The Electrified Future Has Only Just Begun

Motor Design Opportunities for Land, Air, and Sea

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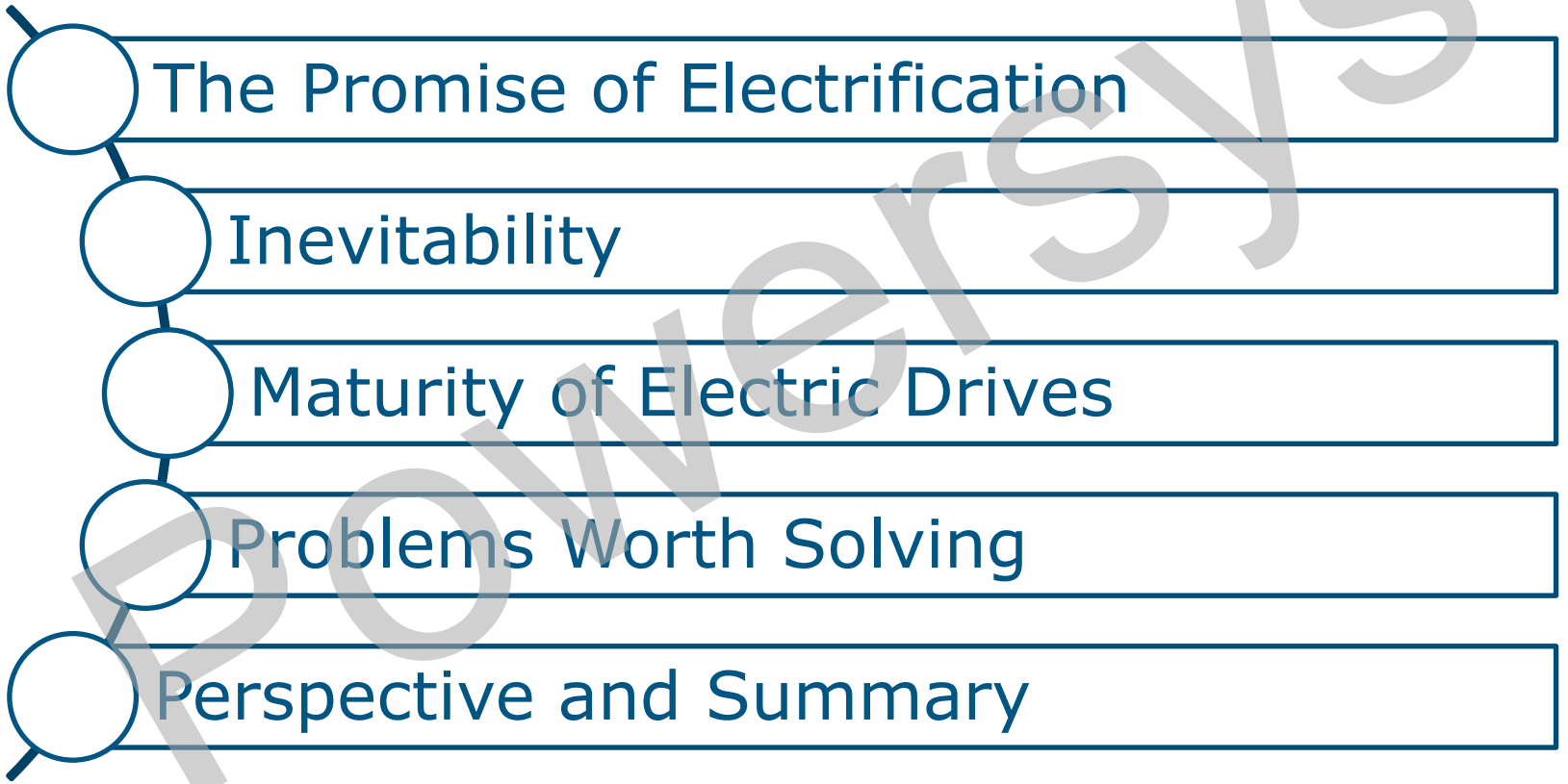
POWERSYS
Advanced eMotor Design Conference

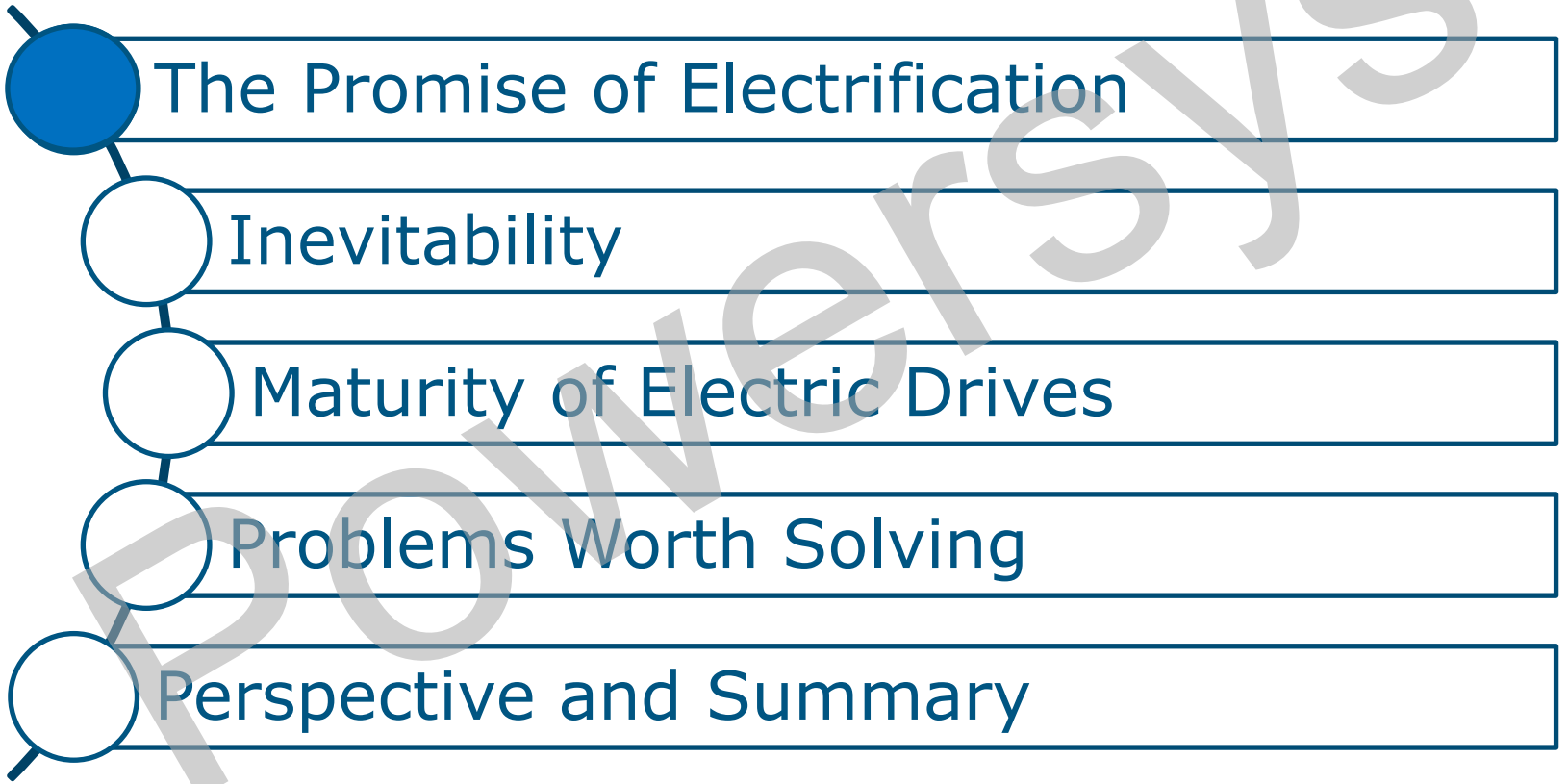
Southfield, MI June 5th, 2025

ELECTRIFIED FUTURE

Motor Design Opportunities



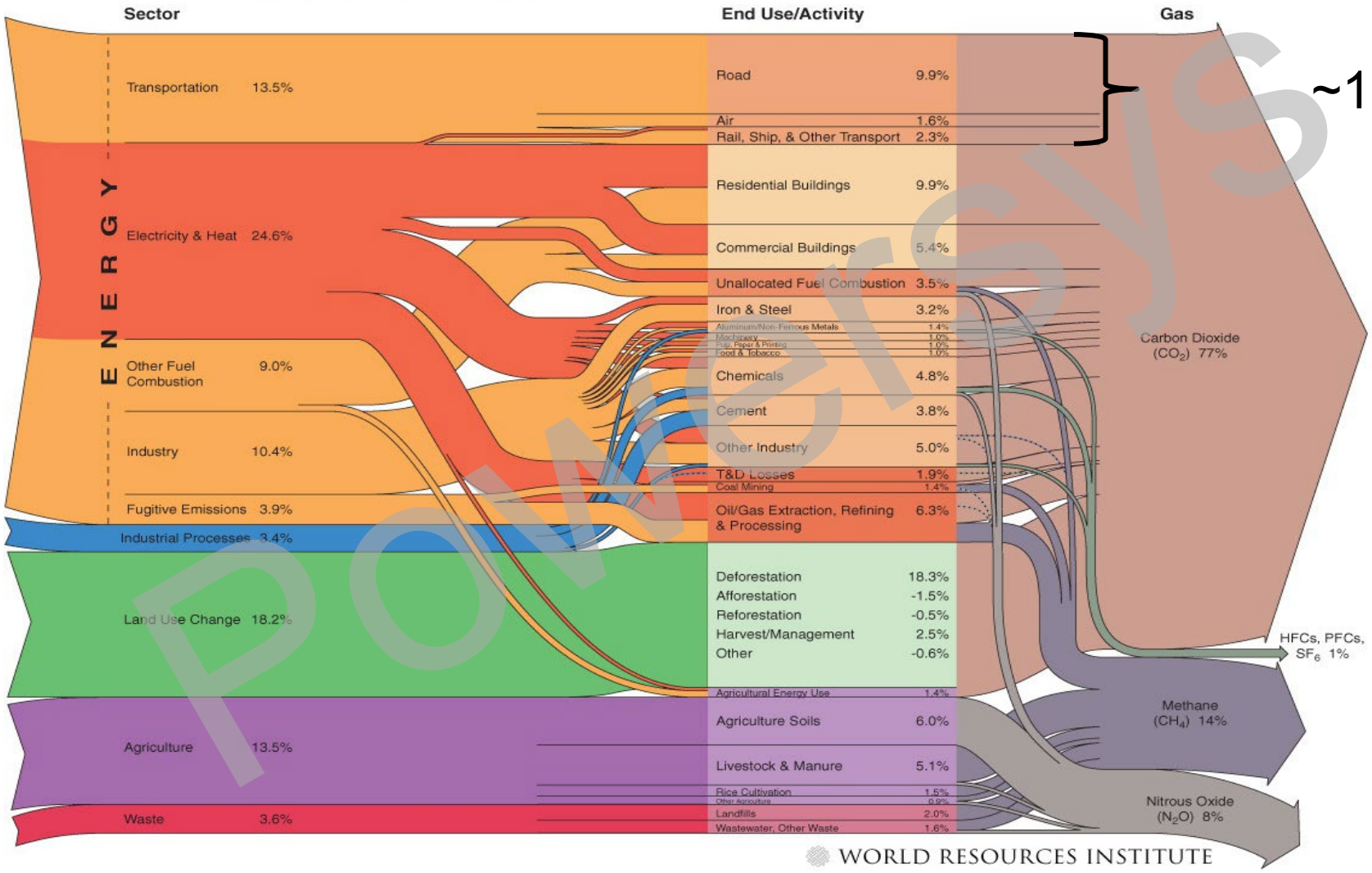
Motor Design Opportunities



The Promise: Electric Propulsion will Transform Mobility and Transport

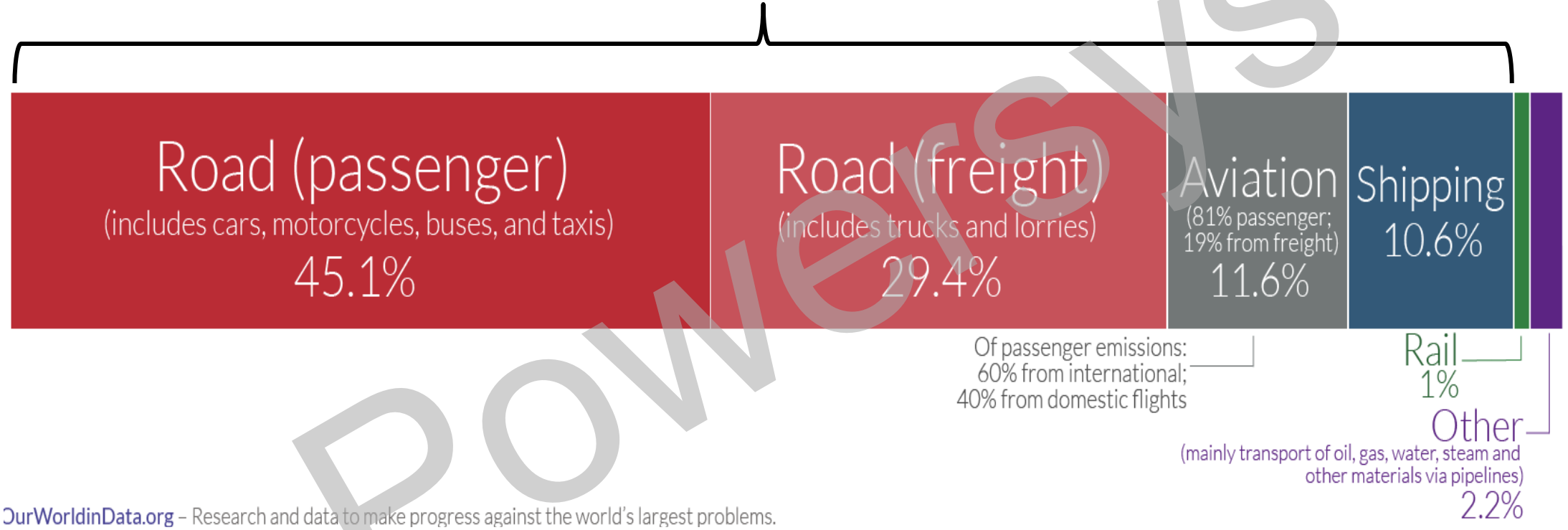
- Address 13% of global CO_2 emissions.
- Best economics relative to alternative technologies for CO_2 reduction.
- Advantage in Total Cost of Operation (TCO).
- Opportunity for new entrants; and
- Transformation challenge (threat) to established players.

Transportation Comprises ~13.5% of World GHG



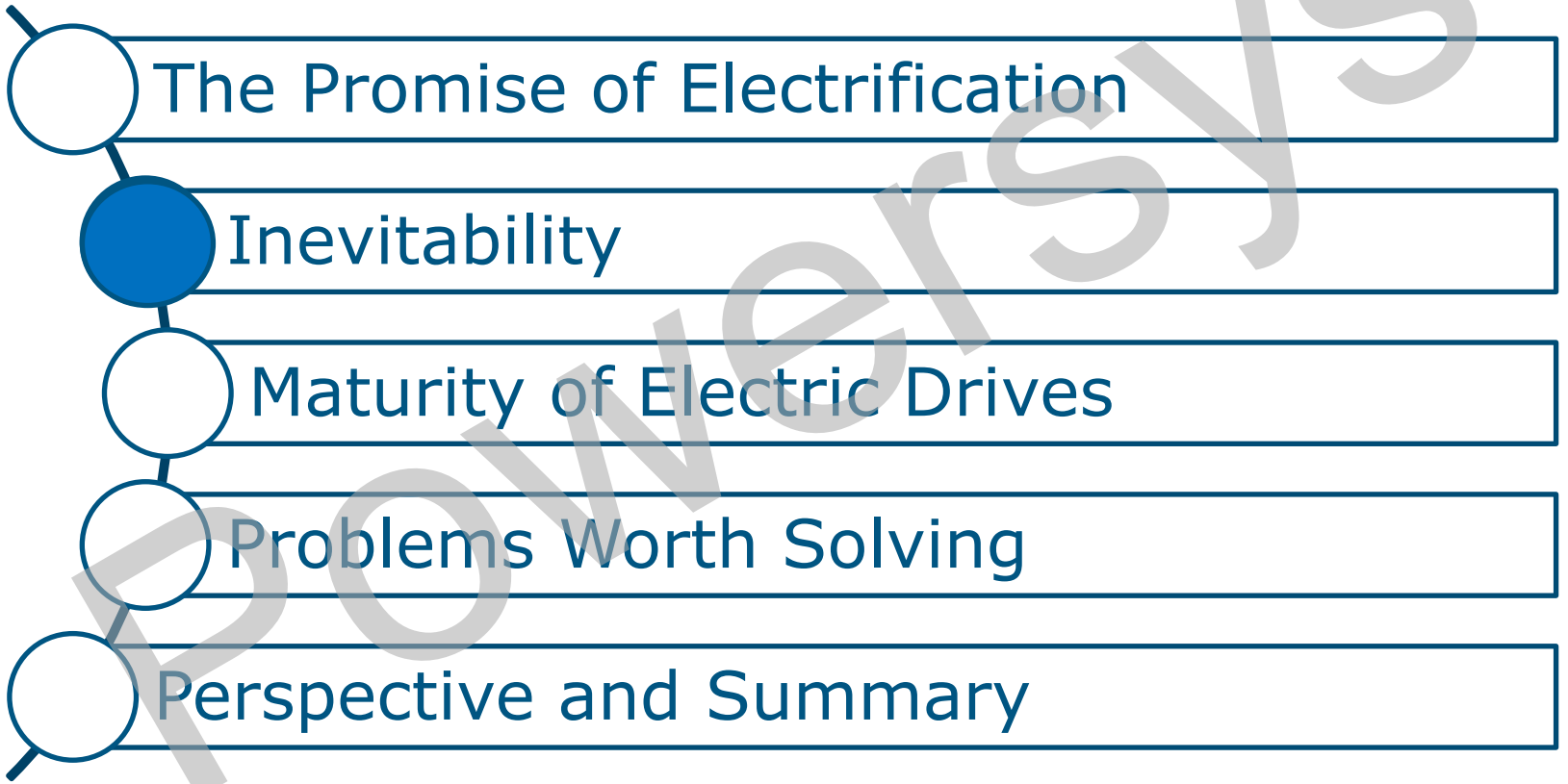
~13.5%

Road, Aviation and Shipping Comprise 97% of Transportation CO_2



Collectively these represent **13% of GHG**

Motor Design Opportunities



Headwinds

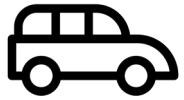
It’s not the Physics, it’s Economic Execution

- ”Can the the bird fly?”

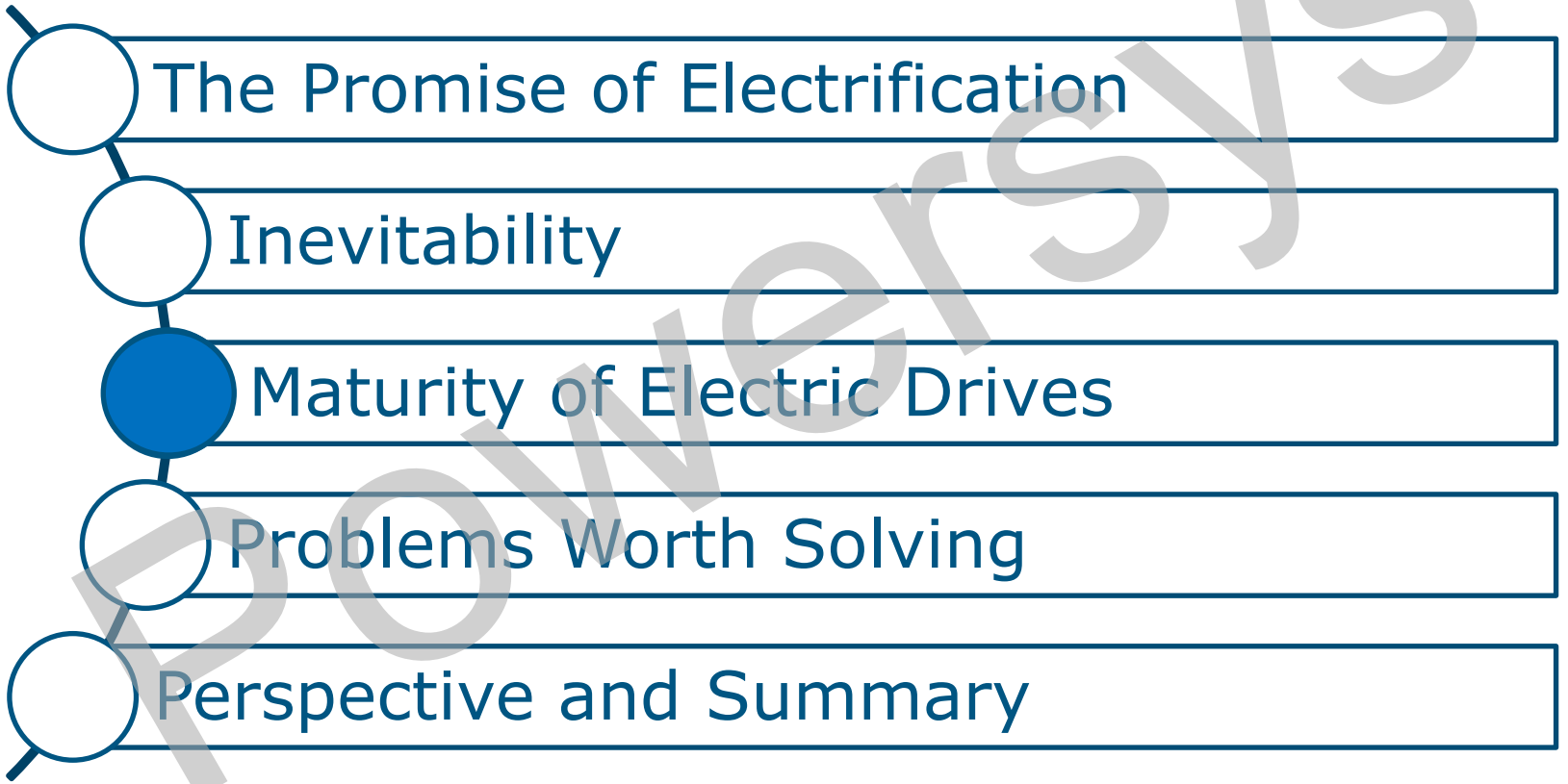
Mobile Electrification is Inevitable

- Less Energy, Less CO2
- Smoother, quieter operation
- More flexible vehicle and propulsion architecture
- Faster product development
- Less capital for a new model
- Decreasing costs of design and production
- Lower Total Cost of Ownership (TCO)

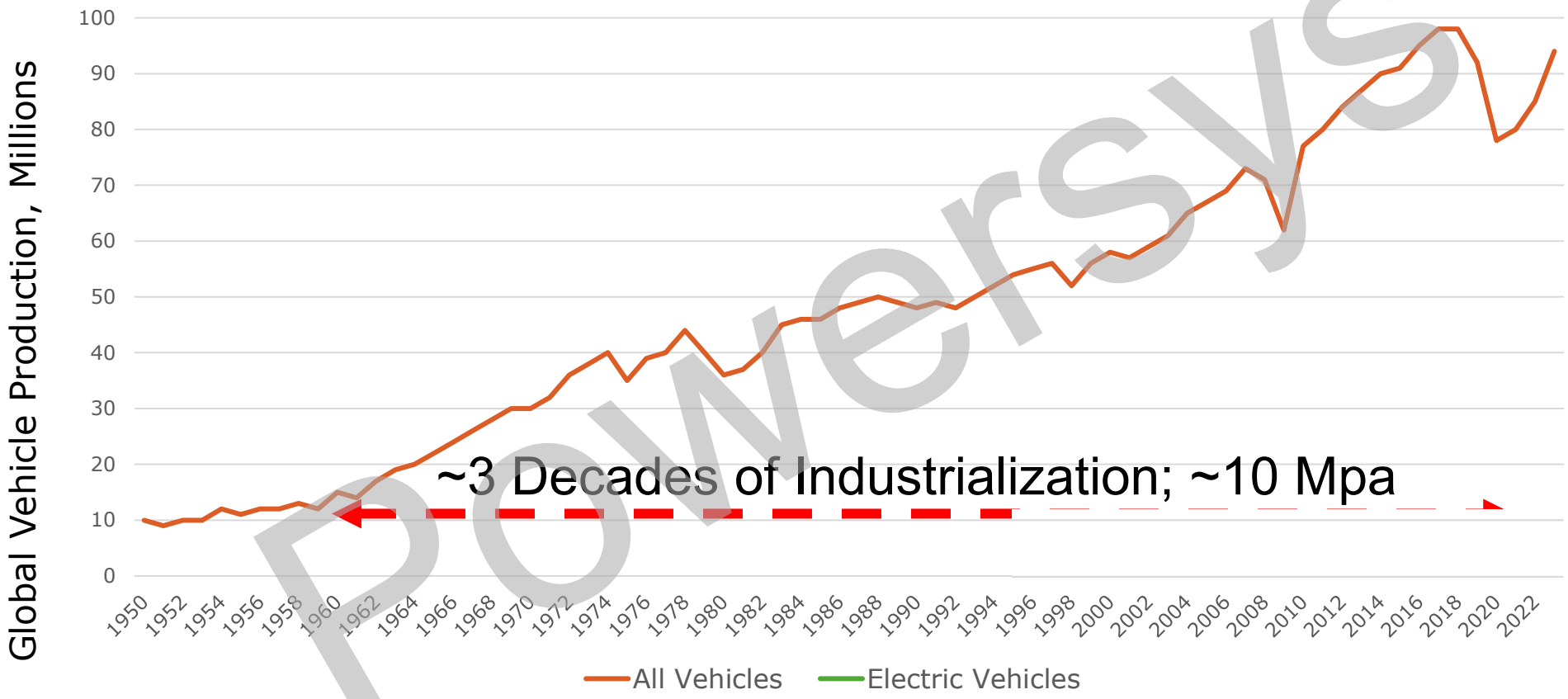
2025 Segment Scorecard, including TCO

Segment	Category	Capability		Technical Sufficiency		TCO
		Utility	Range	Energy	Mass	Advantage
	Small, Med	100%	90%	Yes	Yes	0 to +20%
	PU / Large SUV	70%	70%	Marginal	Marginal	-6 to +12%
	Small, Med Large	100%	90%	Yes	Yes	+25 to +50%
	Small C2 - C3	90%	100%	Yes	Yes	0 to +18%
	Med C4 - C6	90%	90%	Yes	Yes	0 to +20%
	Large C7, 8	90%	40%	No	Yes	0 to +15%
	Regional, <20 pass	70%	20%	No	No	+20 to +50%
	10 – 30 hp Outboard	100%	90%	Yes	Yes	+20 to +30%

Motor Design Opportunities

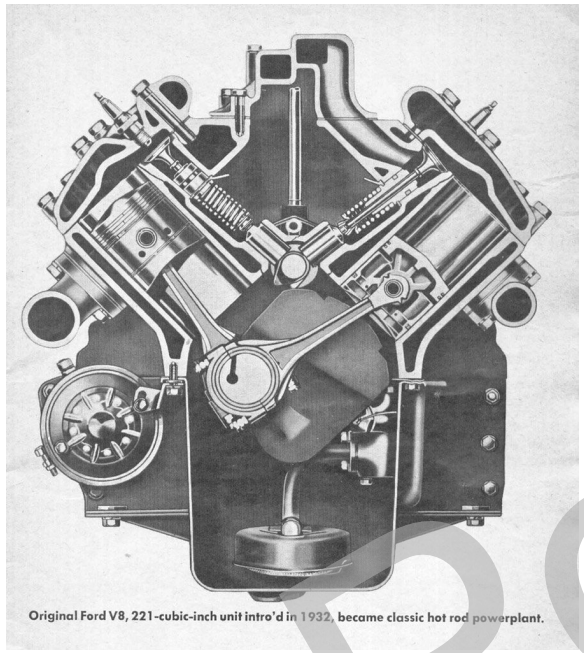


Maturity of Industrialized Technology



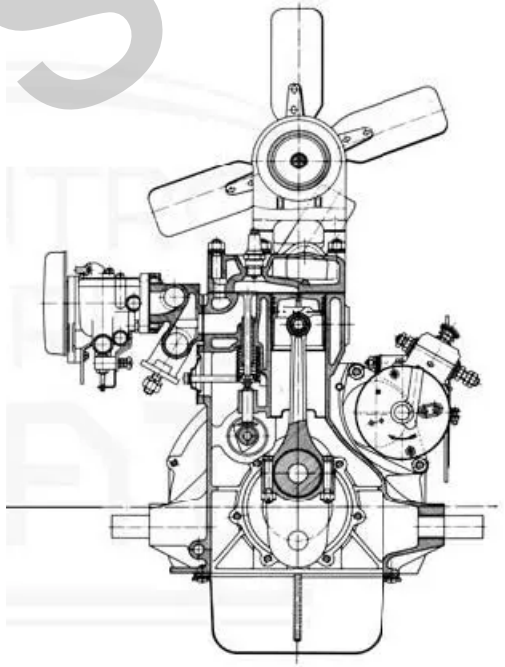
- *EV Tech Today is as Mature as 1950's ICE Tech*

1950's Combustion Engine Technologies



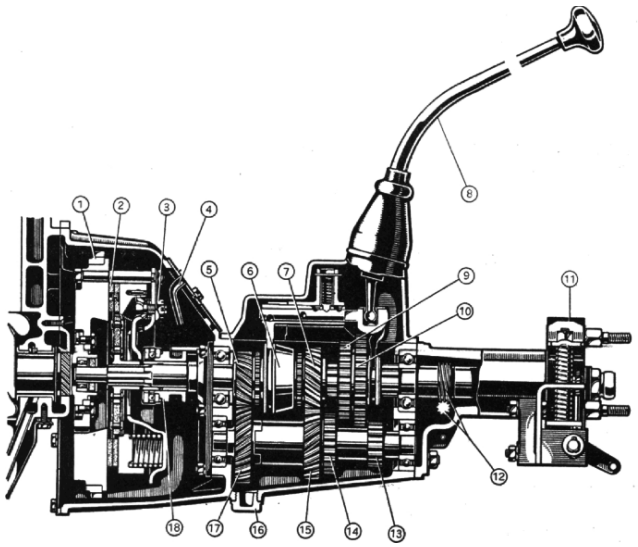
Flat Head

Air Cooled

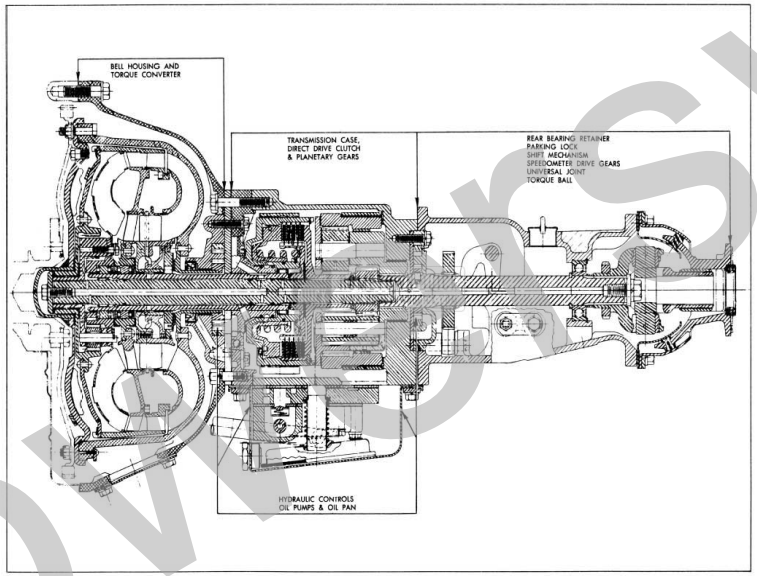


Carburetor

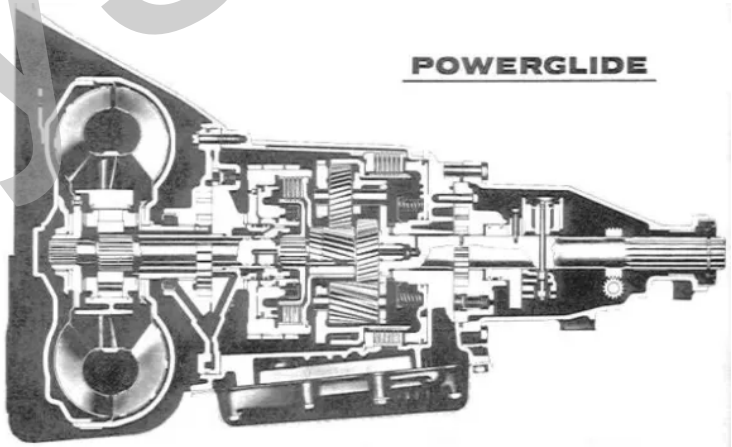
1950's Transmission Technologies



3-Speed Manual

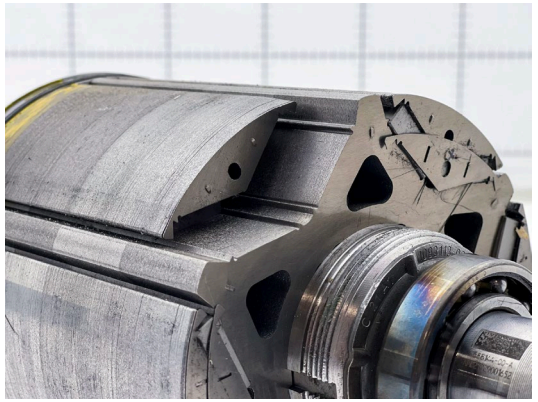


1-Speed Automatic



2-Speed Automatic

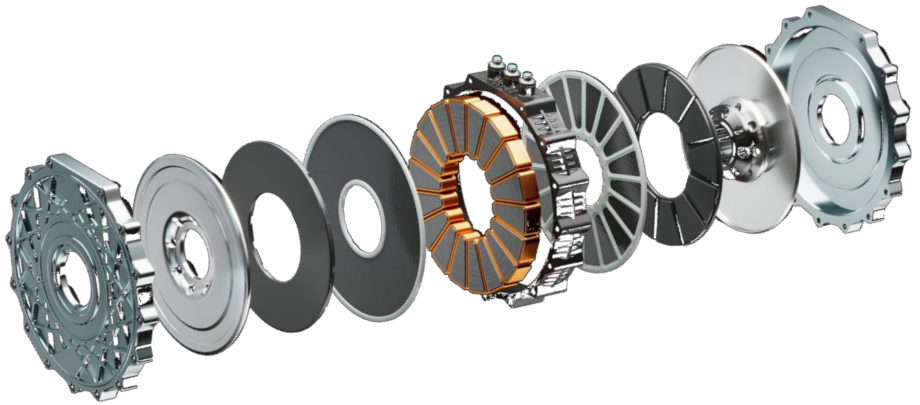
2020's Electric Machine Technologies



Rare Earth IPM

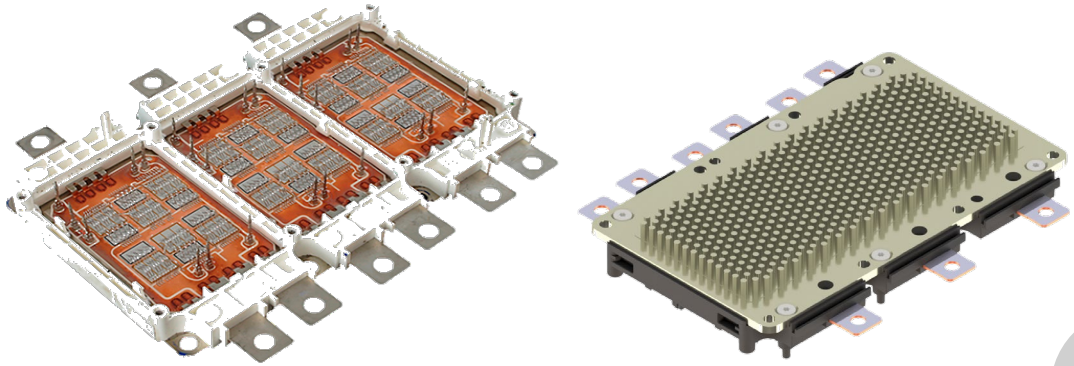
Induction

Wound Rotor, aka EESM

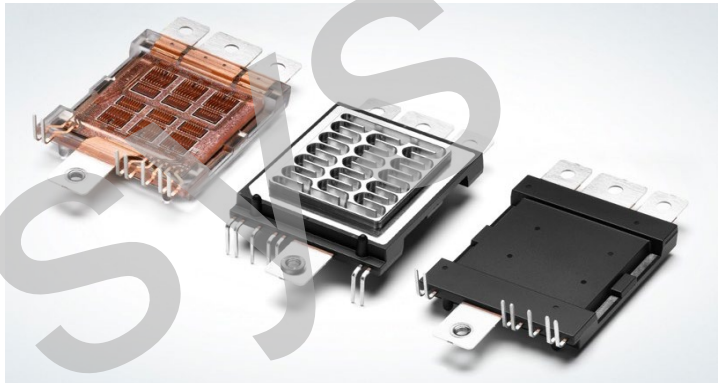


Rare Earth Axial

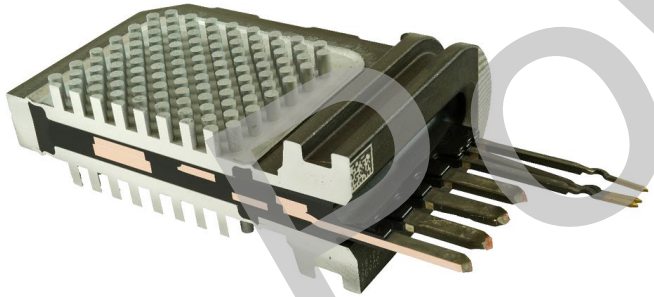
2020's Power Semiconductor Technologies



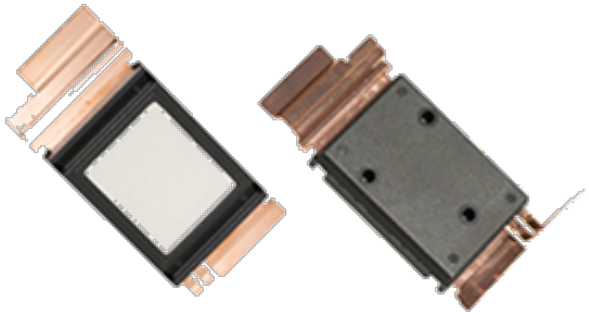
IGBT, Six-pack



SiC, Half Bridge



SiC Single Switch, Two-Sided Cooling

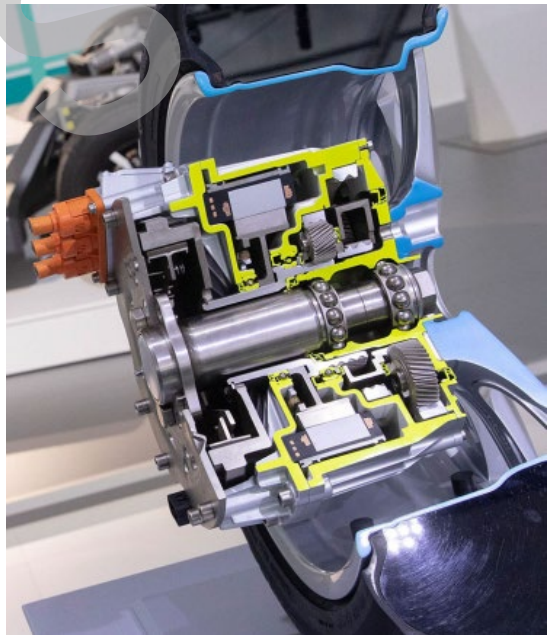


SiC, Single Switch

2020's EV Driveline Technologies

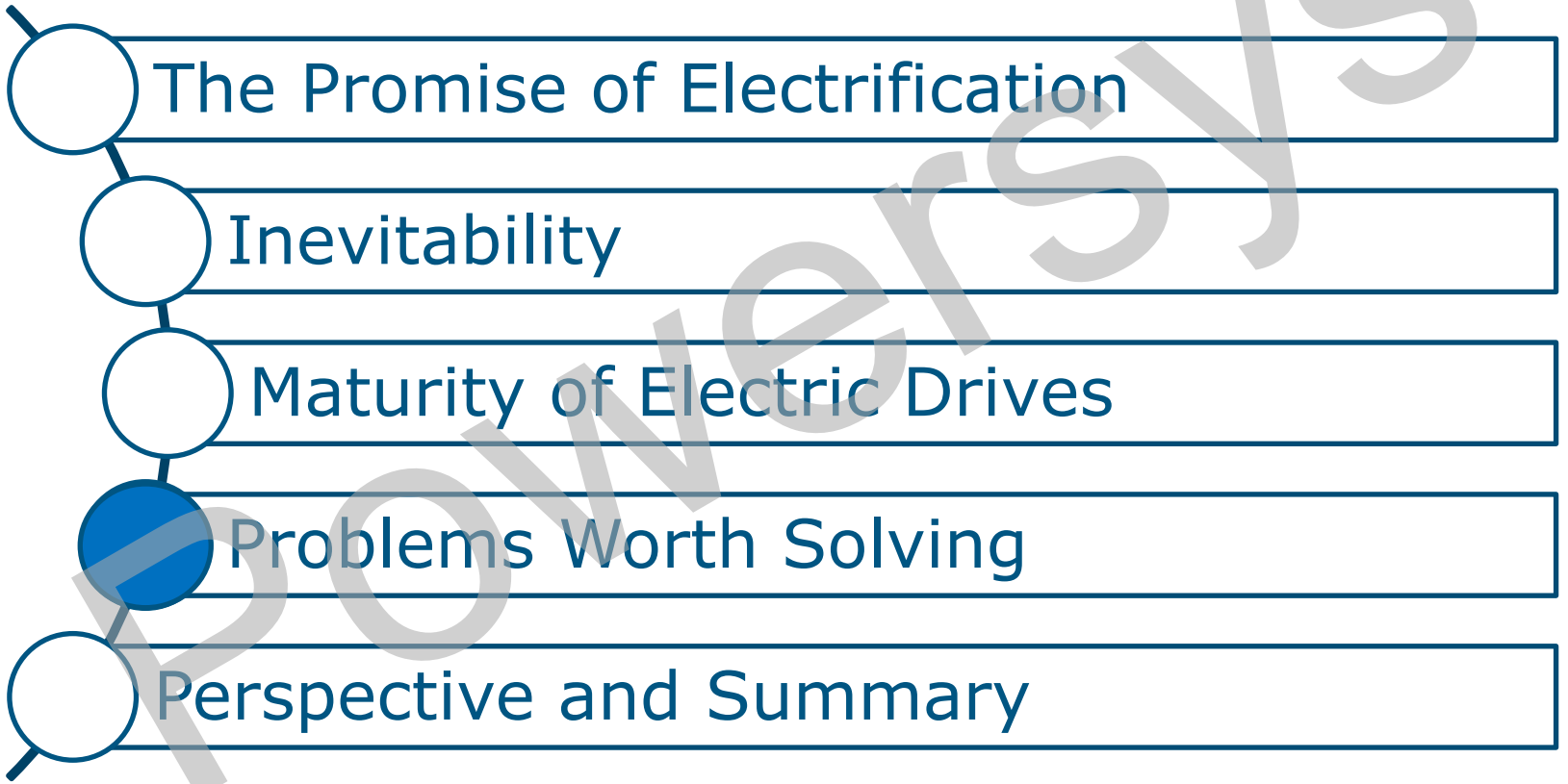
Transverse Axle

Two Motor No-Diff

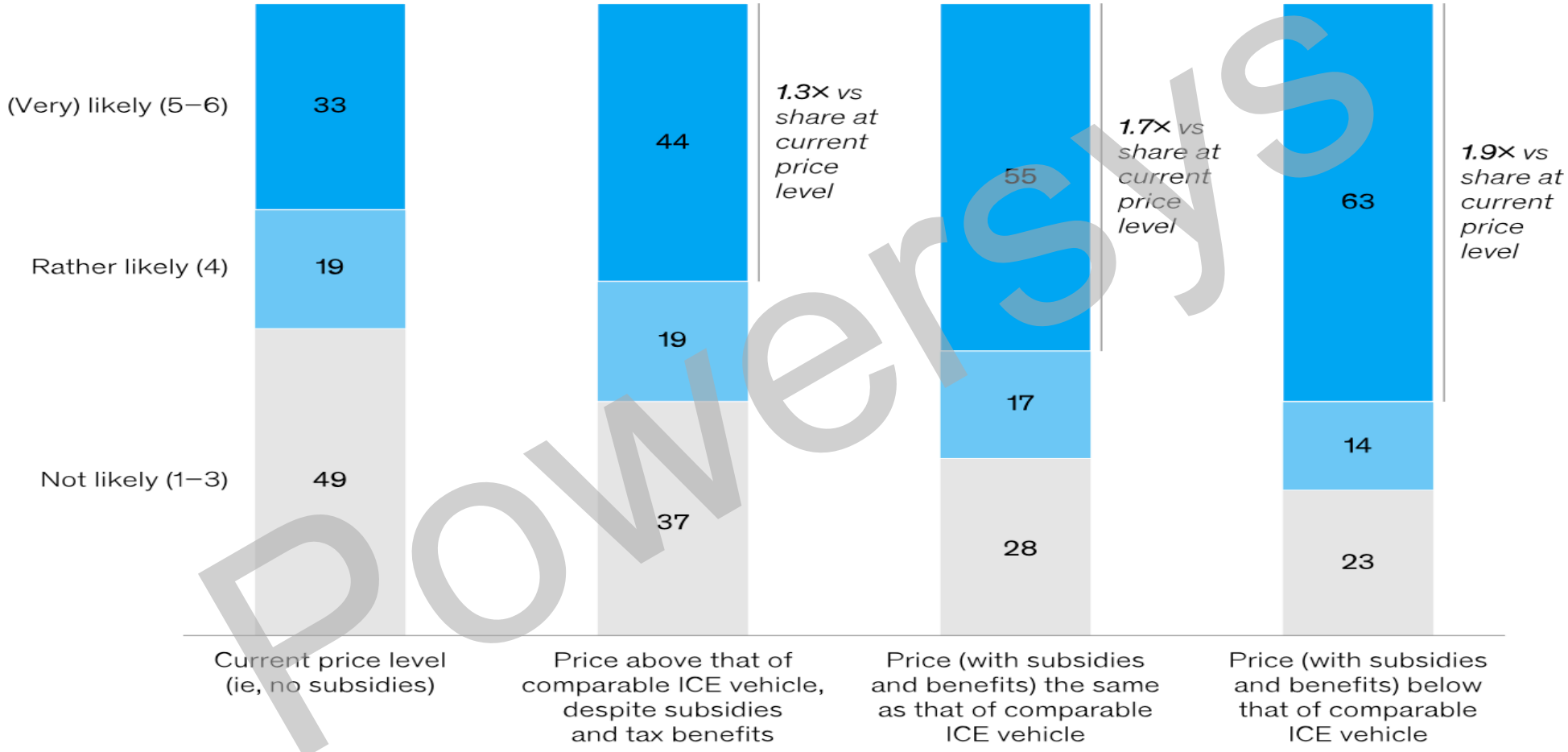


Hub Motor

Motor Design Opportunities

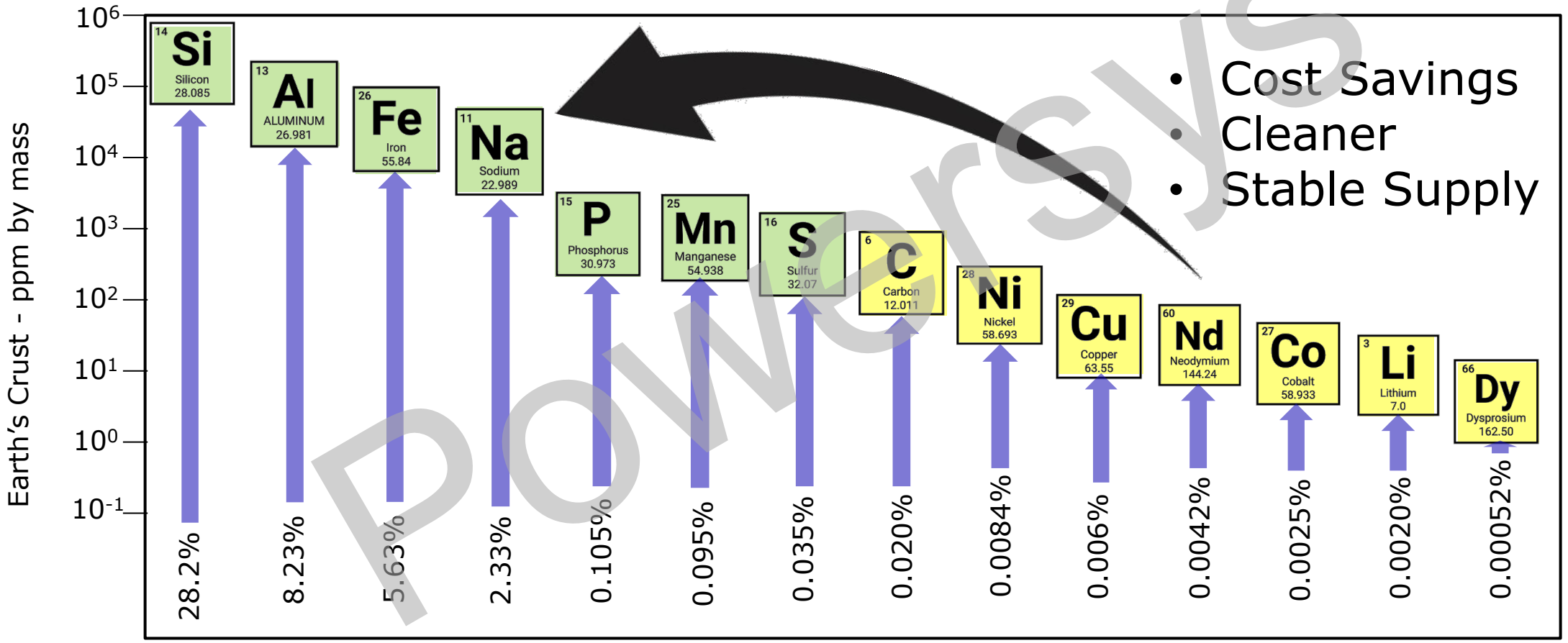


EV Purchase Likelihood, Based on Price



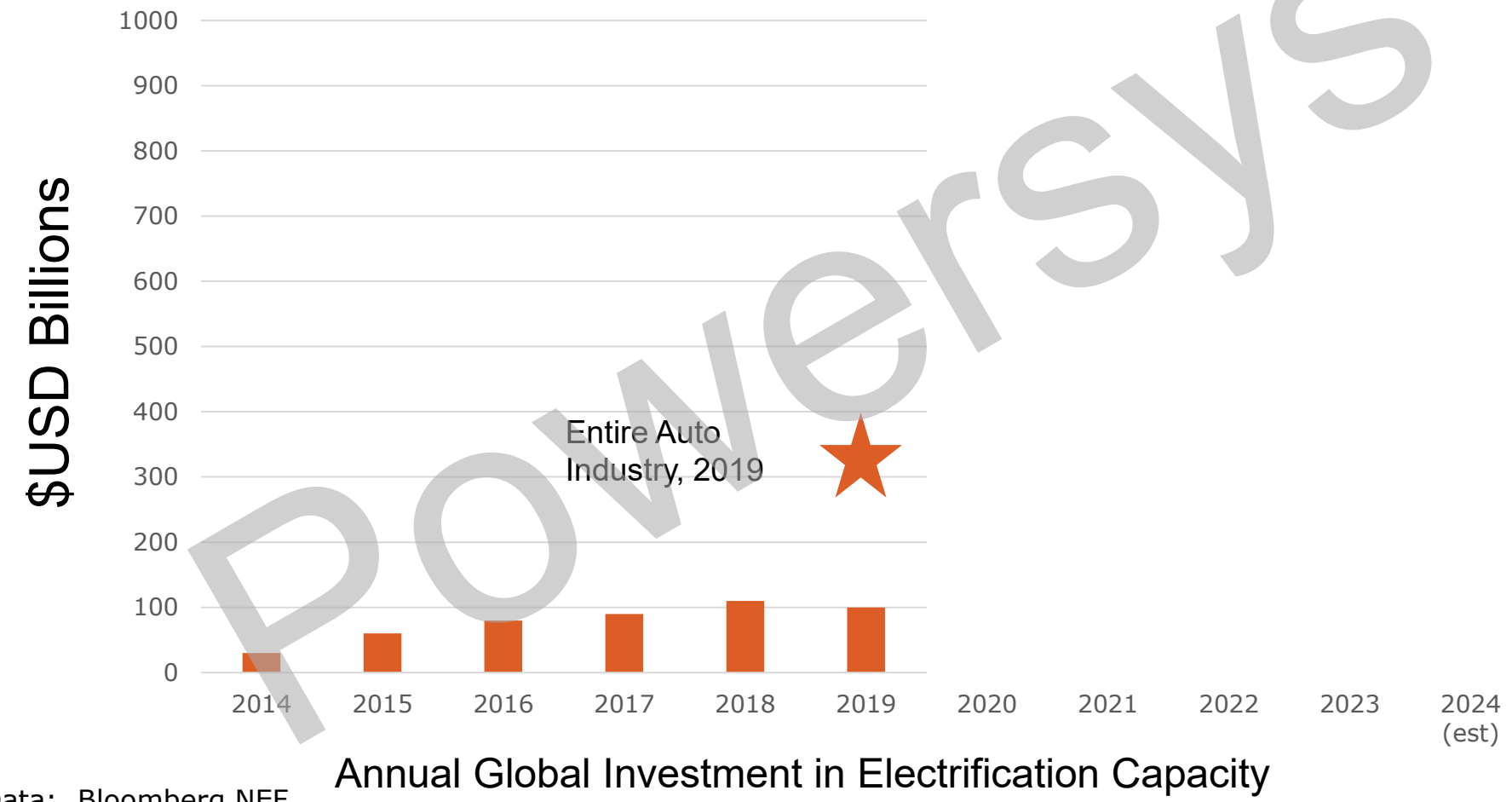
Source: McKinsey Center For Future Mobility Consumer Pulse 2025
25,904 respondents, China, France Germany, Italy, UK and US

Substitute Abundant for Scarce Materials



Source: CRC Handbook, 67th Edition

Automotive Electrification Dominates Capital Outlays



Source Data: Bloomberg NEF 2024 Outlook

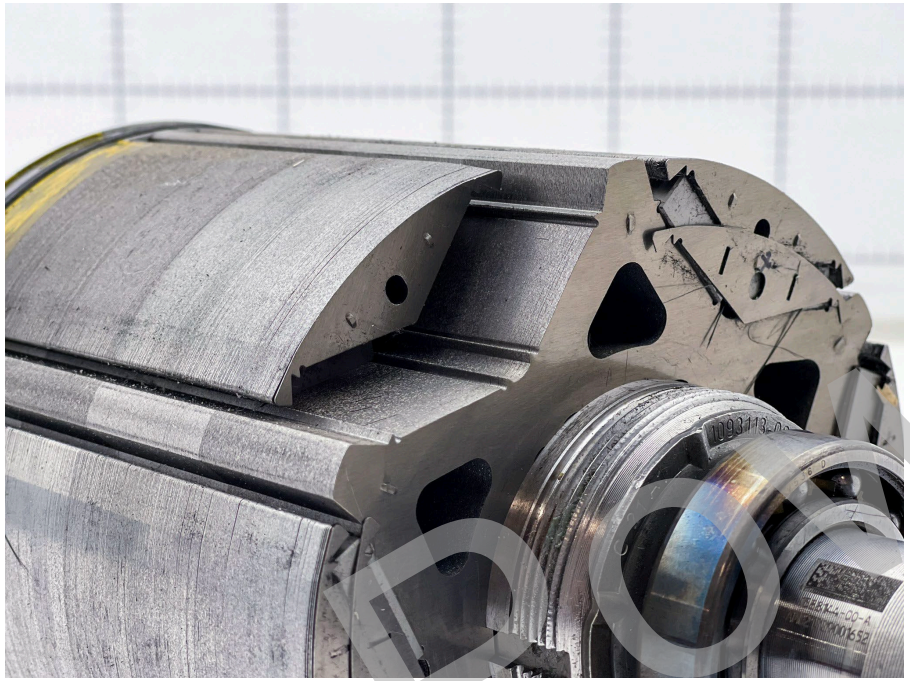
2025 – a Golden Age of Motor Innovation
- a few problems worth solving

- Eliminate Rare Earth Magnets
  - EESM optimization
  - Very high speed
- Proximity losses in windings facing the airgap
- Aluminum windings
- Net shape core – SMC
- Axial flux windings, core, build optimization
- Higher thermal duty

EESM

- Rotor coil retention
- Brush durability
- Rotating transformer – packaging, cooling
- Control optimization – vs. transient performance iq, id, if
- Overall optimization – poles, speed range, size

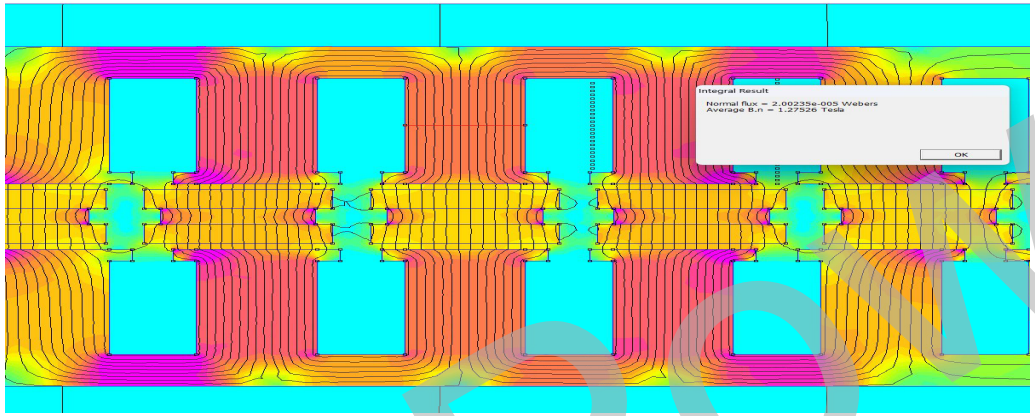
Very High Speed Operation

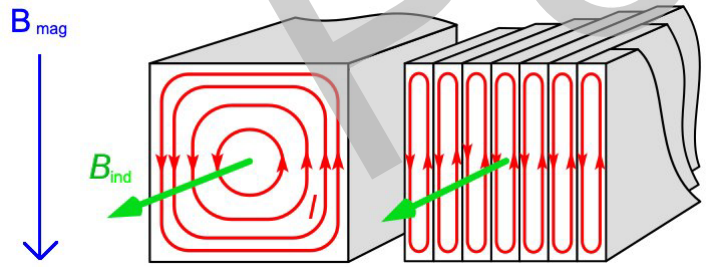


- Stuctural optimization vs magnetic optimization
- Structural wrap
- High frequency losses
- Gear pitchline velocities and lube

Winding Proximity Losses

$$P = \frac{\pi^2 B_p{}^2 d^2 f^2}{6k\rho D}$$

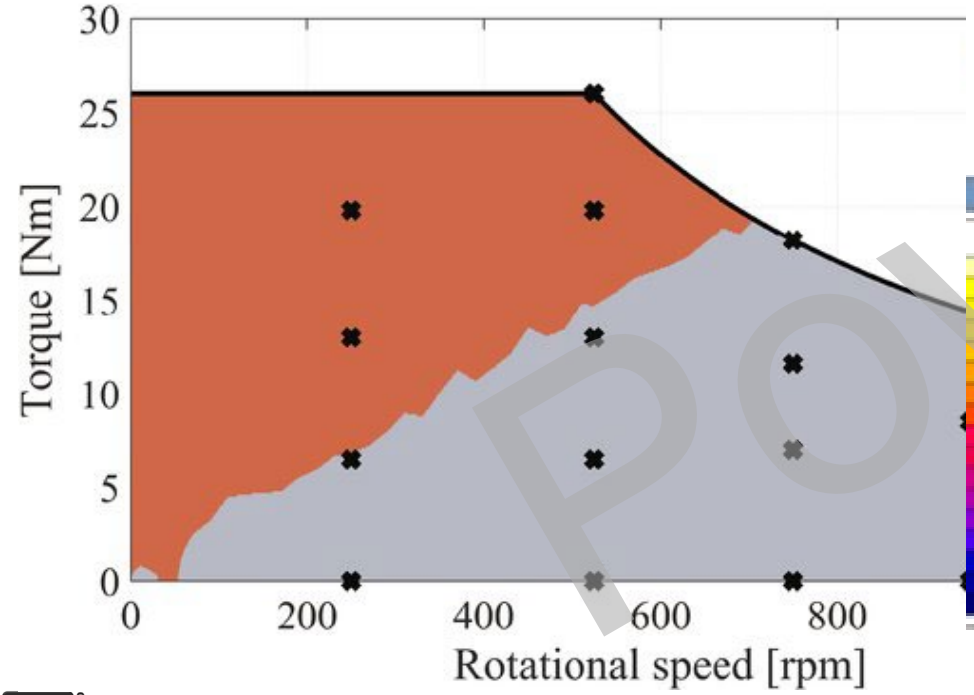


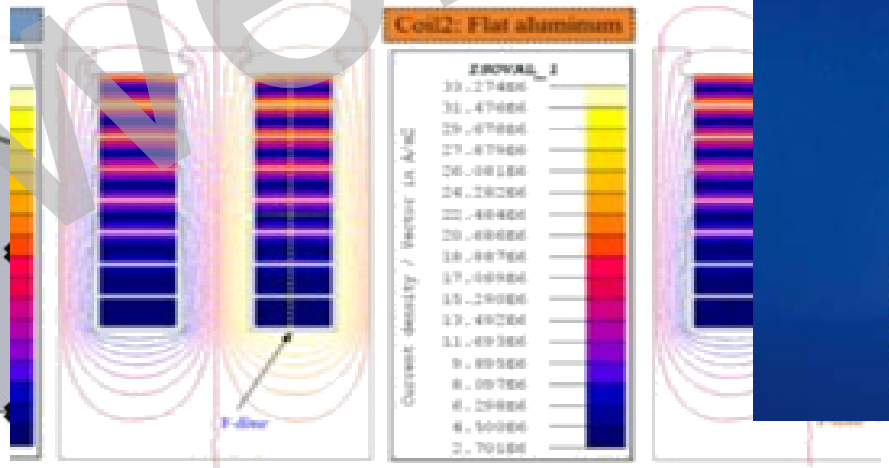


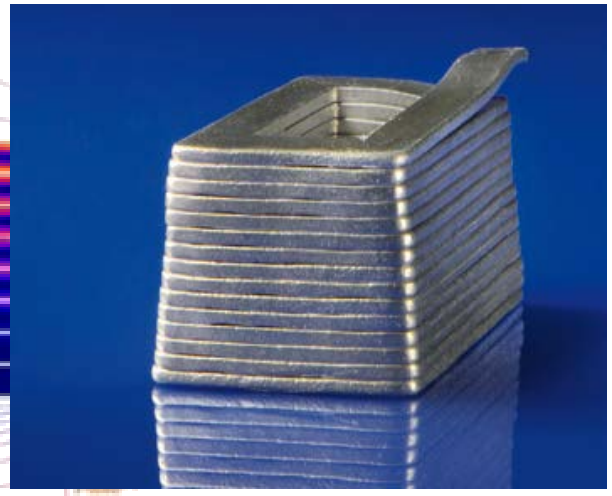
- Conductor size and shape optimization
- Optimization of winding count and conductor size
- Combined thermal and AC loss effects
- Tooth tip / pole shoe / semi-magnetic wedge value
- Airgap optimization

Aluminum Windings

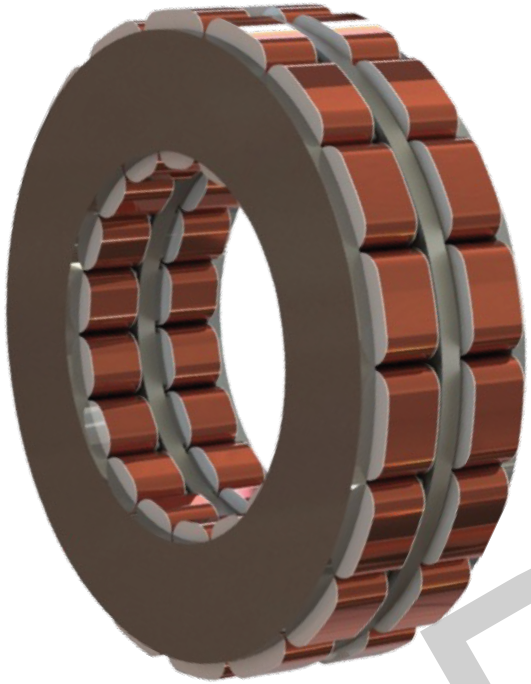
- Machine size, pole, slot optimization for Al
- Speed range optimization AC vs DC losses
- Coil formation, terminations and interconnects







Axial Flux Machine Design Optimization

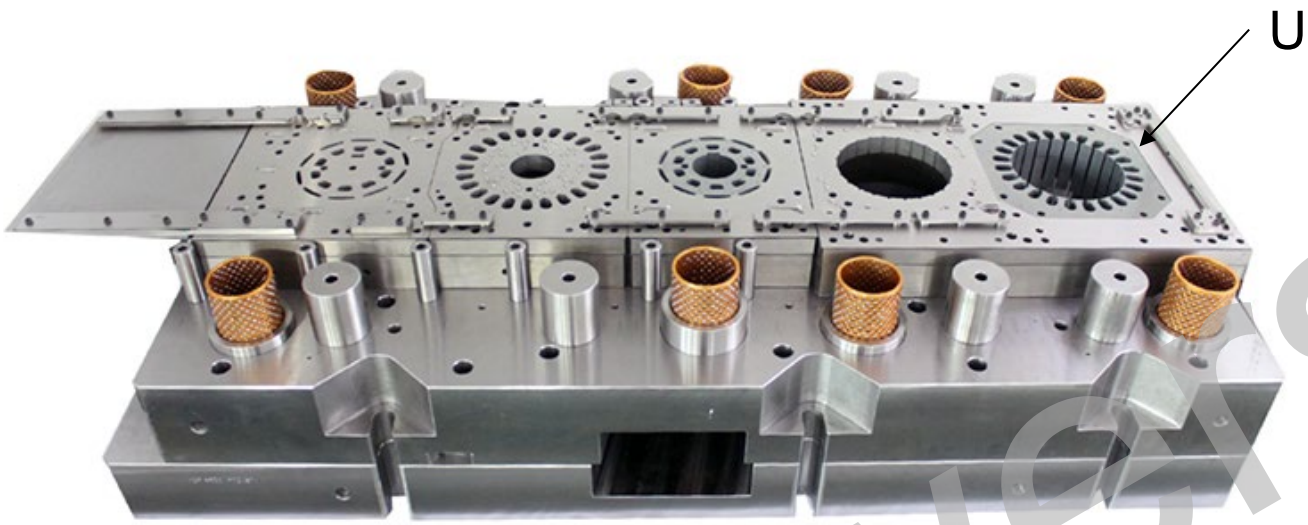


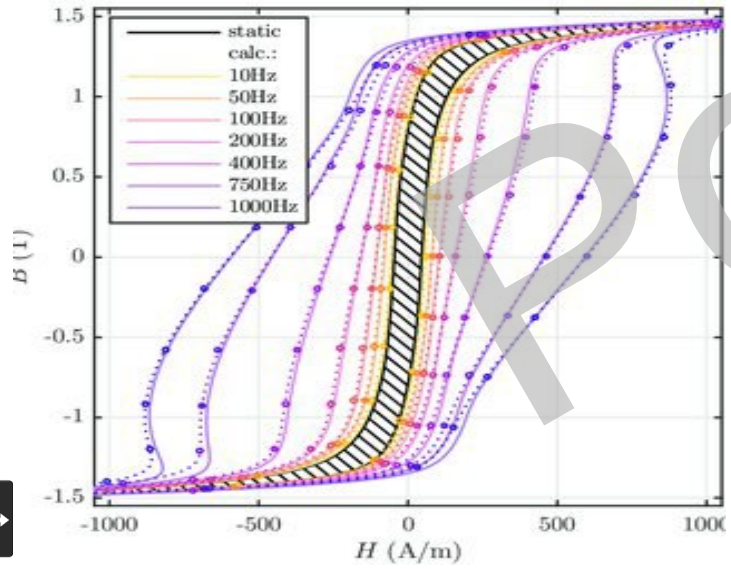
Single Rotor
Double Stator

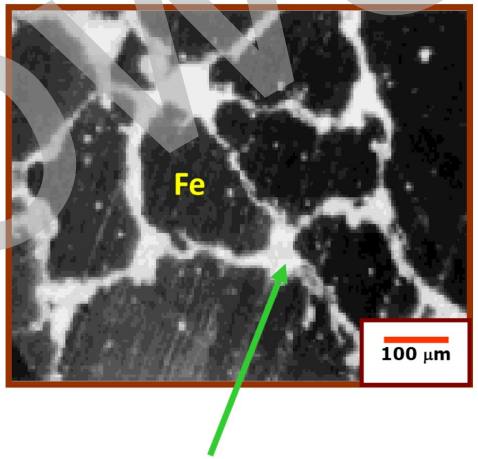
Double Rotor
Single Stator

- Topology selection
- Very high specific torque (hub motor)
- 3d effects
- Coil types and formation
- Thermal
- NVH – rotor ”Cymbal”

SMC – Net Shape Core

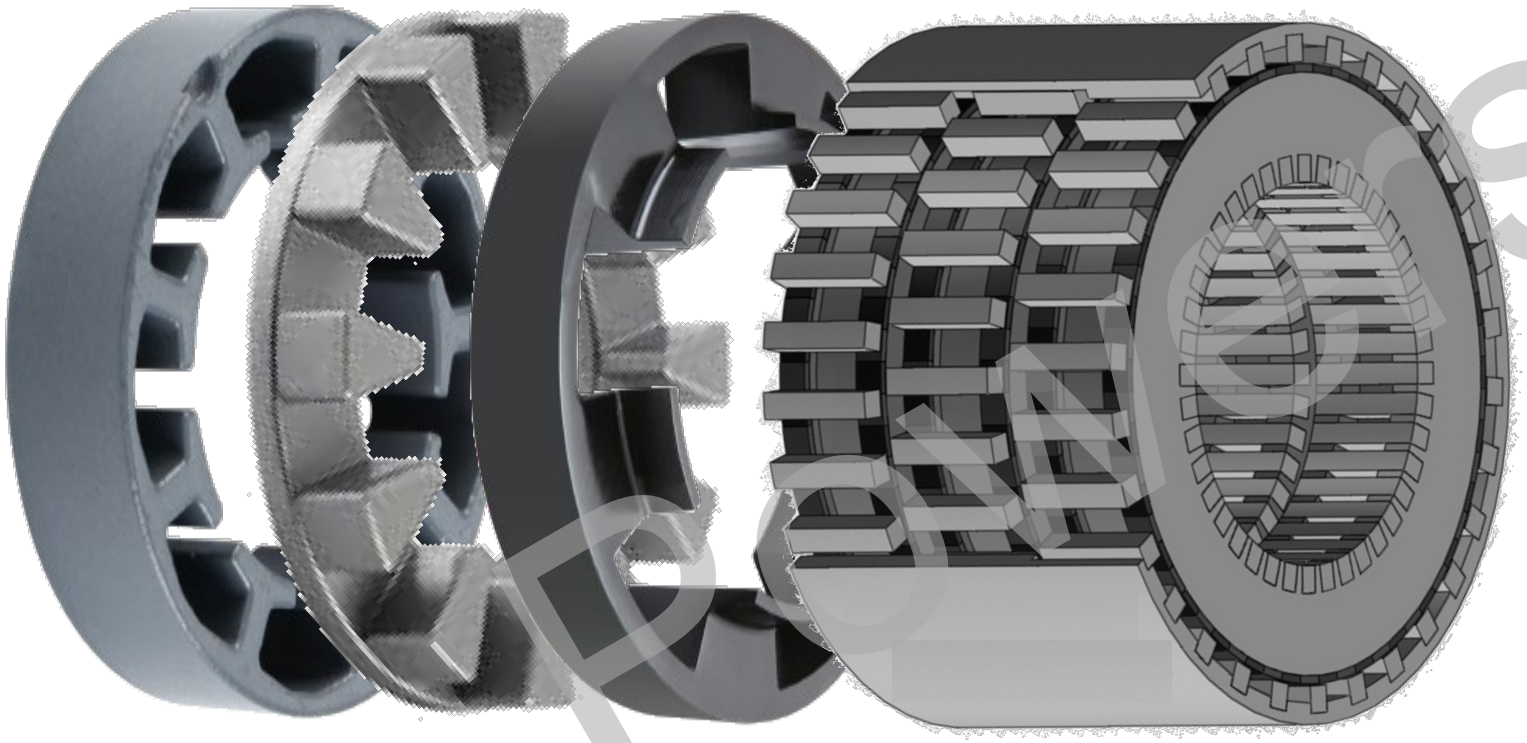






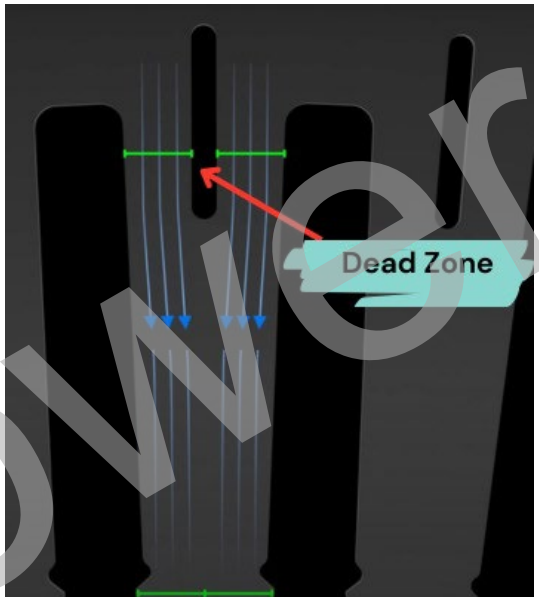
- Size and geometry constraints of PM process
- Lower saturation limit
- Higher hysteresis losses
- Isotropic properties

3d Motor Topologies



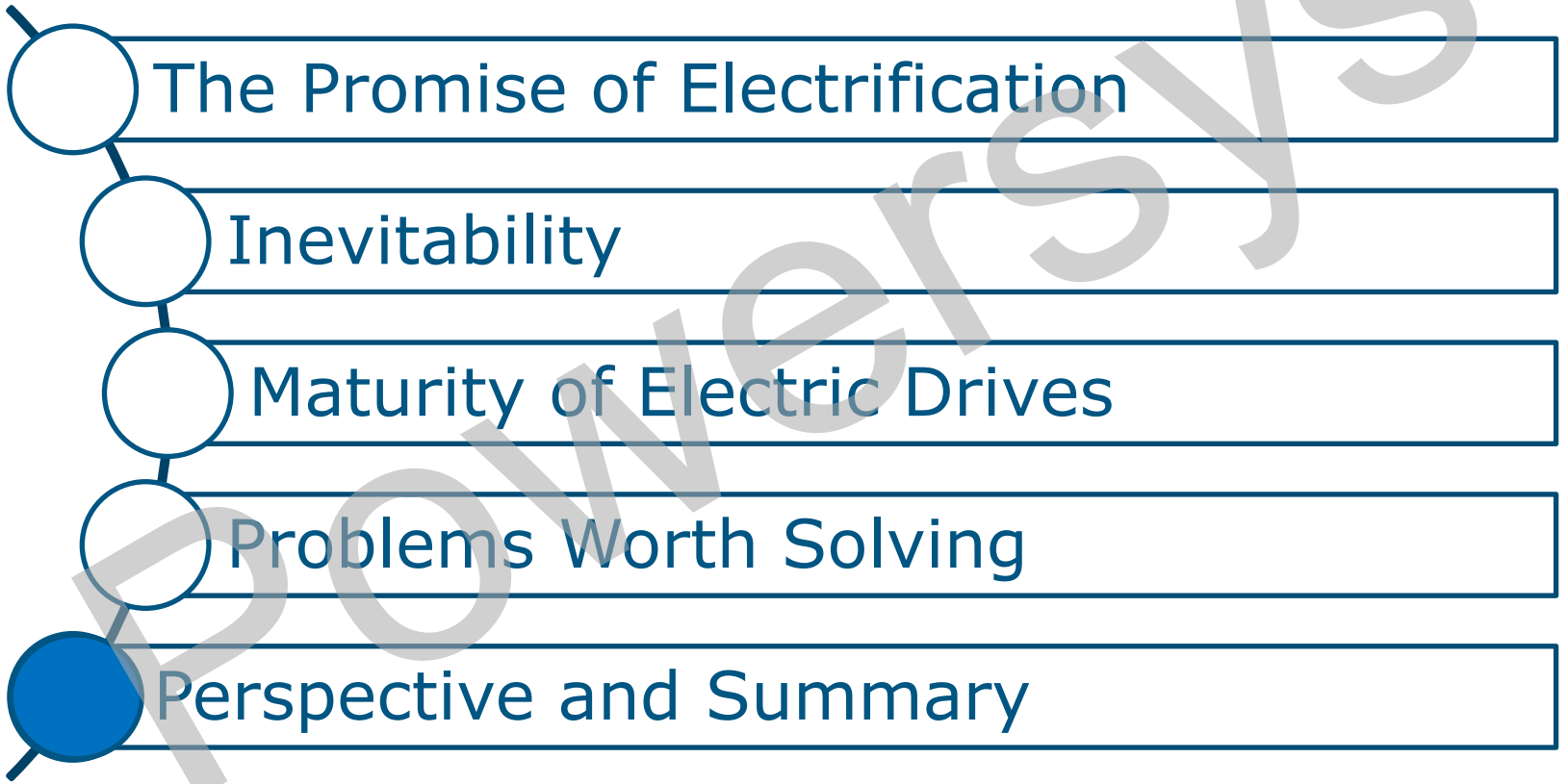
- 3d Flux paths
- 3d Airgaps
- High Frequency losses
- Cooling

Very High Thermal Duty



- Very high temp insulation systems
- Convection optimization
- Potting systems
- Accelerated ageing / durability
- Differential growth, eg rotor to stator
- Transient growth

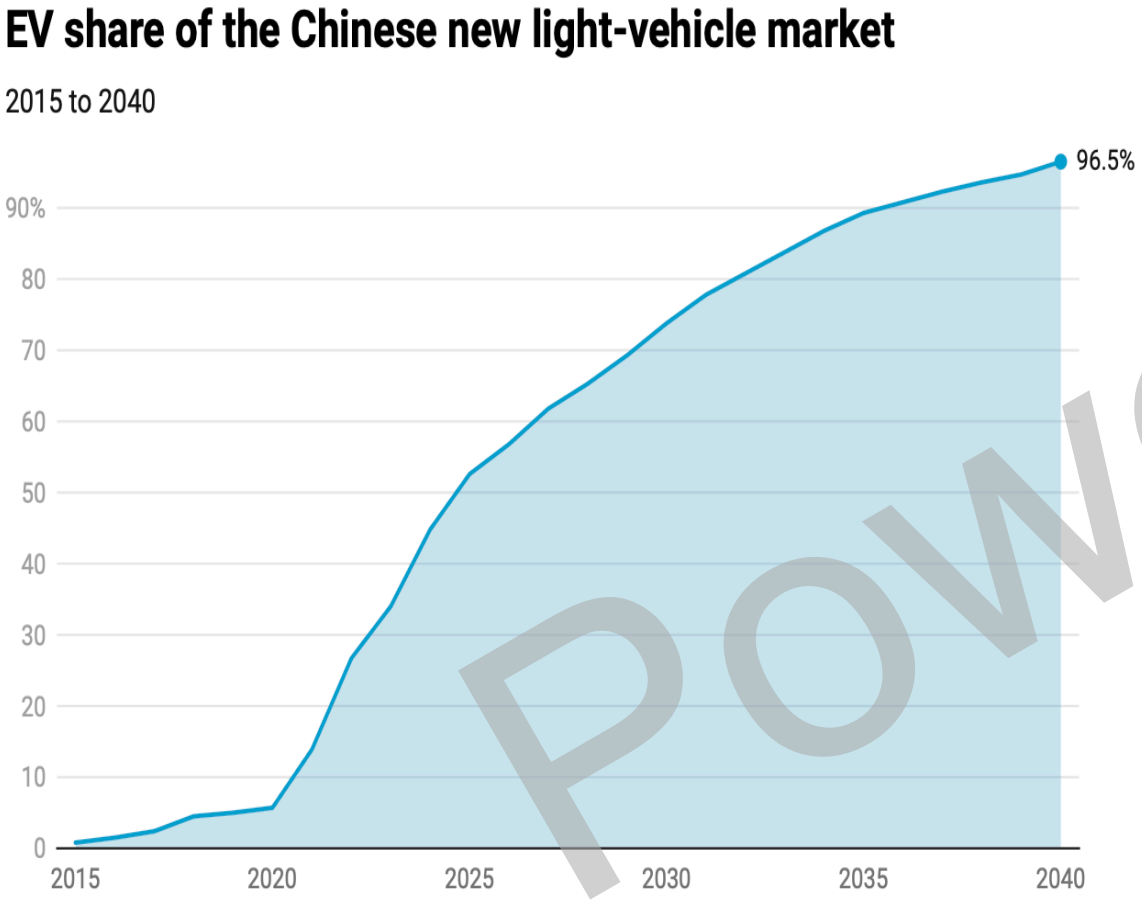
Motor Design Opportunities

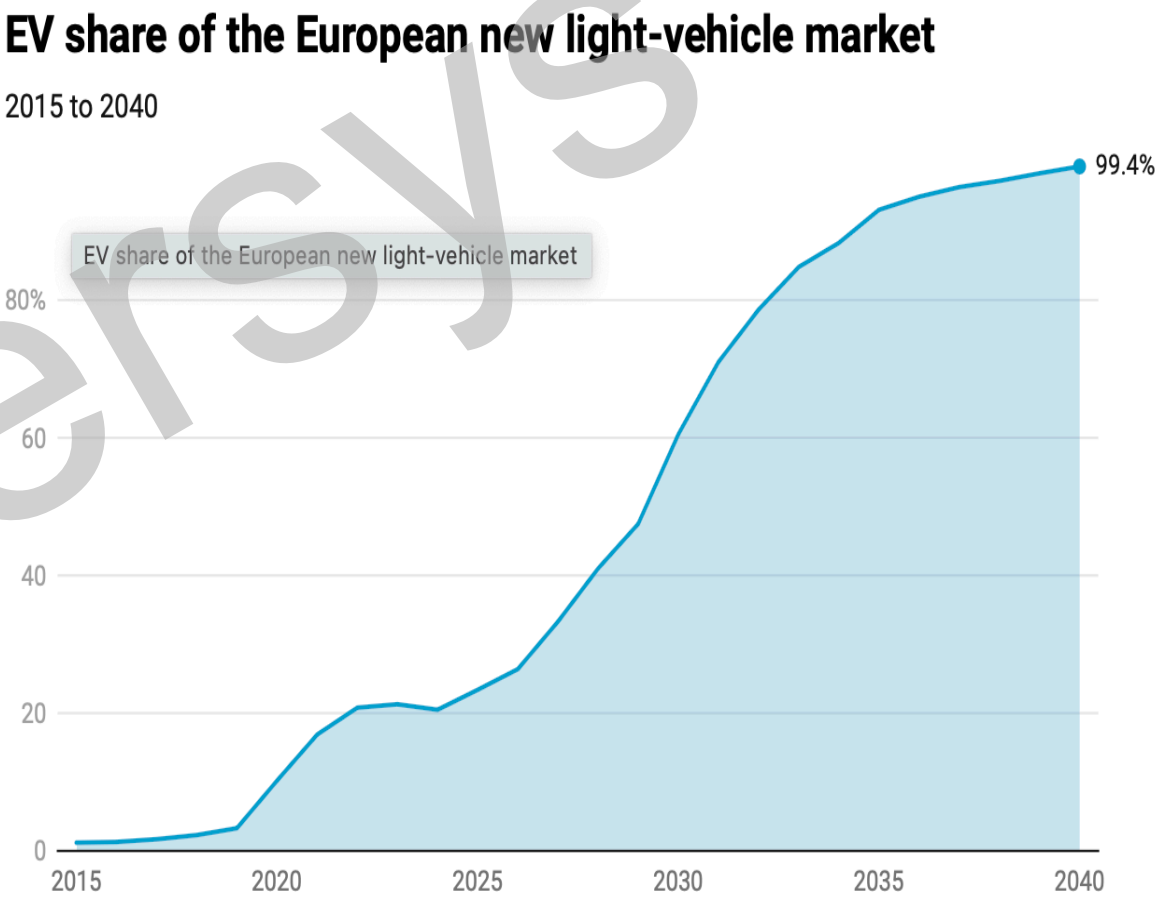


Summary

- Mobile Electrification can address 13% of man-made CO2.
- Recent headwinds in EV growth doesn’t mean that EVs are not superior; it means that some companies have executed poor EVs, ie, products that do not ”fly”.
- Positive Total Cost of Ownership relative to IC powered products is acheivable in many mobility electrification markets today.
- Motor cost improvement will increase TCO advantage.
- EV Drive technology is still immature relative to a fully industrialized product.
- We are in a Golden era of EV drive innovation, with many problems worth solving!

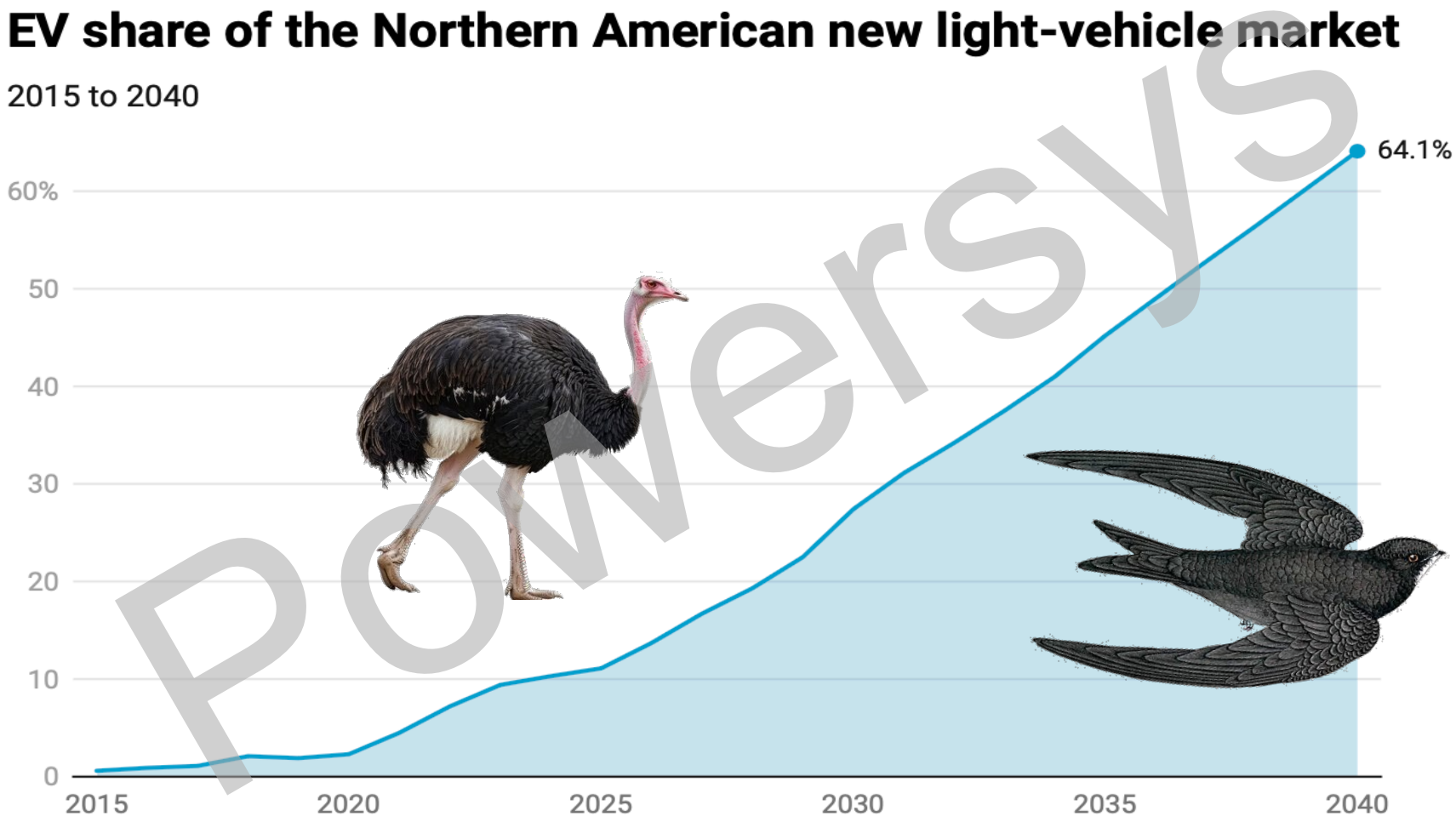
The Sun Shines, Even on Cloudy Days





Source: BNEF EV Outlook 2025

The Sun Shines, Even on Cloudy Days



Source: BNEF EV Outlook 2025

Q and A

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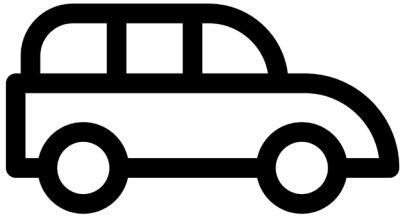
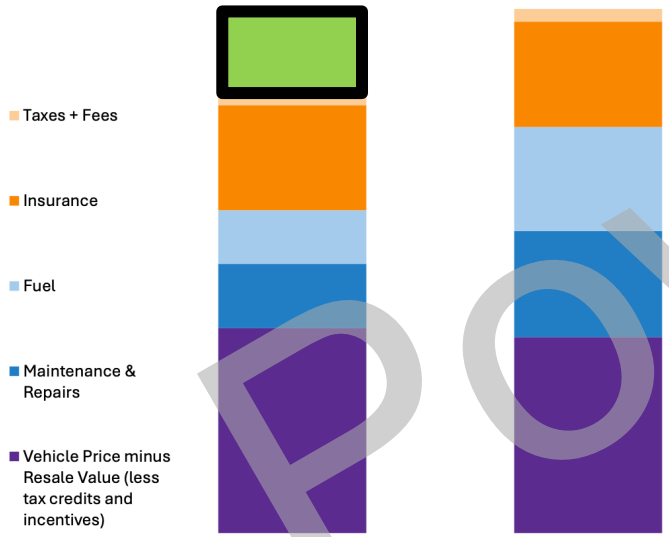
June 5th, 2025 Southfield, MI

EV TCO for US Light Duty Vehicles



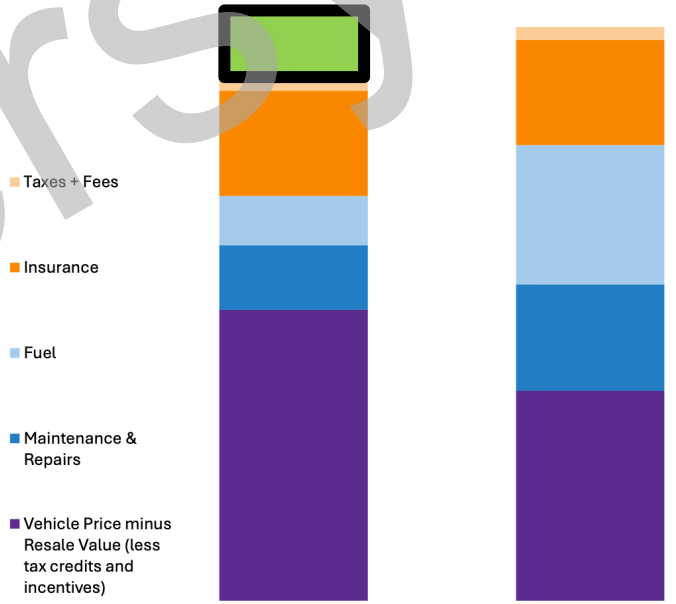
VW ID.4 Pro
TCO Before Incentive: $44.510
TCO After Incentive: **$37,110**

Nissan Rouge SV
TCO $44,209



Tesla Model Y
TCO Before Incentive: $51,425
TCO After Incentive: **$43,925**

Toyota Highlander. L
TCO: $48,286



Comparing the Cost of Owning the Most Popular Vehicles in the United States
Atlas Public Policy March 2024
N. Nigro, D. Wilkins

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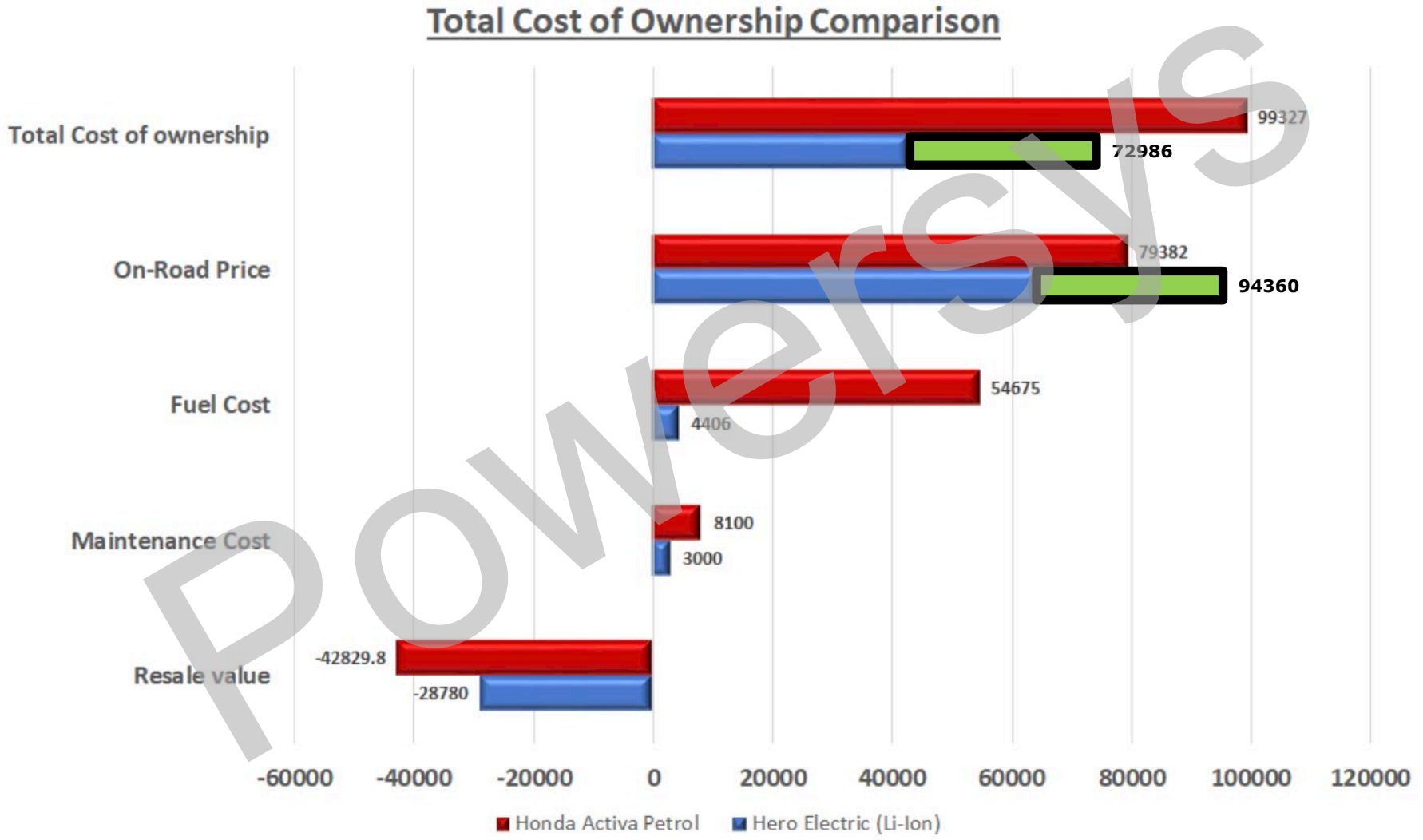
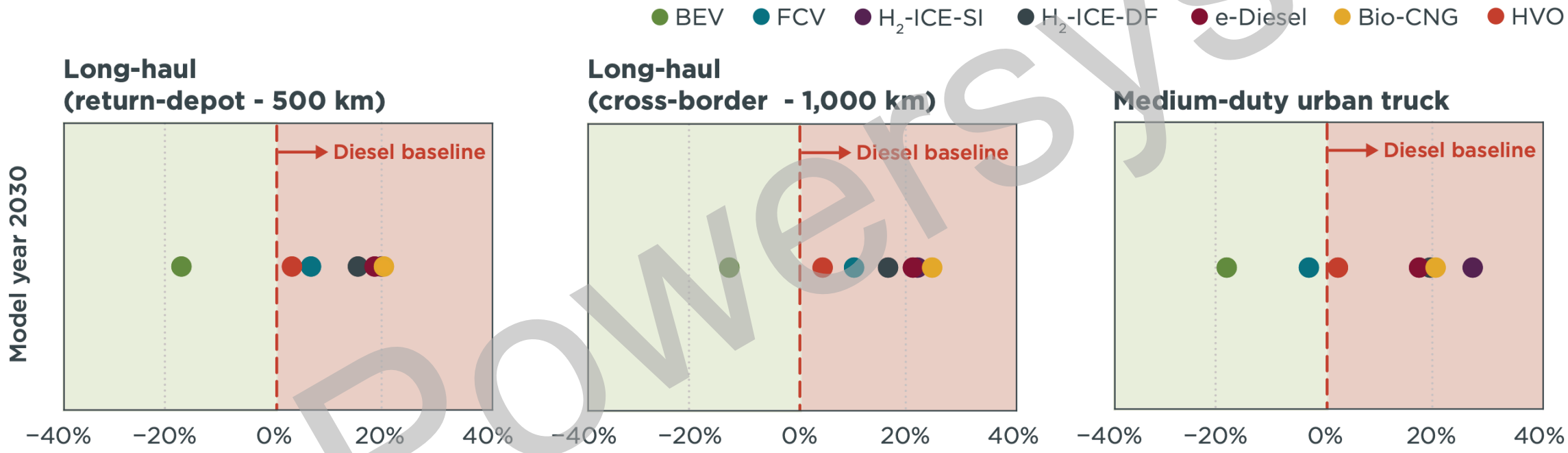
EV TCO for India 2 – Wheelers



EV TCO for European On - Road Trucks



A Total Cost of Ownership Comparison of Truck Decarbonization Pathways in Europe
ICCT Working Paper Nov 2023
H. Basma, F. Rodriguez

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EV TCO for EU Regional Aviation

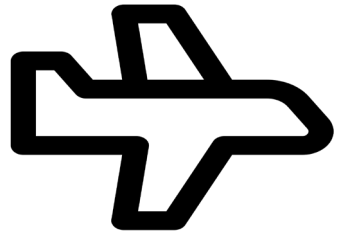

Table 6- DOC, GOC, and TOTAL Cost of the roundtrip to Arlanda from Sveg.

Route	*Distance*		*Beechcraft 1900D*	*Jetstream JS31*	*ES-19*
Sveg-Arlanda	328 km	*DOC*	32 780 kr	34 243 kr	27 193 kr
		GOC	2 610 kr	2 589 kr	2 653 kr
		TOTAL	**35 390 kr**	**36 833 kr**	**29 846 kr**

Operating Cost Analysis of Electric Aircraft on Regional Routes, Shahwan,K., Linkoping U. , Dec 2021

EV TCO for US Outboard

https://equatorial-power.com/uncategorized/e-mobility-for-fishermen-on-lake-victoria-part-4/