DEATHBED OR MIDLIFE CRISIS?

THE PREMATURE BURIAL OF INTERNAL COMBUSTION

Kelly Senecal, Ph.D.

Co-Owner, Co-Founder | CONVERGENT SCIENCE

THE PREMATURE BURIAL

- Short horror story by Edgar Allan Poe from 1844
- At that time, the fear of being buried alive was rooted in Western culture
- In the 19th century, 100's of cases were reported in which doctors mistakenly pronounced people dead
- Internal combustion engines are mistakenly pronounced dead on a daily basis

News › World › Europe

Man pronounced dead by three doctors 'starts snoring' in mortuary hours before post-mortem

January 9, 2018

Gonzalo Montoya Jimenez 'had autopsy markings on him, ready to be opened up"

Tom Embury-Dennis | @tomemburyd | 6 days ago | 34 comments

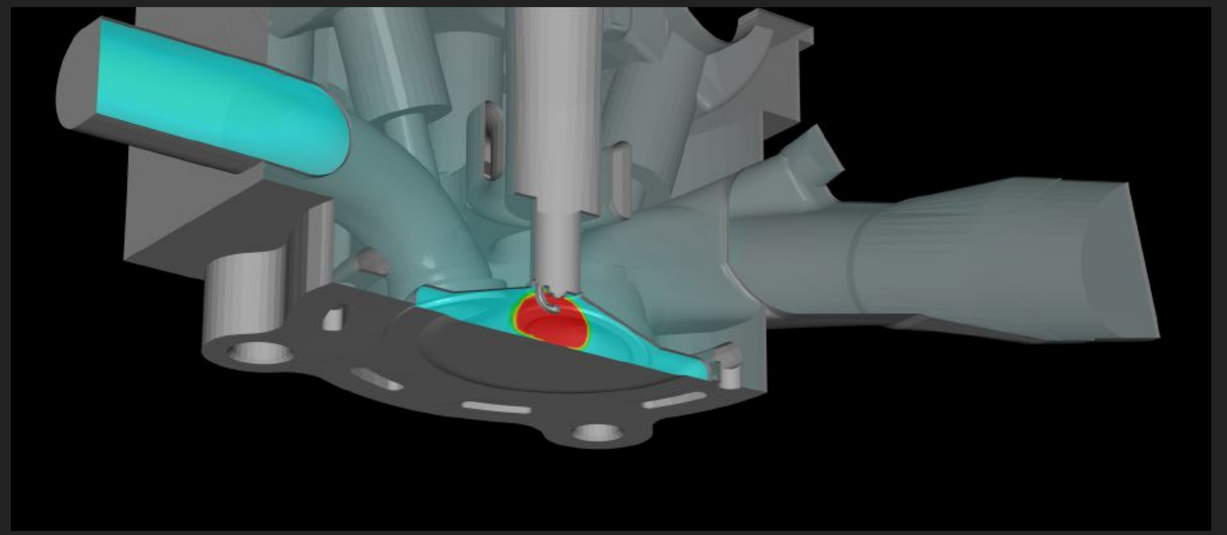
http://www.independent.co.uk/news/world/europe/prison-inmate-dead-wake-up-mortuary-spain-three-doctors-pronounced-gonzalo-montoya-jimenez-oviedo-a8149066.html

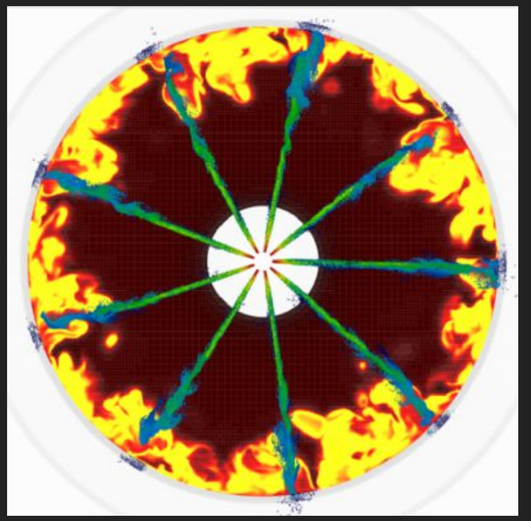
OUTLINE

- Some background
- My view
- Memory lane
- 2017: The year combustion died
- Mythbusters
- Improving engines through modeling
- Wrap-up

SOME BACKGROUND

- I did not grow up a car/engine guy
- Started working on engines as an application of CFD
- Engines are one of the most difficult problems - turbulence, reacting flow, multi-phase, moving boundaries, …

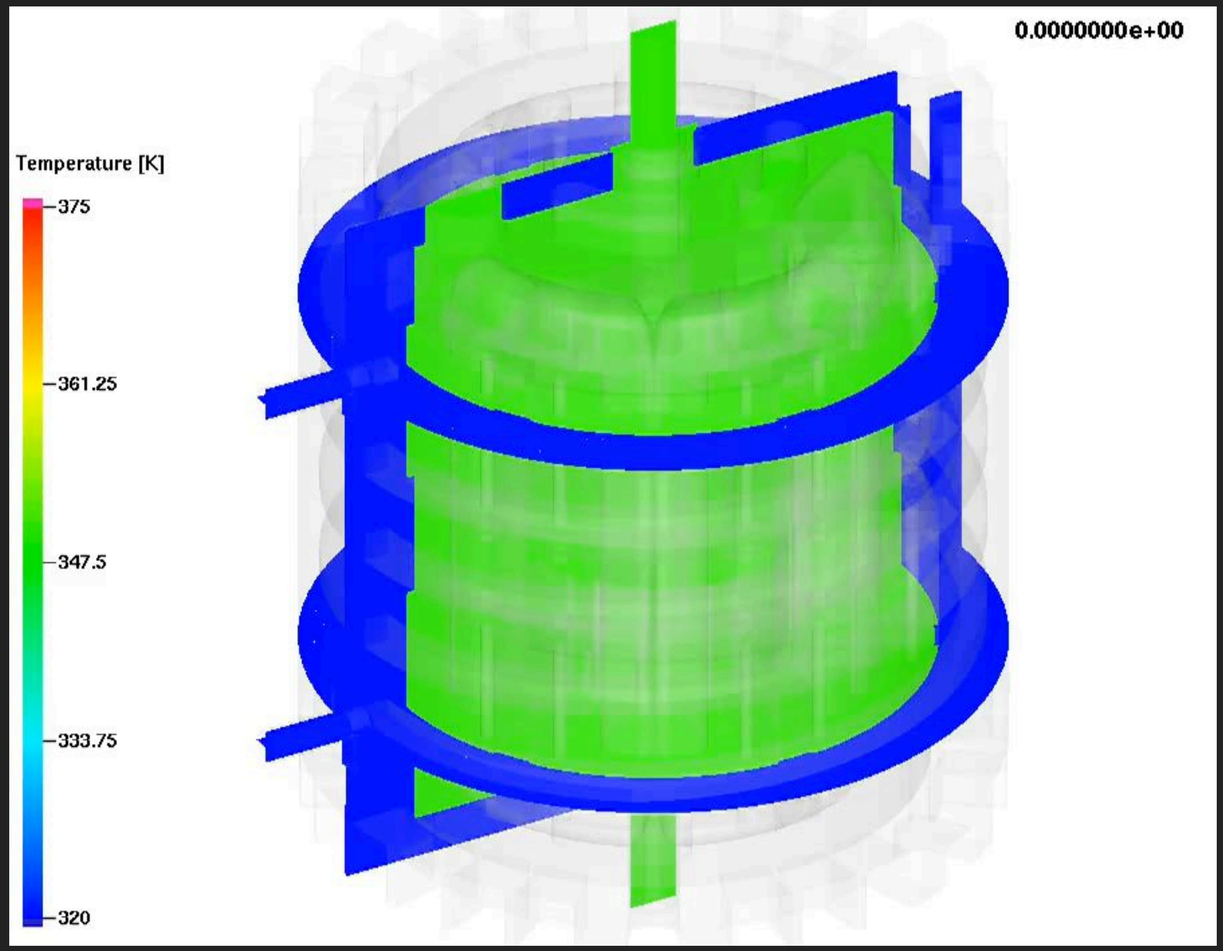




SOME BACKGROUND

- PhD from University of Wisconsin-Madison, Engine Research Center
  - Engine simulations, spray model development, optimization techniques (genetic algorithms)
- Co-founder and co-owner of Convergent Science
- Introduced CONVERGE CFD software in 2008, have grown from 5 to over 100 employees
- Over 80% of engine makers use CONVERGE worldwide
- CONVERGE is also used for gas turbines, after-treatment devices, pumps, compressors, wind turbines, batteries, etc

SOME BACKGROUND



TEDX: IN DEFENSE OF INTERNAL COMBUSTION

- I was invited to give a TEDx talk in October 2016, released on video in March 2017
- My “idea worth spreading” was timely and came just before the Alt-Electric* tidal wave of 2017
  - Almost did my talk on the benefits of CFD!
- Take away points from my talk:
  - One of the most immediate ways to go green is by improving the IC engine
  - The emissions control volume needs to be drawn correctly when comparing technologies
  - We should explore all technologies, not “us vs them”

*A term I coined to mean a group of people who plug their ears to anything that isn’t pro-EV

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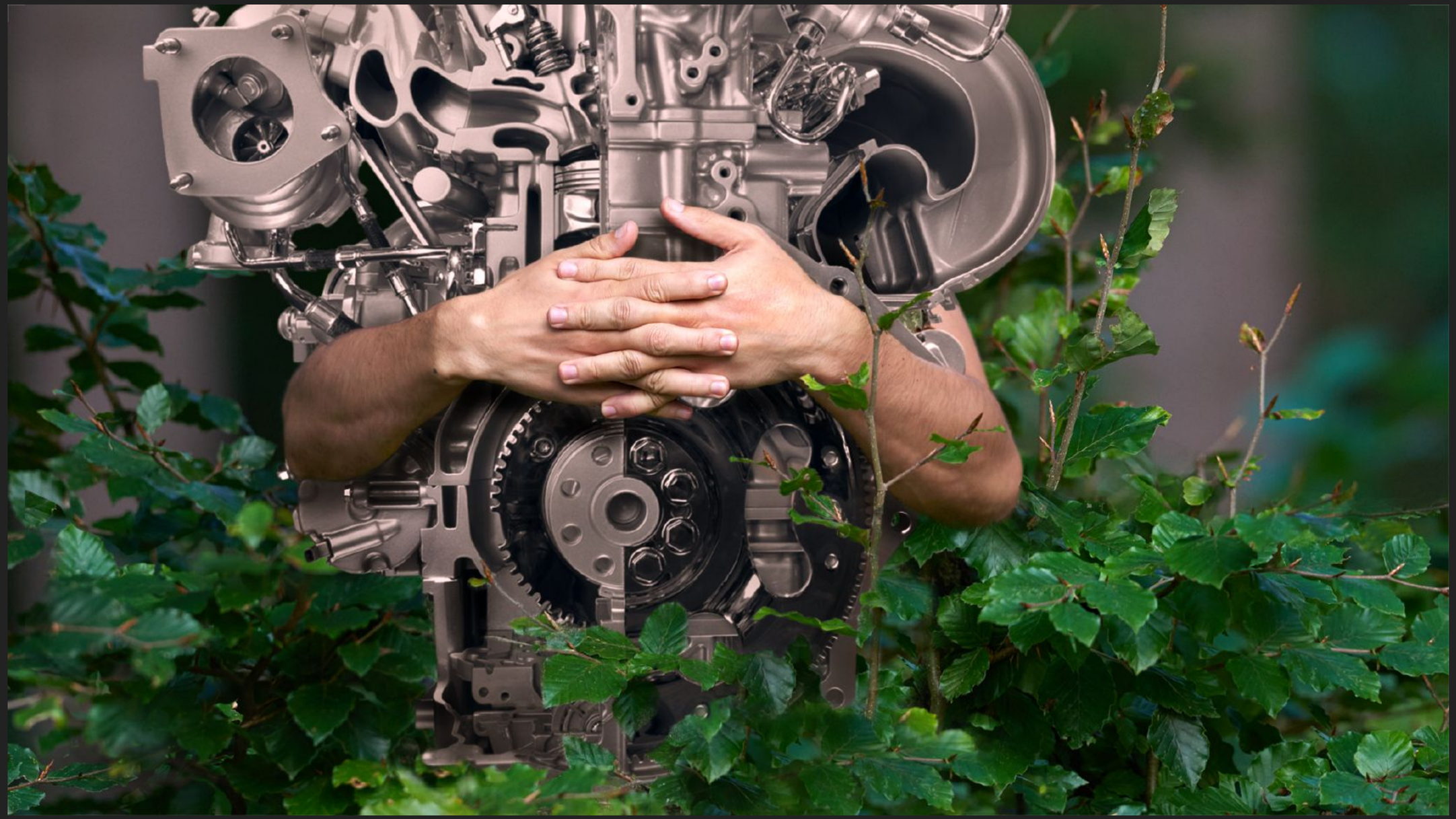


MY VIEW IN A NUTSHELL

- I am not against electric, hybrid, or fuel cell vehicles - all of these technologies have their place and should be explored.
- I am against the demonization of the IC Engine.
- I am against picking winners and losers instead of setting targets and seeing which technologies can get us there.
- There is no silver bullet. All of these technologies have an impact on the environment. We need to weigh the pros and cons for each application and dispel their myths.
- Disclaimer: I cannot guarantee that everything in this presentation is 100% accurate, as much of the material is based on available online information.

DIESELGATE: DAWN OF THE DEMONIZATION

- Affected around 11 million cars worldwide during model years 2009-2015
- VW intentionally programmed TDI diesel engines to activate emissions controls only during lab testing
- Cars met US standards for NOx under testing, but emitted up to 40x NOx in real-world driving
- US EPA issued notice of violation of the Clean Air Act to Volkswagen
- Big fines and jail time

TOYOTA PRIUS

- First mass produced hybrid
- 1997-present
- 6.1 million sold globally by Jan 2017
- Uses both a battery and an internal combustion engine depending on driving conditions
- Battery for slow driving, idling, etc., IC Engine for higher speeds

https://en.wikipedia.org/wiki/Toyota_Prius#/media/File:2008_Toyota_Prius_(NHW20R)_liftback_(2012-06-24).jpg

GM EV1, 1996–2002, 2006

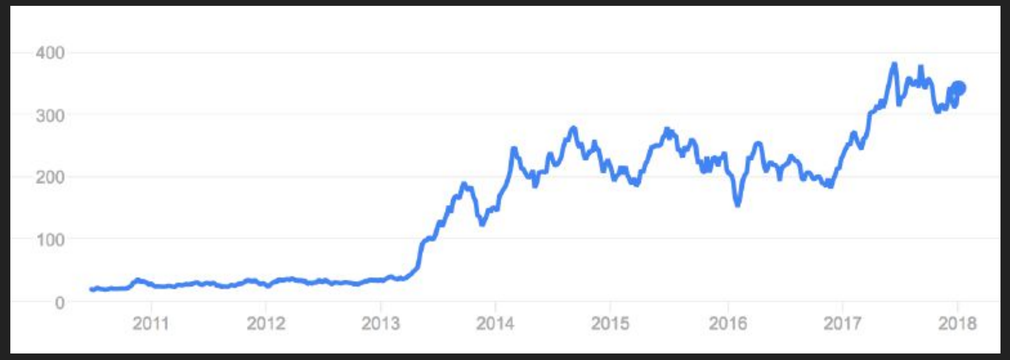
- First mass produced EV of the modern era from a major automaker (lease only, about 1,100 produced)
- Only passenger car to be marketed under GM instead of under one of its divisions
- GM determined they were unprofitable, ZEV turned to SLEV, GM canceled the program, repossessed the cars, and crushed them
- 2006 - Who Killed the Electric Car? Claims that GM hijacked the program, perhaps because it threatened the oil industry
- 2006 - GM claims it spent more than $1 billion developing and marketing the EV1, it just wasn't commercially viable, low demand meant that parts suppliers quit making replacement parts

https://en.wikipedia.org/wiki/General_Motors_EV1

Only GM EV1 that isn't disabled (exhibit at National Museum of American History)

TESLA, 2003-PRESENT

- Founded in 2003 by Martin Eberhard and Marc Tarpenning in response to GM canceling the EV1 program
- Elon Musk came in as Chairman of the Board to help raise money
- July, 2006 the Tesla Roadster was unveiled (sold 2,250 between 2008 and 2012)
- 2008 - Elon Musk becomes CEO, Model S is unveiled at a starting price of 50K
- 2010 - Tesla goes public
- 2016 - Announced that the Model 3 will bring the BEV to the masses, starting at $35,000 and a range of of 220 miles
- 2017 - “production hell”



TESLA, 2003–PRESENT

- 2018 - where is the mass market Tesla?
- Model 3 with no additional options starts at $49,000 - high acceleration vehicles for the wealthy?

JULY 5, 2017


'Historic end' for combustion: Volvo says all of its cars will use electric after 2019

http://business.financialpost.com/transportation/autos/historic-end-for-combustion-volvo-says-all-its-cars-will-use-electric-after-2019

JULY 5, 2017

Volvo creates an historic first and says goodbye to the internal combustion engine

http://www.dailyrecord.co.uk/lifestyle/motoring/volvo-makes-historic-first-says-10743087

JULY 5, 2017

http://www.independent.co.uk/life-style/gadgets-and-tech/news/volvo-car-electric-hybrid-vehicle-petrol-diesel-combustion-engine-a7824316.html

JUNE 3, 2017

India to sell only electric cars by 2030

http://money.cnn.com/2017/06/03/technology/future/india-electric-cars/index.html?iid=EL

JULY 6, 2017

France wants to ditch gas, diesel-powered cars by 2040

http://money.cnn.com/2017/07/06/technology/france-cars-gas-electric-diesel/index.html?iid=EL

JULY 26, 2017

Britain bans gasoline and diesel cars starting in 2040

http://money.cnn.com/2017/07/26/news/uk-bans-gasoline-diesel-engines-2040/index.html

SEPTEMBER 11, 2017

China Says It Will Stop Selling Internal Combustion Engine Cars

There's no date set, but the message is clear: Electric is the future.

http://www.popularmechanics.com/cars/hybrid-electric/news/a28140/china-ban-cars-combustion-engines/

SEPTEMBER 12, 2017


China is banning traditional auto engines. Its aim: electric car domination

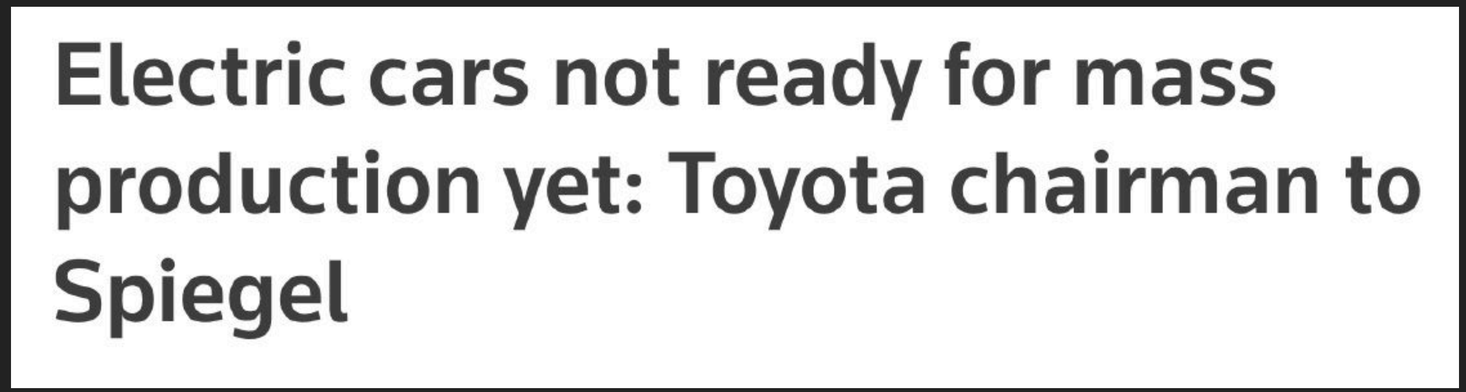
http://www.latimes.com/business/autos/la-fi-hy-china-vehicles-20170911-story.html

NOVEMBER 16, 2017

Amid global electric-car buzz, Toyota bullish on hydrogen

https://phys.org/news/2017-11-global-electric-car-toyota-bullish-hydrogen.html

NOVEMBER 17, 2017



https://www.reuters.com/article/us-toyota-batteries/electric-cars-not-ready-for-mass-production-yet-toyota-chairman-to-spiegel-idUSKBN1DH28U

DECEMBER 18, 2017

Toyota will electrify entire vehicle lineup by 2025

https://techcrunch.com/2017/12/18/toyota-will-electrify-entire-vehicle-lineup-by-2025/

DECEMBER 19, 2017

BMW reaches 100,000 electric vehicle sales target for 2017

https://techcrunch.com/2017/12/19/bmw-reaches-100000-electric-vehicle-sales-target-for-2017/

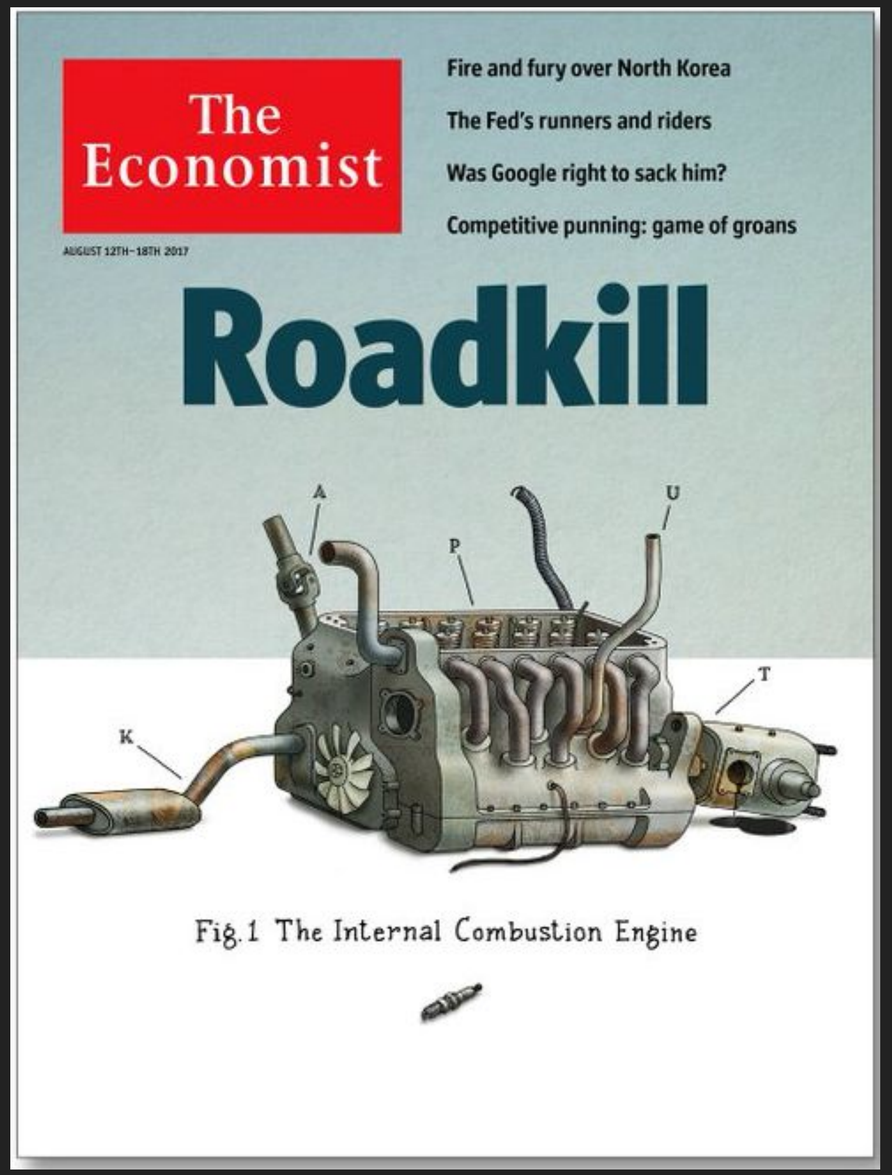
DECEMBER 19, 2017

http://cdn.bmwblog.com/wp-content/uploads/2017/12/BMW-Welt-Battery.jpeg

DEATHBED OR MIDLIFE CRISIS? THE PREMATURE BURIAL OF INTERNAL COMBUSTION

The death of the internal combustion engine.

It had a good run. But the end is in sight for the machine that changed the world.



DEATHBED OR MIDLIFE CRISIS? THE PREMATURE BURIAL OF INTERNAL COMBUSTION

We could not disagree more with your assessment of the death of the internal combustion engine (ICE). Electric vehicles that run on batteries are part of the future. However credible studies suggest that 90% of ground-transportation energy will continue to come from hydrocarbon-based fuels (both renewable and traditional sources) in 2040. Moreover, the electrical generation capacities we have at present do not come close to meeting the needs of an all-electric fleet. Nor is battery production emission free.

As well as road freight, vehicles used in agriculture and construction and for long-distance travel will continue to be powered by the ICE. There is little other choice. You also refer to a ban on new cars “reliant on ICEs”, yet many such vehicles will still contain an ICE as a hybrid.

Today’s ICE is a modern machine; there have been huge leaps in technological innovation to increase its efficiency and decrease emissions. Further advances will enable near pollutant-free mobility; future fuels offer sustainable decarbonisation strategies. If we cease to invest in the ICE there is a danger that we will lose the opportunity to improve its technology, especially if electric cars do not meet expectations.

The demonisation of the internal combustion engine makes good politics, but poor engineering.

FELIX LEACH
Research fellow
Keble College
University of Oxford

+ 16 academics from various UK universities

DEATHBED OR MIDLIFE CRISIS? THE PREMATURE BURIAL OF INTERNAL COMBUSTION

- Electric vehicles that run on batteries are part of the future.
- Many studies show that 90% of ground-transportation energy will continue to come from hydrocarbon-based fuels (both renewable and traditional sources) in 2040.
- Battery production is not emission free.
- As well as road freight, vehicles used in agriculture and construction and for long-distance travel will continue to be powered by the ICE. There is little other choice.
- Further advances in ICEs will enable near pollutant-free mobility; future fuels offer sustainable decarbonisation strategies.
- If we cease to invest in the ICE there is a danger that we will lose the opportunity to improve its technology, especially if electric cars do not meet expectations.
- The demonisation of the internal combustion engine makes good politics, but poor engineering.

VOLVO

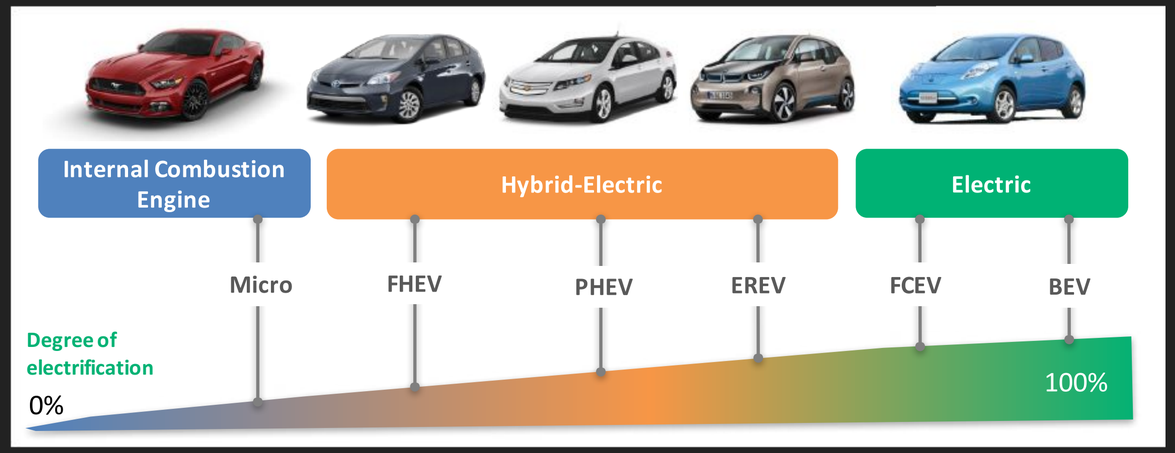
'Historic end' for combustion: Volvo says all of its cars will use electric after 2019

Volvo creates an historic first and says goodbye to the internal combustion engine

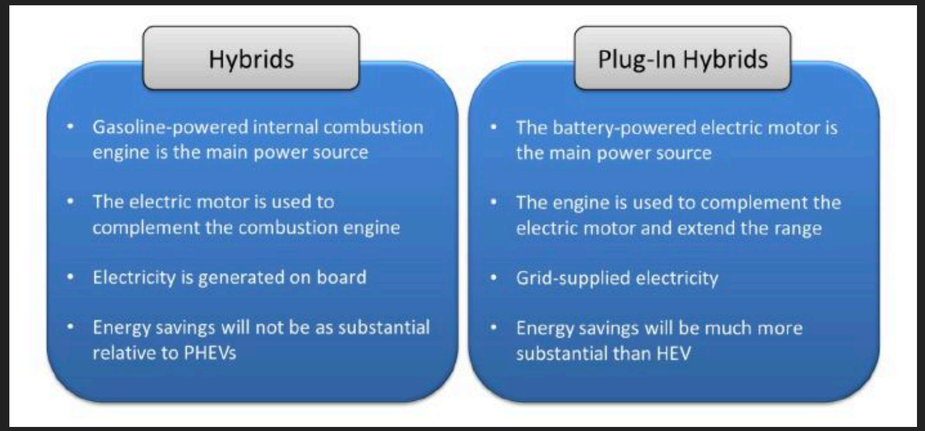
ELECTRIC VS ELECTRIFIED

- An electrified car isn't electric, but an electric car is electrified
- An electric car is 100% electric: a Battery Electric Vehicle (BEV) charged from the grid
- If a car has an exhaust, it's not electric
- Electrified cars include all vehicles that use electric power at varying stages
- To be "electrified," electricity needs to power more than basic accessories
  - Micro hybrid: stop/start, regenerative braking to charge
  - Mild hybrid (MHEV): + electric torque assistance (assist acceleration from stop)
  - Full hybrid (FHEV): + electric driving + battery charging from ICE
  - Plugin hybrid (PHEV): + battery charging from the grid
  - Extended Range (EREV): ICE is only used as a generator to recharge the battery
- Fuel cells (FCEV): hydrogen fuel cell produces electricity which powers the wheels, no ICE

Include ICE!



Graphic Adapted from http://www.eucar.be



https://www.fleetcarma.com/hybrids-what-is-the-difference-between-traditional-and-plug-in/

VOLVO

'Historic end' for combustion: Volvo says all of its cars will use electric after 2019

Volvo creates an historic first and says goodbye to the internal combustion engine

VOLVO

- IC Engine is far from dead, all new cars in 2019 will be *electrified*, not electric
  - 48-volt Mild Hybrid (MHEV)
  - PHEV
  - BEV
- Have set a goal of selling a total of 1 million electrified vehicles by 2025
- ~550,000*/year x 7 years = about 4 million cars between 2019 and 2025 - what are the other 3 million?

*Assumes 2016 sales number stays flat through 2025

BMW

https://techcrunch.com/2017/12/19/bmw-reaches-100000-electric-vehicle-sales-target-for-2017/

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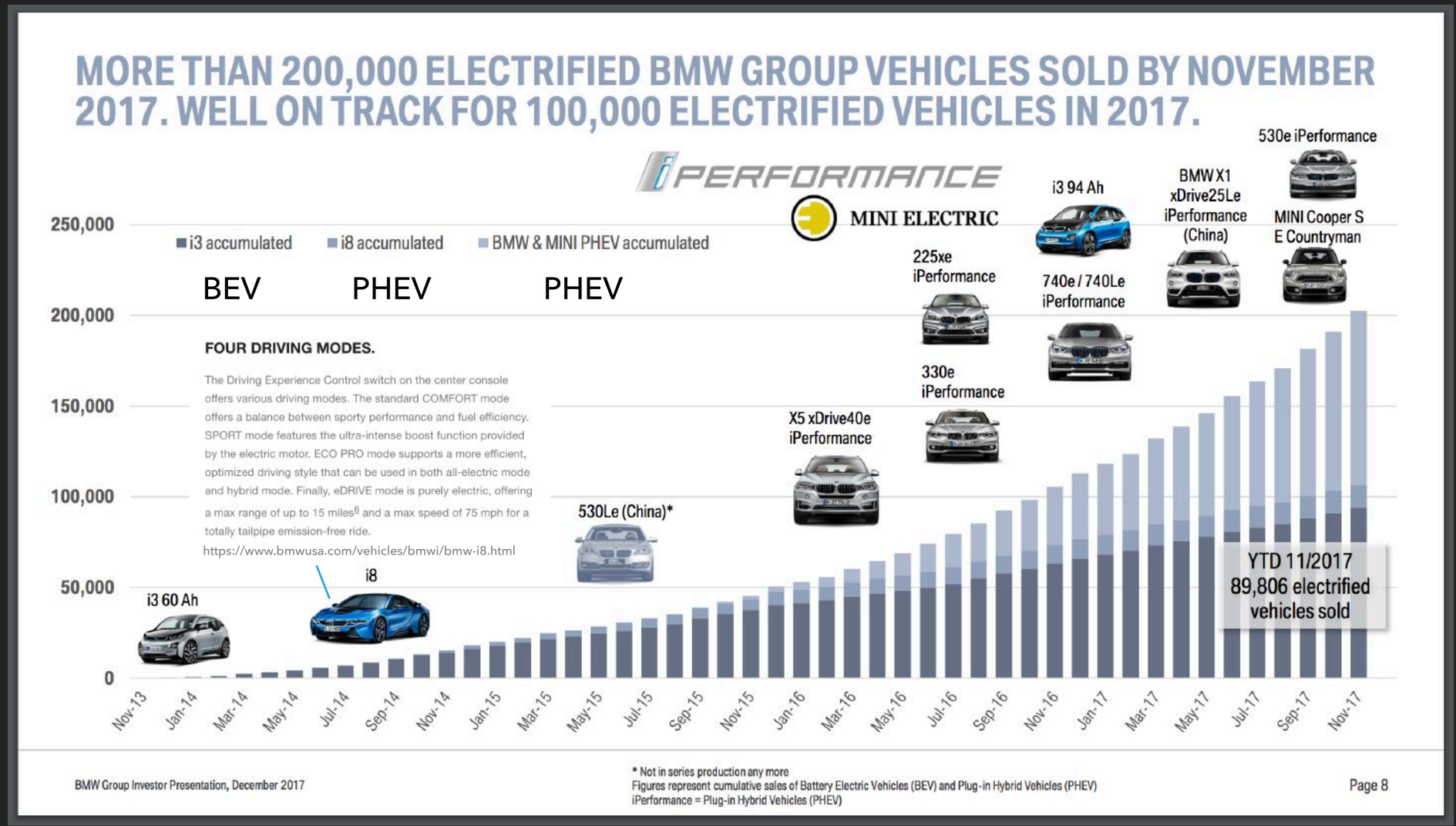
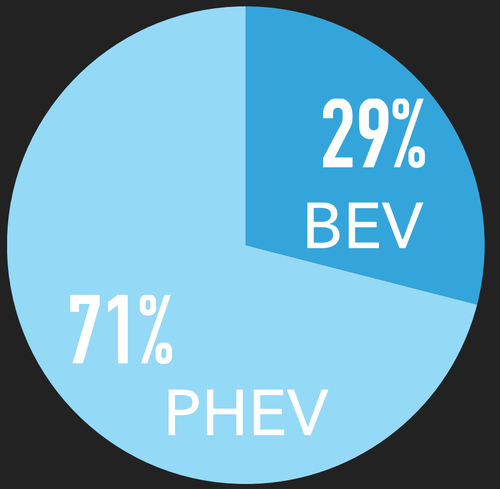
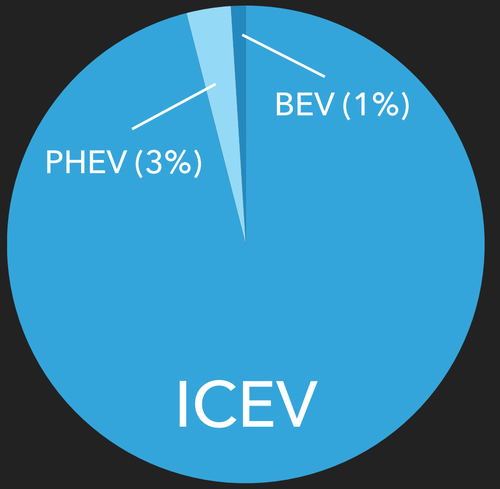
BMW



2017, Electrified Vehicles



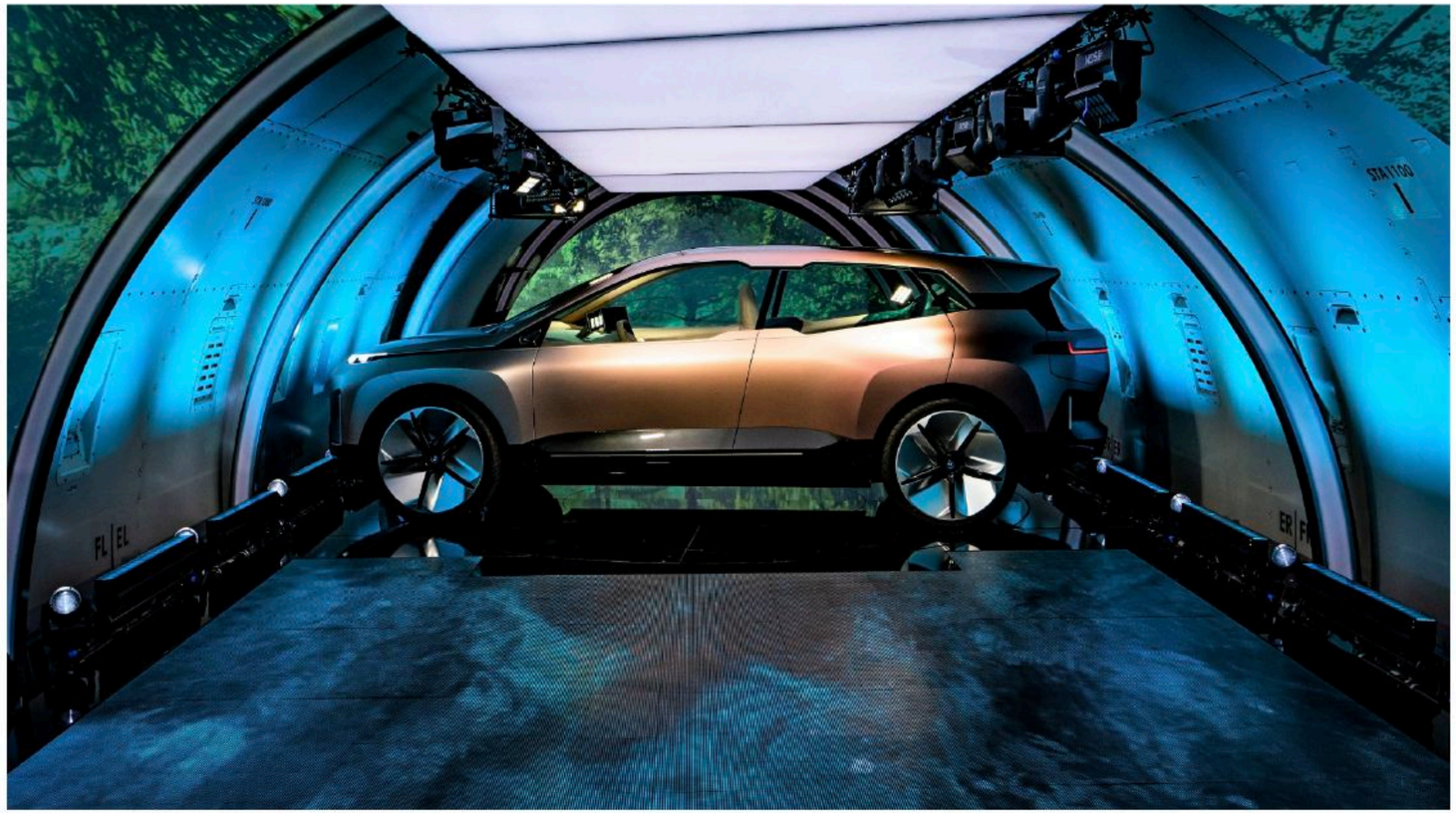
2017, All Vehicles



https://www.bmwgroup.com/content/dam/bmw-group-websites/bmwgroup_com/ir/downloads/en/2017/Investor_Presentation/BMW_Group_Investor_Presentation.pdf

BMW – OCT 14, 2018

BMW Board Member Defends Diesel, Calls Electric Car Hype Irrational



- Board member in charge of development, Klaus Frölich
- His very optimistic scenario still has IC engines in 85% of their fleet in 2030

https://insideevs.com/bmw-defends-diesel-ev-hype-irrational/

TOYOTA

Toyota will electrify entire vehicle lineup by 2025

https://techcrunch.com/2017/12/18/toyota-will-electrify-entire-vehicle-lineup-by-2025/

TOYOTA

- Around 10 million cars sold in 2017 (close to 80 million across all manufacturers)
- Sales of 100 million expected by 2030 - assume 12.5 million from Toyota
- The goal then is about 44% would be electrified, 8% would be BEV, FCEV

Electrification across the entire Toyota and Lexus line-up

- By around 2030, Toyota aims to have sales of more than 5.5 million electrified vehicles, including more than 1 million zero-emission vehicles (BEVs, FCEVs).
- Additionally, by around 2025, every model in the Toyota and Lexus line-up around the world will be available either as a dedicated electrified model or have an electrified option. This will be achieved by increasing the number of dedicated HEV, PHEV, BEV, and FCEV models and by generalizing the availability of HEV, PHEV and/or BEV options to all its models.
- As a result, the number of models developed without an electrified version will be zero.

Zero-emission Vehicles

- Toyota will accelerate the popularization of BEVs with more than 10 BEV models to be available worldwide by the early 2020s, starting in China, before entering other markets—the gradual introduction to Japan, India, United States and Europe is expected.
- The FCEV line-up will be expanded for both passenger and commercial vehicles in the 2020s.

Hybrid Electric and Plug-in Hybrid Electric Vehicles

- The HEV line-up will also grow, thanks to the further development of the Toyota Hybrid System II (featured in the current-generation Prius and other models); the introduction of a more powerful version in some models; and the development of simpler hybrid systems in select models, as appropriate, to meet various customer needs.
- Toyota also aims to expand its PHEV line-up in the 2020s.

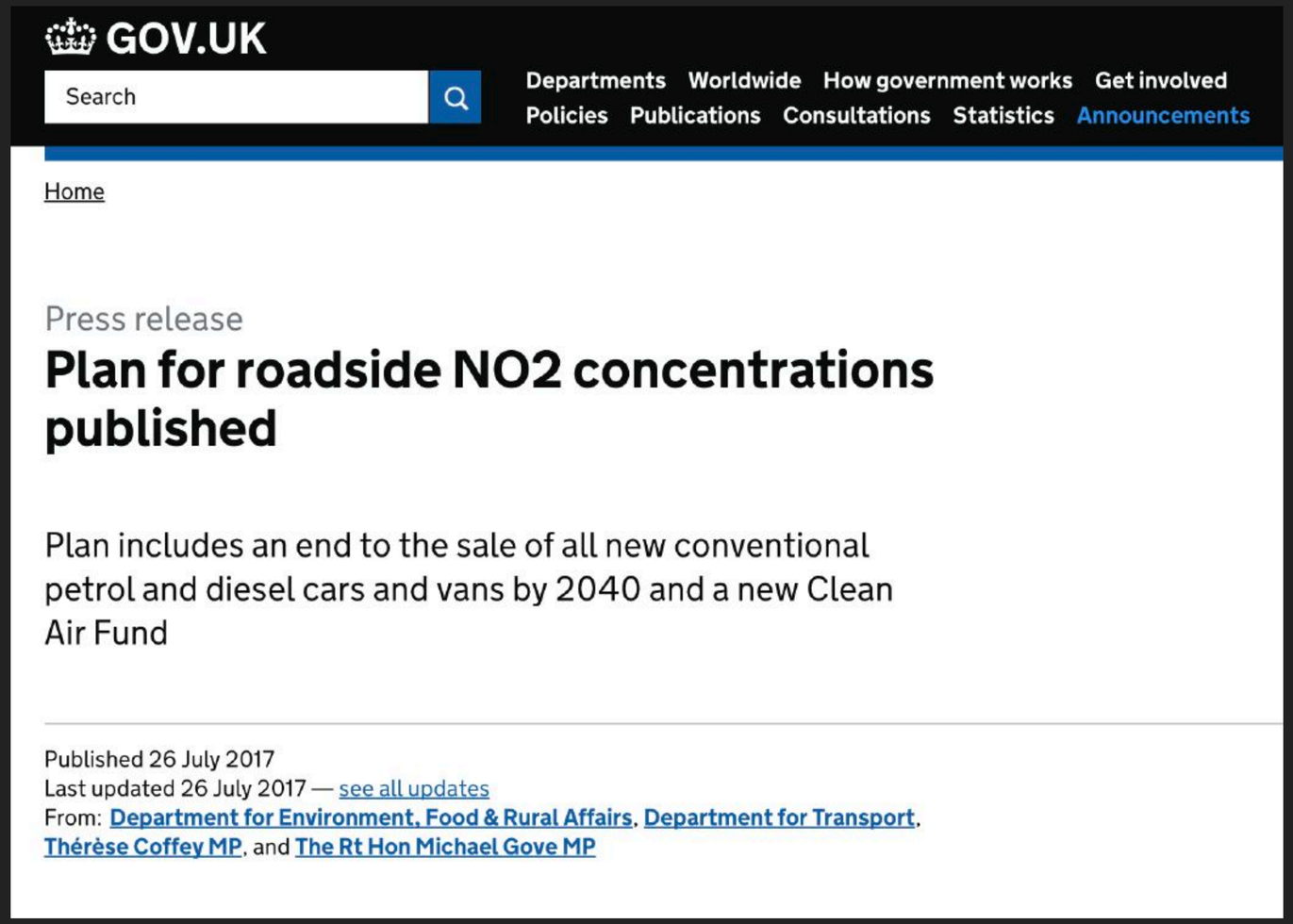
Dec 18, 2017: https://newsroom.toyota.co.jp/en/corporate/20353243.html

BRITAIN

Britain bans gasoline and diesel cars starting in 2040

http://money.cnn.com/2017/07/26/news/uk-bans-gasoline-diesel-engines-2040/index.html

BRITAIN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Press release
Plan for roadside NO2 concentrations published
Plan includes an end to the sale of all new conventional petrol and diesel cars and vans by 2040 and a new Clean Air Fund
Published 26 July 2017
Last updated 26 July 2017 — see all updates
From: Department for Environment, Food & Rural Affairs, Department for Transport, Thérèse Coffey MP, and The Rt Hon Michael Gove MP

MYTH 1: THE IC ENGINE IS DEAD

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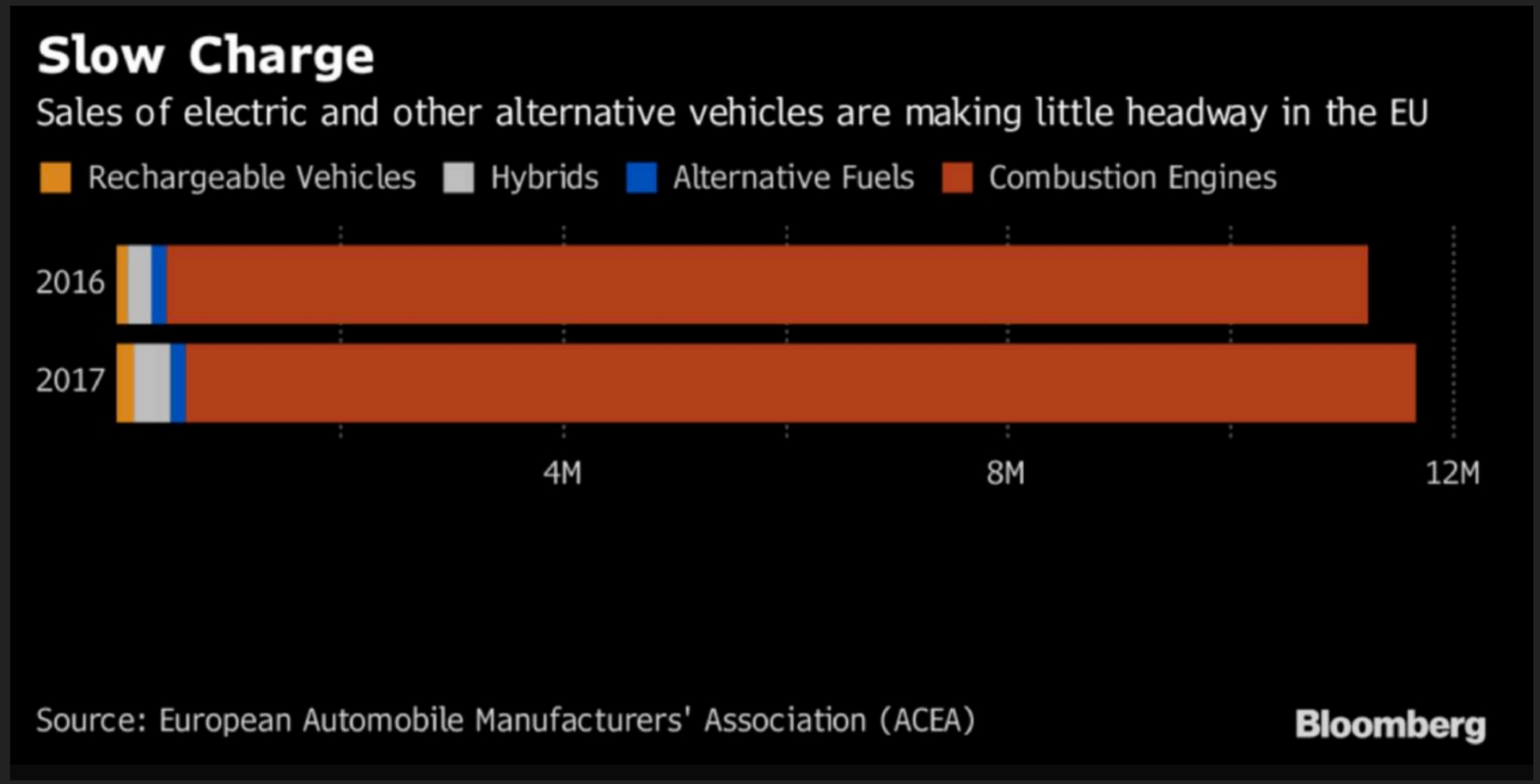

https://www.bloombergquint.com/markets/2017/11/08/europe-steps-up-electric-car-push-to-close-huge-gap-with-china

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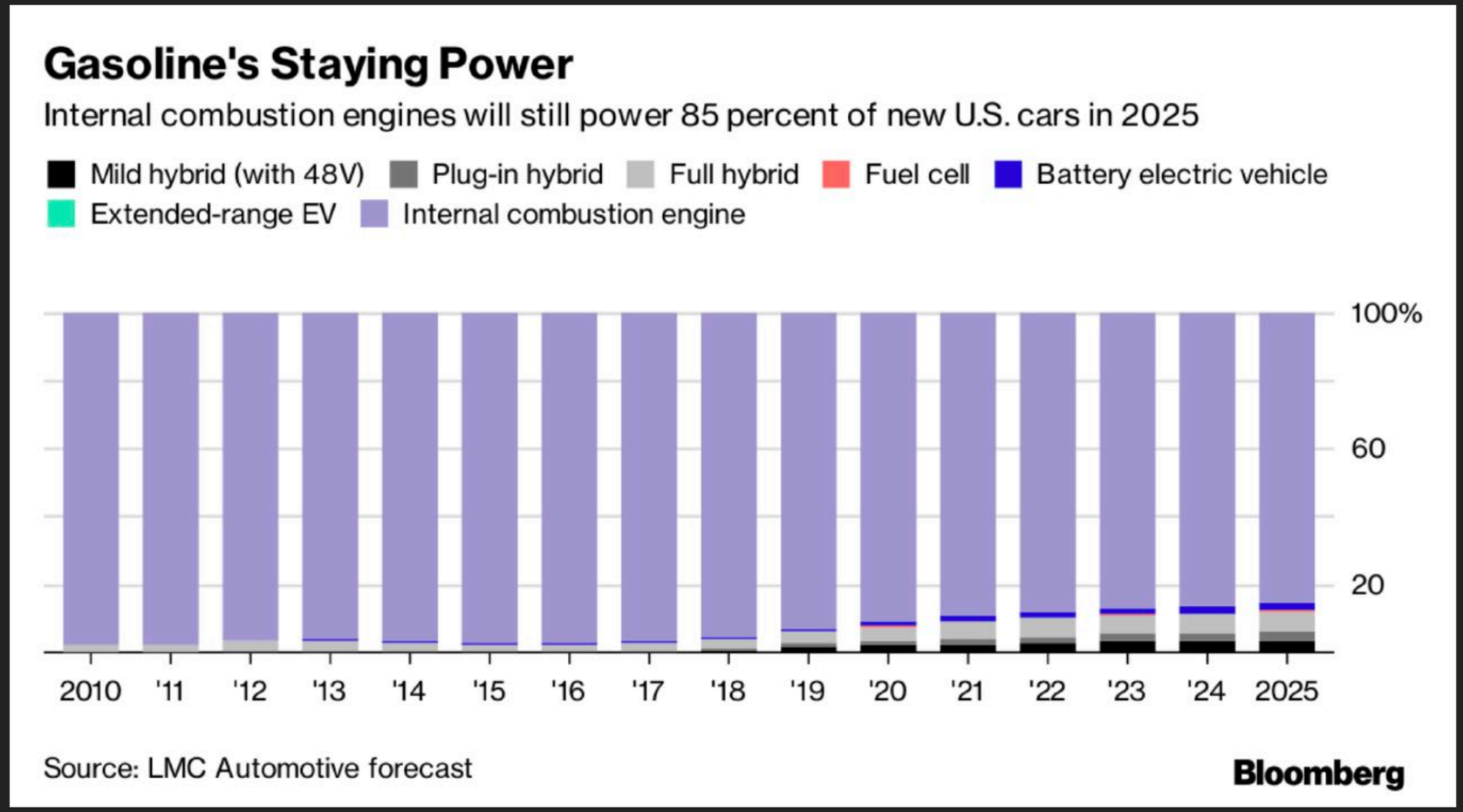
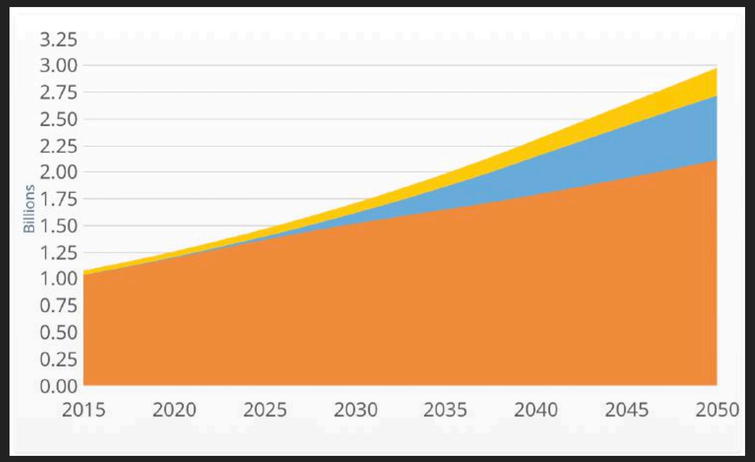


https://www.bloomberg.com/news/features/2017-12-19/the-near-future-of-electric-cars-many-models-few-buyers

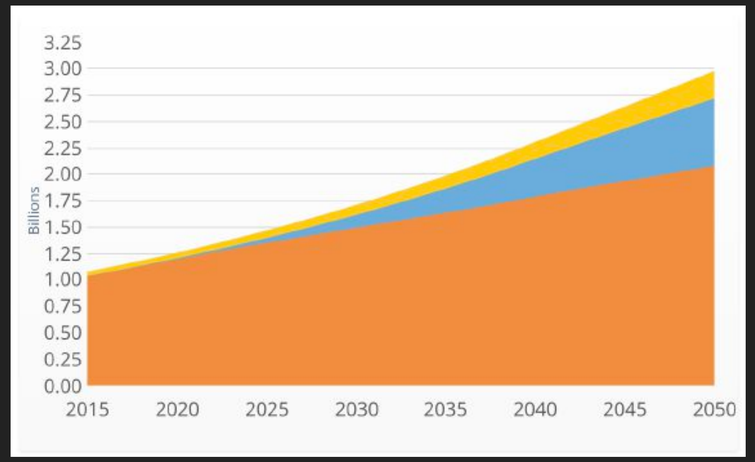
MYTH 1: THE IC ENGINE IS DEAD

Vehicles on the road worldwide

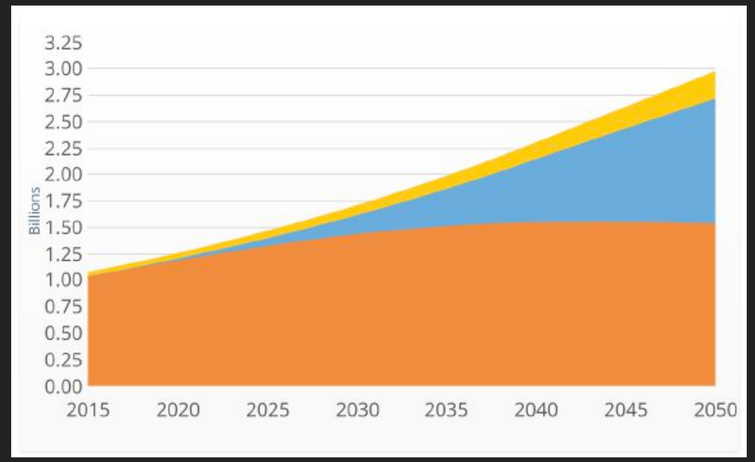
Bloomberg Projection



Goldman Sachs Projection



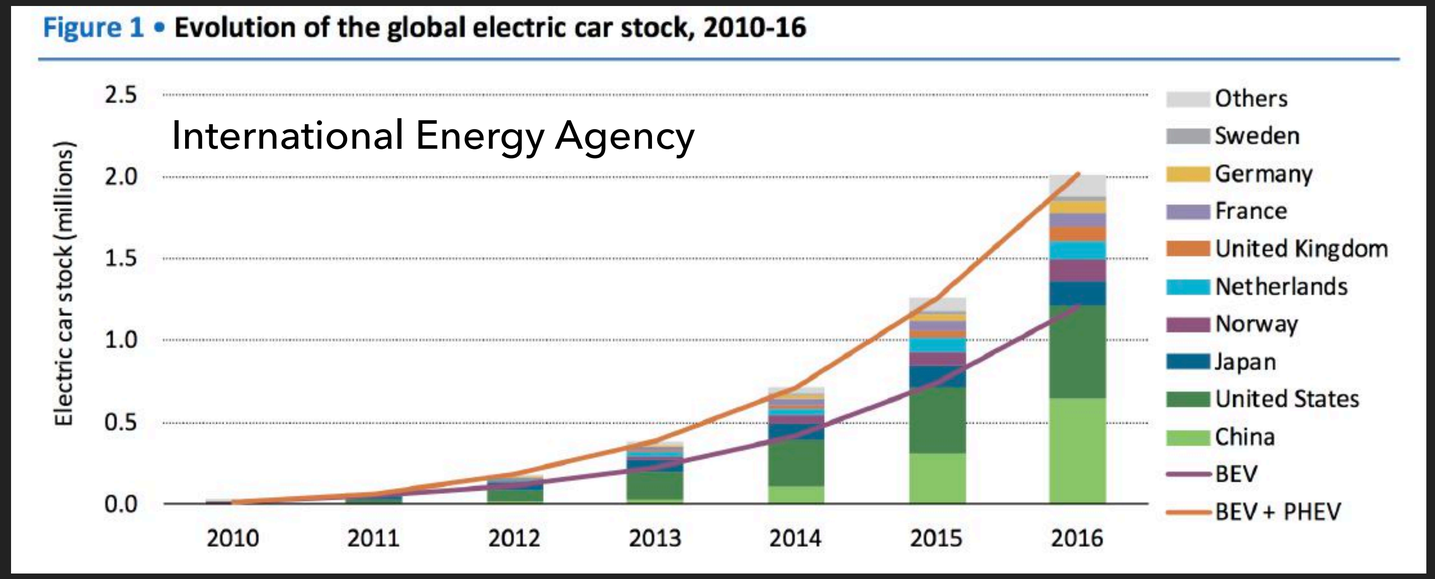
International Energy Agency (highly optimistic roadmap)



- AFVs (Alternative Fuel Vehicles): Hydrogen Fuel Cell Vehicles, Natural Gas Vehicles, and Propane Autogas Vehicles.
- EVs (Electric Vehicles): Battery (all-electric) and Plug-in Hybrid (electric and ICE drivetrains) EVs.
- ICE Vehicles (Internal Combustion Engine Vehicles): Gasoline ICE, Diesel ICE, Flex-Fuel ICE, and Hybrid ICE.

https://www.fuelfreedom.org/cars-in-2050/

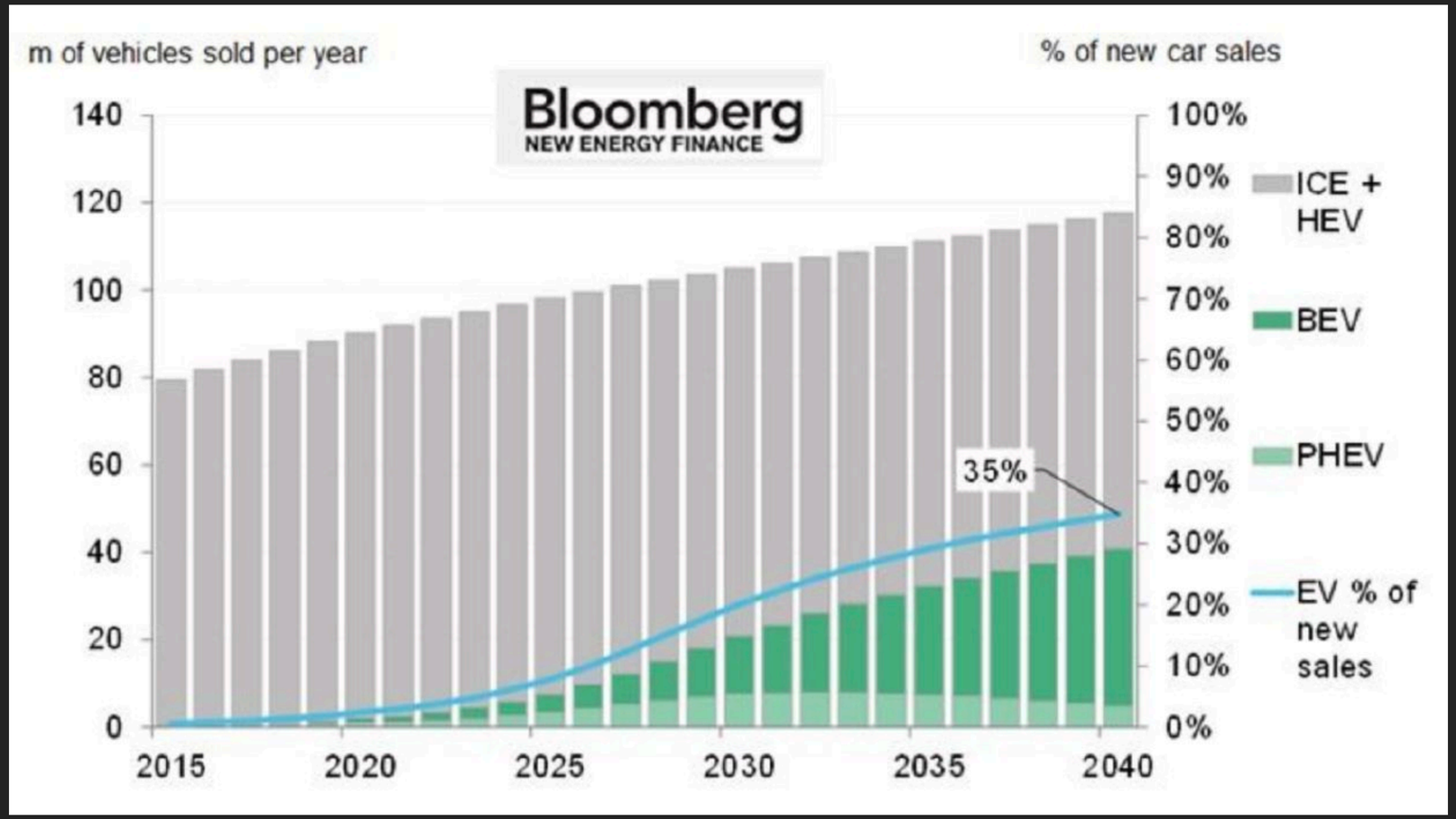
MYTH 1: THE IC ENGINE IS DEAD



https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf

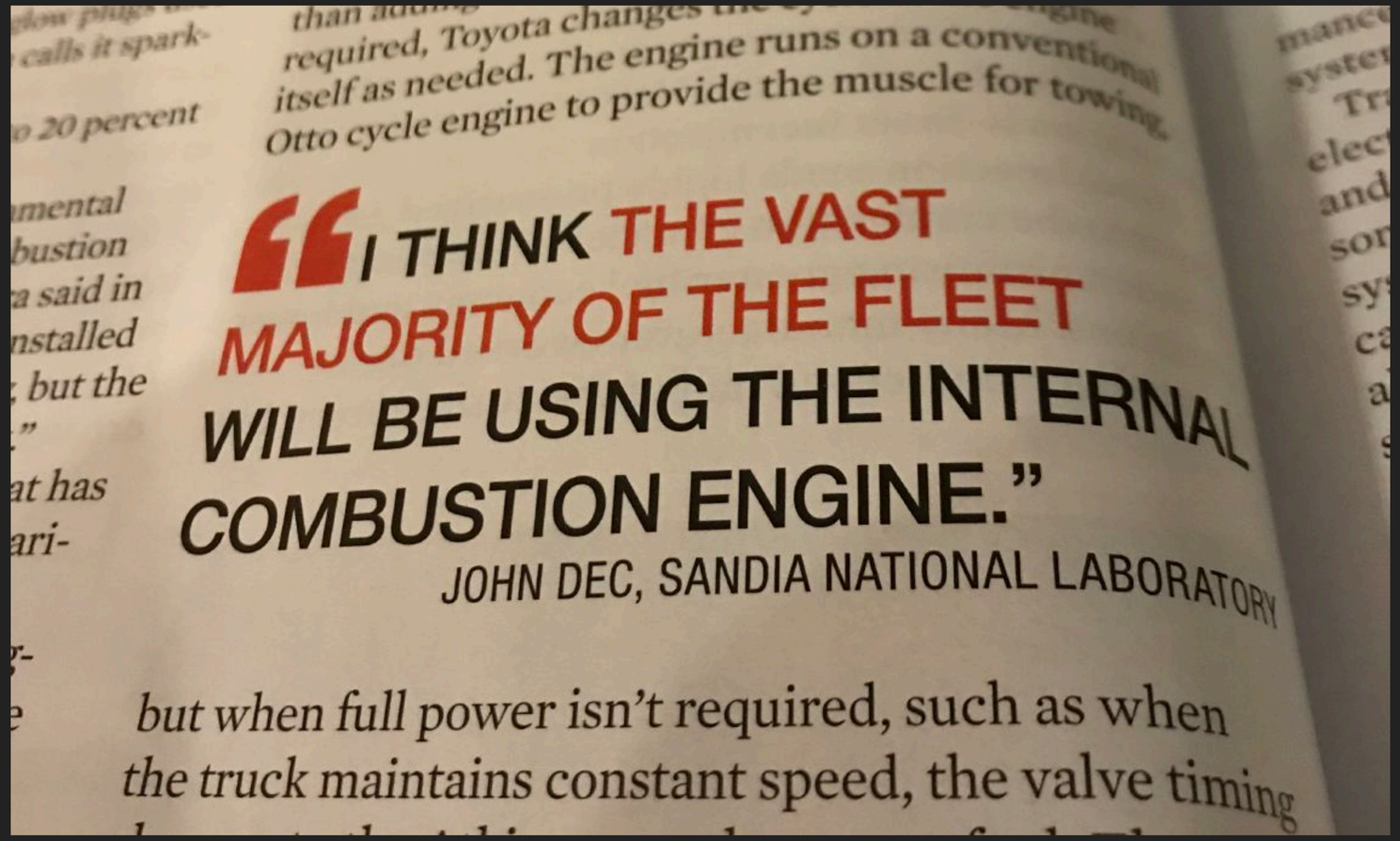
- Calculate yearly additions from this cumulative data
- Fit the data to a cubic polynomial
- Use fit to extrapolate BEVs sold in the future
- Predicts that 10 million will be sold in 2030
- 10% of expected 100 million cars sold in 2030

MYTH 1: THE IC ENGINE IS DEAD



https://about.bnef.com/blog/electric-vehicles-to-be-35-of-global-new-car-sales-by-2040/

MYTH 1: THE IC ENGINE IS DEAD



Rekindling the Spark by John Kosowatz, Mechanical Engineering Magazine, November 2017

MYTH 1: THE IC ENGINE IS DEAD

WCX WORLD CONGRESS EXPERIENCE

NOT DEAD YET:

The resilient ICE looks to 2050

The mobility industry will need to keep evolving the combustion engine for many years, says Dr. John Heywood

Interview by Lindsay Brooke

For the sake of discussion, let's say that 25% of the world's light-vehicle production in 2030 will be battery-electrics.

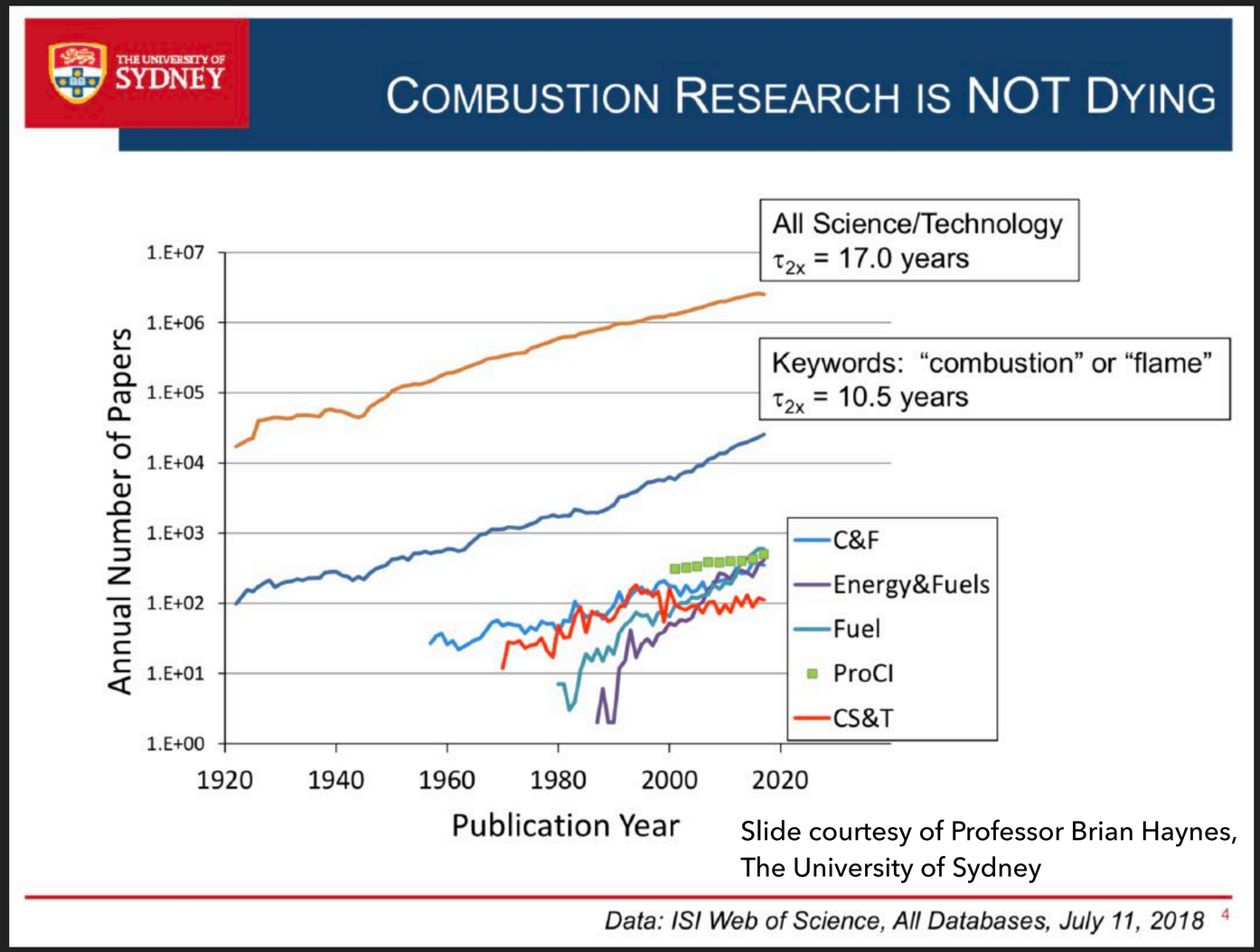
How do you reply to those who ask, "Why is anyone

SAE Automotive Engineering magazine, April, 2018: interview with Professor John Heywood of MIT

"The penetration rates of the various propulsion options are evidence why internal combustion dominates – because it best meets the needs of the market."

MYTH 1: THE IC ENGINE IS DEAD

- Record attendance of 1,864
- 1,610 submitted papers, 650 accepted
- 691 submitted work in progress posters



MYTH 2: BEVS ARE ZERO EMISSIONS VEHICLES

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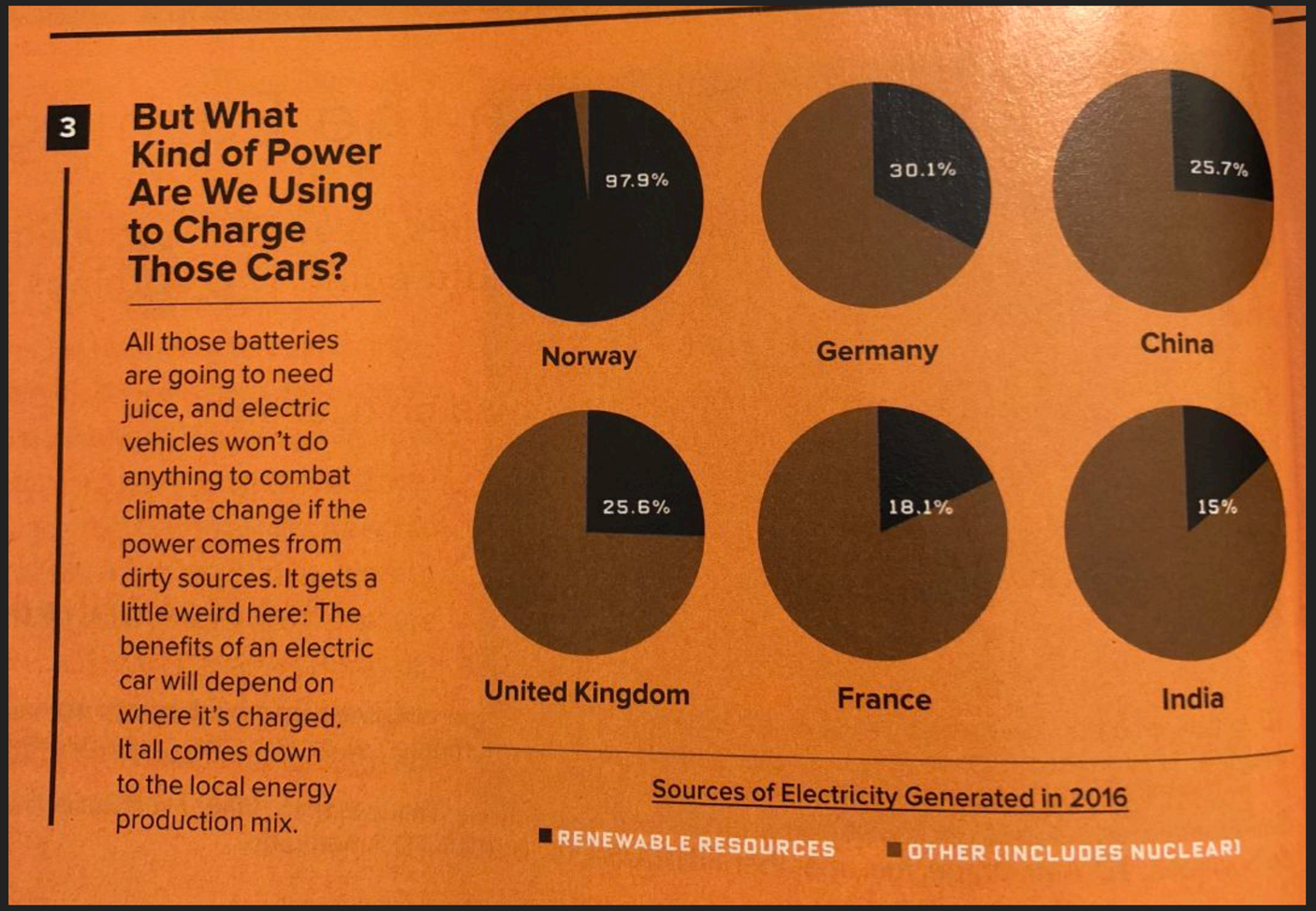
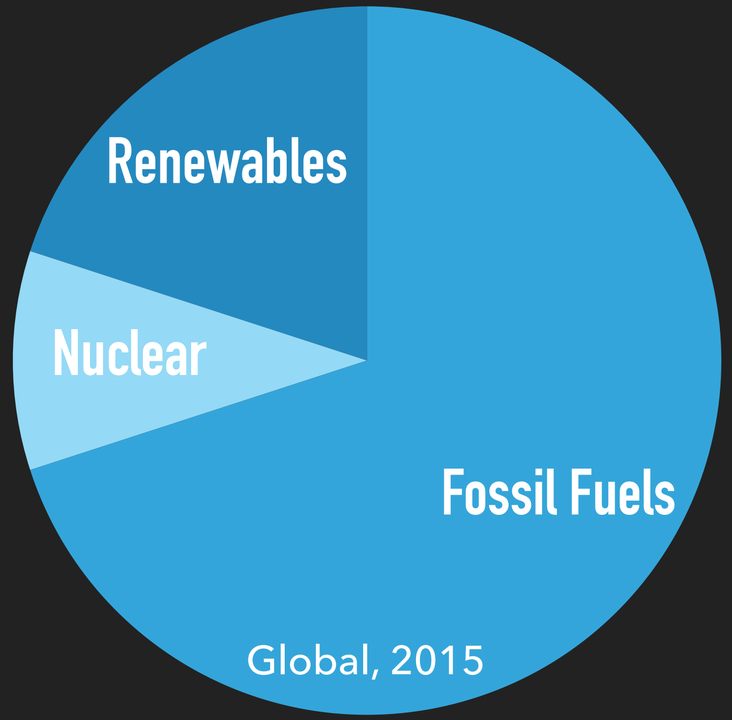


3

But What Kind of Power Are We Using to Charge Those Cars?

All those batteries are going to need juice, and electric vehicles won't do anything to combat climate change if the power comes from dirty sources. It gets a little weird here: The benefits of an electric car will depend on where it's charged. It all comes down to the local energy production mix.

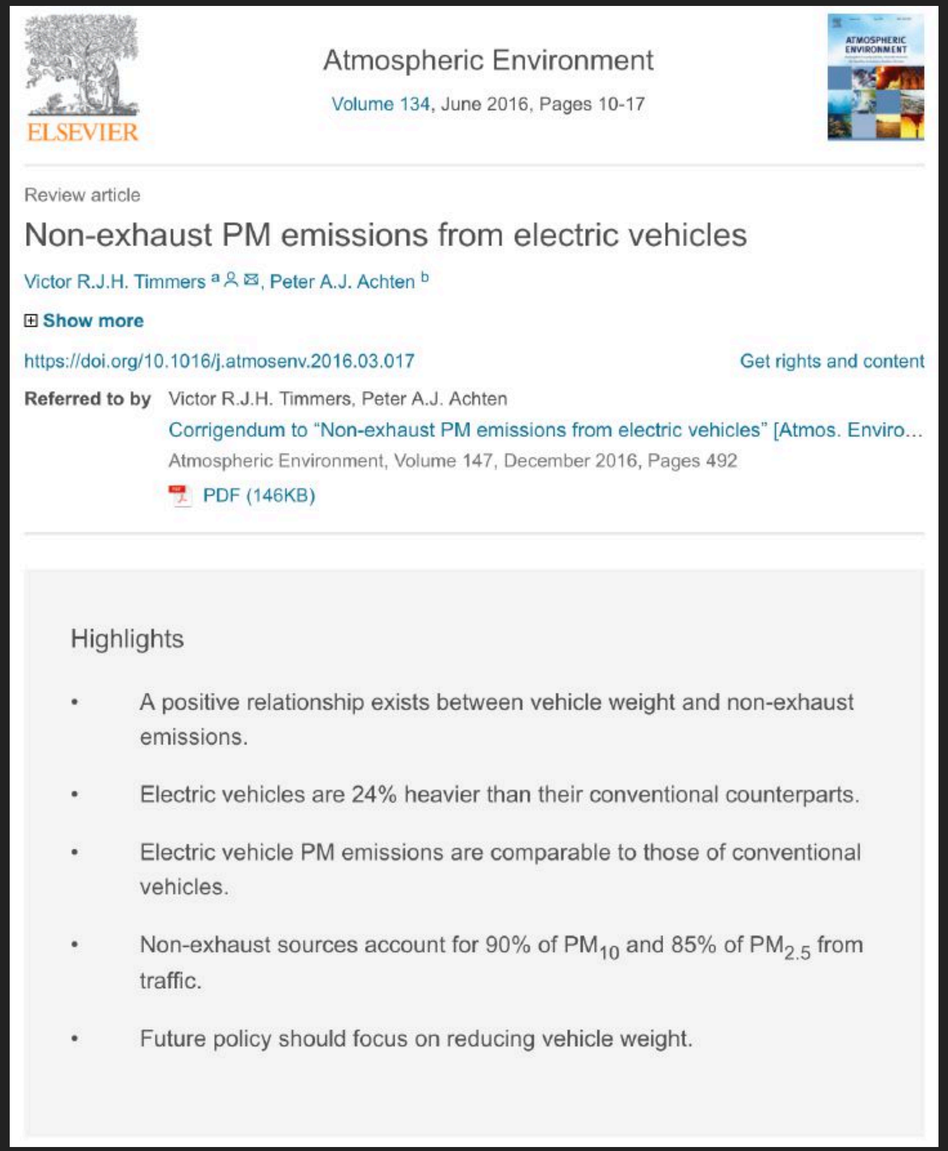
Wired Magazine, January 2018



70/20/10

MYTH 2: BEVS ARE ZERO EMISSIONS VEHICLES

- Non-exhaust particulate emissions from tires, brakes, and road surfaces
- Higher non-exhaust PM from heavier vehicles
- PM emissions are comparable between EV and ICEV (~1-3% lower PM for EV)



ELSEVIER

Atmospheric Environment
Volume 134, June 2016, Pages 10-17

Review article

Non-exhaust PM emissions from electric vehicles

Victor R.J.H. Timmers [a], Peter A.J. Achten [b]

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https://doi.org/10.1016/j.atmosenv.2016.03.017

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Referred to by Victor R.J.H. Timmers, Peter A.J. Achten
Corrigendum to "Non-exhaust PM emissions from electric vehicles" [Atmos. Enviro...
Atmospheric Environment, Volume 147, December 2016, Pages 492

PDF (146KB)

Highlights

- A positive relationship exists between vehicle weight and non-exhaust emissions.
- Electric vehicles are 24% heavier than their conventional counterparts.
- Electric vehicle PM emissions are comparable to those of conventional vehicles.
- Non-exhaust sources account for 90% of PM_{10} and 85% of $PM_{2.5}$ from traffic.
- Future policy should focus on reducing vehicle weight.

MYTH 2: BEVS ARE ZERO EMISSIONS VEHICLES

- Cradle to Gate emissions

Applied Energy 204 (2017) 1399–1411

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Cradle-to-gate greenhouse gas emissions of battery electric and internal combustion engine vehicles in China ☆

Qinyu Qiao, Fuquan Zhao, Zongwei Liu, Shuhua Jiang, Han Hao *

State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China

HIGHLIGHTS

- Cradle-to-gate greenhouse gas emissions of internal combustion engine and battery electric vehicles are compared.
- Greenhouse gas emissions of battery electric vehicles are 50% higher than internal combustion engine vehicles.
- Traction battery production causes about 20% greenhouse gas emissions increase.
- 10% variations of curb weight, electricity and Li-ion battery production affect the results by 7%, 4% and 2%.
- Manufacturing technique improvement, vehicle recycling and energy structure optimization are major mitigation opportunities.

ARTICLE INFO

Article history:
Received 10 January 2017
Received in revised form 6 March 2017
Accepted 4 May 2017
Available online 10 May 2017

Keywords:
Vehicle production
Electric drive vehicle
Greenhouse gas
Life cycle assessment
Li-ion battery

ABSTRACT

Electric drive vehicles are equipped with totally different propulsion systems compared with conventional vehicles, for which the energy consumption and cradle-to-gate greenhouse gas emissions associated with vehicle production could substantially change. In this study, the life cycle energy consumption and greenhouse gas emissions of vehicle production are compared between battery electric and internal combustion engine vehicles in China's context. The results reveal that the energy consumption and greenhouse gas emissions of a battery electric vehicle production range from 92.4 to 94.3 GJ and 15.0 to 15.2 t CO_2eq, which are about 50% higher than those of an internal combustion engine vehicle, 63.5 GJ and 10.0 t CO_2eq. This substantial change can be mainly attributed to the production of traction batteries, the essential components for battery electric vehicles. Moreover, the larger weight and different weight distribution of materials used in battery electric vehicles also contribute to the larger environmental impact. This situation can be improved through the development of new traction battery production techniques, vehicle recycling and a low-carbon energy structure.

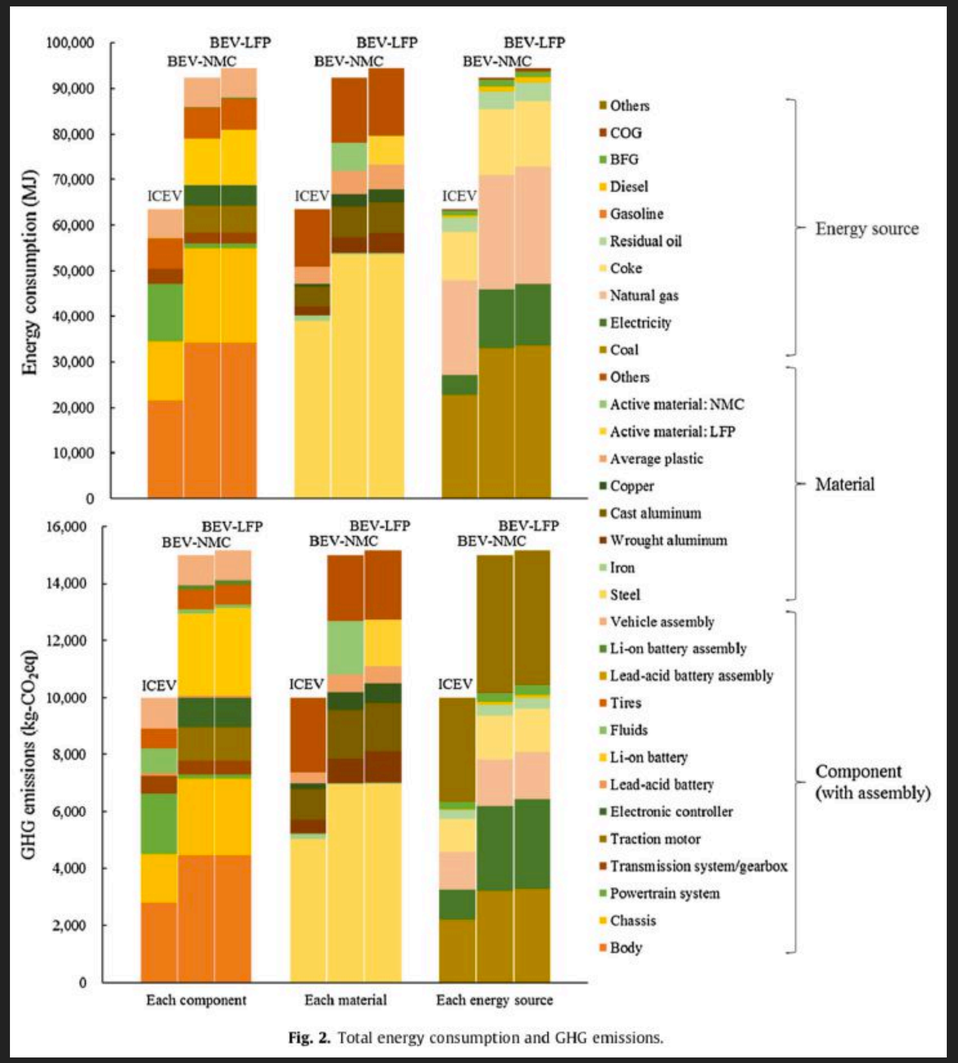


Fig. 2. Total energy consumption and GHG emissions.

MYTH 2: BEVS ARE ZERO EMISSIONS VEHICLES

- Nissan Leaf

  - 150 mile range
  - 40 kWh battery
  - 5,600 kg CO2 from battery production (assuming 140 kg/kWh)
  - CO2 of battery creation = CO2 from driving 31,000 miles in 320d
- Tesla Model S

  - 325 mile range
  - 100 kWh battery
  - 14,000 kg CO2 from battery production (assuming 140 kg/kWh)
  - CO2 of battery creation = CO2 from driving 80,000 miles in 320d

BMW 320d
109 g/km CO2

CO2 of battery creation
= 950 miles of driving

MYTH 2: BEVS ARE ZERO EMISSIONS VEHICLES

January 27, 2016

In coal-powered China, electric car surge fuels fear of worsening smog

Jake Spring

5 MIN READ

BEIJING (Reuters) - Automakers' latest projections for rapid growth of China's green car market have added to concerns of worsening smog as the uptake of electric vehicles powered by coal-fired grids races ahead of a switch to cleaner energy.

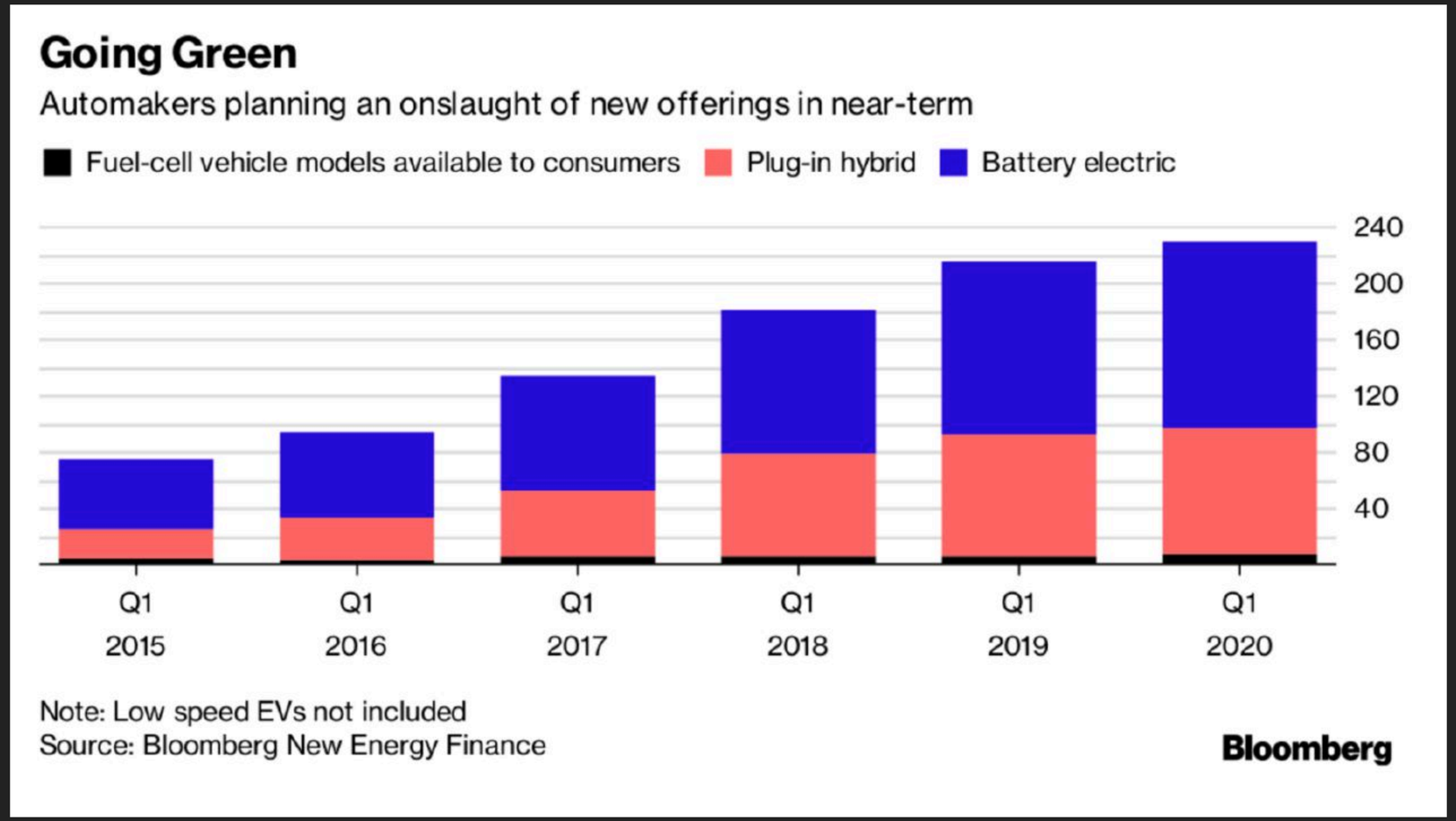
The government has been promoting electric vehicles to cut the smog that frequently envelops Chinese cities, helping sales quadruple last year and making China the biggest market, the finance minister said at the conference. Less than 1 percent of passenger cars are now new energy, but the pace of growth raises their potential to worsen smog.

A series of studies by Tsinghua University, whose alumni includes the incumbent president, showed electric vehicles charged in China produce two to five times as much particulate matter and chemicals that contribute to smog versus petrol-engine cars. Hybrid vehicles fare little better.

https://www.reuters.com/article/us-china-pollution-autos/in-coal-powered-china-electric-car-surge-fuels-fear-of-worsening-smog-idUSKCN0V51BH

MYTH 3: AUTO COMPANIES LOVE ELECTRIC CARS

MYTH 3: AUTO COMPANIES LOVE ELECTRIC CARS



MYTH 3: AUTO COMPANIES LOVE ELECTRIC CARS

CAR INDUSTRY

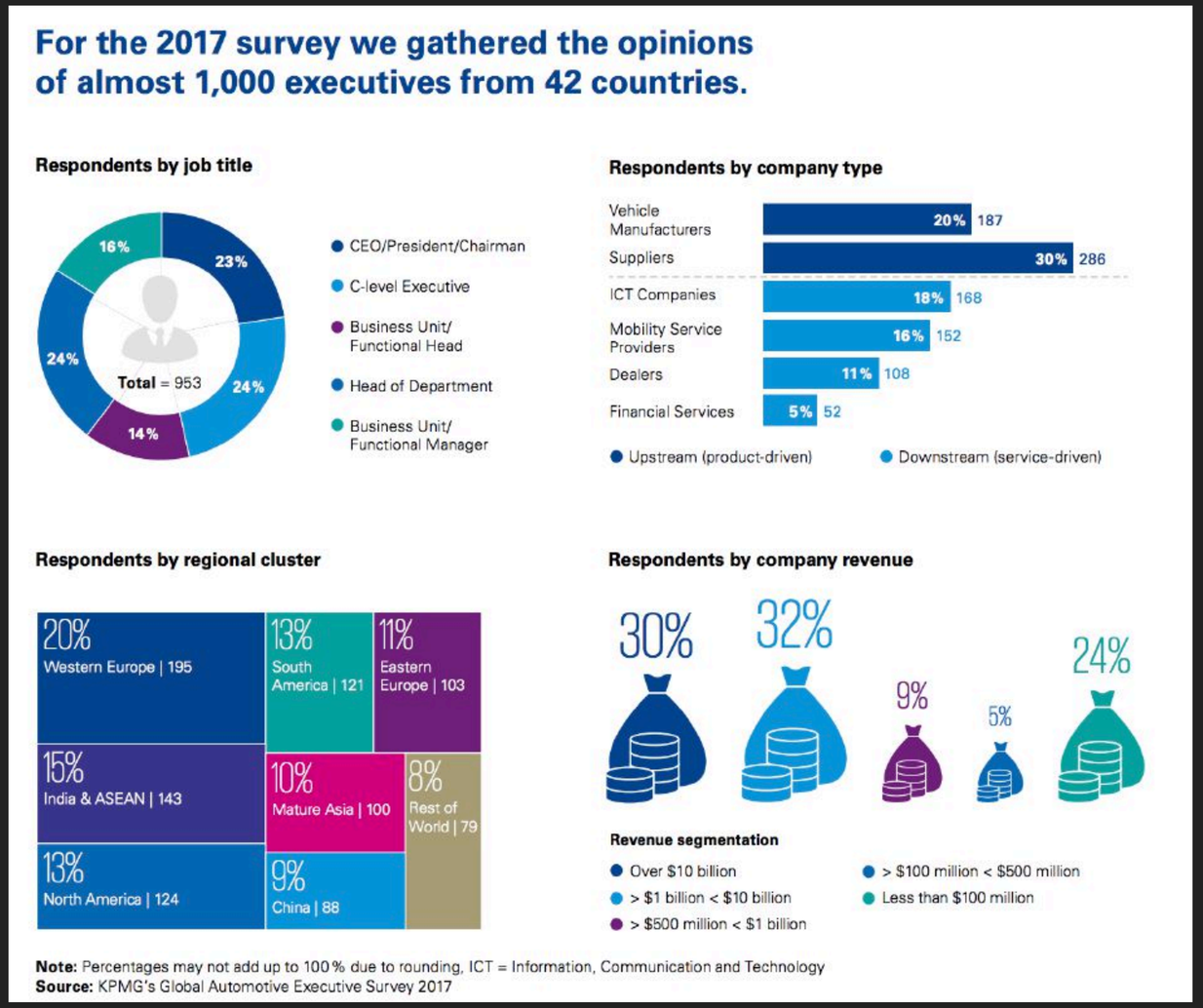
Global auto execs question the future of electric cars, survey says

Despite betting big on EVs, a majority of executives feel electric cars are doomed to fail.

BY **KYLE HYATT** / JANUARY 5, 2018 2:34 PM PST

https://www.cnet.com/roadshow/news/global-auto-execs-question-the-future-of-electric-cars-survey-says/#

MYTH 3: AUTO COMPANIES LOVE ELECTRIC CARS

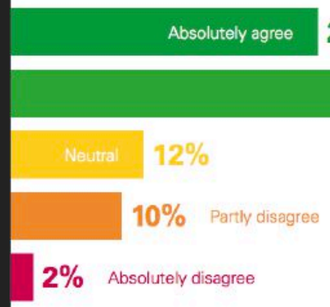


https://assets.kpmg.com/content/dam/kpmg/xx/pdf/2017/01/global-automotive-executive-survey-2017.pdf

MYTH 3: AUTO COMPANIES LOVE ELECTRIC CARS

76% of the executives see **ICEs** as still more important than electric drivetrains for a very long time.

Executive opinion



Laurent des Places
Automotive Leader France

"Execs are torn in between: Traditional combustion engines will be technologically relevant, but socially inacceptable."

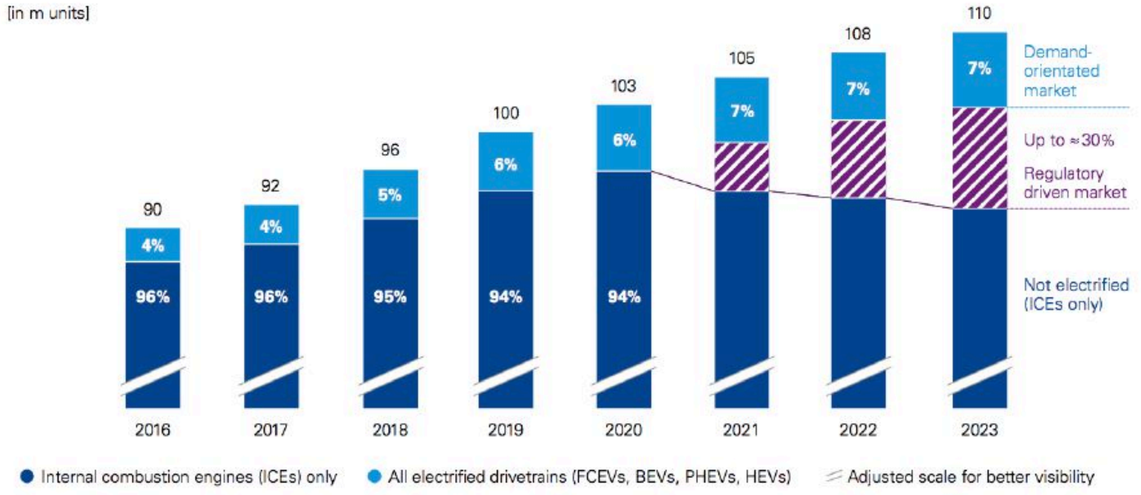
Internal combustion engines (ICEs) will still be important for a long time.

Executives are torn between evolutionary and revolutionary drivetrain technologies.

Ranking tenth on executives' key trend agenda, downsizing the internal combustion engine is by far no longer a crucial key trend compared to the highly rated electrification trends. OEMs see the importance in continuously managing the mainly evolutionary powertrain technology ICE, agreeing that revolutionary electric drivetrains still need time for implementation and cannot be easily integrated into existing platform concepts.

This leads to the question of how the market forecasts for drivetrain technologies will look like by 2023. Considering a demand oriented development, the share of alternative powertrains would increase from 4% in 2016 to only 7% in 2023. However, with the signalized strong influence on the market by regulation fulfilling the set CO_2 goals, we believe developments are much more revolutionary and very likely to convert to a regulatory driven market with an e-mobility share of up to 30% of global automotive production by 2023. In this case it would be the first time in history that the absolute number of produced ICEs would significantly decrease.

NextGen Analytics: Global automotive light vehicle production (< 6t) by drive technology (ICE vs. electrified)



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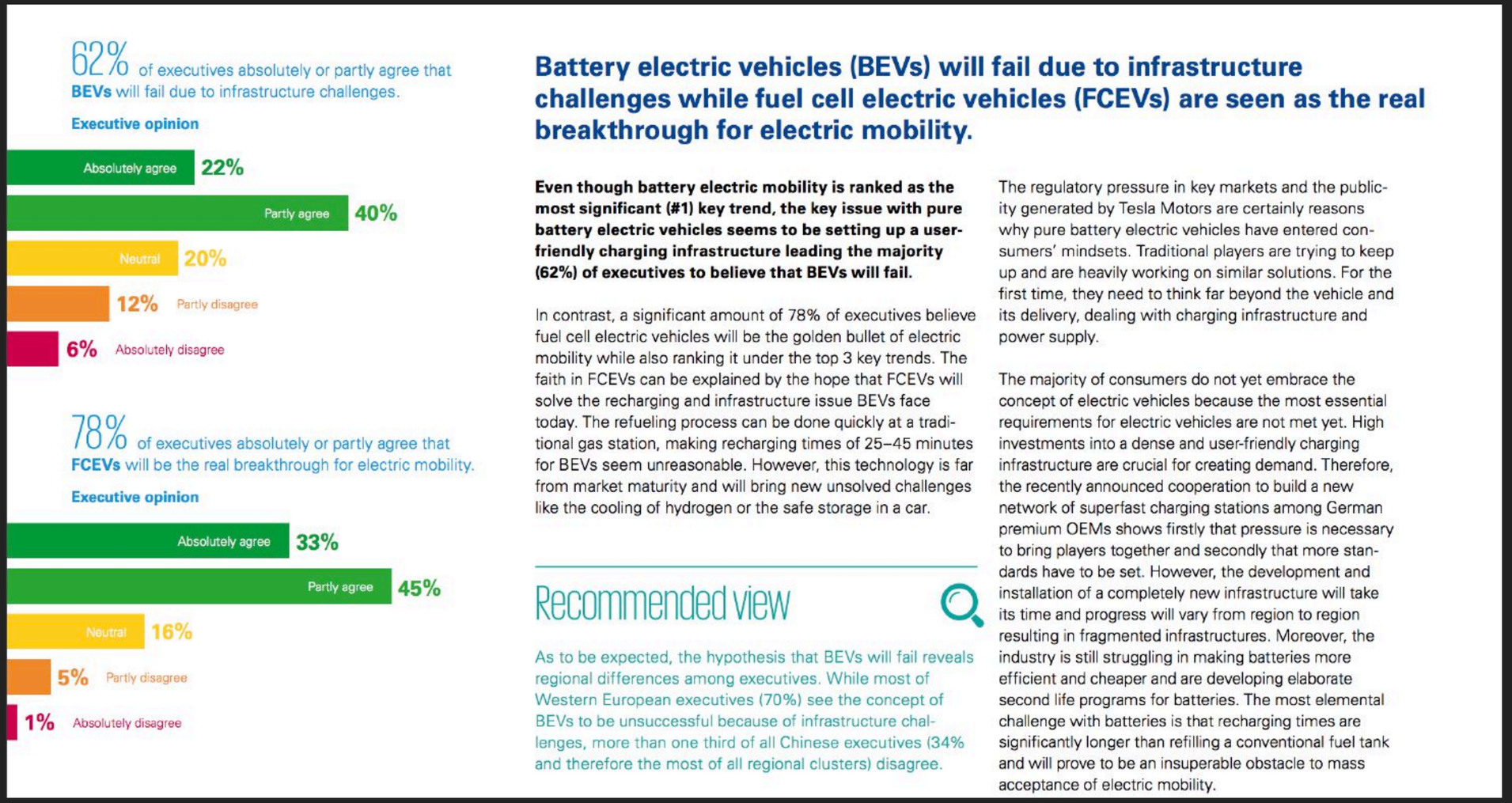
MYTH 3: AUTO COMPANIES LOVE ELECTRIC CARS



62% of executives absolutely or partly agree that **BEVs** will fail due to infrastructure challenges.

Executive opinion

78% of executives absolutely or partly agree that **FCEVs** will be the real breakthrough for electric mobility.

Executive opinion

Battery electric vehicles (BEVs) will fail due to infrastructure challenges while fuel cell electric vehicles (FCEVs) are seen as the real breakthrough for electric mobility.

Even though battery electric mobility is ranked as the most significant (#1) key trend, the key issue with pure battery electric vehicles seems to be setting up a user-friendly charging infrastructure leading the majority (62%) of executives to believe that BEVs will fail.

In contrast, a significant amount of 78% of executives believe fuel cell electric vehicles will be the golden bullet of electric mobility while also ranking it under the top 3 key trends. The faith in FCEVs can be explained by the hope that FCEVs will solve the recharging and infrastructure issue BEVs face today. The refueling process can be done quickly at a traditional gas station, making recharging times of 25–45 minutes for BEVs seem unreasonable. However, this technology is far from market maturity and will bring new unsolved challenges like the cooling of hydrogen or the safe storage in a car.

Recommended view

As to be expected, the hypothesis that BEVs will fail reveals regional differences among executives. While most of Western European executives (70%) see the concept of BEVs to be unsuccessful because of infrastructure challenges, more than one third of all Chinese executives (34% and therefore the most of all regional clusters) disagree.

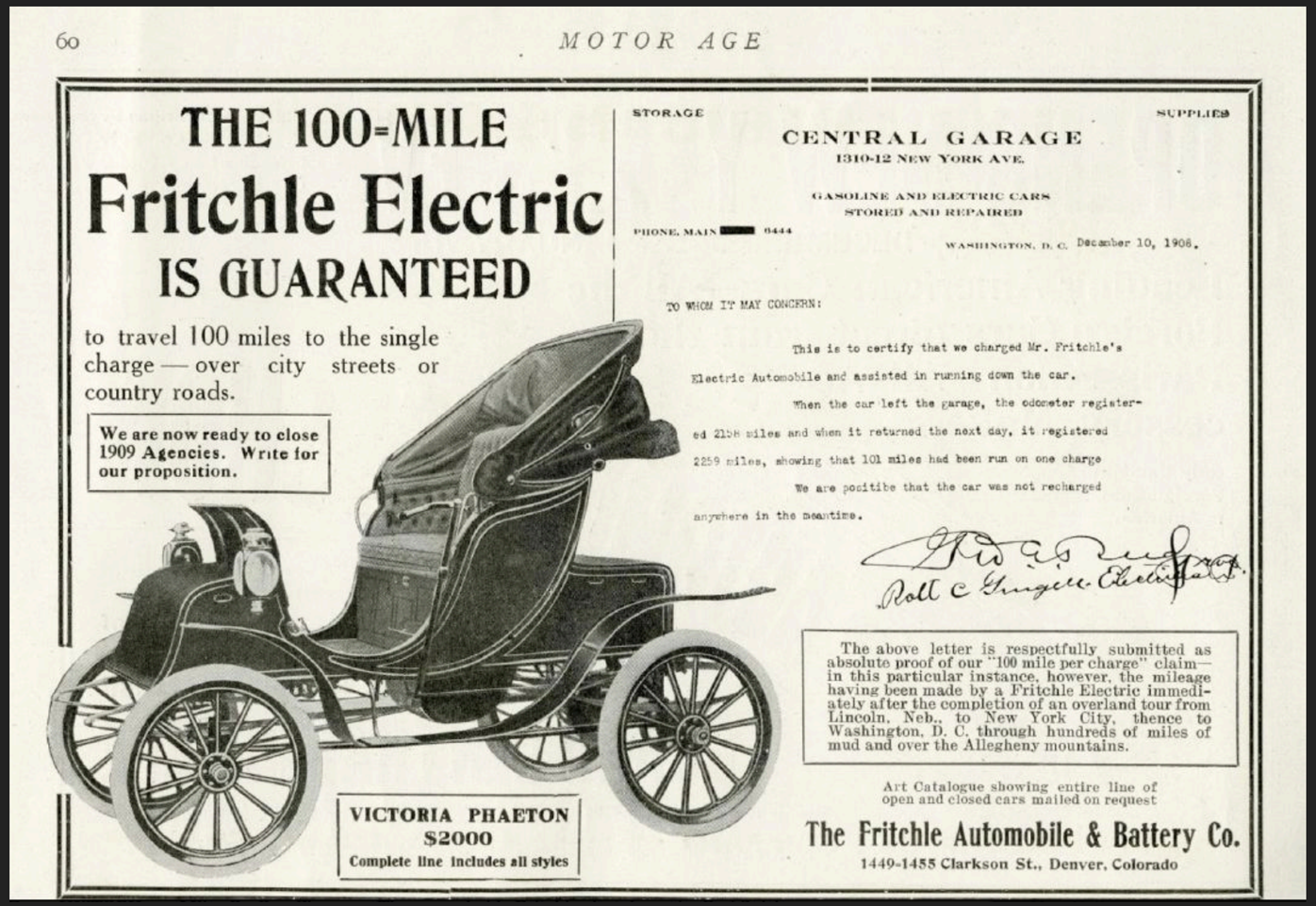
The regulatory pressure in key markets and the publicity generated by Tesla Motors are certainly reasons why pure battery electric vehicles have entered consumers' mindsets. Traditional players are trying to keep up and are heavily working on similar solutions. For the first time, they need to think far beyond the vehicle and its delivery, dealing with charging infrastructure and power supply.

The majority of consumers do not yet embrace the concept of electric vehicles because the most essential requirements for electric vehicles are not met yet. High investments into a dense and user-friendly charging infrastructure are crucial for creating demand. Therefore, the recently announced cooperation to build a new network of superfast charging stations among German premium OEMs shows firstly that pressure is necessary to bring players together and secondly that more standards have to be set. However, the development and installation of a completely new infrastructure will take its time and progress will vary from region to region resulting in fragmented infrastructures. Moreover, the industry is still struggling in making batteries more efficient and cheaper and are developing elaborate second life programs for batteries. The most elemental challenge with batteries is that recharging times are significantly longer than refilling a conventional fuel tank and will prove to be an insuperable obstacle to mass acceptance of electric mobility.

https://assets.kpmg.com/content/dam/kpmg/xx/pdf/2017/01/global-automotive-executive-survey-2017.pdf

MYTH 4: THE BEV IS MODERN TECH, THE IC ENGINE IS ANCIENT TECH

MYTH 4: THE BEV IS MODERN TECH, THE IC ENGINE IS ANCIENT TECH



60 MOTOR AGE

THE 100-MILE
Fritchle Electric
IS GUARANTEED

to travel 100 miles to the single charge — over city streets or country roads.

We are now ready to close 1909 Agencies. Write for our proposition.

STORAGE SUPPLIES

CENTRAL GARAGE
1310-12 NEW YORK AVE.

GASOLINE AND ELECTRIC CARS
STORED AND REPAIRED

PHONE, MAIN [redacted] 9444

WASHINGTON, D. C. December 10, 1908.

TO WHOM IT MAY CONCERN:

This is to certify that we charged Mr. Fritchle's Electric Automobile and assisted in running down the car.

When the car left the garage, the odometer registered 2158 miles and when it returned the next day, it registered 2259 miles, showing that 101 miles had been run on one charge

We are positive that the car was not recharged anywhere in the meantime.

Roll C Gingell Electric Co.

The above letter is respectfully submitted as absolute proof of our "100 mile per charge" claim—in this particular instance, however, the mileage having been made by a Fritchle Electric immediately after the completion of an overland tour from Lincoln, Neb., to New York City, thence to Washington, D. C. through hundreds of miles of mud and over the Allegheny mountains.

VICTORIA PHAETON
$2000
Complete line includes all styles

Art Catalogue showing entire line of open and closed cars mailed on request

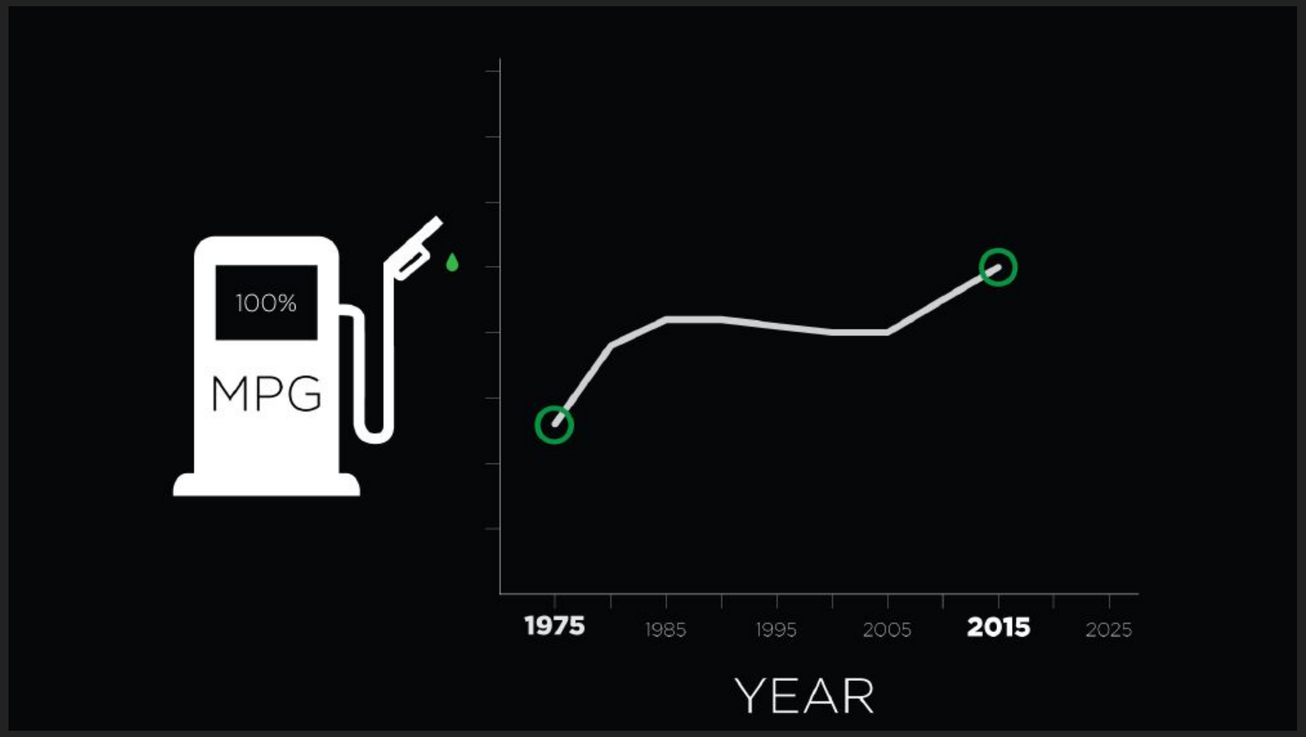
The Fritchle Automobile & Battery Co.
1449-1455 Clarkson St., Denver, Colorado

http://www.colfaxavenue.com/2012/12/fritchle-electric-car-company.html

- Electric vehicles were a significant factor in the early years of automobiles
- EV sales peaked in 1912 and declined to extinction in the 1920's
  - Continually improved IC engine vehicles
  - Limited availability of charging stations

MYTH 4: THE BEV IS MODERN TECH, THE IC ENGINE IS ANCIENT TECH

- IC Engines are 100 year-old technology!
- A combination of government mandates and innovation has led to significantly better technology
- Too many innovations to list here



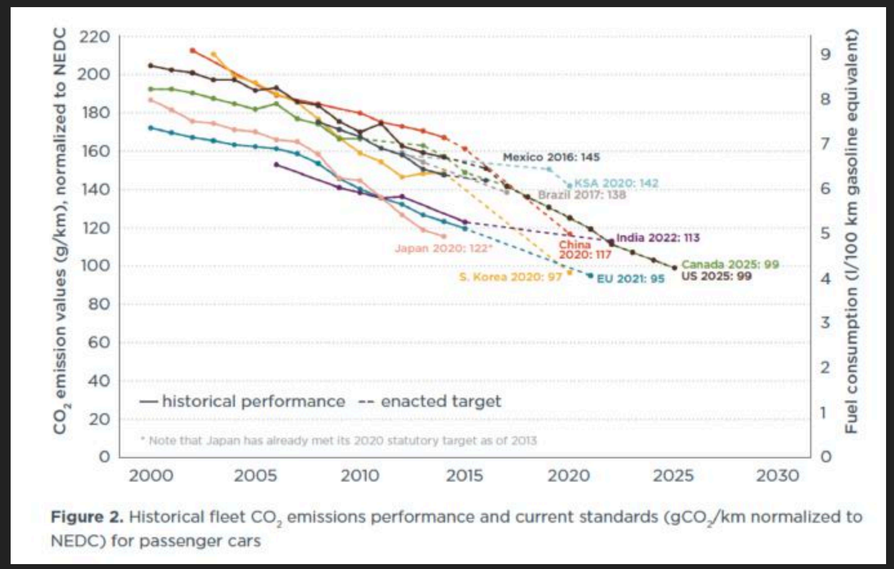
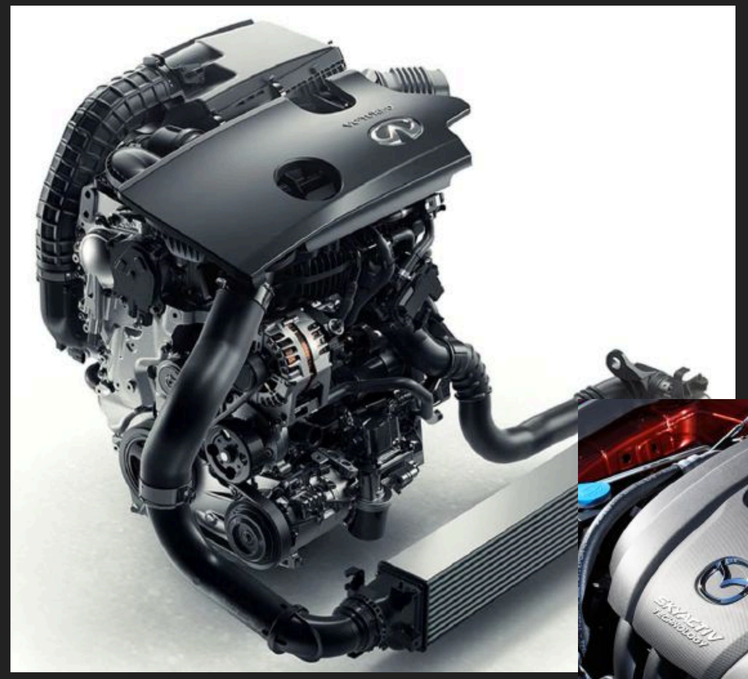


Figure 2. Historical fleet CO_2 emissions performance and current standards (gCO_2/km normalized to NEDC) for passenger cars

https://www.theicct.org/publications/2017-global-update-LDV-GHG-FE-standards

MYTH 4: THE BEV IS MODERN TECH, THE IC ENGINE IS ANCIENT TECH

- Nissan/Infiniti variable compression turbo engine
  - 25-30% efficiency improvement
  - Varies compression ratio depending on driving conditions between 8 (high performance) and 14 (high efficiency)
  - “torque and efficiency of an advanced diesel powertrain without the diesel’s emissions”
- Mazda SKYACTIV-X
  - 20-30% efficiency improvement
  - Extends range of HCCI using a spark
  - SPCCI - Spark Plug Controlled Compression Ignition
  - Combines benefits of both gasoline and diesel

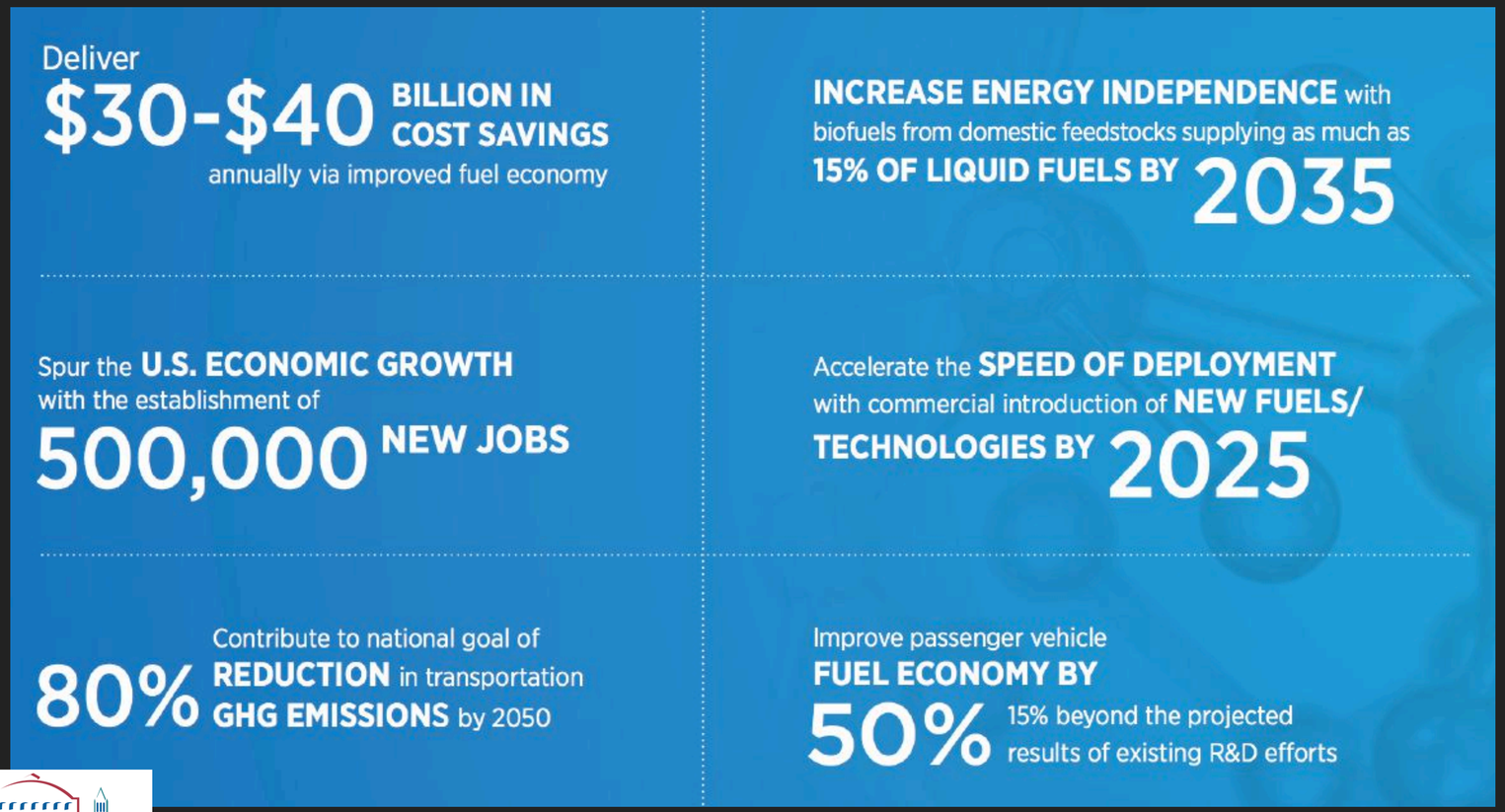


http://www.motortrend.com/news/infiniti-prepares-worlds-first-variable-compression-engine-for-2018/

Photo courtesy of Mazda

MYTH 4: THE BEV IS MODERN TECH, THE IC ENGINE IS ANCIENT TECH

- Co-Optima Program
- Engines designed to run more efficiently on affordable, scalable and sustainable fuels
- Fuels designed to work in high-efficiency, low-emissions engines
- Marketplace strategies that can shape the success of new fuels and vehicle technologies with industry and consumers



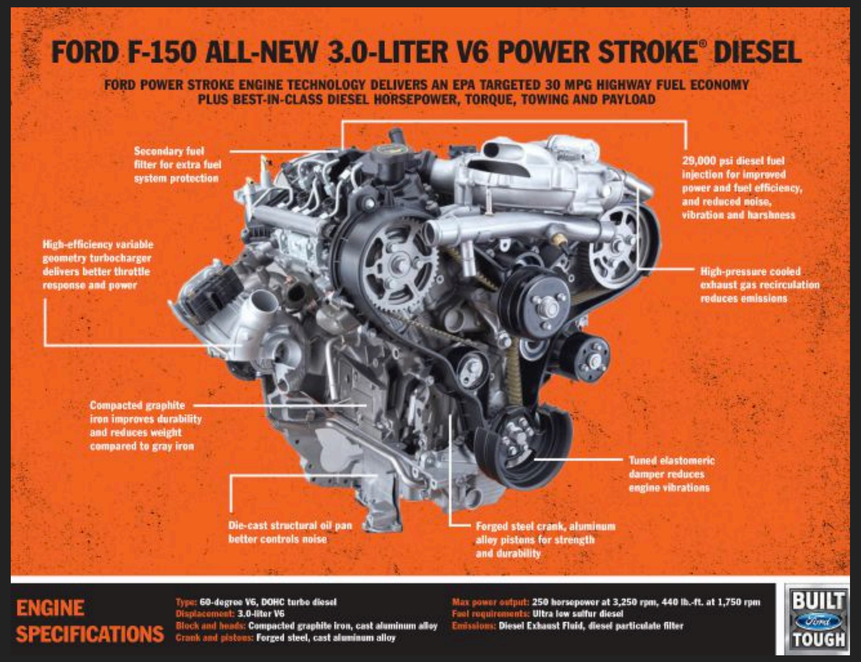
Co-Optimization of Fuels & Engines

NREL National Renewable Energy Laboratory · Argonne National Laboratory · INL Idaho National Laboratory · Berkeley Lab · Pacific Northwest National Laboratory · Los Alamos National Laboratory · Sandia National Laboratories · Oak Ridge National Laboratory · Lawrence Livermore National Laboratory

https://energy.gov/eere/bioenergy/co-optimization-fuels-engines

MYTH 4: THE BEV IS MODERN TECH, THE IC ENGINE IS ANCIENT TECH

- 2018 Ford F-150 Diesel hits 30 MPG
- Some believe they are under-selling MPG until EPA certification (possibly 32 or 33 MPG)



https://blogs.forbes.com/samabuelsamid/files/2018/01/2018-F150-Engine-FactSheet.jpg

http://st.motortrend.com/uploads/sites/10/2016/11/2017-Ford-F-150-XLT-front-three-quarter.jpg

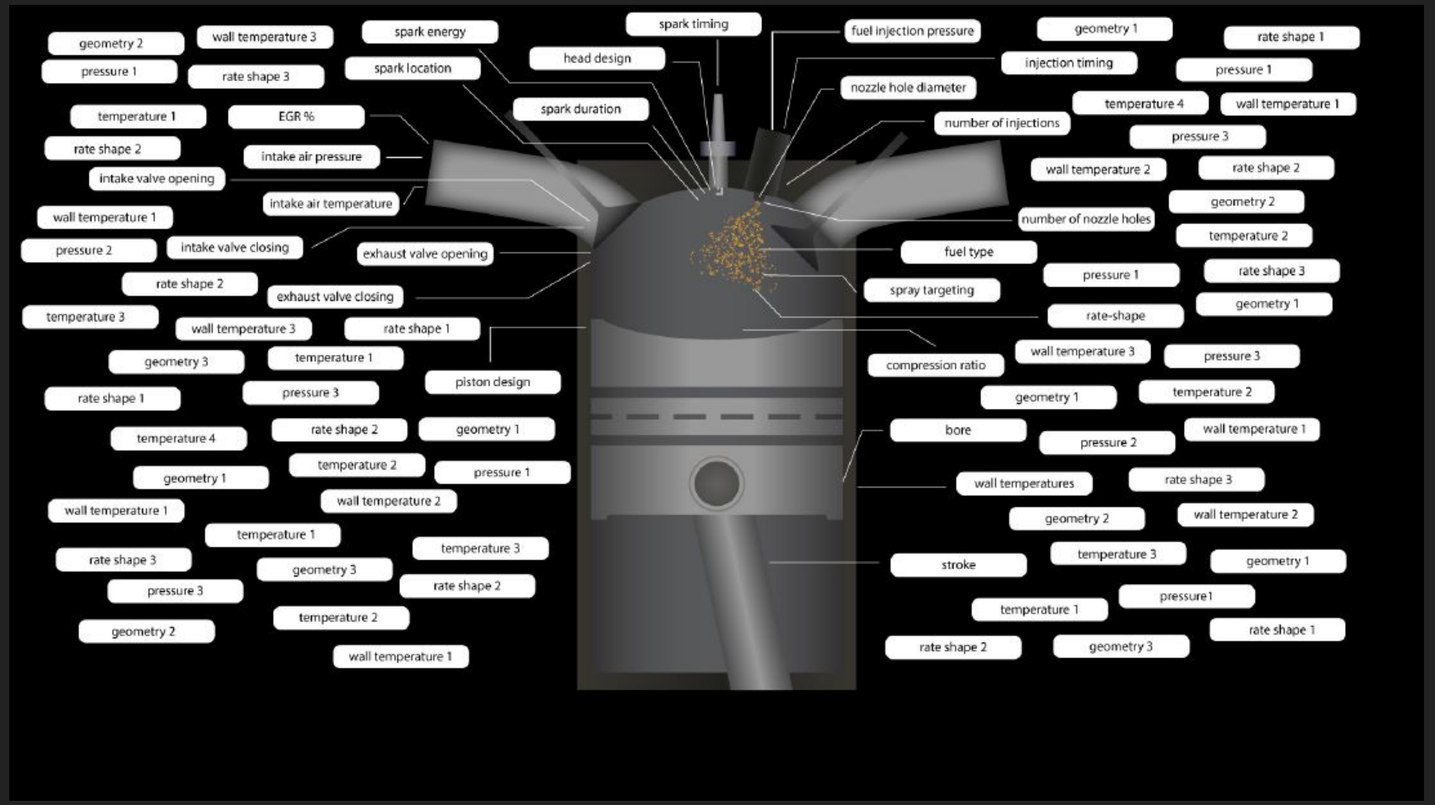
MYTH 4: THE BEV IS MODERN TECH, THE IC ENGINE IS ANCIENT TECH

- January 15, 2018 at the Detroit Auto Show
- Achates Power and Aramco Services are jointly testing a Ford F-150 equipped with an OPGCI engine (opposed piston gasoline compression ignition)
- Will demonstrate 37 mpg, 270 hp, and a 50% emissions reduction

https://www.trucks.com/2018/01/15/detroit-auto-show-achates-aramco-pickup-engine/

MYTH 4: THE BEV IS MODERN TECH, THE IC ENGINE IS ANCIENT TECH

- Very complex system
- This is an opportunity. There's no way we have the optimum yet!



MYTH 5: ADVANCED ALIEN LIFEFORMS WOULDN'T USE INTERNAL COMBUSTION

MYTH 5: ADVANCED ALIEN LIFEFORMS WOULDN'T USE INTERNAL COMBUSTION

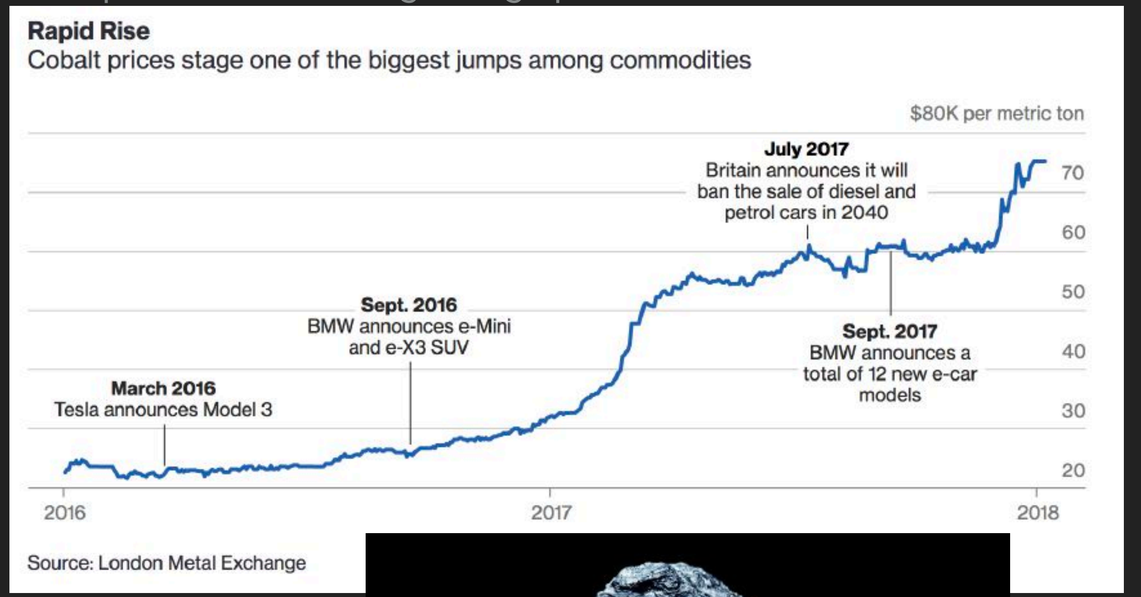
NO SILVER BULLET, PROS AND CONS TO ALL TECHNOLOGIES

- Batteries
  - Fuel flexibility (we can make electricity many ways)
  - Remove pollution from where people live
  - Simplicity of engine?

NO SILVER BULLET, PROS AND CONS TO ALL TECHNOLOGIES

- Batteries
  - How is the electricity generated?
  - Range anxiety
  - Charge time
  - Recharging stations, infrastructure
  - Battery decommissioning and recycling
  - A. D. Little 2016 Report: BEVs generate a much more widely dispersed and damaging set of environmental impacts than ICEVs
  - Cobalt* - primary ingredient in lithium ion battery cathodes, by-product of copper and nickel mining
    - Is there enough Cobalt to support an EV fleet?
    - Cobalt is being produced in heavily polluting mines by child slaves in the Democratic Republic of Congo

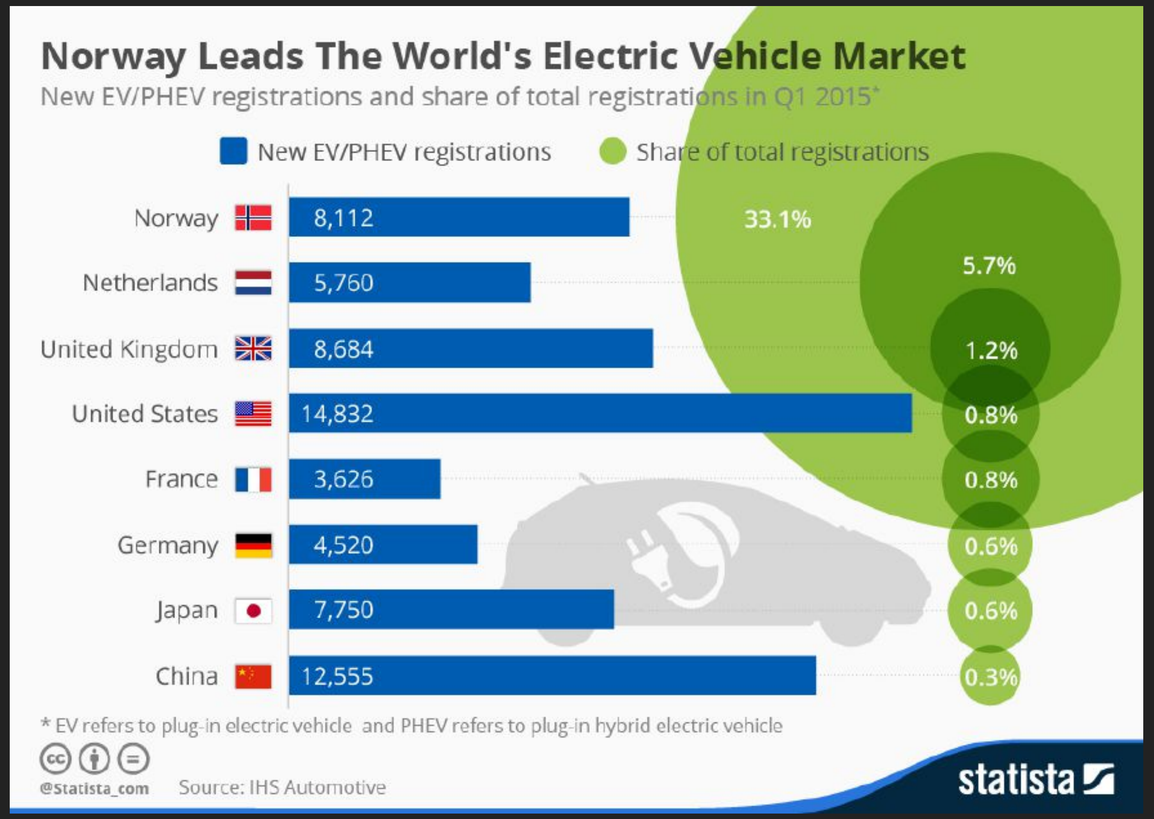
https://www.bloomberg.com/graphics/2018-cobalt-batteries/



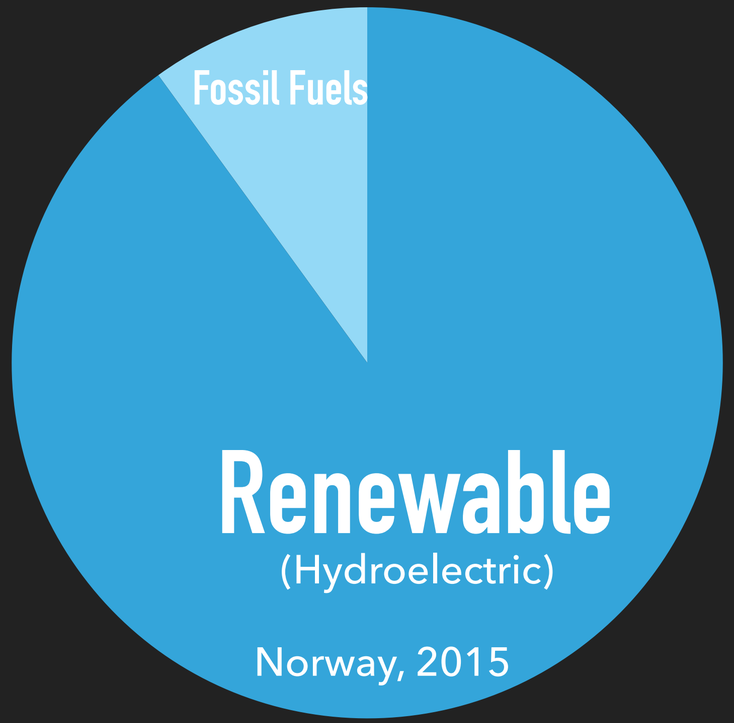
*https://www.freightwaves.com/news/2018/1/3/the-trouble-with-cobalt

NO SILVER BULLET, PROS AND CONS TO ALL TECHNOLOGIES

- Norway



https://www.statista.com/chart/3677/norway-leads-the-worlds-electric-vehicle-market/



90/10

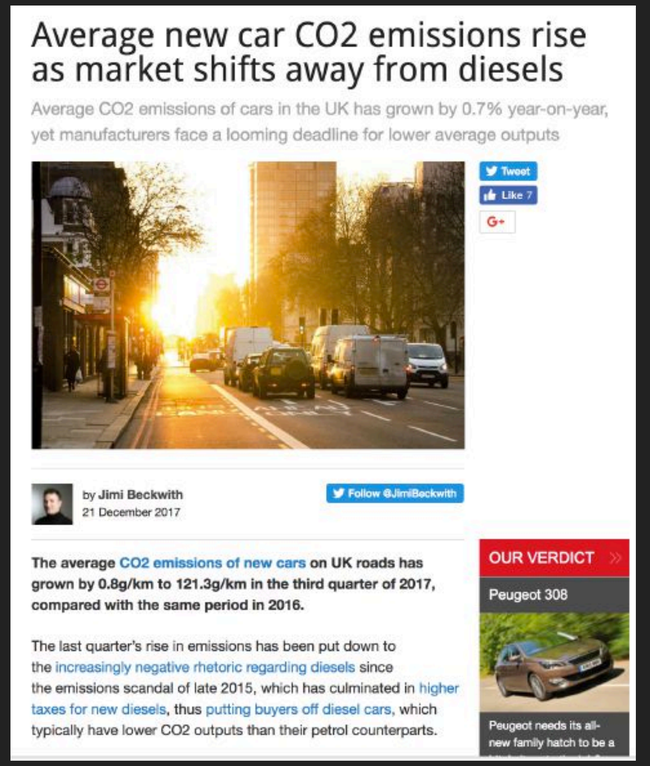
NO SILVER BULLET, PROS AND CONS TO ALL TECHNOLOGIES

- Recent study confirms that a significant amount of greenhouse gases come from man-made reservoirs, held behind dams for electricity generation
- Predominantly methane
- Flooding large areas can lead to tiny microorganisms breaking down organic matter (trees, grass) in the water in the absence of oxygen, leading to methane as a byproduct
- Should be included when evaluating GHGs from hydroelectric
- Accounts for about 1.3% of all manmade GHGs

Switzerland's Grimsel reservoir dam, which provides hydroelectric power; a new study suggests reservoirs contribute more than had been known to greenhouse gases. (EPA/Peter Klaunzer)

UNINTENDED CONSEQUENCES

- UK
- 16% fewer diesel cars sold in 2017 vs 2016
  - Tax rises
  - Stiffer parking charges
  - Threats of inner-city bans



Average new car CO2 emissions rise as market shifts away from diesels

Average CO2 emissions of cars in the UK has grown by 0.7% year-on-year, yet manufacturers face a looming deadline for lower average outputs

Tweet
Like 7
G+

by Jimi Beckwith
21 December 2017

Follow @JimiBeckwith

The average CO2 emissions of new cars on UK roads has grown by 0.8g/km to 121.3g/km in the third quarter of 2017, compared with the same period in 2016.

The last quarter's rise in emissions has been put down to the increasingly negative rhetoric regarding diesels since the emissions scandal of late 2015, which has culminated in higher taxes for new diesels, thus putting buyers off diesel cars, which typically have lower CO2 outputs than their petrol counterparts.

OUR VERDICT

Peugeot 308

Peugeot needs its all-new family hatch to be a

Average new car CO2 emissions increase for first time in 14 years

21 Dec, 2017 12:01am | Dominic Tobin

FACEBOOK TWITTER GOOGLE+ @

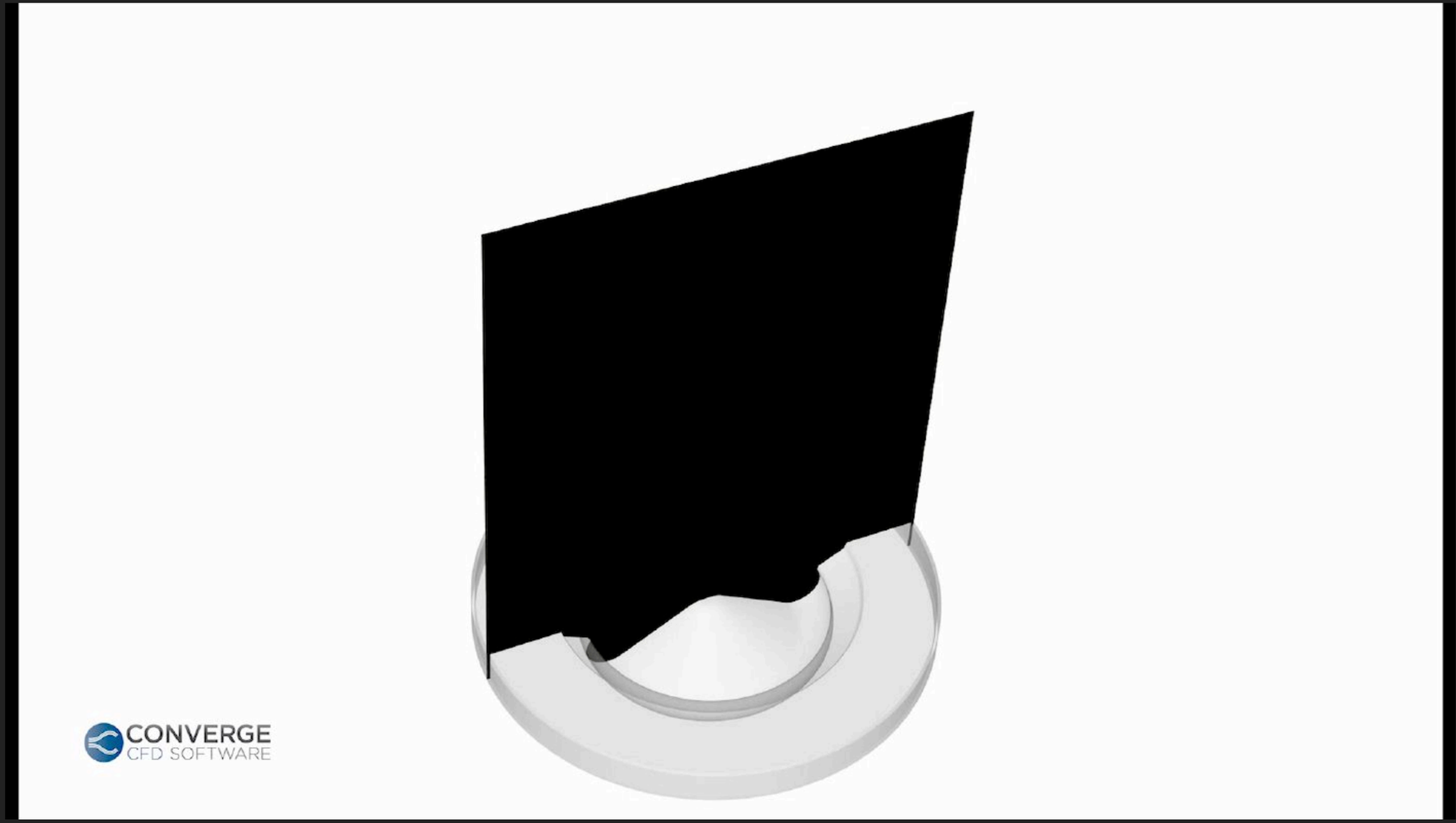
Shift away from diesel likely cause of rise in average new car CO2 emissions

New car carbon dioxide (CO2) emissions have risen for the first time in 14 years, an increase industry chiefs say is likely due to buyers turning their backs on diesel cars.

https://www.autocar.co.uk/car-news/new-cars/average-new-car-co2-emissions-rise-market-shifts-away-diesels
http://www.autoexpress.co.uk/car-news/102142/average-new-car-co2-emissions-increase-for-first-time-in-14-years

HOW DO WE FURTHER ADVANCE IC ENGINES?

MODELING!



THE CHALLENGE

"I think the general guideline for turn-around time of a round of accurate engine simulations is around 15 hours. 15 hours is from about 5 pm to 8 am the next day. With this pace, engineers can do data analysis and engineering during the day, and the computer do all the simulations during the night."

- Manager of CFD group from a major US OEM

FROM POST-DICTION TO PRE-DICTION

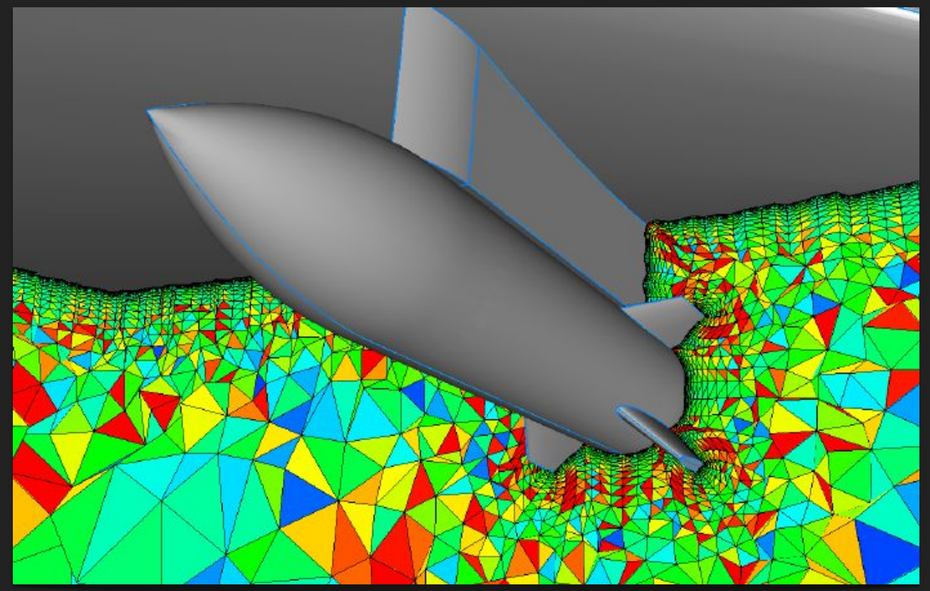
- Mesh generation
- Grid convergence
- Parallel processing
- Combustion and Turbulence modeling
- Nozzle flow and spray modeling

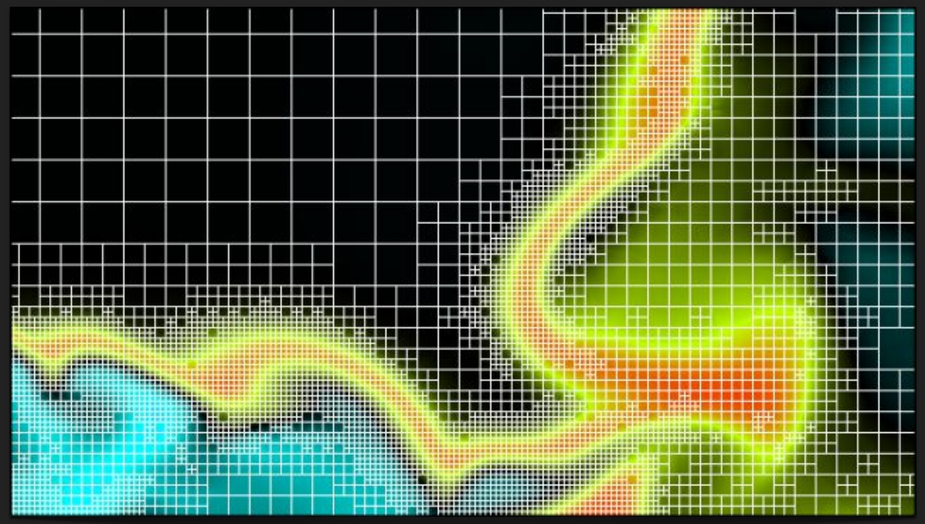
MESH GENERATION

- Traditional Approach

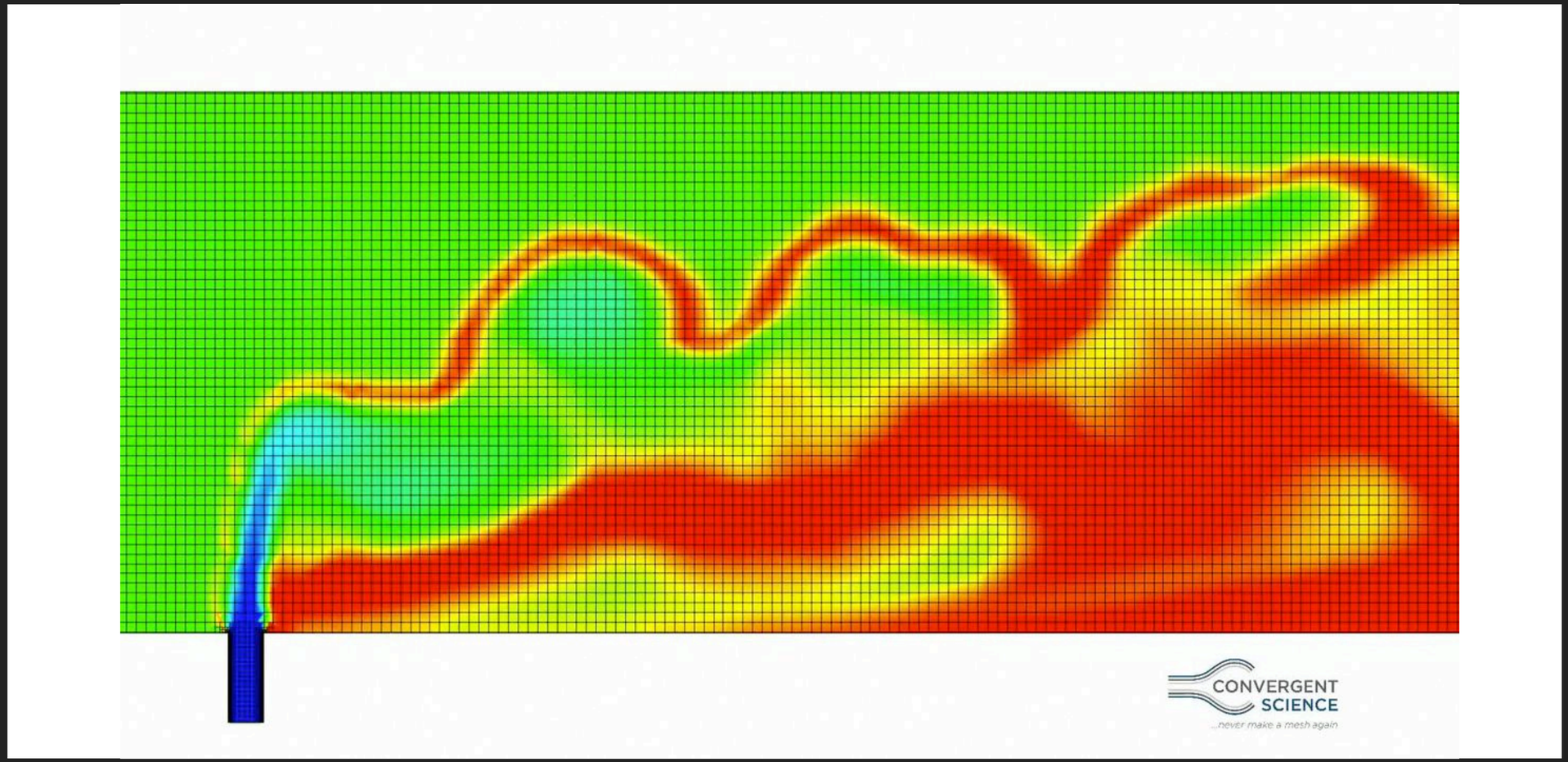
  - Long meshing times
  - Meshing by guessing
  - Skewed cells
  - Grid convergence?
- Current State of the Art

  - Automated meshing (no meshing time)
  - Adaptive Mesh Refinement (AMR) – no more guessing
  - Orthogonal cells
  - Easy to perform grid convergence studies

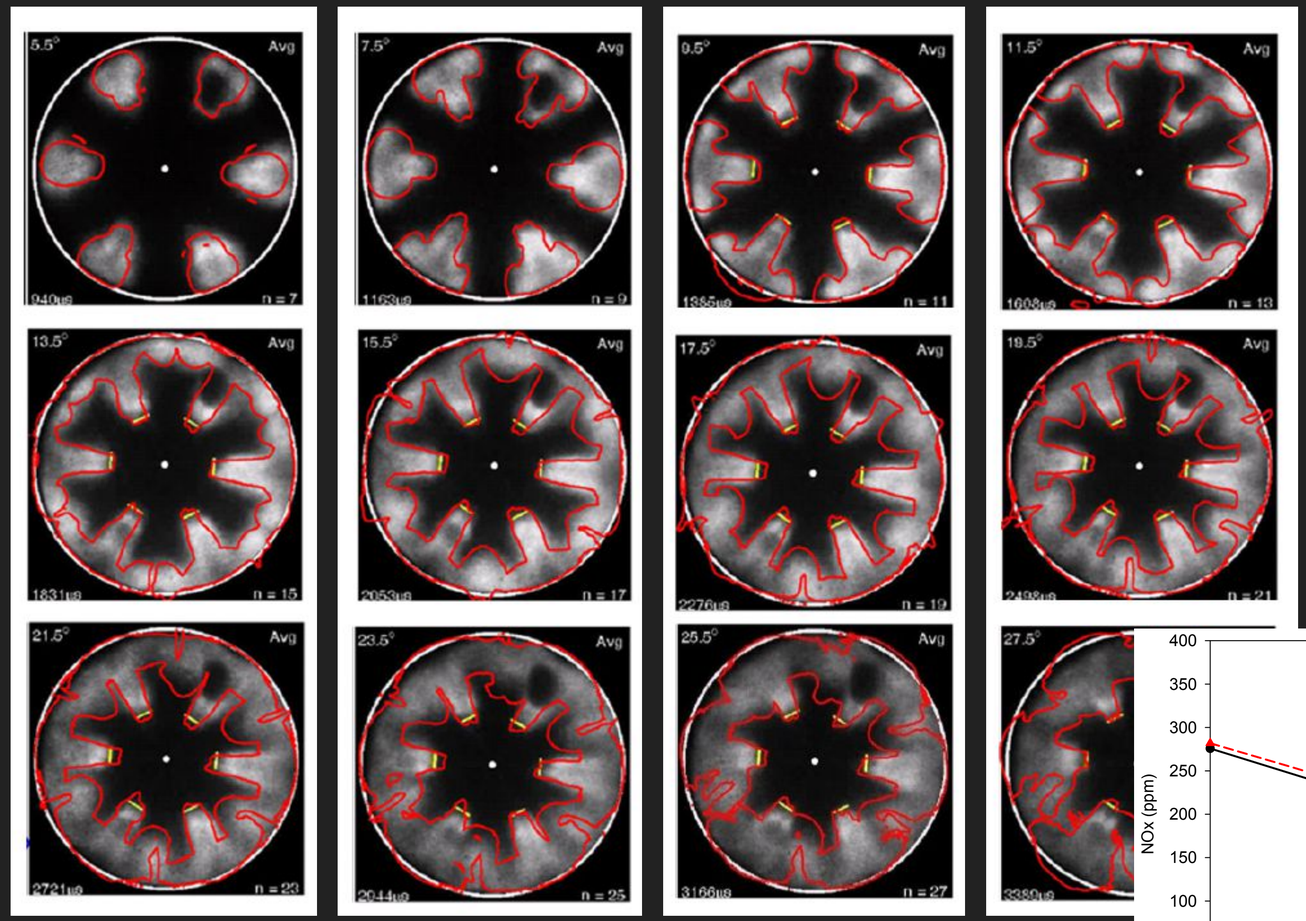


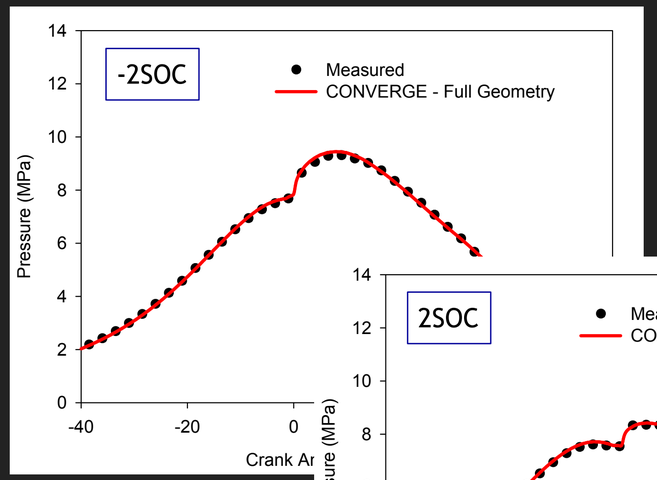


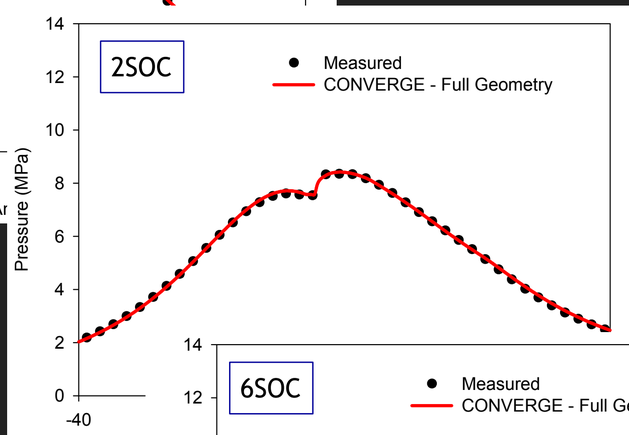
MESH GENERATION

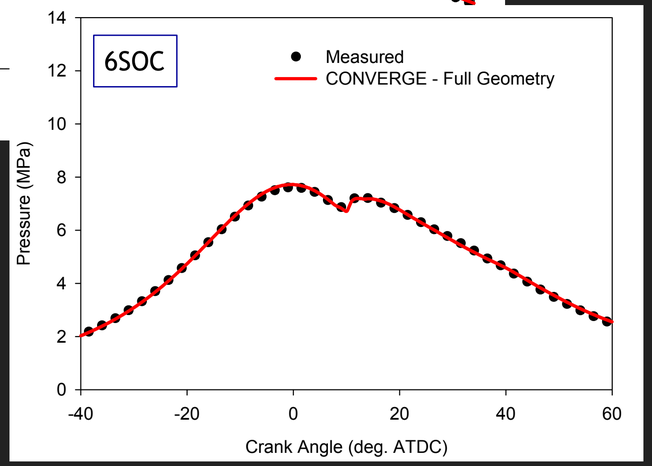


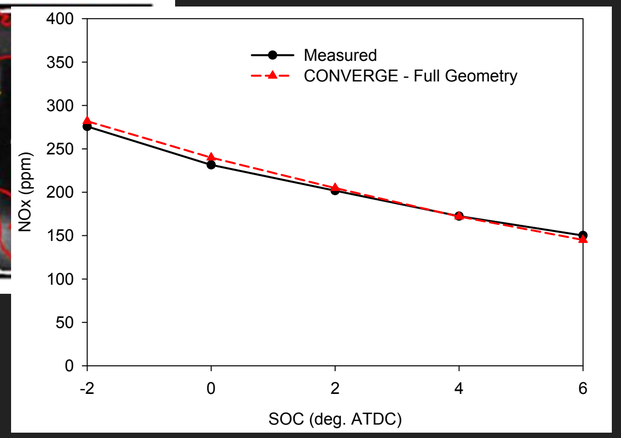
GRID CONVERGENCE











Argonne NATIONAL LABORATORY

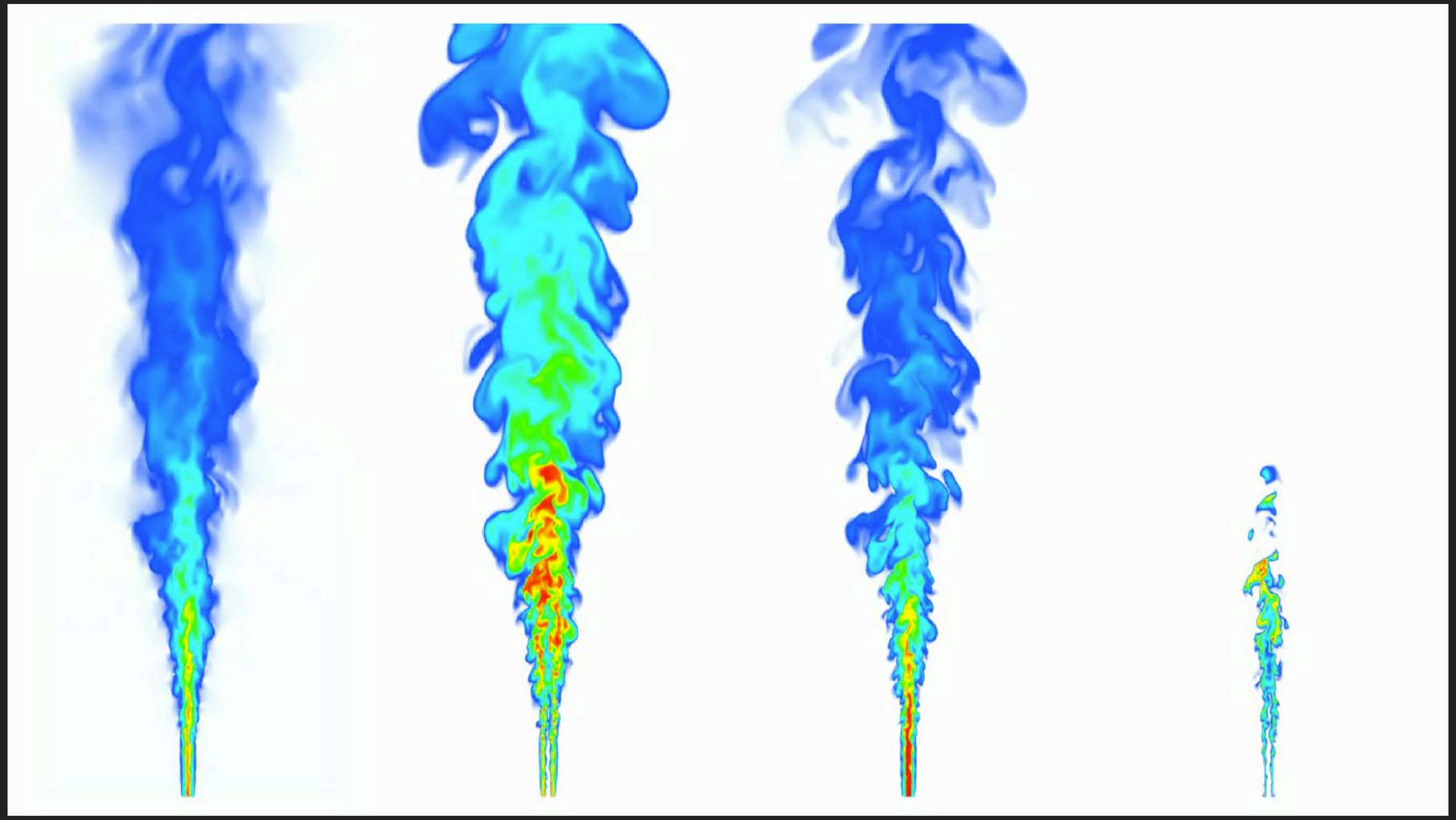
Sandia National Laboratories

CAT

COMBUSTION AND TURBULENCE MODELING

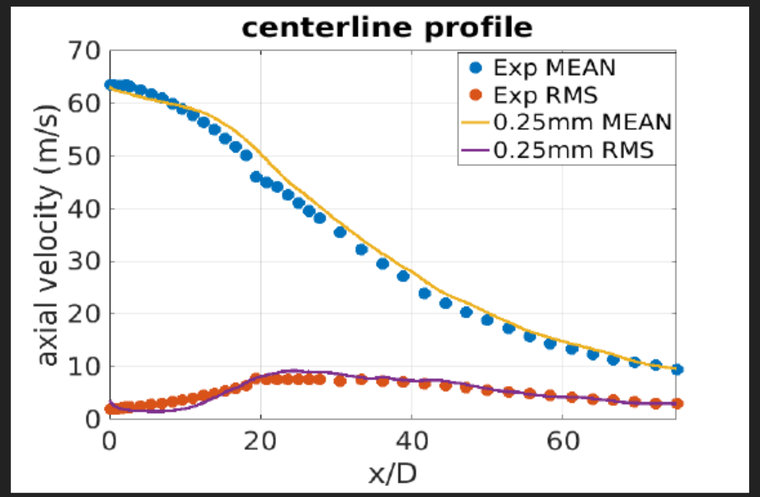
- Sandia Flame D
- Jet flame with burning pilot-stabilizer (avoiding flame extinction)
- Partially premixed methane-air mixture
- Fully developed turbulence (Re=22,400)

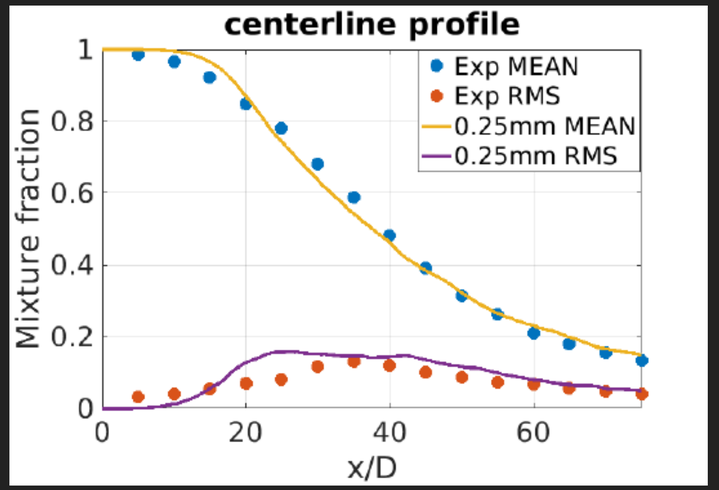
COMBUSTION AND TURBULENCE MODELING

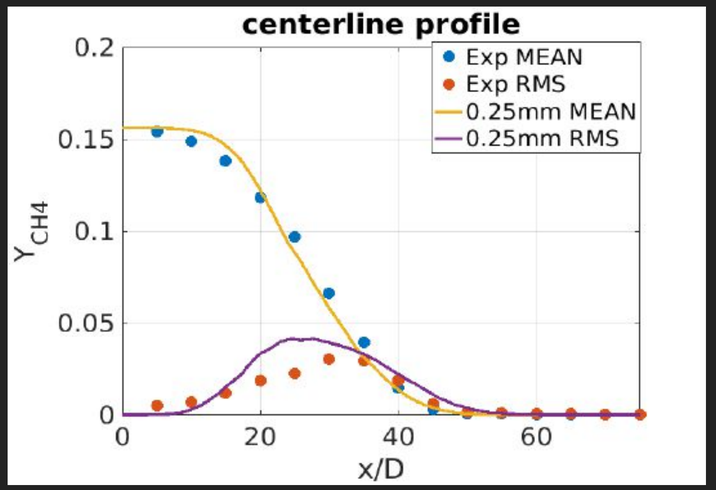


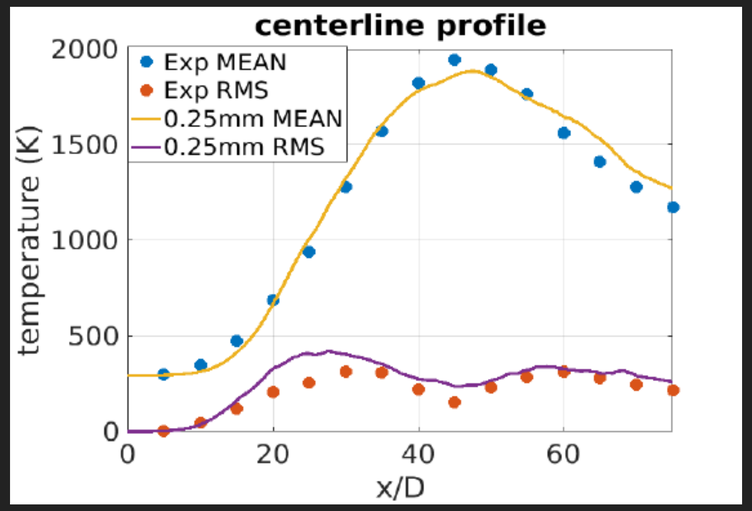
Velocity Temperature Fuel CO

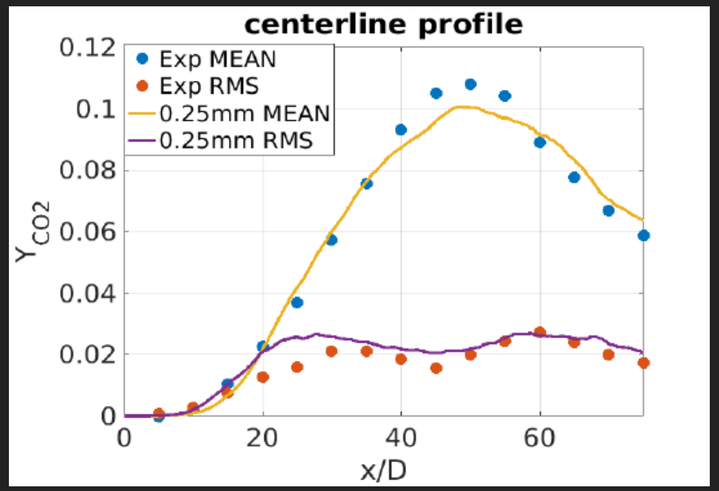
COMBUSTION AND TURBULENCE MODELING

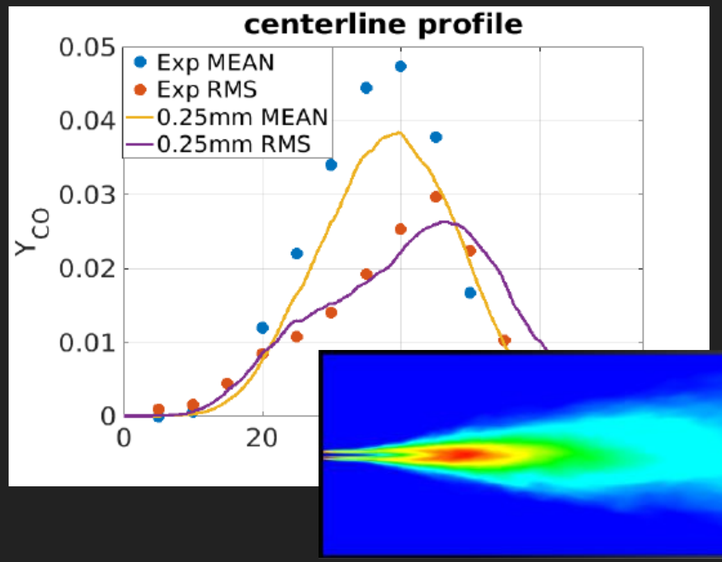




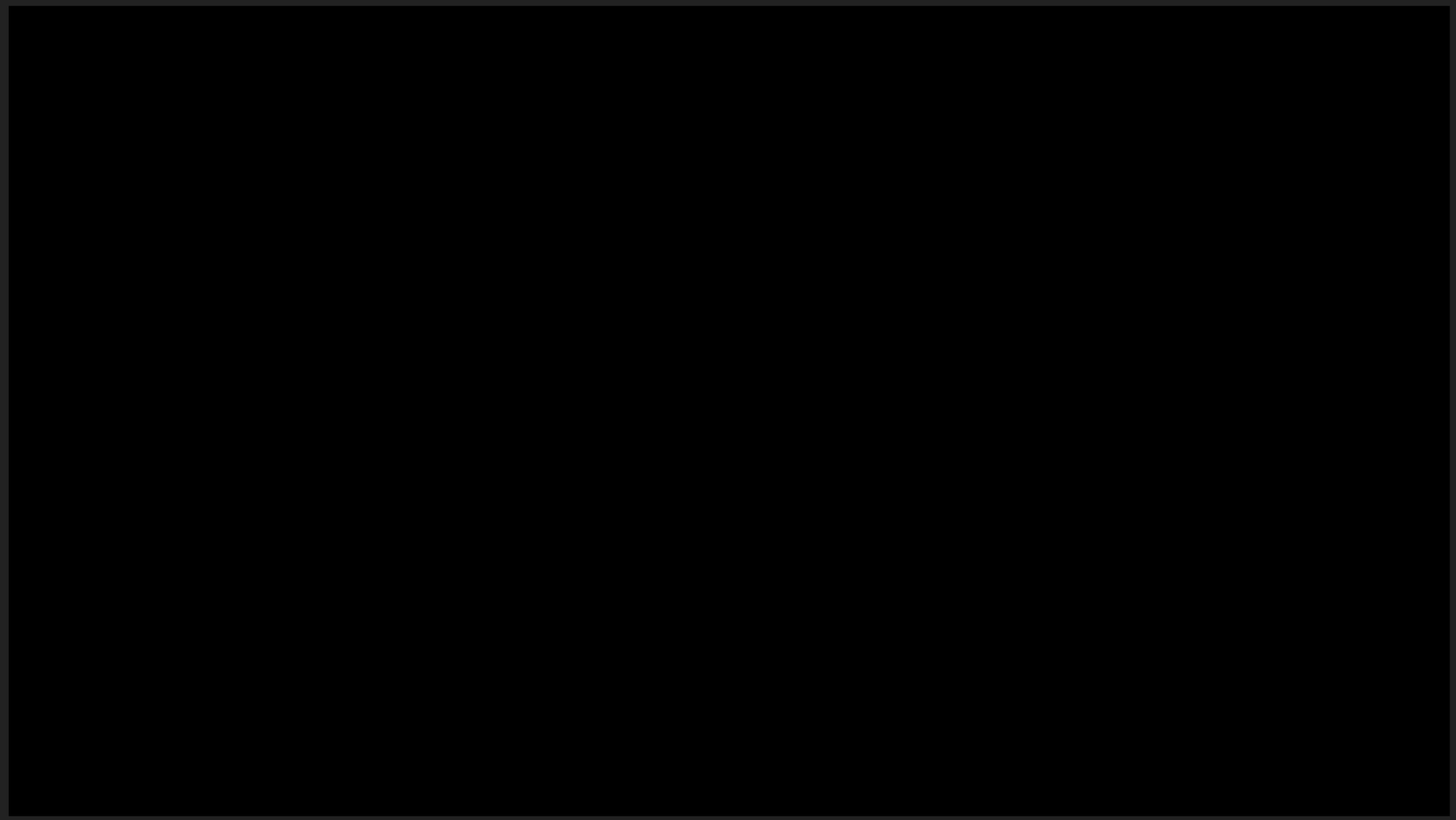








PUTTING IT ALL TOGETHER

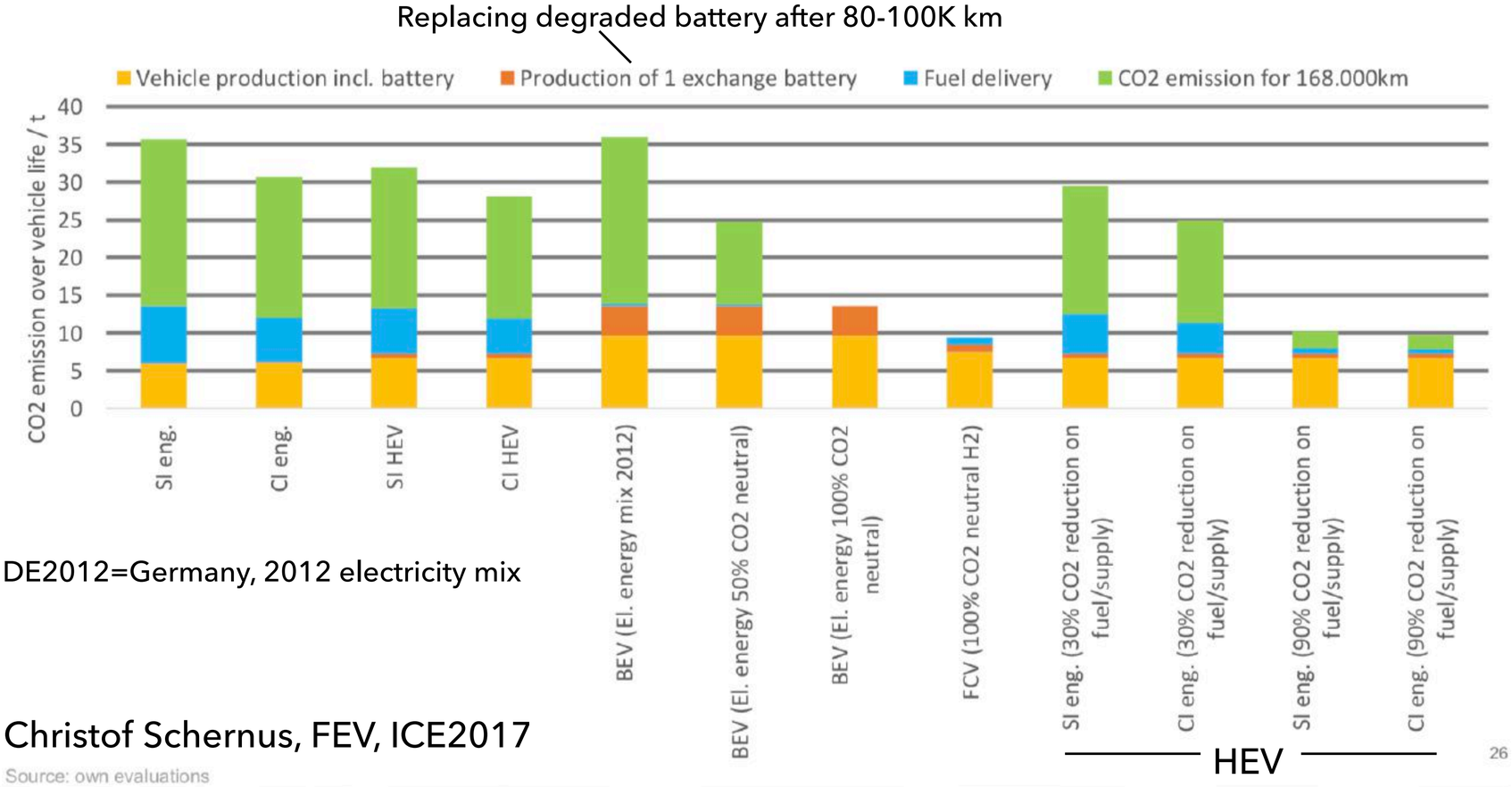


TAKEAWAYS

DEATHBED OR MIDLIFE CRISIS? THE PREMATURE BURIAL OF INTERNAL COMBUSTION

In DE2012 scenario, BEV W2W CO2 is on ICEV level. Decarbonisation of power brings BEV to excellent level, like decarbonized fuels for ICE-HEV

Estimation of lifetime CO2 emission of different driveline and fuel supply variants



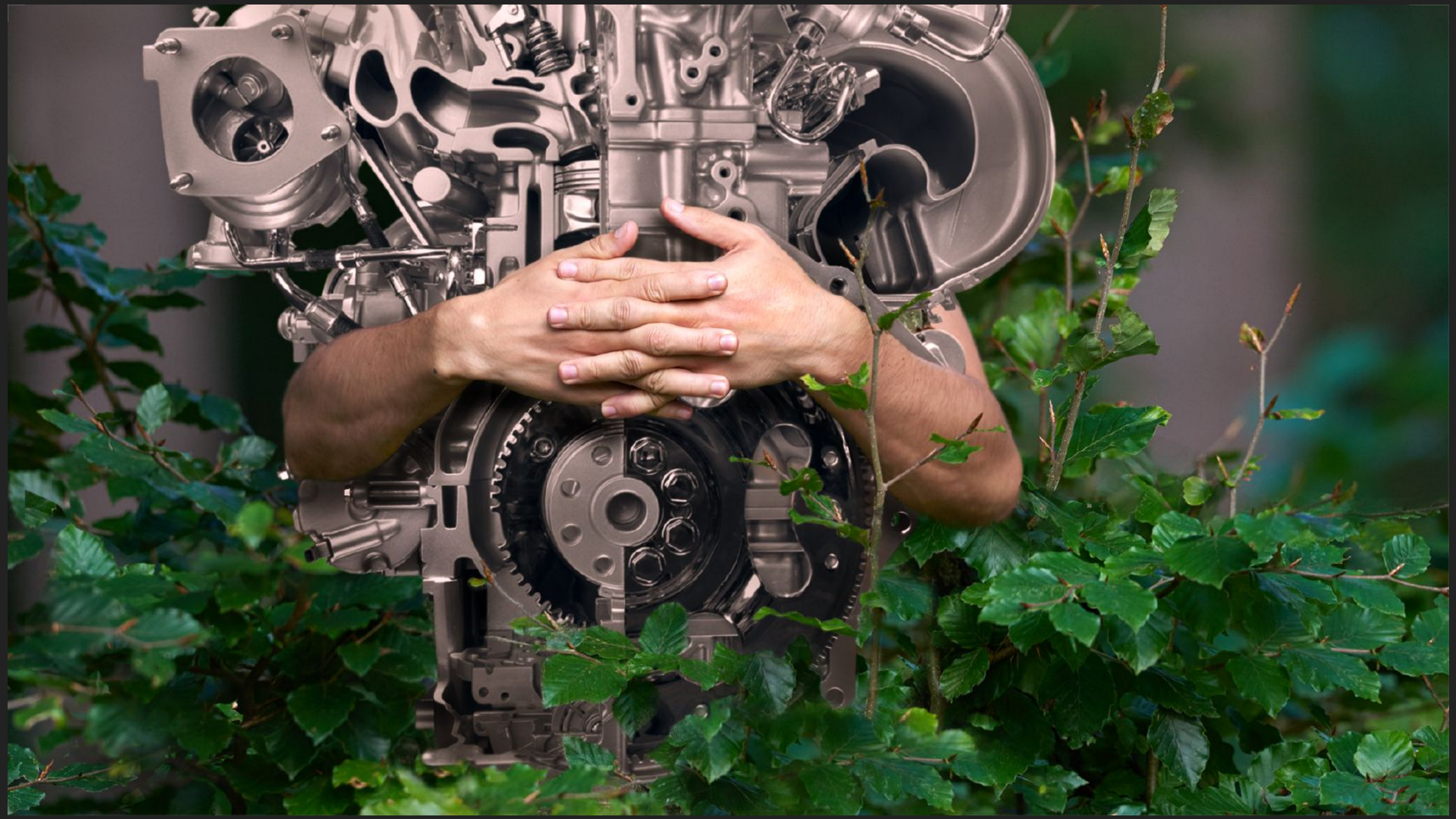
DE2012=Germany, 2012 electricity mix

Christof Schernus, FEV, ICE2017

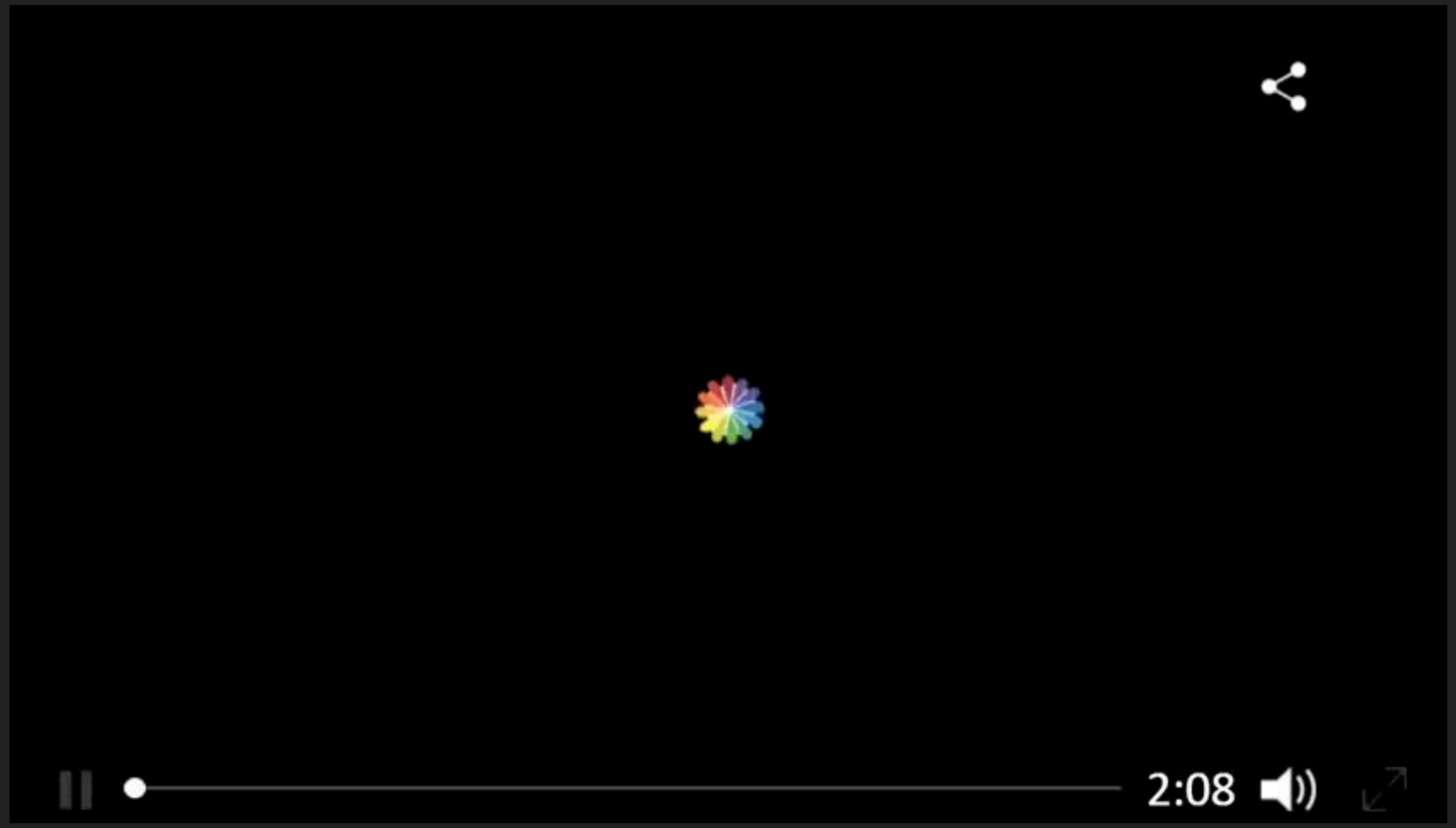
Source: own evaluations

- Assumes electricity production mix of Germany in 2012
- 60% fossil fuels, 24% renewable, 16% nuclear
- CO2 from original + replacement battery is about the same as delivering fuel to and driving a pure CI engine for 4.5 years (assuming 12K km per year)

DEATHBED OR MIDLIFE CRISIS? THE PREMATURE BURIAL OF INTERNAL COMBUSTION



BATTERY CHARGING SOLUTION?



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