Ford-RMIT Alliance Future Mobility and reducing tailpipe emissions

Richard Taube,

Ford-RMIT Alliance Manager

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All new Bronco

Ford Motor Company: A Global Presence

$156B Sales

5.4M vehicles globally

190,000 employees

53 plants (79 incl. JV's)

2 Major brands
- **Ford**
- **Lincoln**

Partnerships with
Volkswagen, Rivian, Mahindra & Argo AI

Great Cars, SUVs And Commercial Vehicles

Our Team

Competency:

- **Technical Fellows**
- **Technical Specialists**
- **Education:**
  - **34% PhD**
  - **42% Masters**
  - **24% Bachelors**

- **Diverse in nationality, culture, and education**
- **Employees from 55 countries**
- **Five major geographical locations**

Reducing Tailpipe Emissions

Challenge

- In the United States, Federal Tier 3 and California Low Emission Vehicle (LEV) III LDV* standards are phasing in from 2015 to 2025
- California LDVs will need to meet the Super Ultra Low Emitting Vehicle (SULEV) standard of combined emissions of NO_x and NMHC of 0.030 g/mile (SULEV30) in 2025
- In the European Union, the Euro 6 LDV standard went into effect in 2015 and real driving emissions (RDE) standards started in 2017
- Increases in stringency in emission limits (i.e., Tier IV and Euro 7) are under discussion and are likely to be implemented post 2025.

*LDV = Light Duty Vehicle

Reducing Tailpipe Emissions

Historical Success

- To meet regulations, advanced vehicle emission after-treatment systems such as three-way catalytic converters, lean NO_x traps, selective catalytic reduction (SCR), and diesel particulate filters (DPFs) have been developed and fuel sulfur concentration reduced
- Gasoline vehicle on-road NO_x emission rates decreased by approximately a factor of 10 since pre-Euro 1 emissions controls.
- In the current Euro 6 regulations, the NEDC has been replaced by the Worldwide Harmonized Light Vehicle Test Procedure (WLTP) and a real driving emission (RDE) component has been added to bring on-road emissions close to the standards as measured in laboratory emissions testing.

*LDV = Light Duty Vehicle

Reducing Tailpipe Emissions

Historical Success

- In the United States, the vehicle miles travelled tripled between 1970 and 2017
- In the European Union, the number of registered passenger cars grew about 45% from 1995 to 2017 and passenger car travel (passenger km) increased 25%
- Despite increased vehicle mileage, U.S. and EU total highway vehicle (LDV, HDV, commercial vehicle and motorcycle) NO_x and volatile organic compound (VOC) emissions have decreased 60–80% since 1990, as shown in Figure 1.

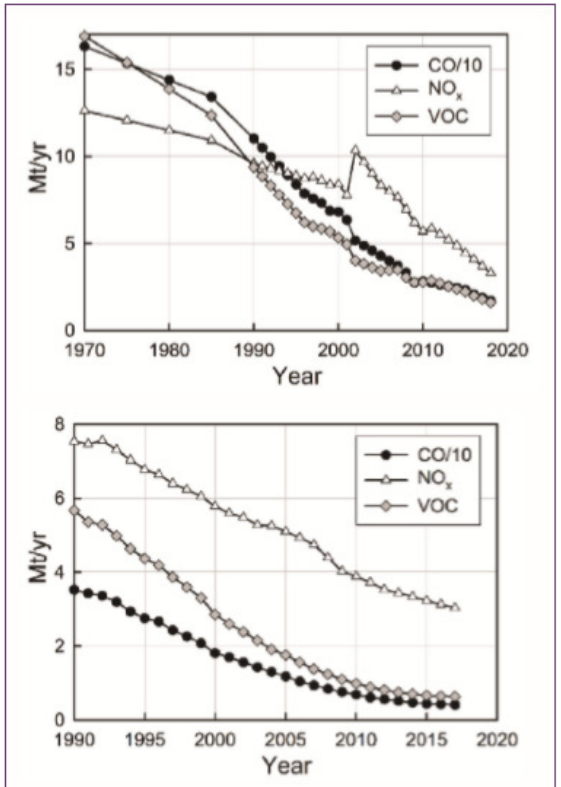

Figure 1. U.S. and EU highway vehicle (LDV, HDV, commercial vehicle, and motorcycle) NO_x, VOC, and CO emissions in millions of tonnes (Mt).

Source: (top panel) U.S. Environmental Protection Agency (EPA); (bottom panel) European Environment Agency (EEA).

Image source: T.J. Wallington, J.E. Anderson, X. He, W.C. Ruona, W. Shen, R. Vogt, S.L. Winkler, What's Ahead for Light-Duty Vehicle Emissions: An Automotive Perspective, Air and Waste Water Management Magazine, April, (2020).

Reducing Tailpipe Emissions

What is ahead?

- Limits or bans on internal combustion engine (ICE) vehicles in several major city centers are being implemented or considered to further control emissions, with the Netherlands, Norway, France, and the United Kingdom considering bans on the sale of new gasoline and diesel cars by 2025–2040
- The EU Parliament is in favour of registering zero-emission vehicles (ZEVs) only, starting 2040, as a contribution to the planned EU target of net carbon neutrality by 2050 (EU Green Deal)
- ZEV mandates are in place in California, 10 other U.S. states, and China.
- ZEVs—including battery-powered electric vehicles (BEVs) and hydrogen fuel-cell vehicles (FCVs)—have zero tailpipe emissions, but are not zero-emission. Upstream electricity
- Generation emissions for a BEV **can be comparable** to ICE vehicle tailpipe emissions.

Reducing Tailpipe Emissions

What is ahead?

- A typical U.S. 2020 BEV has a label electricity consumption of approximately 25 kWh/100 miles.
- The U.S. electric grid, on average, produces 0.33 g NOx/kWh of generated electricity. Assuming 5% grid loss, the BEV produces upstream NOx emissions of 0.086 g/mile (0.053 g/km), the same as the vehicle standard of 0.086 g NOx+NMHC/mile (53 mg/km)[1]
- The best-in-class ICE vehicle, a hybrid electric vehicle (HEV) for example, emits 0.004 g NOx+HC/mile, **21 times less than the BEV**, but ICE emissions occur closer to residential area
- Electricity generation must transition to renewables (e.g., wind, solar) for ZEVs to match ICE vehicle lifecycle NOx emissions

[1] Winkler, S.L.; Anderson, J.E.; Garza, L.; Vogt, R.; Ruona, W.; Wallington, T .J. Vehicle criteria pollutant (PM, NOx, CO, HCs): emissions: How low should we go?; Climate and Atmospheric Science 2018, 1 (26); doi:10.1038/s41612-018-0037-5

Reducing Tailpipe Emissions

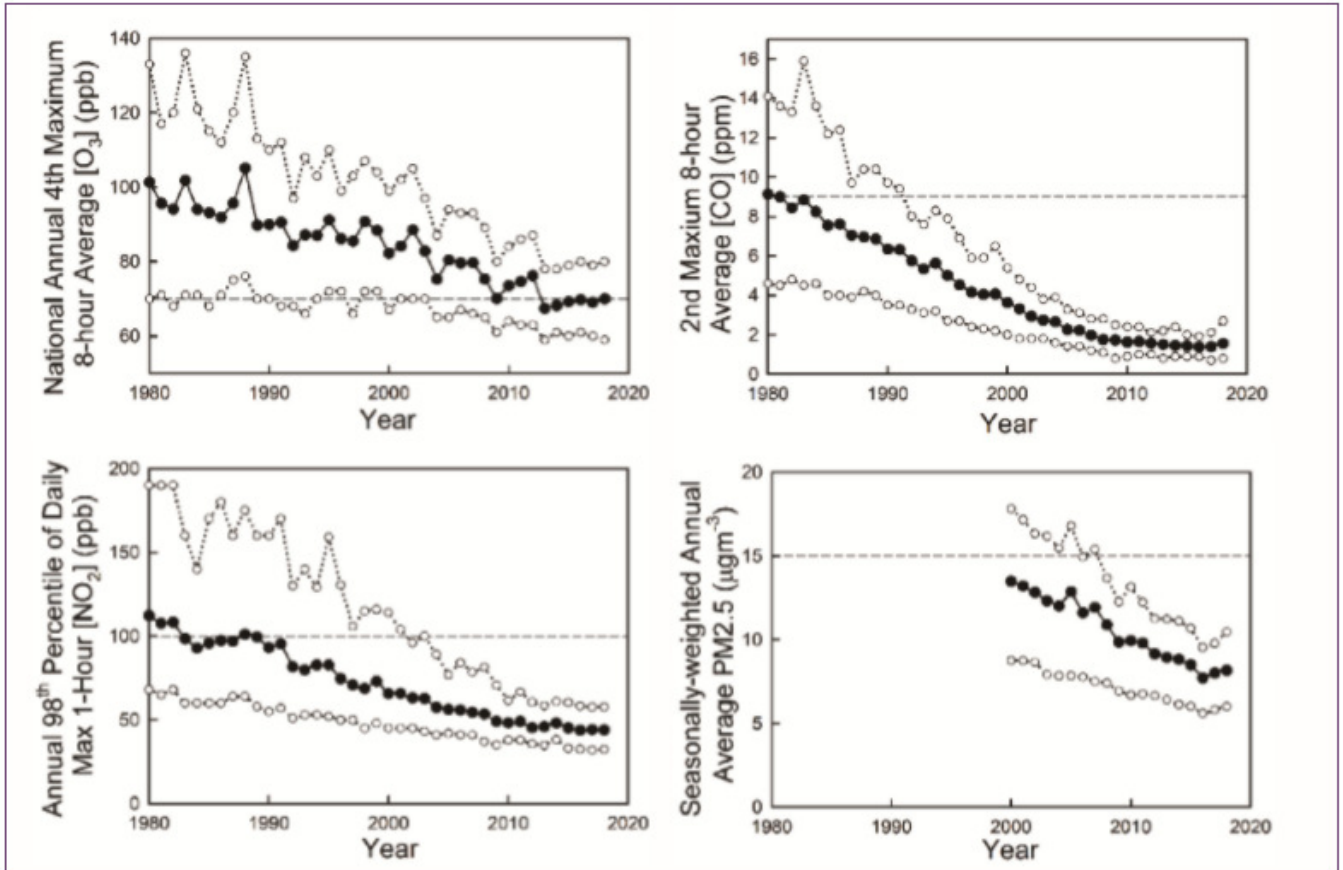

Figure 2. Trends in O_3, CO, NO_2, and $PM_{2.5}$ in ambient air in U.S. cities.

Source: EPA Air Trends (accessed January 2020).

Note: The solid symbols are the averages and the open symbols are the 10th and 90th percentiles. The dashed lines are NAAQS.

Image source: T.J. Wallington, J.E. Anderson, X. He, W.C. Ruona, W. Shen, R. Vogt, S.L. Winkler, What's Ahead for Light-Duty Vehicle Emissions: An Automotive Perspective, Air and Waste Water Management Magazine, April, (2020).

Reducing Tailpipe Emissions

What is ahead?

- Non-exhaust emissions have become relatively more important as the tailpipe emissions have decreased.
- Tire and brake wear PM emissions **are of the same magnitude or perhaps higher** than tailpipe emissions.
- Tire wear is a function of many factors: heavier BEVs are expected to give more tire wear PM emissions while brake wear PM emissions can be lower on electrified vehicles, which use regenerative braking.
- Windshield washer fluid is a source of VOC emissions that is regulated in some locations

Reducing Tailpipe Emissions

Future Air Quality?

- With large reductions in LDV emissions the relative importance of emissions from other sectors have increased.
- Aviation is now the largest transportation source of lead emissions in the United States.
- Air quality modelling[2] indicates that electrification of off-road equipment (e.g., garden equipment, construction equipment) would provide greater air quality improvement than on-road electrification.
- Consumer products (e.g., adhesives, personal care products, etc.) are becoming the single largest source of petrochemical VOC emissions in industrialized cities.

[2]. Nopmongcol, U.; Grant, J.; Knipping, E.; Alexander, M.; Schurhoff, R.; Young, D.; Jung, J.; Shah, T .; Yarwood, G. Air Quality Impacts of Electrifying Vehicles and Equipment Across the United States; Environ. Sci. Technol. 2017, 51, 2830-2837; doi:10.1021/acs.est.6b04868.

Reducing Tailpipe Emissions

Future Air Quality?

- New concepts of “zero-impact emissions” and “zero-impact emission vehicles” (ZIEVs) are being discussed.[3] Zero-impact refers to a level of emissions so low that it has a negligible impact on air quality
- Automotive research suggests additional tailpipe emission reductions are possible
- By adjusting engine operation and the aftertreatment system in a research vehicle, exhaust NMHC+NO_x emissions in the laboratory have been reduced by a factor of 10 below the future SULEV30 standard

3. Reitz, R.D.; et al. Editorial: The future of the internal combustion engine; Int. J. Eng. Res. 2020, 21, 3-10 doi:10.1177/1468087419877990

Reducing Tailpipe Emissions

Reducing CO2

- E-fuels produced using CO_2 captured from the air and renewable (e.g., wind, solar, or hydro) or nuclear electricity offer net-zero carbon emissions for transport
- Would probably see first use in aviation and heavy-duty vehicles where other options are more limited
- Use of fossil fuels combined with capturing and sequestering CO_2 from the air offers an additional net-zero carbon option

3. Reitz, R.D.; et al. Editorial: The future of the internal combustion engine; Int. J. Eng. Res. 2020, 21, 3-10 doi:10.1177/1468087419877990

Reducing Tailpipe Emissions

- Diversity of options available based on renewable electricity to power BEVs, hydrogen FCVs, and E-fueled ICE vehicles

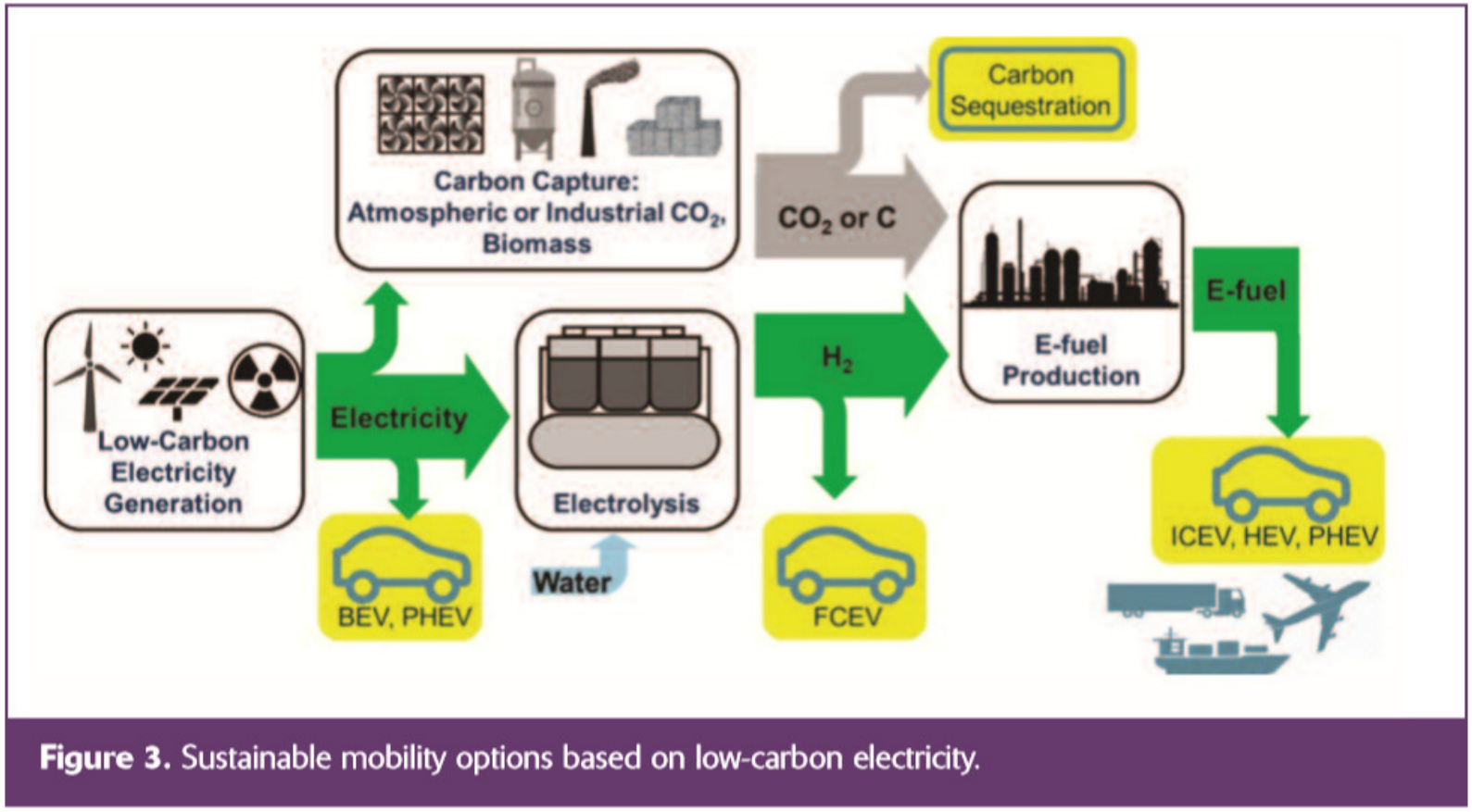

Figure 3. Sustainable mobility options based on low-carbon electricity.

Image source: T.J. Wallington, J.E. Anderson, X. He, W.C. Ruona, W. Shen, R. Vogt, S.L. Winkler, What's Ahead for Light-Duty Vehicle Emissions: An Automotive Perspective, Air and Waste Water Management Magazine, April, (2020).

Reducing Tailpipe Emissions

Future Opportunities

- ICE vehicle criteria pollutant emissions have reached very low levels
- Air quality and human and ecosystem health research is needed to define zero-impact levels for criteria emissions
- Electric vehicles eliminate local emissions and when powered using clean grids (e.g., California) have major CO_2 and criteria pollutant benefits.
- Future vehicle emissions reduction efforts might be targeted on reducing the effect of gross emitters, which represent 2–5% of the fleet, but can produce up to half the emissions
- **A lower emissions future lies ahead, enabled by ultra-clean internal combustion engine vehicles, electric vehicles, and hydrogen fuel-cell vehicles**

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Questions?