2017 was underpinned by extensive consultation with clubs to identify recommendations which improve facilities and align with the Clubs directions and long term viability.

The following table outlines the recommendations for individual sites and/or clubs to achieve improved facilities, build the capacity of clubs and maximise utilisation including community access. These directions provided the rationale for the endorsed capital works program (GC280217R06).

The recommendations were informed by desktop analysis as well as clubs consultation held across 2016 and early 2017.

Site	Club/Partners	Directions	Recommendations
Woodforde Family Reserve	Morphettville Netball Club Ascot Park Tennis Club	<ul style="list-style-type: none"> Ascot Park Tennis Club (Weaver St) and Morphettville Netball Club (Hamilton Park Reserve) support moving to Woodforde Family Reserve The Hamilton Park facilities are in poor condition and do not meet acceptable standards for community sport. The impacts of the gum trees on the courts is significant and maintaining the courts to acceptable standards for the community is likely to be an ongoing burden for Council. 	<ul style="list-style-type: none"> The scope of the project to move the clubs to the Woodforde Reserve site includes <ul style="list-style-type: none"> Conversion of six tennis courts to four multipurpose courts Extension of the courts to accommodate additional space for multipurpose netball and tennis courts Relocation of fences Lighting upgrade Clubroom improvements New lease arrangements and shared management options will need to be negotiated Once the Netball Club has relocated to the Park Holme Courts (Woodforde Res) remove the courts and clubroom from the Hamilton Park Reserve and restore the area to open space. The number of courts required at Weaver Street be reviewed and altered in conjunction with the playspace renewal as part of a total reserve upgrade (It is anticipated the playspace renewal which is categorised as low range
Hamilton Park Reserve		<ul style="list-style-type: none"> Hamilton Park is identified in the Open Space Strategy as an area of low open space provision and therefore should be retained. The Weaver Street reserve is identified in the Open Space Strategy as an area of low open space provision and therefore should be retained. The Weaver Street courts are currently in reasonably good condition and could remain as open community courts in the short to medium term. The courts could be hired on as required basis to the tennis club as an overflow venue from Park Holme (Woodforde). The courts at weaver street could potentially be made available for hire by Denman 	
Weaver Street Reserve			

Site	Club/Partners	Directions	Recommendations
		Tennis Club who currently hire Woodforde Reserve courts.	will be renewed in 8 to 12 years)
Seacombe Heights Tennis Courts (Tarnham Road)	Seaview High School & Tennis SA	<ul style="list-style-type: none"> Council has given in principle support to a joint school, club and Council facility being developed at Seaview High School which would include closing the Tarnham Road courts (GC131216R07) An initial concept design has been developed for the Seaview Heights school A report with potential options for the Tarnham Rd site will be developed for Councils consideration. 	<ul style="list-style-type: none"> A detailed Council Report for the project will be prepared. The final directions will depend on outcomes of negotiations with the school and DECD.
Stanley Street Tennis Club	Stanley Street Tennis Club	<ul style="list-style-type: none"> Both Stanley Street Tennis Club and Ballara Park Tennis Club have indicated they are open to the concept of sharing a site however the times of use clash which makes sharing one site difficult to achieve. 	<ul style="list-style-type: none"> Support the Stanley Street Tennis Club to upgrade courts. As part of the next lease renewal negotiate an agreement that will enable greater community access to the courts.
Ballara Park Tennis Club	Ballara Park Tennis Club	<ul style="list-style-type: none"> Ballara Park Tennis Club has limited use outside of its 23 members and they are open to moving to Sandery Reserve if better shelter and storage is provided for tennis activities. Ballara Park Courts are located in an area identified in Council's Open Space Strategy as an area with a low provision of open space. The kindergarten has indicated it would like Council to consider options for children's activities in the reserve – this could be considered as part of the playspace renewal program (2 to 4 years) 	<ul style="list-style-type: none"> Ballara Park Tennis Club to relocate to Sandery Ave and install a new shelter and storage to support greater use of the tennis courts by the club and community. Once the Ballara Park Tennis Club relocates remove the courts and tennis shelter and restore the reserve to open space. A new court hire agreement will be required for Ballara Park Tennis Club to relocate to the Sandery Reserve Courts.
Kendall Tce Courts	Morphettville Tennis Club	<ul style="list-style-type: none"> The Club has grown substantially in the last 5 years and plan to play at the pennant level (courts cannot be multipurpose) The site is not able to physically accommodate netball courts The Club has a strategic plan and has prioritised a range of projects the Club would like to pursue; <ol style="list-style-type: none"> Lights Root barriers- courts are impacted by trees Improve fencing Provide a sheltered area for spectators to 	<ul style="list-style-type: none"> Support the Clubs plans to improve the site by allocating a potential contribution in the LTFP. <ol style="list-style-type: none"> Lights Root barriers- courts are impacted by trees Improve fencing Provide a sheltered area for spectators to the south of the clubroom

Site	Club/Partners	Directions	Recommendations
		the south of the clubroom	
Hazelmere Reserve	Wesley Netball Club	<ul style="list-style-type: none"> • Increase the number of netball courts available for the netball club and community's use. 	<ul style="list-style-type: none"> • Line mark a new netball court that overlays the tennis court and install netball posts.
Clovelly Park Community Centre	Adelaide Wildcats	<ul style="list-style-type: none"> • Development Application for floodlighting has been approved 	<ul style="list-style-type: none"> • Capital works will be completed in 2017 • As part of the next lease renewal negotiate an agreement that will enable greater community access to the courts
Hallett Cove Beach Tennis Facility	Hallett Cove Beach Tennis Club	<ul style="list-style-type: none"> • The Club is planning to upgrade courts and install new lighting • The Club is planning to pursue grant funding for court resurfacing and lighting upgrade through the Office for Recreation and Sport and following its unsuccessful application in 2016. • 	<ul style="list-style-type: none"> • A Council Report for these works is scheduled for March 2017. • As part of the next lease renewal negotiate an agreement that will enable greater community access to the courts
Warradale Tennis Facility	Warradale Tennis Club	<ul style="list-style-type: none"> • An updated project scope has been developed for a \$500,000 site and clubroom upgrade. • The scope for the project includes <ul style="list-style-type: none"> ○ Court upgrade ○ Fencing upgrade ○ Lighting upgrade ○ Clubroom upgrade • The Club was successful in securing a \$250,000 grant from the Federal Government. • The Club is pursuing an additional \$125,000 grant funding from the Office for Recreation and Sport in April 2017. • The Club has indicated it would like Council to consider a \$125,000 contribution towards the project. 	<ul style="list-style-type: none"> • A Council Report for the project is scheduled for March 2017. • As part of the next lease renewal negotiate an agreement that will enable greater community access to the courts
Trott Park Tennis Facility	Southbank Tennis Club	<ul style="list-style-type: none"> • The Club is planning to upgrade courts and install new lighting • The Club is planning to pursue grant funding for court resurfacing and lighting upgrade following through the Office for Recreation and Sport following its unsuccessful application in 2016. • 	<ul style="list-style-type: none"> • A Council Report for the project is scheduled for March 2017. • As part of the next lease renewal negotiate an agreement that will enable greater community access to the courts

Site	Club/Partners	Directions	Recommendations
Marion Tennis Club	Marion Tennis Club	<ul style="list-style-type: none"> Upgrade court lighting to support increased use of the site. 	<ul style="list-style-type: none"> A Council Report for the project is scheduled for March 2017. As part of the next lease renewal negotiate an agreement that will enable greater community access to the courts
Glandore Oval	Glandore Recreation Centre Board of Management	<p>The current facilities are in poor condition and the sports club has no existing plan for use of the site.</p> <ul style="list-style-type: none"> The tennis club house and courts are in poor condition and not used. The netball courts are open for community use however they are both in poor condition. 	<ul style="list-style-type: none"> Remove all 6 courts and demolish the former tennis club house. Provide two new multipurpose community courts and landscape the surrounding areas.

RECOMMENDED DIRECTIONS FOR COMMUNITY COURTS

Site	Analysis	Recommendation
McConnell Reserve	<p>Strong community response to retain the eastern side of reserve and improve facilities indicating it is a valued community asset.</p> <p>The feedback indicates the western side of the reserve has limited use and value for the community.</p> <p>12 responses indicated they use the western court for children's activities. This could be potentially catered for through facilities on the eastern side of the reserve.</p>	Retain the eastern side of McConnell Reserve.
Nannigai Reserve & Capella Reserve	<p>A petition with 384 signatures opposed any change to facilities at Nannigai</p> <p>The community survey suggests many residents may support a change to the location of facilities.</p> <p>The development of a precinct plan that identifies available options and costs that considers the community consultation feedback would better inform Council before a final decision is implemented.</p>	<p>Develop a concept precinct plan for Nannigai and Capella Reserves</p> <p>Retain the Nannigai Courts in the short term until a holistic informed decision can be made through the Nannigai and Capella precinct planning process.</p>
Roy Lander Reserve	<p>The majority of responses indicted a high level of use for the open space areas.</p> <p>Use of the courts is limited and only 7 respondents indicate they would like the courts retained and upgraded.</p>	Remove the fencing, nets and court and landscape the area.
Yanyarrie Reserve	No responses recorded from the community.	Tennis nets to be removed and court will be modified for other activities such as half-court basketball, skating, scooting and other sidewalk games.

Summary of Courts

Site	Club	Ward	Courts February 2017			Courts October 2019				Access Comment	
			Tennis	Netball	Multiuse	Tennis	Netball	Multiuse	Total		
McConnell Reserve	NA	Coastal	2		1	2		1	3	Open Community Court	
Nanningai Drive Reserve	NA	Coastal	2			2			2	Open Community Court	
Shamrock Road Reserve	Hallet Cove Beach TC	Coastal	6			6			6	Leased - 2 courts open for community use *	
Cove Sports Centre	Tigers Netball	Southern Hills		4			4		4	Leased – No community access Planned expansion to 6 courts	
Roy Lander Reserve	NA	Southern Hills	1						0	Court removed	
Trott Park Tennis Courts	Southbank TC	Southern Hills	6			6			6	Leased - 2 courts open for community use *	
Aldridge Avenue Reserve	NA	Mullawirra			2			2	2	Open Community Court	
Hazelemere Road Reserve	Netball Club/community	Mullawirra	2	2		1	2	1	4	Leased + open courts for community use	
Kendall Terrace Reserve	Morphettville TC	Mullawirra	4			4			4	Leased + book a court	
Mulcra Avenue Reserve	Community	Mullawirra	1		1	1		1	2	Open Community Court	
Stanley Street Reserve	Social TC	Mullawirra	2			2			2	Leased by social tennis club – No community access	
Woodforde Family Reserve	Shared by Morphettville Netball and Ascot Pk TC	Mullawirra	6					4	4	Leased + book a court	
Ballara Park Tennis Club	NA	Warracowie	2			2			2	No access. Courts are in poor condition and will be removed	
Hamilton Park Reserve	NA	Warracowie	2		2				0	Courts removed	
Rajah Street Reserve	NA	Warracowie			2			2	2	Open Community Court	
Sandery Avenue Reserve	NA	Warracowie	1		1	1		1	2	Open Community Court	
Warradale Park Reserve	Warradale TC	Warracowie	6			6			6	Leased + book a court	
Seaview Heights	Dover Sq TC	Warraparinga	8			8			8	Courts closed due to poor condition – proposed 8 courts to be replaced by 4 multiuse courts	
George Street Reserve	NA	Warraparinga	1			1			1	Open Community Court	
Marion Sports and Community Club	Marion TC	Warraparinga	6			6			6	Leased – No community access *	
Mitchell Park Sports and Community Club		Warraparinga	4			4			4	No access due to condition – to be reduced to 1crt Mitchell Park Tennis Club are currently using an alternative courts due to courts condition	
Clovelly Park Community Centre	Adelaide Wildcats Netball Club	Woodlands	5	1	1		5	1	6	Leased – No community access	
Edwardstown Oval	NA	Woodlands	1		1	1		1	2	Open Community Court	
Glandore Oval	NA	Woodlands	4	2			2	2	4	Open Community Courts	
Weaver Street Reserve	Ascot Park tennis (relocating)	Woodlands	4			4			4	Leased – No community access Planned reduction to 2 community courts	
Yanyarrie Avenue Reserve	NA	Woodlands	1					1	1	Open Community Court	
Total Courts			77	9	11	43	13	17	73		

* Planned Book a Court

** Figure's in red text have not been included in totals as they are not accessible for use by clubs or community

Community Courts

Tennis courts

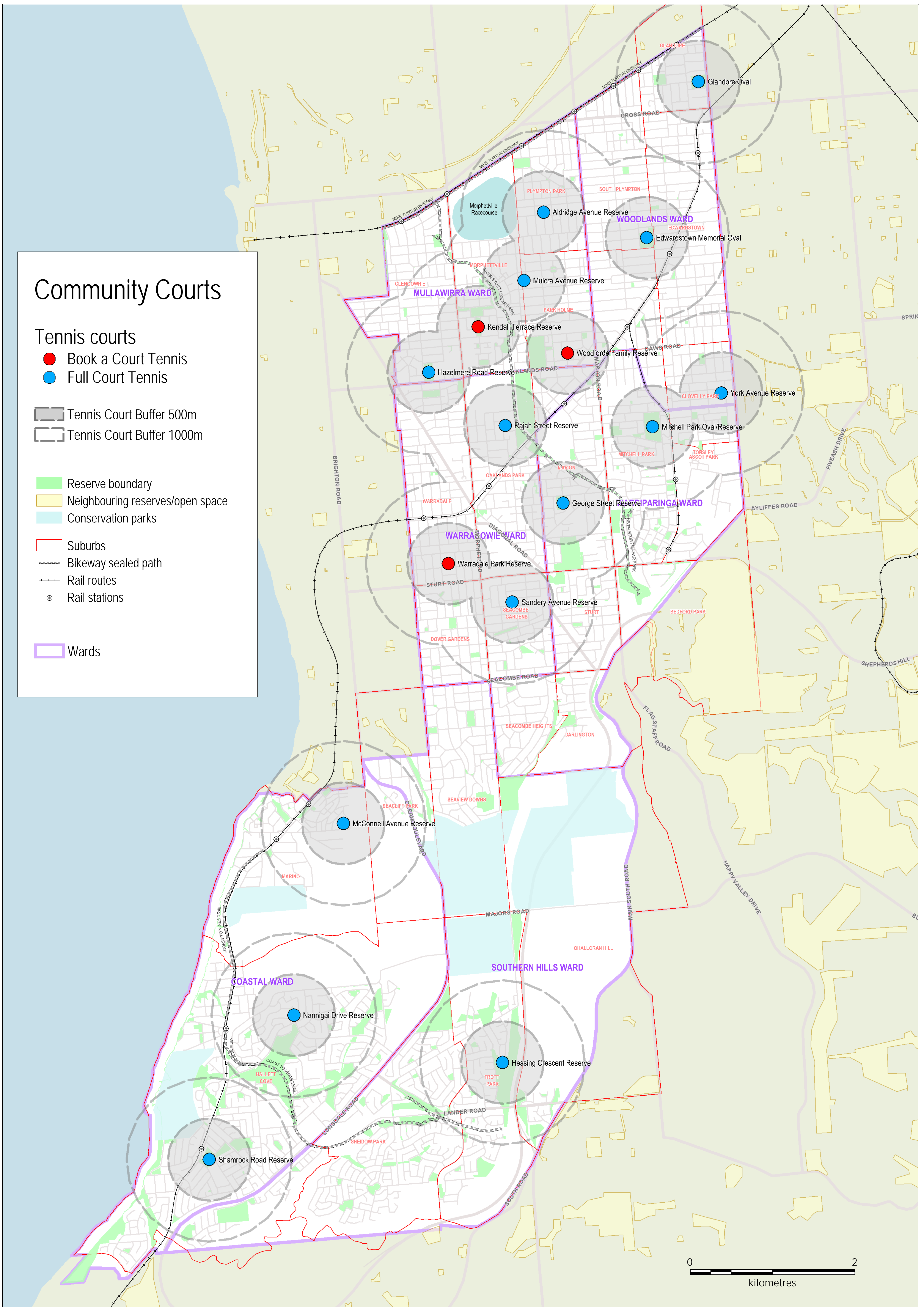
- Book a Court Tennis
- Full Court Tennis

- Tennis Court Buffer 500m
- Tennis Court Buffer 1000m

- Reserve boundary
- Neighbouring reserves/open space
- Conservation parks

- Suburbs
- Bikeway sealed path
- Rail routes
- Rail stations

- Wards



Community Courts

Basketball

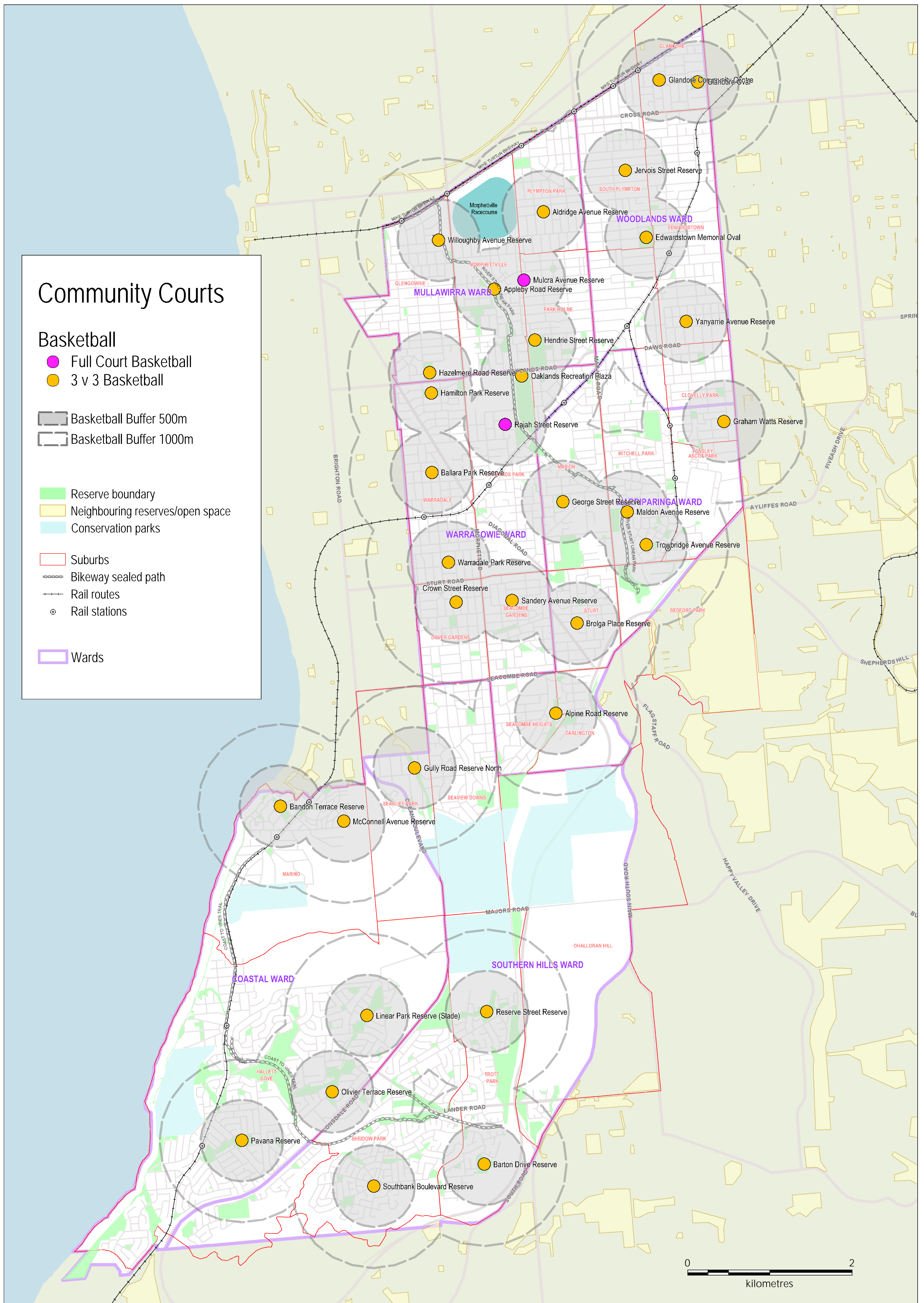
- Full Court Basketball
- 3 v 3 Basketball

- Basketball Buffer 500m
- Basketball Buffer 1000m

- Reserve boundary
- Neighbouring reserves/open space
- Conservation parks

- Suburbs
- Bikeway sealed path
- Rail routes
- Rail stations

- Wards



Community Courts

Netball

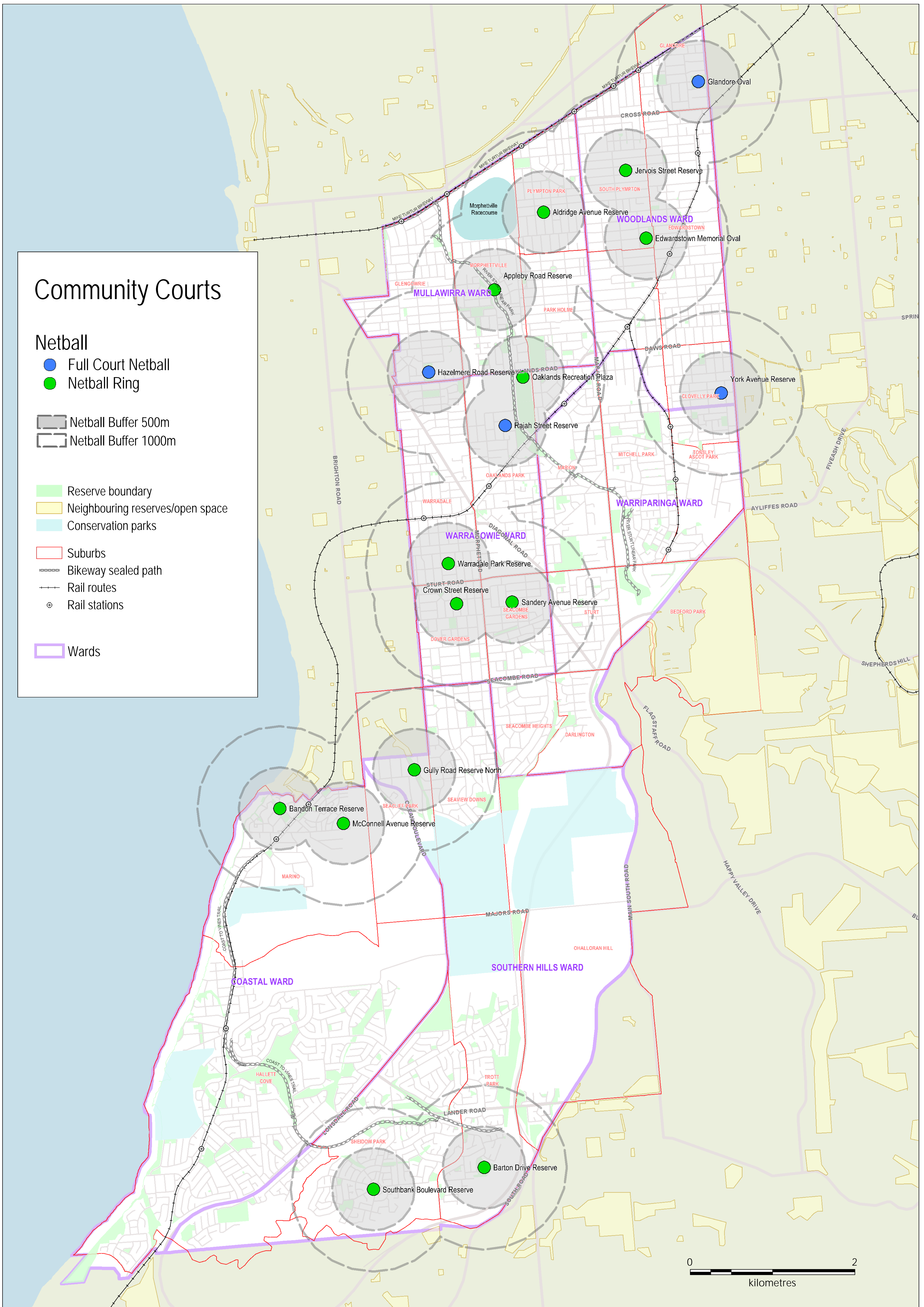
- Full Court Netball
- Netball Ring

- Netball Buffer 500m
- Netball Buffer 1000m

- Reserve boundary
- Neighbouring reserves/open space
- Conservation parks

- Suburbs
- Bikeway sealed path
- Rail routes
- Rail stations

- Wards



Hamilton Park Reserve Public Toilet and Reserve Upgrade Community Engagement Findings



December 2018

Introduction

As an outcome of the 2018 State Government Election, Council received \$180,000 from Member for Gibson Corey Wingard for the construction of a **public toilet at Hamilton Park Reserve, Warradale**. The installation of a new public toilet coincides with the removal of the tennis courts and club house, and provided an opportunity to engage with the public on future reserve upgrades.

Removal of Tennis Courts and Club House

A review of the tennis and netball facilities across the City of Marion was completed in 2017. The review found that the Hamilton Park facilities were in poor condition, did not meet acceptable standards for community sport and were underutilised. The review also stated the ongoing cost of maintaining the courts in good condition would increase due to the impact of nearby trees.

Council endorsed the removal of the tennis courts and club house in February 2017 and to investigate the feasibility of relocating tennis court lighting.

A New Public Toilet

The removal of the club house will include the existing public toilet. Council has received grant funding from the Minister for Recreation and Sport, Corey Wingard MP for the construction of a new public toilet, to be completed by August 2019.

The preferred location for the toilet is within proximity to the old club rooms where services including water, sewer and electricity exist.

Upgrade of the Playground

Council's playground framework has identified the playground is to be upgraded within the next six years.

The preferred location is to relocate the playground to the tennis court area as there are fewer trees in this area allowing for a greater selection of equipment that will not impact tree roots.

Reserve Upgrade

If funds are available following the removal of the clubhouse and courts and the construction of the toilet, other recreation facilities, elements or activities for the broader reserve may be considered within this process.

Community Consultation

Before progressing the installation of the toilet, community feedback was sought to consider the overall development of the site and plan for the future.

The intention for this consultation was to:

- Determine a location for a new public toilet in the reserve
- Determine the location for a future upgrade to the playground
- Gain resident views on other facilities that could be considered at the reserve in the future; and
- Note the proposed upgrades to the reserve would be delivered in stages.

Community consultation was undertaken over a three week period to 12 December 2018 including:

- A Making Marion online survey
- Postcards delivered to 430 households directing them to the online survey
- Signs installed at Hamilton Park Reserve.
- Social media marketing
- On site meeting held from 4pm on Sunday 2nd December 2018

The following report provides an analysis of the feedback that was received.

Executive Summary

In summary, during the 3 week consultation period Council received:

- 34 completed surveys
- 34 written responses within the survey
- More than 20 visitors to the on-site consultation meeting
- 1 letter of response
- 24 Facebook comments (2 relevant to the engagement)

Of the 34 respondents who completed surveys **88.2% supported the installation of a public toilet at Hamilton Park Reserve**. All residents who supported the installation of a toilet supported the proposed location of the toilet in the vicinity of the current club room building.

24 Respondents (70.6%) preferred to relocate the future playground to the current tennis court location.

73.5% of survey respondents had suggestions for other types of activities they would like to see at the reserve. These activities included:

Amenity	Number of comments
Fencing around playground	2
Shade and seating / BBQ	6
Fitness equipment	3
Community garden	1
Bike track	3
Retain tennis courts	7

The on site consultation was well attended and the following items were raised in response to the question “*What would you like to see at the Reserve?*”

- Native trees
- BMX / Dirt Bike track
- If the fencing is still up around the court – use the space
- Plan as a future reserve for grown ups
- Community Garden
- Keep the shelter
- Footpath around the reserve
- Static fitness equipment
- More trees and lower planting
- Party room hire – use existing club room and renovate

- Have equipment for toddlers
- Dog free park or at least dog on leash park
- Make tennis courts good
- Add activities for 7 – 15 year olds
- Options for older kids
- Lighting on a timer system
- Options for young kids (grandchildren) and older carers
- Tennis court
- Kid proof fence

Suggestions were also made to conduct a traffic survey around the site to ensure that parking and ease of movement through the surrounding streets was adequate.

Summary of Consultation Findings

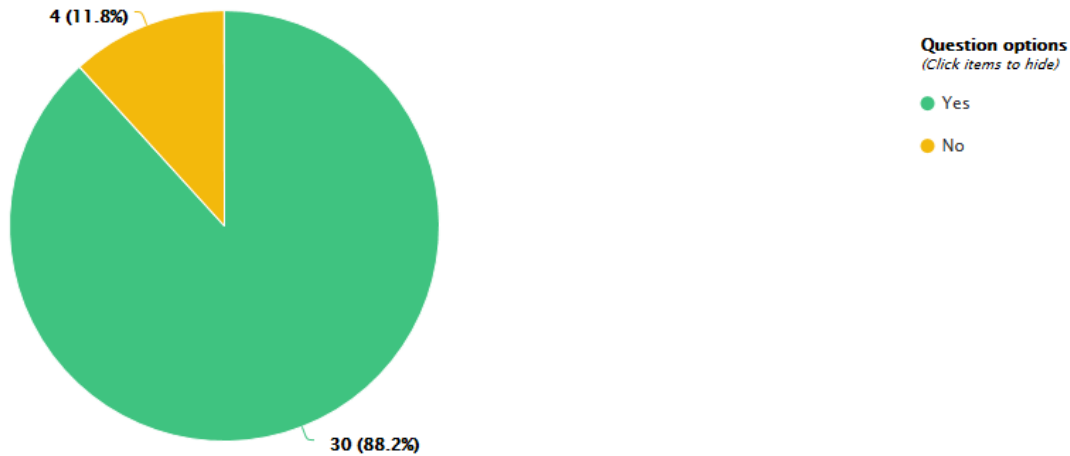
Plan.....



Consultation was held over three weeks, closing on the 12 December 2018. Six questions were asked and the findings are consolidated below.

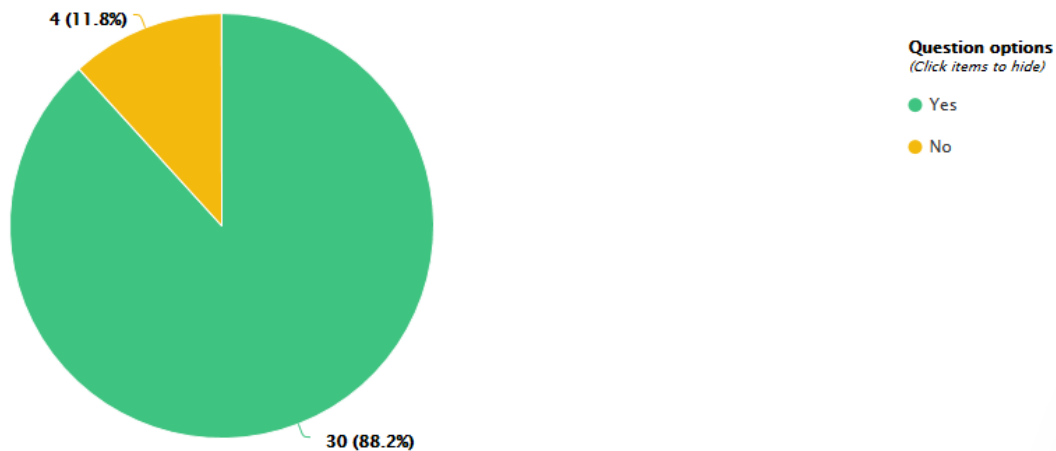
Question 1

Council has received funding for the construction of a new public toilet facility. Do you support the installation?



Question 2.

The reserve upgrade concept plan represents Council's preferred location for the new public toilet facility. Do you support the location?



Question 3.

If no, where is your preferred location / any other comments?

Don't waste your money. Very few use the area and those that do, generally live very close. There are several of these areas near my home and in the last 10 years I cannot remember someone using one. It might sound negative but it only becomes an area for several individuals that will visit very rarely. Try mowing or weeding my council owned front area rather than trying to fine me for parking there.

Don't support public toilet.

Hi

Thank you for the opportunity to provide feedback on the Hamilton Park Reserve proposal.

I strongly object to building new public toilet, bike track, fencing off playground, community garden, fitness equipment, tennis courts and walkway/footpath around perimeter of the park. These facilities were mentioned by a single community member at the community consultation on 2 December and I don't think they represent the wider view of the community and are focused on the needs of her 3 children at a very specific age bracket. I think any changes in the park should focused on longer term solutions that enhance this gem of a park with budget/ongoing maintenance costs in mind.

I don't see any value in building the facilities listed above as they are already provided (other than community garden) at Hazelmere Park which is only 200m north of Hamilton Park.

I think adding these facilities will detract from the beautiful natural open feel of the park.

I support upgrading the playground when current playground reaches end of life – as it stands it is a great little playground and does not require an upgrade. I do not support fencing off playgrounds as it detracts from the open space and natural beauty.

I would like to see Hamilton Park Reserve kept as a beautiful open space with established native trees.

I support the removal of existing tennis courts, lights, fencing and clubroom - rationale for this is:

- o Tennis court is past its usable life – maintaining or upgrading the court is very expensive.
- o No club is currently occupying the space resulting in a lack of maintenance.
- o Clubroom and pergola is reaching its end of life.
- o Fencing restricts public use.

On the vacated site lay turf and plant new native species to match existing trees – rationale for this:

- o Enhance the open space look and feel of the park.
- o Increase trees to provide shade and attract birdlife
- o Reduce maintenance costs to council.

I believe the recommendations above are aligned with Hamilton Park's classification of Neighbourhood Level in accordance with the Marion Playground Policy which states:

Categories Description

Purpose Neighbourhood Level playgrounds will be of a higher quality with a diversity of character in good locations that cater for one or more suburbs. Due to the broader scale of facilities people can use these playgrounds for extended periods of time. They provide similar environmental value as Local Level playgrounds.

User Catchment Distributed within approximately 750m distance to dwellings and work places. Serves surrounding suburbs and is generally within walking or cycling distance, but some may drive.

Types of facilities Sporting and recreation facilities for unstructured sport, park furniture and amenities including at least one seat, pathways for accessibility, diverse opportunities for play for a range of ages, shelter and natural shade with consideration of shade over playground equipment, water sensitive urban design landscaping, limited irrigated grass.

Thanks for the opportunity to provide feedback.

Consideration needs to be given to low mobility visitors and shade for persons waiting for others using the amenities.

It is a long walk for a person on a walking frame or other restriction.

Grandparents mind children and take them to activities. Workcover persons with low mobility need to be able to access the site.

Shade is needed in the vicinity of the amenities.

I do not want a toilet at all !!!

Living directly opposite the park I am often woken up by teenagers / young adults drinking and partying in the park at late hours. I believe a toilet block will;

1. encourage people to drink in the park after hours (if there is a toilet facility available).

2. encourage loitering as has been the experience at other public toilets ie Marion wetlands area.

3. Supply a place for drug use. On several occasions I have found used syringes in the park which I have disposed of at the RAH and Queen Elizabeth Hospitals (where I work).

This park is quiet and used only by locals who surely don't need a toilet block when their homes are so close. This investment is a waste of money for the few who use the park.

Please pay respect to those who live directly opposite the park not the few who live "nearby" who want it for their convenience. It is those who live directly opposite the toilet block who will be affected by the noise, sight, smell and public loitering of a toilet block.

My neighbours don't want it either.

Use the money for better seating, shelter, trees, play, exercise, sport equipment. This could be implemented now rather than in the proposed 6 year time frame.

PLEASE SURVEY the owners directly opposite the park, NOT those living in the surrounding streets / neighbourhood.

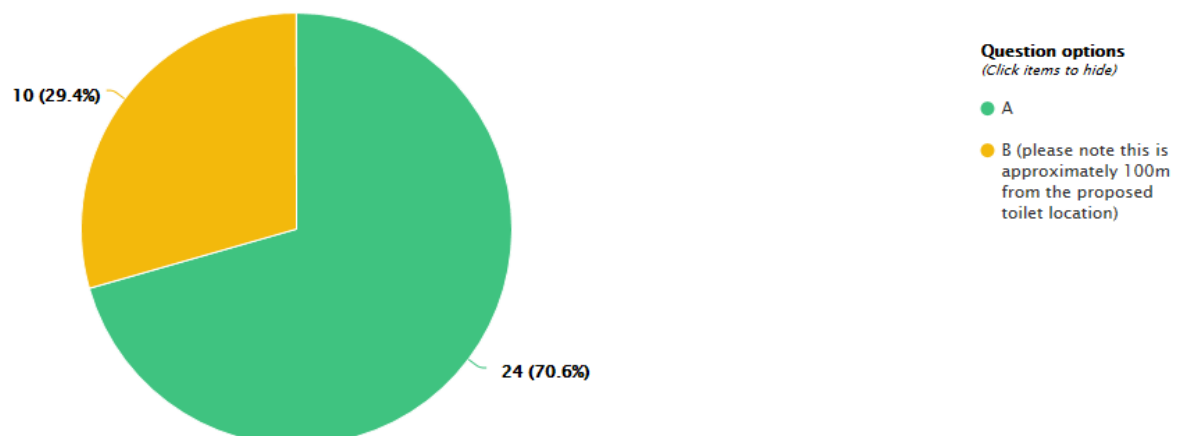
This proposed block is totally unnecessary when Hazelmere reserve is so close with BBQs/ toilets etc available 100-150 meters away.

ABSOLUTELY no toilets on the Western end!!

Yes to revegetation throughout, playgrounds and shade (site A)

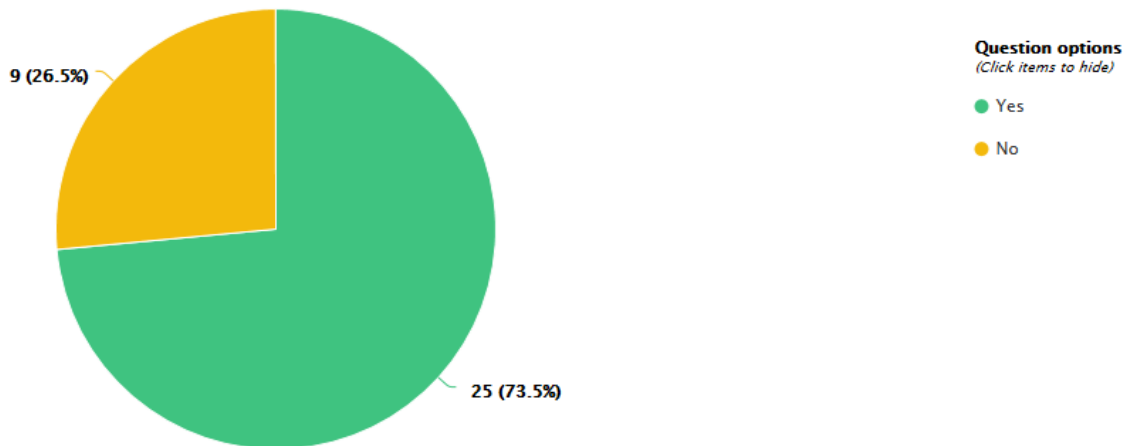
Question 4.

Please choose a preferred location for the upgraded playground:



Question 5.

Are there any other facilities, elements or activities you would like to see at this reserve?



Question 6.

With the limited budget in mind, please choose one activity/facility you would like to see at the site:

As there is no fencing at the reserve, a fence around the new playground would make it safe for children and families.

this park is suited to gym type equipment when budget allows I also believe the cricket practise nets at the dog park on Oaklands Road are unsuited at that site and should be relocated to Hamilton Park. Both to go in area of the former tennis courts

Shade and more seating/tables for barbies. Tap for washing/general purpose

Bike track similar to the one at the new Hendrie st park

A community garden that would make use of part of the enclosure and give people/families who have limited yard space an opportunity to enjoy in order for

Retention of the 2 western tennis courts as they are in the best condition - with open access to the community (currently locked up courts that we cannot use), retention of lights and change to user pay coin operated system. Please!!!

A barbecue similar to the Gully Road playground would encourage groups of friends and their young children to extend their visit.

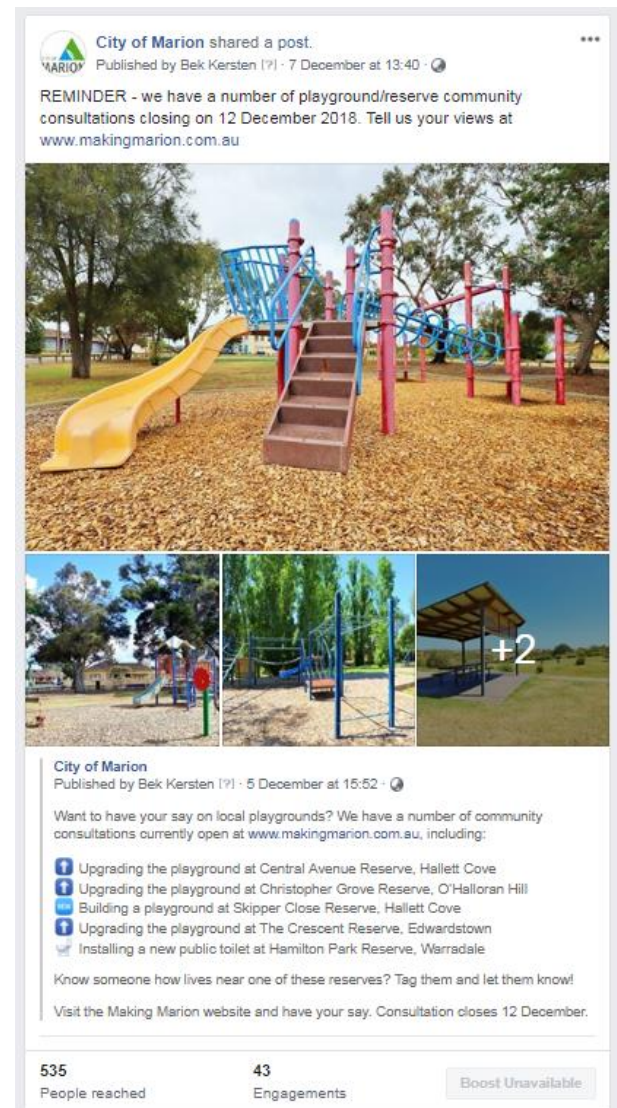
BBQ, Seating and a few shelters. Bigger playground suitable for all aged children not just preschoolers. Get a new contractor for the loo as I could build a further 4 bedrooms and an extra loo and bathroom for the same money!

Solar lighting in the Park, help with keeping the Park and residents safe. To keep one or two tennis courts, they are sought after, not everyone has small children. We've had a family Xmas tennis day every year since moved here, 22 years ago.

Bike path through the park for kids
Pergola with roof next to the bbq facilities. Existing clubhouse location would be ideal. Playground is better where it is. Please make sure both signs advise that reserve is on lead only. Currently the western notice is incorrect
*tennis courts to access whenever
Fence around new playground. As many trees and open green space as practicable.
Hopefully BBQ facilities. It is a great area to hang out in. We would go more often as a family if we could cook a few snags or something.
Natural play equipment (not plastic) - something that fits with the nature of the surrounding area. Play area with water play and sand if possible. Shade area and 1-2 BBQ's around parkland.
large chess set.
Stainless Steel Water Fountain with dog / bird drinking bowls incorporated, tables and benches / seats. Playground should consider needs of population -disability and ageing- including dementia. Feedback re survey: too limited field .
Somewhere where older children could hang out
tennis courts, so the area is inter- generational - where adults of all ages and children can enjoy the facilities. Tables and chairs to accommodate tennis.
tennis courts where the netball courts are, BMX track for young kids and older teens to use (oklands skatepark isn't the safest or most enjoyable place at times.
Re-lay the tennis court and open it up to the public. It has been a locked court for the whole 20 years that i have lived opposite the park. Keep the lights, convert to a user pays coin system so it can light both tennis courts and playground.
Static bar exercise area for teen and adults. Put powerlines underground
static bar exercise area for adults
two tennis courts in place of the existing four. Specify dogs must be on leads at this park (Oaklands Rd Dog Park to be used for when off lead)
more trees to replace recent losses. Upgrade play equipment / sports and recreation equipment instead of toilet block. Not enough people use the park to warrant \$180000 for a toilet block the locals do not want

Social Media

Engagement was undertaken on Facebook to invite community members to have their say via Making Marion.



24 comments were provided to the Facebook posts. Out of the 24 comments only 2 comments were applicable to Hamilton Park Reserve and are included below. The remaining comments related to other City of Marion playgrounds and engagements.

Please please please factor the provision of shade into your costings and design!
Please allow for more fenced in parks!

REPORTS FOR NOTING

Acquisition of Land and CEO Delegation to Purchase Land of a Strategic Nature

Originating Officer	Land Asset Officer/Registered Conveyancer - Heather Carthew
Corporate Manager	Acting Manager City Property - Clare Benn
General Manager	General Manager City Development - Ilia Houridis
Report Reference	GC191105R06

REPORT OBJECTIVE

The purpose of this report is to provide Council with information regarding the acquisition of land.

EXECUTIVE SUMMARY

Section 190 of the Local Government Act 1999 (The Act) states “A council may acquire land by agreement.”

Council has the ability to delegate many of its decision-making powers and functions under the Act and a number of other Acts.

The power to acquire land by agreement has been delegated to the Chief Executive Officer who has sub-delegated this power to the Manager City Property.

This report seeks to set out the use and benefits of Council's delegated and sub-delegated power for the acquisition of land.

RECOMMENDATION

The Infrastructure & Strategy Committee recommends to Council:

- 1. The endorsement of the “Acquisition of Land” procedure; and**
- 2. The CEO have delegated authority for strategic land acquisition, using the approved procedure, up to \$_____**

GENERAL ANALYSIS

At the 11 June 2019 General Council Meeting, the following question on notice was raised -

1. That a report be brought to Council outlining the risks and benefits of a council resolution to allow the CEO to purchase properties to a certain value and to set a criteria regarding how this would be used.
2. Include the strategic intent and value.
3. Governance framework of how to apply and the strategic priorities, together with I&S Committee consultation.

Organisational Excellence: Acquisition of land signed by Council's sub-delegate streamlines the process for both Council and the property owner

Risk Management:

A Governance Framework would provide guidance on what decisions can be made by the Chief Executive Officer and Council

DISCUSSION**Background**

Section 190 of the Local Government Act 1999 (The Act) states “A council may acquire land by agreement.”

Council has the ability to delegate many of its decision-making powers and functions under the Act and a number of other Acts.

As a matter of best practice it is usual for delegations to be made by the Council to the Chief Executive Officer (or equivalent), who may then sub-delegate the powers and functions to relevant Council officers (or such other bodies as are allowable, such as committees in some cases).

The power to acquire land by agreement has been delegated to the Chief Executive Officer who has sub-delegated this power to the Manager City Property.

Majority of Council Land Acquisitions

The majority of land acquisitions by Council are in respect of small areas of land - which are generally required for the purpose of verge widening to correct encroachments or to enable Council to install items such as kerb ramps etc.

These acquisitions are by agreement with property owners for a monetary payment that reflects the value of the land (apart from land that is owned by the State Government, that is generally gifted to Council). The value of the land is usually based on a rate per square metre and where appropriate, an independent Valuer will be engaged to determine the market value of the land.

These acquisitions of land are of an operational nature to assist Council in delivering services of a minor nature to the community. They are low value with the amount of the monetary payments made by Council in the last 18 months ranging from between \$795 to \$20,000.

All such operational acquisitions have been signed under Delegation.

(See Appendix 1 - Current Acquisition process under Delegation)

Benefit of CEO Purchasing Properties (to a Certain Value)

The current Financial Sub- Delegation for the Manager City Development is \$50,000.

Given it is unlikely that acquisitions of land for operational purposes or to correct minor encroachments would be greater than this amount, this existing agreed financial delegation enables operational transactions to be undertaken swiftly, without the requirement for formal Council approval - which streamlines the process for both Council and the property owner.

Risk of 'limited' CEO Purchasing Ability

Where potential strategic acquisitions of larger areas of land with considerable monetary value have been identified, the potential use and acquisition of the property is considered by the Executive and Senior Leadership teams prior to reports being prepared for Council's consideration.

Legally binding contracts are not entered into by the Chief Executive Officer on behalf of Council until such time that a resolution has been passed authorising the acquisition.

This can potentially be a fairly lengthy process, with General Council meetings often being scheduled to only once a month and prohibits quick decision making - This could result in Council potentially missing out on previously identified strategic purchases.

Governance Framework

There are a number of key strategic plans relating to Open Space, Land & Property and Council's recreational facilities that have been adopted by Council, in which potential strategic acquisitions have been identified.

In order to facilitate these 'already identified' strategic acquisitions, a Council Procedure could be developed to enable the Chief Executive Officer to acquire land or property under existing delegation.

The Procedure would provide guidance on what decisions could be made by the Chief Executive Officer on behalf of Council, i.e. the Chief Executive Officer could be permitted to enter into a legally binding contract up to an agreed amount - say \$1m in respect of an already identified strategic acquisition. This would enable administration to automatically proceed with an existing Council Resolution without the need to revert back to Council again for approval.

The adoption of a Procedure would enable administration to make swift decisions and not miss opportunities due to the timing of the next General Council meeting.

Next Steps

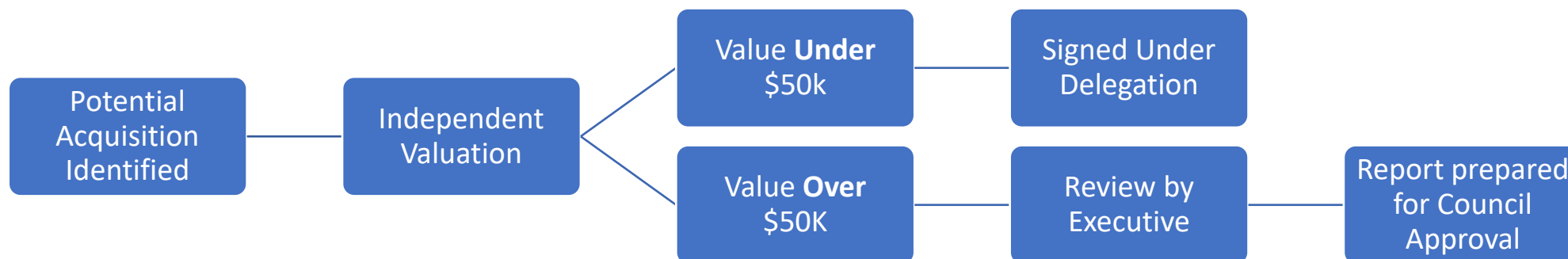
If the Committee agrees, a report can be presented to Council with the process and relevant delegation, with a financial limit, to the CEO to purchase land of a strategic nature (if it becomes available and requires immediate action).

Attachment

#	Attachment	Type
1	Appendix 1 - Current Acquisition Process Under Delegation	PDF File

City of Marion

Current Acquisition of Land Process under Delegation



City Property Strategic Asset Management Plan

Originating Officer	Acting Manager City Property - Clare Benn
Corporate Manager	Acting Manager City Property - Clare Benn
General Manager	General Manager City Development - Ilia Houridis
Report Reference	ISC191105R07

REPORT OBJECTIVE

To provide the Infrastructure and Strategy Committee (ISC) with an update on the progress of the City Property Strategic Asset Management Plan initiative

EXECUTIVE SUMMARY

The 2019-2023 Annual Business plan includes an initiative to develop a 'City Property Strategic Asset Management Plan (CPSAMP) to meet community, sport and recreation needs.

A report presented in the May Elected Member Forum advised a timeline for delivery of the CPSAMP as being December - April 2020.

Due to a delay in finalising the Building Condition Audit, the timeline for delivery of the CPSAMP will be between May - June 2020.

Despite the delay in the commencement of this project it is anticipated that this project will still be delivered this financial year.

RECOMMENDATION

That the Infrastructure and Strategy Committee:

- 1. Notes the update on the progress of the City Property Strategic Asset Management Plan initiative**

DISCUSSION

Background

The 2019-23 Business Plan includes an initiative to 'Develop the City Property Strategic Asset Management Plan (CPSAMP) to meet community, sport and recreation needs. This initiative is due to be delivered in the 2019-20 financial year.

A report was presented at the Elected Member Forum on 21 May 2019 that provided an overview of the initiative and a high level time frame for delivery. The scope of the program to be delivered between May 2019 and June 2020 included:

- Determining service levels
- Determining type and location of assets required
- Monitoring performance of assets
- Initiating regular upgrading of assets to ensure performance meets agreed service levels

A budget of \$360,000 was committed for this project:

- \$200,000 - building and asset condition audit (committed in 2018/19 and carried forward)
- \$100,000 - transitional property asset IT system
- \$60,000 - consultants to support development of the Strategic Plan

The CPSAMP's objectives are to:

Support Council in informed decision making and priority setting in the development and management of its asset portfolio

- Develop a whole of portfolio strategy that is equitable and adds value to the community and CoM and supports the delivery of services to the service levels adopted by Council
- Determine the life-cycle costs and budgeting implications of the portfolio to support Council's Long Term Financial Plan to ensure that adequate funding is available to meet asset management requirements
- Determine whether we hold, divest or develop each asset
- Ensure that CoM complies with all relevant legislative, political, social, environmental and economic requirements as an asset owner and manager
- Ensure CoM is well placed to deliver strategic objectives related to City Property assets

CPSAMP Key Stages

The CPSAMP initiative is planned to be delivered in 4 key stages (Appendix 1):

Stage 1	Building and associated assets condition audit	Dec 2019	In Progress
	Ongoing Maintenance Plan	Feb 2020	In Progress
Stage 2	Urgent Capital works identified from the building condition audit	Jan-Jun 2020	
Stage 3	Strategic analysis of City Property Asset data with key data sets including urban development, environmental, community needs, demographics to determine services levels, provision, performance and long term management	Dec 2019-Apr 2020	
Stage 4	Finalise and present Strategic'Plan/Platform'	May-Jun 2020	

The overall program is delayed compared with the timeline presented in May 2019 which showed the project commencing in May 2019 and being completed by March 2020. It is important to note that the revised timeline will still meet the commitment in the 4 year Business Plan for the project to be delivered in 2019/20.

The delays have been a result of:

- changes in personnel and leadership in the City Property team
- investigation into a transitional Property IT solution to manage the Building condition audit data (stage 1). This investigation originally determined that a dedicated asset IT solution would be required, with an associated investment of \$90-100k. Further discussions internally and with the contractors engaged to conduct the building condition audit has resulted in this system no longer being the best solution, with an associated \$90-\$100k saving for the project. It is proposed for the data to be provided by Sproutt Consulting Group in an Excel database format which will allow the information to be manipulated to identify programmes of capital works for individual financial years. CoM is working closely with Sproutt to ensure the data is collected in a database that can be connected with our current databases, meets CoM's data standards and can be used easily and effectively by officers managing maintenance and capital works programs. Processes are also being put in place to ensure that the integrity of this information is maintained for the short-term until a permanent enterprise and asset management system is identified, which is a priority in the IT system transformation plan.
- A need to determine an accurate, comprehensive 'single point of truth' dataset and naming convention for all city property assets. This exercise was critical to ensure the condition audit would be conducted in a comprehensive way, with all building assets audited. This dataset (which will be authenticated through the condition audit process) will now be the master dataset utilised for all building and associated assets going forward. This work was also critical in preparation for the transition to a new enterprise asset management system.

Building Condition Audit (Stage 1)

The building and associated assets condition audit has commenced and will conclude December 2019. Sproutt Consulting group were selected through an open tender process to undertake this work.

The audit will cover 58 sites in total and will provide an assessment of all assets on each site. The level of detail of information collected at each site is dependent on the 'category' of asset i.e. high complexity, value and utilisation e.g. neighbourhood centres, Administration building, through to low complexity, value, utilisation e.g. sheds. It will also provide an overall condition rating for each property.

The program of works also includes the provision of building floor plans for high priority buildings and photographs of assets and defects.

A significant output of the condition audit task is the development of a 10 year maintenance program based on priorities, with associated costings. This will provide a strong position to shift from reactive to proactive maintenance programming, budgeting and resource allocation from 2020/21 onwards.

Committed Capital and Maintenance Programs

Whilst this project is progressing, all committed capital works and maintenance programs are continuing. Already identified projects that are committed through plans, strategies, council resolutions and programs are progressing over this period. This includes projects in the 4 year Business Plan, Annual Business Plan, Playground Framework, Open Space Plan, and Tennis and Netball plans.

In addition to these projects, a number of facility renewal and improvement projects such as re-carpeting, re-painting and air-conditioning replacements are progressing on the understanding that there are a number of sites where these are a high priority.

The information and plan that will result from the CPSAMP initiative will inform Capital programs for 2020/21 and beyond.

Property Maintenance / Capital Works

There is currently an unallocated portion of the Capital works budget which has been set aside for urgent works identified in the building condition audit which is being finalised in December. A portion of this budget may need to be re-timed to 2020/21 financial year in order to allow sufficient time to develop and award 'programmes of works' following the finalisation of the Building Condition audit and CPSAMP. This will be identified in Q3 and addressed in the Q3 budget review.

City Property Strategic Plan/Platform

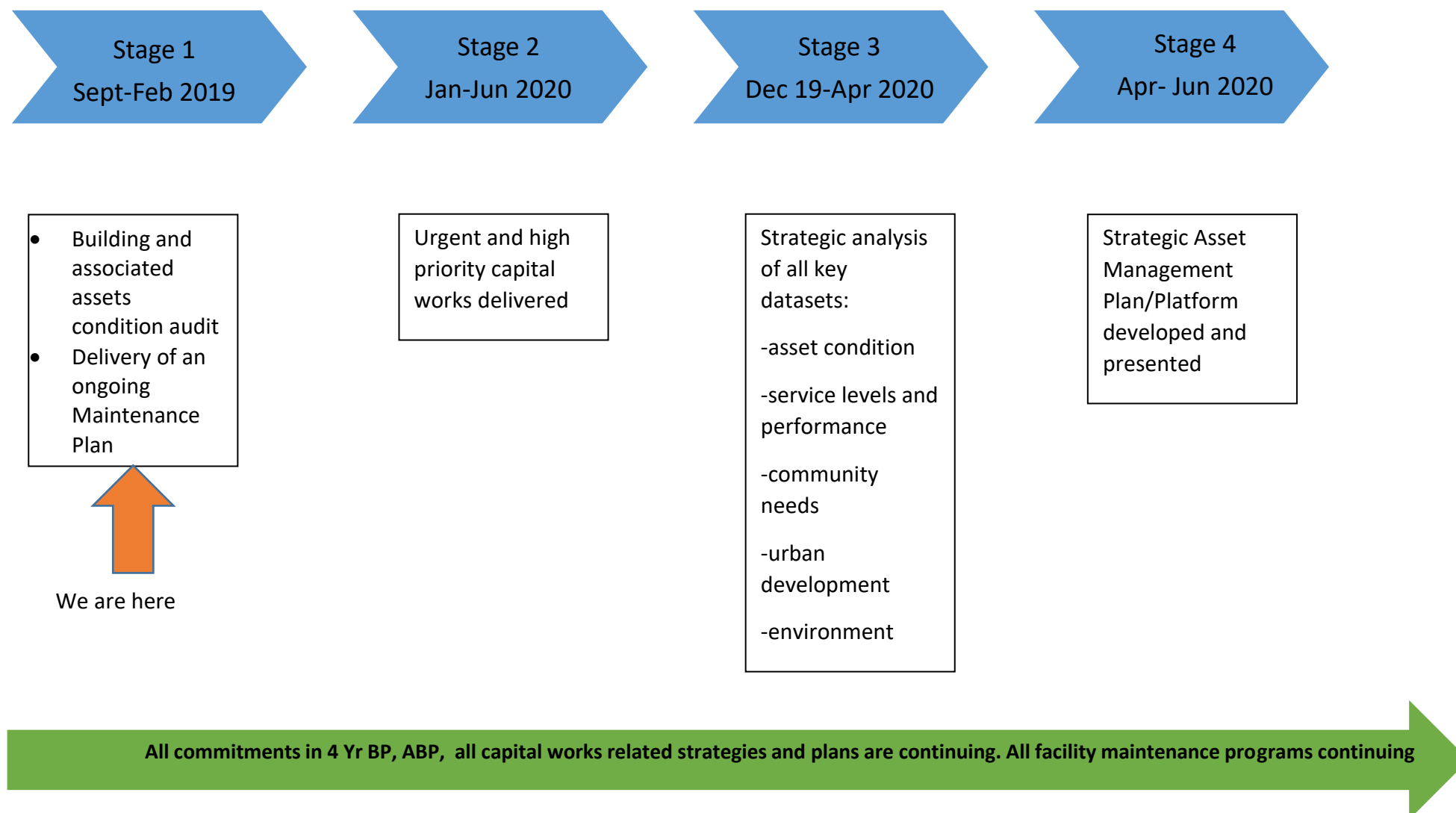
The collection of the building condition data, overlayed with key data sets about the city, community and environment will be strategically analysed to develop a long term plan to be delivered in June 2020 for property provision, service levels and performance.

It is important that this element of the project delivers a product that is valuable for ongoing decision-making and programming, rather than a 'point in time' strategy or plan that will require ongoing revision as new datasets are collected. An opportunity to engage a consultant to co-develop a platform that is map-based, able to be updated regularly and able to be used for ongoing scenario modelling is being investigated.

Attachment

#	Attachment	Type
1	Appendix 1 - CPSAMP - Key stages	PDF File

City Property Strategy Asset Management Plan – Key Stages



WORKSHOP / PRESENTATION ITEMS

Autonomous vehicle trial experience

Originating Officer	Executive Assistant to General Manager Corporate Services - Louise Herdegen
Corporate Manager	Manager Innovation and Strategy - Fiona Harvey
General Manager	General Manager City Development - Ilia Houridis
Report Reference	ISC191105R08

REPORT OBJECTIVE

To provide an updated on the current and future trends in electric vehicles.

GENERAL ANALYSIS

Mr Christian Reynolds to provide a verbal update on the status of electric vehicles in Australia and expected future trends.

Appendix 1 shows the EVANT passenger vehicle range. The first 3 prototypes will arrive in Australia by the end of the year.

Attachment

#	Attachment	Type
1	Appendix 1 - APC roadmap-report-26-6-18	PDF File

THE ROADMAP REPORT

TOWARDS 2040: A GUIDE TO AUTOMOTIVE
PROPULSION TECHNOLOGIES

FURTHER INFORMATION

For further information on this report
contact the Advanced Propulsion Centre

info@apcuk.co.uk

+44 (0)2476 528 700

www.apcuk.co.uk

The Advanced Propulsion Centre UK,
University Road, Coventry CV4 7AL

ACKNOWLEDGEMENTS

The Advanced Propulsion Centre would like to thank all those who were involved in the workshop and interview process. Your input was valuable in delivering the updated set of roadmaps and ensuring they reflect the challenges facing the automotive industry. A special thanks must also go to E4tech and Appleseed Solutions for assisting the APC with the data gathering as well as Market Engineering and Spell Creative in helping write and design this report.



THE ROADMAP REPORT

TOWARDS 2040: A GUIDE TO AUTOMOTIVE
PROPULSION TECHNOLOGIES

CONTENTS

Introduction	p 6
--------------	-----

Section 1	Trends and drivers affecting the automotive industry	p 13
-----------	--	------

Section 2	How to use the roadmaps	p 21
-----------	-------------------------	------



PRODUCT ROADMAPS

Section 3	Passenger car	p 25
-----------	---------------	------

Section 4	Bus	p 33
-----------	-----	------

Section 5	Commercial and off-highway	p 43
-----------	----------------------------	------



Section 6	Technology roadmaps – cross cutting themes and their implications	p 51
-----------	---	------



TECHNOLOGY ROADMAPS

Section 7	Electrical energy storage	p 57
-----------	---------------------------	------



Section 8	Electric machines	p 71
-----------	-------------------	------



Section 9	Power electronics	p 85
-----------	-------------------	------



Section 10	Thermal propulsion systems	p 101
------------	----------------------------	-------



Section 11	Lightweight vehicle and powertrain structures	p 113
------------	---	-------



Section 12	Working together to commercialise the products and technologies identified in the roadmaps	p 129
------------	--	-------



INTRODUCTION

DR. GRAHAM HOARE OBE – CHAIR OF THE UK AUTOMOTIVE COUNCIL TECHNOLOGY GROUP



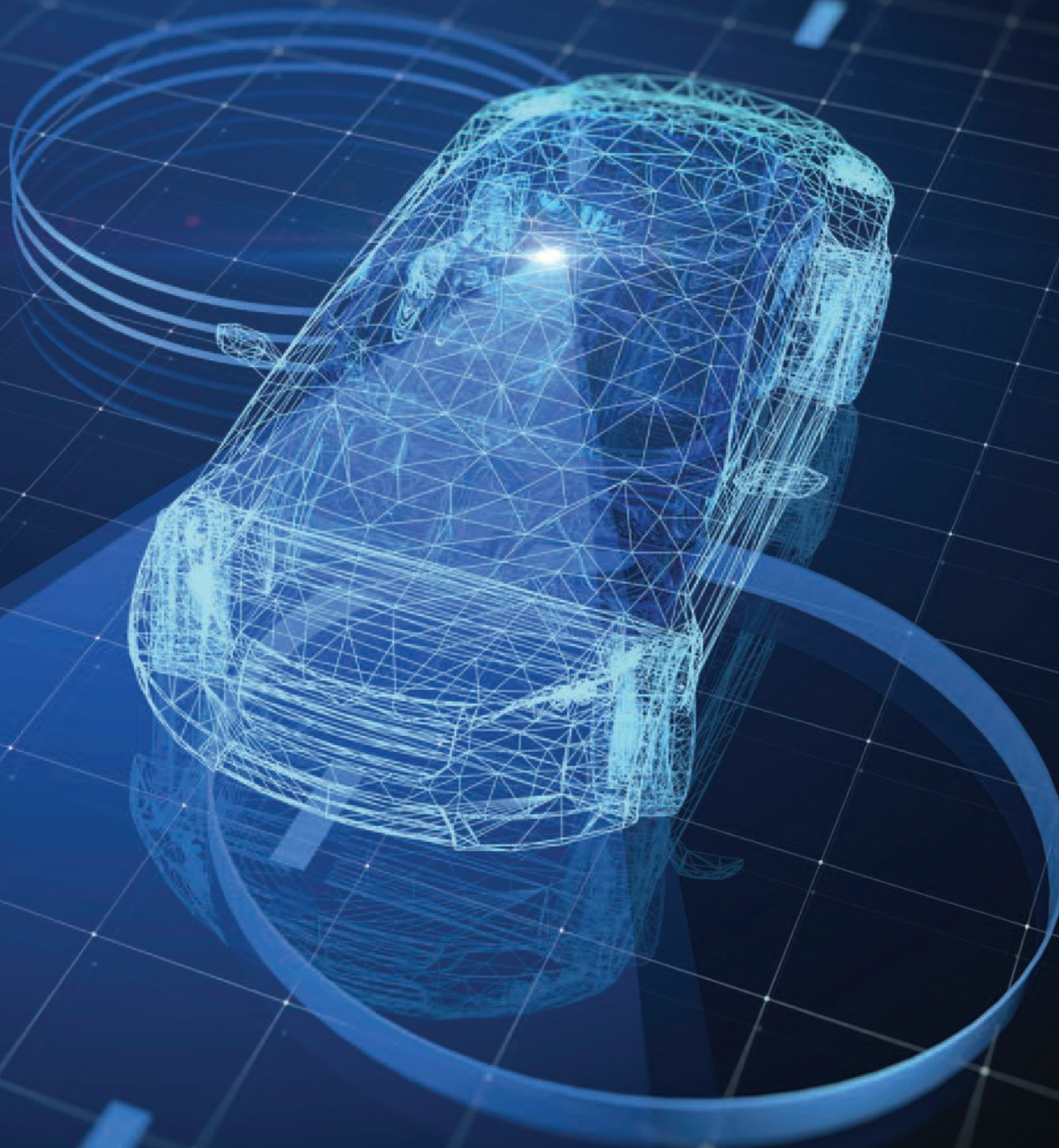
In response to numerous environmental and societal pressures, the automotive sector is embarking upon a period of unprecedented technological change that has the potential to revolutionise mobility. Autonomous, Connected and Electrified (ACE) are the key trends that have been identified by the UK Automotive Council as driving the automotive sector and continue to challenge the global engineering community. These changes will take place over future vehicle development cycles, so stakeholders should respond in a considered manner and view the roadmaps as informed trajectories to the future.

Since they were first published in 2009, the Automotive Council's roadmaps have been instrumental in visualising the evolving automotive landscape and communicating a shared view of the future. Reflecting consensus at a particular point in time, the insights gathered from the roadmap report were

derived from a wide range of stakeholders: from global OEMs right through to local technology developers and academia. While individuals may have differing views, it's this consensus driven approach, combined with a detailed exploration of key technologies that make these roadmaps truly world leading. The Automotive Council looks forward to continuing working with UK Government, academia and industry to ensure that the barriers to adopting new vehicle and powertrain architectures can be addressed and capitalised upon to provide sustainable benefits to us all.

Since they were first published in 2009, the Automotive Council's roadmaps have been instrumental in visualising the evolving automotive landscape and communicating a shared view of the future.

Autonomous, Connected and Electrified (ACE) are the key trends that have been identified by the UK Automotive Council as driving the automotive sector



FOREWORD

NEVILLE JACKSON – DEPUTY CHAIR OF THE UK AUTOMOTIVE COUNCIL TECHNOLOGY GROUP



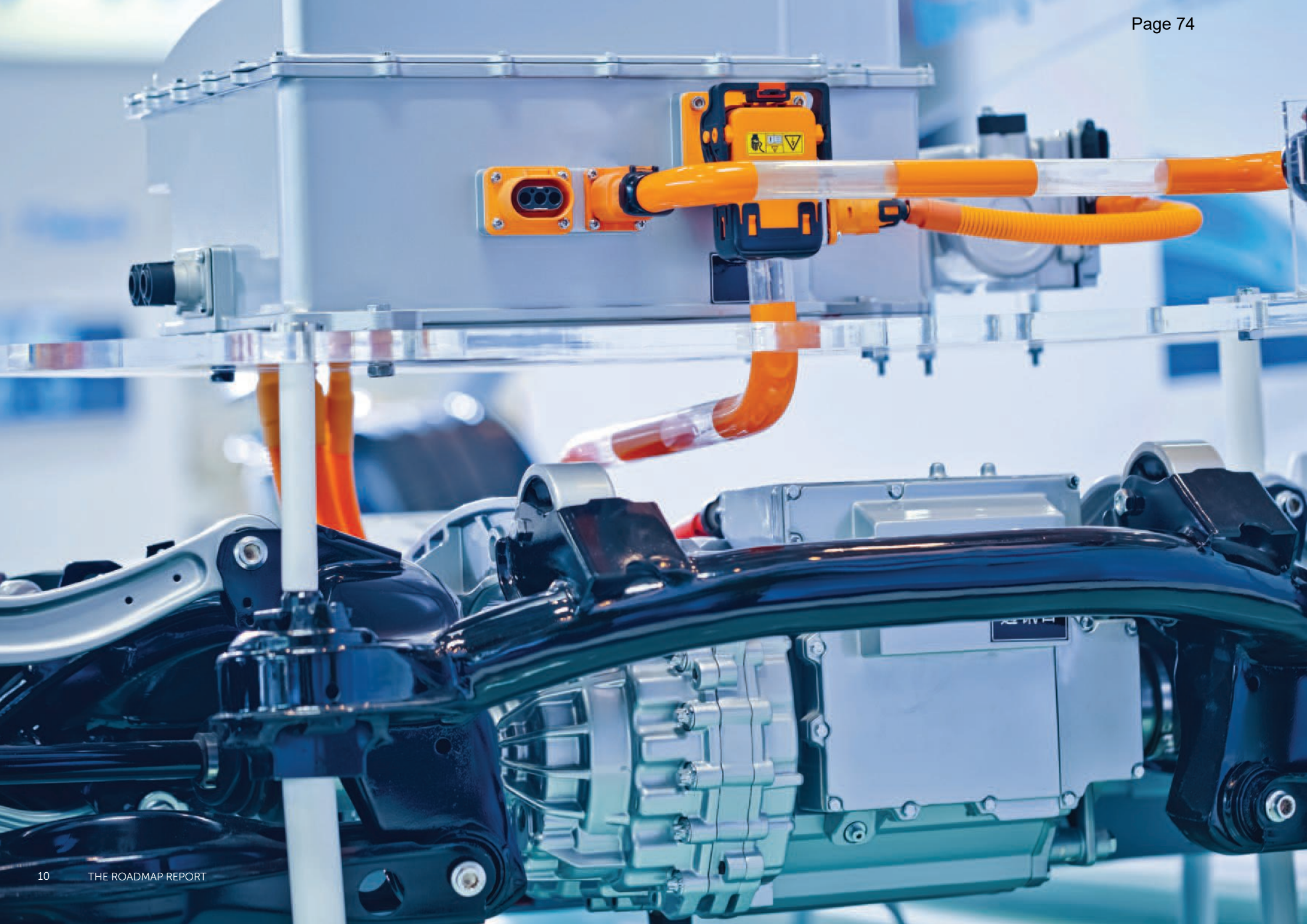
The updated set of propulsion roadmaps in this report build upon the foundations of the Automotive Council Technology Group roadmaps created in 2013 and reflect today's complex landscape. Whilst the longer term vision for sustainable, clean and low or near-zero carbon transport is now well established, this will only be realised if we can find a technically and economically viable pathway to get to this vision. The 2018 roadmap report astutely identifies the key trends that will determine future powertrain development and summarises how future vehicles and technologies might evolve to meet both customer and environmental requirements.

The report rightly identifies that in the short term, vehicle tailpipe emissions will drive powertrain choices in order to meet legally binding CO₂ targets and emission limits. However as the impetus to decarbonise the global economy intensifies and new mobility business models emerge, there is a need to

develop powertrains that satisfy a wider range of societal and environmental demands. An important theme throughout this report is that the automotive sector must not only understand the life cycle impacts of vehicle manufacturing, but also understand the role for transport fuels and energy vectors within the wider energy system and its associated infrastructures. I hope this report resonates not only with those organisations in existing automotive supply chains but also those outside the automotive sector as it will require more than just UK automotive to overcome future challenges in mobility.

An important theme throughout this report is that the automotive sector must not only understand the life cycle impacts of vehicle manufacturing, but also understand the role for transport fuels and energy vectors within the wider energy system





139

ORGANISATIONS ENGAGED WITH THE APC ROADMAPPING ACTIVITY



- OEM
- Supplier
- Technology Developer
- Engineering Service Provider
- Academia
- Other

SUMMARY

This document provides a thoroughly researched overview of the technology trends that will determine how the automotive industry meets pressing environmental and sustainability challenges. Covering each of the major sectors, including passenger cars, commercial vehicles, busses and off-highway, it describes the direction that technologies are most likely to take, illuminates the technical and manufacturing challenges that affect their adoption and discusses the impact of wider initiatives encompassing social and infrastructure changes.

Information can be viewed by sector, at-a-glance in the tables and graphical roadmaps, or reviewed in more detail through the written commentary. Written for a wide range of stakeholders, including industry leaders, politicians, legislators and investors, each roadmap is based on the learning of a wide range of industry experts so provides professional opinion supported by

numerical targets, with sufficient technical detail to inform technology developers and strategists.

It is evident that optimum results can only be achieved through 'joined up' thinking, first at a powertrain system level, then moving out to consider energy policy and the wider transport system. By placing the discussion of the technology trajectories within this context, the document indicates where investment, including support from government, will deliver the greatest benefits.

The roadmaps are not intended to assess the UK's capability to deliver on the identified technology streams or to map out skills, supply chain, financing, policy or regulatory requirements. However, they provide a valuable tool to help identify specific targets and technology trajectories in these areas, helping to ensure that related decisions are taken based on the best available expertise.

ABBREVIATIONS USED

ADAS	Advanced Driver Assistance Systems
BEV	Battery Electric Vehicle
CAV	Connected Autonomous Vehicle
CFD	Computational Fluid Dynamics
CNG	Compressed Natural Gas
ECU	Electronic Control Unit
EV	Electric Vehicle (FCEV and BEV)
FCEV	Fuel Cell Electric Vehicle
g	Gram
GaN	Gallium Nitride
GHG	Green House Gas (predominantly CO ₂)
GWh	Gigawatt-hour
H₂	Hydrogen
HGV	Heavy Goods Vehicle
HVEMS	High Volume E-Machines Supply (an APC-funded project into future manufacturing methods)
IGBT	Insulated Gate Bipolar Transistor

IPM	Interior Permanent Magnet
JIVE 2	Joint Initiative for hydrogen Vehicles across Europe (second stage of a fuel cell bus project)
kg	Kilogram
km	Kilometre
kW	Kilowatt
kWh	Kilowatt hour
l	litre
Li-S	Lithium-Sulfur
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MaaS	Mobility-as-a-Service
mm	Millimetre
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
NdFeB	Neodymium/Iron/Boron (Neodymium magnet)
NiMH	Nickel Metal Hydride
NVH	Noise, Vibration and Harshness

OEM	Original Equipment Manufacturer (vehicle manufacturer in this document)
PEM	Proton Exchange Membrane (type of fuel cell)
PHEV	Plug-in Hybrid Electric Vehicle
SiC	Silicon Carbide
SMC	Soft Magnetic Composite
SOFC	Solid Oxide Fuel Cell
SPM	Surface-mounted Permanent Magnet
TPS	Thermal Propulsion System (internal combustion engines of all types)
ULEZ	Ultra Low Emissions Zone
V	Volt
VECTO	Vehicle Energy Consumption Calculation Tool
VOC	Volatile Organic Compound
WLTP	Worldwide harmonised Light Vehicle Test Procedure
xEV	generic abbreviation for a mild hybrid, full hybrid, PHEV, BEV and FCEV
ZEV	Zero Emissions Vehicle

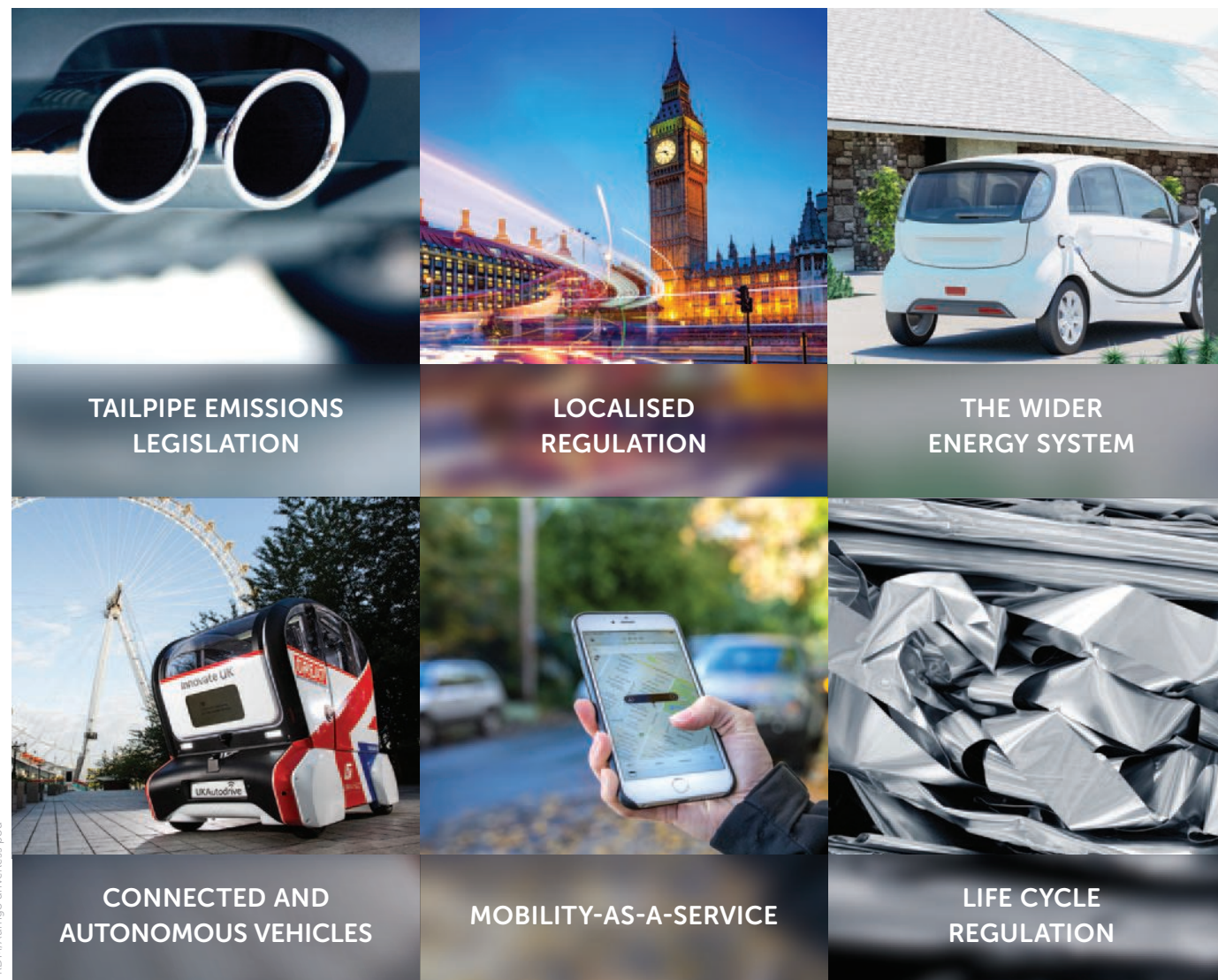


1 TRENDS AND DRIVERS AFFECTING THE AUTOMOTIVE INDUSTRY



OVERVIEW

A number of economic, environmental and social factors are influencing future vehicle designs and powertrain choices. Many areas of automotive propulsion technology are now advancing more quickly than at any time in the last 100 years. The lack of a single, agreed solution to these diverse drivers is leading to a substantial diversion from known technologies, with the range of technology choices now wider than it has ever been and growing.



RDM/Aurigo driverless pod



1.1 TAILPIPE EMISSIONS LEGISLATION

Given the limitations of tailpipe regulation, its impact on powertrain strategy will be most profound in the short to medium term. In the long term life cycle analysis could emerge as a more significant driver.

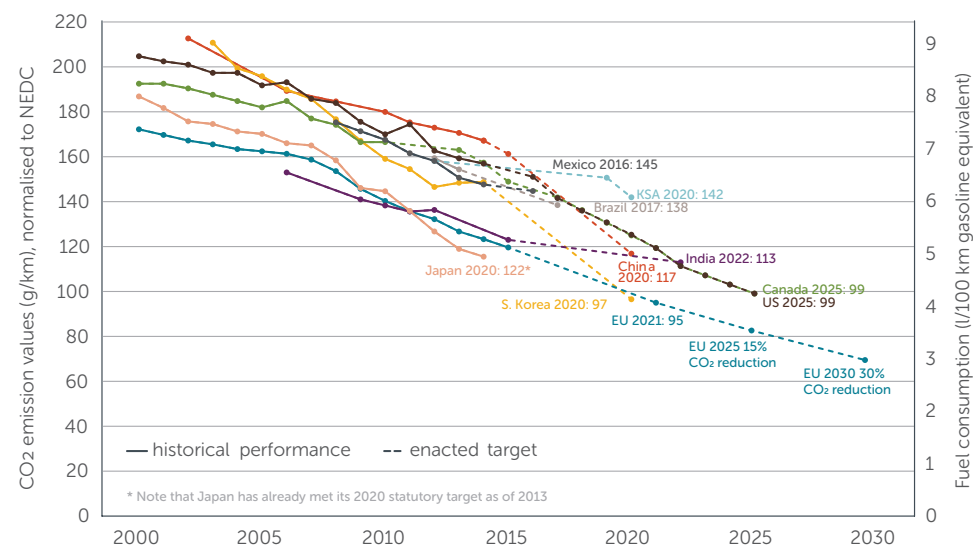
Despite widely reported discrepancies between official tests and the real world, tailpipe regulation has been successful in reducing both CO₂ and pollutant emissions from new vehicles. However, the time taken to renew the vehicle parc means that the CO₂ and air quality benefits are not immediately seen. To provide further certainty in European markets, post-2020 CO₂ emission proposals were introduced by the European Commission in November 2017 (as shown in the top graph). The Commission also suggested that it might consider extending the use of Real Driving Emissions (RDE) to CO₂ after 2025.

For the time being, air quality has superseded CO₂ as the main driver for powertrain strategies in urban areas and this is reflected in various national and local policies. It is expected that as Euro VI trucks, Euro 6c light duty vehicles and zero emissions tailpipe capable vehicles replace older ones in the fleet, the focus will return to CO₂ and achieving the proposed EU light duty CO₂ targets for 2025 and 2030.

Electric Vehicles (EVs, which includes BEVs and FCEVs) can achieve the required pollutant emissions and CO₂ standards, however short and medium term solutions are required to enable the automotive industry to transition into the longer term vision of cleaner transport systems.

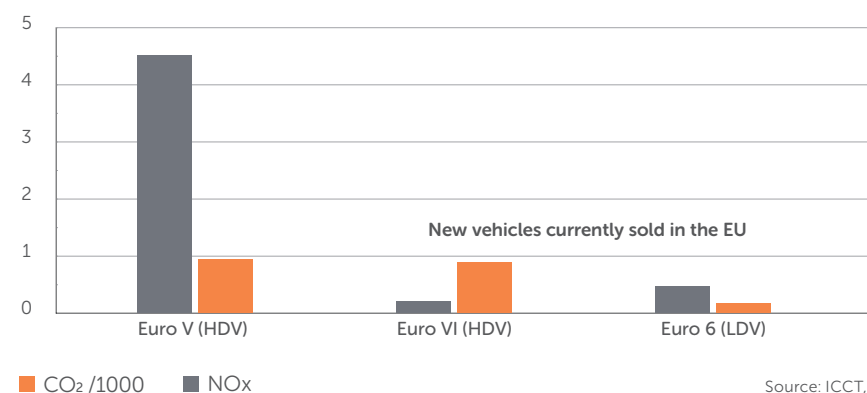
Heavy duty vehicles including buses, trucks and off-highway vehicles have been affected by pollutant emissions legislation more profoundly than CO₂ regulation (as shown in the bottom graph). However if the European Commission's proposed heavy duty CO₂ reduction targets for 2025 and 2030 are enacted, it will bring Europe more in line with CO₂ and fuel efficiency standards established in Japan and the US. It is expected that the 15% reduction in CO₂ by 2025 and 30% reduction in 2030 could create an even greater market demand for new fuel saving technologies in the heavy duty sector.

Historical fleet CO₂ emissions performance and current standards (gCO₂/km normalised to NEDC) for passenger cars



Source: ICCT, 2017

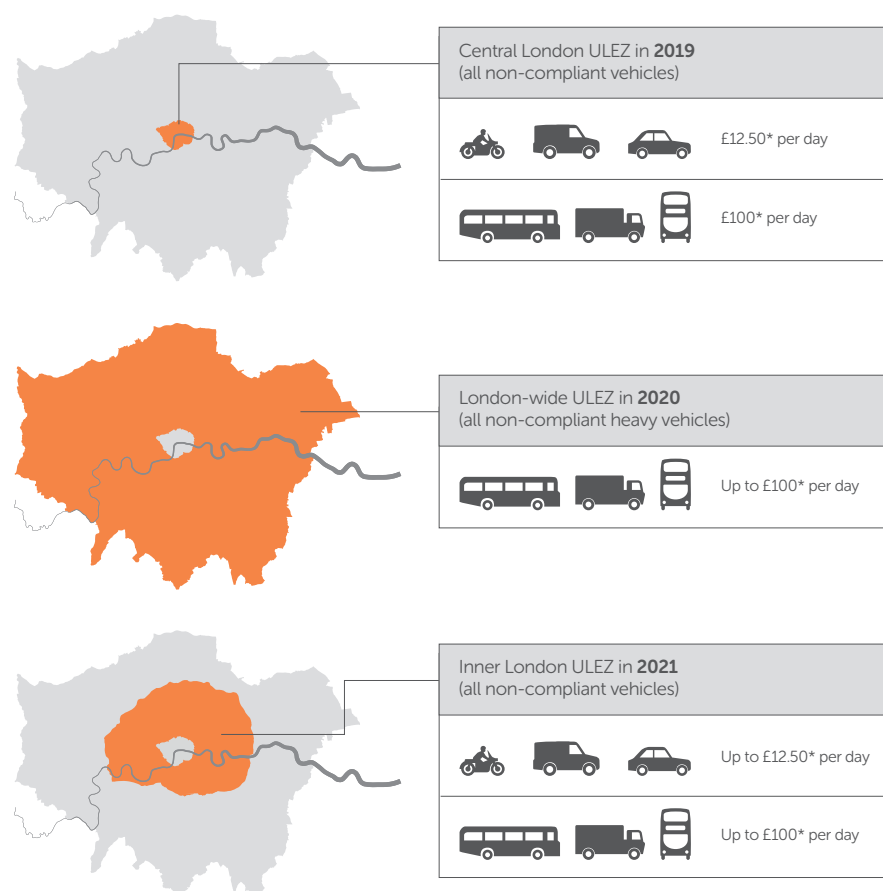
Real-world gaseous emissions [g/km]



Source: ICCT, 2016a



London Mayor's ULEZ Proposal



ULEZ standards: Petrol – Euro 4; Diesel – Euro 6/VI; Motorcycle and L-Cat – Euro 3
 *ULEZ charge levels are indicative only and refer to the current scheme proposals

Source: Transport for London, 2017

1.2 LOCALISED REGULATION

Localised rather than national policy is already impacting powertrains and evolving societal changes could sustain the influence of local policy in the longer term. The UN (2016) forecast that by 2030, 60% of the global population will live in cities, increasing the influence of local and regional authorities in determining transport, health and energy policy.

In Europe and China, a popular policy for managing poor local air quality is to restrict vehicle access by establishing controlled emissions zones. Over time these zones are likely to transition into zero tailpipe emissions zones, something which is already planned for areas such as Central London and Oxford in the UK. Other 'soft' policy mechanisms are emerging such as increased parking charges for (usually older) diesel vehicles and additional surcharges for driving older cars in cities.

However a risk associated with this type of local response is the creation of numerous local standards, making it increasingly difficult for consumers to comply. This pressure will be most felt by heavy duty fleet operators who may need to enter numerous cities across many jurisdictions. Therefore legislative harmonisation, at a national or supranational level, would be beneficial to ensure organisations can respect local legislation without incurring disproportionate costs.

In California the approach has been different. Instead various state governments have adopted the ZEV regulation which stipulates OEMs must sell a percentage of xEVs (electrified and electric vehicles) based on their sales across 10 US states. For 2018 the legislation requires approximately 2.5% of sales to be ZEVs and by 2025 it will require roughly 8% of sales to be ZEVs. If OEMs do not supply zero emission vehicles in the various states, they can face considerable barriers in selling other vehicles in that jurisdiction.

In the medium term, as vehicles become increasingly connected, smart cities may be able to communicate with electrified vehicles and turn their thermal propulsion systems off to ensure compliance with zero emission zones. In the longer term, as congestion increases and cities become space-constrained, cities will prioritise seamless mobility solutions that are space effective and can transport goods as efficiently as possible. This will benefit mass transit systems over personalised mobility and incentivise goods delivery methods that push very large vehicles further away from city centres.



1.3 THE WIDER ENERGY SYSTEM

The immediate priority for OEMs is to produce vehicles that meet tailpipe emission standards, with the potential impact this has on the energy system a secondary concern. However, as the number of PHEVs and BEVs increase, this presents two problems for the electricity grid, both of which could influence powertrain development.

The first problem concerns the ability of local distribution network operators to manage the increased electricity demand. Significant additional pressure could be placed on the distribution system, especially as battery capacity increases and 7kW home charging becomes more widespread. This impact intensifies in areas where there are 'clusters' of plug-in vehicles and could accelerate the need to reinforce local electricity grids (Electric Nation, 2018). One mitigation approach being investigated by the automotive sector is the use of vehicle-to-grid strategies which help manage demand but could result in more complex power electronics technologies, such as bi-directional chargers. This is currently being trialled by Nissan in the UK who are using vehicle-to-grid technologies in collaboration with Enel.

Other solutions to this challenge are load balancing, potentially using batteries removed from end-of-life vehicles, and smart charging. The former allows energy to be stored off-peak and then used to charge the vehicle on-demand without significantly increasing peak demand on the grid. The second allows the electricity supplier to manage demand, potentially using dynamic pricing to encourage charging during off-peak periods.

The second problem stems from the immature nature of the charging infrastructure. The first obstacle to mass market EV adoption is the ability to conveniently charge vehicles in areas where consumers do not have access to off-road parking. Potential solutions to overcome this obstacle have been installing charging stations in public lamp posts or inductive charging placed in strategic locations such as parking bays and traffic lights. The latter approach would also enable opportunity charging for taxis and buses but require investment in the road infrastructure.

Another obstacle to mass market adoption, which is an inconvenience to consumers, is the myriad of charging options and standards that have emerged which can frustrate early adopters. OEMs are now beginning to cluster around certain charging standards and form joint rapid charging networks (such as the IONITY charging

network in Germany) but no clear standard is emerging. Some companies such as Continental and Renault are trying to mitigate this issue by using the on-board power electronics to enable plug-in vehicles to use multiple charging stations, as seen in the Renault ZOE.

However whilst a significant proportion of road transport will be electrified, it's predicted that not all vehicles will be electrified within the next two decades. The energy system therefore requires other energy vectors to help power road transport, especially in locations where the electricity grid infrastructure is immature. In Brazil, for example, the high penetration of biofuels could encourage novel TPS architectures or solid oxide fuel cells (which can run on hydrogen reformed from the biofuel), whereas Japan's promotion of the hydrogen economy is stimulating the production of vehicles using Proton Exchange Membrane fuel cells.

Moreover heavy duty commercial vehicles and off-highway vehicles will also need alternative energy sources. The high power demands of battery electric trucks and construction equipment could put extreme pressure on local electricity grids as rapid charging will be desirable to minimise downtime. The combined demand from all such vehicles could be so great as to make battery electrification of the entire commercial vehicle fleet infeasible.

Finally the well-to-wheel impacts of vehicles is expected to be legislated as a first step towards full life cycle analysis, therefore the source of the fuel will be under greater scrutiny, putting more pressure on energy suppliers to decarbonise their generation. This raises issues for electricity generated by burning fossil fuels, and hydrogen reformed from fossil fuels.



1.4 CONNECTED AND AUTONOMOUS VEHICLES

CAVs could revolutionise powertrain and vehicle design through the transition to Mobility as a Service (MaaS, see section 1.5). Although this is expected to reshape personal transportation, for propulsion technology the impact is more likely to stem from a change in the vehicle ownership model and full autonomy, rather than connectivity.

CAVs are already used in the mining and agricultural sectors. For these and other heavy duty vehicles it is expected that the impact of CAV technology on the propulsion system will be mainly the addition of significant extra control functionality. For passenger cars, CAVs will provide an increasingly seamless experience between the consumer's personal smart technology and the one in the car. The impact on the propulsion system is currently limited to managing energy consumption, such as pre-heating of the vehicle and the setting of drive styles.

The growing availability of real-time accurate information about traffic, roads, charging infrastructure and other relevant conditions is increasingly used for vehicle energy management purposes. Zero tailpipe emissions-capable vehicles in low emissions zones are a good example of this, where geo-fencing technology will directly impact the control of the propulsion system, as demonstrated by the Ford Transit zero tailpipe emissions-capable vehicle project. Automatic transmissions are already beginning to use geographic data to inform gear change points. This type of data combined with other reasons for changing speed such as congestion or red traffic lights, will increasingly be used to inform the energy management decisions made by hybrid vehicles.

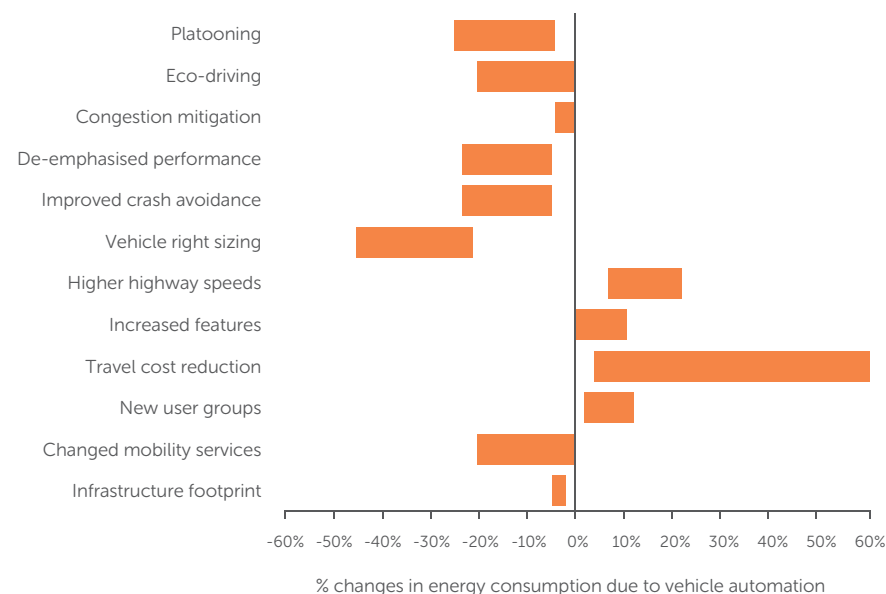
As autonomous features become more embedded in new vehicles, it will allow further light weighting and powertrain downsizing as vehicles will operate within a narrower operating window, reducing the need to cope with driver misuse. As the industry approaches Level 5 automation, it is also likely that the need for multiple powertrain specifications will be greatly reduced as powertrains will be rightsized for the service each CAV is performing.

In the very long term, as advanced CAV features are embedded into the majority of vehicles on the road, they are expected to have a profound impact on the propulsion system, primarily through greater reductions in vehicle weight from reduced crash and body

structures. This would in turn require significantly less energy, further reducing the vehicle weight leading to lower power requirements for the propulsion system.

Finally autonomy and connectivity will enable the propulsion system to be better utilised and integrated into wider energy system. For example through using the vehicle's fuel cell to power the home, power tools and other equipment or using the battery for grid balancing and other control purposes. Cities, local authorities and large organisations could also utilise CAVs to provide grid balancing services in times of peak demand.

Automated vehicle factors and their respective impacts on fuel consumption



Source: US Energy Information Administration, 2017



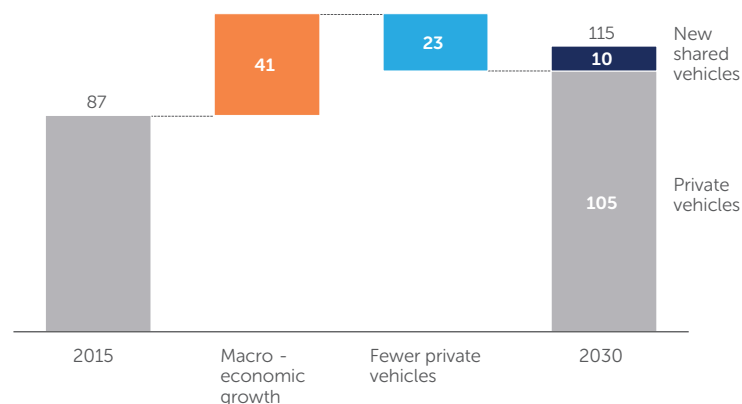
1.5 MOBILITY-AS-A-SERVICE

Mobility-as-a-service may not affect powertrain development in the short term but, as services mature, this could change the requirements for reliability and overall vehicle design, through changes to drive cycles and the operating environment. The underlying disruptor is a significant change to the vehicle ownership model, which is already underway through mobility companies in urban areas and leasing of vehicles for personal use.

Shared usage is expected to drive high levels of utilisation of the vehicle, which will have significant impact on the propulsion system, its lifespan and maintenance requirements. Requirements for high levels of vehicle utilisation (including grid services) are expected to influence the specification of the on-vehicle energy storage, its capacity and density. Moreover powertrains could increasingly become commoditised, as entertainment systems, comfort and appealing human machine interfaces are more likely to incentivise the usage of shared vehicle

In the long term, mobility providers could hold the connection to the end-customer and will therefore choose the propulsion system. Some OEMs might elect to become mobility providers, therefore becoming fully vertically integrated and controlling a larger proportion of the vehicle life cycle.

Current and future annual global vehicle sales, millions



Source: McKinsey, 2017





1.6 LIFE CYCLE REGULATION

Despite not being a regulatory requirement, life cycle analysis is already undertaken by a number of OEMs in order to assess the social and environmental impact of their existing vehicle platforms. However, as the focus shifts beyond tailpipe emissions, legislation to control the full environmental impact of vehicles will affect future decisions on powertrain technologies. Some life cycle legislation has already been enacted through regulation such as the European Union's End of Life Directive, but as yet its impact on low-volume alternative powertrain technologies has been minimal. However if regulators transition from discrete legislation on tailpipe emissions and recycling to more holistic legislation that controls the full environmental impact of vehicles, this will significantly influence future decisions on powertrain technologies.

Whole life emissions regulation is currently implemented by the industrial sector and it has been recognised that this presents issues for cross-sector industries such as transportation. A life cycle approach might be adopted after 2030 and is being considered by the EU. This is likely to include vehicle production, in-service life, disposal, end-of-life recycling as well as ensuring the materials can be reused as part of a circular economy. It could well include Green House Gas emissions and other external factors associated with vehicle manufacturing which will need to be addressed, such as waste materials, water use, land degradation and volatile organic compounds (VOC) emissions.

Today's electrified powertrain technologies depend upon a wide range of materials such as nickel, neodymium, cobalt, natural graphite and platinum which are not only costly but can incur a significant environmental and societal cost in their extraction. This will encourage the automotive industry to commercialise new powertrain components that can be easily recycled using environmentally friendly processes.



2 HOW TO USE THE ROADMAPS



2.1 ROADMAP CATEGORIES

The Automotive Council roadmaps track a range of technologies as they are researched, prototyped and improved. There are two categories of roadmap – Product roadmaps and Technology roadmaps.

PRODUCT ROADMAPS

(see sections 3 to 5 of this report)

Product roadmaps focus on the future of different products. The three product roadmaps are:



Passenger car



Bus



Commercial and off-highway

TECHNOLOGY ROADMAPS

(see sections 7 to 11 of this report)

Technology roadmaps focus on the future development of specific technologies. The five technology roadmaps are:



Electrical energy storage



Electric machines



Power electronics



Thermal propulsion systems

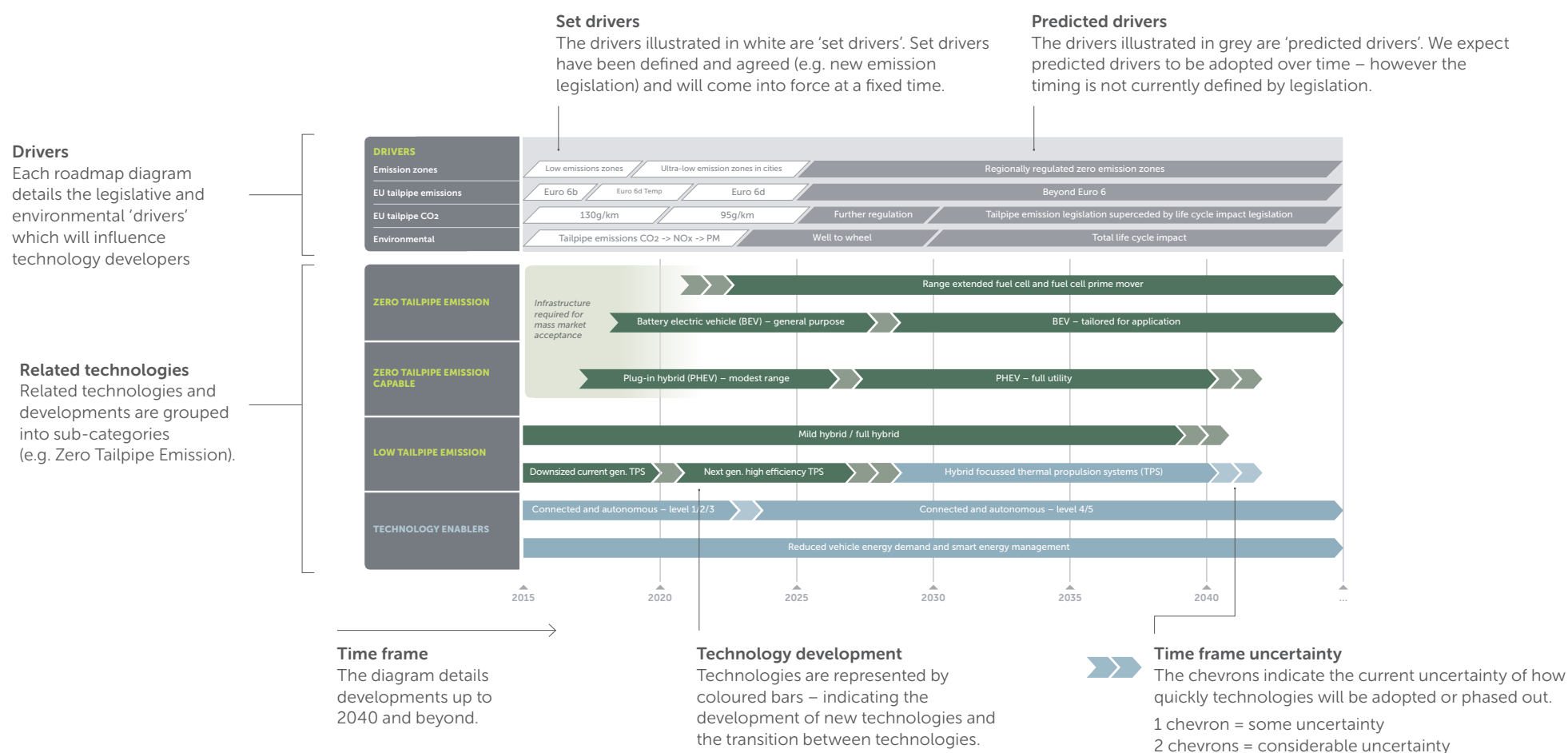


Lightweight vehicle and powertrain structures



2.2 ROADMAP DIAGRAMS

Each roadmap section in the report begins with a roadmap diagram. The roadmap diagrams show a condensed view of how different technologies will be influenced, developed and adopted over time. The predictions in the short term have higher confidence than those in the long term. Furthermore, highly disruptive technologies cannot be forecast with confidence and are therefore not captured.



2.3 PREDICTIONS AND SUPPORTING INFORMATION

Predictions and supporting information are included in each section to help organisations understand how the market will develop in the coming years.

PREDICTION: Rapid advances in lithium-ion technology could displace some existing battery chemistries but are also stimulating research into alternatives

5.1.4 MODULES, PACKS AND BATTERY MANAGEMENT SYSTEMS

PREDICTION: The desire for improved range, reduced cost and faster charging rates will stimulate innovative battery pack designs, increased packing densities and innovative cell-module-pack concepts

As the number of PHEVs and BEVs increase, battery packs will need to be manufactured in much higher volumes. Assembling battery packs cost-effectively at high volume has been identified as a key challenge. Current manufacturing facilities require high levels of cleanliness and have high "work in progress" costs due to conditioning requirements. Maximising the efficiency of existing manufacturing processes and labour was therefore deemed crucial in reducing costs in the short term. Moreover identifying areas where battery packs have been over-engineered and reducing the percentage of inactive material is also deemed a crucial research area as the industry moves to higher volumes.

In the longer term, it is envisaged that battery packs will need to cater for mixed cell types (i.e. a blend of high power and high energy density) or include super capacitors with the possibility of new concepts that blur the boundary between cells and modules. These may use existing manufacturing processes or require new ones to realise these new concepts.

PREDICTION: Advances in battery management, most notably to deliver improved thermal management strategies, will be required before battery performance can be extended.

Battery cells, whether traditional Li-ion or next generation chemistries, need pack-level management to ensure they can operate with maximised efficiency. Developments in battery management systems (BMS), and especially thermal management strategies, will make a significant contribution to improving safety and extending battery lifetime.

In time it's expected the BMS will transition from passively sensing at the module level to actively predicting performance and self-parameterising through data from sensors embedded within each cell, an advanced BMS also enables more targeted thermal management strategies, controlling the temperature of each cell so it can be individually optimised based on its condition. In the short term, it is predicted that tab and surface cooling strategies will be optimised using either air, water or glycol, but as cell chemistry advances, passive cooling systems could be utilised in which the battery is inherently thermally stable.

64 THE ROADMAP REPORT

2.4 SHORT, MEDIUM AND LONG TERM CHALLENGES

The five technology roadmap sections conclude with a summary of the short, medium and long term challenges which lie ahead for each technology. The summaries include analysis from the APC technology spokes and a table detailing the future challenges.

ELECTRICAL ENERGY STORAGE ROADMAP			
Identification of key research and pre-competitive development challenges to help facilitate academic / industrial collaboration on longer term product and manufacturing research and development			
Research Challenge	SHORT TERM (0-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (15-30 years to mass market)
1 Cost effective battery packs	All research challenges listed below imply efforts to reduce cost wherever possible, or demonstrate an improvement in performance that mitigates the increase in cost		
2 Improve safety	• Safer cells and packs, with improved cell-level fault containment	• Cell level solutions to make fault conditions benign, including thermal shut-down separators and sensors integrated into the cell	• Eliminating thermal runaway at a pack level by using electro-chemistries that are inherently stable
3 Fast charging capability for BEVs	• Pack charge rate capability to 1.5-2C	• Pack and cell charge rate capability to 2.5-5C	• Pack and cell charge rate capability to 5+ C
4 Increase power density for high power applications	• Combining hybrid Li-ion and ultracap cells in a pack • Utilise current materials and approaches to create cells tolerant to high power densities (i.e. blended silicon and carbon anodes)	• Reducing interconnect resistance • Mixed lithium ion cells that mix high power and high energy performance • Advanced cooling strategies in operation to achieve high power densities	• New materials (including graphene morphologies) for higher power and higher energy density capacitors (i.e. supercapacitors, pseudo capacitors)
5 Increase energy density in existing lithium-ion chemistry	• Improving existing electrolytes, electrode structure and cell packaging in known chemistries • Introducing elements into lithium based cathodes that enhance energy density (i.e. NMC-622 or NMC-811)	• Higher voltage (5V) electrolytes • Developing safety concepts for high voltage modules and packs	



3

PRODUCT ROADMAPS

PASSENGER CAR



Nissan LEAF



OVERVIEW

The 2018 passenger car roadmap acknowledges that tailpipe emissions (both CO₂ and pollutants) will be the main drivers of powertrain strategy in the short to medium term, with the emphasis moving away from outdated test procedures to more accurate and demanding simulations of 'real world' driving. A stratification of passenger car powertrain options is anticipated, with customers able to choose from a zero tailpipe emission vehicle or a selection of hybridised vehicles ranging from a mild to a plug-in hybrid. This section identifies and discusses the key technologies for each powertrain type.

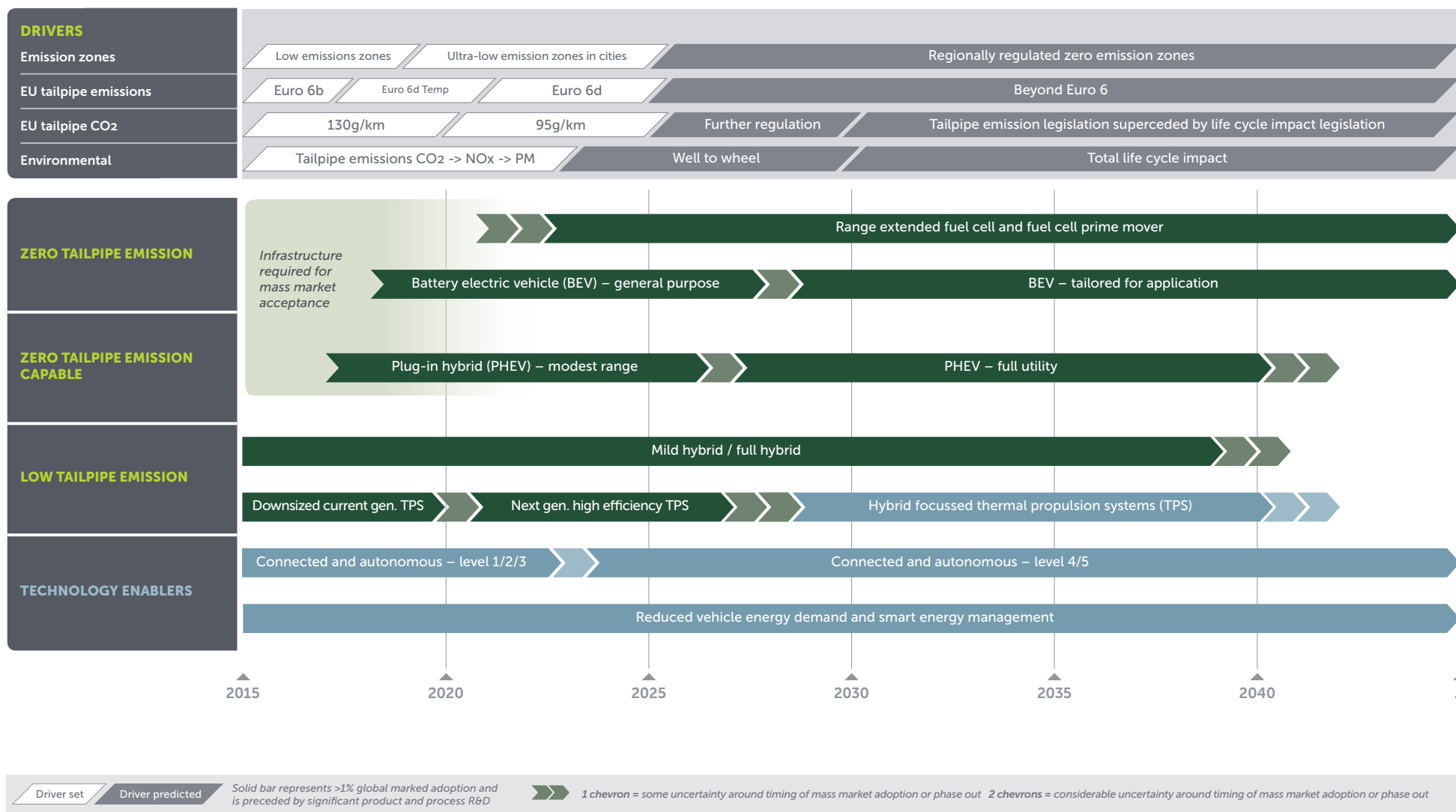
Tailpipe emissions (both CO₂ and pollutants) will be the main drivers of powertrain strategy in the short to medium term



Jaguar i-Pace



PASSENGER CAR





3.1 LOW TAILPIPE EMISSIONS

PREDICTION: Thermal propulsion systems will become part of a hybrid system, instead of the sole propulsion device

Thermal propulsion systems (TPS, largely internal combustion engines) for passenger cars are expected to evolve through more ambitious downsizing with higher levels of boost, advanced valve train control and more precise injection and breathing strategies to achieve higher efficiencies. However, in order to achieve low pollutant emissions, more sweeping changes, involving newer architectures and novel combustion cycles, are required. Examples include Nissan's variable compression ratio engine scheduled for launch in 2019 and Mazda's new HCCI engine accompanying their existing SkyActiv range.

These alternative TPS designs, though a significant departure from existing approaches, offer a cost-effective route to reducing tailpipe emissions in the short to medium term. They should help the TPS to transition from being the sole propulsion device to operating as part of a wider propulsion system, with their design optimised for operation in a mild, full or plug-in hybrid vehicle. Volvo's announcement of their aspiration to sell only electrified vehicles by as early as 2019 underlines the immediacy of this transition.



Prototype Mazda with SkyActiv-X engine

PREDICTION: In the short to medium term, mild and full hybrids are seen as a more cost-effective route to lower CO₂ and pollutant emissions than EVs

Mild and full hybrid powertrains differ mainly in their operating voltages; both can provide cost-effective solutions for reduced CO₂ and pollutant emissions but neither offers significant range nor performance in zero tailpipe emissions mode.

Full hybrid technology has mainly been adopted by Japanese OEMs, such as Toyota, Honda and Nissan, using economies of scale to reduce costs and offering full hybrid powertrains across their various product ranges. In contrast, mild hybrids seems to be preferred by European OEMs as they can be used in both diesel and gasoline thermal propulsion systems whereas full hybridisation is less compatible with diesel powertrains.

A strategy popular with OEMs is to supplement the standard 12V electrical architecture with a 48V system. This enables enhanced energy regeneration capability and allows the propulsion system to cope more effectively with the transient nature of city and urban journeys. Various mild hybrid architectures are possible, with the ones achieving higher efficiency gains requiring more fundamental vehicle changes. As mild hybrids become more sophisticated, it is expected that the TPS and the electrified components will need to be co-developed to achieve greater consistency of emission reductions.

Depending on policy, it is possible that both current mild and full hybrid architectures will eventually phase out as they do not offer consumers sufficient zero tailpipe emissions capability. Nevertheless some OEMs view full hybrids as a potential long term solution as they mitigate the infrastructure challenges associated with plug-in vehicles. However it was acknowledged that significant advancements in their on board electrical energy storage must occur if full hybrids are to achieve the zero tailpipe emission range required to navigate urban areas.



3.2 ZERO TAILPIPE EMISSIONS CAPABLE

PREDICTION: Plug-in hybrids, though providing some electric range, may need to evolve to ensure future compliance and greater zero tailpipe emissions capability

The sustained growth of plug-in hybrid (PHEV) sales has been driven by a mixture of local regulation manifesting in local emission zones, soft incentives, such as company car tax relief in the UK, as well as the ambitious supranational CO₂ targets set for 2025 and 2030.

Current generation PHEVs typically achieve a modest electric range of between 10 and 40 miles – which is enough to navigate an emissions zone but not adequate for inter-city driving. With today's technology, the choice of when to operate in electric mode is made manually, leading to variations in the utilisation of the electric capability. This questions the scope of the emissions certification and creates challenges in enforcing future zero emissions zones.

Current PHEVs have also proved challenging to perfect as integrating the electrical and thermal propulsion systems requires significant system engineering capability. This has led to heavier powertrains which contain separate cooling systems and more high voltage wiring compared to mild and full hybrids. However the larger battery capacity and power rating can enhance performance over other forms of hybrid vehicles.

In order to meet future regulatory standards, PHEVs are likely to evolve, increasing their electric range using batteries capable of delivering higher energy density and power density. A more abundant recharging infrastructure in urban areas will also drive uptake as consumers will be able to easily recharge and make the majority of their journeys using the electric range. In addition, improvements in city communication infrastructure could enable the intelligent charging of PHEVs ahead of entering a zero emissions zone, where the vehicle would then recognise it was entering a geo-fenced emissions zone and switch off the TPS. In the roadmap, PHEVs extend beyond 2040 as they offer zero tailpipe emissions capability.





3.3 ZERO TAILPIPE EMISSIONS

PREDICTION: Increasing the range is the short term priority for Battery Electric Vehicles (BEVs) but as range reaches an acceptable level, a shift to mobility business models could change their design

Battery electric vehicles (BEVs) produce no CO₂ or pollutant emissions at the tailpipe, however significant barriers to mass adoption are their greater up-front cost, limited range and recharging inconvenience compared to other powertrain options. Therefore in the short-to-medium term, the focus will be to overcome these three barriers so that BEVs are comparable to conventional powertrains.

However, as improvements take effect in battery, motor and power electronics technologies, the roadmap illustrates that range may no longer be the primary driver of BEV powertrain innovation. Instead, understanding the duty cycle becomes more important as new mobility business models may drive the development of vehicles tailored differently for specific applications.

In the roadmap, BEVs start to displace conventional propulsion systems in the next 5-10 years, assuming that they become cost competitive on a total-cost-of-ownership basis. BEVs are expected to dominate beyond 2040 but this depends on the availability of a sufficient charging infrastructure. The automotive industry must therefore work with the energy system operators to ensure BEVs (and PHEVs) are powered by a supply of sustainable energy. If emissions are to be based on total life cycle impact, a focus is also required on the use of materials, manufacturing and end-of-life processes for electric drives and batteries.

PREDICTION: Fuel cell vehicles need infrastructure investment and economies of scale of fuel cell stacks to stimulate mass market acceptance

Like BEVs, fuel cell electric vehicles (FCEVs) offer zero tailpipe emissions but mass market introduction is uncertain due to their relatively high purchase cost and immature refuelling infrastructure at present. Current sales volumes are measured in hundreds per year, well short of mass market levels (defined as 1% of global sales in the roadmap). However, the latest KPMG executive survey cited fuel cell technology as the top trend to 2025 and this is reflected in public announcements from OEMs such as Toyota, Honda, Hyundai, Daimler and GM. For example, Toyota maintain they are on track to manufacture 30,000 FCEVs by 2020 and Honda and GM committed \$85 million to build a new fuel cell manufacturing venture in southeast Michigan. From a powertrain perspective, significant cost reductions are required for both the fuel cell stack and hydrogen storage tanks, which are expected to come largely from economies of scale.

FCEVs could become more attractive if the costs of reinforcing the electricity grid becomes too high and a hydrogen infrastructure proves more cost competitive. FCEV uptake could be further simulated if hydrogen production can complement the electrical grid by storing surplus energy generated from renewable sources. In this scenario, fuel cell vehicles and refuelling stations could provide grid balancing services during peak demand.



3.4 ENABLERS

PREDICTION: Providing a resilient and seamless refuelling infrastructure will be a critical enabler for the mass market acceptance of vehicles with new powertrains

Mass market adoption of BEVs and FCEVs is highly dependent on introducing a refuelling/re-charging infrastructure capable of handling the significant energy demand from transport. However as the infrastructure is established, consumers must also be incentivised to change their refuelling behaviour to enable the transition to these powertrains.

Meeting environmental objectives for BEVs will require further reduction in the carbon footprint of electrical power generation. The same criteria apply for hydrogen powered vehicles such as FCEVs; a widespread network of refuelling stations will be required, supplied with sustainably generated hydrogen.

It is likely that transport will increasingly become part of a highly complex energy system. For electrification this not only means sufficient availability of re-charging points but also active demand management (the smart grid) to ensure that the electricity distribution network can be adapted cost-effectively.



Toyota Mirai being refuelled at an ITM Power station

PREDICTION: Existing principles of lightweighting and smart energy management will remain relevant to all powertrain architectures

In addition to powertrain related innovations, two broad strategies exist for reducing energy demand: reducing the energy required to move a vehicle (largely through weight reduction) and better utilisation of the given energy by improving efficiency.

Vehicle weight can be reduced through the use of innovative materials, better manufacturing processes and more efficient design but lightweighting must be considered against other concerns. It is important to assess the fuel economy/range improvements, emissions advantages and total cost benefit against the implications for crashworthiness and safety as well as the total life cycle impact.

A number of strategies exist for utilising energy more efficiently in the vehicle. These include: reducing electrical loads and improving energy conversions efficiencies; greater integration of vehicle systems such as heating ventilation and air conditioning systems (HVAC) and increasing the energy recovered during braking. As autonomous vehicles become more widely adopted, the increased energy demand from computing and sensors for autonomous operation will require careful management.

Vehicle weight can be reduced through the use of innovative materials, better manufacturing processes and more efficient design



PREDICTION: Connected and autonomous features will improve efficiency across all powertrain types but the more advanced stages of autonomy will impact PHEVs, BEVs and FCEVs the most

In the short term there will be a gradual adoption of driver assist functions and features that enable conditional autonomy; defined here as the vehicle managing specific aspects of driving like motorway driving. This could lead to improved real world powertrain efficiency and lower emissions through managing speeds or effectively navigating traffic.

As connected and autonomous vehicles (CAVs) become more advanced, achieving Level 4 and 5 autonomy, new vehicle ownership and usage patterns are likely to emerge which could encourage new design priorities, reflecting the different types of mobility. New operational models could emerge in which passenger vehicles are integrated with mass transit systems, though this would require effective communication between the vehicles and the road infrastructure. Such communication could also enable vehicles to efficiently manage charging and energy recovery, utilising V2X data to optimise driving strategies as well as routes and enforce zero tailpipe emissions zones.



Westfield autonomous pod



4

PRODUCT ROADMAPS

BUS



Volvo Electric Bus



OVERVIEW

The bus roadmap reflects the divergent technology strategies emerging due to the growing influence of air quality and zero tailpipe emissions operating zones. In the short to medium term, bus operators need a cost-effective emissions reduction solution for semi-urban and rural routes and a practical zero emissions bus for city centre and urban operations. In the long term, it is envisaged that the vast majority of new buses will become zero tailpipe emissions, enabled by new powertrain technologies and closer integration with intelligent transport systems.

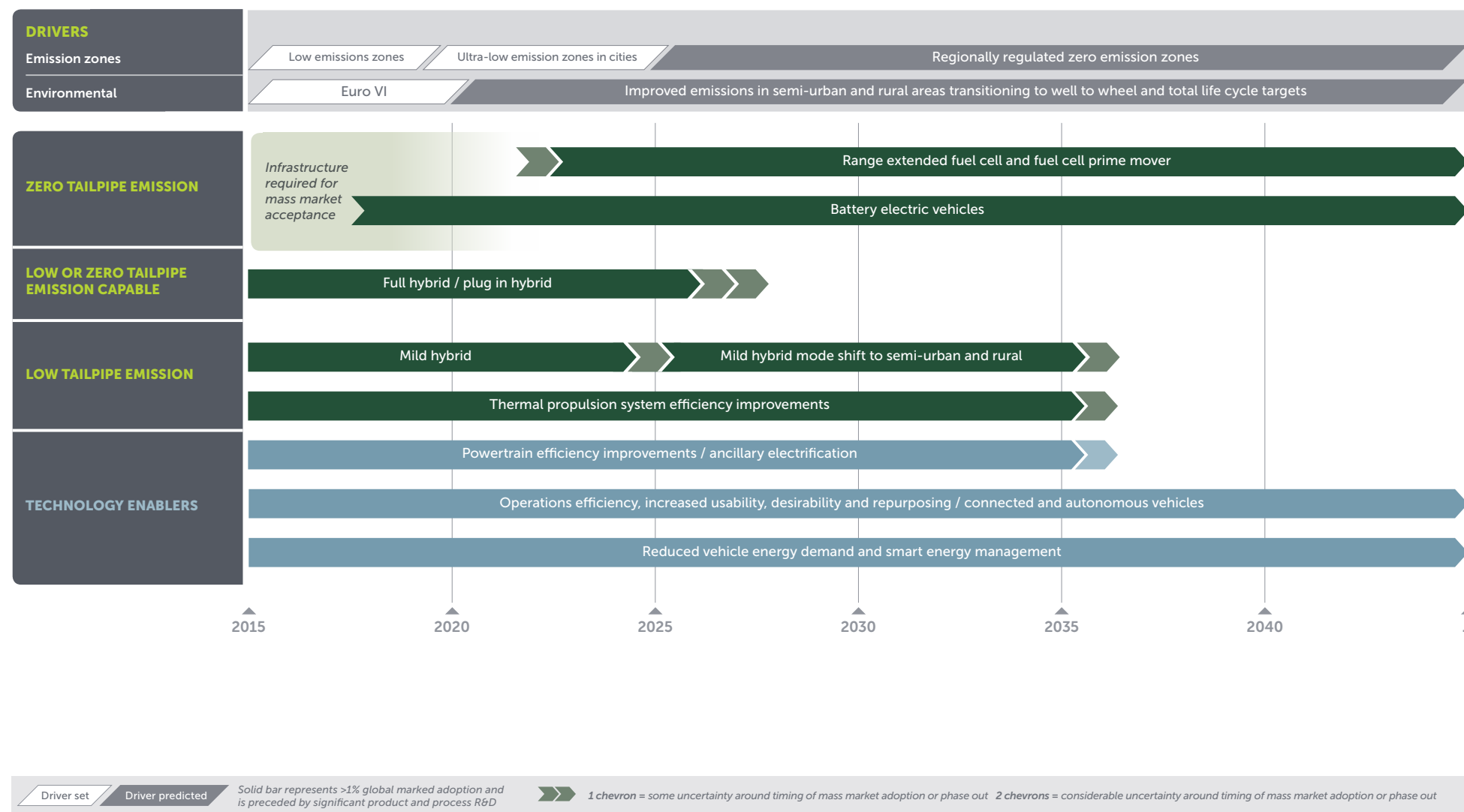
In the long term, it is envisaged that the vast majority of new buses will become zero tailpipe emissions enabled by new powertrain technologies and by integration within intelligent transport systems



Wrightbus Routemaster



BUS





4.1 LOW TAILPIPE EMISSIONS

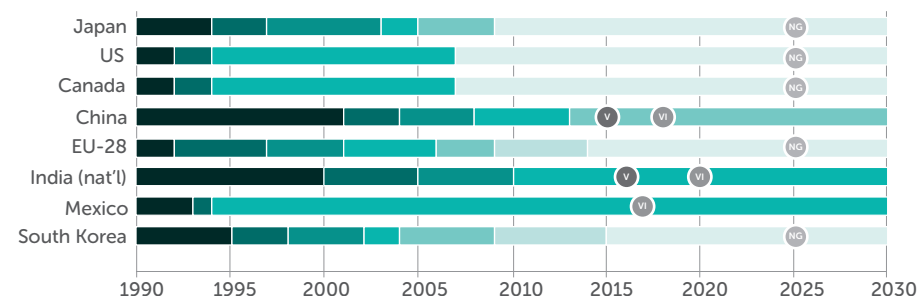
PREDICTION: While Euro VI standards have led to a step change reduction in emissions from diesel buses, the push towards zero tailpipe emissions buses will slow their sales

Historically, developments in TPSs for buses have largely centred on reducing pollutant emissions, with fuel economy and GHG regulation being introduced much later on (see graphs). In Europe, since emissions regulations were introduced for heavy duty vehicles, harmful emissions from buses using TPSs have been significantly reduced. Real-world testing undertaken by the Low Carbon Vehicle Partnership indicates Euro VI diesel buses have achieved around a 95% reduction in NOx from previous Euro V buses and are cleaner than the first generation Euro 6 diesel passenger cars. This is because the heavy duty standards were more comprehensive than the original Euro 6 passenger car requirements, requiring a far more capable and expensive aftertreatment approach. Euro VI heavy duty vehicles, including buses, are therefore fitted with urea seeded selective catalytic reduction and particulate traps to ensure real world emission reductions. More efficient aftertreatment technologies are also likely to deliver further tailpipe emissions reductions in the future.

Despite this step change, more stringent local regulation of toxic emissions is set to change the bus market. For example, the climate leadership group C40 Cities – comprised of the mayors of some of the world's largest cities – has pledged to procure only zero tailpipe emissions buses from 2025 and that only zero tailpipe emissions vehicles will be allowed to operate in some areas of their cities by 2030. Such initiatives will push diesel buses out of cities and eventually out of circulation, though they could still be used in rural and semi-urban areas as an intermediate solution.

In some specific cases, rural routes could utilise lower carbon fuels such as CNG, LNG or bio-methane as a longer term approach to reducing CO₂ if the electricity grid is not suitably reinforced or hydrogen stations are too widely dispersed. However, debate is ongoing as to how great a share of these cleaner fuels should be allocated to the bus sector, given the pressing need to decarbonise HGVs, marine operations and air transport. Localised production of sustainable fuels, such as creating bio-methane from farming waste in rural areas, could be one route to satisfy this demand.

HDD vehicle policy timelines (ICCT Bosmal 5/14)



Baseline standards ■ Pre-Euro ■ Euro 1 ■ Euro 2 ■ Euro 3 ■ Euro 4 ■ Euro 5 ■ Euro 6
Accelerated standards ■ Euro III ■ Euro IV ■ Euro V ■ Euro VI ■ NG Next generation

Source: Johnson Matthey, 2015

Estimated implementation timeline for heavy-duty vehicle efficiency standards

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Japan				PHASE 1					PHASE 2					
U.S.				PHASE 1					PHASE 2					
Canada				PHASE 1					PHASE 2					
China	PHASE 1		PHASE 2						PHASE 3					
EU								MONITORING, REPORTING	PHASE 1					
India									PHASE 1					
Mexico									PHASE 1					
S. Korea									PHASE 1					

Hashed areas represent unconfirmed projections of the ICCT.

Source: ICCT, 2016b

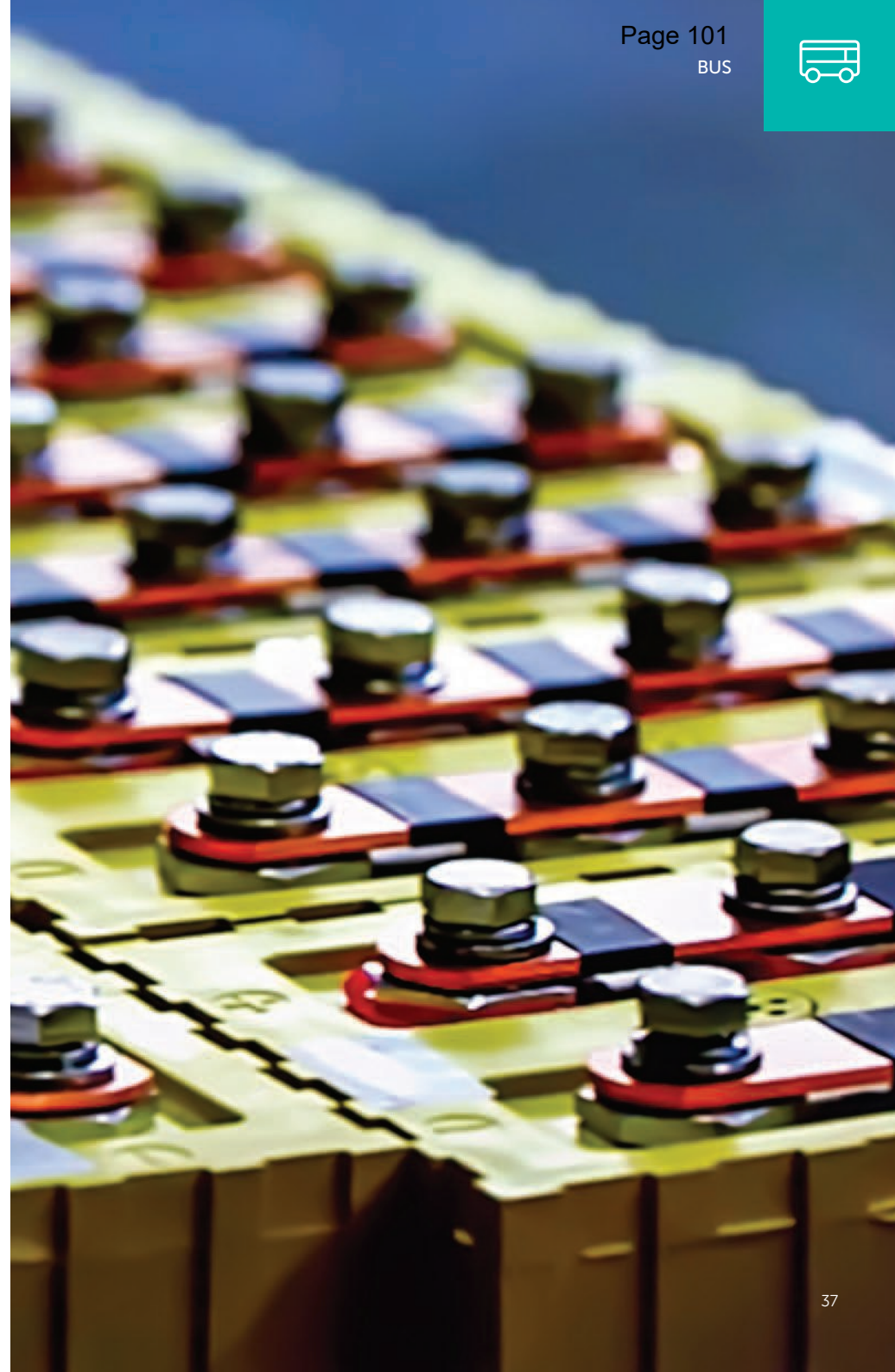


PREDICTION: Mild hybrid buses will face the same pressures as diesels in urban areas but are a cost effective strategy for reducing CO₂ and emissions on rural and semi-urban routes

Mild hybrids offer a low-cost route to reduced emissions by enhancing existing TPSs through energy recovery devices and higher voltage systems. Power dense batteries, supercapacitors and flywheels, together with torque dense electrical machines, have been common strategies to reduce the emissions from existing diesel powertrains. However, as cities begin to set up zero emissions zones and procure only zero tailpipe emission buses, demand for mild hybrids will fall. The roadmap indicates that mild hybrids may only be relevant in semi-urban and rural areas where there is a limited refuelling infrastructure and operators find it difficult to deploy zero emissions-capable buses.

Looking further ahead, it is expected that mild hybrids will eventually be phased out for two reasons. First, improvements in powertrain technology will enable zero emissions vehicles to operate across a broader area as the energy density of batteries increases and the cost of fuel cells falls, leading to cost-effective vehicles with greater range. Second, it is likely that MaaS could extend to semi-urban and potentially rural areas, reducing the requirement for traditional buses.

It is predicted that intelligent transport systems will be established by 2035, enabling semi-urban communities to become better integrated into existing public transport networks via shared ownership and autonomous vehicles. However, for this to be realised, both the energy and communication infrastructures in these areas need to improve. Bus operators will not only need access to clean, affordable renewable energy (either hydrogen or electricity) but for MaaS to operate effectively advanced connected and autonomous features need to function in rural areas.





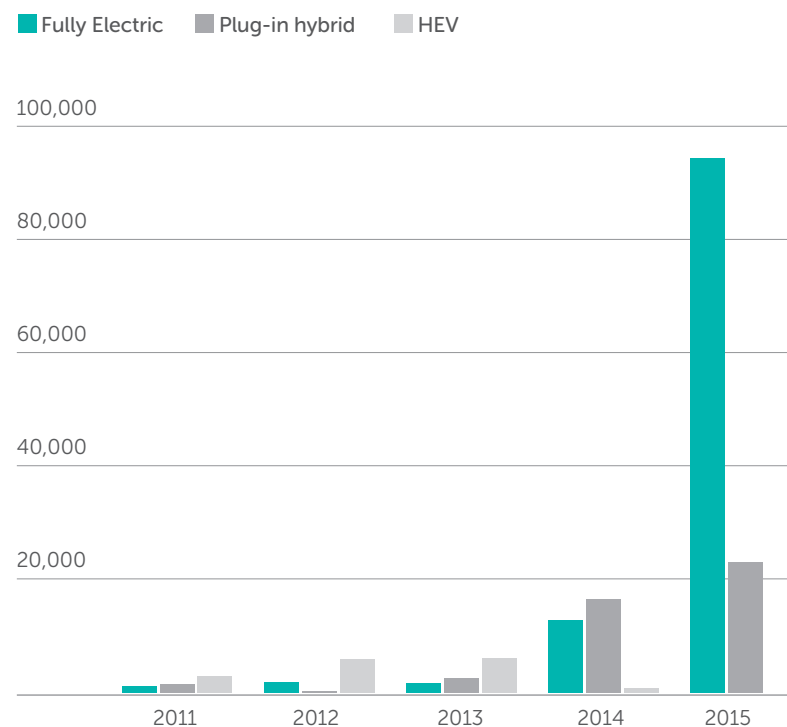
4.2 ZERO TAILPIPE EMISSIONS-CAPABLE

PREDICTION: Full hybrid buses are vulnerable to be phased out quickly as mild hybrids are more cost-effective, while the market for plug-in hybrids will erode as zero emissions options become more viable

Full hybrid and, to a lesser extent, plug-in hybrid buses will be phased out due to competition from better solutions. Improvements in diesel technology mean that full hybrids offer only marginal benefits over Euro VI diesels and mild hybrids, with the latter providing energy capture capability through regenerative braking in a similar way to full hybrids, yet without the cost, weight, complexity and service issues associated with high voltage full hybrid powertrains. Even the most advanced full hybrid heavy buses have insufficient electric range to make them practical for operation in zero emissions zones. On this basis, operators find it difficult to justify the high price premium of a full hybrid. Plug-in hybrids offer a zero emissions tailpipe capability of limited range, causing uncertainty over future demand for this solution.

The expectation is that the bus sector, heavily influenced by substantial subsidies in China and local regulation, could move rapidly towards zero tailpipe emissions vehicles in cities and lower cost mild hybrid vehicles in semi-urban and rural areas. The early signs from the Chinese market support this view; the graphic shows full hybrids were only bought in small quantities then largely phased out by 2015, whereas plug-in hybrids have increased in volume, but their increase is dwarfed by the growth in BEVs. While the uptake in China has been stimulated by subsidies, they provide a useful insight into the largest single market for low carbon buses and provide a helpful indication of the future direction that global demand may follow.

Electrified bus sales in China



Source: CleanTechnica, 2016

The expectation is that the bus sector, heavily influenced by substantial subsidies in China and local regulation, could move rapidly towards zero emissions vehicles in cities and lower cost mild hybrid vehicles in semi-urban and rural areas



4.3 ZERO TAILPIPE EMISSIONS

PREDICTION: The defined operating routines of buses make BEVs an attractive option but to generate significant sales outside China, their weight and cost must be reduced

The roadmap identifies battery electric buses as a long term solution to decarbonising the global bus fleet and improving air quality. A number of cities are already procuring fully electric buses but those on the roads today are mainly used in fleet trials or bought in relatively small volumes, such as Alexander Dennis and BYD jointly operating four BEV routes in London, and Proterra and New Flyer trialling five BEV buses each in New York.

An exception to this trend is in China where sales of BEV buses reached over 94,000 in 2015 and increased to 115,700 in 2016. This fast uptake was instigated by an ambitious bus electrification plan devised by the Chinese central government in 2009 and supported by national and regional subsidies. China's success is a positive sign for battery electric buses, however, the roadmap identifies a number of challenges in trying to reproduce the Chinese model globally without the corresponding subsidies.

A major challenge for fleet operators is the trade-off between vehicle range and weight. Companies can either opt for a larger battery pack that requires charging overnight, or a smaller battery pack that needs to be frequently topped up during the day through rapid and/or 'opportunity' charging. Larger batteries increase up-front cost and kerb weight and decrease passenger capacity due to the maximum axle weight limits imposed on buses. While opting for a smaller battery pack reduces these disadvantages, it introduces significant installation costs due to needing a rapid and/or opportunity charging infrastructure, however, this approach can increase passenger capacity. Whichever strategy a bus operator selects, increasing the uptake of BEV buses depends on improving battery technology and installing the appropriate recharging infrastructure.

If these barriers can be overcome, battery electric buses are likely to displace diesels and hybrids in urban areas. Where electricity costs are lower and routes are shorter, evidence from Bloomberg New Energy Finance's EV Outlook 2018 suggests that by 2019 battery electric buses in almost all charging configurations will have a lower total cost of ownership than conventional diesels. Total cost of ownership is more significant for buses than passenger vehicles because buses have much higher utilisation; in key metrics such as fuel costs, maintenance costs and durability, BEVs perform better than diesels and this has begun to influence fleet operators' purchasing decisions. Nevertheless, despite their promise for urban areas, challenges remain in commercialising BEV buses in rural areas where the lack of grid infrastructure and longer routes mean fewer opportunities for recharging.



BYD and Alexander Dennis electric bus



PREDICTION: Fuel cell buses, though more expensive than battery electric buses, could be more attractive for some operators because of their lower weight, longer range and shorter refuelling times

A number of distinctive benefits have driven the continued development and deployment of fuel cell (FC) buses. The focus of public-private partnerships across the world has shifted from isolated FC bus demonstrator fleets, supplied in small volumes, to delivering significant cost reductions through higher volumes.

In Europe, the proposed JIVE2 initiative aims to deploy 152 FC buses at a capital cost target of €625,000 each, representing a significant cost reduction from earlier models which were estimated at €1.2m to 1.6m each (E4tech, 2017). Despite this progress in market deployment, a number of barriers remain to FC bus uptake including the up-front costs, relatively large fuel tanks and lack of refuelling infrastructure.

Despite these issues, as technical innovation and higher volumes continue to reduce costs, there are opportunities for FC buses in urban areas. Their longer range and shorter refuelling times allow higher utilisation for bus fleet operators. The high initial cost of the refuelling infrastructure means, once installed, it will incentivise the accelerated uptake of FC buses in order to maximise the utilisation of the capital-intensive refilling station. Furthermore, as electrified buses become more popular in cities, FC buses provide the opportunity to reduce the strain on the electricity grid during peak times whereas additional BEV buses would increase the load, given their high charging requirements.

The roadmap therefore identifies BEV and FC buses as complementary technologies; both platforms share many common components and the appropriate technology for individual bus operators will be dependent on the local context and constraints. It is thought that FC powertrains are particularly suited to heavier buses, such as articulated or double-deck vehicles, covering either a high daily mileage or traversing challenging terrain that leads to high energy consumption.

A useful combination identified during the roadmap process was the FC range-extended BEV. This powertrain architecture uses a mid-sized fuel cell coupled with a downsized battery pack to reduce weight compared to a battery electric bus while also reducing cost compared to a normal FC bus, by downsizing the fuel cell and the (currently expensive) hydrogen storage requirement.



Hydrogen bus in London



4.4 ENABLERS

PREDICTION: Local electricity grids will need to manage the high power required for BEV charging; hydrogen refuelling stations will need high utilisation to make them viable

Mass market adoption of the next generation of buses is highly dependent on introducing a refuelling/recharging infrastructure capable of supplying the energy demanded. For both types of electric bus, the siting of the charging infrastructure is less of a challenge than for passenger cars as bus routes are predefined.

The issue for BEV buses is the cost associated with installing higher kW charging and the demand this will place on city infrastructures – especially during peak times and at high demand locations such as bus terminals. For FC buses, a limited number of hydrogen refilling stations are needed but the capital costs of installation are high (in the region of \$1 – \$5 million depending on the size), making fuel vendors reluctant to invest as the stations need high utilisation levels to make them viable. Clearly, maximising infrastructure utilisation through creating clusters of hydrogen vehicles such as buses, forklifts, delivery vans and HGVs, could accelerate adoption and create a stronger economic case for investment.



Volvo 7900 electric bus recharging



PREDICTION: While weight saving will be desirable to reduce propulsion energy demands, buses have numerous additional energy demands which could be minimised by smart energy management and auxiliary power units

Weight reduction for buses, especially BEVs, will be desirable through design optimisation and selective use of lightweight materials. Wrightbus and Proterra have already used composites in their buses to help compensate for the heavy battery packs. Considerable amounts of energy are used by bus HVAC systems, on-board entertainment features and ancillary power requirements, such as doors and lights. While electrification will allow an increasing range of auxiliary devices to be operated more efficiently, attention needs to be given to how these additional loads will contribute to reduced range in BEV buses. In recent years there have been various proposals for novel auxiliary power units, such as the heat batteries developed by Sunamp, to store and utilise waste heat to reduce the load on the thermal propulsion system or battery.

PREDICTION: Greater emissions reductions will be achieved by integrating buses more closely with existing transport networks to create intelligent transport systems that are more attractive to travellers

Evidence from a study conducted by MRCagney (2017) shows that, even at 20% capacity, a diesel bus produces approximately a third of the CO₂ emissions per passenger kilometre of the equivalent number of private vehicles. By increasing the desirability of buses through better HVAC systems, comfort, Wi-Fi connectivity and enhanced accessibility, a shift in travel habits could be encouraged that would bring significant emissions reductions.

With the advent of CAVs, buses will benefit from powertrain optimisation which is likely to significantly reduce operating costs and enhance the passenger experience. In the longer term, fully autonomous buses integrated into an intelligent transport systems will offer further cost and emissions benefits as operators are able to maximise efficiency as traffic flows can be greatly improved making buses a more attractive travel option.

However the key enablers in unlocking this opportunity will be the development of new business models and stimulating behavioural change. Greater use of buses could be incentivised through more attractive customer options and the ability to move easily from one transport mode to another. Therefore government and industry need greater awareness of customers' willingness to share data, use autonomous transport services and understand what factors will encourage people to forego journeys in personal vehicles.

PREDICTION: Increasingly modular approaches to powertrain and vehicle configuration will accommodate the repurposing of city buses for subsequent rural and semi-urban use, and increase the flexibility offered by BEV buses

Modular bus designs are increasingly being considered in order to accommodate the zero emissions requirements of city operation during 1st life use, followed by refurbishment and a powertrain change for a 2nd life in an inter-urban or rural environment. BEVs with modular powertrains will also enable bus manufacturers to match their products to particular range and duty cycle requirements. BEV manufacturer Proterra use a modular approach to vehicle configuration, offering customers an online simulation tool to select the right battery capacity and charging solutions to meet the needs of specific routes.



5

PRODUCT ROADMAPS

COMMERCIAL
AND OFF HIGHWAY



JCB E-TEC digger



OVERVIEW

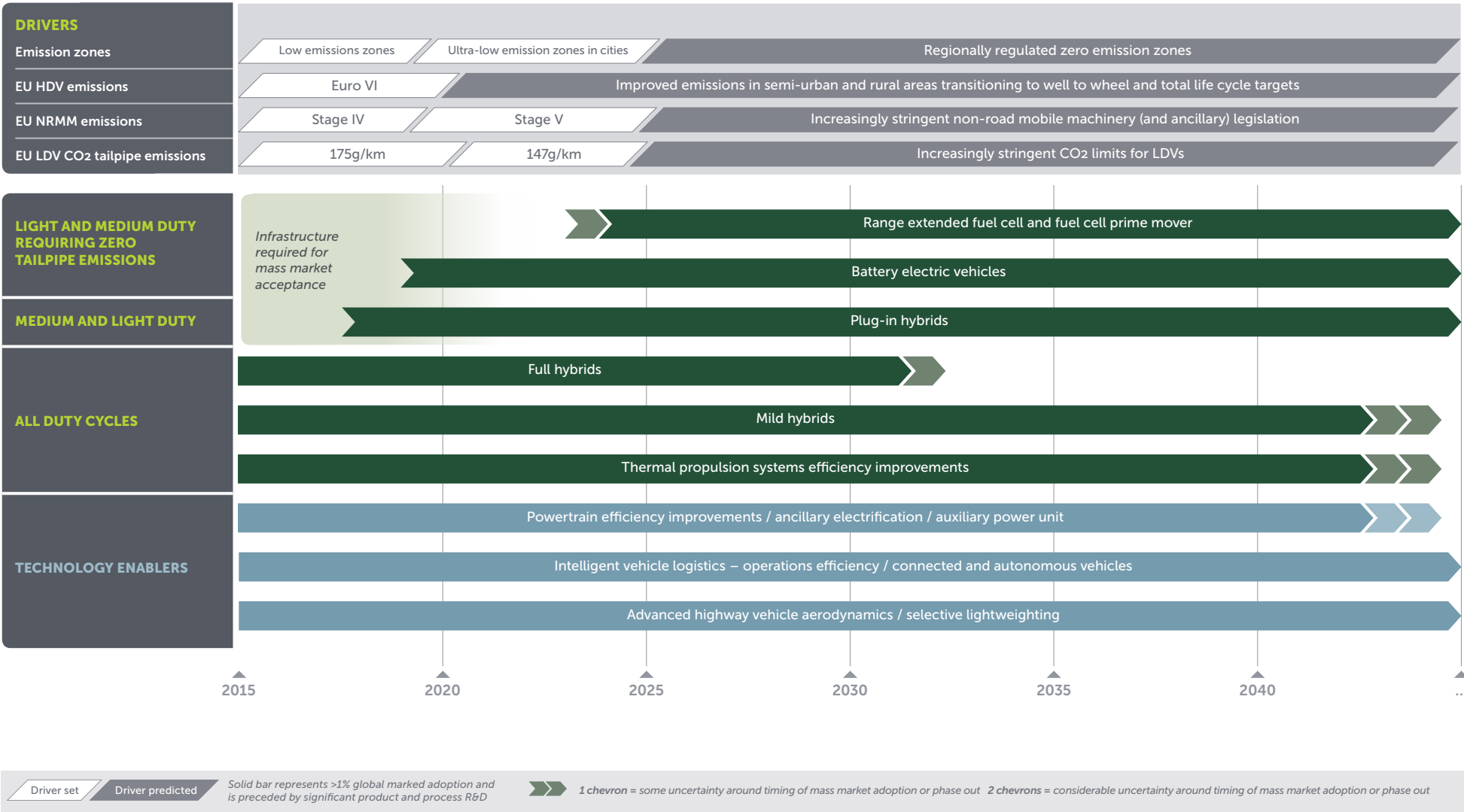
The commercial and off-highway roadmap contains a broad spectrum of different vehicle segments, ranging from long distance haulage trucks, mining equipment, forklifts to urban delivery vehicles. Whilst the duty cycles and operating cycles vary greatly, recent advances in hybrid technology, coupled with the growing influence of emissions operating zones, are effecting all commercial vehicle and off-highway technology choices. For heavy duty vehicles, or those operating in rural/semi-urban environments, strategies to fully decarbonise are challenging and expected to require a high efficiency TPS operating on a low carbon fuel with some degree of hybridisation. For smaller vehicles and those operating in urban areas, a zero tailpipe emission capability is required to comply with the expected emission legislation in cities.

Recent advances in hybrid technology, coupled with the growing influence of low emissions operating zones, are effecting all commercial vehicle and off-highway technology choices



DAF LF

COMMERCIAL AND OFF HIGHWAY VEHICLE





5.1 ALL DUTY CYCLES

PREDICTION: The TPS will continue to be a vital part of a commercial or off-highway vehicle due to its exceptional energy density and cost

Diesel powertrains deliver unrivalled power and performance for a range of medium and heavy duty applications, particularly for vehicles covering long distances or operating in remote zones. The introduction of the VECTO toolset by the European Commission is expected to provide operators with the means to objectively assess fuel saving technologies in this sector, which is heavily driven by total cost of ownership, and is expected to drive the uptake of the most beneficial technologies. Moreover, the European Commission has now published proposals for a 15% reduction in CO₂ emissions by 2025 and a 30% reduction by 2030, all relative to a 2019 baseline which mirrors other jurisdictions such as Japan and the US.

The solutions in the roadmap rely on technologies that reduce both harmful and GHG emissions; these include advanced after treatment systems, waste heat recovery and the electrification of ancillaries with mild hybridisation. 44 tonne heavy duty trucks currently provide the majority of long range haulage and are the most significant energy consumer; electrifying these vehicles using batteries will be difficult technically and commercially even if battery technology continues to improve. Overhead charging, as proposed by Siemens, and fuel cells, as proposed by Toyota, might provide longer term options if the significant infrastructure barriers can be overcome.

The difficulties of fully electrifying long haul trucks and heavy machinery opens up the possibility of commercialising radical thermal propulsion systems that offer a step change in brake thermal efficiency. One example offered was a split cycle combustion system, whereby one cylinder is used for intake and compression, and another for power and exhaust which facilitates efficient exhaust heat recovery and differential compression/expansion.

PREDICTION: Large off-highway machinery must harness the transient energy that would otherwise be wasted during typical operating cycles

Off-highway machinery is of considerable importance to UK manufacturing but has been identified as a significant contributor to pollutant emissions in certain urban areas. This has triggered more stringent legislation covering Non-Road Mobile Machinery (NRMM) emissions. The often heavily transient duty cycles of these machines are not well-suited to diesel and provide significant after-treatment challenges for pollutant control. However this duty cycle does provide significant energy recovery opportunities, therefore, technologies that provide a return on investment, increase productivity and do not negatively impact the residual value are expected to prevail.

PREDICTION: Mild hybrids can cost-effectively reduce fuel consumption and therefore CO₂ through varying degrees of electrification and a range of kinetic energy recovery systems

Heavy and medium duty trucks are technically the most suitable categories for partial electrification, especially as vehicle manufacturers need to meet more challenging decarbonisation targets. It is expected that the cost-effectiveness of mild hybridisation will see it become the standard route to reduced fuel consumption for most trucks; greater depth of electrification, and therefore the degree of torque assist and energy recovery possible, is likely to be determined by the duty cycle in which the vehicle is most frequently operated. Mild hybridisation is particularly effective in reducing the heavy transients that greatly increase both the emissions and fuel consumption of off-highway diesels.

In addition to electric hybrid solutions, mechanical energy recovery using advanced flywheel systems could offer a cost-effective alternative for commercial and off-highway vehicles operating with a repetitive duty cycle.



5.2 MEDIUM AND LIGHT DUTY

PREDICTION: Some medium and light duty vehicles will require a zero tailpipe emissions capability but their diverse drive cycles will require an additional power source

Certain commercial and off-highway vehicles will experience both inner city and long distance operation, requiring two power sources. Coaches and medium duty construction could prove challenging as they cover long distances, or experience sustained periods of work, but will also operate within urban emissions zones. Some light duty vans will also require an additional power source until battery technology reaches a sufficient energy density to cover the required distances. Therefore a plug-in hybrid or range extender seems the most viable option for these vehicles in the short to medium term. To ensure compliance with emissions zones, some form of geo-fencing function will be needed, as seen in the Ford Transit PHEV being trialled in London.

To ensure compliance with emission zones, some form of geo-fencing function will be needed, as seen in the Ford Transit PHEV being trialled in London



Ford Transit PHEV

5.3 MEDIUM AND LIGHT DUTY REQUIRING ZERO TAILPIPE EMISSIONS

PREDICTION: The powertrains used in zero tailpipe emissions light duty commercial vehicles will closely resemble those used in passenger cars

Light duty commercial vehicle technology (below 3.5 tonnes) is driven by EU pollutant emissions standards and fleet average CO₂ standards and is therefore likely to evolve in the same direction as passenger cars. Early market developments indicate that for zero emission vehicles, a number of components will be shared between cars and vans. Nissan and Renault utilise the battery pack and electric drivetrain from the LEAF and ZOE for the e-NV200 and Kangoo Z.E respectively. This commonality enables OEMs to quickly introduce zero emissions van platforms without incurring additional development costs.



LEVC's TX5 being recharged

PREDICTION: Demand for zero tailpipe emissions commercial and off-highway vehicles will be driven by the growth of urban zero emissions areas and the frequency with which vehicles enter such zones

Cities are powerful authorities that can instigate change quickly in response to direct challenges such as air quality; London, Paris and Oslo are good examples of where the need for low or zero tailpipe emissions vehicles drives the market towards a significant uptake of alternative technologies. Cities can also exert influence through various mechanisms including public procurement, incentives, parking charges and emissions charges. Local government activism in this area is encouraging, however, it requires effective management from national and supranational legislatures (see section 1.2).

For commercial vehicles, BEVs and FCEVs are likely to be popular solutions in situations where vehicles will predominately operate in an emissions restriction zone or where the duty cycle is predictable. Their continued uptake will depend on total cost of ownership, vehicle utilisation and easy access to the relevant energy infrastructure.

There is also significant scope for zero tailpipe emissions vehicles in smaller non-road applications that operate in confined spaces (such as underground mines) or in local emissions zones. In response to urbanisation and greater awareness of air quality, JCB has developed a 1.9 tonne fully electric excavator with fast charging capability to work in urban areas and under mines. Warehouses have also been early adopters of hydrogen fuel cell forklift trucks, as they can deliver significant benefits over diesel and electric powertrains when considering the total cost of ownership.



5.4 ENABLERS

PREDICTION: Increased operational efficiency and productivity could be achieved through intelligent vehicle logistics, irrespective of powertrain type

Regardless of powertrain type, managing fleets of vehicles so they consume less energy will be required in order to minimise emissions and reduce fuel costs. Therefore the focus of legislation may shift to g/CO₂ per ton/km which means optimising vehicle loading via advanced logistics so all commercial vehicles operate at close to full capacity.

Improved, smart and connected logistics has the potential to contribute through route optimisation and congestion avoidance, but this has so far not materialised as an emissions reduction tool. Increasing transport costs are expected to stimulate further investigation into these approaches as part of the drive for improved productivity.

Advanced autonomous features are already used in some off-highway vehicles in the agricultural and mining sectors. This has removed the need for humans to work in dangerous environments, improving safety and operational efficiency. Longer term it is expected that CAVs will impact commercial vehicles by improving platooning efficiency, regulating speeds and optimising powertrains for maximum fuel economy. Fleet owners also gain operational benefits if drivers can obtain rest credits when not driving in a platoon.

Longer term it is expected that CAVs will impact commercial vehicles by improving platooning efficiency, regulating speeds and optimising powertrains for maximum fuel economy

PREDICTION: Increasingly stringent local legislation on emissions, safety and noise may influence the size of vehicles

As more stringent local legislation on emissions, safety and noise are introduced, larger vehicles may be slowly phased out of inner city areas to make way for smaller vehicles. Smaller vehicles are not only easier to electrify, but they can improve the safety of pedestrians. For commercial vehicles this could facilitate the creation of new business models with a potential approach being a 'hub and spoke' delivery model. In this approach, larger vehicles enter the outskirts of a city at a delivery node and smaller zero tailpipe emissions vehicles deliver goods inside the city limits. However organisations such as Transport for London have identified that the proliferation of many smaller vehicles may increase congestion so the increase in smaller vehicles will need to be managed to minimise congestion. For off-highway vehicles, increasingly localised legislation is driving manufacturers to move away from a one-size-fits-all machine to developing more bespoke vehicles. These bespoke vehicles will typically be low carbon and emissions to meet the new legislative drivers. As more off-highway vehicles become autonomous, driver cabins and comfort features can be eliminated offering further opportunities to create smaller more efficient vehicles.



Arrival T4 Hero



PREDICTION: Improved aerodynamics, selective weight saving and other technologies provide attractive routes to reduce CO₂ emissions in certain vehicle classes

CO₂ emissions and other pollutants from commercial vehicles can be reduced by minimising the energy consumed for propulsion through reducing tyre friction, aerodynamic drag and the effects of vehicle weight. Designing vehicles for platooning, especially for long haulage trucks on selected motorways, deliver some immediate efficiency gains, as demonstrated by recent trials by the UK government.

Weight reduction is a promising route for improving fuel consumption but the benefits are not uniform across all commercial and off-highway vehicle platforms. In some instances, customers may profit from increased weight due to enhanced stability, especially in vehicles such large backhoe loaders and excavators. However there is a trend of selective lightweighting of certain components, such as excavator arms, which then allows larger amounts of material to be lifted. The VECTO software toolkit from the European Commission is expected to lead to greater awareness and adoption of the latest technical approaches.

Weight reduction is a promising route for improving fuel consumption but the benefits are not uniform across all commercial and off-highway vehicle platforms

PREDICTION: Apart from propulsion, many heavy duty vehicles have significant auxiliary and ancillary energy demands; managing these more effectively could greatly reduce pollutant and CO₂ emissions

The electrification of ancillary and auxiliary power systems presents a further significant opportunity for improving the energy efficiency of commercial and off-highway vehicles. For many vehicles, these functions represent a substantial energy consumption at relatively low efficiency levels. Heavy duty vehicles could potentially utilise a zero emission auxiliary power unit (APU) allowing the engine to be switched off and ancillaries to still receive power e.g. refrigeration trucks or cement mixers. It is expected that increased electrification will be of most benefit to those vehicles with relatively modest, mostly urban duty cycles, particularly those operating in low emissions zones or at night.



Dearman engine



6

TECHNOLOGY ROADMAPS – CROSS CUTTING THEMES AND THEIR IMPLICATIONS



During the roadmapping process, a number of overarching themes emerged, demonstrating important cross-links between technologies.



6.1 HIGH VOLUME AND LOW VOLUME MANUFACTURING

PREDICTION: Technologies used for high volume passenger car manufacturing will largely take a different route to those for lower volume and bespoke vehicle applications, yet there is considerable potential for knowledge transfer between the sectors

The development of electrified powertrains and weight saving technologies for high volume passenger vehicles will take a different development path to smaller volume vehicles such as performance cars, trucks and buses, where the differing duty cycles, customer requirements and cost sensitivities will drive varied technical solutions.

The technology roadmaps for electrical energy storage, electrical machines, power electronics and lightweighting all contain targets that relate to high volume passenger cars because this sector will be largely responsible for driving cost reductions and manufacturing innovation in these technologies. Away from high volume passenger cars, other attributes are valued more highly (such as peak performance and reliability) and these will drive the technology choices. For example, while a high volume passenger car requires energy-dense batteries and cost-effective electrical machines, luxury passenger vehicles and sports cars will tend towards high-power electrical machines and specialised batteries.

The exception to the low/high volume distinction is the TPS roadmap where the split is based on duty cycles. For light duty cycles, encompassing all passenger cars and buses, the dominant short-medium term solution will be an increasingly hybridised TPS, whereas heavy duty applications, such as long distance trucks and off-highway machinery, will require more thermally efficient TPSs. Nevertheless, there remains the potential for the transfer of technologies, such as advanced battery management systems, from motorsport and performance vehicles into high volume passenger cars.



6.2 INTEGRATING POWERTRAIN TECHNOLOGIES

PREDICTION: Optimising the whole powertrain as a single system will be vital for maximising vehicle-level efficiency improvements

While the individual technology roadmaps provide a commentary on the potential evolution of specific technologies, this approach may overlook nuances and potential synergies between complementary powertrain technologies. Perhaps the strongest theme underlining all of the technology roadmapping workshops was that maximum powertrain and vehicle efficiency will only come from optimising the separate technologies coherently as a whole system.

Certain technologies demonstrate strong interaction, so the specification and performance criteria of one technology will significantly influence another. For example, understanding the optimum calibration for a TPS in a hybrid vehicle requires knowledge of the loads the electrical machine and its interaction with the transmission. This awareness enables the electrical systems to more effectively reduce ancillary engine loads whilst maintaining or improving performance. Fully electric drives also demonstrate great opportunity for closer integration and are being explored by GKN Driveline's ACeDrive project, funded by the APC. The project will integrate the core functions of an e-Drive system, reducing the number of connecting components while using a high frequency inverter, enabling a higher-speed, smaller, lighter motor and advanced cooling, yielding greater system efficiency.

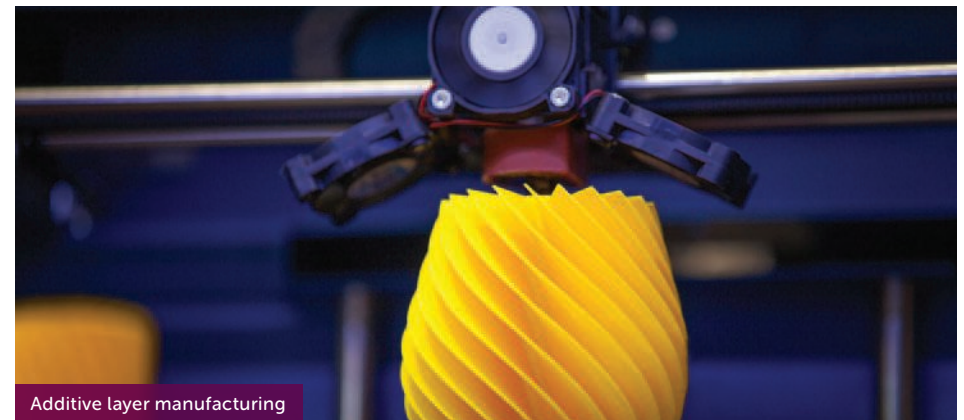
The strongest theme underlining all of the technology roadmapping workshops was that maximum powertrain and vehicle efficiency will only come from optimising the separate technologies coherently as a whole system

6.3 IMPROVED MODELLING, SIMULATION AND TESTING

PREDICTION: Utilising better modelling capability, simulation and virtual testing will improve performance and shorten product cycles

The Virtual Product Engineering roadmap published by the Automotive Council in 2016 described the importance of improved modelling and simulation. The roadmap identified that advances in computing power, increased validation in a virtual environment and reducing the time from initial concept to production are all vital for improving productivity and vehicle energy efficiency.

In each technology area, the use of advanced modelling techniques and design tools could improve existing technologies and accelerate the uptake of new ones. Multi-physics modelling, for example, enables multiple phenomena, such as thermal, electrical and mechanical characteristics, to be simulated together which is crucial in accelerating the development of individual powertrain technologies. Improved virtual design allows better system integration and identifies optimal manufacturing routes as individual technologies can be coupled together in a virtual environment, assessed to better understand the system-level trade-offs, then re-engineered to deliver powertrain-level benefits.



Additive layer manufacturing



6.4 NEW MANUFACTURING PROCESSES

PREDICTION: Utilising new manufacturing techniques could provide a step change in cost reduction through higher levels of automation, or enable more complex designs through techniques such as additive layer manufacturing

New manufacturing processes and advanced manufacturing techniques will be key enablers for both increased productivity and the manufacture of new powertrain technologies. A short term trend is to develop manufacturing innovations alongside products, going beyond the traditional 'design for manufacture' ethos in which product innovation is constrained by existing manufacturing techniques. This approach can apply to both new powertrain component types as well as established products, such as fuel injector systems.

Automation, though already widespread in the automotive industry, could be applied further. For example electrical machine manufacture requires high levels of precision to perform complex procedures, such as coil winding. In the APC HVEMS project, automated manufacturing equipment from the medical industry is being used to achieve the high levels of accuracy required for machine assembly processes.

Additive layer manufacturing was also identified as a key enabler across all of the technology themes, due to its ability to create complex shapes, reduce parts count, integrate functions and reduce manufacturing process steps. However, the technique is currently only used in relatively small volumes such as motorsport; significant cost reductions are needed for it to be used for higher volumes. Other advanced techniques have been identified as promising, such as metal injection moulding, cold forging and tailoring existing steel manufacturing processes to suit other materials.

6.5 LEARNING FROM PARALLEL SECTORS

PREDICTION: Applying expertise, technology or manufacturing processes from parallel sectors could ease the automotive industry's transition to new powertrains

Collaboration with other sectors, such as aerospace, chemical or power generation, could accelerate the commercialisation of many new powertrain technologies. This could include utilising known manufacturing procedures from other industries, using cutting-edge technology from aerospace or motorsport whereby automotive applications serve as a test-bed to reduce costs, or leveraging expertise from the software industry to improve design. A number of specific examples of these points have been identified.

First, the manufacturing processes used to make paint and pigments are relatively similar to those used in battery chemicals so sharing this expertise with the automotive industry could help advance both sectors. Second, next generation power electronics and lightweight materials used in aerospace, motorsport and power generation show massive performance increases over current automotive technology.

The roadmap workshops examined how these advanced technologies could be adapted to fit automotive requirements. The electrical machine workshop recognised that next-generation machines will require materials scientists to help e-machine designers make the best use of unfamiliar materials. Finally, it was identified that the current shortfall in software engineering capability in the automotive sector could be mitigated by collaboration with industries such as gaming; their software expertise and design tools could enable more accurate simulation and the construction of more complex models, with virtual reality already delivering some case study examples.



6.6 LIFE CYCLE ANALYSIS

PREDICTION: Each technology will be subject to greater life cycle analysis, with electrified powertrains facing particular scrutiny

Ensuring the sustainability of all future powertrains and vehicles will be a crucial long term driver for the automotive industry. Even in the short to medium term, well-to-wheels analysis will become more important as consumers become more aware that the energy needed, both to produce and fuel new powertrains, may not be carbon neutral. In the long term, it will be important to ensure powertrain systems are designed for disassembly, manufactured using recyclable materials, manufactured using energy from low carbon sources and have little negative impact on the local environment. In fact, a full life cycle analysis incorporates more than just carbon, including water use, VOC emissions, land degradation and the wider social impacts of a manufacturing site. This may benefit some technology choices over others.

The manufacture of electrified powertrains will result in a greater use of both rare-earth and politically strategic materials. Extracting these materials and manufacturing components such as the batteries and e-machines will generate significant amounts of CO₂ and other pollutants, which impact on their sustainability. This emphasises the need to commercialise cost effective end-of-life recovery processes to ensure a circular economy is established.

Finally, while existing body structures are largely recyclable by established processes, future body structures will increasingly use materials (and intimately mixed combinations of materials) that currently do not have robust recovery and reuse processes. Moreover existing materials such as steel have relatively low environmental impacts in their production, whereas other materials, such as virgin aluminium and carbon fibre, currently have a larger environmental footprint.



Cross-section of a Nissan Leaf



MTC automated machine

6.7 FLEXIBLE AND CONNECTED SUPPLY CHAINS

PREDICTION: Mobilising a UK supply chain that can deliver competitive costs and higher productivity for electrified powertrains will require significant manufacturing innovation

While technology innovation creates new opportunities, it also threatens the existing supply chain. To ensure sustainable economic growth, today's strong UK automotive technology supply chain must adapt quickly. Numerous workshops articulated the risks associated with scaling up new technologies where market demand is currently low but predicted to sharply rise. Reference was made both to the ability of companies to push technology development so it's ready to be integrated into a vehicle platform as well as the capability of new supply chains to meet future demand.

A recurring theme, offered as a potential solution to the problem, is the need for flexible, low volume manufacturing facilities that can manufacture new technologies for trials and low-volume production vehicles, allowing in-field experience and process validation prior to integration with a high volume vehicles. As innovation in manufacturing is key to both productivity and product performance, ensuring that a high degree of expertise is developed and maintained in the UK will be vital to the delivery of next-generation products. Without this, the UK risks constant reliance on imported tooling and processes, continually having to adapt to other nations' manufacturing methods and unable to stay ahead of developments.

As innovation in manufacturing is key to both productivity and product performance, ensuring that a high degree of expertise is developed and maintained in the UK will be vital to the delivery of next-generation products



7

TECHNOLOGY ROADMAPS

ELECTRICAL ENERGY STORAGE

WMG battery facility

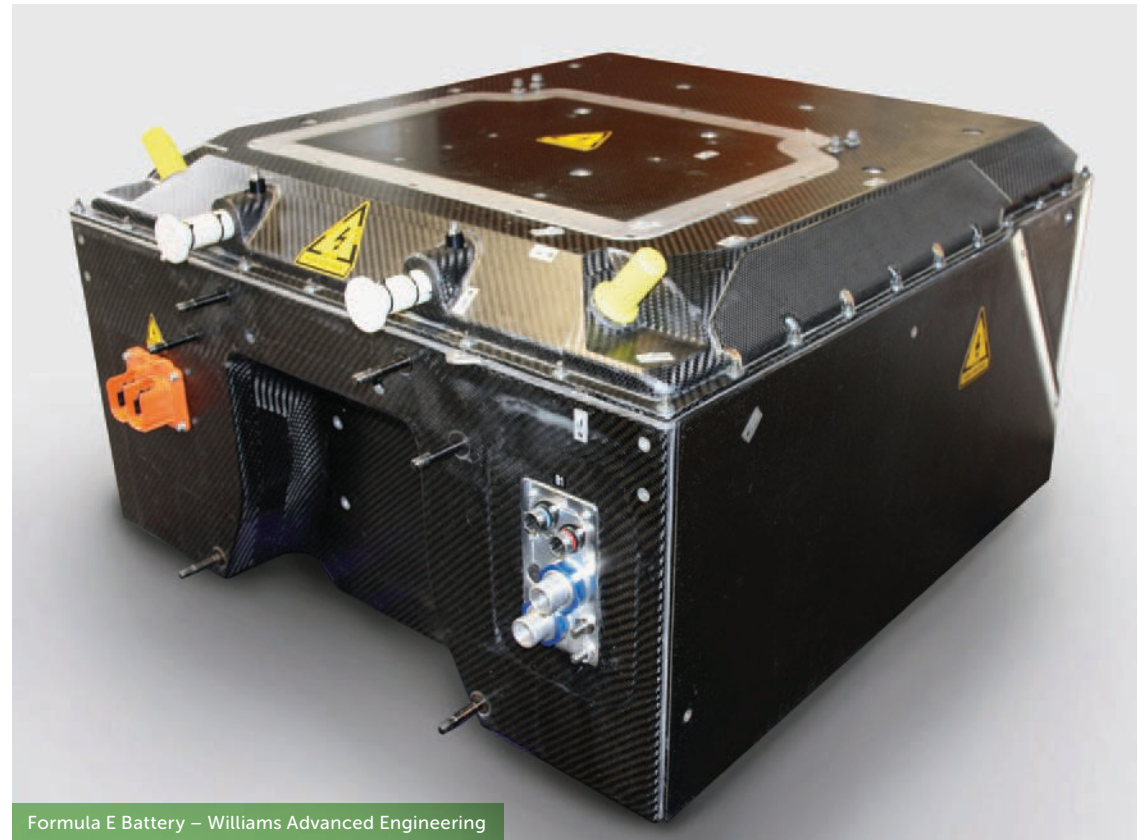


OVERVIEW

Existing lithium-ion (Li-ion) batteries* are likely to dominate the market throughout the current vehicle cycle and the next. In order to reach the challenging roadmap targets set for 2035, better cell chemistry, battery management and manufacturing processes will have to be developed and commercialised to improve energy density, power density and cost.

Whether the cells are traditional Li-ion or next-generation chemistries, they need to be assembled into modules and packs to make them usable for OEMs, so pack-level innovations are equally important for the industry to progress. Manufacturers will also need to develop packs that can accept the higher charging rates being developed, without considerably degrading pack performance.

One of the biggest long term challenges in establishing a sustainable battery supply chain is minimising the life cycle impact of battery manufacturing. A key risk identified in the roadmap is the current absence of a sustainable, high volume solution for end-of-life recycling.

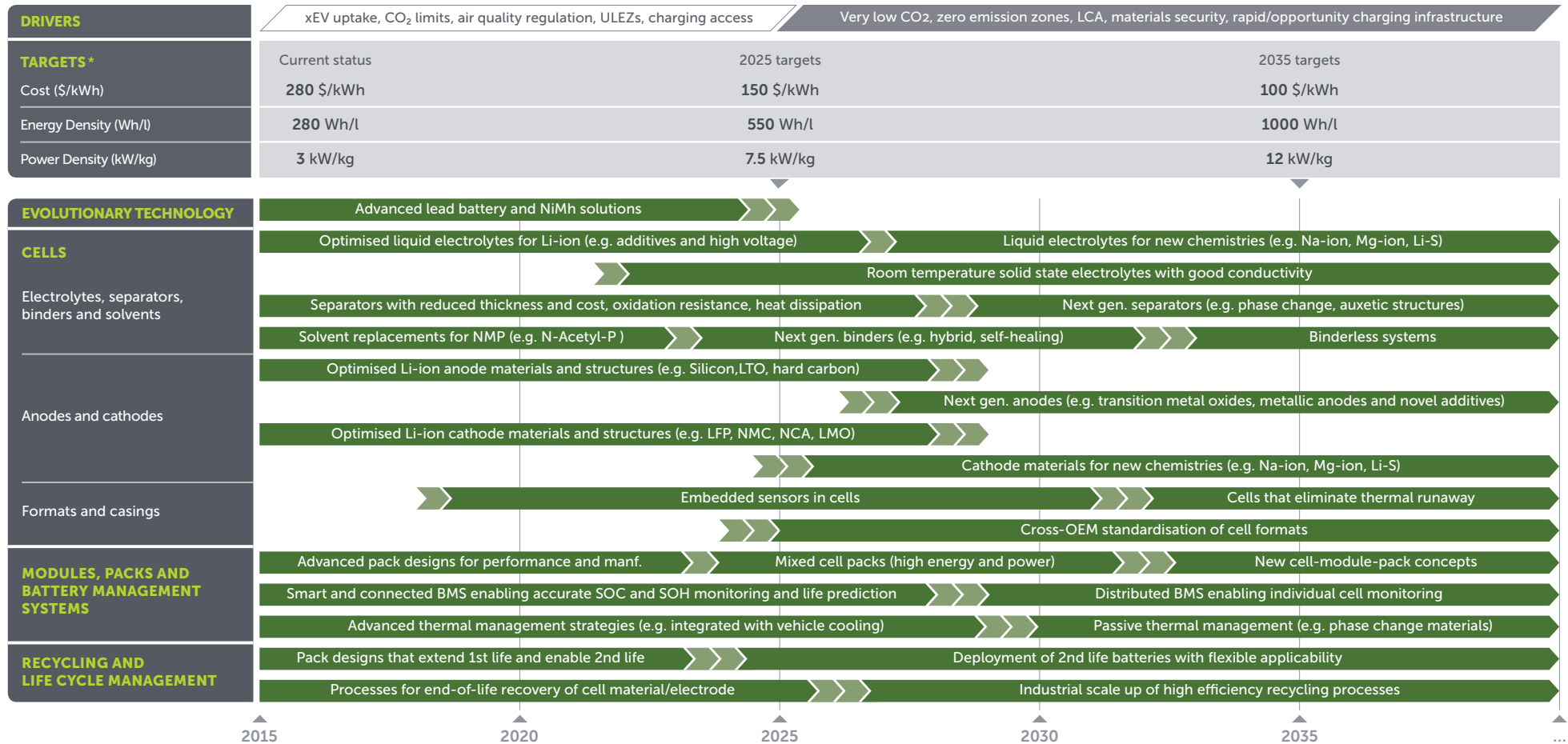


Formula E Battery – Williams Advanced Engineering

* The importance of both capacitors and batteries is recognised when considering electrical energy storage for automotive propulsion. The roadmap focusses mainly on energy storage devices as these are initially required to provide zero-emissions capability potentially supported by capacitors under transient driving conditions.



ELECTRICAL ENERGY STORAGE



Driver set Driver predicted Solid bar represents >1% global marked adoption and is preceded by significant product and process R&D 1 chevron = some uncertainty around timing of mass market adoption or phase out 2 chevrons = considerable uncertainty around timing of mass market adoption or phase out



7.1 TARGETS

In order to meet future mainstream automotive demands, significant improvements in cost, energy density and recyclability are required and the ambitious long term targets reflect this. Storage system targets may be considered as energy-led, typified by the range requirements of a BEV, or power-led, exemplified by PHEV or bus applications.

The targets on the roadmap are defined at pack level as vehicle manufacturers and battery pack suppliers take cells and assemble them into modules and packs for more effective integration into the vehicle. While cell level metrics are informative (and are included in this report), they do not communicate the final cost or the required packaging space to the OEM. Therefore showing battery pack targets on the roadmap performs the dual function of reflecting the vehicle manufacturers' requirements while simultaneously encouraging research in areas other than just battery cells.

	Energy-led ¹	Power-led ¹	2017	2025	2035
Pack Targets					
Cost (\$/kWh) ²	•		280	150	100
Energy Density (Wh/l)	•		280	550	1000
Power Density (kW/kg)		•	3	7.5	12
Pack Life (Years)	•	•	8	10	15
Recyclability (%)	•	•	10 -> 50	75	95
Cell Targets					
Cost (\$/kWh) ²	•		130	80	50
Energy Density (Wh/l)	•		750	1000	1400
Energy Density (Wh/kg)	•		250	350	500
Operating Temperature range (°C) ³	•	•	-20 -> 60	-30 -> 70	-40 -> 80

1. Energy-led applications typified by BEV, power-led by PHEV or bus

2. Cost targets relate to EV passenger car volume production

3. Temperature range: bottom end is limit of charge acceptance, top end where de-rating required



7.2 EVOLUTIONARY TECHNOLOGY

PREDICTION: Rapid advances in lithium-ion technology could displace some existing battery chemistries but are also stimulating research into lead acid batteries

Lead acid batteries will provide the most cost-effective solution for 12V applications for the immediate future because the rapidly reducing cost of Li-ion has stimulated additional research into their performance. Organisations such as the Advanced Lead Acid Battery Consortium, are now enhancing lead acid batteries, keeping them technically competitive and upgrading their performance for conventional and mild hybrid vehicles.

However, if the cost of Li-ion batteries falls rapidly enough, or if 48V becomes the standard voltage level, Li-ion could challenge traditional lead acid batteries; Hyundai have dispensed with the lead acid battery in their Ioniq hybrid in favour of an isolated 12V Li-ion starter embedded in the traction battery pack.

Despite the large production volume of nickel metal hydride (NiMH) batteries in both Japan and China, it is expected that this chemistry will be slowly phased out. This is because it's one of the only battery chemistries to contain rare earth elements and existing Li-ion exhibit enhanced performance. In fact Toyota now offer a Li-ion variant of the Prius alongside the existing NiMH chemistry.

If the cost of Li-ion batteries falls rapidly enough, or if 48V becomes the standard voltage level, Li-ion could challenge traditional lead acid batteries

7.3 CELL MATERIALS

PREDICTION: Optimising current graphite anode technology will complement enhancements in lithium-based cathodes, but as new chemistries are developed and charging rates increase new anode technologies will be needed

Graphite has been the state-of-the-art anode material for the last 25 years, but the automotive sector's demand for higher energy densities and faster charging rates is stimulating research into improved anode technology. A number of short term incremental improvements are possible, such as adding silicon (which is Panasonic's approach) or exploring the use of hard carbon, however there is a limit to the concentrations of silicon that can be added due to volumetric expansion and reduced lifetime.

New anodes will also be required to enable new cathode materials to work effectively. For example, sodium-ion cannot intercalate into graphite very well due to the unfavourable thermodynamics; new anode materials such as tin, antimony or metal oxides need to be commercialised for sodium-ion batteries to operate more effectively. Similarly for solid state batteries to be successfully commercialised, new lithium metal anodes need to be developed in conjunction with the solid electrolyte.



Faradion sodium ion battery



PREDICTION: Lithium-based cathodes will predominate in the short term but new cathode materials are required to deliver cost reductions, better energy/power densities and greater recyclability

Optimising cathode materials and structures in existing Li-ion cells will be an important strategy to improve automotive battery packs in the short term. The public workshops identified altering the chemical composition of cathodes as a promising route to reduce costs or improve energy density. For example, increasing the nickel and cobalt content offers improved energy density, but raises costs significantly and leaves OEMs exposed to raw material price increases. If reducing cost is the priority, then more abundant materials such as iron could be utilised, but at the expense of lower energy density.

High power Li-ion cathodes are predicted to take a different development path to that of energy dense cathodes, due to their higher currents and lower nominal voltages. In the short term this is expected to increase overall pack costs due to more sophisticated cell designs, advanced thermal management strategies and techniques to minimise lithium plating.

Regardless of whether the priority is lower cost, better energy density or greater power density, achieving the 2035 targets will require new cathode structures and materials. For high energy density batteries, cathode development will be required to commercialise new chemistries such as lithium sulfur, metal-air and multi-valent chemistries, whereas for the lower cost chemistries, such as sodium-ion or calcium ion, completely different cathode materials and manufacturing processes will be needed.

PREDICTION: The content of binders, solvents and additives required to create the anode and cathode will be reduced

Manufacturing battery electrodes requires the use of binders, solvents and additives to form a slurry so the active material binds to the current collector (typically copper foil in the anode and aluminium foil in the cathode). These materials are called inactive or indirect materials because, though needed for the production of battery cells, their inclusion contributes nothing to cell performance.

Reducing content of these materials could reduce manufacturing process steps and improve performance whilst also reducing costs. The roadmap process highlighted that using more sustainable and cheaper materials, as well as removing harmful solvents such as N-Methyl-2-pyrrolidone (NMP), are effective short term measures. Longer term, transitioning the binder material from a liquid additive to a dry particle coating would significantly enhance performance and improve the proportion of active material in the cell.



WMG employee mixing battery slurry



PREDICTION: Liquid electrolytes have provided a relatively low cost route to rapid commercialisation of automotive Li-ion cells, but solid-state electrolytes could offer a step change in cell performance

In a Li-ion cell, the electrolyte transports positive lithium ions between the cathode and anode. The performance of the electrolyte strongly influences the battery's current density and reliability. In the short term, higher purity, more stable and higher voltage electrolytes are key to improving the conductivity (which influences efficiency), thermal performance and robustness of Li-ion cells.

For new anode and cathode materials, next-generation liquid electrolytes (e.g. ionic liquid electrolytes) will be required that operate at much higher temperatures, that are self-healing and which exhibit very high conductivity.

If commercialised successfully, solid-state electrolytes will offer greater stability than liquid-based electrolytes, increased battery life and greater energy densities, but early incarnations of the technology have tended to weigh more and do not currently match the ionic conductivity of liquid electrolytes at higher voltages. For solid state batteries to compete with traditional Li-ion in the future, they need considerable manufacturing innovation as the technology has only been demonstrated scientifically and has not been manufactured at scale.

PREDICTION: Separators currently fulfil a safety-critical role but the next generation will need to work with new electrolyte concepts

Separators in existing Li-ion cells fulfil two important functions: provision of a physical barrier for the anode and cathode, preventing thermal runaway, and holding an electrolyte reservoir that allows ions to move between the anode and the cathode. A separator must be highly porous, a good electronic insulator and a good ionic conductor.

As manufacturers increase cell current densities, maintaining the safety of Li-ion battery packs requires separators that are thinner, dissipate heat quicker and are resilient to chemical breakdown in the more challenging operating conditions. In the longer term, as the industry moves to alternative battery chemistries, separators will need to evolve further, with new materials also providing increased functionality; for example, advanced chemistries such as Li-S may require separators to help prevent a build-up of ions between the cathode and the separator as this could lead to capacity fades.

Multifunctional separators could also be developed to enhance performance, for example through auxetic structures (separators that become thicker perpendicular to the applied force), advanced thermal management strategies (i.e. phase change materials that store heat) or fire resistant materials that improve safety.

As manufacturers increase cell current densities, maintaining the safety of Li-ion battery packs requires separators that are thinner, dissipate heat more quickly and are resistant to chemical breakdown in the more challenging operating conditions



7.4 MODULES, PACKS AND BATTERY MANAGEMENT SYSTEMS

PREDICTION: The desire for improved range, reduced cost and faster charging rates will stimulate innovative battery pack designs, increased packing densities and innovative cell-module-pack concepts

As the number of PHEVs and BEVs increase, battery packs will need to be manufactured in much higher volumes. Assembling battery packs cost-effectively at high volume has been identified as a key challenge. Current manufacturing facilities require high levels of cleanliness and have high 'work in progress' costs due to conditioning requirements.

In light of the manufacturing challenges, maximising the efficiency of existing manufacturing processes is deemed crucial in reducing costs in the short term. Leveraging help from adjacent sectors was viewed as a key enabler, as other sectors could assist with critical processes such as: cell assembly, cell formation, module/cell welding, in-line and end-of-line testing. Another short term focus is identifying areas where existing battery packs have been over-engineered, especially in early products. This could reduce the percentage of inactive pack material and assist the industry in moving to higher volumes.

In the longer term, it is envisaged that battery packs will need to cater for mixed cell types (i.e. a blend of high power and high energy density) or include super capacitors with the possibility of new concepts that blur the boundary between cells and modules. These may use existing manufacturing processes or require new ones to realise these new concepts.

Current manufacturing facilities require high levels of cleanliness and have high 'work in progress' costs due to conditioning requirements. Maximising the efficiency of existing manufacturing processes is therefore deemed crucial in reducing costs in the short term.

PREDICTION: Advances in battery management, most notably to deliver improved thermal management strategies, will be required before battery performance can be extended.

Battery cells, whether traditional Li-ion or next generation chemistries, need pack-level management to ensure they can operate with maximised efficiency. Developments in battery management systems (BMS), and especially thermal management strategies, will make a significant contribution to improving safety and extending battery lifetime

In time it's expected the BMS could transition from passively sensing at the module level to actively predicting performance and self parameterising. This can be achieved either through data from embedded sensors within each cell or leveraging 'virtual sensors' which uses simpler measures to predict cell characteristics but needs advanced modelling capability to understand cell chemistry. An advanced BMS also enables more targeted thermal management strategies, controlling the temperature of each cell so it can be individually optimised based on its condition. In the short term, it is predicted that tab and surface cooling strategies will be optimised using either air, water or glycol, but as cell chemistry advances, passive cooling systems could be utilised in which the battery is inherently thermally stable.



7.5 RECYCLING AND LIFE CYCLE MANAGEMENT

PREDICTION: Mobilising numerous industries to collaborate with the automotive sector to appropriately recycle or re-use batteries will determine their credibility as a long term powertrain solution

Two main possibilities have emerged for automotive battery packs when the vehicle has reached the end of its life. The first of these is to reuse the battery for second life applications such as home energy storage or grid balancing. Data from Bloomberg New Energy Finance (2017) suggests that an estimated 95GWh of batteries will come from cars between now and 2025, of which 26GWh would be suitable for stationary storage.

The second option is to recycle xEV battery packs and reuse the materials in the manufacture of new batteries. Irrespective of whether older automotive batteries are successfully commercialised for second life applications, the repurposed batteries will eventually need to be recycled, as will those not suitable for second life applications. There are broadly two approaches to battery recycling: early stage standardisation leading to volume-driven recovery, or dedicated processes for differing battery chemistries. Current market trends suggest that OEMs are using several variations of Li-ion and will continue to do so. The implication is that dedicated recycling processes will be required for each variation, incurring significant extra costs. Therefore designing cells for remanufacture will be crucial in minimising the cost of recycling processes.

Irrespective of whether older automotive batteries are successfully commercialised for second life applications, the repurposed batteries will eventually need to be recycled, as will those not suitable for second life applications





7.6 RESEARCH AND DEVELOPMENT CHALLENGES FOR THE SHORT, MEDIUM AND LONG TERM



Professor Dave Greenwood
Professor of Advanced
Propulsion Systems, WMG
APC Electrical Energy
Storage Spoke



Batteries are a defining component of an electrified vehicle and will need to halve in cost and double in energy density in the next two decades without using unsustainable materials or manufacturing processes. The fourteen research themes outlined in the following table include a broad range of technology innovations, manufacturing processes and design approaches that help deliver the challenging targets identified on the roadmap. Developed by the Electrical Energy Storage Spoke community, they represent the pressing challenges our community need to address.

The short term focus centres on optimising existing lithium ion cells and pack technologies to meet the imminent demand for electrified vehicles. Hence the challenges listed in the short term are largely manufacturing ones, with incremental technical innovations such as fine tuning the chemical composition of anodes and cathodes as well as managing the health of battery packs.

As time progresses, and the potential pathways for satisfying future performance requirements

diverge, more profound technical and manufacturing challenges arise. Perhaps the most important long term change is that future improvements in battery packs will shift from improving in-use performance to the total life cycle impact of battery manufacturing. This will not only drive the automotive industry to scale-up recycling facilities but also ensure the chemicals used in batteries are sustainably sourced and manufactured.

What's clear is that for the automotive industry to address these battery challenges, we need help from adjacent industries. We hope that these research and development challenges will help facilitate discussions between interested companies and aid those organisations in other sectors wishing to navigate the automotive battery landscape.

Batteries will need to halve in cost and double in energy density in the next two decades without using unsustainable materials or manufacturing processes



Identification of key research and pre-competitive development challenges to help facilitate academic / industrial collaboration on longer term product and manufacturing research and development

Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
1 Cost effective battery packs	All research challenges listed below imply efforts to reduce cost wherever possible, or, demonstrate an improvement in performance that mitigates the increase in cost		
2 Improve safety	<ul style="list-style-type: none"> • Safer cells and packs, with improved cell-level fault containment 	<ul style="list-style-type: none"> • Cell level solutions to make fault conditions benign, including thermal shut-down separators and sensors integrated into the cell 	<ul style="list-style-type: none"> • Eliminating thermal runaway at a pack level by using electro-chemistries that are inherently stable
3 Fast charging capability for BEV's	<ul style="list-style-type: none"> • Pack charge rate capability to 1.5-2C 	<ul style="list-style-type: none"> • Pack and cell charge rate capability to 2.5-5C 	<ul style="list-style-type: none"> • Pack and cell charge rate capability to 5+ C
4 Increase power density for high power applications	<ul style="list-style-type: none"> • Combining hybrid Li-Ion and/or ultracap cells in a pack • Utilise current materials and approaches to create cells tolerant to high power densities (i.e. carbon anodes) 	<ul style="list-style-type: none"> • Reducing interconnect resistance • Mixed lithium ion cells that mix high power and high energy performance • Advanced cooling strategies in operation to achieve high power densities 	<ul style="list-style-type: none"> • New materials (including graphene morphologies) for higher power and higher energy density capacitors (i.e. supercapacitors, pseudo capacitors)
5 Increase energy density in existing lithium-ion chemistry	<ul style="list-style-type: none"> • Improving existing electrolytes, electrode structure and cell packaging in known chemistries • Introducing elements into lithium based cathodes that enhance energy density 	<ul style="list-style-type: none"> • Higher voltage (5V) electrolytes • Developing safety concepts for high voltage modules and packs 	



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
6 Better battery pack design through improved predictability of performance, durability and ageing via modelling, simulation and testing	<ul style="list-style-type: none"> • Predictive modelling tools with greater accuracy <5% margin of error (e.g. prediction of life models) • System engineering solutions to improve pack robustness to >8 years (1st life) • Better understand response of cell structures to mechanical stimuli (bending, impact, vibration, crush) and the effect on health • Better modelling of battery lifetime requirements of applications with heavier duty cycles (e.g. trucks, off-highway machinery) 	<ul style="list-style-type: none"> • Testing techniques for accurately predicting life and performance degradation in 1st and 2nd life applications • Better modelling and understanding of battery lifetime requirements for CAVs 	<ul style="list-style-type: none"> • Holistic predictive modelling tools with <1% margin of error • In-situ electrochemical analysis techniques leading to improved fundamental understanding and predictive modelling capabilities encompassing electrochemical, electrical, mechanical and thermal properties • Improved understanding of degradation mechanisms to enable more radical materials and engineering solutions to increase pack durability to 15 years (1st life), including self-healing binders, separators and electrolyte
7 Reduce mass and volumes overheads at vehicle level	<ul style="list-style-type: none"> • Utilising multi-material solutions, plus integrating structures to increase the % of active materials in battery packs (45% active material) 	<ul style="list-style-type: none"> • New multi-material approaches to increase the % of active materials in battery packs (55% active materials) 	<ul style="list-style-type: none"> • Structural batteries with novel structure and form • New concepts for integration of the cell, module and pack to increase the % of active materials in battery packs (65% active materials)
8 Increase operating temperature range and efficiency of thermal management systems	<ul style="list-style-type: none"> • Battery packs with -30°C / +70°C capability • Higher temperature capable electrolyte • Reducing the power consumption of thermal management systems 	<ul style="list-style-type: none"> • Thermal management systems fully integrated with vehicle thermal management systems that leverage new technologies (such as phase change materials) to improve efficiency and reduce parasitic loss 	<ul style="list-style-type: none"> • Battery packs with -40°C / +80°C capability • Cells with passive cooling capability



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
9 Improve BMS systems	<ul style="list-style-type: none"> • Embedding accurate real time cell models into BMS • In-situ diagnostic techniques 	<ul style="list-style-type: none"> • Cell level monitoring systems • Real-time prognosis and active SOH management 	<ul style="list-style-type: none"> • Predict failures with >95% reliability • On board machine learning to self-parameterise and self mitigate in event of degradation and failure
10 Increase the speed, improve the quality, reduce the cost and improve the sustainability of manufacturing	<ul style="list-style-type: none"> • High volume automotive standard production and quality assurance processes • Improved cell to busbar joining technology • Production variability and process control • Improved electrode processing methods and structures at higher volumes • Develop low cost high speed deposition processes and evaluate in larger footprint and alternative cell formats • Understand and validate life cycle impact analysis 	<ul style="list-style-type: none"> • More consistent processes to improve the homogeneity of cells • Lower cost formation processes • Actively reduce lifecycle impact of manufacturing • Mass manufacturing processes for new chemistries • New production process and equipment reducing cell manufacturing times • Material solutions to increase cell durability and improved cell joining technologies 	<ul style="list-style-type: none"> • Developing chemistries and processes to reduce formation time and speed up conditioning • Standardisation of formats for vehicle applications • Better integration of pack and vehicle manufacturing • Creating a circular economy for automotive battery packs
11 Identifying the next-generation chemistry to displace existing Li-Ion		<ul style="list-style-type: none"> • Example: Lithium-Sulfur (Li-S) as an automotive technology capable of delivering > 25% improvement in energy density at equivalent cost relative to contemporary lithium ion • Example: Sodium-ion (Na-ion) as an automotive technology capable of delivering similar performance levels at >25% cost reduction relative to contemporary lithium ion • Developing room temperature solid state electrolytes with high ionic conductivity 	<ul style="list-style-type: none"> • Breakthrough concepts such as: lithium-air and alternation metal-ion chemistries, higher energy capacitors and more sustainable cells • Anodes for higher energy density (e.g. lithium metal) and higher power density (e.g. graphene) • Exploring whether multi-valent chemistries such as Zn, Al and Mg can tolerate higher voltage levels (5V+)



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
12 Mobilising a UK supply chain that demonstrates cost competitiveness and higher productivity	<ul style="list-style-type: none"> • Develop flexible pilot and high volume manufacturing capability to capitalise on future cell technologies • Leveraging and adapting manufacturing processes and materials used in adjacent sectors (e.g. chemicals industry) to improve UK battery manufacturing capability 	<ul style="list-style-type: none"> • Manufacturing capabilities that are automated and flexible enough to capitalise upon different potential technology paths (e.g. cylinder vs. pouch vs. prismatic, liquid vs. solid electrolyte etc.) • Aligning manufacturing processes with next generation chemistries (see medium term challenge 11) • Flexible rapid prototyping / proof-of-concept capabilities for new module & pack concepts • Flexible rapid digital prototyping / proof-of-concept capabilities for new materials and cell concepts • Large volume (i.e GWh) manufacturing capability and capacity 	<ul style="list-style-type: none"> • 3D printed, multipolar formats, conformable cells, electrochemically functionalised materials • Aligning manufacturing processes with next generation +1 chemistries (see long term challenge 11)
13 Develop an economically viable value chain for 2nd life reuse	<ul style="list-style-type: none"> • 1st life design systems that meet 2nd life End-of-life diagnostic tools • Model and test aggregation of aged batteries for energy storage applications 	<ul style="list-style-type: none"> • Scaling up of repurposing facilities to enable roll-out • Design packs for 2nd life to enable easy interoperability • Predictive performance and life models for 2nd life applications 	<ul style="list-style-type: none"> • Understanding the economic case of using 2nd life batteries compared to virgin materials • Techniques for post-crash health diagnostics, remanufacturing cell components and processed materials (e.g. cathode powder) into new cells
14 Develop and scale up of cell and pack recycling processes	<ul style="list-style-type: none"> • Define and develop processes for material recovery from cells (including value modelling) • Design methodologies and cost models for design for disassembly of modules and packs • Understanding the logistical and economics implications of recycling 	<ul style="list-style-type: none"> • Interconnects that enable removal of individual cells • High throughput end of life testing and recycling processes (including automation) • Increased use of recycled materials in battery packs 	<ul style="list-style-type: none"> • Methods to recycle 100% of a cell and pull materials back into new material streams • Develop a circular economy for battery packs



8

TECHNOLOGY ROADMAPS

ELECTRIC MACHINES

YASA motor



Saietta brushed motor

OVERVIEW

The roadmap illustrates how developments in e-machines will broadly focus on three main areas:

1. Achieving a step change in performance (power density or efficiency) for high-end applications
2. Reducing cost for mass market applications
3. Minimising the environmental impact of manufacture and end of life recycling.

As a result, the automotive industry has pursued a wide variety of e-machine architectures to meet various performances requirements.

Existing e-machine designs can be optimised to either reduce costs or improve performance but a number of technology evolutions that reduce this compromise are shown from 2025, reflecting the immaturity of the current e-machine automotive mass market and the need for targeted R&D on future applications. To ensure the effective integration of e-machines into the wider powertrain, closer collaboration with the power electronics and engine communities will be needed to understand the benefits and trade-offs at system level.

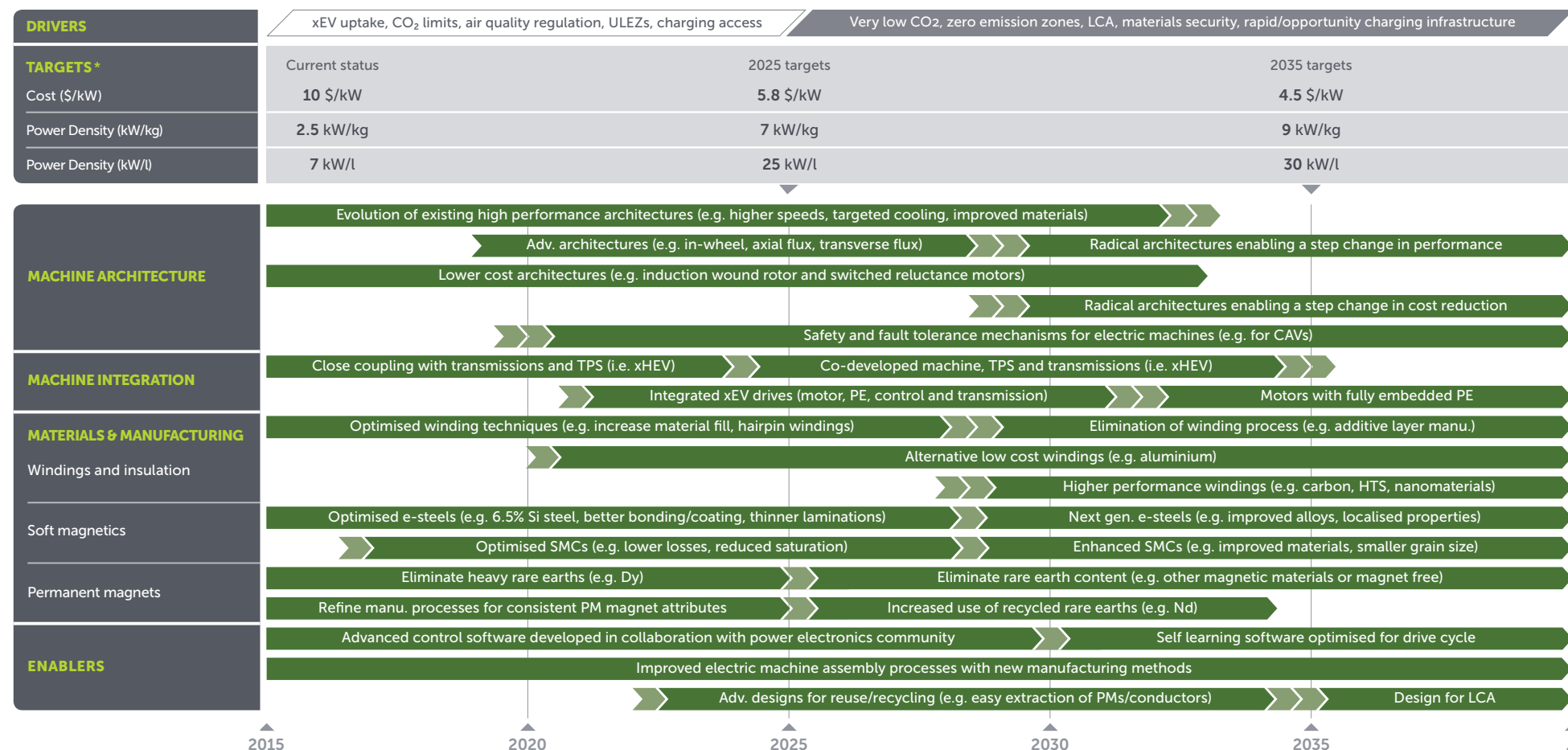
To reach the long term performance and cost targets identified in the roadmap, the e-machine community will have to explore new materials and manufacturing processes. This will require motor designers to work closely alongside adjacent sectors, such as metallurgists and manufacturing equipment suppliers, in order to achieve the ambitious technical targets.

As it stands today, the majority of e-machines are made using materials and manufacturing processes that currently have a negative impact upon the environment. Therefore innovative processes are needed to recover and recycle them with the aim of establishing a circular economy.

To ensure the effective integration of e-machines into the wider powertrain, closer collaboration with the power electronics and engine communities will be needed to understand the benefits and trade-offs at system level



ELECTRIC MACHINES



Driver set Driver predicted Solid bar represents >1% global marked adoption and is preceded by significant product and process R&D 1 chevron = some uncertainty around timing of mass market adoption or phase out 2 chevrons = considerable uncertainty around timing of mass market adoption or phase out



8.1 TARGETS

The performance targets set by the Electric Machine roadmap are expressed in kW/kg for gravimetric power density and kW/l for volumetric power density; cost is shown in \$/kW. While sustainability and design for recycling has no defined metric, reducing the negative environmental impact of e-machine production and improving end of life recycling feature prominently in the drivers and the visual roadmap.

Different targets have been set for passenger cars and heavy duty applications because each vehicle type has particular drive cycles requiring different e-machine designs. However for consistency, all the targets on the roadmap assume the same input voltages, material price mark-up and efficiencies based on the Worldwide Harmonised Light Vehicle Test Procedure (WLTP).

For the passenger car targets the cost, power density and drive cycle efficiency metrics represent expected improvements for a C-segment BEV traction machine and should be all read together. All power density targets are based on continuous power output rather than peak power as this is a fairer representation of real-life operation than a transient peak figure. Nevertheless, the roadmap acknowledges that greater power densities could be achieved for higher performance applications.

	2017	2025	2035
Passenger Car Traction Motor ¹			
Cost (\$/kW) ²	10	5.8	4.5
Continuous power density (kW/kg)	2.5	7	9
Continuous power density (kW/l)	7	25	30
Drive cycle efficiency (%) ³	86.5	92.5	93
Truck and Bus Traction Motor ¹			
Cost (\$/kW) ²	60	15	12
Continuous power density (kW/kg)	1.5	2	2.5
Continuous power density (kW/l)	4.5	6	7
Drive cycle efficiency (%) ³	83	88	90

8.2 MACHINE ARCHITECTURE

PREDICTION: In the short term a number of strategies will be used to optimise existing machines, with reducing costs and improving performance within established machine architectures the two primary goals

Existing e-machines can be redesigned for higher performance through high fidelity thermal modelling that can precisely simulate temperature distribution in the machine. Understanding the key hotspots in a machine allows more targeted thermal management such as internal rotor cooling or the targeted cooling of printed stators. Performance can be further optimised through operating at higher speed, with novel bearings (e.g. ceramic and/or air bearings), more compact motors and faster inverter switching frequencies being potential options.

Lower cost e-machines require more effective utilisation of existing materials, reducing copper losses through better winding designs and reducing iron losses. An emerging trend is the use of lower cost topologies for mild hybrid applications. For example Renault have opted to use a Continental induction motor for their 48V mild hybrid Scenic and Controlled Power Technologies (now Federal Mogul) are aiming their switched reluctance motors initially at 48V applications.

1. All assume 350V / 450Amps @ 65°C inlet

2. Prices are 300% mark-up on material costs

3. Drive cycle based on WLTP



PREDICTION: Advanced high performance motor designs will soon reach the market, but new materials and manufacturing techniques could enable lower cost designs in the longer term

Advanced architectures, not traditionally used in automotive applications, are being explored and are close to mass market launch. These new e-machine designs are for specialist applications such as heavy duty vehicles or high performance passenger cars. The architectures can be defined by their method of integration into the vehicle (e.g. distributed such as wheel-hub motors) or their novel magnetic/mechanical design (i.e. axial, radial and transverse flux motors). The increased performance of power electronics will further enhance the performance of a number of motor architectures, making them suitable for higher performance applications. For example the performance of switched reluctance motors can be greatly enhanced through the higher switching frequencies attained by wide band gap power electronics.

In the longer term, lower cost e-machines could be achieved through both technology and manufacturing innovations. One technology innovation is ironless machine topologies which eliminate costly laminated steel from the stator (removing iron losses) and iron from the rotor which could instead use low cost plastics to secure the magnetic materials. Manufacturing innovations include the proliferation of high precision, automated manufacturing equipment which will increase production efficiency, with additive layer manufacturing providing the opportunity to reduce manufacturing steps enabling further cost reductions.



Equipmake facility



8.3 MACHINE INTEGRATION

PREDICTION: Electric machines will become better integrated into existing powertrain architectures to achieve short term emissions and CO2 reduction

Existing full hybrid architectures such as the Toyota Prius have achieved mature levels of integration of the thermal propulsion system (TPS) and e-machine. In order for mild hybrids to more effectively meet near term emissions legislation, their e-machines will require closer coupling with the transmission and TPS to deliver the optimum performance.

In the short term, 48V e-machines will replace existing 12V alternators, providing attractive fuel consumption improvements to meet the imminent CO2 targets under the new driving cycles and test procedures. However, in the medium term, the e-machines of mild hybrids will need to be co-developed with the TPS and transmission to enable engine rightsizing and utilisation of novel combustion strategies, which will require a larger, or potentially multiple, e-machines integrated at different points in the drivetrain. In these more advanced mild hybrid applications, vehicles will be able to operate with the TPS off under defined conditions (e.g. coasting, parking and 'e-creep'). However a challenge with integrating power dense, high speed machines into the transmission is that the gear reduction drive becomes more complex which can create losses.

For heavy duty applications, e-machines may also require closer integration with other energy storage mechanisms such as flywheels and hydraulic systems, especially in the off-highway sector.

PREDICTION: As BEV and PHEV platforms become more sophisticated, closer integration of motor and power electronics is expected

Integrating both the e-machine and power electronics into a single unit is one potential route for OEMs to reduce costs and packaging requirements. For 48V architectures, the inverters and e-machines can already be integrated into one housing which reduces the cost and weight of external cables. This enables integrated drives to be packaged between the TPS and transmission where space is constrained.

However, integrated drives with higher power outputs for EVs present a number of challenges. First, managing the thermal differences between the inverter and motor proves challenging, as both can often run at different temperatures, especially if wide band gap materials are used. Second, ensuring integrated drives for EVs can be manufactured cost effectively at higher volumes was cited as a key concern during the workshop process. In the long term, the potential exists for a combined manufacturing processes for integrated drives where the power electronics and e-machine are fabricated together. This could be enabled by reducing the costs of additive layer manufacturing processes in conjunction with developing sophisticated, multi-physics modelling tools that can design fully integrated electric drives.

In the long term, the potential exists for a combined manufacturing processes for integrated drives where the power electronics and e-machine are fabricated together



8.4 MATERIALS AND MANUFACTURING

PREDICTION: Alternative winding materials and different manufacturing techniques could deliver e-machines with improved performance at lower cost

Losses in copper windings are one of the major sources of efficiency loss in e-machines, so development is intensely focused on reducing these losses wherever possible. Both different winding techniques and replacing copper with other materials are being investigated and have the potential to significantly reduce costs or radically improve performance.

For lower cost applications, aluminium windings have been identified as a cheaper, lighter alternative that is more readily recyclable than copper. Significant research has been conducted into aluminium windings in the UK within the Innovate UK Evoque_e project, exploring the use of aluminium windings for traction machines.

Higher performance materials were also identified as being attractive for luxury and performance vehicles, as well as heavy duty vehicles. These applications need high power densities, greater torque densities and ultra-high efficiencies, which cannot be attained using existing approaches. Materials offering higher conductivity and lower losses compared to copper include: carbon nanotubes (embedded in copper or on the surface), graphene, nano-materials or high temperature superconductors. However these advanced materials are currently in the research stage and command a price premium.

Alternative winding strategies, including distributed, concentrated and hairpin, also offer the potential to maximise performance and reduce machine losses. However, each approach must dissipate heat effectively while delivering increased material fill factors. In the long term, the use of advanced additive layer manufacturing may be promising as it could remove the requirement for dedicated winding processes, eliminating a costly manufacturing step. However this will only become feasible if the complex e-machine designs possible with additive layer manufacturing can be scaled up to sufficient volumes.



Both different winding techniques and replacing copper with other materials are being investigated and have the potential to significantly reduce costs or radically improve performance



PREDICTION: Breakthroughs in metallurgy and manufacturing processes could enable the commercialisation of advanced electrical steels and soft magnetic composites

Iron losses are another major source of loss in e-machines so advances in soft magnetics are identified as a crucial area of further research. Two soft magnetic materials highlighted in the roadmap are electrical steels and soft magnetic composites.

Electrical steels are currently the most popular approach for automotive applications, so improving their magnetic and chemical properties is deemed crucial to reducing eddy and hysteresis losses. In the short term, development is underway using thinner laminations (0.1-0.2mm) and optimising the crystal structure of grain-orientated steels, to improve electrical steel properties. In addition, better electrical steel coatings are recognised as a promising area of research and can help in minimising losses and mechanical stress. Potentially useful areas of long term research include the cost effective introduction of additional materials such as silicon, cobalt, manganese, vanadium or chromium into electrical steels, and tailoring the properties to deliver performance in specific areas in order to more effectively manage flux paths.

Soft magnetic composites (SMCs) are less commonly used in automotive applications than electrical steels, but allow more complex shapes to be produced through net-shape manufacturing. As a result, machines can be designed where the magnetic flux can travel freely in the e-machine, allowing radically different topologies to be used for higher performance applications. Using SMCs has also been recognised as easier to manufacture than thin laminated electrical steels, offering the potential for more cost effective volume manufacturing. This is because the iron cores and parts can be die-pressed to the desired shape and dimensions, minimising machining and processing steps. From a performance perspective, the surface coating and adhesives used to bond the powder reduce the eddy current losses compared to steel (especially at higher frequencies) however the hysteresis losses in SMCs are more pronounced.

PREDICTION: The automotive sector must reduce its reliance on rare earth permanent magnets in future traction machines in order to achieve a sustainable supply chain

The short term priority is the removal of heavy rare earth materials such as Dysprosium and Terbium, added to improve the temperature resistance of Neodymium. These are expensive and mined mainly in China, so eliminating them not only reduces cost but shields many e-machine manufacturers from potential prices rises and supply issues.

Many automakers are currently trying to reduce the content of rare earth magnets in automotive e-machines, but the roadmap recognises that in the longer term the focus will shift to reducing the content of light rare earth magnets (e.g. Neodymium), which also represent a significant cost in current e-machines.

Continuously optimising the properties of magnetic materials to allow thinner laminations, reduce eddy current losses and improve the strength, durability and high temperature capability was identified by the roadmap as a development priority. Utilising alternative magnetic materials, such as ferrite magnets, is also seen as a potential alternative to rare earth materials.

Designing e-machine architectures that reduce magnet use (such as the motors in the BMW i3 and i8) and using machine topologies that do not use permanent magnets (i.e. induction and switched reluctance) have been identified as promising routes to reducing the automotive sector's use of rare earths. However removing permanent magnets from the machine may introduce additional costs in the power electronics, which occurs in switched reluctance motors in order to achieve the equivalent peak power and torque densities of permanent magnet machines. Finally, reducing the environmental impact of NdFeB magnet refining and manufacturing by reusing magnetic materials was highlighted as being a crucial development for permanent magnets.



8.5 ENABLERS

PREDICTION: System performance could be improved by developing motor control software in conjunction with the power electronics community

Innovative control strategies will help improve noise, vibration and harshness (NVH) with the potential for wireless and/or sensorless control. The introduction of advanced data analytics, vehicle-to-vehicle communications and self-learning software could enable e-machines to self-adapt for high efficiency, peak power or reliability based on driving styles.

PREDICTION: Advanced manufacturing techniques could help reduce costs or enhance performance through higher levels of automation, including additive layer manufacturing

Automotive e-machines (especially traction machines) will require significant manufacturing innovation in order to cost-effectively scale up to the desired volumes. Refinement of existing manufacturing techniques will deliver short term improvements in performance, but utilising experience from adjacent sectors that have expertise in manufacturing e-machines in large volumes will be crucial.

Increased levels of automation with higher precision tooling will support advanced manufacturing techniques, such as additive layer manufacturing, by reducing process steps and enable more complex e-machine designs not possible with conventional manufacturing processes. Another crucial challenge identified in the roadmap process is a viable route for manufacturing integrated drives as the complexity and tooling equipment is currently not available for high volume production.

PREDICTION: Life cycle management and design for recycling will help ensure that e-machines deliver environmental benefits over a TPS

The development of e-machines that are less harmful for the environment is key to ensuring that electrified powertrains remain a viable solution for the automotive industry. To satisfy end-of-life requirements, two routes exist for improving their sustainability: designing machines that do not contain rare earth materials, or creating a closed loop supply chain whereby rare earth materials (and all other materials) are recycled and re-used within the supply chain.

Current e-machine designs, such as interior permanent magnet machines, are difficult to recycle as the magnets are embedded inside the rotor and bonded with strong adhesives, making extraction difficult. Furthermore e-machine windings are currently designed with significant copper content to maximise performance. These windings are fixed in place by strong adhesives, ensuring optimal performance making recycling more challenging. Once extracted, recycling copper is costly because different recycling processes are required for electrical steels, copper and rare earth magnets.

In light of these challenges, the roadmap recognises that e-machines need to be designed for remanufacture. In addition, new recycling processes to enable sensing, sorting, separation, purification and reprocessing of materials is required in order to improve the environmental and economic sustainability of e-machines.

Current e-machine designs, such as interior permanent magnet machines, are difficult to recycle as the magnets are embedded inside the rotor and bonded with strong adhesives, making extraction difficult



8.7 RESEARCH AND DEVELOPMENT CHALLENGES FOR THE SHORT, MEDIUM AND LONG TERM



Dr James Widmer
Director of the Newcastle
University Centre for
Advanced Electrical Drives

APC Electric
Machines Spoke



The electrification of road transport is facilitating an unprecedented level of innovation in electric machines. Novel architectures, better materials and advanced manufacturing processes are all being explored in response to the diverse and demanding requirements of the automotive sector.

As the number of electrified cars, buses and heavy duty vehicle increases, electric machines will play an ever greater role in creating and safeguarding jobs, as the manufacture of conventional powertrains begins to plateau and eventually decline. Therefore electric machines provide an attractive opportunity to ensure national industries can continue to export powertrain components.

The exciting thing is companies and academics from many different disciplines can contribute to the development of electric machines, from material scientists right through to manufacturing equipment providers, system integrators and computer modellers. In light

of this opportunity the APC, in collaboration with the Electric Machine Spoke community, has identified nine broad research themes that capture a range of innovation areas.

The Spoke community quickly recognised that for the UK to be internationally leading, we need to harness the broadest range of skills possible. This isn't limited to just technology innovations but also the manufacturing technologies used to make electric machines. For us to be innovation leaders, we need to develop electric machines and manufacturing technologies in tandem to reap the greatest benefits. In light of this, manufacturing innovations feature strongly in the following research and development challenges.

As the number of electrified cars, buses and heavy duty vehicle increases, electric machines will play an ever greater role in creating and safeguarding jobs



Identification of key research and pre-competitive development challenges to facilitate academic / industrial collaboration on longer term product and manufacturing research and development

Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
1 More efficient, higher speed power-dense machines	<ul style="list-style-type: none"> • Safer and higher speed capable (up to 30,000rpm) bearings and magnet retention systems • Effectively integrating machines: understanding the implications of different bearing types (aerofoil, hydrodynamic, hydrostatic etc.) and chosen gearbox/transmission arrangements • Developing higher speed machines that: minimise AC and iron losses, do not compromise NVH and maintain efficiency 	<ul style="list-style-type: none"> • Machines that are optimised for higher switching frequencies enabled via innovations in wide band gap materials • Mechanisms for managing rotor losses at extreme speeds (i.e. how to alleviate gas friction on rotor) 	<ul style="list-style-type: none"> • Low cost, novel bearing types (e.g. air, composite or magnetic) • Active NVH management • Machines designed in conjunction with ultra-wide band gap materials
2 Effective and efficient thermal management systems fully integrated with vehicle thermal management systems	<ul style="list-style-type: none"> • Machines capable of running on 85-105°C cooling circuits shared with ICE and transmission • Targeted cooling strategies in the machine i.e. cooling of rotor to allow lower grade magnets, or, better magnet temperature distribution to enable removal of Dysprosium 	<ul style="list-style-type: none"> • Electric machine and power electronics thermal management systems fully integrated with vehicle thermal management systems that leverage new technologies (such as phase change materials) to improve efficiency & reduce parasitic loss • Advanced low cost insulations materials with ultra low film thickness • Accurate modelling of temperatures that can enable the machine to run as close as possible to its thermal threshold • High surface area AM heat exchanger 	<ul style="list-style-type: none"> • New motor structures and materials to maximise heat rejection • Windings with integrated cooling channels • Heat pipe technology in conductors • Ceramic coatings for higher temperature capabilities



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
3 Improved materials and processing technologies	<ul style="list-style-type: none"> • Effective winding insulation materials that deliver higher temperature operations (300°C) with shorter cycle manufacturing processes • Wire insulation that doesn't degrade with various cooling strategies (e.g. oil spray and jet cooling) • Lower cost machines with aluminium windings that maintain the weight, size and power density as copper wound machines, including their manufacturability and termination challenges for aluminium windings • Net (or near net) shape manufacturing techniques for PM magnets (i.e. metal injection moulding, casting rotor magnets onto rotor shaft) • Moving high fill density (i.e. 80% of stator slot) automated winding technology from prototype to higher volumes 	<ul style="list-style-type: none"> • Cost effective multi stranding (e.g. Litz) and lamination of windings • Practical and affordable, high strength non-oriented electrical steel laminations • Alternative solutions to coil winding • Permanent magnets improved strength, durability, electrical resistivity and higher temperature capability • New techniques to create laminated (rolled) permanent magnets <2mm thickness without machining losses and grains <1micron • Optimising SMC designs for higher frequency operations • Cost effective manufacturing processes capable of stamping of 6.5% silicon steel quickly • Faster lamination cuttings without impairment on material properties • Treatment of laminations to modify permeability and saturation 	<ul style="list-style-type: none"> • Developing room temperature superconductors, carbon-based conductors and replacements for electrical steels with non-magnetic steels to radically improve machine performance • Alternatives to rare earth magnets to improve sustainability, reduce cost and reduce the risk of price volatility • Improved thermal conductivity (20W/mK) insulation materials • Deposition techniques to 3D print magnets • Coreless/ironless machines eliminating electrical steels/SMCs
4 Holistic multi-physics modelling capability to improve the performance of integrated systems	<ul style="list-style-type: none"> • Validated models compliant with auto industry safety standards/processes • Accurate electric machine datasets (materials, electrical, mechanical thermal etc.) as well as the platforms to share this data openly and securely across industry • Improvements in simulation of NVH and CFD • Modelling tools that accurately predict high frequency effects • Full specification material data (beyond 50Hz) to enable better designs • Improved condition monitoring systems with <10% margin of error 	<ul style="list-style-type: none"> • Digital twins of machine and inverters to optimise system level designs • Design tools which allow designers to make system level trade-offs (i.e. increase in costs of x provides y amount of efficiency) • Cloud based system level multi-physics models to enable faster collaboration across industry (and between organisations not co-located) 	<ul style="list-style-type: none"> • Real time modelling of in motor stresses and losses • High fidelity modelling looking at vehicle level trade offs and interaction with environment • Multi-physics modelling of machines and power electronics with <1% margin of error



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
5 Improved sensing and monitoring technology to improve performance and facilitate predictive maintenance	<ul style="list-style-type: none"> Improved rotor temperature sensors to allow operation closer to the thermal limit Data gathering and sharing to facilitate an open knowledge base 	<ul style="list-style-type: none"> Systems leveraging 'virtual sensing' techniques and big data analysis to enable predictive maintenance with a margin of error <5% Sensors modifying machine control (i.e. to extend life in certain operations) Multi-purpose sensors which do numerous jobs 	<ul style="list-style-type: none"> Systems leveraging 'virtual sensing' techniques and big data analysis to enable predictive maintenance with a margin of error <1%
6 Machines that leverage advances in manufacturing technology	<ul style="list-style-type: none"> Additive layer manufacturing for prototype and low volume production motors Laser cutting electrical steels to improve processing speed and enable production (with a need to investigate effect on laminations) Modularity of sub-components and machines to promote interchangeability and recyclability 	<ul style="list-style-type: none"> Additive layer manufacturing of stator and rotor with high bulk resistivity utilising new materials such as SMCs to create more complex geometries Fully automated machine assembly processes 	<ul style="list-style-type: none"> Additive manufactured printed higher power density drives Collaborative manufacturing utilising machine learning to optimise motor designs (Industry 4.0) Higher utilisation of sintered and compacted components Injection moulding of windings in machine
7 Mobilising a UK supply chain that demonstrates cost competitiveness and higher productivity	<ul style="list-style-type: none"> Develop flexible prototyping and high volume pilot manufacturing capability to capitalise on future machine topologies High volume automotive standard production and quality assurance processes Understanding the key performance variations and challenges associated with scaling from prototype to production Leveraging and adapting manufacturing processes and materials used in adjacent sectors for electric machine manufacturing capability Develop new manufacturing technologies for automotive traction machines 	<ul style="list-style-type: none"> Integrated manufacturing of e-machine, power electronics and transmission 	<ul style="list-style-type: none"> Automated prototyping facilities (informed by models) that have iterative design loops to auto- optimise machine designs



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
8 Improved materials, machine design and processes to facilitate a sustainable and economically viable value chain for end-of-life recovery, re-use and recycling	<ul style="list-style-type: none"> • Scaling up recycling technologies to sense, sort, separate, purify and reprocess small sub-components with uniform design • Prototype facilities capable of cost effectively extracting rare earths from IPM and SPM machines without breaking or demagnetising the magnets • Design for recycling: optimised machine designs (including encapsulating materials, coatings and housings) to aid recycling of magnetic materials, soft magnetics and windings • Pilot facilities for use of recycled magnets from adjacent sectors (i.e. consumer electronics) 	<ul style="list-style-type: none"> • Cost effective processes for recycling net shape magnets which are harder and more expensive to recycle • Recycle 50% of all PM magnets contained in automotive electric drive trains • Increased use of recycled materials in electric machines • Processes that can recycle integrated drives (power electronics and electrical machines) 	<ul style="list-style-type: none"> • Achieve >95% economically viable end-of-life recycling rates via material selection and design for recycling • Removal of rare earth materials and copper to create more streamlined recycling processes • Cost effective recycling technologies to sense, sort, separate, purify and reprocess different machines sizes with different topologies
9 Design verification plan and validation facilities	<ul style="list-style-type: none"> • Address national infrastructure limitations in terms of automotive electric machine testing • New test equipment concepts • Clear standards and targets for e-machine testing and verification 	<ul style="list-style-type: none"> • Development of future testing capacity informed by the agreed standards 	



9

TECHNOLOGY ROADMAPS

POWER ELECTRONICS

Equipmake control board



OVERVIEW

Power electronics play a crucial role in regulating the voltage levels, controlling power flow to the electric traction motor and enabling plug-in vehicles to charge from the electricity grid. As the number of electrified vehicles on the road increases, more sophisticated power electronic solutions will be needed to reduce electrical losses, system weight and cost.

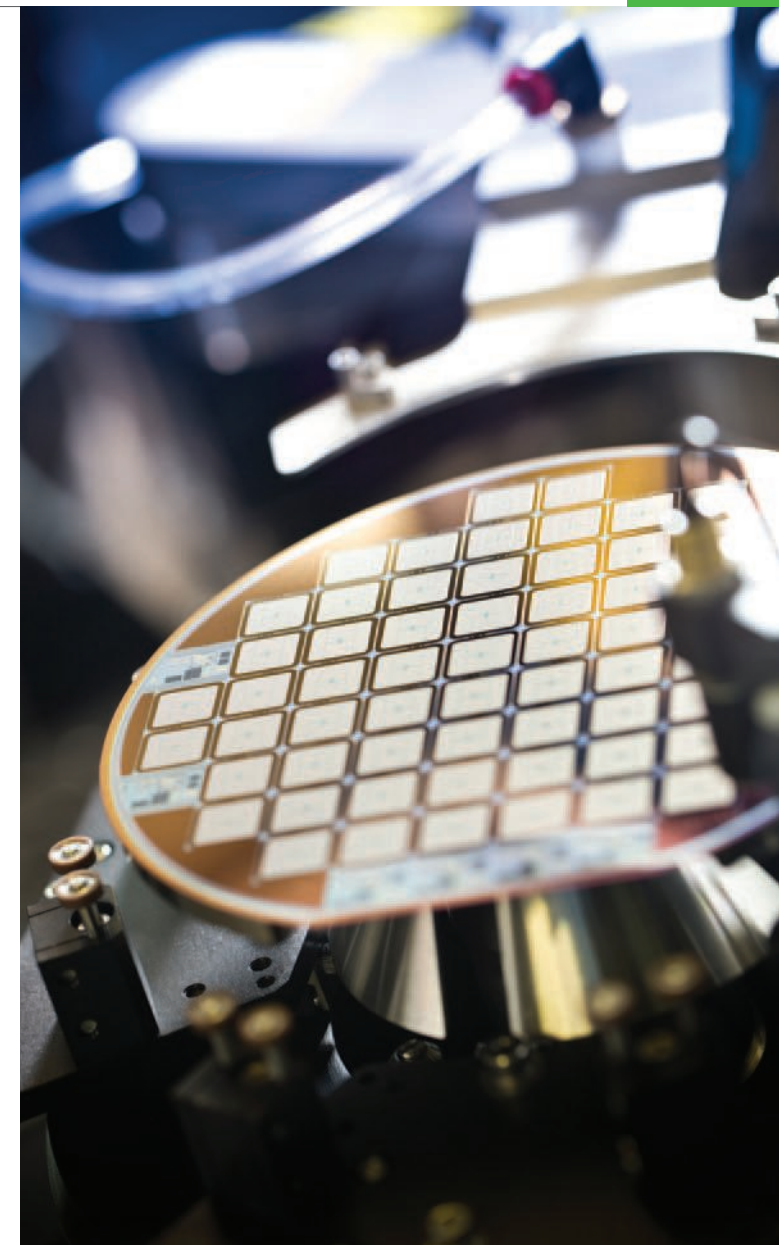
Silicon-based semiconductor devices will continue to play an important role in the automotive sector, due to their manufacturability, established supply chain and suitability for lower voltage applications. However, the roadmap recognises that new wide bandgap* semiconductor materials, such as silicon carbide and gallium nitride, will soon enter the automotive market, especially for high-power traction applications.

These new devices will offer improved thermal and electrical performance over traditional silicon devices, but bring challenges around their manufacturability, integration and cost.

To maximise the potential benefits of wide bandgap materials, advanced components, converter topologies and techniques for circuit integration will need to be co-developed alongside them.

Future strategies for the integration of power electronics present a number of opportunities for the supply chain. The roadmap identifies two such paths; fully integrated drives, where motor and power electronics are co-developed, or a single power management converter able to manage power across the vehicle.

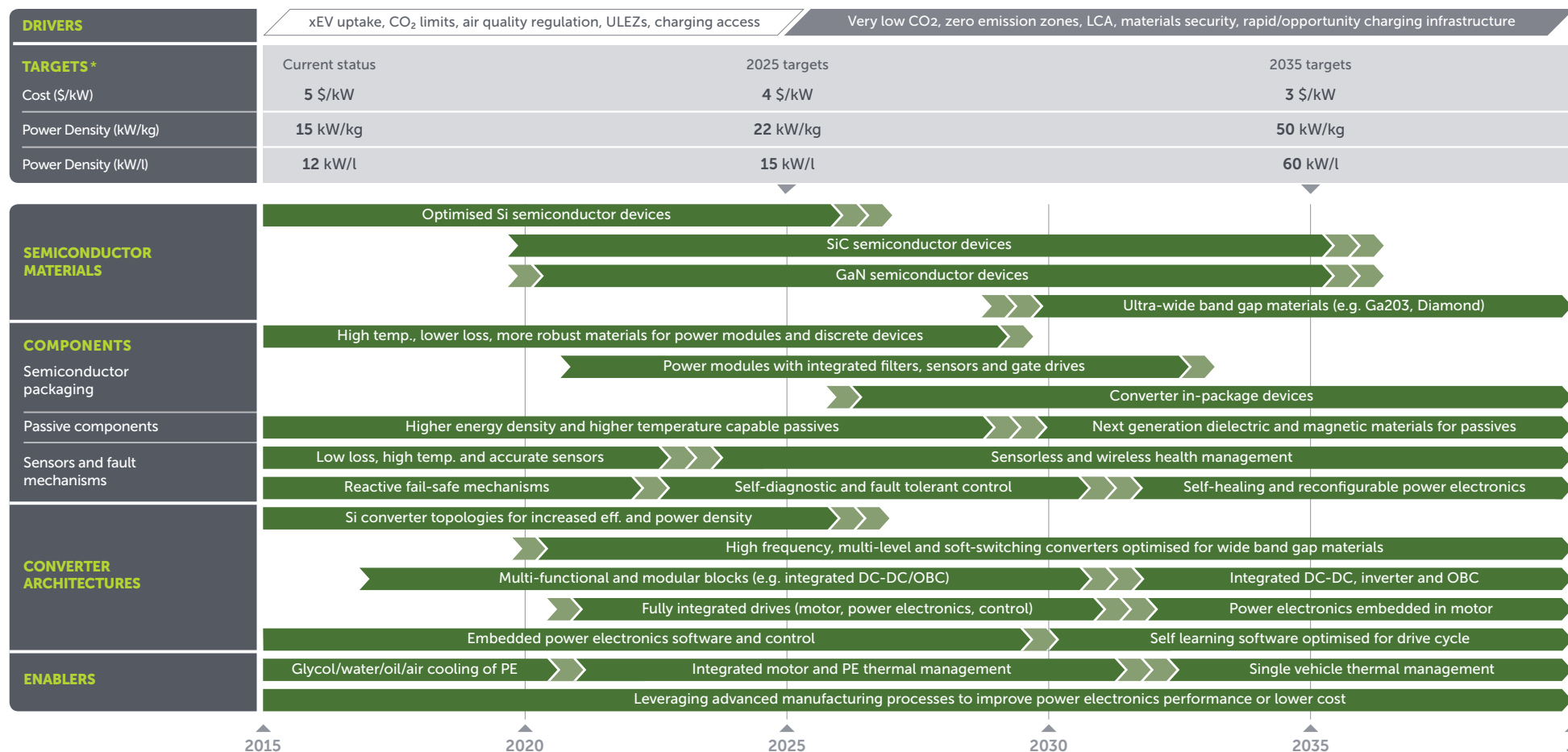
* A bandgap refers to the energy needed to excite electrons from a material's valence band into the conduction band. Materials with larger bandgaps such as silicon carbide (SiC) and gallium nitride (GaN) are able to operate more efficiently at higher voltages and can withstand higher temperatures compared to silicon.



A Dynex Semiconductor wafer



POWER ELECTRONICS



Driver set Driver predicted Solid bar represents >1% global marked adoption and is preceded by significant product and process R&D 1 chevron = some uncertainty around timing of mass market adoption or phase out 2 chevrons = considerable uncertainty around timing of mass market adoption or phase out



9.1 TARGETS

Power electronics are required by all xEV formats, becoming increasingly sophisticated in BEV and PHEV applications. The future roadmap targets cannot be attained with existing technologies and architectures. Meeting mainstream automotive demands will therefore require higher efficiencies, improved power densities and lower system costs. In response to these challenges, ambitious power electronics targets have been set to drive innovation in inverters, DC-DC converters and integrated chargers/DC-DC converters: the key power electronics components for BEVs and PHEVs.

Cost and power density targets should be read independently from one another as different OEMs will prioritise different targets based on their product requirements.

	Cost effective applications	Specialist applications	2017	2025	2035
Inverter¹					
Cost (\$/kW)	•		5	4	3
Power Density (kW/kg)		•	15	22	50
Power Density (kW/l)		•	12	15	60
Efficiency (%)	•	•	96	97	98
DC-DC Converter (2-port)²					
Cost (\$/kW)	•		15	10	6
Power Density (kW/kg)		•	8	15	50
Power Density (kW/l)		•	6	12	60
Efficiency (%)	•	•	97	98	99
Integrated Charger/DC-DC Converter³					
Cost (\$/kW)	•		30	15	8
Power Density (kW/kg)		•	3	6	12
Power Density (kW/l)		•	2	4	15
Efficiency (%)	•	•	94	96	97

1. 3-phase with dc-link and controls

2. 2-port non isolated, bidirectional buck-boost

3. PFC front-end, isolated DC-DC with HV and LV battery outputs, bidirectional by 2030 (or earlier depending on V2G introduction)



9.2 SEMICONDUCTOR MATERIALS

PREDICTION: The low cost and embedded manufacturing capacity of silicon-based devices will maintain their attraction for automotive applications

Silicon-based power semiconductors currently dominate automotive power electronics due to their low cost, suitability for high volume manufacturing and reasonably high efficiencies. In the short term, performance gains can still be achieved in silicon-based semiconductors through smaller chip sizes, thinner wafers and innovative insulated-gate bipolar transistor (GBT) and metal-oxide-semiconductor field effect transistor (MOSFET) designs (e.g. fast IGBTs; reverse blocking and conducting IGBTs). Longer term, silicon could still remain popular as wide bandgap materials may not provide sufficient efficiency improvements to justify a cost premium in applications such as 48V mild hybrids.

Silicon wafers will still be required in a future of wide bandgap materials because a cost effective way of commercialising gallium nitride (GaN) is using silicon wafers to grow it.

PREDICTION: Silicon carbide and gallium nitride, though offering significant performance improvements over silicon, will initially emerge for high performance and specialist applications

New wide bandgap devices are smaller, faster, and more efficient than silicon, with greater tolerance to high temperatures, making SiC and GaN power semiconductors key enablers for more efficient electro-mobility.

Currently, SiC and GaN technologies are both relatively immature. SiC based semiconductor devices are being used in the Formula E series, with ROHM supplying the devices to a number of Formula E teams. Other manufacturers, such as Mitsubishi,

Wolfspeed and Infineon, are producing SiC-based devices for mainstream automotive applications which are anticipated to enter the market in the next few years. SiC is likely to be introduced into the traction inverter market before GaN as its better suited to higher power and high temperature applications. Notable challenges with SiC include: accelerating the speed of wafer growth; increasing the production rate while reducing the cost of growing different wafer types; and making reliable and higher temperature devices suitable for automotive standards.

The roadmap identifies GaN as more being suitable for lower voltage and power applications that require higher switching frequencies (above 100 kHz which strains the comfortable operating limit of silicon). Therefore initial applications of GaN semiconductors are likely to occur in on-board chargers and DC-DC converters where the power requirements are lower but the higher switching frequency is desirable to increase efficiency. GaN could also be attractive for lower voltage applications such as mild hybrids if the costs can be reduced. Challenges associated with GaN include: growing substrates in bulk; lattice mismatch with silicon; and the reduced thermal performance of GaN on Si. Currently, the optimum voltage operation of GaN is below 600V, but this may be extended in future devices, potentially displacing SiC.

PREDICTION: Ultra-wide bandgap materials such as gallium oxide or diamond, though offering further improvements over today's wide bandgap materials, require significant additional development before use in automotive applications

The roadmap identifies numerous next-generation semiconductor materials called 'ultra-wide' bandgap materials that could, in the long term, displace SiC and GaN. Frontrunner technologies identified include diamond, gallium oxide and aluminium nitride. While these materials offer a step change in performance they are still only at a fundamental level of research and require significant technical improvement and cost reduction to satisfy automotive requirements.



9.3 COMPONENTS

PREDICTION: Methods of packaging semiconductor devices will be re-evaluated as increasingly compact solutions are required with greater power density

The packaging of semiconductor devices is crucial in managing their thermal and electrical performance, as well as mechanical stability. In the short term, material improvements are needed to increase their temperature range; this includes better thermal interface materials, novel substrate concepts and improved encapsulation technologies. There is also a need for alternative materials to provide better mechanical stability and robustness, as well as improved bonding mechanisms for each level of component assembly, to better withstand repeated power and temperature cycling.

In the longer term, existing methods of packaging semiconductor devices need to be reevaluated; the benefits of SiC and GaN power electronics devices cannot be realised if they are treated as drop-in replacements for silicon devices. New packaging techniques and circuit designs are required that take full advantage of their properties, in turn reducing the size of cooling and auxiliary circuit components. For example, the introduction of wide bandgap materials reduces the need for some passive components, enabling more highly integrated solutions with sensing, gate drivers and filters incorporated within the semiconductor.

A potential opportunity exists to use converter-in-package technologies by replacing single and multi-chip modules, housing just semiconductor components, with fully integrated power modules. This new semiconductor topology could accept higher currents and temperatures, contain fewer interfaces and incorporate multifunctional sub-components and materials (e.g. multi-functional PCBs). However more complex designs will create new manufacturing challenges. Therefore new design concepts need to consider the impact on manufacturing technologies from the outset and may leverage new production processes such as additive layer manufacturing.

PREDICTION: Passive components will need to be optimised to work alongside new semiconductor materials and converter architectures

Passive components, such as capacitors and inductors, are crucial in building functioning circuits but are often limiting factors in terms of the achievable levels of operating temperature and power density. A key short term requirement identified in the roadmap is for passive components to be co-developed alongside the new wide bandgap semiconductors. For example, as frequency increases the required capacitance and inductance values decrease allowing smaller components to be employed.

Capacitors and other passive components that remain in the circuit must, however, operate satisfactorily at the same high temperatures and high frequencies to the new semiconductor materials. In the longer term, this requires new materials for passive components. Candidates include carbon nanotube windings for inductors, high temperature ceramic capacitors and improved magnetic and dielectric materials to achieve higher energy storage densities.

A key short term requirement identified in the roadmap is for passive components to be co-developed alongside new wide bandgap semiconductors



PREDICTION: Sensors and fault tolerance mechanisms will need to evolve to deliver multi-functional prognostics and health management

Sensing and fault tolerance are important in ensuring safety, improving performance and overall system health management. In the short term, the roadmap identifies that sensors will need to become tolerant to higher temperatures and generate lower losses while maintaining accuracy. However, as wide bandgap materials start to proliferate, sensors will also need to become smaller to fit within the reduced package sizes and operate at higher frequencies. Multifunctional sensors may be employed to reduce cost, packaging space while improving functionality.

In the long term, the roadmap anticipates that more wireless sensors will be used to reduce weight, wiring as well as to simplify packaging. Advances in sensing technology will support the transition of reactive fail-safe mechanisms into predictive health management, enabled by in-field data collection, and potentially extending into self-healing and reconfigurable power electronics enabled by AI/ machine learning. Turning captured data into value will require advanced data analytics to be commercialised.





9.4 CONVERTER ARCHITECTURES

PREDICTION: Converter architectures using silicon can be further optimised but the introduction of wide bandgap materials will encourage a wider range of enhanced converter topologies

In the short term, existing silicon-based converter topologies will dominate in many applications until the additional cost of wide band gap materials can be absorbed and the system level benefits realised. Therefore innovations in silicon-based technologies are expected to continue in order to maximise efficiency. Strategies are likely to include the use of SiC diodes and Si switches, more efficient circuit topologies, distributed architectures (with many small converters paralleled) and parallel/interleaving systems.

The full potential of advanced converter topologies will be unlocked when wide bandgap materials are introduced. These may include soft-switching topologies for high frequency applications; adaptive power inverters; higher frequency modulation schemes; resonant converters and multi-level converters.

In the short term, existing silicon-based converter topologies will dominate in many applications until the additional cost of wide band gap materials can be absorbed and the system level benefits realised

PREDICTION: As BEV and PHEV platforms become more sophisticated, there will be a closer integration of motor and power electronics

The trend towards smaller electrical drives with higher power density, to meet the performance needs and evolving packaging requirements of OEMs, has led researchers to consider integrated drives that could offer a more efficient and power dense solution. This allows interconnections to be deleted, a move from cables to busbars for motor phases and common cooling circuits. However the physical integration of the converter and the e-machine requires careful mechanical, structural and thermal optimisation in order to manage the temperature differentials between different components. The introduction of wide bandgap semiconductors could make integrated drives more attractive because they are smaller, more efficient and capable of operation at higher temperatures.

Some specialists anticipate that advances in manufacturing technologies will enable more radical integrated drives in the longer term; specifically there is potential for motors and power electronics to be fabricated together using additive layer manufacturing which would create a truly multifunctional, light weight electric drive.



PREDICTION: In a move to reduce complexity and costs, there could be an integration of power electronics where a single converter is able to manage power across the vehicle

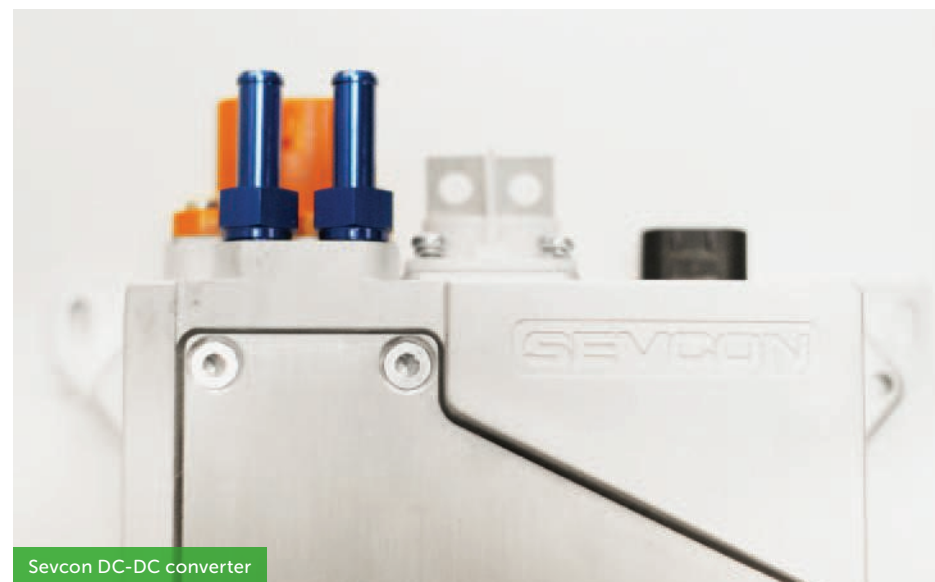
Multifunctional converter topologies reduce complexity and hardware, freeing up packaging space while reducing weight and cost. This approach is already implemented on the Nissan LEAF where the DC-DC converter and on-board charger have been merged to provide enhanced functionality and a more compact power electronics solution. A similar approach has been used in the Renault ZOE whereby the motor inverter is used to charge the vehicle. This approach enables the ZOE to charge from numerous charging stations and eliminates the need for a separate on-board charger.

The use of modular blocks is also an attractive approach; as the volumes of electrified vehicles increase, modularity enables higher volume manufacturing with greater commonality. In the long term, to meet the requirements of vehicle-to-grid, ultra-compact power electronics solutions may be required that can be redeployed to provide other on-vehicle functions. A single power electronics block that can provide all functions is one possible route to achieving this.

To meet the requirements of vehicle-to-grid, ultra-compact power electronics solutions may be required that can be redeployed to provide other on-vehicle functions

PREDICTION: More powerful control hardware will be needed to complement new convertor architectures, with the potential for adaptive control functionality as connected vehicles become more widespread

Advanced control software provides significant opportunities for product differentiation as hardware costs fall. Wide bandgap power electronics will require faster controls and more powerful control hardware. As control technology advances, advanced data analytics, vehicle-to-vehicle and self-learning software could enable converters to adapt for high efficiency, peak power or reliability, based on driving styles.





9.5 ENABLERS

PREDICTION: Despite the higher operating temperatures of new semiconductor materials, system level thermal management strategies will still be needed to provide effective cooling

Currently the emphasis is on simplifying the cooling arrangements across the vehicle platform, e.g. by applying a single cooling loop. More advanced cooling strategies may emerge in response to demands for deeper integration of power electronics with other components such as e-machines and batteries. This could entail the operation of power electronics at higher or lower temperatures, with the possibility of using the heat generated to bring the battery up to optimum temperature.

The absence of a thermal propulsion system (TPS) will require BEVs to implement new thermal management strategies to support vehicle-wide comfort and operational requirements. Oil cooling, shared with the TPS and transmission, may still be prominent in hybrid vehicles but as BEVs become more abundant, a number of strategies prove attractive. Air cooling, either passively or forced, may be a popular solution for mass market BEVs or those not experiencing high power operation. Cooling by submerging the electronics, or by circulation of water based coolant through passages in the converter, may be better suited to higher performance applications where high amounts of heat are generated and manufacturers are less sensitive to cost.

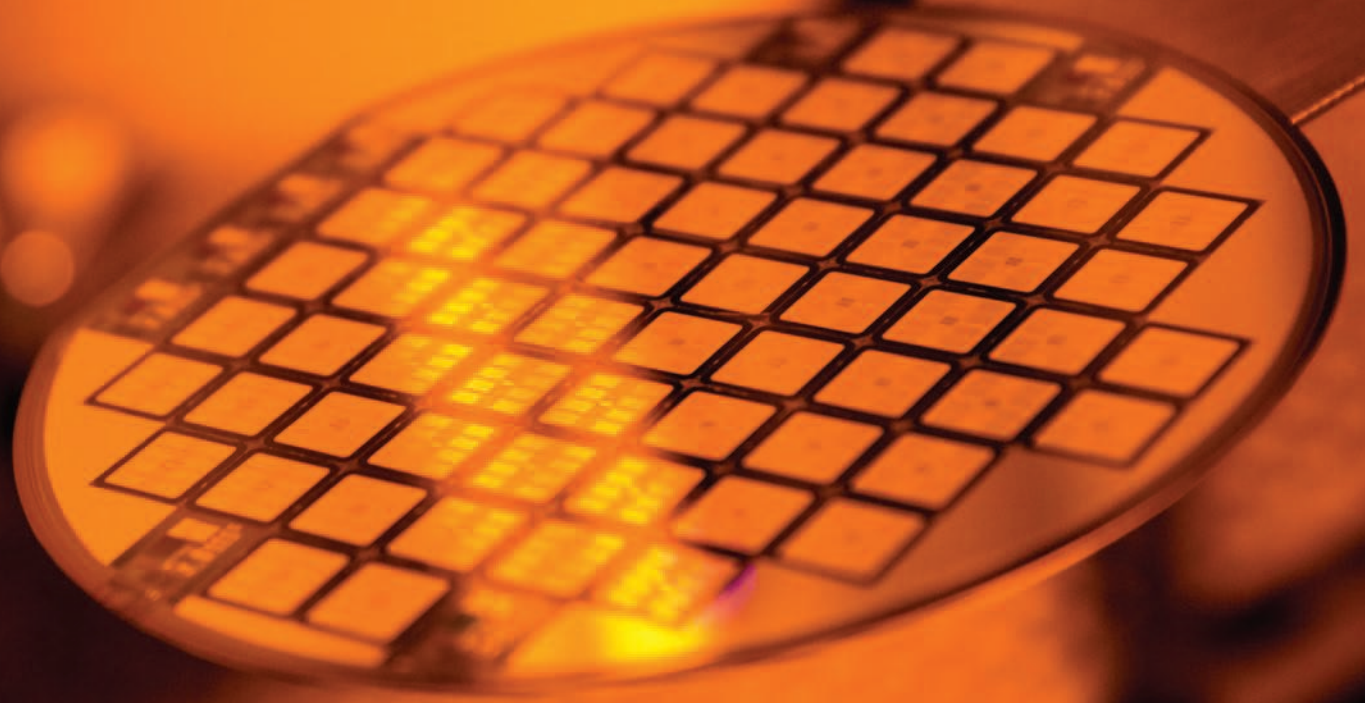
In the long term, it is envisaged that power electronics cooling may become part of single vehicle-wide loop including waste heat recovery and storage.

PREDICTION: Advanced manufacturing techniques could reduce costs through higher levels of automation and new design for manufacturing options enabled by additive layer manufacturing

The roadmap identifies that time-to-market for new products could be accelerated through the use of advanced manufacturing technologies such as additive layer manufacturing to produce complex prototypes, or by automation to reduce costs. As additive layer manufacturing becomes increasingly attractive for high volume manufacturing, this offers significant cost savings by reducing process steps and improving the consistency of manufacturing resulting in less variations.



Newport Wafer Fab



Dynex Semiconductor wafer



9.6 RESEARCH AND DEVELOPMENT CHALLENGES FOR THE SHORT, MEDIUM AND LONG TERM



Mark Johnson
Professor of Power
Electronics

APC Power
Electronics Spoke



Existing approaches in power electronics have served the automotive sector well, but with the advent of electric vehicles, silicon based devices and converter topologies are reaching their performance limitations. The wide range of requirements in the automotive sector is driving demand for higher temperature materials, higher switching frequencies, improved reliability and more power dense solutions. More importantly, new, promising technologies need scaling up to meet the demands of the automotive sector, which creates both technical and manufacturing challenges.

Developed through the APC's Power Electronics Spoke community, the twelve research themes identified below articulate a host of challenges facing the automotive power electronics community. A key message across the research themes is that the progressive introduction of wide bandgap materials will impact the whole supply chain, from semiconductor device manufacturers through to companies integrating power electronics into a vehicle platform.

It is clear that to get the best out of these new materials, collaboration between different disciplines within power electronics is essential.

For the UK supply chain the window of opportunity is narrowing. Strong competitors from Europe, Asia and the United States are amassing considerable capability in automotive power electronics and the UK must build upon its strengths and protect areas where considerable value can be created. The research themes identified below therefore act as a blueprint to aid organisations seeking to understand how they can help overcome the future challenges in automotive power electronics.

The wide range of requirements in the automotive sector is driving demand for higher temperature materials, higher switching frequencies, improved reliability and more power dense solutions



Identification of key research and pre-competitive development challenges to help facilitate academic / industrial collaboration on longer term product and manufacturing research and development

Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
1 Improved power semiconductor materials and devices	<ul style="list-style-type: none"> Continued improvement of Si device designs: IGBTs, MOSFETs, Power ICs Reducing cost and improving quality of SiC and GaN epitaxy and substrates Alternative substrate materials e.g. GaN and SiC on Si Identifying commonality in Si and wide band gap device manufacturing and adjusting processes to create reduced cost manufacturing capability for wide band gap devices 	<ul style="list-style-type: none"> SiC and GaN devices with enhanced reliability operating to >250°C SiC on Si substrate scale-up and reduced cost GaN Power ICs GaN devices with improved stability 	<ul style="list-style-type: none"> Cost effective, higher voltage >1500V GaN and SiC Large area, low-cost GaN substrates GaN vertical devices Diamond & Gallium Oxide materials and device processes Exploring new materials and/or devices that radically improve breakdown fields, thermal conductivity & electron velocity of semiconductors
2 Improved power semiconductor packaging technology	<ul style="list-style-type: none"> Development of standard interfaces to allow multisourcing-manufacturers Embedded chip and planar interconnect for low-inductance High reliability joining and interconnect technologies Modules with integrated passive components Low-cost integrated cooling (e.g. double sided cooling for flip chip) Materials and assembly processes for wide temperature range cycling and power cycling with rapid transients 	<ul style="list-style-type: none"> Integration of gate drives, filters, controls and sensors Embedded power and control elements Integrated EMI suppression Converter-in-package for increased power density Materials and assembly processes for 250°C capability including wide temperature range cycling and power cycling with rapid transients 	<ul style="list-style-type: none"> Easy to design and manufacture power modules with elementary bricks, pre-packaged chips High volume, low-cost manufacturing platform 3D integrated heterogeneous assemblies Low-cost substrate & laminate materials with low CTE (<16ppm) and high thermal conductivity (>20W/(mK)) Reconfigurable, multi-functional Converter-in-Package Materials and assembly processes for >250°C capability including wide temperature range cycling and power cycling with rapid transients



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
3 Integrated control functionality within power semiconductors		<ul style="list-style-type: none"> • Monolithic gate drives and power transistors (SiC and GaN) • Stable, reliable on-chip current sensing with wide bandwidth • GaN/SiC devices with intelligent gate drives • Integrated multi-functional sensors for health check and control 	<ul style="list-style-type: none"> • GaN/SiC half bridge on-chip with current/temperature sensing @ 1000V, 400A • Integrated direct optical control
4 Higher performance passive components	<ul style="list-style-type: none"> • Higher energy density ($>0.01\text{J}/\text{cm}^3$) wound components through improved thermal management • Higher temperature (200°C) passive components • Low-cost, high-performance and higher frequency capacitors for $>125^\circ\text{C}$ • Connectors with higher current, temperature and voltage capability 	<ul style="list-style-type: none"> • Magnetic and dielectric materials with higher energy density and lower losses • Magnetic and dielectric materials with higher temperature ($>250^\circ\text{C}$) capability • Higher temperature (250°C) passive component • Magnetic component designs for improved flux confinement and lower loss 	<ul style="list-style-type: none"> • Super capacitors with high temperature ($>200^\circ\text{C}$) capability • Higher temperature ($>250^\circ\text{C}$) passive components • Smart/multi-functional materials for passive components • Peltier technology for active cooling • Integrated, multi-functional passive components
5 Improved driving, sensing and monitoring technology	<ul style="list-style-type: none"> • Compatibility of gate drivers with range of WBG semi conductors • Better sensor technology (e.g. stable, reliable, low-cost current sensing with wide bandwidth; high temperature sensors; low loss sensors) • Semiconductor temperature estimation and/or monitoring • Algorithms to improve the interpretation, management and analysis of sensor data 	<ul style="list-style-type: none"> • Alternative approaches for sensing e.g. embedded and/or wireless sensors for condition monitoring • Condition monitoring of mechanical stress, displacement, electrical resistance and thermal resistance 	<ul style="list-style-type: none"> • Sensor-less drivetrain monitoring and control based on system-level observations • Utilising data from vehicle fleets (enabled through wireless networks and CAVs) to better manage PE performance • Understanding and mitigating the effects of interactions between CAV sensors and power electronics (e.g. EMC aspects)



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
6 Advanced converter topologies	<ul style="list-style-type: none"> Multi-level & modular topologies suited to >800V using Si MOSFET, IGBT and WBG devices Multi-functional, reconfigurable converters (Inverter, DC-DC, OBC combinations) 	<ul style="list-style-type: none"> Soft-switching ultra-high frequency topologies for inverter, DC-DC and OBC employing WBG devices Converter-in-Package integration leading to power densities > 60kW/litre Submersible converters Structural materials for building WBG based converters that can withstand higher temperatures, EMC etc. 	<ul style="list-style-type: none"> Multi-level & modular topologies for 1500V to 25kV Converter-in-Package integration leading to power densities > 120kW/litre Reconfigurable, fault-tolerant & self-healing converters
7 Closer integration of power electronics into vehicle powertrain	<ul style="list-style-type: none"> Integrated drives with thermal separation (12kW/l) High temperature capable power electronics (>105°C coolant) Multiphase and modular inverters for better integration 	<ul style="list-style-type: none"> Integrated drives with common thermal management (30kW/l) Modular inverter topologies that can be used with different motor topologies 	<ul style="list-style-type: none"> Low-cost, high-volume integrated drives supported by common manufacturing platform (>30kW/l) Cost effective fabrication (i.e. additive layer manufacturing) of power electronics into motors
8 Improved system level thermal management	<ul style="list-style-type: none"> Active thermal control of PE Merging of ICE/PE cooling loops using >105°C water/glycol Two-phase cooling for high heat flux and high power density 	<ul style="list-style-type: none"> Common heat transfer loop for BEVs (battery, e-machine, PE, HVAC) 	<ul style="list-style-type: none"> Removal of dedicated power electronics cooling, integrated into the powertrain Optimised vehicle level thermal management for BEVs with active thermal control (battery, e-machine, PE, HVAC) Integrating advanced heat recovery (i.e. phase change materials) into a system wide thermal management system to deploy heat effectively
9 Improved control software	<ul style="list-style-type: none"> Software & control for high-speed (>50 kHz) switching Thermal and power management using adaptive modulation strategies 	<ul style="list-style-type: none"> Software and control for ultra-high-speed (>1MHz) switching Condition and load-adaptive control algorithms Spread spectrum loss optimising control for soft switched converters Higher performance integrated control hardware 	<ul style="list-style-type: none"> Reconfigurable, fault-tolerant, self healing control algorithms Utilising advancements in vehicle-to-vehicle and vehicle-to-infrastructure technology to understand vehicles situation and location to modify power electronics performance



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
10 Improved fault tolerance mechanisms and overall system reliability	<ul style="list-style-type: none"> • Understanding PE degradation and failure mechanisms and FIT • Condition monitoring for key PE components (power semiconductors, modules, capacitors) 	<ul style="list-style-type: none"> • In-service prognostic and health management for PE converters • Machine learning based prognostics • In-service life consumption estimation and predictive maintenance • Fault tolerant control systems 	<ul style="list-style-type: none"> • Reconfigurable, fault-tolerant, self healing PE systems
11 Improve predictability of performance and reliability through modelling, simulation, testing and analysis techniques and facilities	<ul style="list-style-type: none"> • Predictive modelling tools with <5% margin of error • EMI testing for high power wide band gap materials • Improved physics-based reliability models for PE (e.g. SiC and GaN devices) • Improved modelling of specific phenomena (e.g. better EMI modelling, improved thermo-mechanical modelling) • Use of NDE to characterise PE degradation • Accelerated test methods • Open-access powertrain-level HiL evaluation facility for PE & integrated drives • Life-time estimation through modelling during the design phase 	<ul style="list-style-type: none"> • Multi-domain virtual prototyping environment (electrical, thermal, mechanical, reliability) • Accelerated test methods for advanced packaging • Design for sustainability • Cloud based system level multi-physics models to enable faster collaboration across industry (and between organisations not co-located) 	<ul style="list-style-type: none"> • Holistic, through-life predictive design tools with <1% margin of error • Tools for multi-domain, multi-time-scale rapid design optimisation
12 Mobilising a UK supply chain that can demonstrate cost competitiveness and higher productivity	Leveraging advanced manufacturing techniques and establishing rapid prototype facilities are both key in mobilising a UK supply chain		
	<ul style="list-style-type: none"> • Open-access prototyping and scale-up facility for PE manufacturing • Open-access powertrain-level HiL evaluation facility for PE • Open-access reliability test and characterisation facility for PE • High-density 3D circuit-board technologies • Scaling PE manufacturing to high volumes • Automation of manufacturing processes for low-cost & high-volume • Leveraging capability and previous learning from adjacent industries (i.e. aerospace, military, rail) to improve automotive power electronics • Establishing recycling technologies to sense, sort, separate and reprocess small sub-components with uniform design 	<ul style="list-style-type: none"> • Open-access prototyping and scale-up facility for embedded 3D PE on common manufacturing platform • Extended evaluation and validation facilities for 3D PE manufacturing • 3D integrated manufacturing technologies for PE converters to 100kW+ • Manufacturing of embedded component technologies and Converter-in-Package • Open-access facilities that can test power electronics to 250kW and above • Fully recyclable power electronics taking into consideration new materials 	<ul style="list-style-type: none"> • Open-access prototyping and scale-up facility for integrated drives on common manufacturing platform • Transition to low-cost 3D automated manufacturing • Additive layer and printed 3D manufacturing of PE • Flexible, automated manufacturing facilities (informed by models) that auto-optimize power electronics designs based on requirements • Establish and scale up processes that can disassemble and recycle integrated drives (power electronics and electrical machines)



10

TECHNOLOGY ROADMAPS

THERMAL PROPULSION SYSTEMS

Ford EcoBoost



OVERVIEW

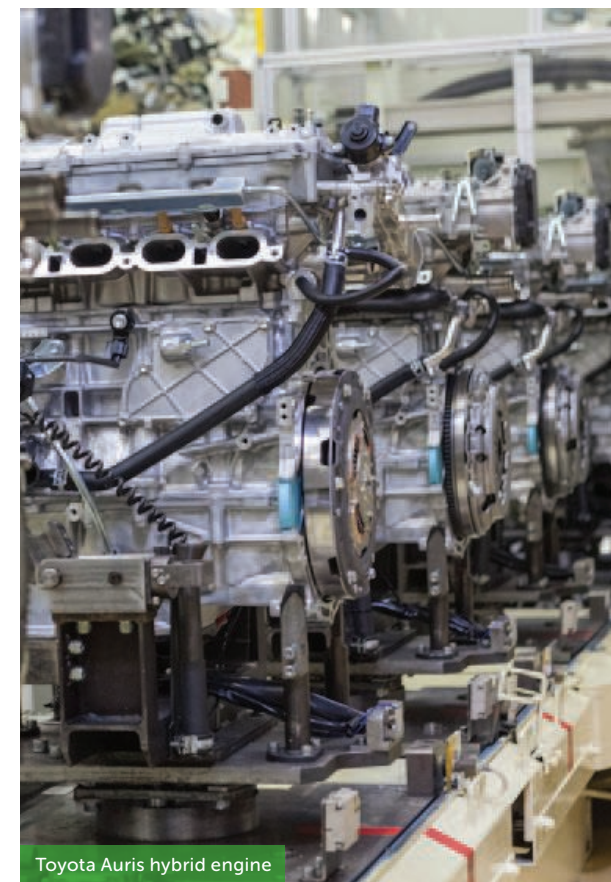
Despite the high expectations for electrification, thermal propulsion systems (TPS) will continue to have a significant role to play to 2035 and beyond, especially in heavy duty vehicles. It is recognised that this requires further improvements in real world efficiency and emissions in order to stay relevant.

Improved system efficiency means doing the basics better despite it becoming harder; this includes reducing friction, minimising weight through improved system design and utilising novel materials and production processes. It is assumed that these measures will be implemented in parallel with the other changes identified in the roadmap.

In the short to medium term, light duty vehicles are expected to focus on combining the best elements of the TPS with electrification to cost-effectively improve system efficiency. The roadmap reflects this, indicating that the evolving duty cycle of the TPS may lead to a

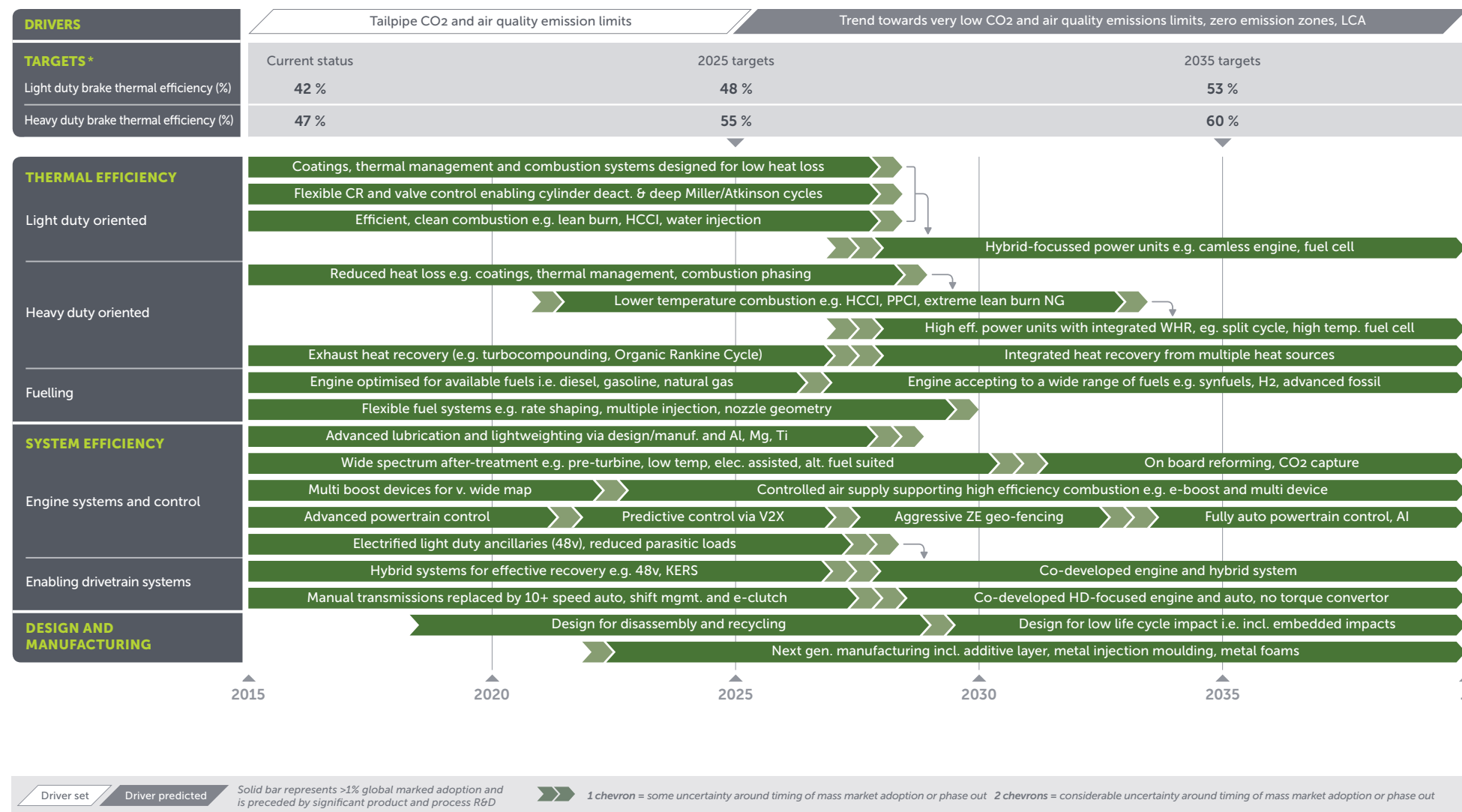
reduced operating window, which will allow further simplification and efficiency gains. Therefore it is expected that the engine will be progressively simplified while becoming more sophisticated in its design and more closely integrated within the propulsion system. This will range from 48V mild hybridisation where the TPS remains the heart of the overall system to a fully serial hybrid where the TPS provides power to an energy storage device via a generator.

Electrification of heavy duty propulsion systems will likely be limited to short distance vehicles with pre-determined journeys. The roadmap therefore suggests significant focus on thermal efficiency improvements to the base engine, supported by improvements in the complete system, including the electrification of some functions. It is envisaged that sustainable, low-carbon fuels will be required to further reduce the CO₂ emissions of these vehicles. This is expected to be driven by an increased use of lifecycle emission approaches sometime after 2030.



Toyota Auris hybrid engine

THERMAL PROPULSION SYSTEMS





10.1 TARGETS

Despite the significant real-world improvements made by TPSs in both CO₂ and pollutant emissions over the last 20 years, public confidence has been severely damaged by news stories about the growing gap between certified test results and real world emissions. This has led to a reaction from policy makers at local, national and international level leading to divergence in requirements. Real World Driving Emissions (RDE) testing procedures will be at the heart of any new legislation. Heavy duty vehicles in particular have shown that meeting stringent limits under RDE are achievable. The aggressive TPS targets in the roadmap for both efficiency and tailpipe emissions reflect the need to do more to improve pollutant and CO₂ emissions from both light and heavy duty vehicles.

The efficiency values quoted in each case represent a mid-point between diesel and gasoline efficiencies. Peak values are shown but the roadmap recognises the increasing importance of achieving high efficiencies across the reduced operating ranges in which the TPS will function as part of a hybrid powertrain that is designed as a single, highly integrated hybrid solution.

	2017	2025	2035
Light Duty			
Engine System Brake Thermal Efficiency (%) ^{1,2}	42	48	53
Tailpipe NOx & Particulates (Mass & Number)	In line with legislated limits	Zero impact in emissions controlled zones ³	
Heavy Duty			
Engine System Brake Thermal Efficiency (%) ^{1,2}	47	55	60
Tailpipe NOx & Particulates (Mass & Number)	In line with legislated limits	Zero impact in emissions controlled zones ³	

1. Peak efficiency values shown. Increasingly important to achieve high efficiency across a wider operating range, in keeping with testing cycles based on real world performance
2. Values reflect mid point between diesel and gasoline efficiency (current difference ~5%)
3. Below measureable limits or below ambient (background) levels

10.2 THERMAL EFFICIENCY

PREDICTION: Light duty TPSs are expected to increasingly form part of the wider propulsion system, allowing substantial changes in combustion strategy

Efficiency improvements for light duty vehicles are expected to come from increasingly integrating the TPS into the wider propulsion system and leveraging the synergies between the TPS and the e-machine. This permits further optimisation of the engine through novel cycles, improved combustion regimes and improved thermal management. Downsizing the TPS had been a popular approach over the past couple of years, but it was observed by a number of OEMs that ‘rightsizing’ the TPS presents a strong alternative to ensure improvements are delivered under real world driving conditions.

In the short to medium term, novel valve control is a key enabling technology for improving thermodynamic cycles, offering higher thermal efficiency and fuel-saving strategies. One route being explored by companies is cylinder deactivation. Ford’s approach has been to implement cylinder deactivation in their downsized three cylinder engine whereas Delphi Technology’s system, developed in partnership with Tula, adopts a ‘skip fire’ cylinder deactivation control strategy that determines which cylinders to fire on each cycle.

Other combustion strategies enabled through more flexible valve control include: variable compression ratio systems (now being used by Nissan), and advanced Miller/Atkinson cycles, exploited by Toyota in the Prius and now being advanced by other OEMs. Nissan’s variable compression ratio system, launched in 2017 for their Infiniti brand, adjusts its compression ratio via a multi-link system. The link system continuously raises or lowers the pistons’ reach to adjust compression ratio – offering both power and efficiency.

As electrification provides the greatest opportunities for improvement, including zero tailpipe emissions capability, it is expected that in the longer term the TPS

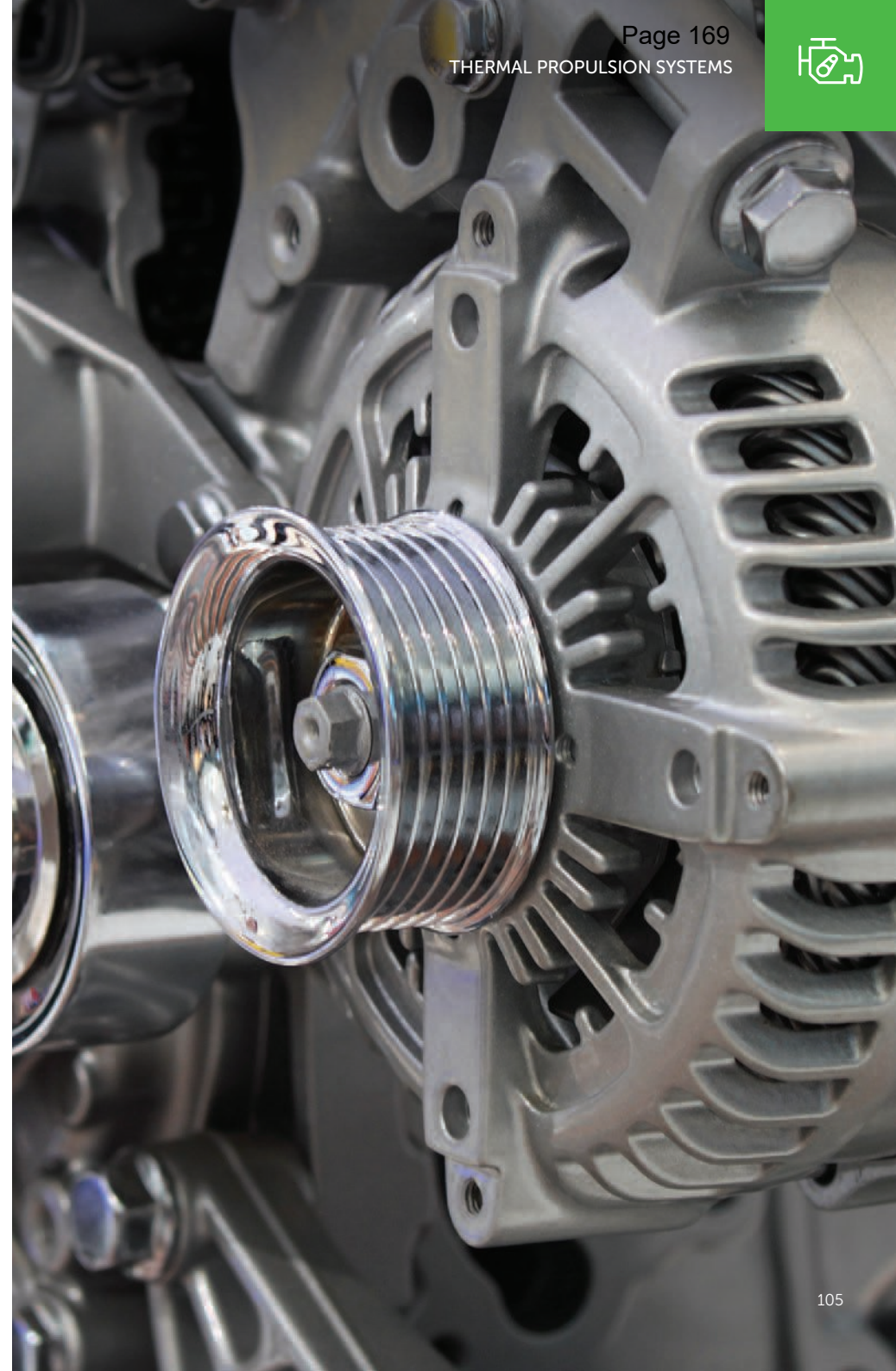


will increasingly be designed with this function in mind, leading to simpler, more cost-effective architectures but with more sophisticated combustion systems and controls. The Toyota Prius and BMW i3 (ReX) demonstrate this trend in an early form while Mazda has announced that it will bring its HCCI engine to market in 2019.

PREDICTION: Further thermal efficiency improvements are expected for heavy duty TPSs, initially through highly efficient low temperature combustion processes and heat recovery then, potentially, novel combustion cycles

It is expected that efficiency improvements will be largely incremental, focusing initially on exhaust heat recovery and improved combustion systems, as indicated by improvements demonstrated on the US Supertruck programme. In order to meet the aggressive targets set in this roadmap, more significant changes to the combustion systems will be required. These are likely to include a low temperature combustion regime, such as HCCI, PPCI or very lean burn, which combines high efficiency with low levels of engine-out pollutants. These systems currently operate well in controlled conditions; the challenge is to ensure satisfactory operation under wide ranging real-world conditions.

Longer term the roadmap recognises that fuel cells - both Solid Oxide Fuel Cells (SOFC) and Polymer Electrolyte Membrane Fuel Cells (PEMFC) - are the ultimate in low temperature oxidation that could lead to further efficiency and emission improvements. Novel power units could also be commercialised to reach the 2035 target but are currently in the early stages of research. Examples cited in the public workshop were split cycle concepts, integrating the heat recovery function within the thermal propulsion system and linear piston generators.





10.3 SYSTEM EFFICIENCY

PREDICTION: The development of sustainable fuels could take two directions, fuels tailored for specific TPS designs or fuels that work in numerous TPS designs

In the short term, it's recognised that reducing the carbon intensity of conventional fuels whilst retaining current fuel quality standards would deliver a substantial reduction in CO₂ emissions. This remains an attractive strategy and has now been adopted as a primary objective for the fuels industry in Europe.

Long term, in order to achieve deeper reductions in the carbon footprint of heavy duty vehicles, traditional diesel fuel is likely to be displaced by lower carbon fuels. Two pathways were identified for how the TPS could evolve alongside next generation fuels. The first route is to develop a TPS that is tolerant to a wide variety of fuels. The second pathway identified, which is the approach used today with diesel is to optimise the TPS for one fuel type.

Various alternative fuels are in different stages of development and commercialisation; LNG/CNG/LPG seem attractive short term alternatives assuming methane slip across the life cycle can be significantly reduced and enhanced combustion techniques, such as HPDI, can be commercialised. In the longer term, increasing competition for fuel resources could drive the development of novel TPS approaches that are tolerant to a wider range of fuels while maintaining high levels of efficiency.

PREDICTION: Further integration will be required to improve whole-system efficiency across the wide-ranging operating conditions

Further reductions in pollutant emissions during real-world use, even on a very efficient low temperature TPS, will require significant further development of after treatment systems. This is expected to lead to a combination of devices in the exhaust system that provide cover across a wide spectrum of operating conditions. These might have to be supplemented by further systems for vehicles operated outside even this wide spectrum, such as when using particular alternative fuels or for extensive operation at low ambient temperatures.

In the longer term, on-board reforming and CO₂ capture could be feasible for very heavy duty applications; light duty systems are expected to follow the opposite trend with aftertreatment systems only having to work with a TPS operating within a restricted band, due to increased levels of electrification.

A similar divergence between light and heavy duty is likely for air supply systems. Initially wider operating envelopes are likely to be required, especially for light duty thermal propulsions systems, requiring multiple devices and electrically driven boosters. Increasing the level of electrification will present both opportunities and challenges. Multiple boosting systems, linked to 48V architectures, could enable greater energy recovery capability in both light and heavy duty system. However for light duty applications, the TPS will potentially require more precisely controlled air delivery across a smaller operating window, relying on better control of the energy available within the system.

In the short term, the powertrain control unit will assume additional responsibilities, allowing it to deliver the high levels of control integration that ensure maximum efficiency of the complete system. In the longer term, additional data from outside the vehicle will enable further efficiency improvements, ranging from actively taking account of road and traffic situations to being fully integrated into an automated transport system.



10.4 DESIGN AND MANUFACTURING

Significant system efficiency improvements can also be achieved through the electrification of ancillaries. This route is recognised as a cost-effective way to reduce CO₂ emissions, especially in light duty vehicles, where 48V is expected to be the new standard for mild hybridisation. Beyond 2025 it is uncertain which development path non plug in hybrids will take. While some believe higher-voltage 'full' hybrids will displace 48V hybridisation in the mid-term, others have plotted a roadmap that shows growing complexity and integration of 48V system architectures. Initially, this path shows the integration of a single e-machine into the engine or transmission, followed by the application of multiple or higher powered e-machines, for example to provide energy capture and torque control for each wheel.

PREDICTION: Electrification and transmissions are the key enabling technologies to further improve thermal propulsion systems

Brake energy recovery offers significantly improved vehicle efficiency. Although the energy can be recovered by a number of means, partial electrification of the propulsion system is thought to be the most attractive for light duty vehicles because it also provides zero tailpipe emissions capability. For heavy duty vehicles, electric, hydraulic, mechanical and pneumatic energy recovery systems have been explored due to the diverse range of applications and ease of which they can be integrated.

Improved transmissions and increasing levels of electrification will allow the TPS to be optimised for further efficiency improvements, with automatic transmissions expected to become dominant and to work with the TPS to optimise the operating requirement.

PREDICTION: Enhanced modelling and simulation tools, coupled with advanced manufacturing techniques, will reduce the required number of manufacturing steps for a TPS and reduce complexity

End-of-life recycling requirements for vehicles are expected to become increasingly demanding, leading to improved designs in terms of disassembly and part count. In the longer term, emissions assessment based on life cycle impact is expected to drive further design and manufacturing improvements, including novel manufacturing processes such as additive layer, metal injection and metal foam technologies, enabling the use of innovative design techniques.

Whilst not explicitly pulled out in the roadmap, enhanced modelling and simulation tools are crucial to unlocking new TPS designs and manufacturing routes. Utilising real world performance data, leveraging virtual prototyping and testing as well as simulating manufacturing processes will enable more sophisticated, lightweight products. This will accelerate new products time to market and enable manufacturers to reduce CO₂ and emissions earlier.

Utilising real world performance data, leveraging virtual prototyping and testing as well as simulating manufacturing processes will enable more sophisticated, lightweight products



10.5 RESEARCH AND DEVELOPMENT CHALLENGES FOR THE SHORT, MEDIUM AND LONG TERM



Dr Robert Morgan
Reader University
of Brighton

APC TPS Thermal
Efficiency Spoke



Professor Chris Brace
Professor of
Automotive Propulsion

APC TPS System
Efficiency Spoke



Thermal propulsion systems will continue to be essential for our future transport systems. The exceptionally high energy density of liquid hydrocarbons offer unparalleled utility and versatility that's critical for many applications and geographical areas. It is important that as we move to a more sustainable future we continue to improve the efficiency and cleanliness of thermal propulsion systems as these will constitute a significant part of the installed capacity for many decades to come.

The research and development challenges, identified by the Thermal and System Efficiency Spoke communities, illustrate the greatest challenges facing thermal propulsion systems. In the short term, opportunities centre on optimising existing approaches to combustion systems, after treatment systems, control

strategy and boosting, to name a few. Longer term, the table articulates the challenges in achieving achieve clean, ultra-low carbon combustion systems in tandem with sustainable fuels. This offers consumers the prospect of a cost-effective, high utility propulsion future that combines the best aspects of thermal propulsion and electrified systems.

It is important that as we move to a more sustainable future we continue to improve the efficiency and cleanliness of thermal propulsion systems as these will constitute a significant part of the installed capacity for many decades to come



Identification of key research and pre-competitive development challenges to facilitate academic / industrial collaboration on longer term product and manufacturing research and development. As identified in the roadmap, research priorities will differ depending on whether an application is for lighter or heavier duty cycles.

Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
1 Reduced air quality impact	The implications of improving air quality both in cylinder and post-combustion need to be considered together and not taken in isolation		
	In-cylinder approaches <ul style="list-style-type: none"> • Novel ignition systems for dilute operation • Multiple/split injection strategies to overcome the NOx/soot trade-off (inc. including understanding problems such as cavitation associated with new injection methods) • Fast cycle – cycle control of homogenous compression ignition • On board water recovery for water injection • Dilute homogenous combustion (both CI and SI) After treatment approaches <ul style="list-style-type: none"> • Develop more efficient approaches for reducing NOx, and oxidizing PM, HC, and CO in low temperature exhaust (150°C). • Portable emissions measurement systems (PEMS) for future requirements (e.g. particulate numbers, future EU-7 and gaseous vehicles) • Improved DPF and GPF efficiency for smaller particles (below >23nm) • Low temperature (below 350°C) oxidation catalysts for CH4 	Technologies that achieve zero emission impact thermal propulsion systems <ul style="list-style-type: none"> • Zero emission combustion systems / architectures compatible with carbon neutral fuels (e.g. nitrogen scrubbing, full cycle HCCI, catalytic combustion) • Radical near 100% efficient after treatment systems that convert over the whole operating cycle • Low cost, mass manufacturable and recyclable fuel cells (both high and low temperature) • Cost effective technology for on vehicle hydrogen storage 	



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
2 Improved thermal propulsion system efficiency and real world fuel consumption/GHG reduction	Challenges in improving real world fuel consumption / reducing GHG emissions occur during combustion and systems that operate around the TPS		
	Optimising current combustion cycles <ul style="list-style-type: none"> Improving conventional combustion cycles (i.e. through better valve control, deeper Miller/Atkinson cycles, altering combustion cycles depending on load) to improve thermal efficiency Cascading technologies and principles from lighter duty (i.e. cylinder deactivation and downsizing) into heavier duty cycles Improving existing techniques for thermal management and friction loss <ul style="list-style-type: none"> Cost effective surface treatments for friction and heat loss (e.g. thermal barrier coatings and new lubricant formulas) Lower cost WHR systems and components (i.e. turbo-compound, thermoelectric, thermo-acoustic) Optimising current air handling strategies <ul style="list-style-type: none"> Improved turbocharger efficiency over wide map, including down speeding (e.g. better twin scroll, e-boost) 	Advanced combustion strategies to achieve higher engine efficiencies <ul style="list-style-type: none"> Advanced efficient combustion systems such as ultra lean and SACI Geometric variable compression ratio concepts New concepts for thermal management and friction loss <ul style="list-style-type: none"> Novel thermal barrier coatings (e.g. temperature swing) Fast warm up systems (e.g. on board thermal storage, low thermal inertia systems) WHR combining high grade and low grade heat, including direct powertrain cooling High efficiency expander that can operate over a wide turn-down ratio Novel fluids for high efficiency WHR Advanced air handling strategies integrated with other systems <ul style="list-style-type: none"> Integrated WHR (thermoelectric) and electric turbocharger (e-boost, e-turbine) and integration (e.g. water recovery) Fuel injection systems <ul style="list-style-type: none"> High flexibility FIE (including injection rate and nozzle geometry) 	Technologies that achieve carbon neutral thermal propulsion systems <ul style="list-style-type: none"> Thermodynamic cycles with integrated waste heat recovery (e.g. split cycles, on board fuel reformation) Multi fuel combustion systems that deliver ultra-low life cycle CO₂ On board CO₂ capture (pre and post combustion) Low cost, mass manufacture fuel cells (high and low temperature) with advanced WHR systems



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
3 Reducing the cost and complexity / attribute trade-off of electrified thermal propulsion systems	<ul style="list-style-type: none"> Modifying current engine architectures and platforms to operate as part of a hybrid system 	<ul style="list-style-type: none"> New, flexible and modular thermal propulsion system for hybrid applications applicable across vehicle platforms 	<ul style="list-style-type: none"> New architectures for low cost and complexity PHEV / REEV thermal propulsion systems
4 Improved powertrain control and operation using approaches such as machine learning or connected data	<ul style="list-style-type: none"> Utilising connected vehicle data for improved powertrain control Advanced model based control with reduced reliance on base maps Improved sensor technologies (e.g. better accuracy, more parameters, lower cost) 	<ul style="list-style-type: none"> Design systems for cyber security Prognostics – improved software capability to better sustain health of engine and powertrain E-horizon enabled powertrain control considering V2V interactions, geo-fencing and optimising vehicle level energy management. Application of machine learning to powertrain control, calibration, validation and OBD 	<ul style="list-style-type: none"> AI led, adaptive and collaborative control schemes, fully connected with city infrastructure Low power consumption control, sensing and processing Human-like autonomous control focussed on customer experience
5 Decarbonising thermal propulsion systems via co-developed engines and de-carbonised fuels	Two possible research pathways: TPS fully optimised with fuels or TPS that is flexible and accepts a wide range of alternative fuels		
	<ul style="list-style-type: none"> Higher efficiency engines for lower GHG-intensity fuels (i.e. bi and dual fuel concepts, lean burn DI CNG/LNG combustion systems with negligible methane slip) Novel concepts to extend the utility of low grade or renewable fuels and/or reduce the need for high grade fuels Global energy system analysis tools to inform fuel pathway choices and engine development 	<ul style="list-style-type: none"> Mass production of fuels tailored for clean, efficient TPS e.g. on vehicle fuel reforming, lean homogenous combustion, high temperature fuel cells TPS tolerant to wider fuel specification (higher bio content, fuels from recycled waste) Drop-in low carbon fuels to decarbonise existing fuel content Mass production of paraffinic fuels (e.g. Fischer-Tropsch, HVO) On board fuel conversion from a low cost liquid source 	<ul style="list-style-type: none"> Alternative thermodynamic cycles for ultra high efficiency (inc. fuel cells) using sustainable, low cost drop in 'sun-to-liquid' fuels and /or tailored bio-fuels Co-developed engines and tailored 'sun-to-liquid' fuels for near zero emissions Sustainable fuel production processes from recycled waste with zero emissions TPS tolerant to variable fuel specifications Offering electrical network system resilience via TPS in V2G mode



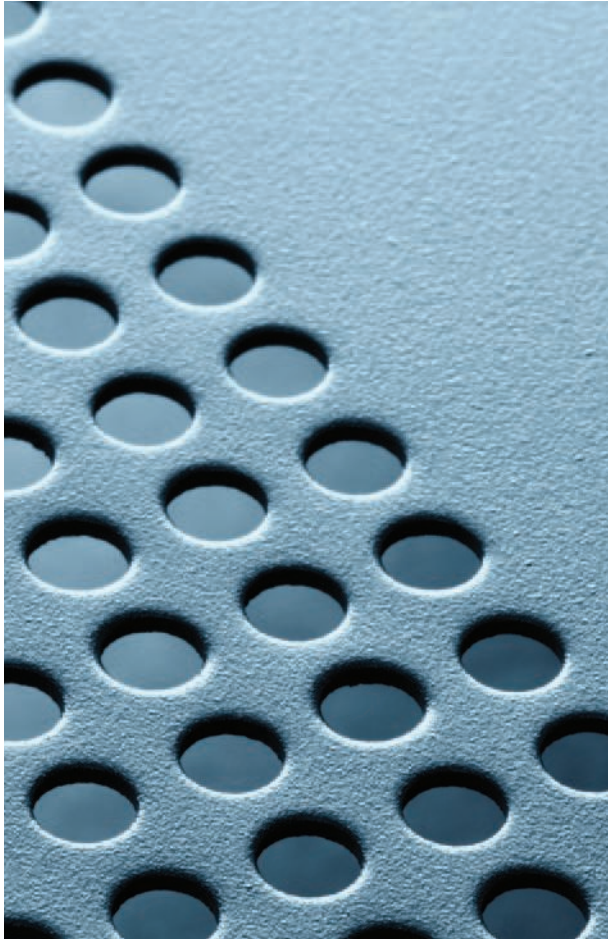
Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
6 Manufacturing and materials for improved attributes, recyclability or life cycle impact	<ul style="list-style-type: none"> Engines designed for serviceability and manufacture In-engine lightweight technology with mid and end of life in mind Additive manufacturing for niche applications Low cost thermoelectric materials Develop deeper LCA insights into powertrain materials, their manufacture and end of life 	<ul style="list-style-type: none"> Cost effective next generation surface treatments such as temperature swing coatings or ceramics for exhaust Mass production additive manufacturing techniques and associated evolution in component design Greater use of bio materials and recycled materials in TPS components 	<ul style="list-style-type: none"> Chemical heat storage materials Lubricant free materials Low cost, volume production using additive layer manufacturing (i.e. fully printed powertrains) Fully automated manufacturing tools that auto optimise and self regulate Low LCA and environmental impact of TPS materials and manufacturing processes
7 Minimising time to market, efficiency of development and product attributes via improved methods and toolchains	<ul style="list-style-type: none"> Virtual calibration based on improved representation of physics in engine models Use of big data for harnessing in-service data to inform engine design, control and OBD Models that can effectively simulate engine combustion and in-cylinder emission formation processes through to the performance degradation of after treatment systems for existing and new combustion cycles 	<ul style="list-style-type: none"> Multi-physics system level modelling to understand powertrain level trade-offs and optimise powertrain architectures Predictive simulation tools for industry to design advanced thermal propulsion systems 70% virtual testing and verification for thermal propulsion systems 	<ul style="list-style-type: none"> AI led design and optimisation techniques 95% virtual testing and verification for thermal propulsion systems



11

TECHNOLOGY ROADMAPS LIGHTWEIGHT VEHICLE AND POWERTRAIN STRUCTURES

Williams Advanced Engineering EV chassis



OVERVIEW

Historically, vehicle weight has increased through the addition of more content such as passive and active safety features and more sophisticated comfort and convenience features. Efforts to offset these increases have ensured vehicle weight has remained stable across most classes whilst still improving performance and fuel economy.

The increasing influence of tailpipe emission regulation combined with the increased sales of electrified vehicles has sharpened the industry's focus on reducing vehicle weight. For conventional vehicles the reduced energy requirement for propulsion results in lower CO₂ emissions as well as improved performance and fuel economy. For electrified vehicles the challenges of reducing vehicle weight are more pronounced due to the heavy battery pack but reductions in weight can contribute to an extended range. In both conventional and electrified powertrains, weight reduction can also create a virtuous circle, whereby the weight saved in one area permits further savings in other areas, such as the brakes or suspension in conventional vehicles, or the battery in electric vehicles.

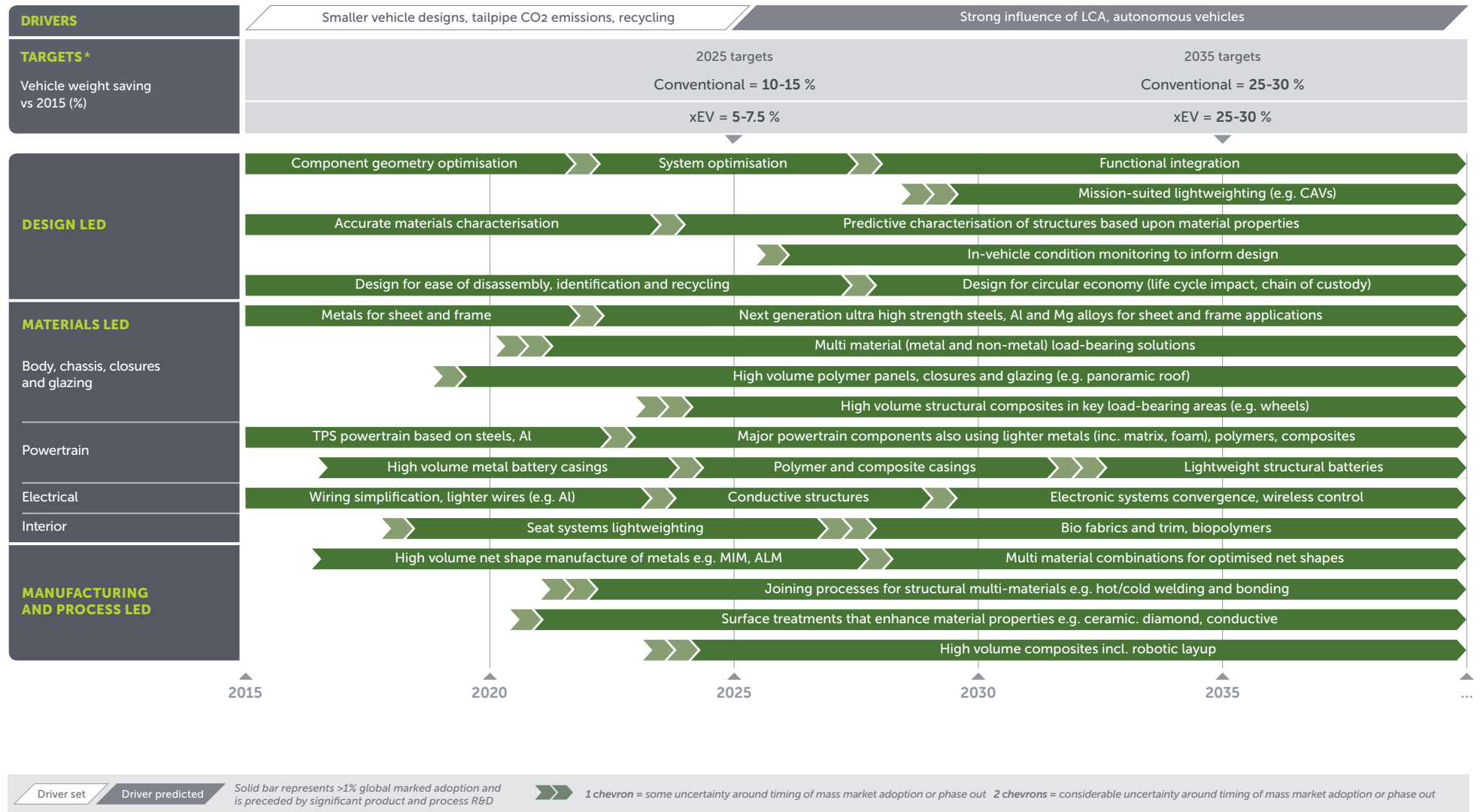
The roadmap identifies developments in design, materials and manufacturing as being the key routes to lower weight. High volume vehicles are predicted to take a different development path to premium vehicles produced in lower volumes, where different approaches to materials specification and manufacturing processes can be employed.

Individual short term weight reduction targets have been provided for conventional vehicles and for xEVs, as the weight of the battery pack makes weight reduction harder for the latter in the short term. In the longer term, improvements in electrified powertrain technologies will enable weight reductions but the effect of CAVs in conjunction with a change in ownership models is predicted to radically alter vehicle duty cycles, eliminating the extremes of manual operation and enabling lighter designs.

All developments in lightweight technology will be subject to increasing sustainability constraints, requiring due consideration of cost effective end-of-life recyclability before implementation.



LIGHTWEIGHT VEHICLE AND POWERTRAIN STRUCTURES





11.1 TARGETS

In order to meet future CO₂ targets, incremental reductions in weight are not sufficient, so ambitious long term targets have been set to drive innovation. The short term targets recognise that electrification poses additional challenges for vehicle weight; for PHEVs and BEVs especially, the larger batteries and electrified propulsion components make these vehicles heavier than conventional vehicles. It is assumed that no adverse effect on vehicle cost, safety or emissions will be accepted as a consequence of weight saving.

	2015	2025	2035
Passenger Car			
Conventional vehicle weight decrease (%) ¹	Baseline	10 -> 15% ²	25 -> 30% ²
xEV vehicle weight decrease ³	Baseline	5 -> 7.5%	25 -> 30%
Recyclability of material (%)	85%	85% ⁴	95%

1. Some components will be untouched during this period, so those which are redesigned must have a higher % saving than the vehicle % saving required
2. Future vehicle weight reductions will need to counter weight gains from e.g. ADAS, infotainment, NVH, safety systems, refinement solutions (weight gain estimated to be around 5% in 2025 and up to 10% by 2035)
3. The target for 2025 is lower than conventional ICE because larger batteries will increase the weight of next generation xEVs. However the improved energy density of batteries, as well lighter motor and power electronics solutions, are keeping weight increases as small as possible.
4. Number remains the same to reflect the inclusion of battery packs in end of life regulations

11.2 DESIGN-LED WEIGHT SAVING

PREDICTION: Improved simulation and design tools will enable greater optimisation of components and, in the longer term, could enable functional integration of key components

Increasingly accurate material datasets that inform design and simulation tools will enable component weight reduction through geometry optimisation.

In the short term, creating open access material databases that provide an accurate understanding of real life performance characteristics could enable designers to utilise existing modelling tools to reduce material usage and choose more suitable materials, or combinations of materials, to optimise component design. Examples of this approach include hollow structures and the use of multi-materials with the stronger material deployed only where most needed.

As modelling tools evolve and encompass more elements of analysis (potentially including whole-life aspects such as second life usage), functional integration to reduce system level complexity was identified as an attractive option for further weight reduction. An example of this approach can be seen in Renault's DTI 5 engine which achieved a 25% weight reduction using a novel metal additive manufacturing processes. The prototype engine Renault demonstrated a reduced part count compared to existing models and eliminated a number of manufacturing processes, all enabled by 3D modelling.



PREDICTION: Vehicles will become increasingly tailored for specific applications as CAVs become more widespread, leading to different designs depending on use case and driving environment

The majority of vehicles are designed for personal ownership so must satisfy a number of different requirements such as large luggage capacity, five or more occupants, and the corresponding crash and safety regulations that all add significant weight. Designing vehicles specifically for certain applications, such as smaller vehicles for urban environments, would dramatically reduce vehicle weight through more appropriate design.

Vehicles such as Daimler's Smart car range, Renault's Twizy and the many Japanese Kei cars are already designed along such lines, however the impact of CAVs combined with shifting mobility business models could spur on the development of smaller, lighter concepts such as autonomous pods. An initial design benefit of CAVs will be the elimination of over-engineered components that are usually designed to cope with user-induced peak loads and performance demands. This will enable smaller and lighter components that do not need to accommodate a wide variety of performance extremes. Understanding what will incentivise consumers to adopt personalised mobility services will further drive demand for these services and encourage the production of these vehicles.

In the long term, as vehicle ownership declines in favour of using autonomous and shared services, and primary safety can be improved by geo-fenced environments for CAVs, the level of crash protection needed could be reduced, enabling the use of new designs and innovative material choices. However the impact of CAVs on weight reduction could be diminished by additional sensors, actuators and computer processors, especially if duplication occurs due to safety requirements.

Nevertheless the automotive industry is already investigating these possibilities, with UK company Westfield trialling autonomous pods in Greenwich and Toyota announcing their 'e-palette' concept at the CES 2018 event. For CAVs, it is expected there will be a trade-off between the level of weight reduction possible and the increasing weight of systems required for enhanced CAV operation and on-vehicle entertainment systems.

PREDICTION: Increasing data collection from vehicles will enable live condition monitoring and enable designers to optimise vehicles based on real-world data

In-situ data gathering using embedded sensors is essential for informing next-generation vehicle designs and managing the health of existing fleets. Immediate applications for this technology are most appropriate in vehicles that experience very high utilisation such as buses, trucks and delivery vans. For such applications, in-service reliability and longevity is crucial to maximising commercial return, so actively managing vehicle health and using the data to schedule preventive maintenance could prevent failures, reduce vehicle downtime and improve traffic flows to avoid congestion. High performance passenger cars could utilise this technology by leveraging advanced data analytics used in the motorsport sector to inform next generation vehicle design. For example, since 2012 Mercedes AMG has been leveraging advanced data analytics to improve TPS design, reduce validation times and improve manufacturing efficiency. It's envisaged that this approach could extend beyond TPS analytics and encompass the whole vehicle.

In the longer term, growing volumes of real-life data can be used to inform modelling tools, helping to optimise designs and improve vehicle efficiency. As embedded sensors are increasingly adopted in commercial vehicles, the technology is likely to migrate into passenger cars as the ownership model changes towards shared and autonomous vehicles with higher utilisation.

As embedded sensors are increasingly adopted in commercial vehicles, the technology is likely to migrate into passenger cars as the ownership model changes towards shared and autonomous vehicles with higher utilisation



11.3 MATERIALS-LED WEIGHT SAVING

PREDICTION: Though many vehicles are already designed for disassembly and recycling, as powertrains evolve vehicles need to be designed for a circular economy that captures and reuses valuable materials

Legislation for passenger cars already includes end-of-life requirements, such as the EU End-of-Life Directive which defines how recyclable they should be and the recovery rate of materials by mass. However, as the emphasis shifts towards total life cycle analysis, the embedded impacts of a vehicle's materials and manufacturing processes will become increasingly important, profoundly affecting the types of materials and processes used by the automotive industry.

Weight-saving materials that bring benefits during a vehicle's use will be less attractive if they produce detrimental environmental impacts during their production or recycling phase, for example multi-materials may deliver impressive vehicle weight savings but create significant challenges for recycling. Separating dissimilar materials during recycling has been identified as a significant challenge as the processes which currently exist can damage the materials, making them less desirable for reuse.

As the emphasis shifts towards total life cycle analysis, the embedded impacts of a vehicle's materials and manufacturing processes will become increasingly important, profoundly affecting the types of materials and processes used by the automotive industry

PREDICTION: Advanced steels will dominate in key load-bearing and body structures for high and medium volumes, but alternative metals and polymers could be used in structures that are less integral to vehicle safety and in lower volume or niche applications

In the short to medium term, high strength steel is seen as the lowest risk option for high volume applications involving important load bearing structures. Divergence from steel is seen largely in low and medium volume applications or on selected models with sufficiently high margins to absorb the added material costs. Ford and Jaguar Land Rover in particular use aluminium body structures, with Ford's largest selling product, the F-150, transitioning from steel to aluminium bodies in 2014 and Jaguar Land Rover's Castle Bromwich plant exclusively producing cars with aluminium body structures.

Audi and BMW have opted for a multi-material approach; the new Audi A8 uses four different materials (steel, aluminium, magnesium and carbon fibre reinforced polymers) for its weight-bearing body structure and the BMW i3 uses carbon fibre body panels joined to an aluminium frame.

In some heavy duty applications, such as buses, carbon fibre and aluminium are more commonplace; Proterra use carbon fibre body panels in their Catalyst buses and Wrightbus used composites in the body structure to help minimise the weight of their hybrid buses.

The automotive sector's interest in alternative materials for integral crash structures has triggered the steel industry to develop more innovative products to protect its market share. Advanced ultra-high strength steels that are not only lighter but have improved mechanical properties are being continuously developed by the steel industry to meet future weight reduction requirements. The aluminium industry is also investing in new grades and especially in improved manufacturing techniques that extend the range of applications while also reducing costs. Ensuring a closed-loop material value chain, to reduce the reliance on expensive and energy-intensive virgin aluminium, is crucial before such material can be applied in higher volumes.



Low-cost thermoplastics are promising for areas such as panoramic roofs, bumpers and selected closures but carbon composites would need a dramatic improvement in manufacturing processes, reducing the takt time to seconds rather than minutes, to suit high volume applications (see section 11.4).

PREDICTION: TPS-based powertrains will continue to be constructed largely from metals but the use of alternative materials is becoming more widespread

For TPS-based powertrains, metals will continue to dominate due to the high temperatures experienced and the pre-existing high volume manufacturing capability. To reduce weight in the short to medium term, more exotic materials for the TPS such as foams, titanium springs, magnesium alloy castings and metal matrix composites could be used. Driveline components offer good potential for weight reduction, for example thermoplastic differential and e-machine casings and carbon fibre reinforced polymer prop shafts are actively being researched and developed.

As the powertrain becomes increasingly electrified, opportunities will arise to use lighter materials, particularly for the battery pack which comprises a significant percentage of weight in PHEVs and BEVs. Most battery casings and internal support structures are metal, in part due to simplicity but also to provide some structural support and heat transfer. However, to reduce the weight of batteries, the roadmap identifies the potential to use polymers and composites casings, enabling OEMs to consolidate parts and integrate functions into fewer, lighter components. Longer term, the potential exists for batteries to be more thoroughly integrated into the vehicle, with the active chemistry embedded within the floor or body structure.

PREDICTION: As vehicle electrical systems increase in complexity, through infotainment systems, connected features and electrified powertrains, the weight of these systems must be reduced

The volume of electrical systems in vehicles is set to increase through electrified powertrains, infotainment systems, connected and autonomous features and safety equipment. Without substantial effort from OEMs to reduce the weight of wiring, terminals and connectors, these additional systems will contribute significant additional weight.

In the short term, copper wiring could be replaced with lighter alternatives such as aluminium (providing the oxidation challenge is overcome) or copper-clad aluminium. Rationalisation of key circuits and the integration of some components may reduce the number of wiring harnesses and control units in the vehicle. The next step is to commercialise conductive body structures through embedded strips, or data and power transfer in composite materials. In the longer term, it is envisaged that functional integration of electrical architectures and wireless control should be employed in order to radically reduce the complexity and weight of vehicle electrical systems.

The Automotive Council's Electrical and Electronic Architectures roadmap also highlights the move from distributed to more centralised control, driven by the dramatic escalation in power and communication requirements for CAVs, as another key driver for electrical systems convergence.

The volume of electrical systems in vehicles is set to increase through electrified powertrains, infotainment systems, connected and autonomous features and safety equipment



Interior of Nissan LEAF

PREDICTION: Vehicle interiors, predominately seats in the short term, show great potential for weight reduction

Seating systems are the largest weight contributor in a vehicle interior because of the growing number of comfort and safety features included, making lightweight seating systems an attractive short term path for interior weight reductions. A range of materials have been identified that could be utilised in seats, ranging from next generation ultra-high strength steels developed by Tata, to thermoplastic seats developed by Brose for Jaguar Land Rover. Opportunities exist for multi-material approaches to cut the weight of seats even further, with Adient using magnesium, glass and carbon fibre reinforced plastics as well as aluminium in their seating range.

In the long term, as life cycle analysis becomes a prominent driver, sustainable bio-fabrics and bio-materials for interior applications will become more relevant, not only for seating systems but for interior trim, with the potential for bio-polymers and bio-composites to be used in structural applications. For this to become feasible, improvement is required in the technical performance of bio-composites and more cost-effective methods of creating the organic materials are needed.

Seating systems are the largest weight contributor in a vehicle interior because of the growing number of comfort and safety features included, making lightweight seating systems an attractive short term path for interior weight reductions



11.4 MANUFACTURING AND PROCESS-LED WEIGHT SAVING

PREDICTION: Advanced forming technologies will be key in creating near net shapes with the possibility of manufacturing multi-material components in one process step

The roadmap process identified a number of potentially attractive forming techniques, particularly net shape forming which could, in the short term, improve existing metalworking processes by reducing the need for machining and enable the fast, low cost production of accurate parts. Examples of this approach include metal injection moulding, cold forming to enable plastics to undergo the same processes as metals, and additive layer manufacturing for some applications. In time it is envisaged that highly automated processes may enable multi-material net shape manufacturing to achieve maximum component performance with minimum cost and weight.

PREDICTION: Existing joining processes for similar materials will be adopted for dissimilar materials but new techniques will be required to improve joint quality and simplify end-of-life disassembly

Currently, the lack of suitable joining processes for dissimilar materials is one of the biggest barriers to reducing the weight of vehicle platforms. The immediate focus is on enhancing current mono-material processes that utilise existing manufacturing tooling. While various joining options exist for new materials, there is limited application knowledge or experience. This illustrates the need for more accurate material databases and creates issues in using more advanced lightweight materials as the joint is often thought of as the weak link in the whole vehicle structure. Therefore better understanding of joint technology will be pivotal in accelerating the uptake of lighter materials.

Processes for joining multi-materials that have been actively researched include: multi-point joining (e.g. remote laser welding, hot, cold and thermoplastic welding), bonding (e.g. quick cold cure resins), mechanical joining (e.g. self-piercing rivets, fasteners and friction bit joining). While these techniques can provide mechanically strong joints, further research into the disassembly of multi-materials is required, such as that conducted at Michigan University on disassembly techniques for plastic joints using reversible adhesives.

Advances in joining technology are becoming an enabler for new materials applications, with the highly focussed properties of some new materials requiring a combination of techniques. For example, very thin materials, specified for weight reduction, will require a higher joined surface area to spread the load, yet bonding may not provide the resistance to peel that this requires. A solution increasingly employed is to complement bonding with mechanical fastening.

PREDICTION: New surface treatments will be needed to enhance material properties

Surface treatment technologies are traditionally employed to enable materials to be formed or joined together, or to achieve a desired surface property. However, advances in materials science are producing a wide range of new materials and processes that, when applied to the surface of other materials, can improve the properties or enable dual functionality. Properties that can be modified include conductivity, thermal performance, hardness, friction and aesthetics.



PREDICTION: High levels of automation will be crucial in scaling up composite manufacture to higher volumes suitable for mainstream automotive applications

Carbon fibre reinforced polymers have been identified as materials that can be used to save weight across the vehicle structure, powertrain and interior. Early adopters of carbon fibre include McLaren Automotive, who used carbon fibre in their hybrid McLaren P1, and BMW who used body panels for the electric i3. However to encourage carbon fibre's adoption in other vehicle segments, a significant reduction in the manufacturing cycle time must occur so it aligns with high volume vehicle assembly processes. The roadmap explicitly highlights this as a critical barrier to the commercialisation of carbon fibre reinforced polymers, requiring manufacturing innovations such as robotic automated fibre placement to increase speed, accuracy, reduce waste and enable full automation of pressing and curing steps.

High volume application of carbon fibre reinforced polymers will also require improved end-of-life recovery and re-use of the costly carbon component. Recycling facilities have already been established in the UK, such as ELG Carbon Fibre's factory in the West Midlands, but these are currently processing low volumes of materials, predominately from aerospace, rail and low volume automotive applications.

High volume application of carbon fibre reinforced polymers will also require improved end-of-life recovery and re-use of the costly carbon component



McLaren P1



ELG Carbon Fibre facility



11.5 RESEARCH AND DEVELOPMENT CHALLENGES FOR THE SHORT, MEDIUM AND LONG TERM



Jon Beasley
Director of Technology
and Projects,
APC



Increasing vehicle weight, driven by additional safety features, enhancing passenger comfort and electrified powertrains, has stimulated intense research to reduce overall vehicle mass. From material designers exploring advanced steels, aluminium and more exotic hybrid materials, to reimagining vehicle designs to exploit autonomous capability, the suite of options today's engineers have at their disposal is broad. An immediate challenge is the initial adoption of modularised technology which will lead to deeper product integration, where interfaces are removed and supporting operational systems shared.

The eight research themes identified through a public workshop and an expert Steering Committee highlight the pressing need for research in better design tools, improved materials and more efficient manufacturing processes. However a consistent message throughout the update process was that improvements in these three areas strongly overlap and shouldn't be taken in isolation.

The short term challenges reflect the fact that optimising future components will increasingly utilise advanced design tools that will successfully leverage new material datasets and require

complex multi physics simulation to determine optimum system solutions. This approach could lead designers to using new materials, or combinations thereof, to cost effectively reduce weight. Therefore material suppliers are not only required to continuously improve existing and new materials, but, to understand how materials will perform and interact within a multi-material or hybrid structure. Once this is understood, new manufacturing methods that reduce process steps, reduce wastage from forming and effectively join multi-material structures need to be established. More importantly, these manufacturing processes need to deliver on both automotive quality standards and takt times.

Longer term the challenges reflect the expected impact of CAVs and shared mobility on vehicle design, the growing influence of life cycle analysis on both material selection and manufacturing processes as well as higher levels of automation and cost effective additive layer manufacturing processes. These challenges should not be seen as an exhaustive list of all the exciting development in design, materials and manufacturing, but, indicate those areas that respondents expected to see considerable technical innovation.



Identification of key research and pre-competitive development challenges to help facilitate academic / industrial collaboration on longer term product and manufacturing research and development

Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
1 Enhancing modelling and design tools capability	<ul style="list-style-type: none"> • Open access datasets to inform models (i.e. standards, interoperability, reuse, openness) • Component level digital twins (i.e. chassis, body structures) to optimise subcomponents and reduce costs associated with real life testing • Better modelling and understanding of: distinct phenomena (i.e. NVH, thermal performance, crash properties); less familiar materials (i.e. composites, Mg, multi-materials/ hybrid materials) and; manufacturing processes (e.g. joining, forming) • Improving the processing speed of simulations (e.g. days to hours) • Low cost simulation technologies incorporating simple user interfaces and highly parallel simulation on high performance computer networks • Integration of augmented and virtual reality into design and development 	<ul style="list-style-type: none"> • Vehicle level digital twins to model system interactions and improve overall vehicle design • Integrated multi-scalar modelling of crash, stiffness, electromagnetic characteristics • AI driven structural optimisation techniques • Highly optimised high performance computer network simulation codes to minimise development timeframes (e.g. hours to minutes) 	<ul style="list-style-type: none"> • AI driven digital twin that incorporates: through life cost, detailed material datasets, simulated manufacturing processes, in vehicle use data and vehicle end of life/second life. • Advanced supercomputing capability to generate complex simulations rapidly (e.g. minutes to seconds)
2 Leveraging advanced digital and sensing technologies	<ul style="list-style-type: none"> • Embedding sensors into current vehicle structures to inform next generation vehicle design • Through process sensing to reduce scrap • Glass fibre sensors embedded in composite materials 	<ul style="list-style-type: none"> • Wireless sensing systems to assess structural health of critical components • Embedded real time material property data and traceability (e.g. RFID) from pre-form to second life. • Prognosis and health management techniques 	<ul style="list-style-type: none"> • Ultra low cost, low energy wireless sensors to address the increased monitoring required for CAVs and shared vehicles • Low energy wireless communication standards • Localised power systems to reduce complexity • Develop multifunctional materials with self-diagnostics using dielectric material properties (i.e., the material itself provides sensing)



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
3 Improved surface treatments	<ul style="list-style-type: none"> • Low cost, innovative chromate free surface treatment of aluminium through environmental friendly reagents and processes • Lowering steel hardening and coating temperatures to enabling plastics to undergo electro-coating processes • Laser hardening and surface treatment • Improved traditional surface treatments such as carburising and nitriding • Low cost, environmentally friendly surface treatments to prevent Mg corrosion 	<ul style="list-style-type: none"> • In process laser hardening and surface treatment to reduce manufacturing steps • Advancements in chemical etching processes • Surface treatment of materials to allow 'reversible' bonds making separation of multi-materials easier 	<ul style="list-style-type: none"> • Coatings and surface finishing that allow multiple functionalities (e.g. tailored friction, self-cleaning, data transfer etc)
4 Improving the material characteristics of metals, polymers, hybrid and multifunctional materials	<ul style="list-style-type: none"> • Steels that can achieve a tensile strength of 2000MPa without compromising formability • Reduced cost improved formability and weldability AHSS with strength 1000 - 1500 MPa • Aluminium alloys that achieve a tensile strength of more than 500MPa without compromising formability and recyclability • Tailoring the material properties of metals/polymers to enable injection moulded components • Cost effective metal/composite fibre mixed weave materials for powertrain applications (i.e. for high temperature operations, components susceptible to wear etc.) 	<ul style="list-style-type: none"> • Development of particulate and nano-materials to improve performance of existing materials • Increase of scandium alloy aluminium • Alternatives to problematic elements (Lead and Beryllium) for free machining metals • Aluminium alloys that achieve a tensile strength of more than 750MPa without compromising formability and recyclability • Higher Tg polymers at lower cost (e.g. for engine and drivetrain components) • Cost effective high stiffness, high strength, high elongation polymers (e.g wishbones + wheels) • Polycarbonate with hard surface (scratch resistant) for glazing • Multi-structural and multi-powder components 	<ul style="list-style-type: none"> • Advanced grain structures of UHSS to enable cold forming • Aluminium alloys that achieve a tensile strength of more than 1000Mpa without compromising formability and recyclability • New materials and structures for super capacitors that can enable regeneration into body structures • Lightweight smart glass (e.g. energy harvesting, HVAC, embedded electronics, better structural characteristics) • Memory shape alloys and polymers for vehicle structures • Multi-material blanks • Data transfer through materials • Leveraging AI to explore new material compositions • Structural battery – energy storage and power storage in the body structures.



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
5 Improving forming technologies	<ul style="list-style-type: none"> • Elimination of defects and repeatability of ultra-thin wall net shape casting • Zero waste, reduced steps and reduced tooling requirement of forming using existing processes • Energy efficient warm/hot formed sheet metals with complex cooled tooling geometries (AM tooling) • Improved blank utilisation on stamped metal parts • Improved material utilisation for composite forming • Develop new extrusion methods for Mg that do not rely on rare earth elements for its strength, ductility and energy absorption properties 	<ul style="list-style-type: none"> • Lower temperature forming technologies that improve environmental impact • Localised magnetic pulse welding • Microwave induction heat • Low cost, higher volume Mg extrusion techniques for appropriate components (i.e. bumper beams, crush tips and intrusion beams) • Improved 3D roll forming with high D/t ratios • Improved hydroforming for high strength thin wall high D/t tubes 	<ul style="list-style-type: none"> • Complete 3D printed vehicles
6 Efficient joining processes	<ul style="list-style-type: none"> • Joining without surface activation technologies • Zero waste, reduced steps and reduced tooling requirement of joining using existing processes • Fasteners capable of joining metals and polymers • Rivetless cold joining • High speed laser spot welding • Remote/distributed laser welding of sub-assemblies 	<ul style="list-style-type: none"> • Low cost joining technologies for dissimilar materials that have zero impact on material properties • Fixtureless joining on the assembly line • Adhesive inkjet printing • Unjoining and de-bonding processes to facilitate improved material recovery 	<ul style="list-style-type: none"> • Complete 3D printed vehicles



Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
7 Improving the environmental impact of vehicles in their production, use and end of life	<ul style="list-style-type: none"> Aluminium automotive alloys made from at least 50% process scrap and 25% end of life vehicle scrap Harmonised industry standards for life cycle analysis Utilisation of green energy for energy intensive processes Hydrogen capture and cleaning technologies Industrial fuel cell integration Closed loop recycling and higher utilisation of scrap in the material production process High speed continuous casting of metals 	<ul style="list-style-type: none"> Scale up of carbon fibre recycling processes e.g. pyrolysis and solvolysis without impairing material properties Reduce manufacturing energy use of high volume composite manufacture Aluminium automotive alloys made from at least 50% process scrap and 50% end of life scrap Utilising waste materials from other sectors for use in automotive whilst maintaining (or enhancing) material properties Direct raw materials conversion processes Technologies to reduce manufacturing energy and environmental impact (i.e. carbon capture and storage technologies, waste heat capture) 	<ul style="list-style-type: none"> Fully circular economy for vehicle manufacturing 100% manufacturing energy from renewable or carbon neutral sources (i.e. CCS)
8 Developing new manufacturing methods to reduce takt time, enable more complex geometries and reduce manufacturing steps	<ul style="list-style-type: none"> Develop faster oxidation processes to remove the bottleneck of carbon fibre conversion to further lower the cost of carbon fibre Composite in process qualification to reduce takt time. Net shape metal injection moulded steel components Complex geometry hollow forging Combining joining and forming to minimise process steps 	<ul style="list-style-type: none"> Machine learning additive layer manufacturing components to improve component functionality and reduce overall system complexity Automated in-line inspection utilising Industry 4.0 techniques Larger scale metal injection molding with hollow section Hybrid machined and additive layer manufacturing part development In process laser heat treatment New tool materials for increased machining speeds Tailor forged blank Thin wall hollow forging 'Smart Manufacturing' proactively responding to variations in input parameters on a part by part basis to minimise scrap, tool wear and energy use Single stage production processes for powder metal production 	<ul style="list-style-type: none"> Reconfigurable manufacturing processes Low cost high volume/large scale additive layer manufacturing processes Fully automated vehicle assembly processes that are sensitive to demand



12

WORKING TOGETHER
TO COMMERCIALISE
THE PRODUCTS
AND TECHNOLOGIES
IDENTIFIED IN
THE ROADMAPS



12.1 NEW OPPORTUNITIES TO CONNECT, COLLABORATE AND GROW

The roadmaps clearly demonstrate emerging societal needs and how these will lead to changes in propulsion technology requirements. There is now a clear and rapidly growing market pull for new low carbon technologies globally, underpinned by more local policies such as the UK's 'Road to Zero' strategy. Traditionally the automotive industry has responded to changing market requirements through incremental technology steps mainly led by OEMs and their first tier suppliers. The scale and speed of the change is unprecedented and requires a systems approach to introducing new technology into the market. This provides an opportunity for a more collaborative approach to overcome significant technical challenges and bring new low carbon products to market quicker. In parallel, rapid growth in the capability and capacity of the complete supply chain

is required to deliver this new technology in sufficient volumes and cost-effectively.

The APC is built on a collaborative approach having originated from the UK's Automotive Council. The enormity of the challenge calls for organisations and individuals from around the globe to collaborate to bring about the required change. The APC, together with our spokes, academia, policy makers and industry are here to actively support the development, industrialisation and manufacturing of new technology in order to support this required change.

The enormity of the challenge calls for organisations and individuals from around the globe to collaborate to bring about the required change



**ADVANCED
PROPULSION
CENTRE UK**



APC networking event





12.2 CONCLUSION

IAN CONSTANCE – CEO, THE ADVANCED PROPULSION CENTRE



This report is intended to be a catalyst for further dialogue between industry, academia and government regarding the future technology pathways for zero and low emission vehicles and propulsion technologies. The true value of the roadmaps will only be realised if organisations work collaboratively to deliver the technologies the community have identified.

The roadmaps provide a consensus view of the main challenges in commercialising technology. These challenges represent a significant opportunity for those who embrace change and are willing and able to work closely with other sectors in new areas. For example, how can the UK's impressive chemical sector progress automotive battery development? How can our steel industry metallurgists help progress advanced traction motors? These are the types of questions that the roadmapping process

has raised while helping to form the view that extending the automotive supply chain will significantly accelerate technology delivery.

In a period of unprecedented change in the automotive industry, we expect these roadmaps to facilitate activity between the key organisations operating in these fields as well as helping those businesses and researchers in adjacent sectors to understand and engage with the automotive industry challenges.

The roadmaps provide a consensus view of the main challenges in commercialising technology. These challenges represent a significant opportunity for those who embrace change and are willing and able to work closely with other sectors in new areas.

ROADMAP REPORT REFERENCES

Bloomberg New Energy Finance, 2017

Lithium Ion Battery Costs and Market

Clean Technica, 2016

Electric Bus Sales Exploding In China (2010–2015)

E4tech, 2017

Fuel Cell Industry Review

Electric Nation, 2018

International Council on Clean Transportation, 2016a

NOX emissions from heavy-duty and light-duty diesel vehicles in the EU: Comparison of real-world performance and current type-approval requirements

International Council on Clean Transportation, 2016b

United States Efficiency and Greenhouse Gas Emissions Regulations for Model Year 2018–2027 Heavy Duty Vehicles, Engines and Trailers

International Council on Clean Transportation, 2017

Light Duty Vehicle Green House Gas and Fuel Economy Standards

Johnson Matthey, 2015

SAE 2014 Heavy-Duty Diesel Emissions Control Symposium

McKinsey, 2017

Future of Mobility: Trends and implications

MRCagney, 2017

Electric Bus Technology

Transport for London, 2017

Mayor's Draft Transport Strategy

United Nations, 2016

The World's Cities in 2016

US Energy Information Administration, 2017

Study of the Potential Energy Consumption Impacts of Connected and Automated Vehicles

CONTACT

Advanced Propulsion Centre

University Road

Coventry CV4 7AL

info@apcuk.co.uk

+44 (0) 2476 528700

www.apcuk.co.uk



OTHER BUSINESS

MEETING CLOSURE

The meeting shall conclude on or before 9.30pm unless there is a specific motion adopted at the meeting to continue beyond that time.