

Power Electronics 5.0

Johann W. Kolar, et al.



Swiss Federal Institute of Technology (ETH) Zurich
Power Electronic Systems Laboratory
www.pes.ee.ethz.ch

Sept. 6, 2023



Power Electronics 5.0

J. W. Kolar, L. Imperiali, D. Menzi, J. Huber, F. Musil*



* Fronius International GmbH, Austria
Swiss Federal Institute of Technology (ETH) Zurich
Power Electronic Systems Laboratory
www.pes.ee.ethz.ch

Sept. 6, 2023



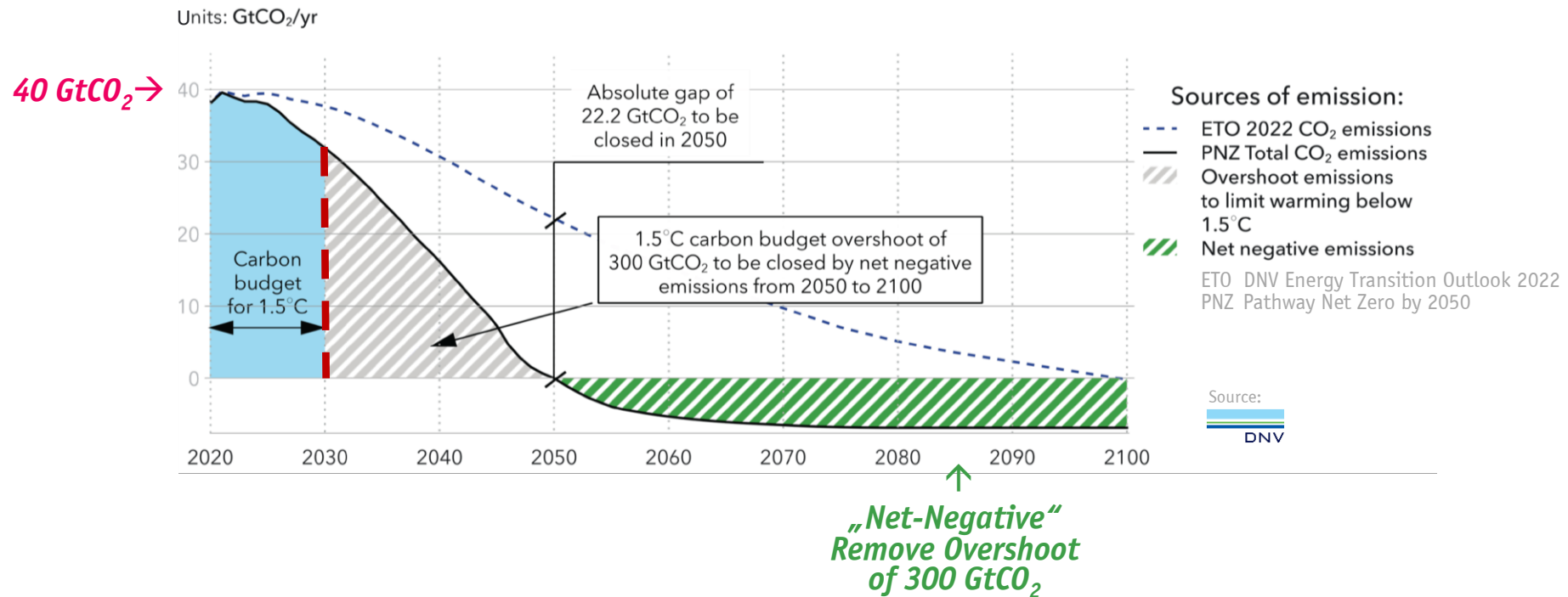
Outline



- ▶ *Decarbonization*
- ▶ *Internet of E-Energy*
- ▶ *Power-E-Waste*
- ▶ *Paradigm Shift*
- ▶ *Power Electronics 5.0*

Decarbonization

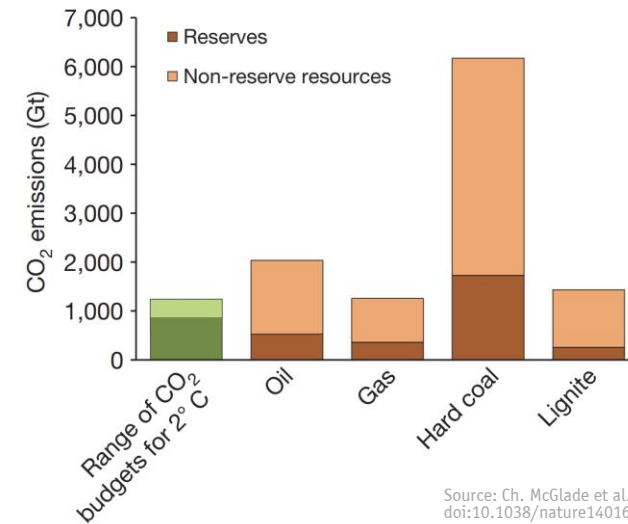
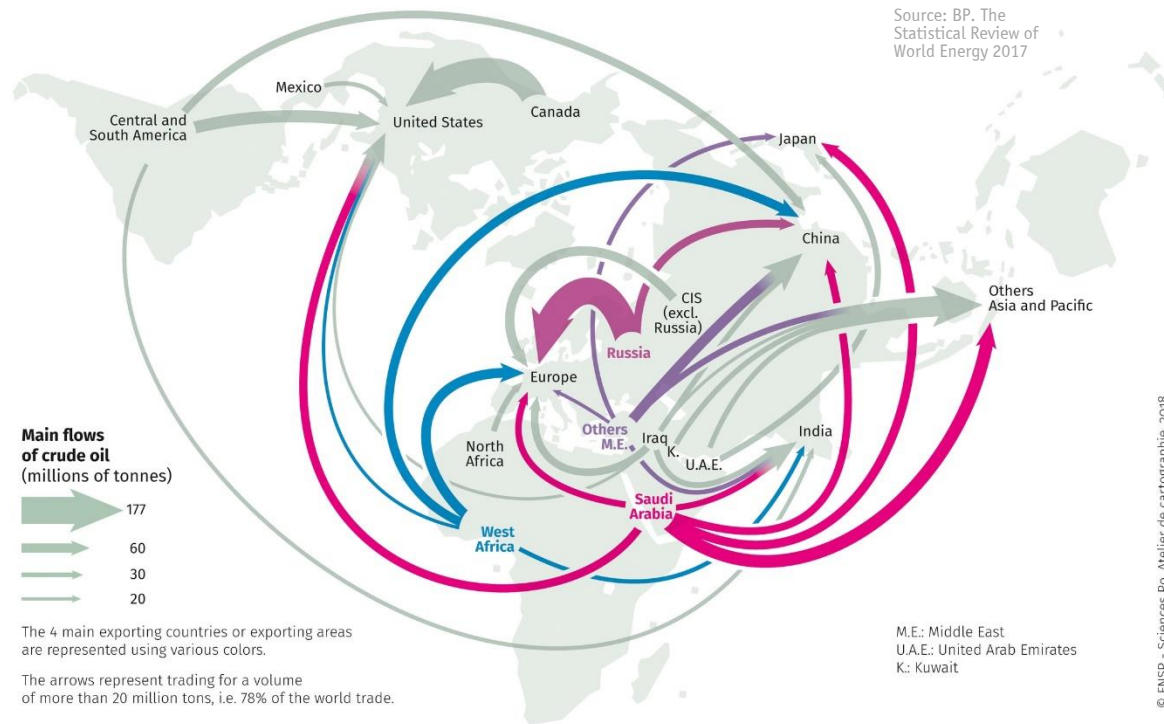
- **“Net-Zero” Emissions by 2050 & Gap to be Closed**
- **50 GtCO_{2eq} Global Greenhouse Gas Emissions / Year → 280 GtCO₂ Budget Left for 1.5°C Limit**



- **Challenge of Stepping Back from Oil & Gas**
- **Human History — Transition from Lower to Higher Energy Density Fuel — Wood → Coal → Oil & Gas**

Energy Independence / Security of Supply

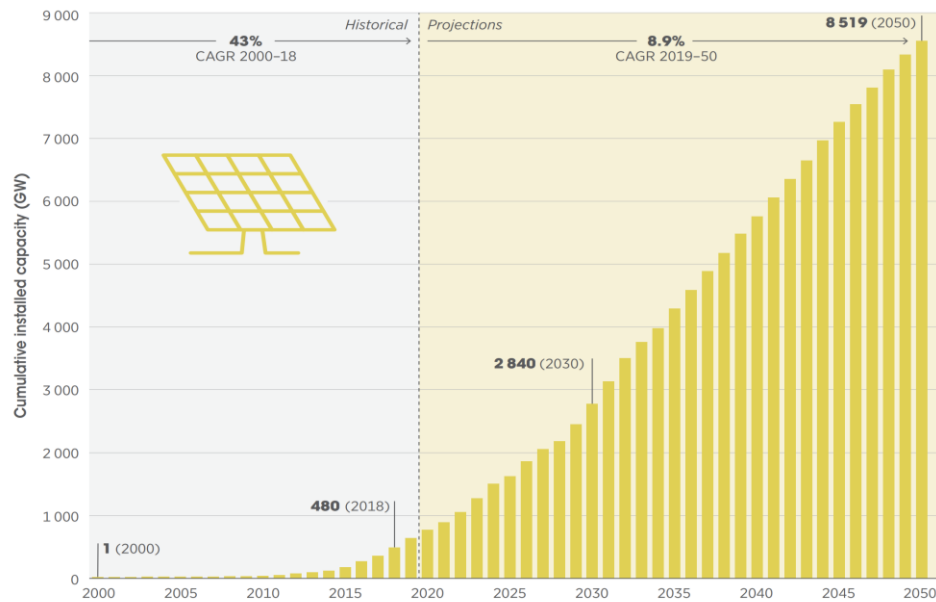
■ Global Oil Trade (2016) — High Import Dependency of Leading Economies



- **2°C Target → Globally, 30% of Oil Reserves | 50% Gas Reserves | > 80% Coal Reserves Should Remain Unused (!)**
- **“The Stone Age Didn't End for Lack of Stone — The Oil Age will End Long Before the World Runs Out of Oil”**

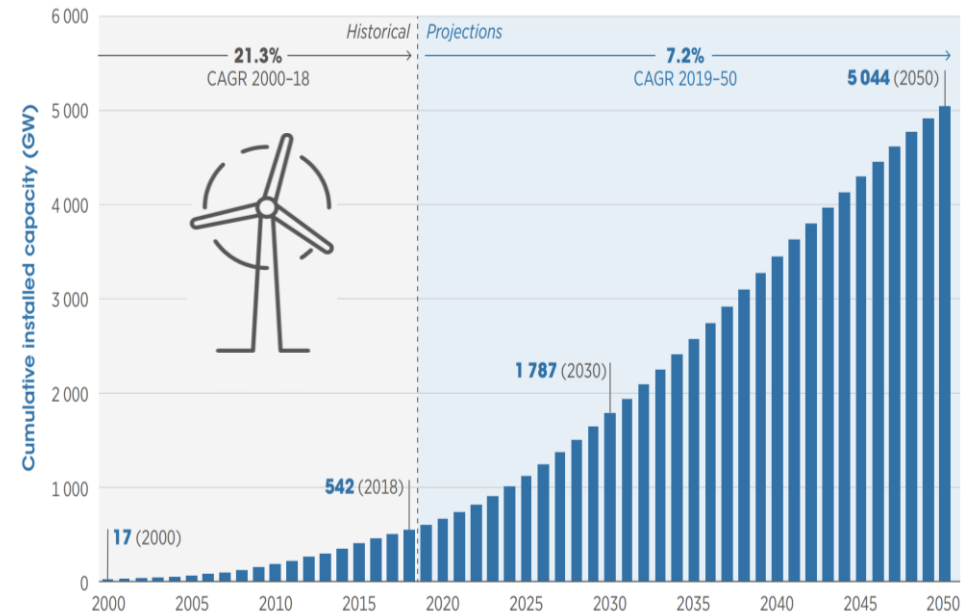
PV & On-Shore Wind Power Installations

- Outlook of Global Cumulative Installations Until 2050 / Add. 1000 GW Off-Shore Wind Power
- In 2050 Deployment of 370 GW/Year (PV) & 200 GW/Year (On-Shore Wind) incl. Replacements



Sources: Historical values based on IRENA's renewable energy statistics (IRENA, 2019c) and future projections based on IRENA's analysis (2019a).

■ CAGR of $\approx 9\%$ up to 2050 \rightarrow 8500 GW

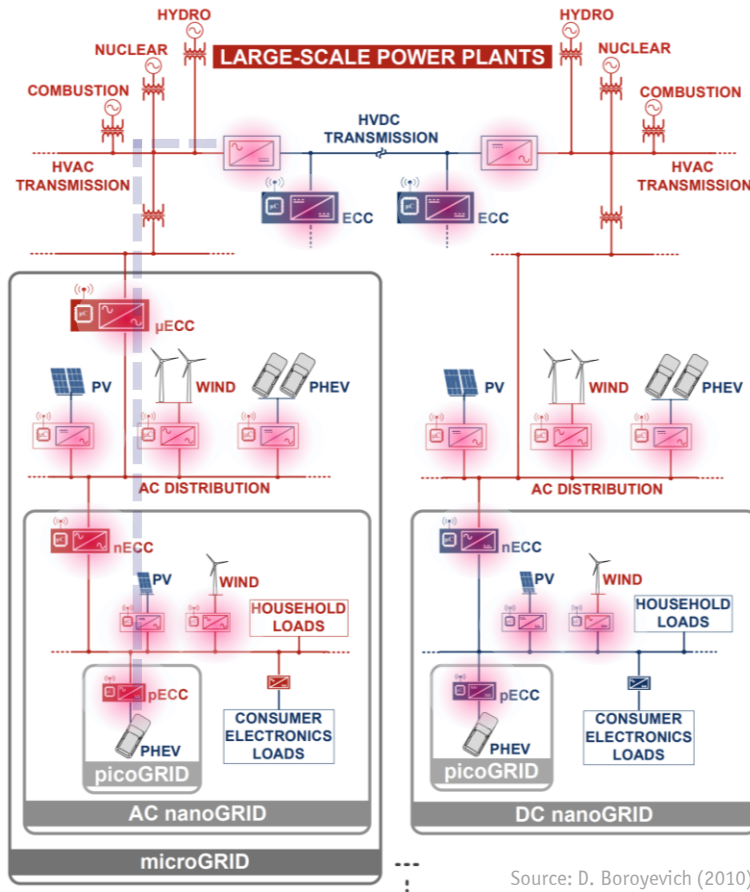


Source: Historical values based on IRENA's renewable capacity statistics (IRENA, 2019d) and future projections based on IRENA analysis (IRENA, 2019a).

■ CAGR of $\approx 7\%$ up to 2050 \rightarrow 5000 GW

The in the Room —

WHAT WE'RE NOT TALKING ABOUT



Source: D. Boroyevich (2010)

- 25'000 GW Installed Ren. Generation in 2050
- 15'000 GWh Batt. Storage
- 4x Power Electr. Conversion btw Generation & Load
- 100'000 GW of Installed Converter Power
- 20 Years of Useful Life

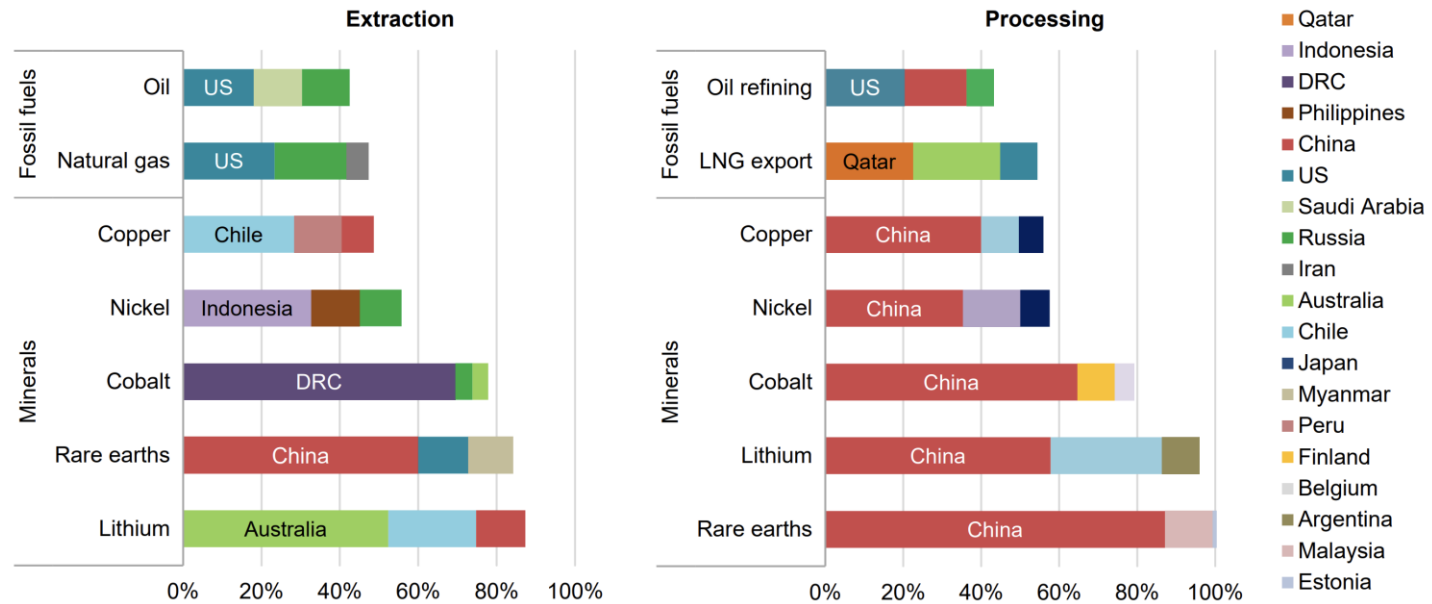


Source: www.e-waste-recyclers.co.in

- 5'000 GW_{eq} = 5'000'000'000 kW_{eq} of E-Waste / Year (!)
- 10'000'000'000 \$ of Potential Value

Critical Minerals

■ Production of Selected Minerals Critical for the Clean Energy Transition



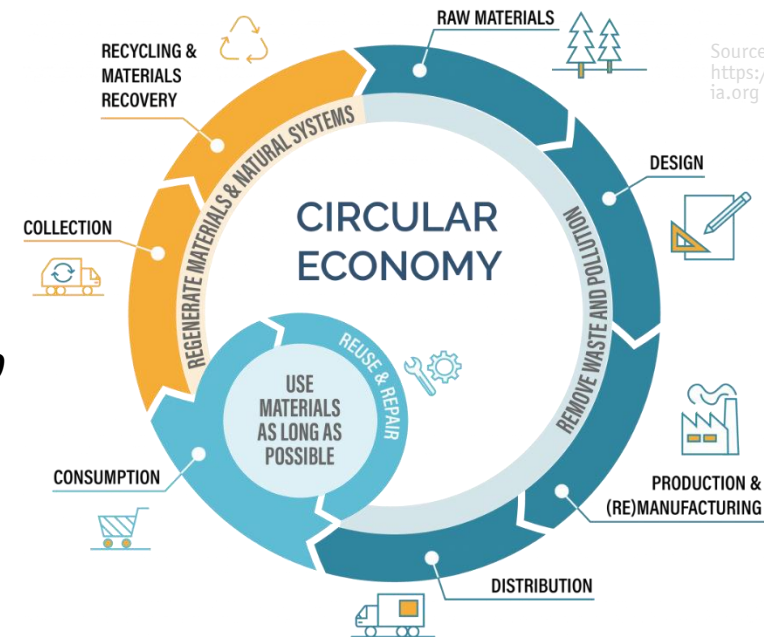
Source: IEA / The Role of Critical Minerals in Clean Energy Transitions (2021)

Shares of top three producing countries, 2019

■ Extraction & Processing More Geographically Concentrated than for Oil & Nat. Gas (!)

Paradigm Shift

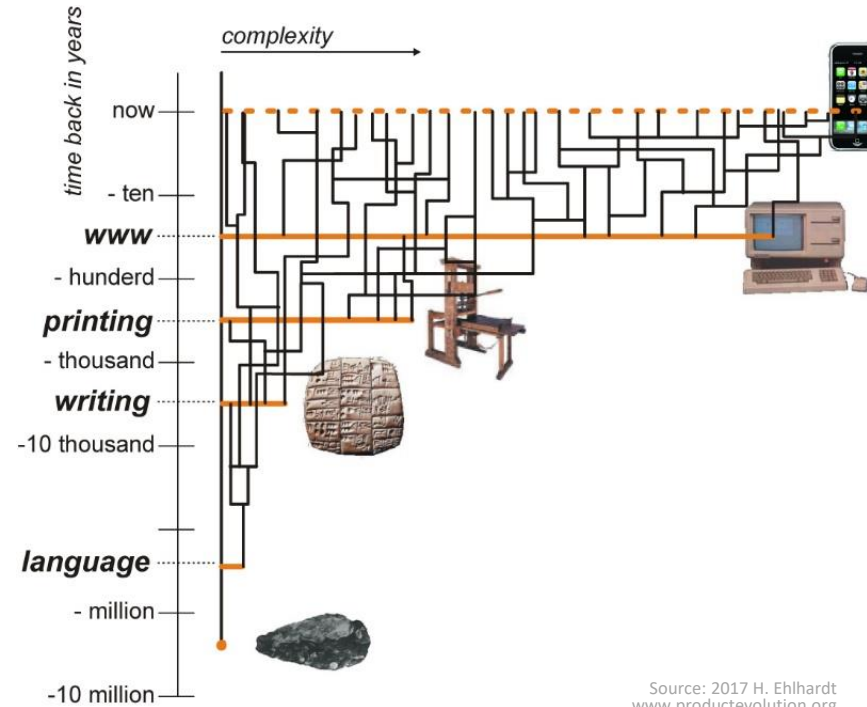
- **Growing Global E-Waste Streams / < 20% Recycled**
- **120'000'000 Tons of Global E-Waste in 2050**



- **“Linear” Economy / Take-Make-Dispose → “Circular” Economy / Perpetual Flow of Resources**
- **Resources Returned into the Product Cycle at the End of Use**

Complexity Challenge

- Technological Innovation — **Increasing Level of Complexity & Diversity of Modern Products**
- Exp. Accelerating Technological Advancement (R. Kurzweil)



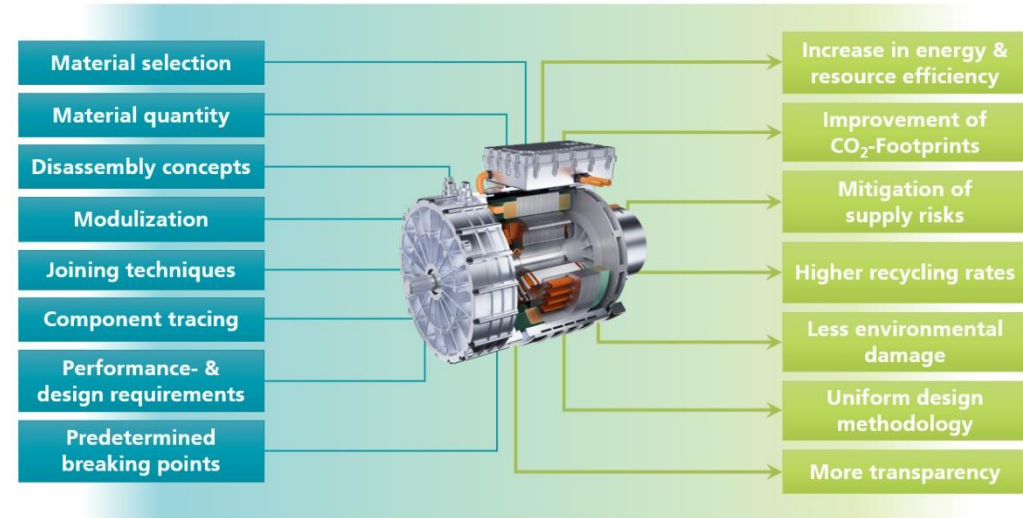
Source: 2017 H. Ehlhardt
www.productevolution.org

- **Ultra-Compact Systems / Functional Integration — Main Obstacle for Material Separation**

Design for Repairability & Circularity

- **Eco-Design** — Reduce Environmental Impact of Products, incl. Energy Consumption Over Life Cycle
- **Re-Pair / Re-Use / Disassembly / Sorting & Max. Material Recovery, etc. Considered**
- **EU Eco-Design Guidelines (!)**

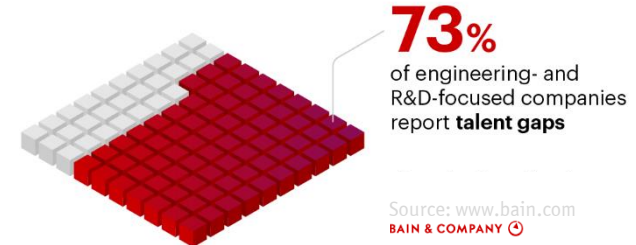
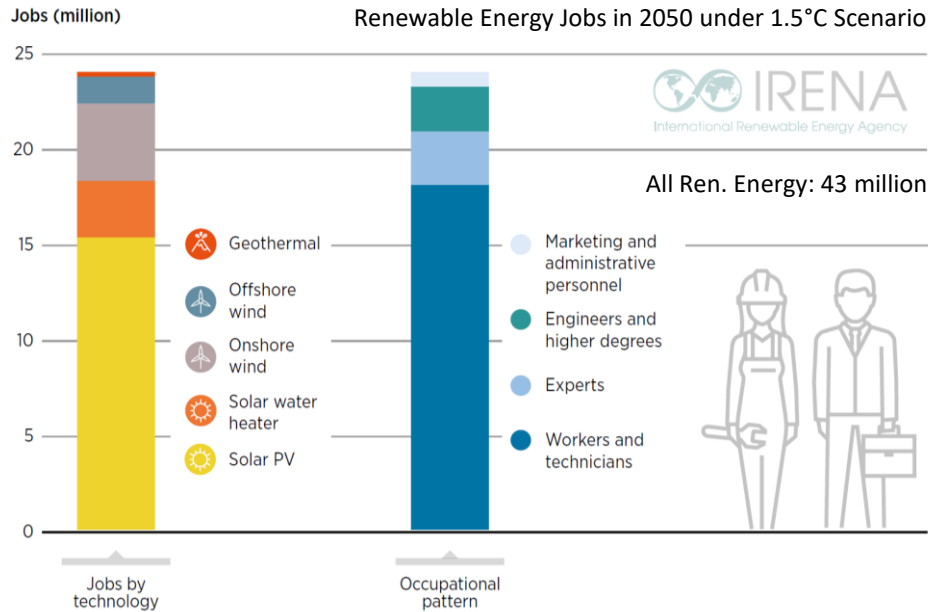
Source: 



- **FAIRPHONE** — Modular Design | Man. Replaceable Parts | 100% Recycl. of Sold Products | Fairtrade Materials

Remark Scarcity of Specialized Talent

- *Increasingly Complex Technologies — Increasing Difficulty to Find Adequate Skills*



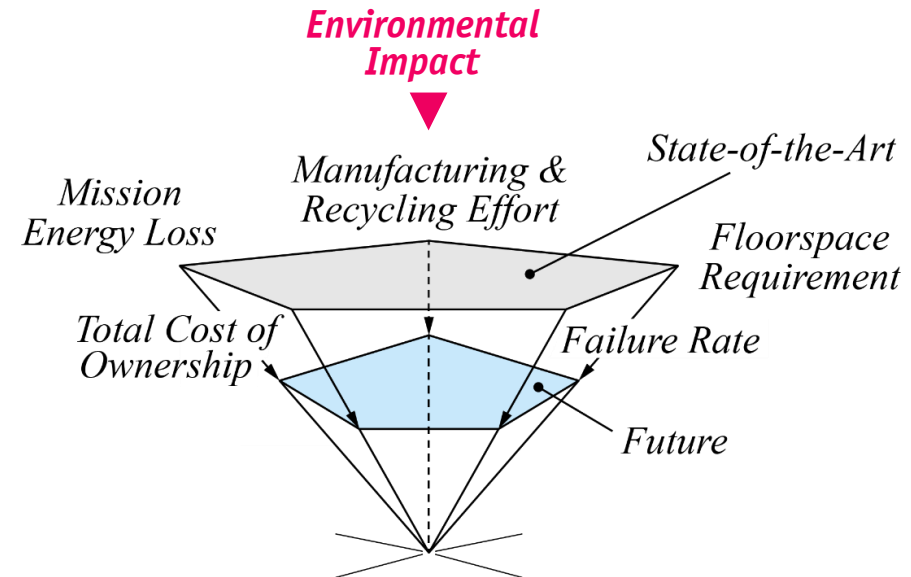
- *Demography (!) — Aging Society / Retirements / Mid-Career Engineers Transitioning to Non-Eng. Roles*
- *Reskill (Oil & Gas) & Upskill Programs & Use of AI Mandatory for Achieving the Renewables Goals*

Future Performance Indicators

- *Assuming 20+ Years Lifetime → Systems Installed Today Reach End-of-Life in 2050 (!)*
- *Life-Cycle Analysis (LCA) Mandatory for All Future System Designs*

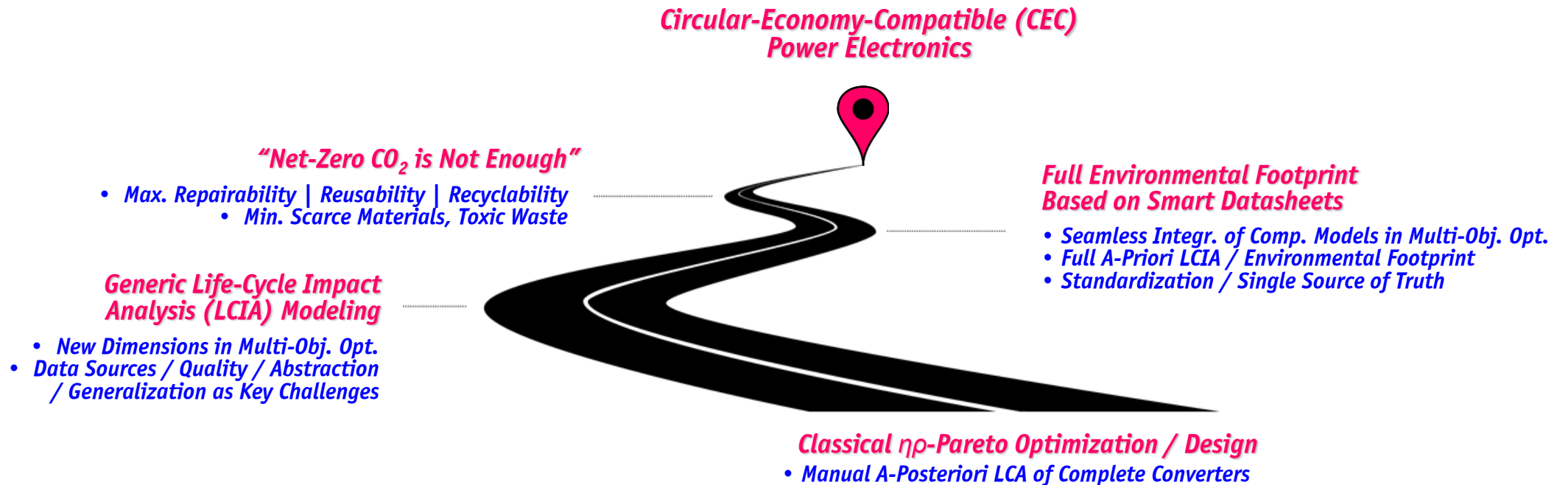
- **Complete Set of New Performance Indicators**

- **Environmental Impact** [kgCO₂eq/kW]
- **Resource Efficiency** [kg_{xx}/kW]
- **Embodied Energy** [kWh/kW]
- **TCO** [\$/kW]
- **Power Density** [kW/m²]
- **Mission Efficiency** [%]
- **Failure Rate** [h⁻¹]



CEC-Power Electronics Roadmap

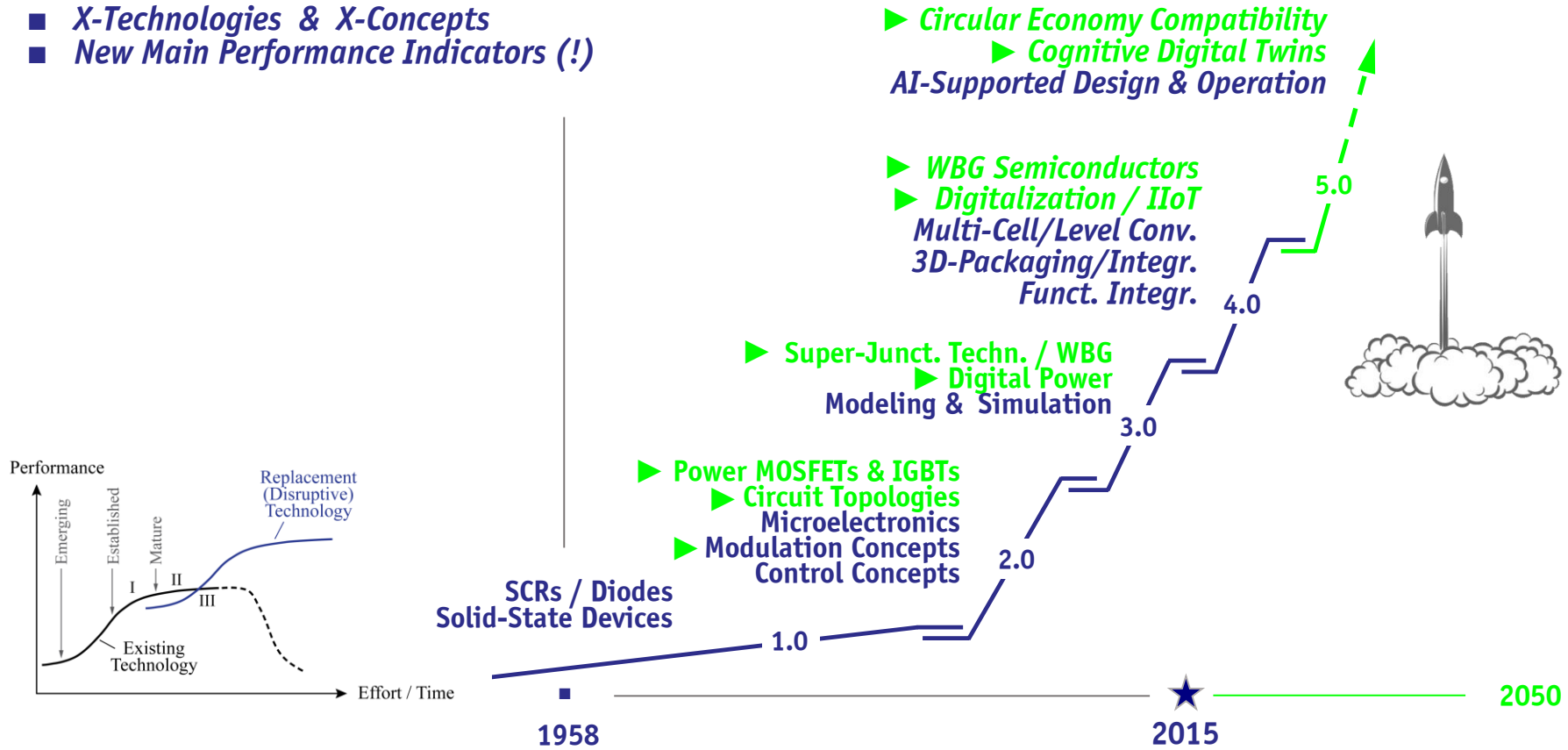
■ *Environmental Awareness as Integral Part of Power Electronics Design*



■ *Automated Design | On-Line Monitoring | Prev. Maintenance | Dig. Product Passport*

Power Electronics 5.0

- Power Electronics 1.0 → Power Electronics 5.0
- X-Technologies & X-Concepts
- New Main Performance Indicators (!)



Thank You !

