How Does an EV Work?
Motor and Energy Storage

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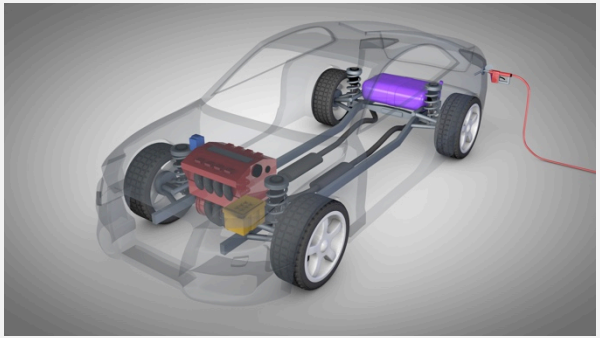
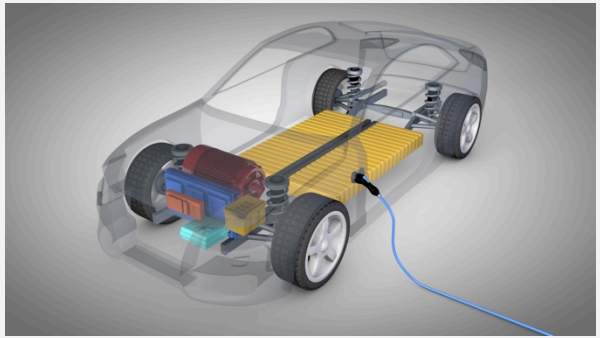
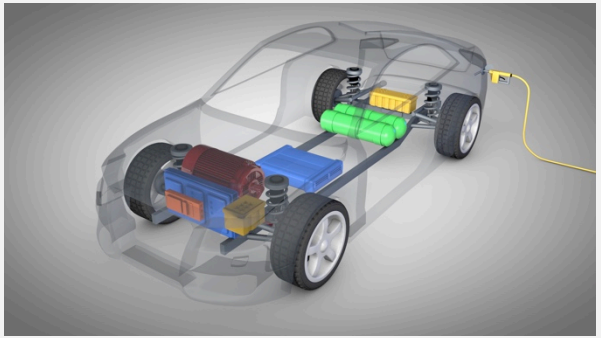

TU Delft

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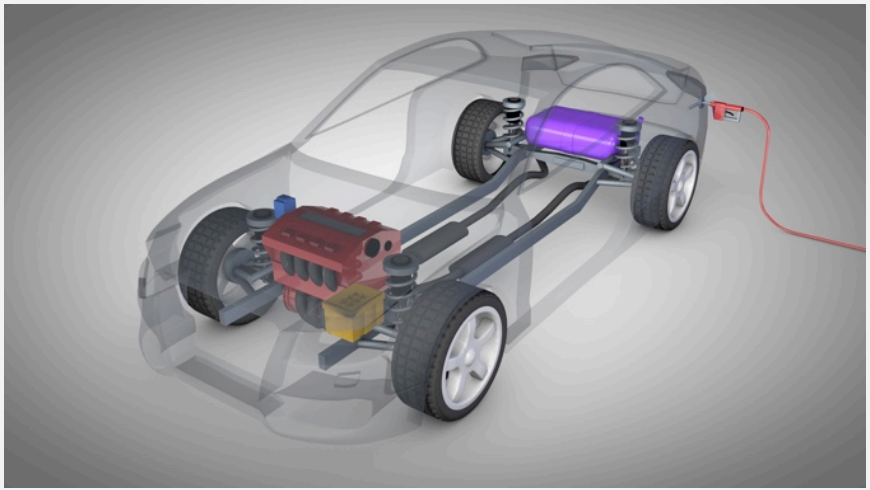
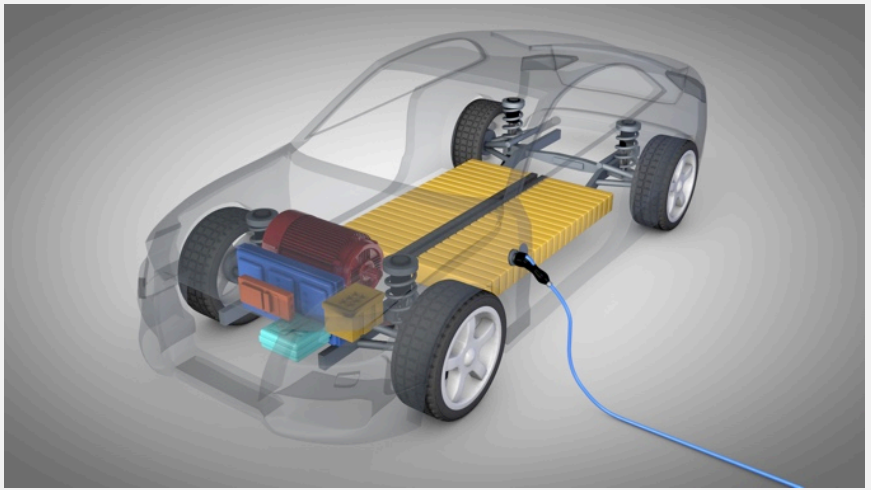
Two fundamental characteristics of every car

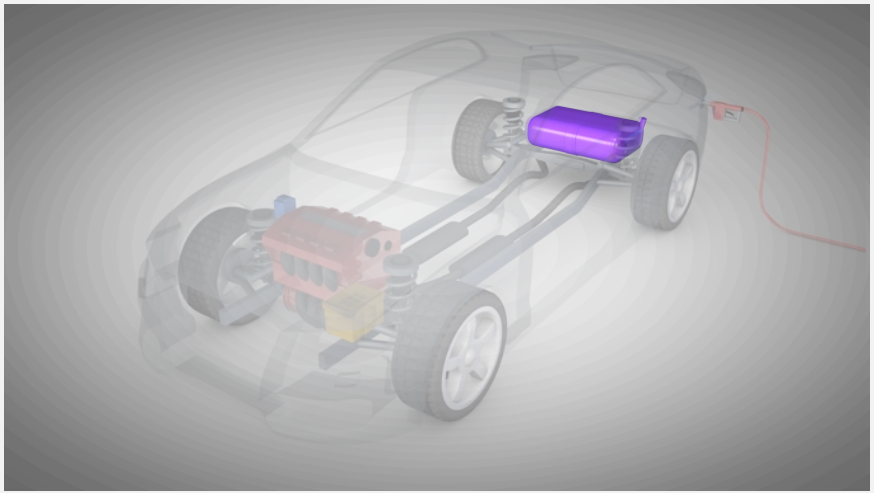


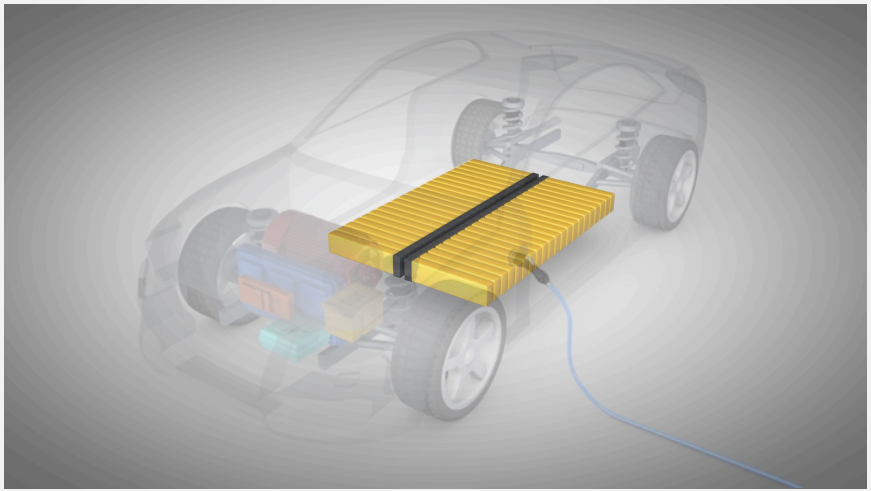


Energy storage

Motor

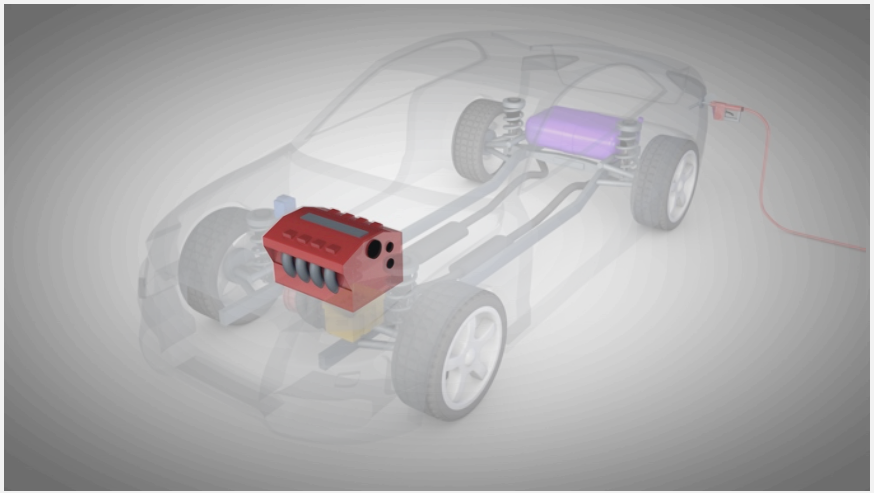
Two fundamental characteristics of every car

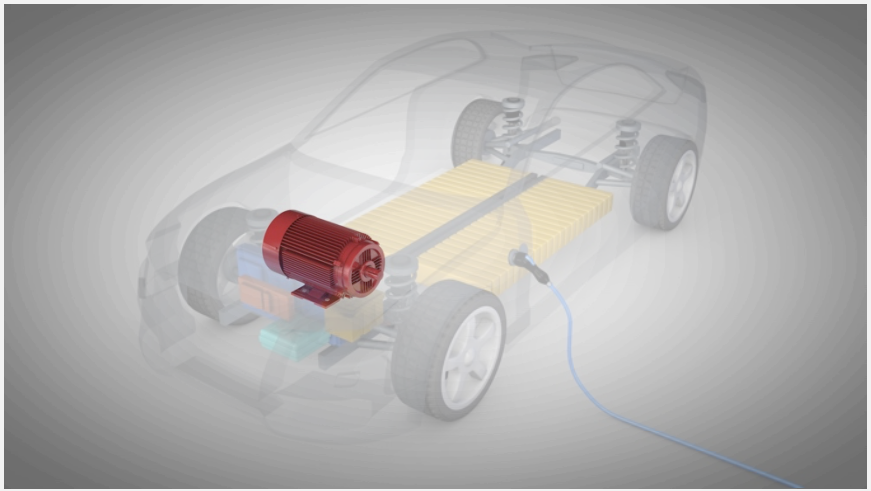




Energy storage

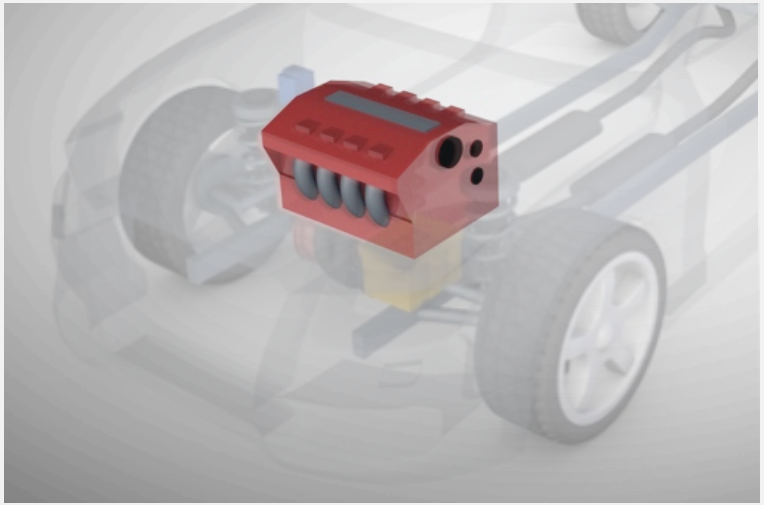
Two fundamental characteristics of every car



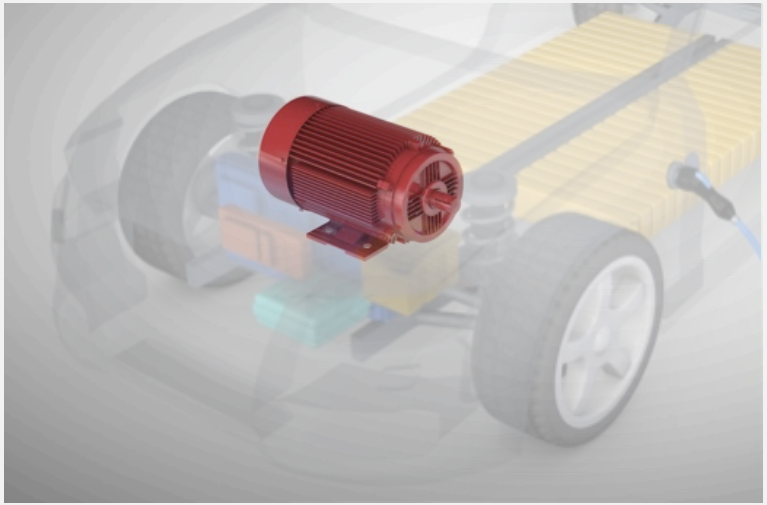


Motor

Fundamentally only two types of car motors



Heat engine



Electric motor

Heat engine: how it works

Here a four stroke engine:

1. Inject fuel
2. Compress fuel
3. Ignite fuel:
   - Free energy
   - Create motion
4. Emit exhaust

1

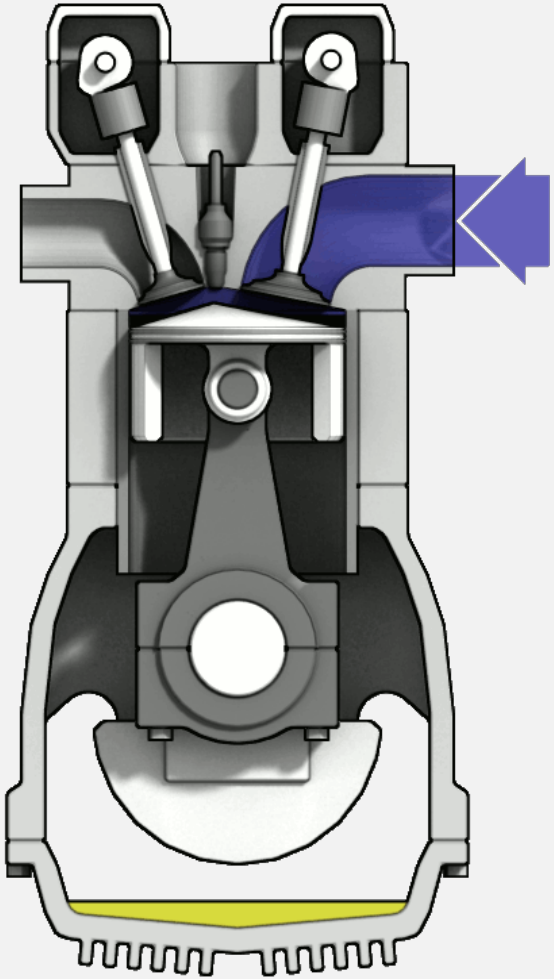
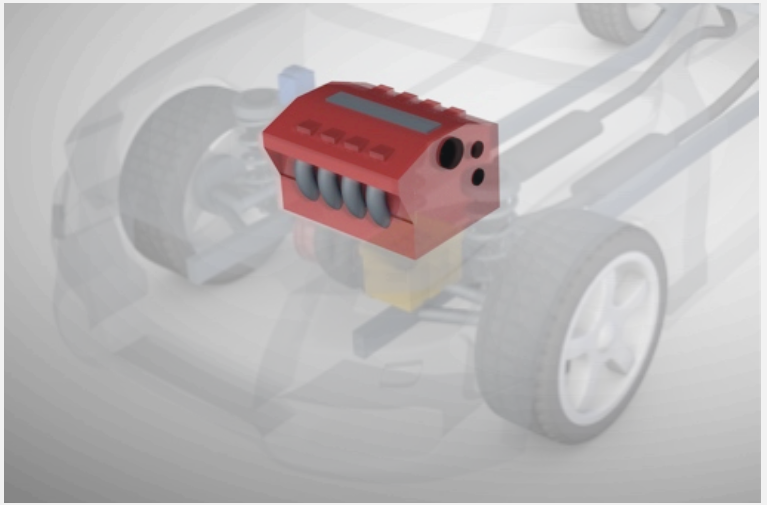


Image source: Own work – Zephyris, Wikipedia

Heat engine: drawbacks

- Complex, heavy, big & expensive
- Maintenance & wearing out
- 75% of energy is wasted
  (95% with a Bugatti Veyron)
- Doesn’t run on renewable energy from solar or wind
- Unhealthy exhaust
- Every liter of gasoline produces 2.3 kg of CO_2



Electric motor: how it works

- Magnetic field reject and attract based on polarity

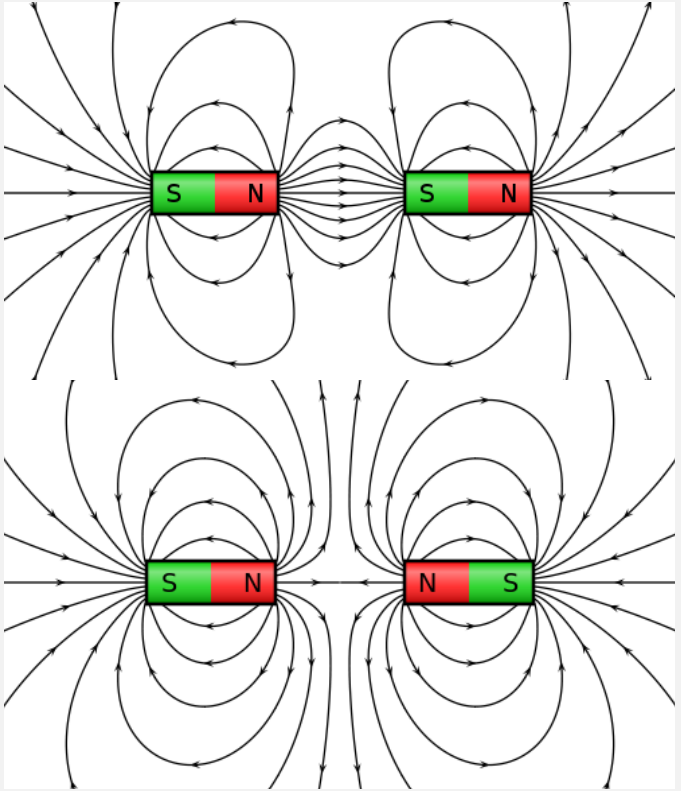


Image source: Own work - Geek3, Wikipedia

Electric motor: how it works

- Magnetic field reject and attract based on polarity
- Electricity flowing through a coil creates a magnetic field
- A coil between magnetic fields starts to rotate

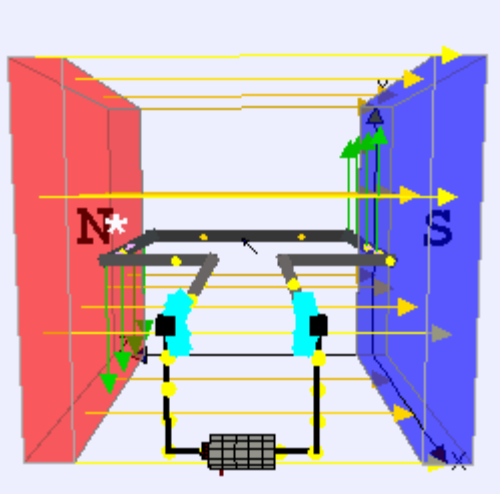
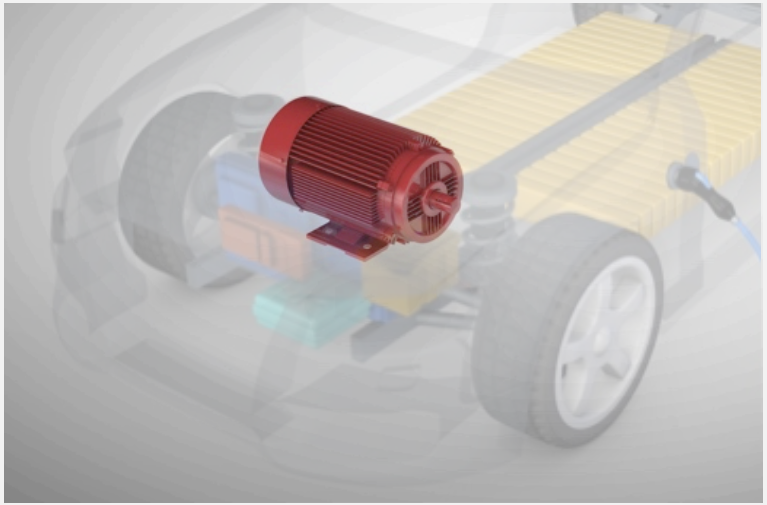


Image source: DC Motor, Lookang, Wikipedia

Electric motor: advantages

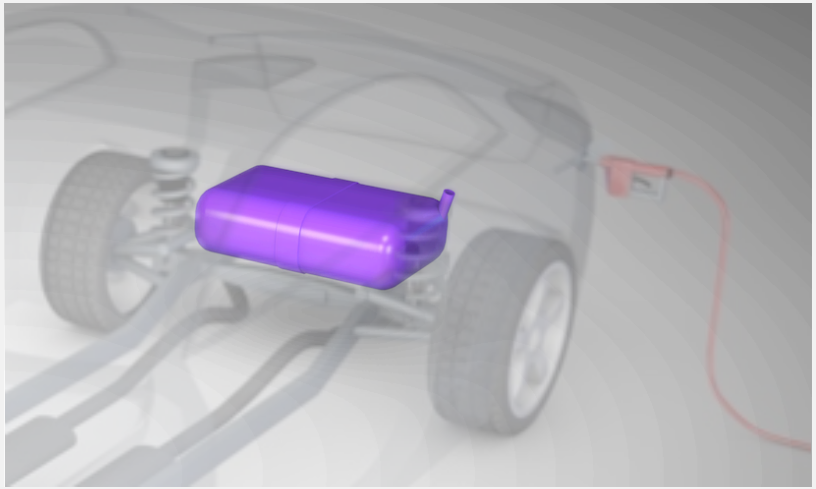
- Only one moving part (rotor)
- Light, compact, simple, no maintenance and inexpensive
- Lasts essentially forever
- Efficiency close to 100% & braking can charge battery:
  - 4x better than average car
  - 20x better than sportscar
- Much better acceleration
- Can run on renewable energy
- No exhaust gases



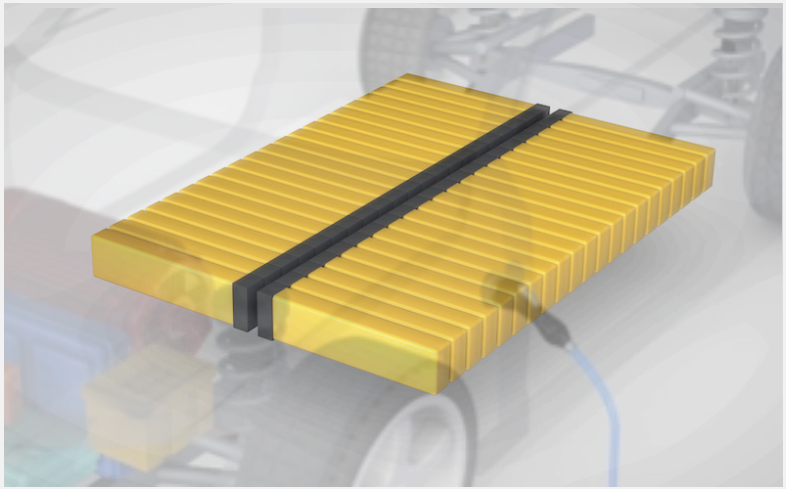
Heat engine vs electric motor

Internal combustion	Electric motor	Electric motor is...
1-3 kW/kg	3-10 kW/kg	3x more powerful
0.4 kW/L	13.6 kW/L	40x smaller
5-30 % efficient	93-96 % efficient	3-20x more efficient
Many moving parts	One moving part	Maintenance free

Fuel versus batteries



Fuel



Batteries

The extra weight of batteries

Energy source	Year	Energy (Whr/kg)	Compared to gasoline
Gasoline	1900-20??	12 000	-

Image source: appletips.nl

The extra weight of batteries

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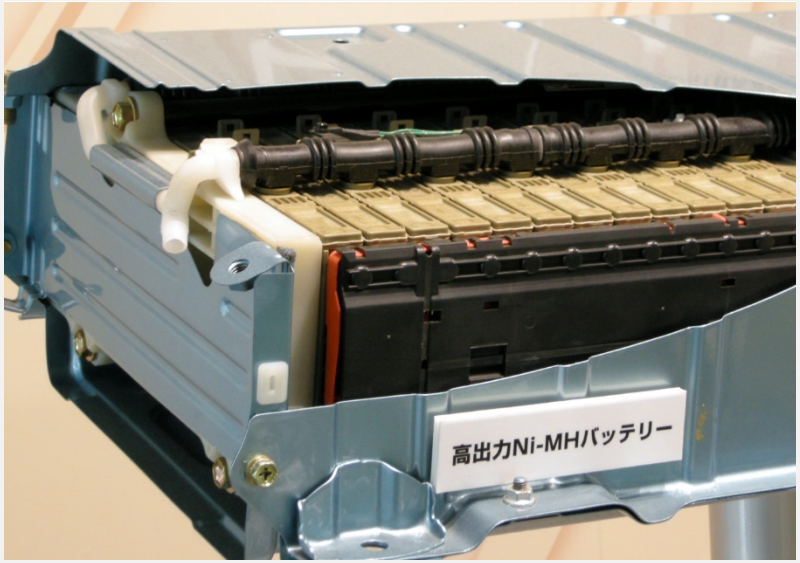
Lead-acid	2000	35	350 worse
NiMh	2000	80	150x worse



The extra weight of batteries

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Lead-acid	1900	10	1200x worse
Lead-acid	2000	35	350 worse
NiMh	2000	80	150x worse
Lithium	2015	250	50x worse

Image source: Nokia Li-ion battery – Kristoferb, Wikipedia

The extra weight of batteries

Energy source	Year	Energy (Whr/kg)	Compared to gasoline
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Lead-acid	1900	10	1200x worse
Lead-acid	2000	35	350 worse
NiMh	2000	80	150x worse
Lithium	2015	250	50x worse
Lithium	2025	400	30x worse

Image source: Cylindrical cell (18650) prior to assembly – RudolfSimon, Wikipedia

The extra weight of batteries

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NiMh	2000	80	150x worse
Lithium	2015	250	50x worse
Lithium	2025	400	30x worse
Lithium-air	????	12 000*	same

?

*This is the theoretical maximum energy content of lithium air batteries.

The extra weight of batteries, simplified

Energy source	Year	Extra kg for 500 km	Equals
Lead-acid	1900	10 000	Elephant

Image source: A female African bus[illegible]hant - Muhammad Mahdi Karim, Wikipedia

The extra weight of batteries, simplified

Energy source	Year	Extra kg for 500 km	Equals
Lead-acid	1900	10 000	Elephant
Lead-acid	2000	3 000	Rhinoceros

Image source: Diceros Bicornis – Jonathunder, Wikipedia

The extra weight of batteries, simplified

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Lead-acid	1900	10 000	Elephant
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Image source: Male silverback – Brocken Inaglory, Wikipedia

The extra weight of batteries, simplified

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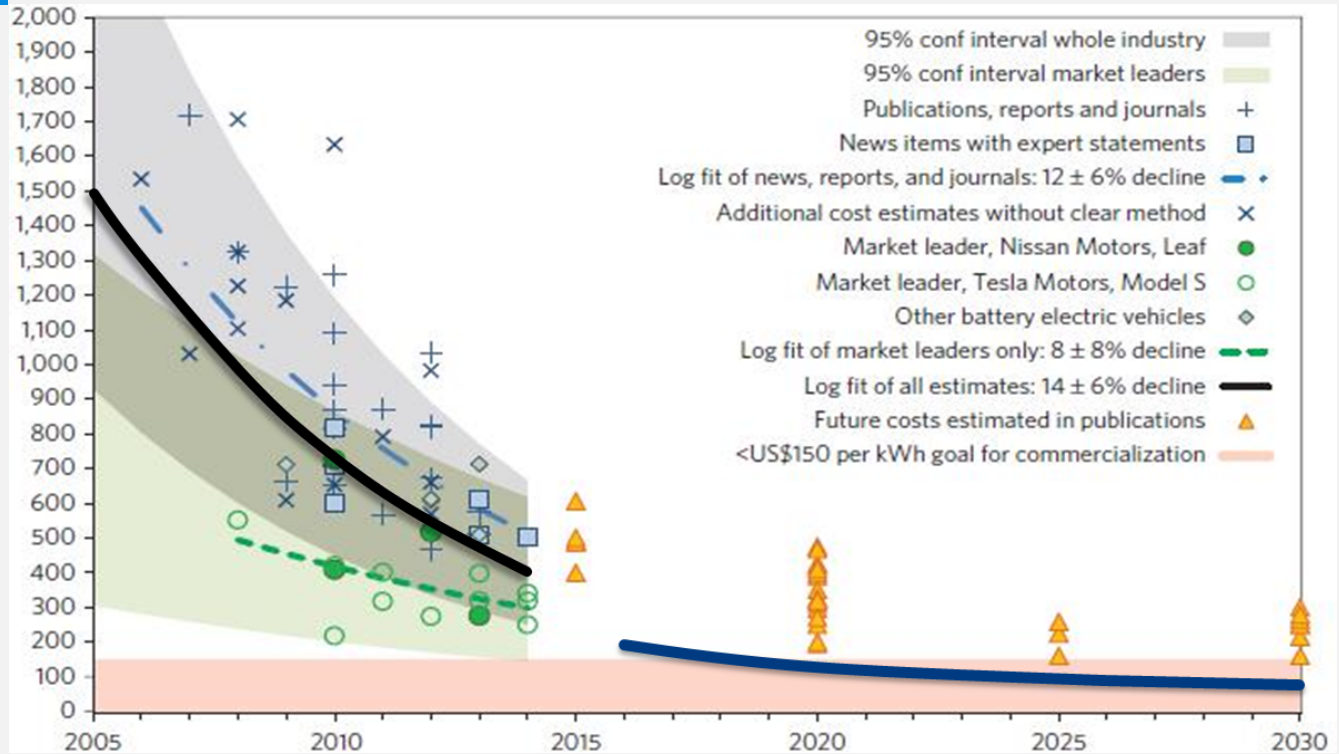
Lead-acid	2000	3 000	Rhinoceros
NiMh	2000	800	Bison
Lithium	2015	400	Gorilla
Lithium	2025	200	Pig*

*Taking the weight of the drivetrain into account, the electric car is ~200 kg lighter.

The rapidly falling cost of batteries



Source: “Rapidly falling costs of battery packs for electric vehicles” by Björn Nykvist and Mans Nilsson, Nature Climate Change, March 2015

Added blue line is original research.

Image source: appletips.nl

Conlusions

- Only two motors for cars and internal combustion is no match for electric
- Batteries were prohibitively heavy (elephant) but not anymore (pig) and EV now lighter
- Plummeting battery prices make EV the cheaper option

Thank you for your attention