EV & Transportation Applications of Permanent Magnet Materials

IEEE Magnetics Society

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Permanent Magnet Materials

OUTLINE

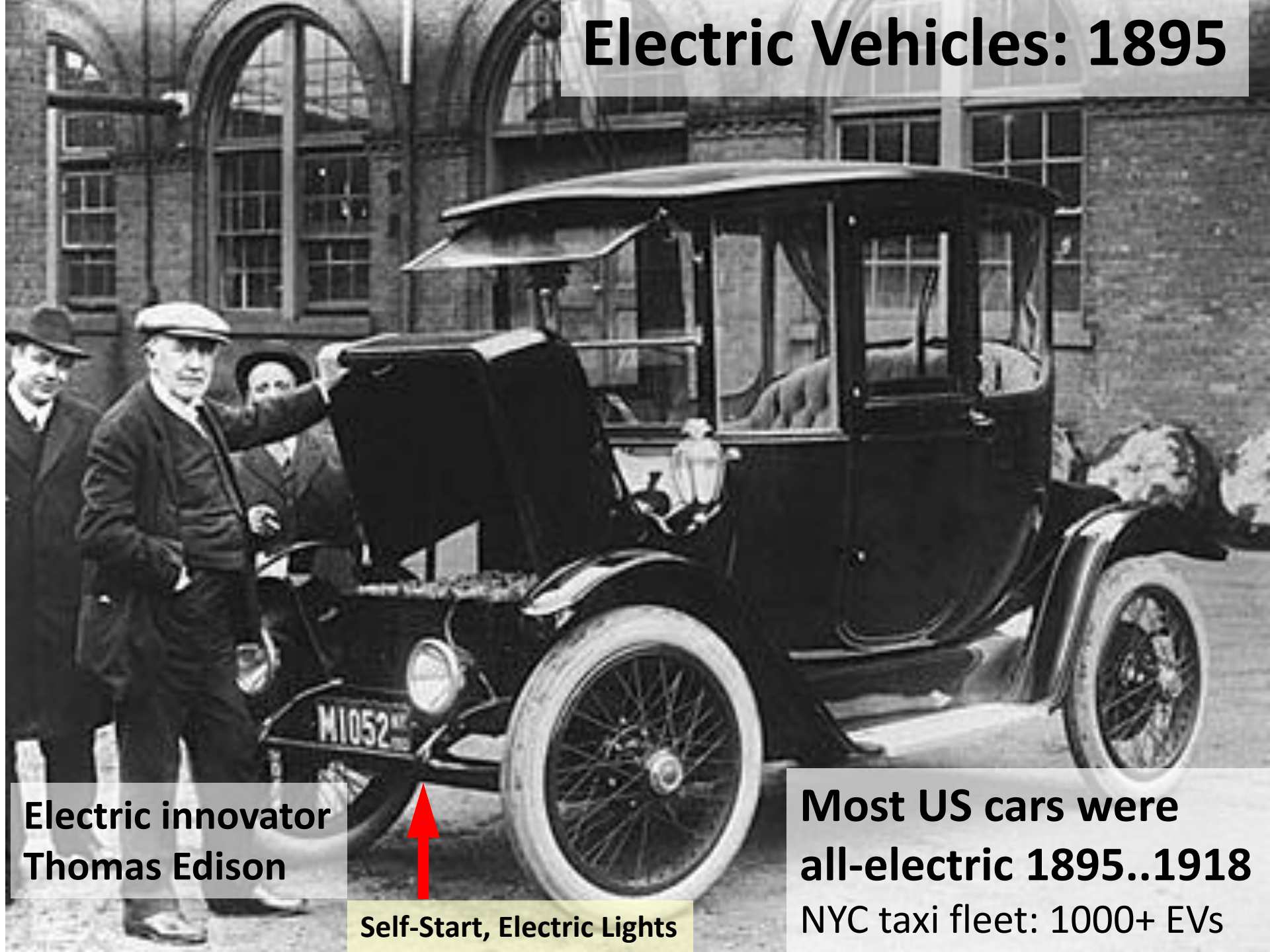
1. What are key Permanent Magnet motor materials?
2. How are they used? Why important?
3. How are the materials manufactured? What is the PM supply chain?
4. What is the outlook for economy, ecology, & security?

Permanent Magnet Materials

RECENT HISTORY

- Electric Vehicles increasingly use Permanent Magnets made from Rare Earth material NdFeB
- USA no longer produces Rare Earths (since 2002)
- PM materials demand in transportation and many high-tech products is booming
- Criticality is increasing in product supply chains
- Few or no substitutes
- 2011 Price Shock caused a short market alarm
- Prices moderate since 2012, now increasing again

Electric Vehicles: 1895



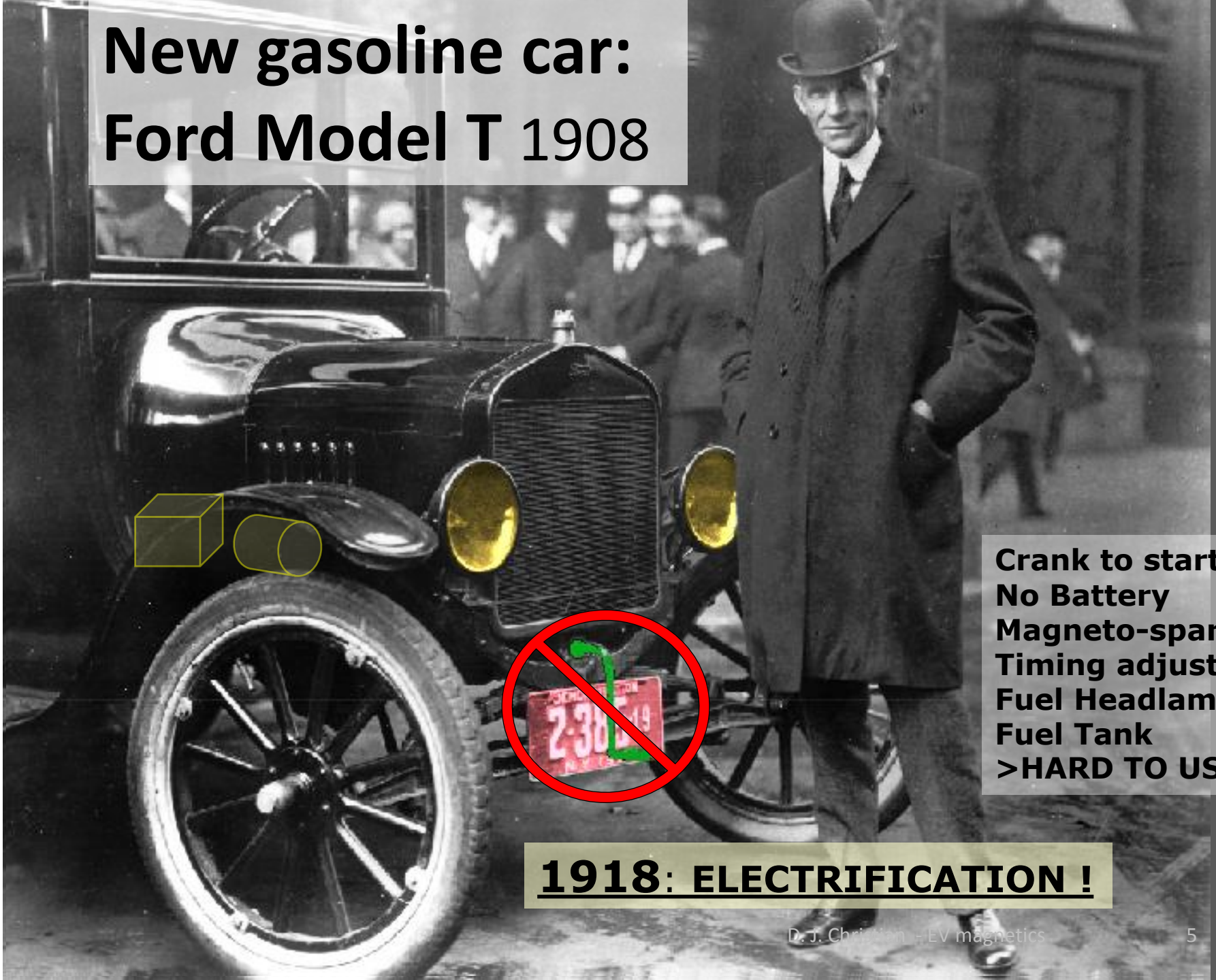
Electric innovator
Thomas Edison

Self-Start, Electric Lights

Most US cars were all-electric 1895..1918

NYC taxi fleet: 1000+ EVs

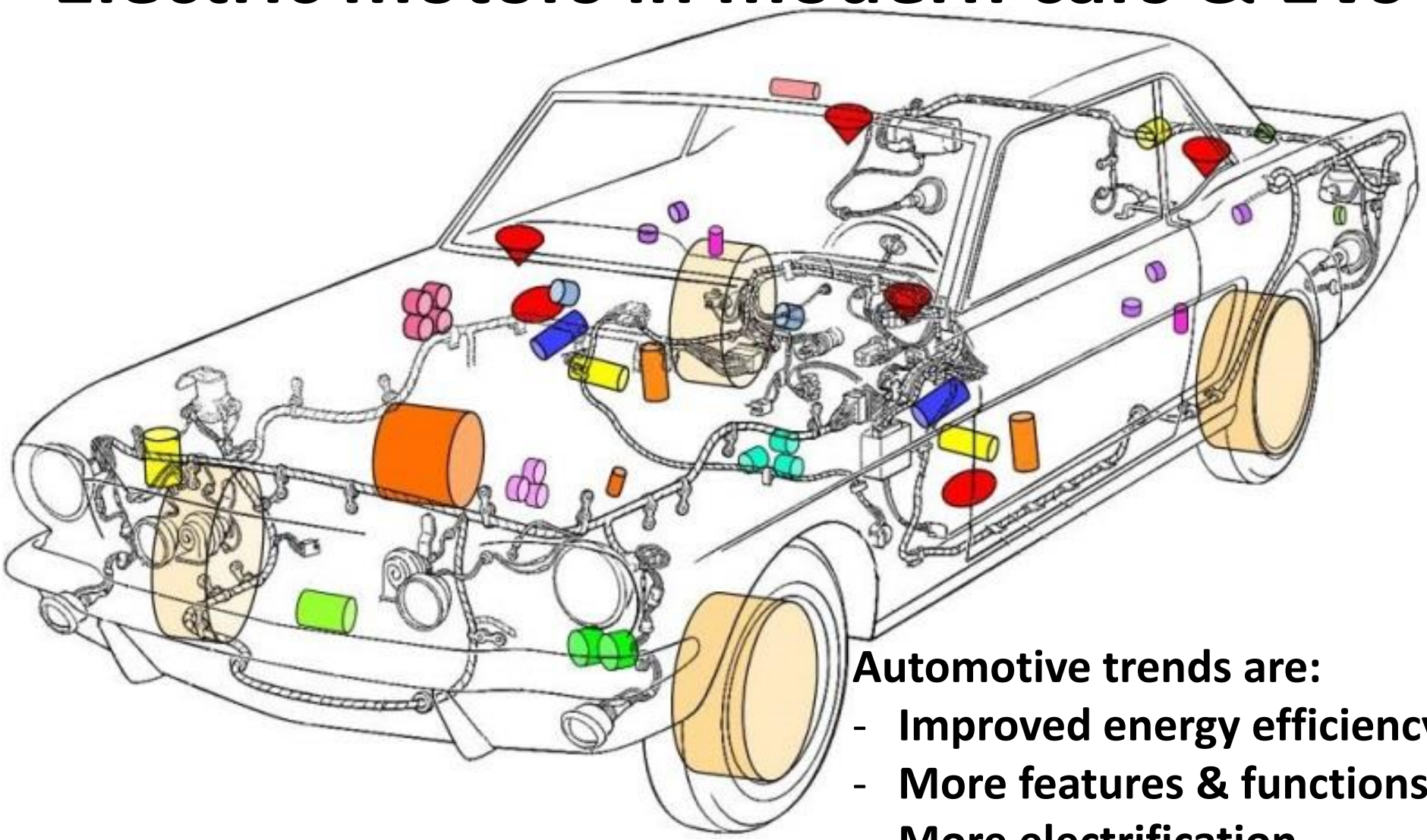
New gasoline car: Ford Model T 1908



Crank to start
No Battery
Magneto-spark
Timing adjust
Fuel Headlamps
Fuel Tank
>HARD TO USE

1918: ELECTRIFICATION !

Electric motors in modern cars & EVs



Automotive trends are:

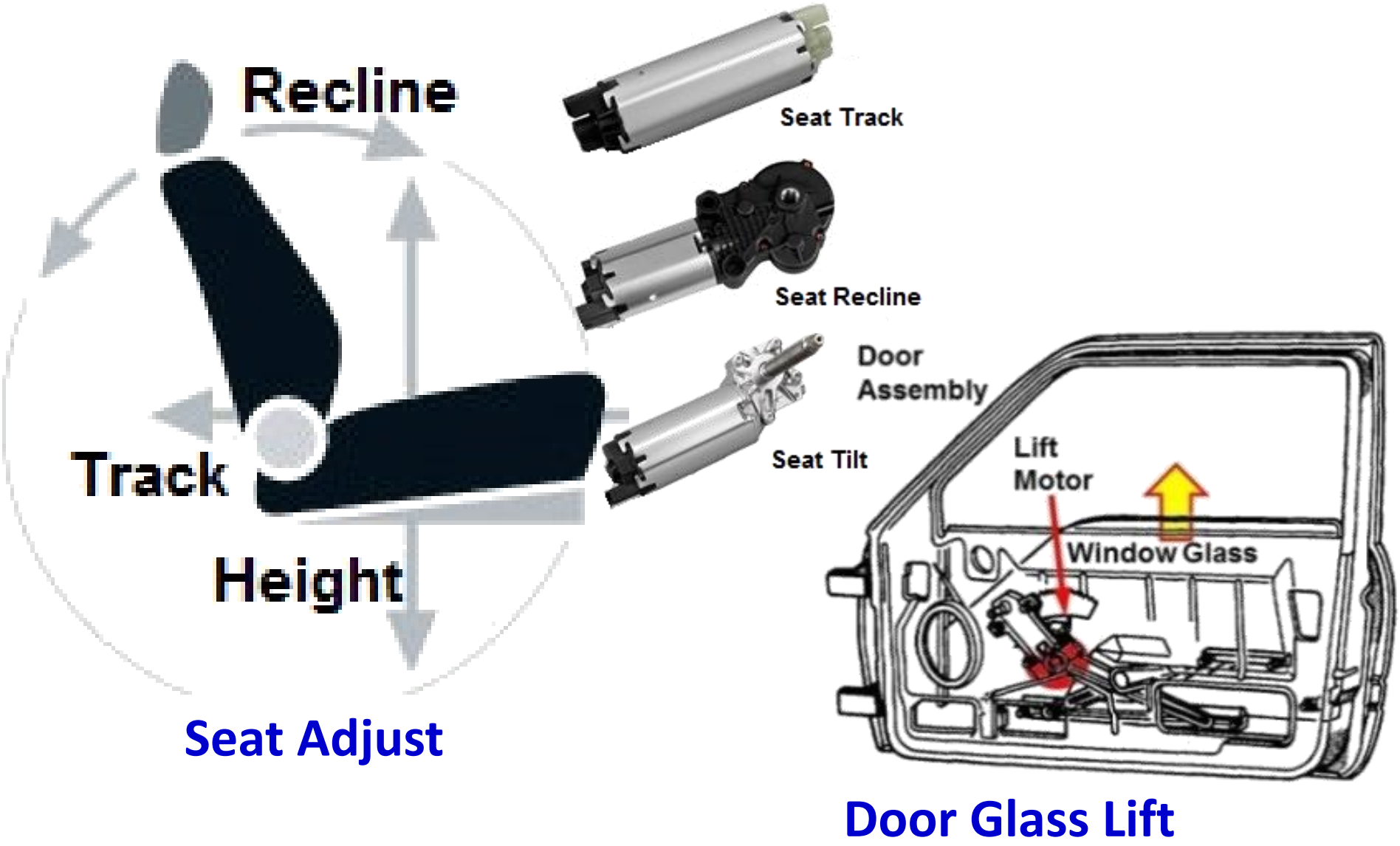
- **Improved energy efficiency**
- **More features & functions**
- **More electrification**
- **More batteries**
- **<u>More motors</u>**

Why electric motors ?

1. Wide speed range (+10kRPM..0..-10kRPM), variable
2. Directional reversibility with high bandwidth
3. High Torque. Good torque at all speeds & zero RPM
4. Small Size. Flexible: shape can be tailored to fit.
5. Light weight. Down-sized to fit the job
6. High Efficiency. Low heat loss. Cool running
7. Wide environmental operating range
   Temp, pressure, humidity, vibr.
8. Durable. Low maintenance, little or no lubrication
9. Reliable. Long MTBF, simpler mechanicals
10. Quiet acoustics, low EM radiation emissions
11. Natural affinity with electronic controls
    "intelligent" functions: safety
12. Energy scavenging through regeneration

Motors work better !

Electric motor applications in modern cars: Interior



Seat Adjust

Door Glass Lift

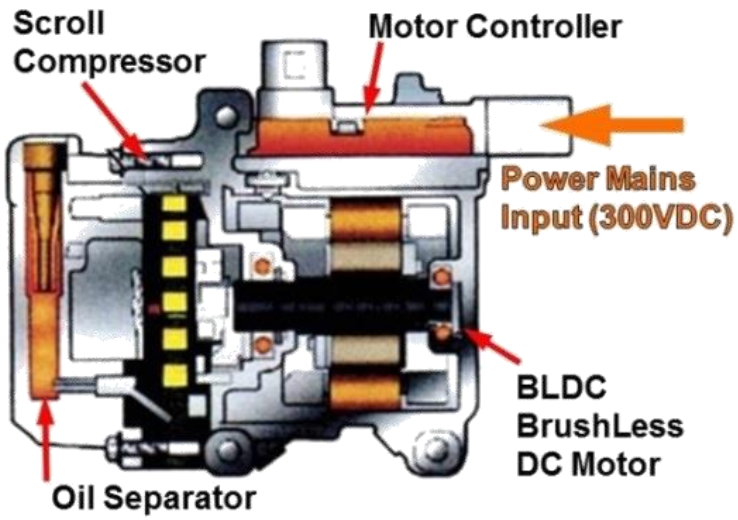
Electric motors in modern cars
Under-Hood

Windshield Wiper

Heater Valve

Coolant Pump

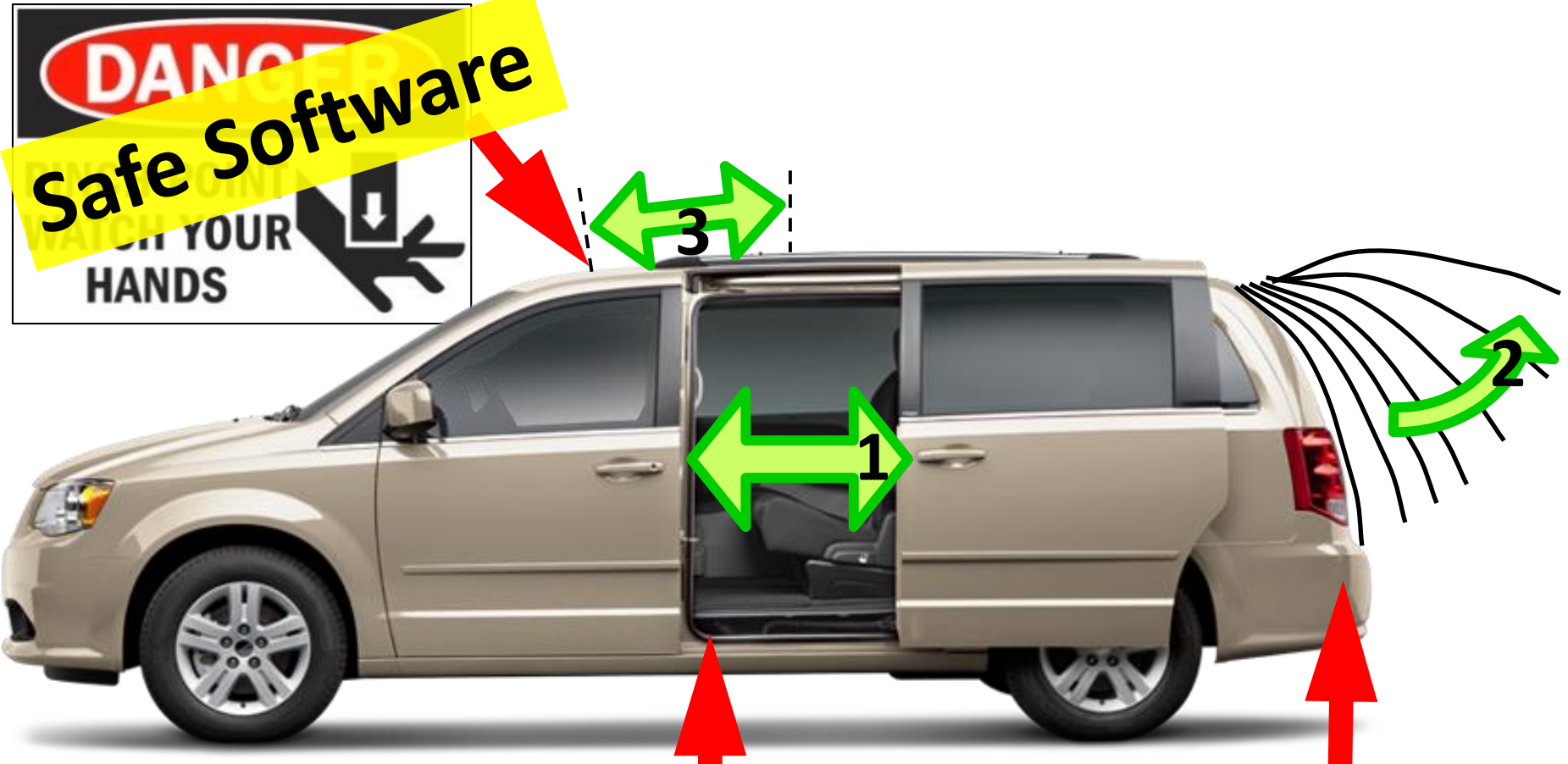
Vacuum Pump



A/C Compressor

Transmission Actuators

Electric motor applications: Doors



Power Doors

Automatic Folding Side Mirrors

Motorized operation, sensor logic control

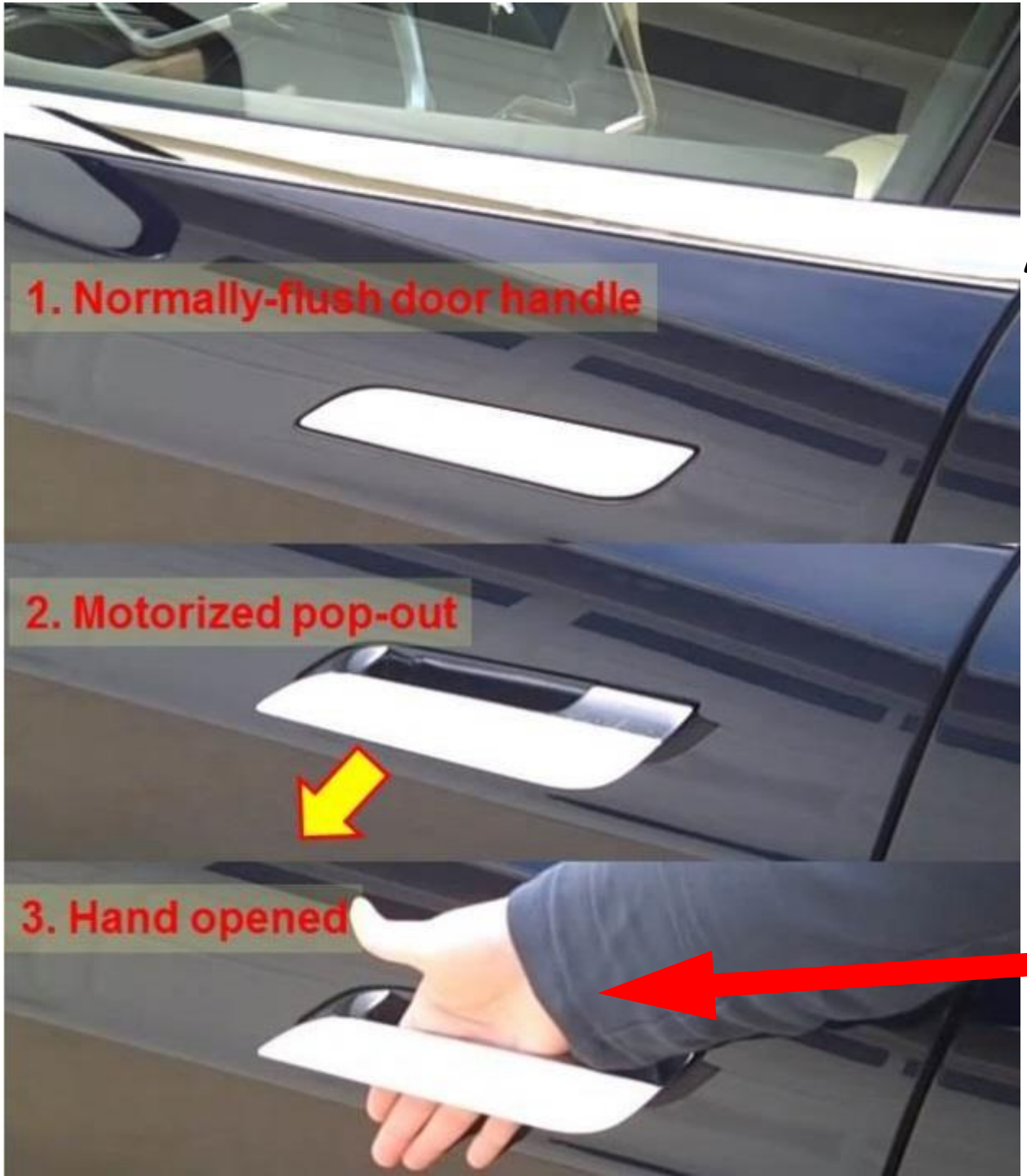
Electric motor applications in modern cars: Entertainment

Audio Speakers

This application is cost-sensitive !

After 2011 Rare Earth price shock

- **>> magnet substitutes were developed**
- **>> RE use was sharply reduced in speakers**
- **>> Advertised as “Green RareEarth Free”**



New motor Applications

Automatic Door Handle Presentation

Safe Software

Traction Motor Applications: EV

Larger motor = more torque = more RE materials

Hybrids & PEVs (Plug-in Electric Vehicles)

Electric propulsion

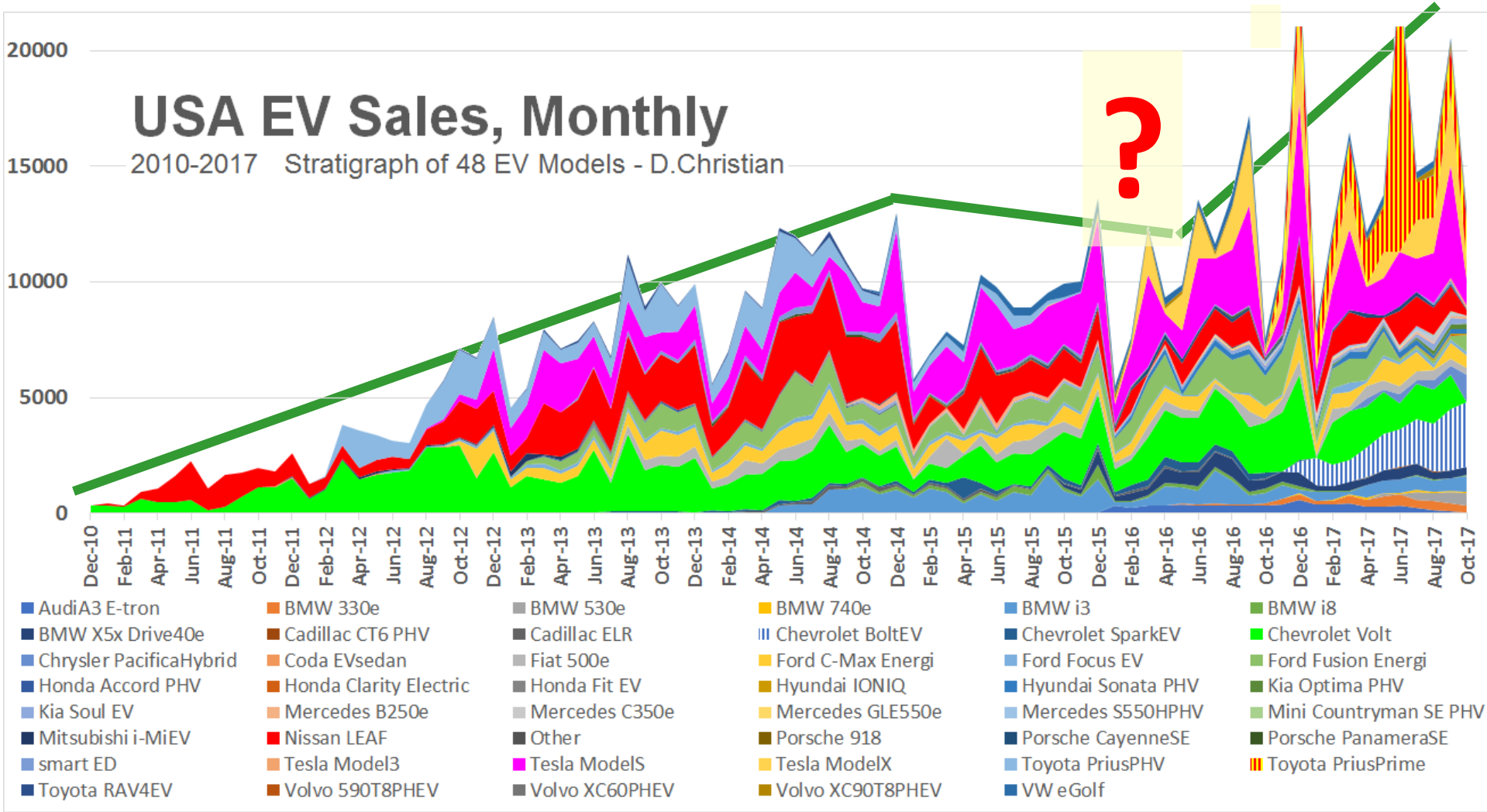
Hybrid Propulsion reduces transport cost

New motor Applications:

BEV = Battery All-Electric Vehicles

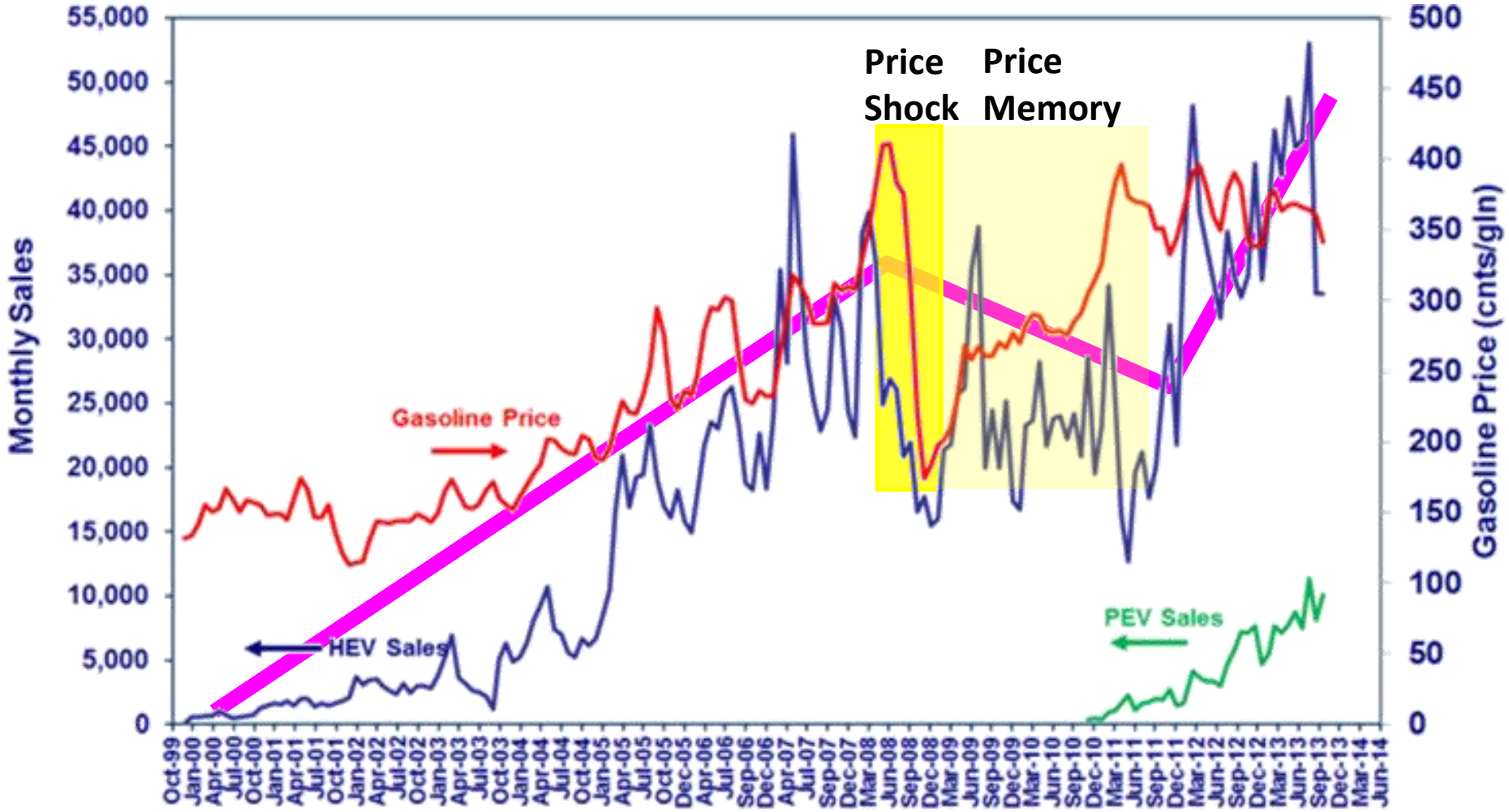
All-Electric Propulsion

Recent EV sales history (Oct 2017)



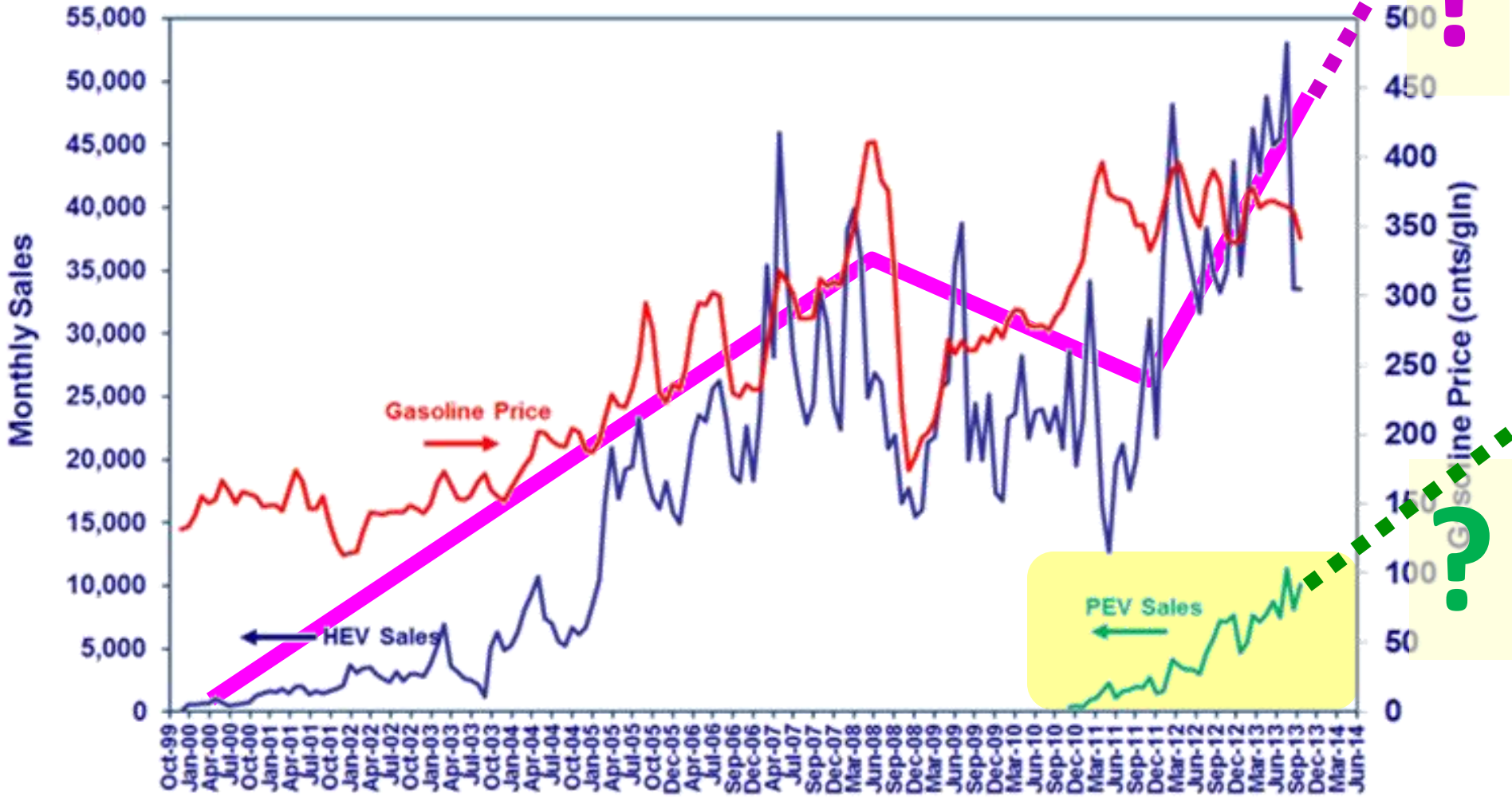
Steady sales growth

Strong Correlation in USA: Fuel prices -and- EV sales



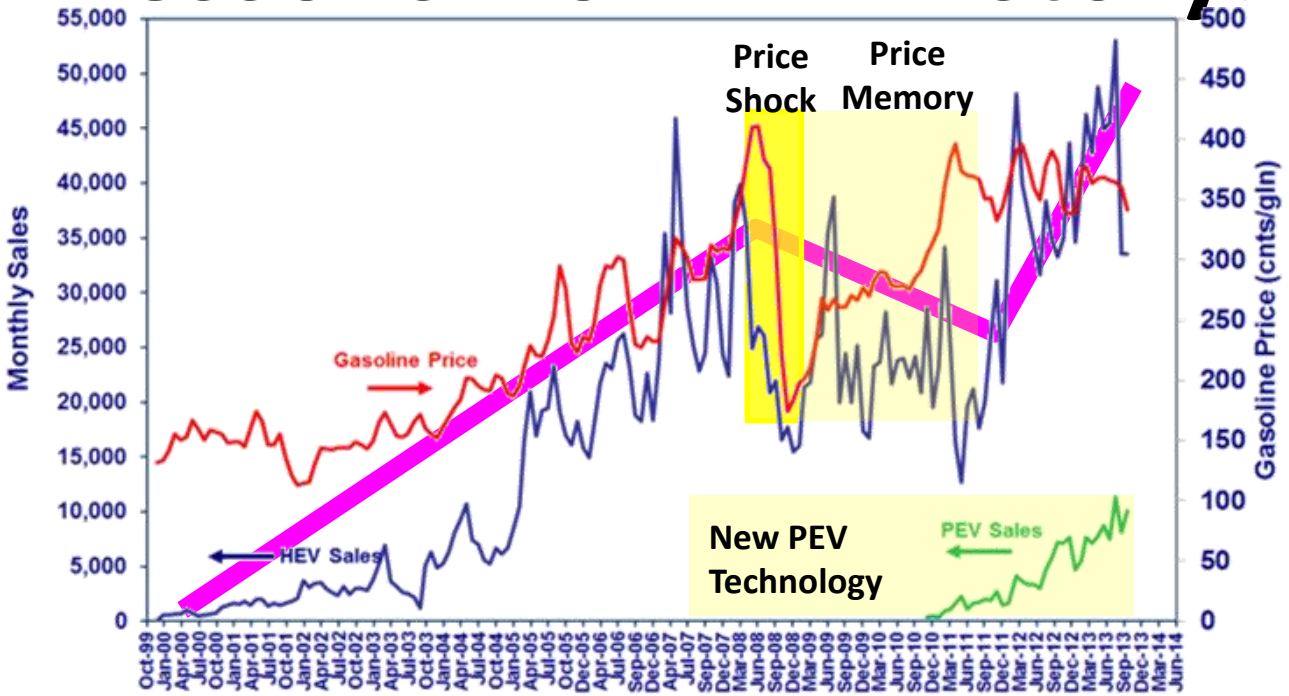
Customers remember price shocks

Strong Correlation in USA: Fuel prices -with- EV sales



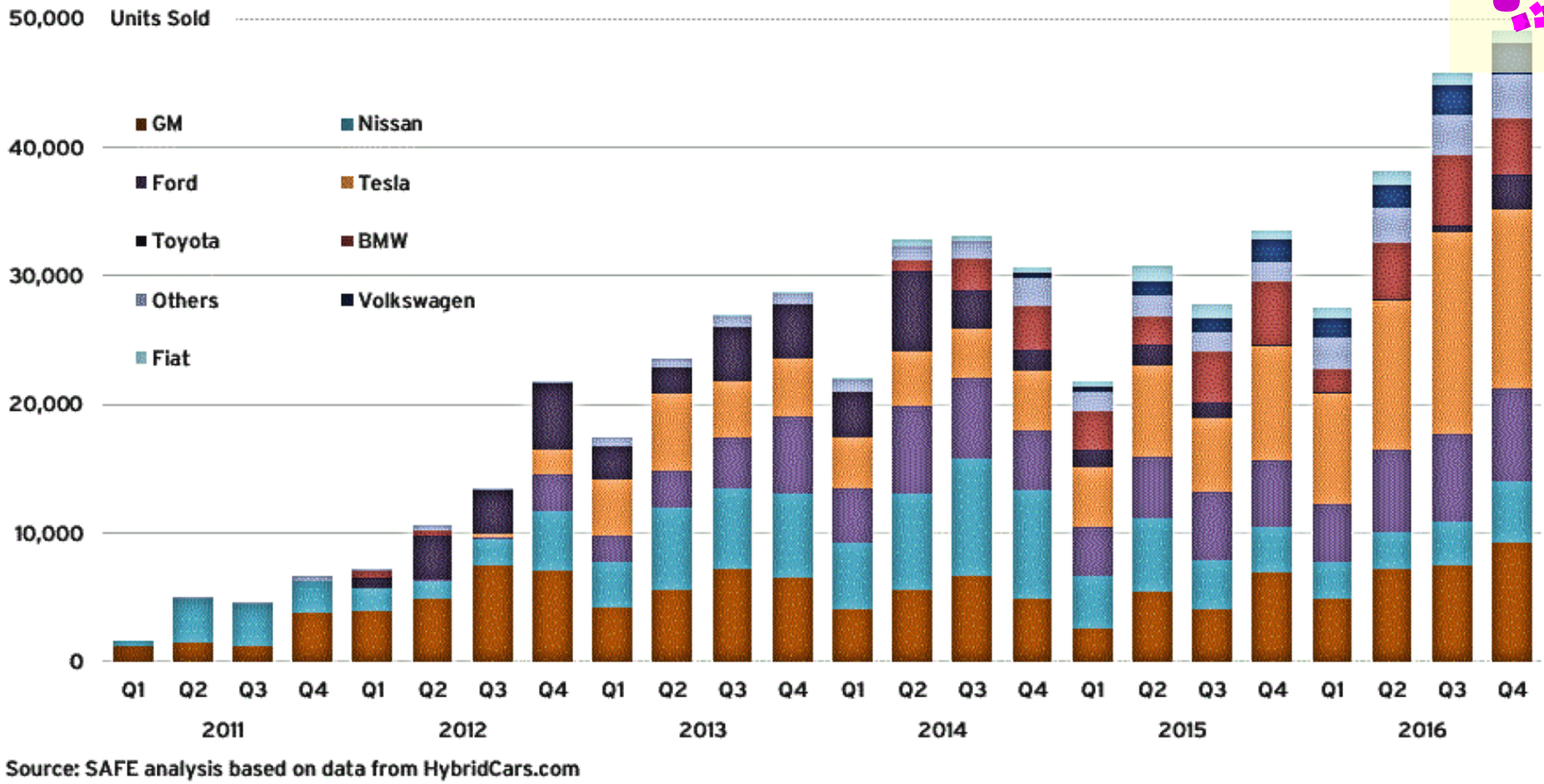
PEV reduces the risk of petrol price-shock

Lessons from EV history:



1. Customers are very sensitive to fuel cost
2. Customers remember price shock volatility
3. New PEV cars reduce total cost TCOO
   - Many US customers don't believe PEV is real
   - As PEV benefit gains confidence, sales increase

BEV sales prospects

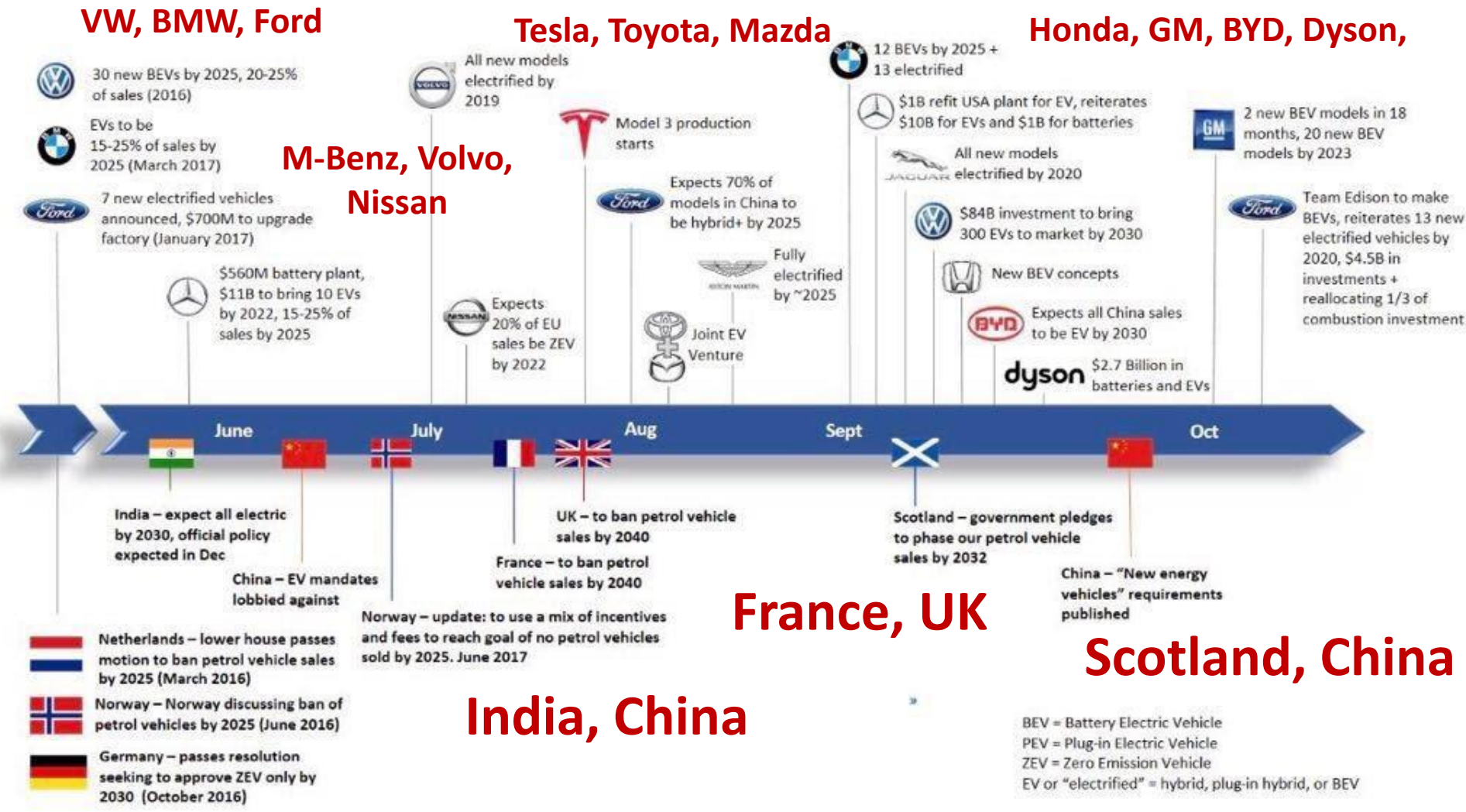


Source: SAFE analysis based on data from HybridCars.com

Expectation: brisk EV sales growth

Primarily use PM motors

2017: OEM & Governments outlawing non-electric drivetrains !



Alternatives to PM/rare earth Motors?

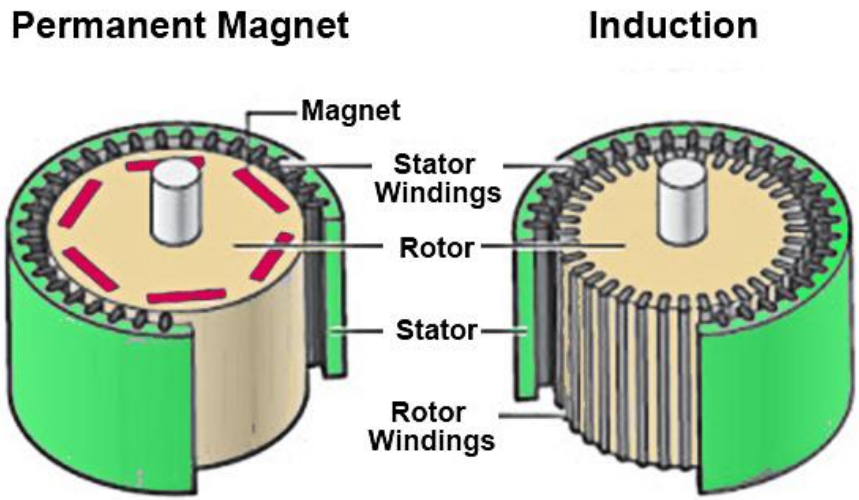
- **Automotive RE applications are cost-sensitive.**
- **Delicate balance: Performance vs Cost**
- **PM/RE Performance is good.**
- **Risk: future RE cost-shock?**

  (memories of 2011 RE price shock)

> Fear of price shock motivates R&D for alternatives:

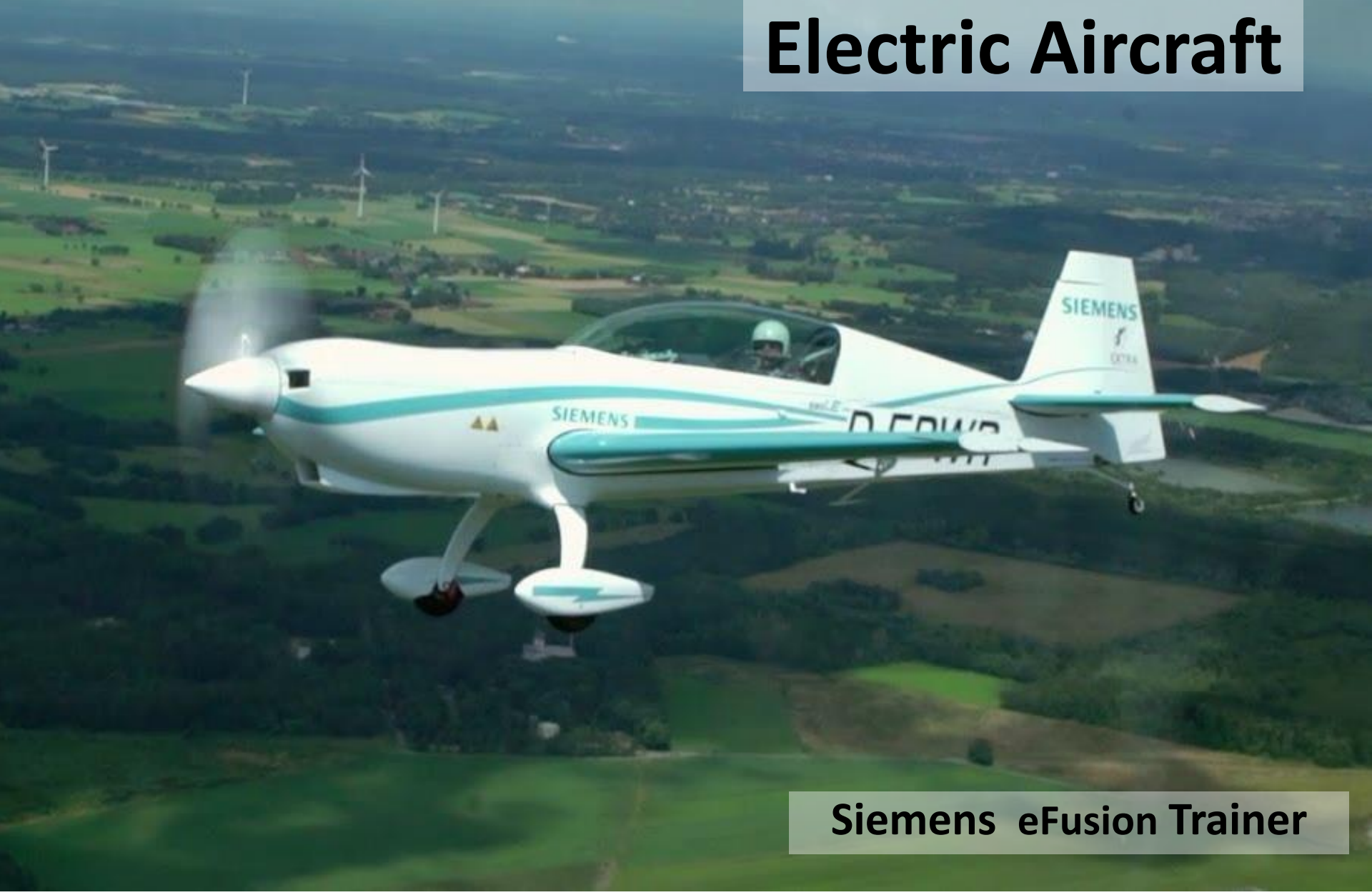
- **new *Lower*-RE motors** (reduced RE use)
- **new *Zero*-RE motors** (total elimination)

PM Technology Alternatives



- Modern Motor Designs:
  - Permanent Magnet (baseline)
  - AC Induction (popular, cheapest)
  - Switched Reluctance
- Requirements vary greatly between applications
- Motor designs have been iterated for 150 years
- PM performance is competitive or superior in all niches
- Most modern EVs use PM motors (Nissan, Ford, GM)
- Tesla's Model 3 will use PM propulsion motor
- PM continues as the the most popular technology

Electric Aircraft

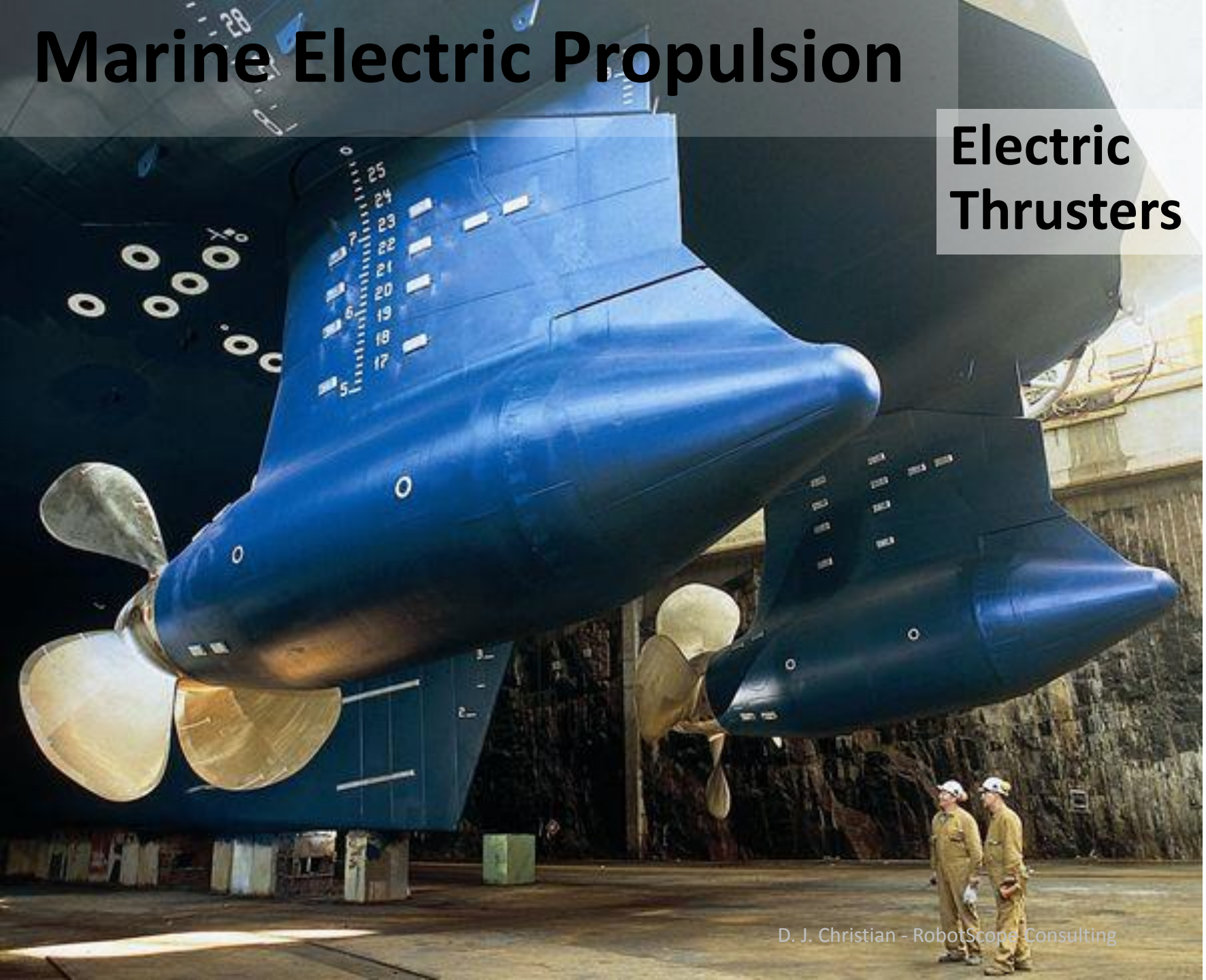


Siemens eFusion Trainer

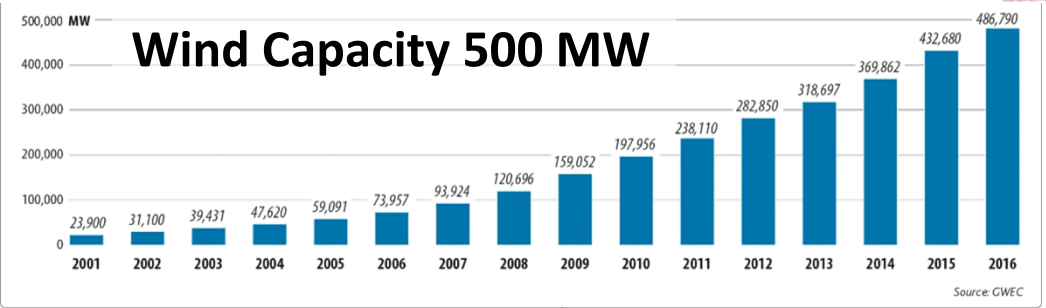
Benefits: Efficient, Silent, Clean, Light, Safe, **Economic**

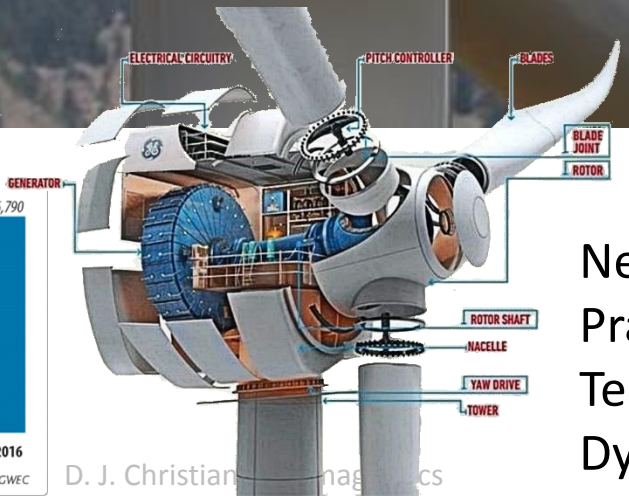
Marine Electric Propulsion

Electric Thrusters



Rare Earths in Wind Energy





Neodymium
Praseodymium
Terbium
Dysprosium

Cell Phone Rare Earths

Vibrator Magnets
Neodymium
Praseodymium
Terbium
Dysprosium

Electronics
Neodymium
Praseodymium
Dysprosium
Gadolinium

Speakers
Neodymium
Praseodymium
Terbium
Dysprosium

Headphones
Neodymium
Praseodymium
Terbium
Dysprosium

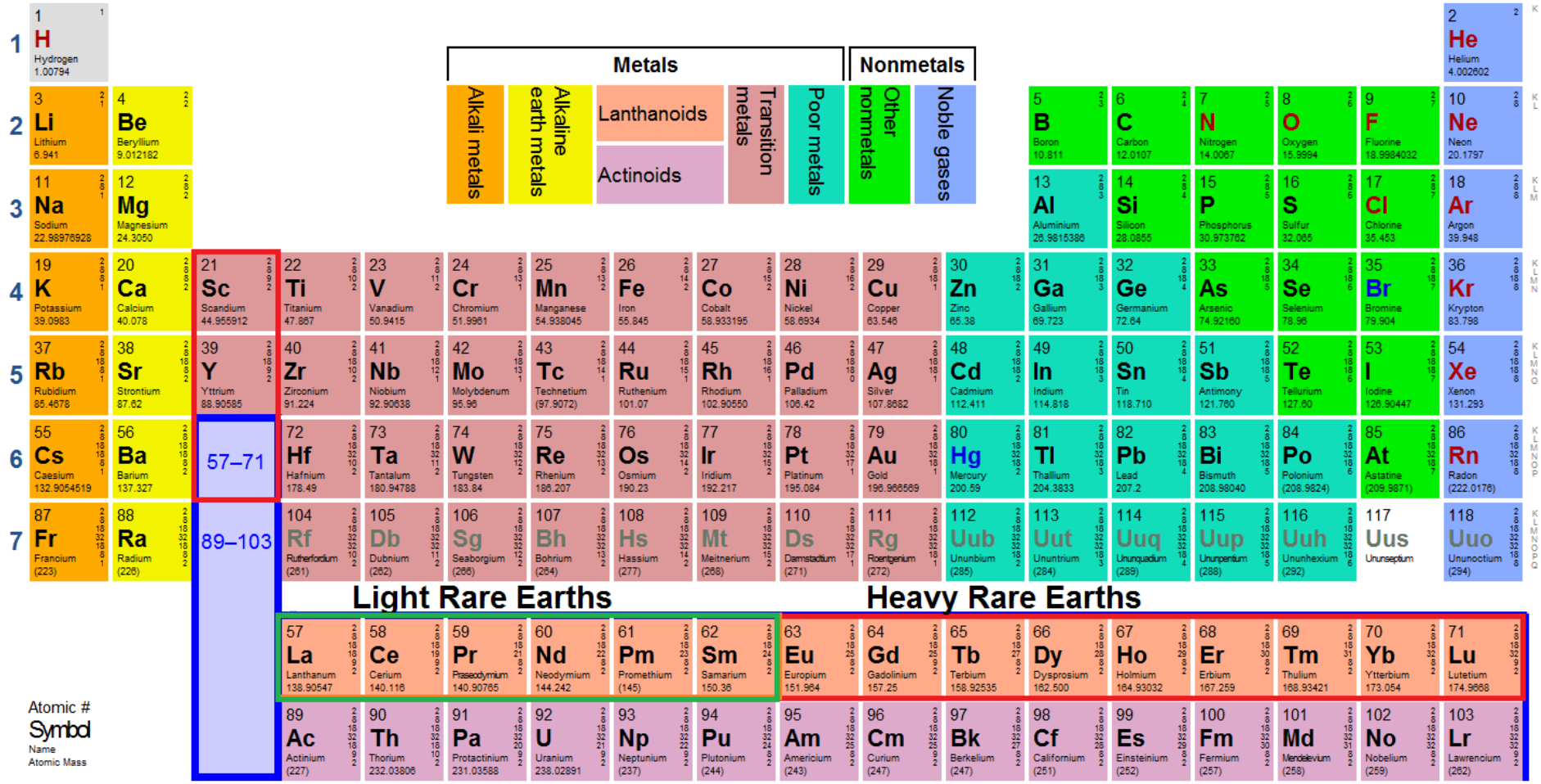
Display Screen
Europium
Praseodymium
Yttrium
Lanthanum
Terbium
Dysprosium
Gadolinium

Glsss Polishing
Cerium
Lanthanum
Praseodymium

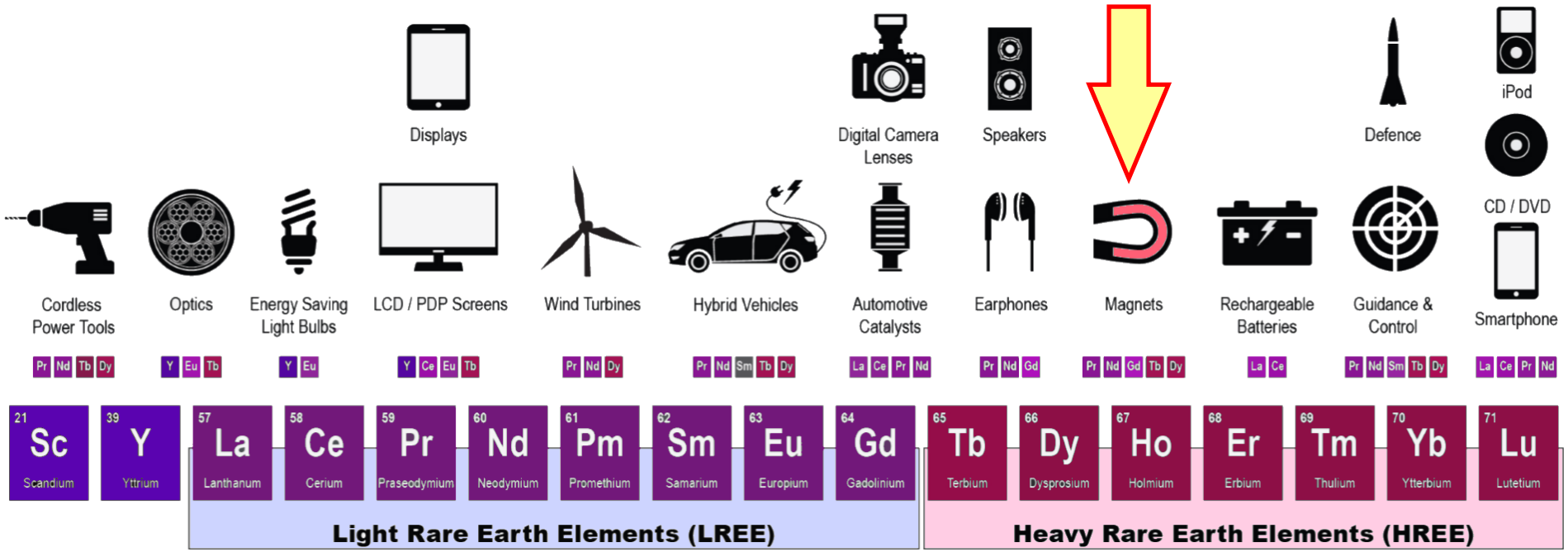
What are PM materials ?

“Super-Magnets” Neodymium Iron Boron, NdFeB

Rare Earths or Lanthanide elements



Where are rare earths used ?



A broad range of <u>performance-critical</u> applications

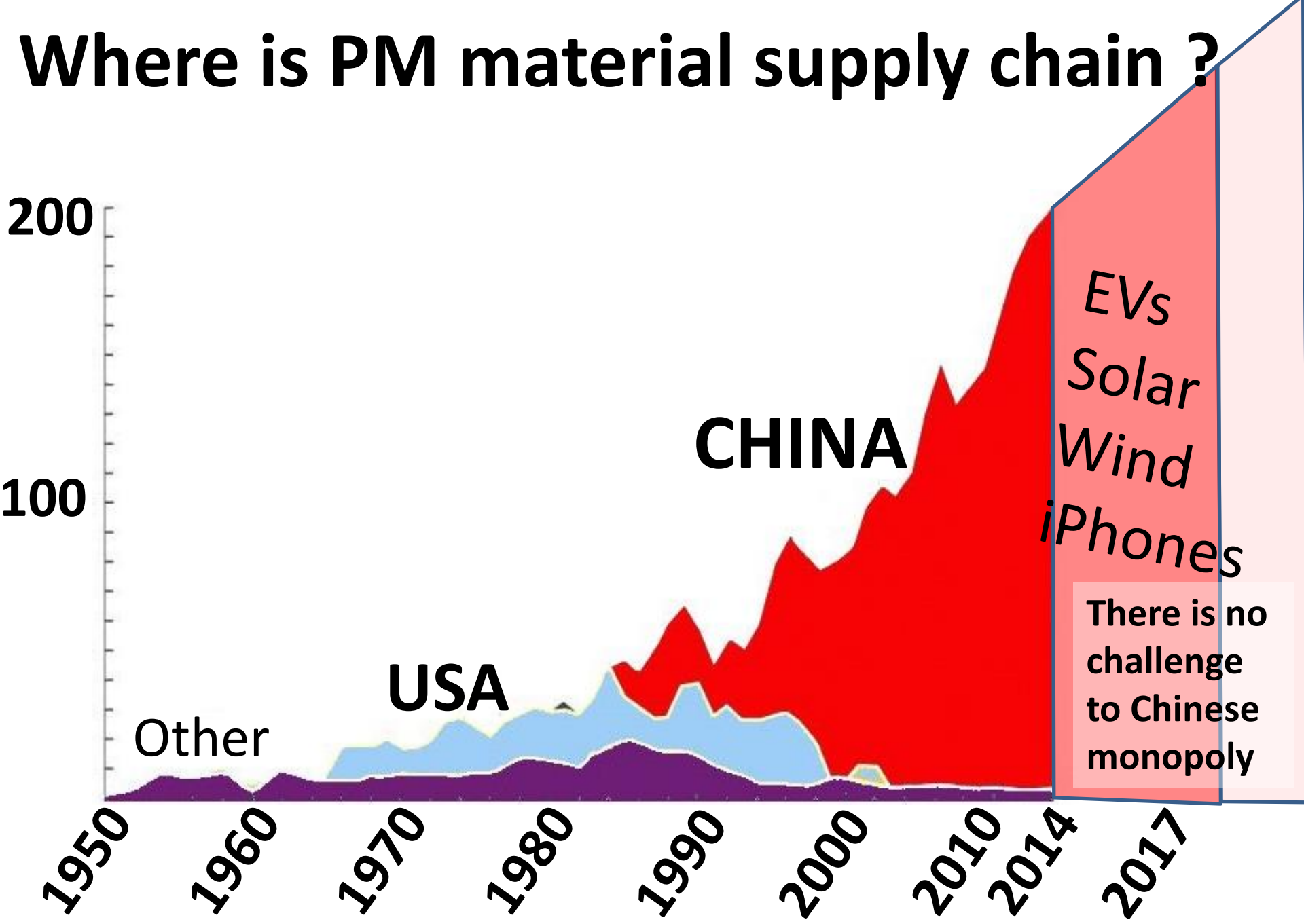
Power, weight, temperature, sensitivity, color,…

How are PM materials manufactured ?

Mountain Pass mine, Calif

Plentiful ore: Bastnasite, Monazite

Where is PM material supply chain ?



Source: USGS, CRS,

Electromagnetic Rail-Gun Artillery

Navy

USNS Zumwalt
USNS Millinocket

Army

Bulk consumer of Rare Earth materials

rcraft Carrier: Electromagnetic Catapult

USNS Gerald R Ford

commissioned July 2017 with EM catapults

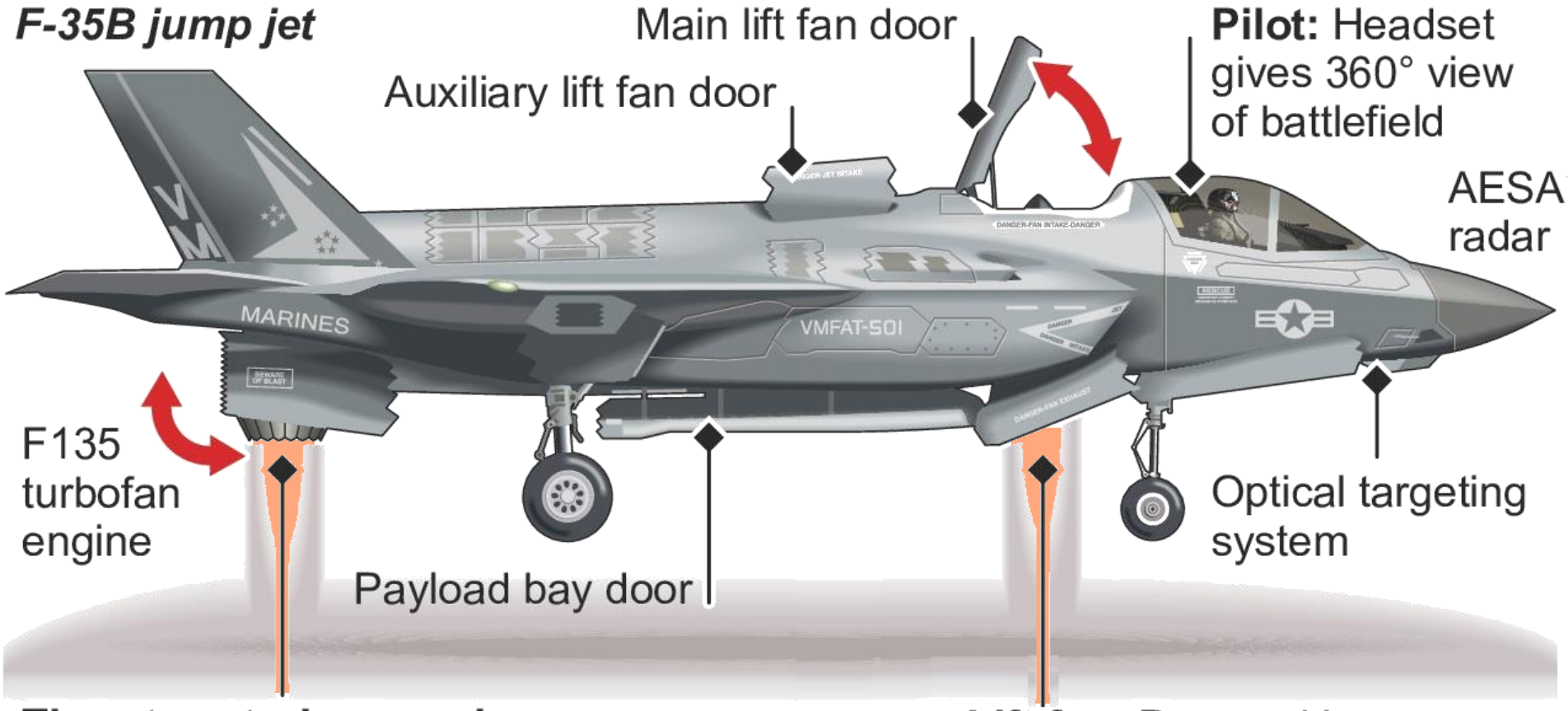
nese Nacy Carrier Liaoning

missioned Nov 2016

pgrades in development

Bulk consumer of Rare Earth materials

F35 Fighter: "Flying Periodic Table"



Thrust vectoring nozzle
Directs full thrust of engine down for vertical takeoff and landing

Lift fan: Powered by driveshaft from jet engine – balances lift generated at tail

F-35 orders

U.S.	2,443	Norway	52
Britain	138	Japan	42
Australia	100	South Korea	40
Turkey	100	Netherlands	37
Italy	90	Israel	33
Canada	65	Denmark	27

Bulk consumer of Rare Earth materials

Transportation Markets for Rare Earth materials

Trends are clear:

-Greater electrification for transportation

-More motors used in transportation

-More EV penetration: sales & operating fleet

-More motors electronically commutated

-More magnet rare earth material used

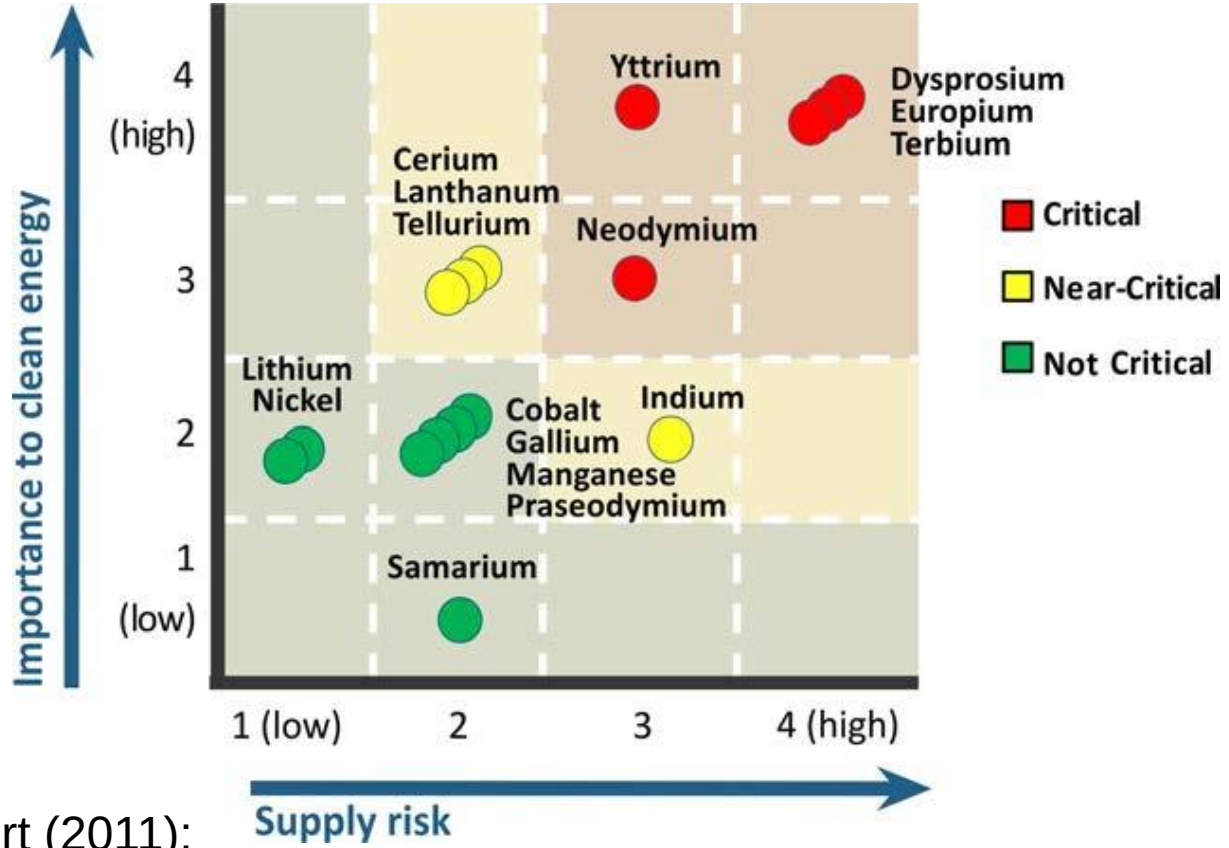
Projections (opinion):

- **RE applications will continue to grow**
- **Some substitutes may be found, cost-driven**
- **If RE prices remain competitive, then RE markets will continue to grow**

Critical Materials Institute

- Study and recommend supply chain strategies
- US Dept Of Energy initiative at Ames Laboratory

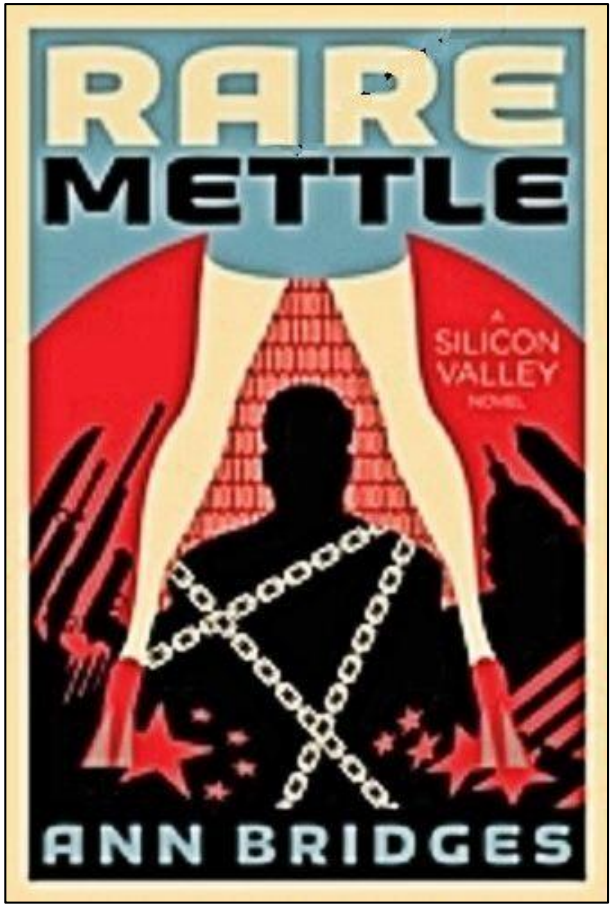
Criticality Matrices:
Risk vs Strategic Importance



CMI Critical Materials Report (2011):
https://energy.gov/sites/prod/files/DOE_CMS2011_FINAL_Full.pdf

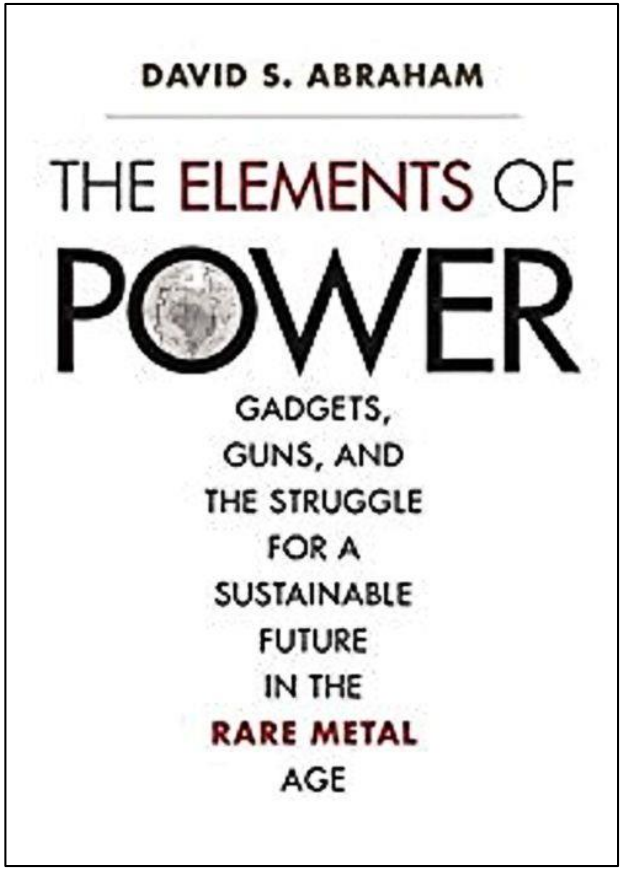
Further reading:

Fiction



"Rare Mettle"
By Ann Bridges

Non-Fiction



"The Elements of Power" by David S Abraham

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Thank You
for your attention !

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