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Future Fuels & Energy for Road Transport

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Caveat Emptor

“Anyone that tries to predict more than five to ten years ahead is a bit of an idiot, so many things can change unexpectedly”

James Lovelock CH CBE FRS
– Ex NASA and Earth Scientist – Aged 99

“I don’t think we’re yet evolved to the point where we’re clever enough to handle as complex a situation as climate change”

Summary

- **Mitigating climate change** will be a significant challenge and we must prepare for **significant disruption**. **Net zero** GHG emissions will require a more holistic view of **total life cycle impacts** and **sustainability**. Whilst Battery Electric Vehicles (BEV's) emit zero tailpipe emissions, life cycle impacts can be significant

- Meeting our transport GHG goals will require a **systems approach**; efficiency, utilisation, de-fossilisation and an integrated energy system. The most **efficient use of renewable energy** is through **BEV's** but we are likely to require **H_2, renewable chemical fuels** and additional **zero and negative GHG energy** options for long range/heavy duty applications to meet a net zero target

- A **consumer/user centric** approach to BEV utility such as **range** and **charging** availability will encourage mass market scale-up. However, **investments** in electricity **distribution**, charge point **availability**, battery technology, critical materials supply and **recycling** will not be fast enough to meet our intermediate goals

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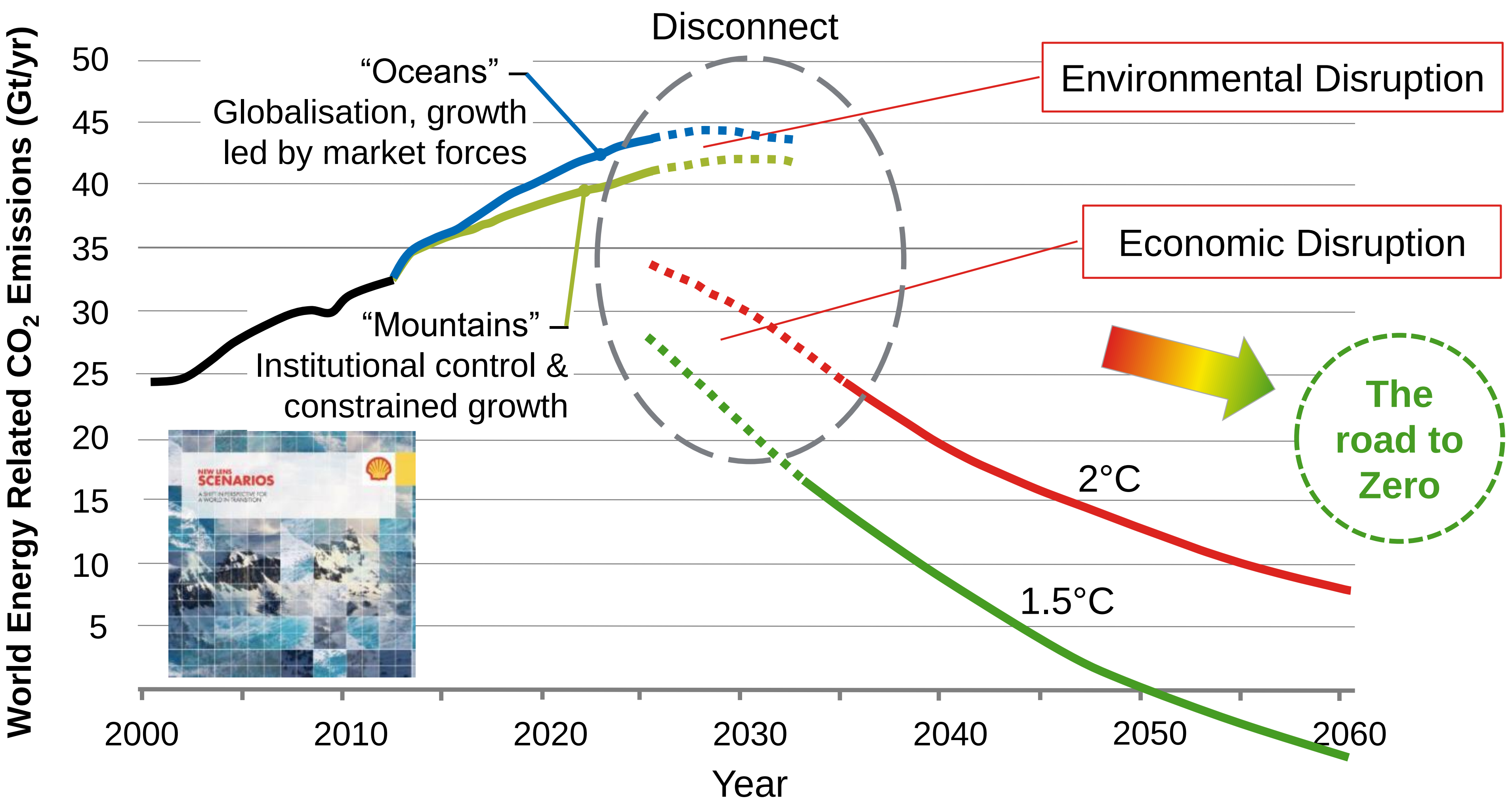
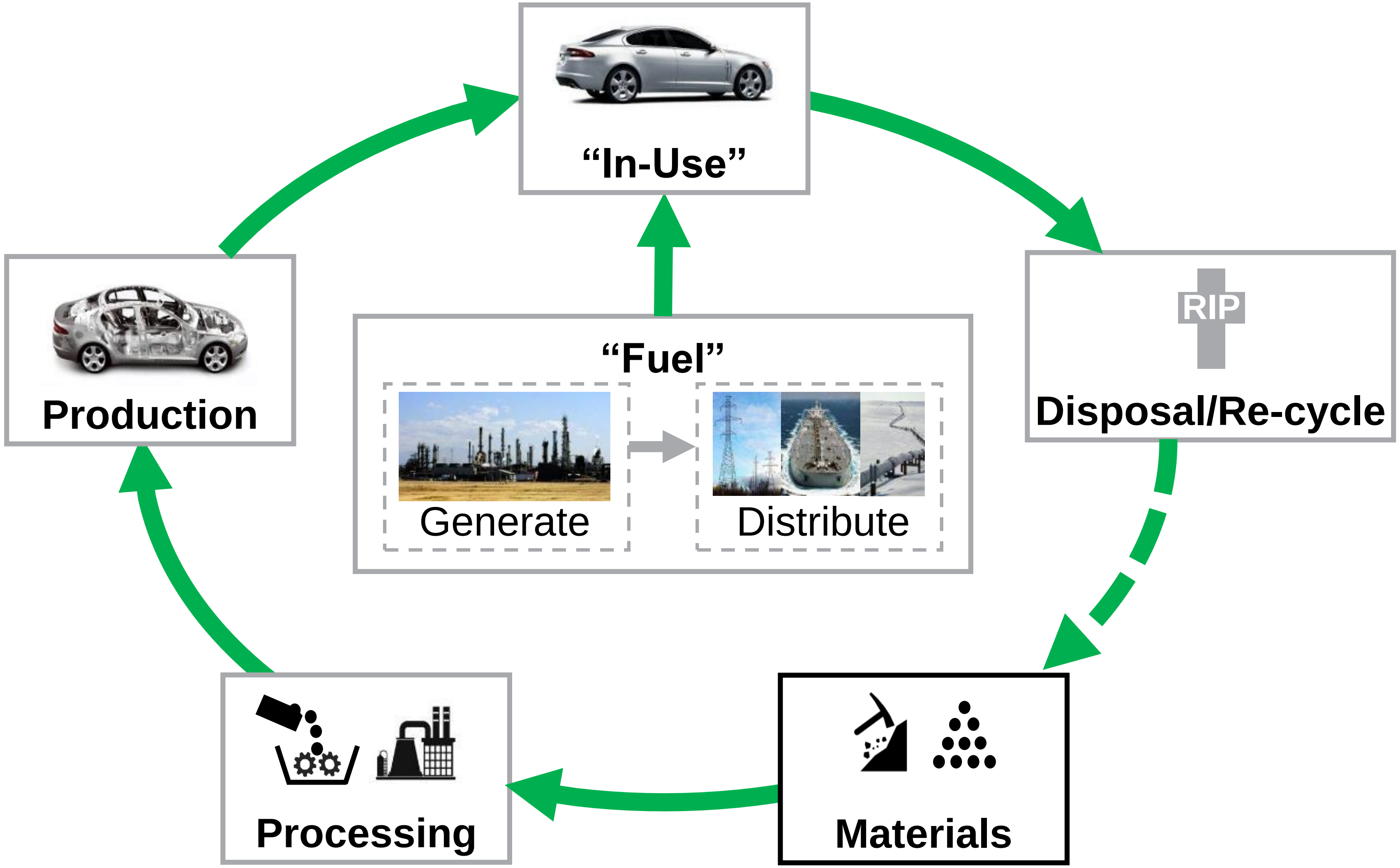
The Energy/Climate challenge and projected future energy scenarios reveal a significant discontinuity – disruption the likely outcome



- Policymakers in Europe increasingly focused on "Zero" emissions for road transport
- Reducing carbon intensity in other sectors perceived to be more difficult

Source: Shell New Lens Scenarios; Gert Jan Kramer, Utrecht University

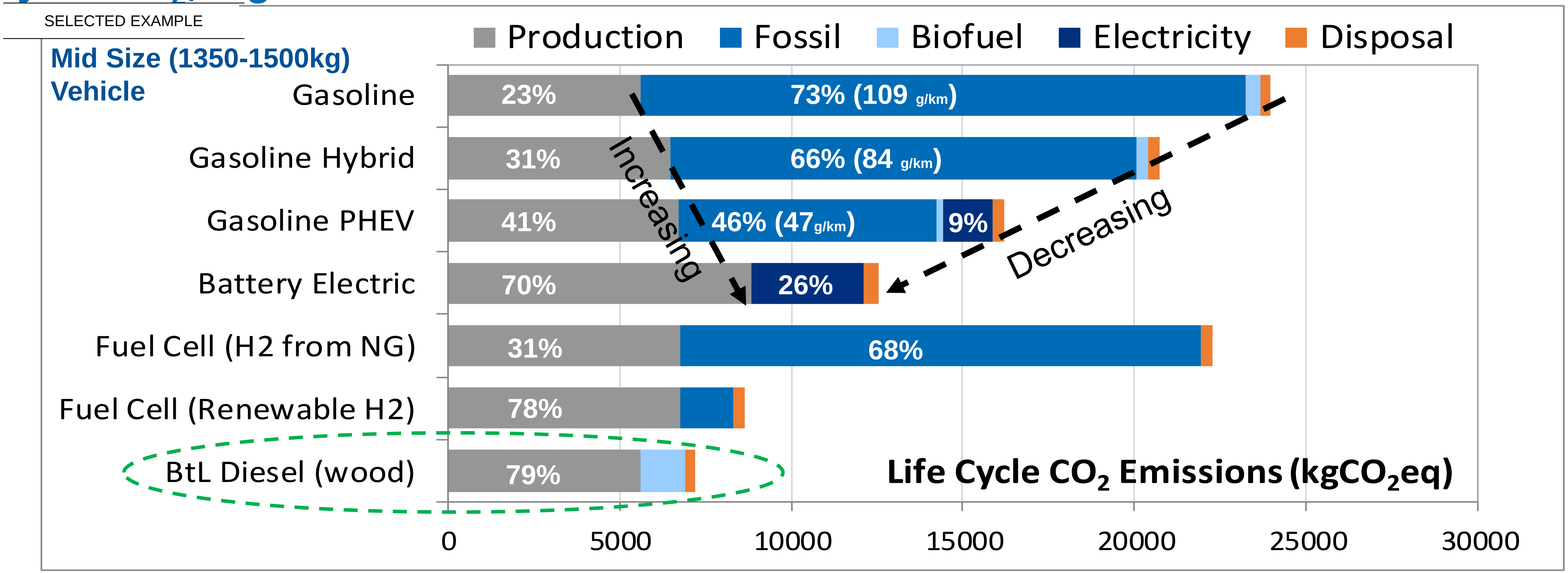
If our objective is to reduce environmental impacts and improve sustainability, are we looking at the bigger picture?



- Impacts from conventional combustion engine vehicles mostly from "in-use" phase
- Electric & H_2 Fuel cell vehicles can increase impacts from energy or fuel generation, materials, processing & production & recycling
- Life Cycle Impacts to be implemented in EU regulations by 2026
  - Details TBD!

Source: Ricardo

Light Duty Vehicle - Ricardo analysis - hybrids & EVs have lower life cycle CO_2, higher embedded emissions – bio/e-fuels also attractive?



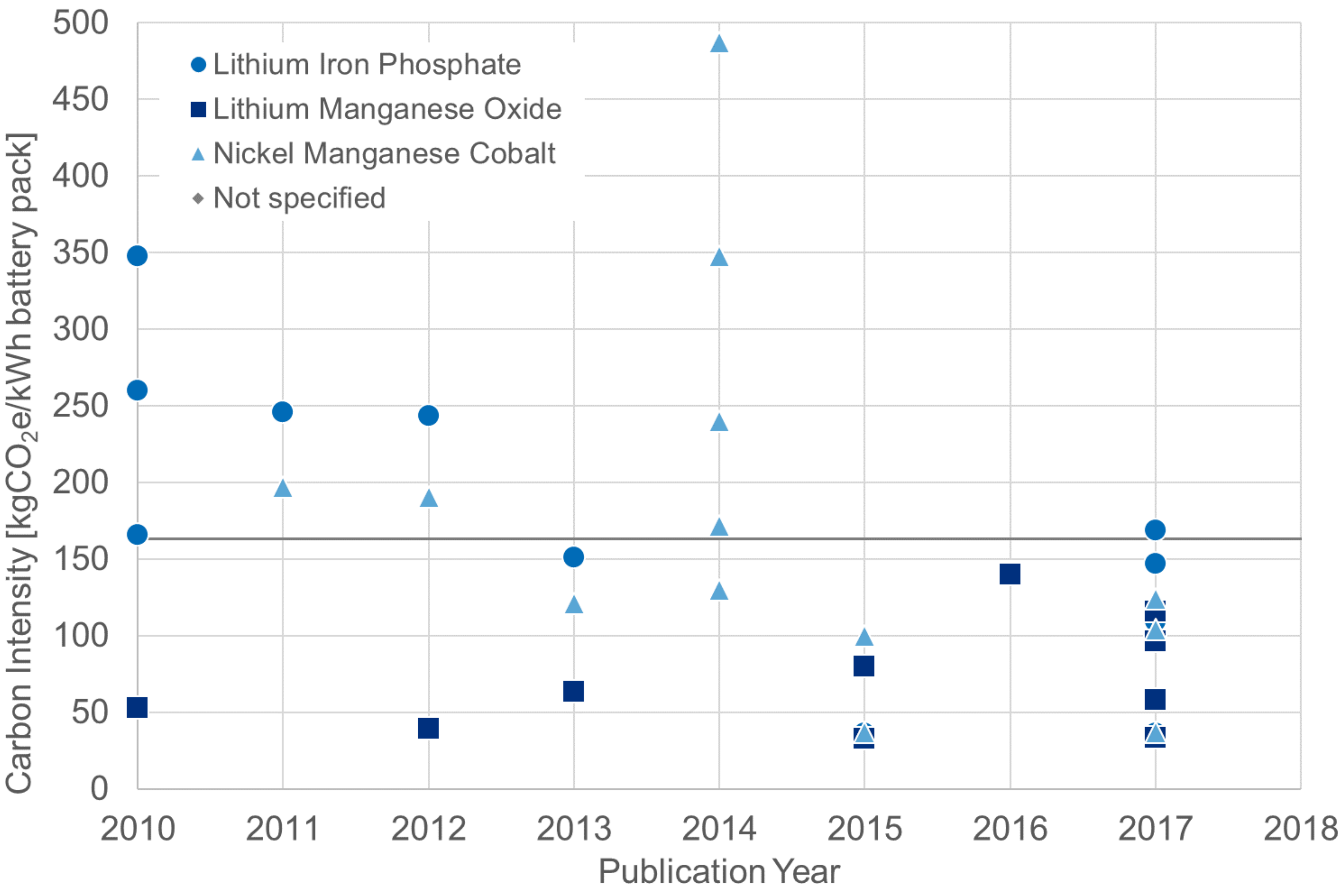
Source: Based on "Preparing for a Life Cycle CO_2 Measure", Low Carbon Vehicle Partnership

Assumptions:

Vehicle specifications based on real world 2020 values
Assumed lifetime mileage 150,000 km.
Gasoline fuel E10. Diesel fuel B7
Fischer-Tropsch diesel from farmed wood (WTW = 6 gCO2eq/MJ)
Hydrogen carbon intensity 99.7 gCO_2e/MJ (NG Steam Reforming)

Electricity carbon intensity 200 gCO_2/kWh (~2025 best case)
Hybrid Battery 1.8 kW.hr NiMH, 56 kW Motor
EV Battery 32 kW.hr Li-ion ~ 150 km range
PHEV Battery 5 kW.hr ~ 20 km range
FCEV Battery 1.8 kW.hr

Life Cycle Emissions data for batteries - wide variation - embedded GHG emissions ~100-150kg CO_2eq/kW.hr - 11 tons CO_2 for a 75 kW.hr battery



- Average embedded CO_2 is estimated at 150-200 kg/kW.hr
- About half from material extraction & processing, the other half from manufacturing:
  - Manufacturing emissions dominated by electricity use
    - Factory emissions will reduce with grid carbon intensity reductions
- The majority of embedded GHG emissions are from the battery electrodes
- ***Embedded GHG for a 300+ mile range battery equivalent to an efficient (80-100 g/km) ICE vehicle travelling ~70,000 miles***

Source: Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies – Ricardo/Low Carbon Vehicle Partnership

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COP21 GHG targets in transport not straightforward – Need efficiency improvements, new energy vectors & carbon intensity reductions

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Future Demands:

Zero net Carbon
Zero Impact
Customer Needs
Business Case

CASE
Connected Autonomous
Shared Electrified

Efficiency Improvements

- Vehicle (energy per vehicle mile)
- Passenger, Goods (energy per person mile or ton mile)

Mobility Supply & Services

- Ride Share, Mobility as a Service, Autonomy, Logistics/Load Optimisation

Energy/Fuel Carbon Intensity

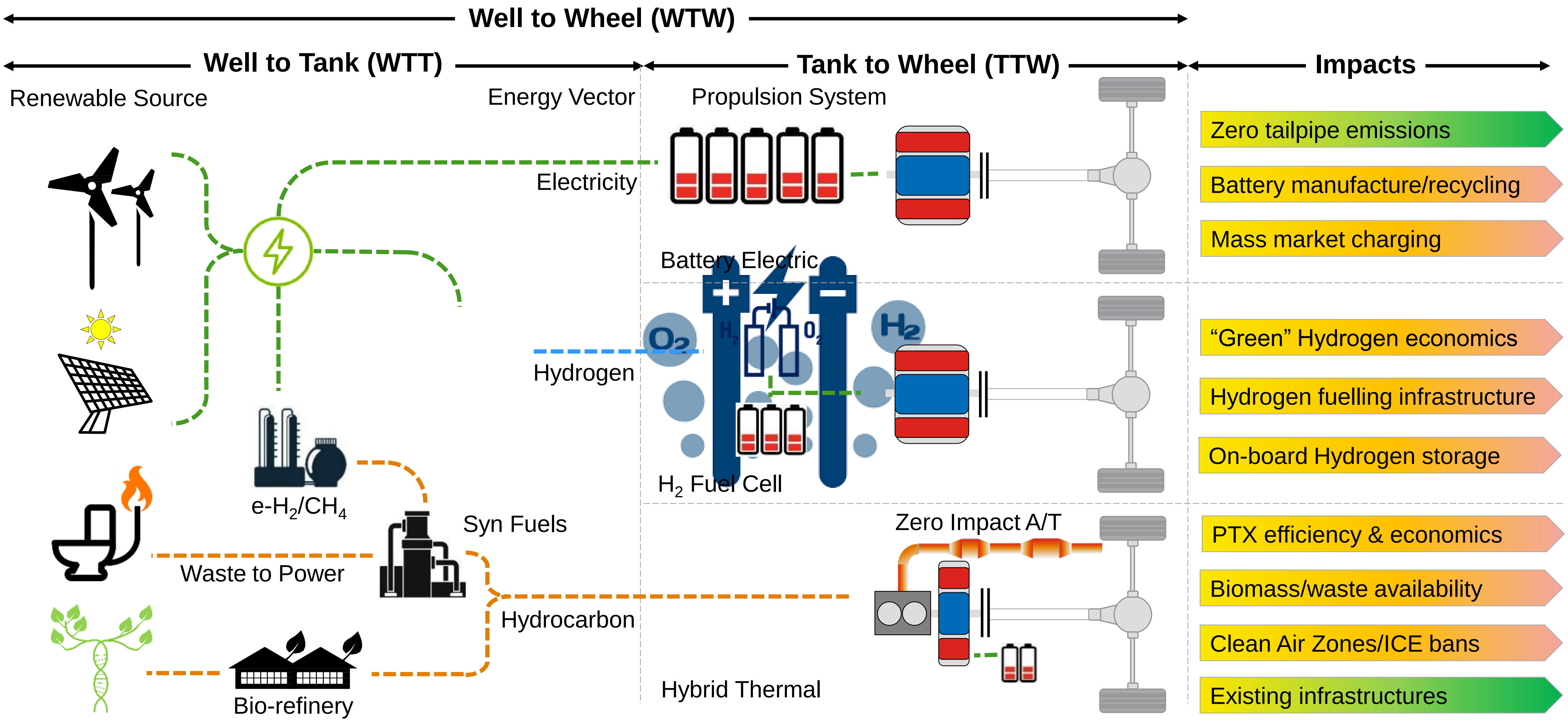
- Gas/Diesel - Increasingly renewables
- NG - Increasing H_2 content, RNG, e-gas
- Electricity – Reducing GHG intensity
- Hydrogen – From renewable sources

Significant Interactions

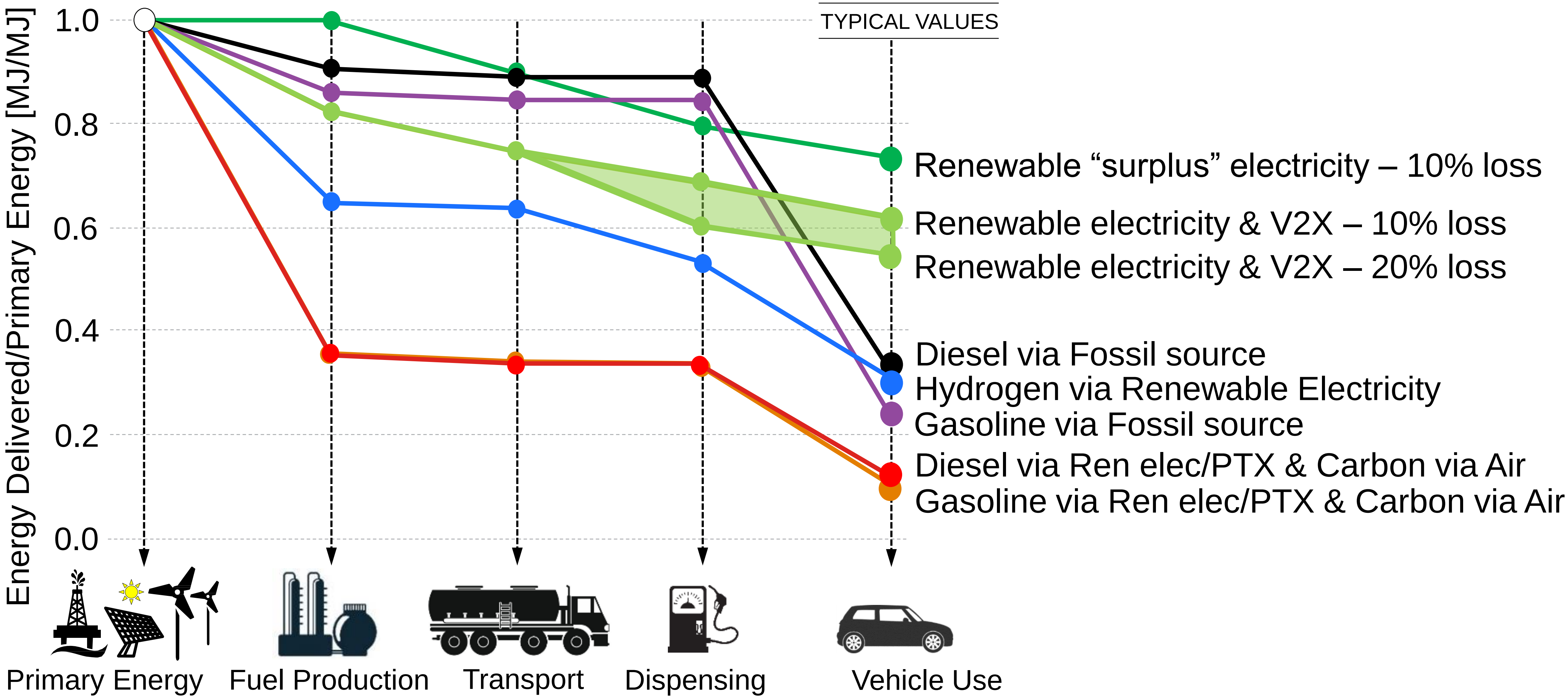
Multiple options for renewable H_2 use:
- Heat (via NG networks)
- Transport
- Displacing fossil H_2 in oil refineries

Increasing requirement for intermittent renewable energy storage – H_2 may be lowest cost approach?

Potential routes to clean vehicle powertrains – alternative pathways to use renewable & sustainable energy sources in transport

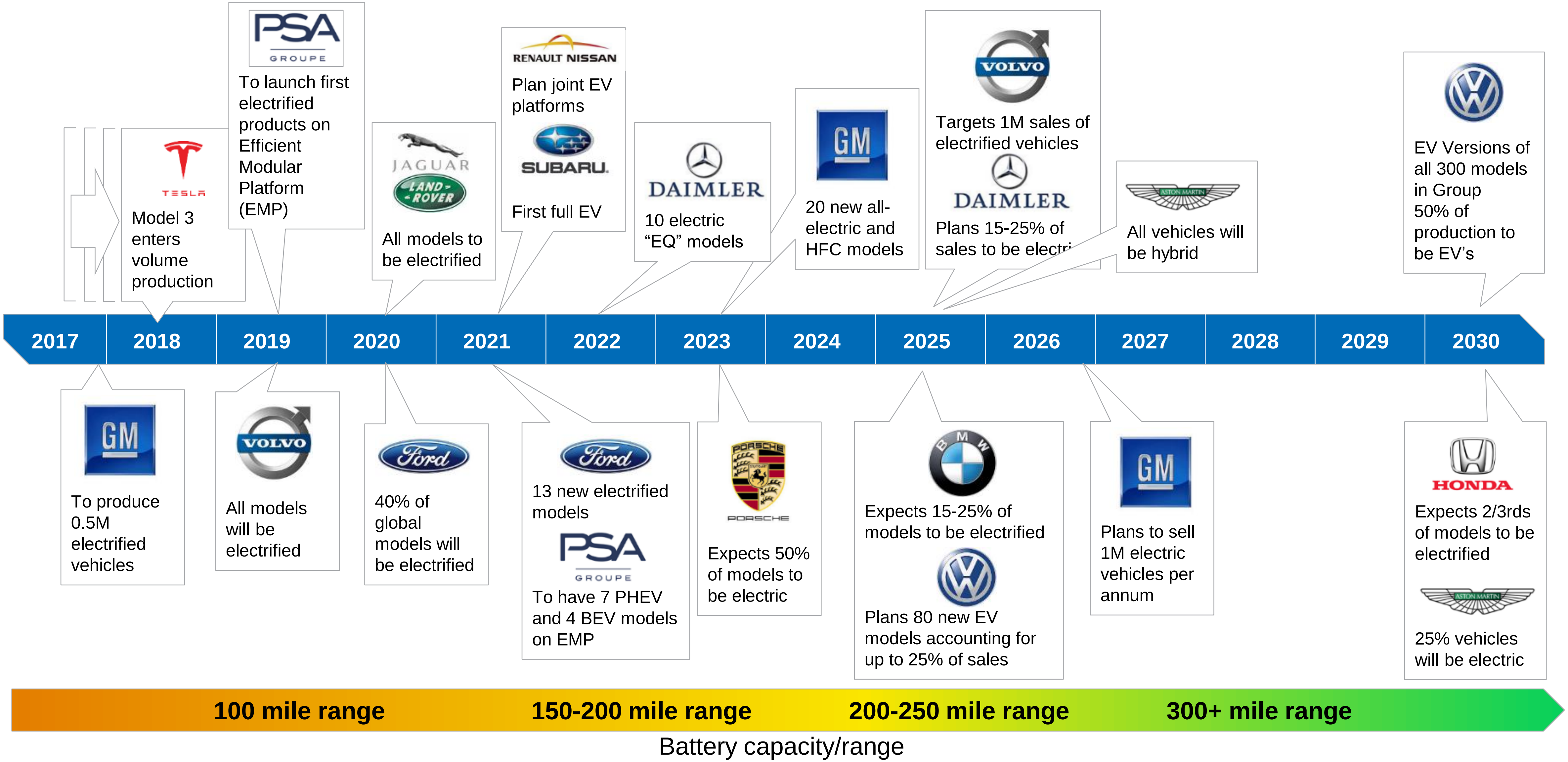


"Well to Wheels" - EV's offer efficient use of renewable energy – H_2 less efficient – Power to Liq/Gas inefficient but uses existing infrastructures



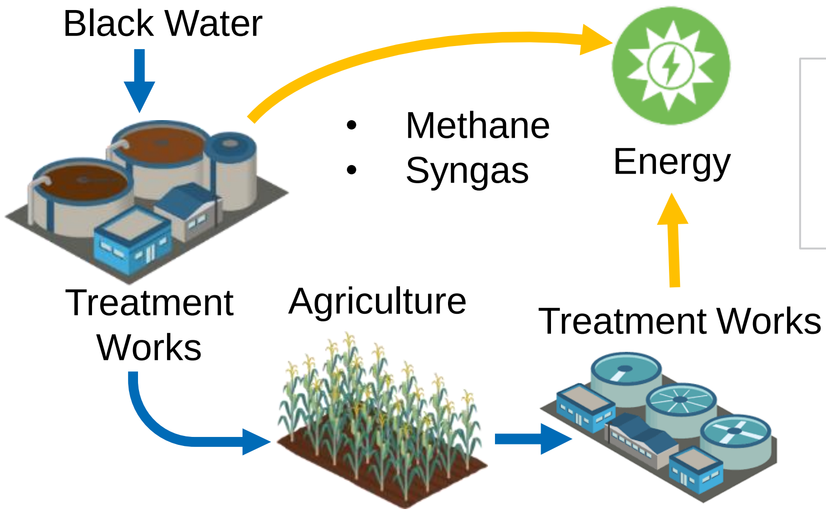
Source: The Road to Sustainable Fuels for Zero Emissions Mobility – Shell/OVK

Environmental challenges/policies have accelerated Vehicle OEM commitments to introduce more electrified vehicles & larger batteries



HFC = hydrogen fuel cell

Ultra Low or Zero carbon HD trucks – probably a choice between H_2 Fuel cells with renewable hydrogen or Bio-Waste/Power to Liquid/Gas Fuels



Waste to Hydrocarbon Liquid Fuels

H_2 FC Trucks – e.g. Toyota/Nikola Motors < > **Waste to Power & "Synthetic" Fuels**

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Global consumer surveys suggest that range, price and lack of charge points/charging time remain key barriers to BEV uptake

										
Driving range	**31%**	31%	**35%**	4%	**26%**	**25%**	14%	18%	10%	24%
Cost/price premium	28%	**32%**	22%	19%	24%	9%	14%	**31%**	22%	**26%**
Lack of electric vehicle charging infrastructure	20%	16%	20%	**44%**	22%	18%	**25%**	23%	**34%**	22%
Time required to charge	9%	11%	11%	18%	13%	12%	11%	11%	17%	10%
Safety concerns with battery technology	5%	4%	5%	7%	6%	22%	22%	9%	11%	8%
An all battery electric powertrain is not offered in the type of vehicle I want (e.g., SUV, truck)	2%	3%	3%	4%	3%	11%	7%	3%	4%	5%
The brand I prefer doesn't offer electrified vehicles	3%	2%	2%	3%	4%	3%	7%	3%	1%	3%

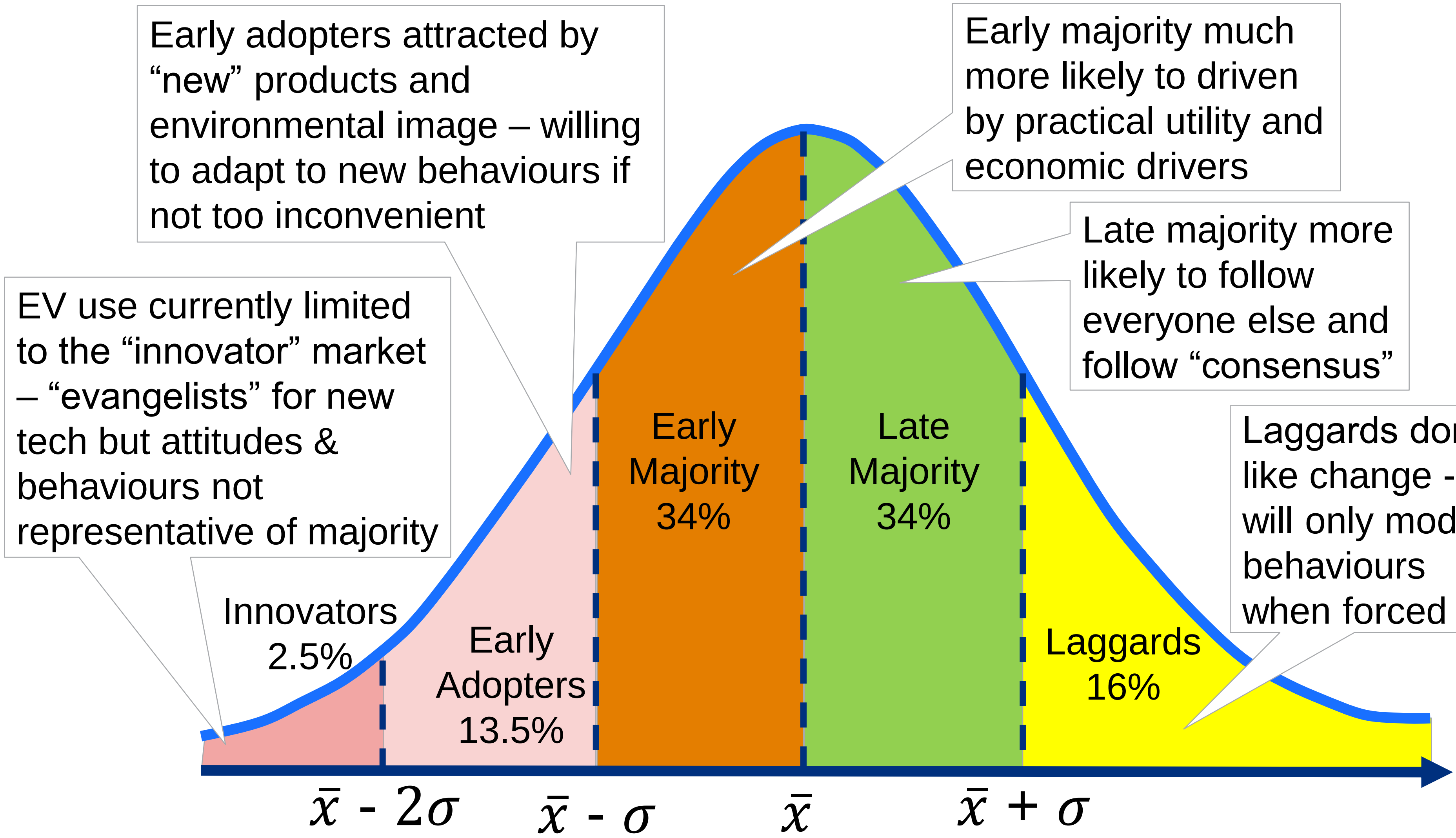
% = largest concern in each market

Deloitte Consumer Survey:

- Top 4 global consumer concerns for BEV's are:
  - **Driving range**
  - **Cost premium**
  - **Lack of charging infrastructure**
  - **Time required to charge**
- Forecasts suggest that total cost of ownership will be comparable to ICE by Mid 20's
  - Initial price and re-sale value likely to remain more important for consumers

Source: Deloitte Global Automotive Consumer Survey 2018

To accelerate EV/PHEV penetration and move beyond the innovator/early adopter market, focus on "User Centric" attributes and requirements?

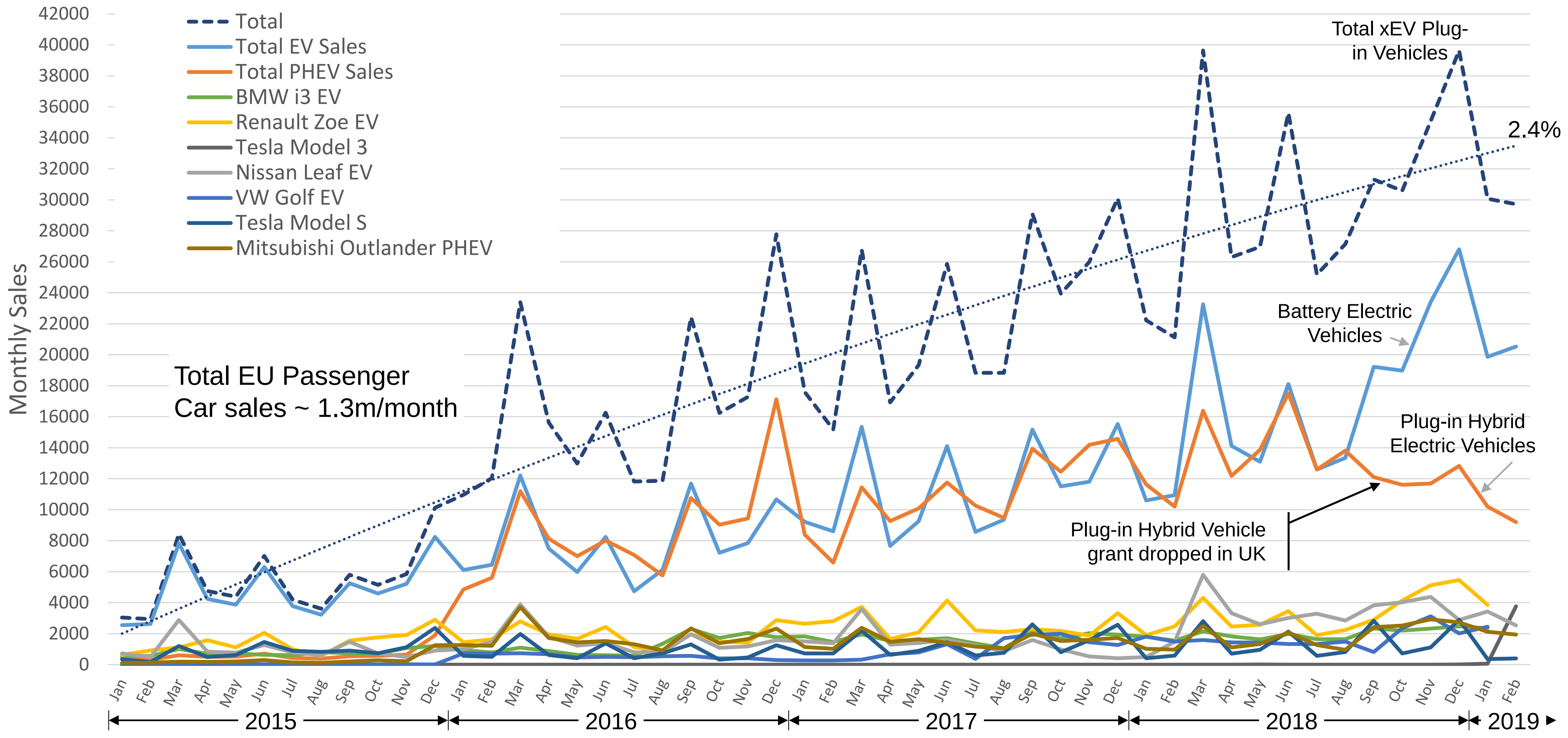


Reaching the early and late majority market:

- Focus on "User Centric" approach
- A more attractive EV/PHEV experience for consumers:
  - Ease of charging – wireless?
  - Improving charge availability?
  - More connected?
  - Preferential usage – HOV lanes/ Parking etc.
  - New ownership models?

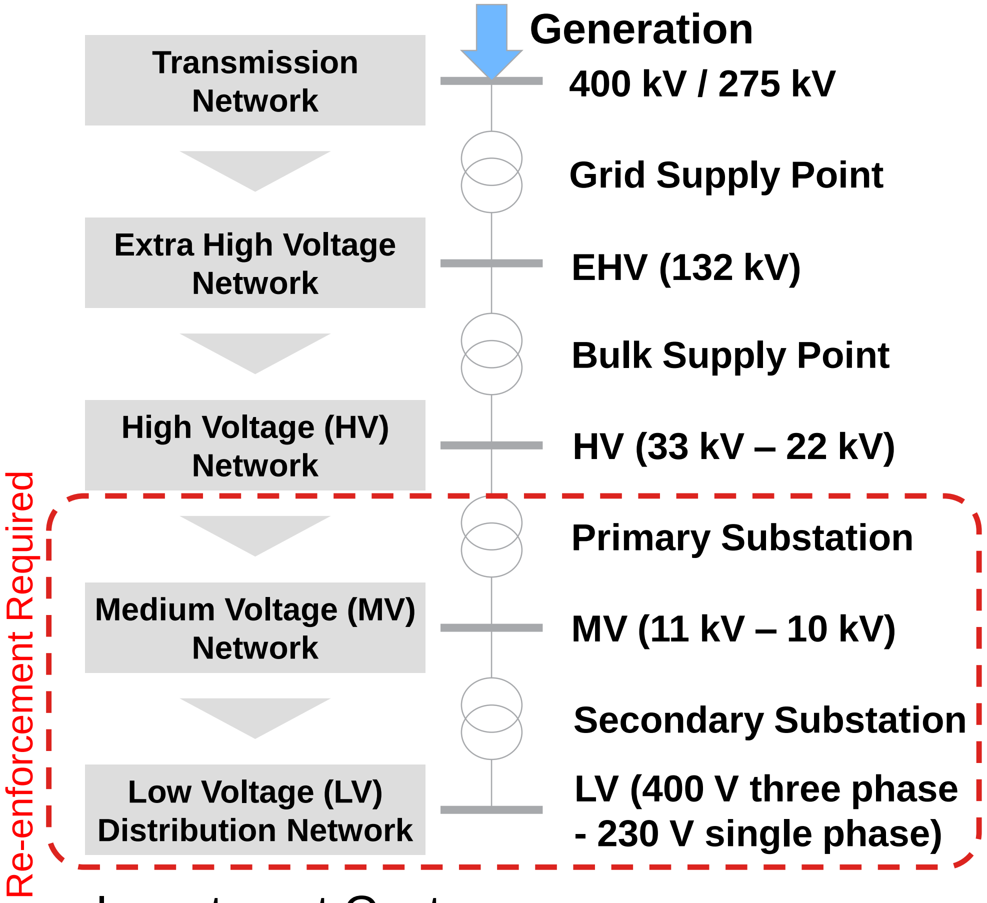
Source: Everett Rogers; Diffusion of Innovations, 1962

Battery Electric and Plug-in Hybrid sales in Europe continue to gradually increase but PHEV sales have slowed since loss of UK grant



Major challenges for infrastructure reinforcement (beyond 15-20% EV penetration) - Supply of critical materials at scale and recycling

Charging/Supply Infrastructure

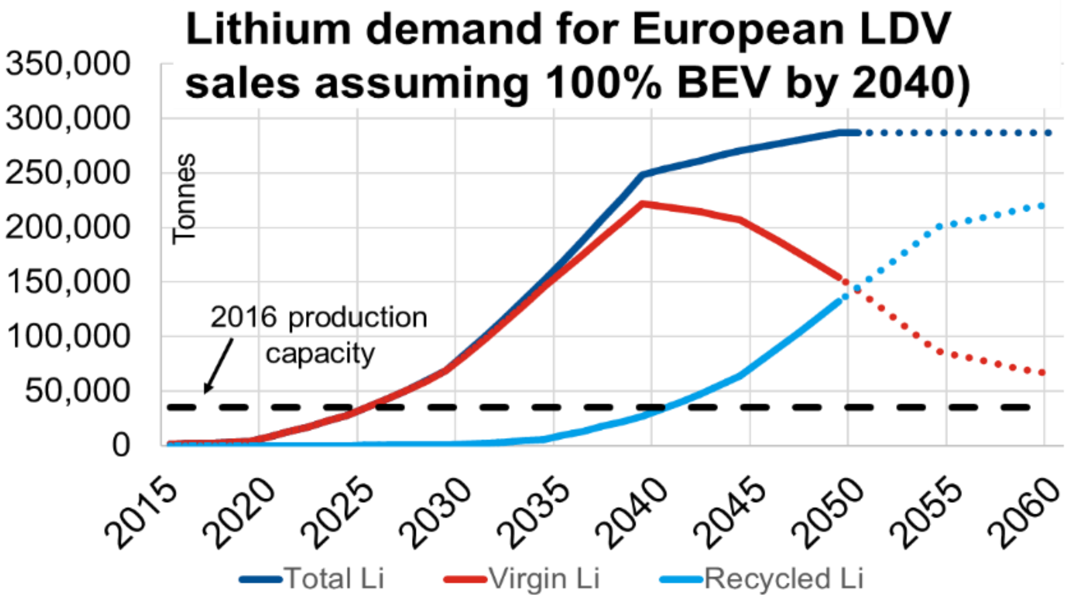


Investment Cost:

EU: €630b assuming primarily “home” charging
€830b assuming “grazing” frequent top-up

Critical Materials & Recycling

- Rare Earths: Neodymium, Dysprosium, Lanthanum
- Batteries: Cobalt, Nickel, Lithium etc.
- China supplies 70% of global critical raw materials
- Currently <1% of lithium recovered at end life
  - Lithium demand for 100% EU BEV sales by 2040 scenario: 6 times global lithium supply in 2016 (35kt)
- Major growth opportunity for battery recycling



Source: Impact Analysis of Mass EV Adoption – Ricardo, Defossilizing the transportation sector - FVV

Summary & final comments…

- In the real world, **economics rules**
- De-fossilising **transport** is only the **appetiser,** de-fossilising **heat** will be the **main course**
- It's not always about the extra cost, but who is able and **willing to pay** for it
- There is **no single tech**nology that will viably address our low carbon energy/transport challenges
- **Battery electric** vehicles are the **most efficient** route to use of renewable electricity but:
  - **Significant issues** associated with **battery** manufacture at scale (**cost/embedded energy/environment**)
  - **Electricity distribution** networks not designed to support mass EV re-charging & electric heating
- To meet climate goals:
  - **Electrify as much as possible** – but focus on sustainable battery design/manufacture (**materials/recycling**)
  - Develop **solutions** for low/zero carbon **longer distance/heavy duty** transport applications:
    - Zero carbon **Hydrogen** and supply network **initially for B2B/commercial** applications
    - Further **cost reductions** and efficiencies for "**PTX" liquid and gaseous fuels** as "drop-in" solutions compatible with **existing infrastructures** and vehicles
    - Continue to **invest in efficient combustion engines** – both **evolutionary** & **disruptive**
    - **Fiscal policies** to encourage **low/zero carbon sustainable** fuels in road transport market