Power Electronics Enabling a Net-Zero-CO_2 Integrated Multi-Carrier Energy System

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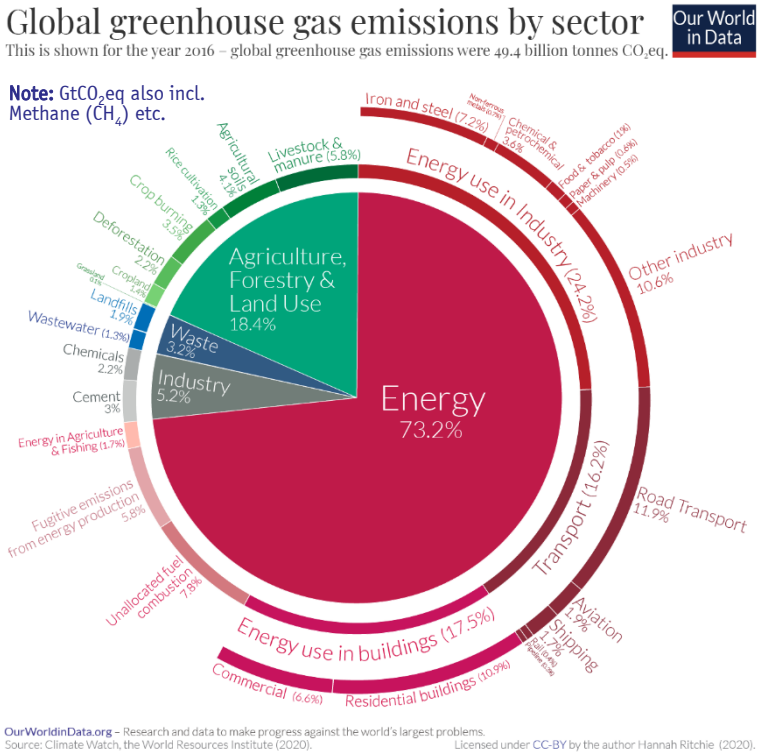
Outline

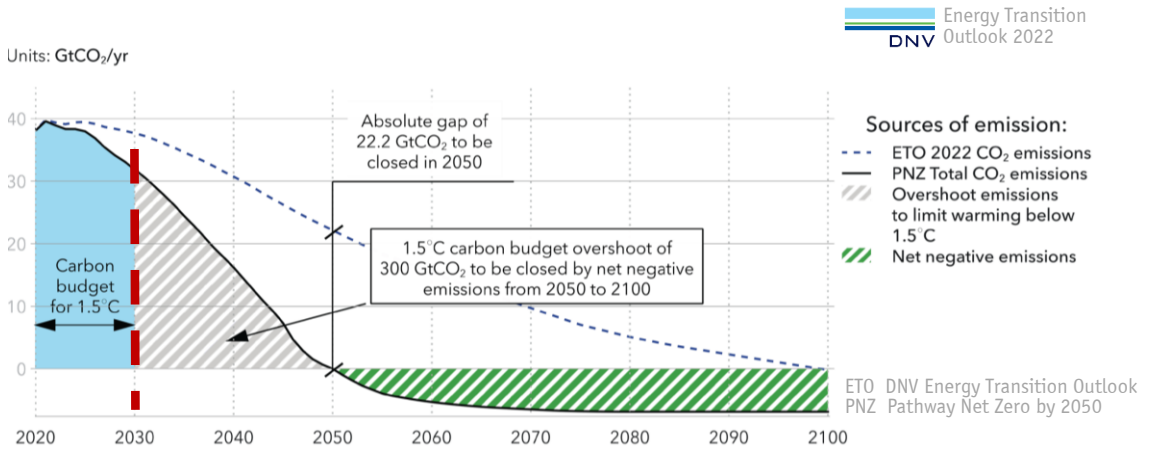
- *Introduction*
- *The Challenge*
- *The Solution ?-!*
- *The Restriction*
- *The Elephant*
- *The New Paradigm*
- *Next Steps*

The Obligation



- *Pathway to "Net-Zero" Emissions & Gap to be Closed*

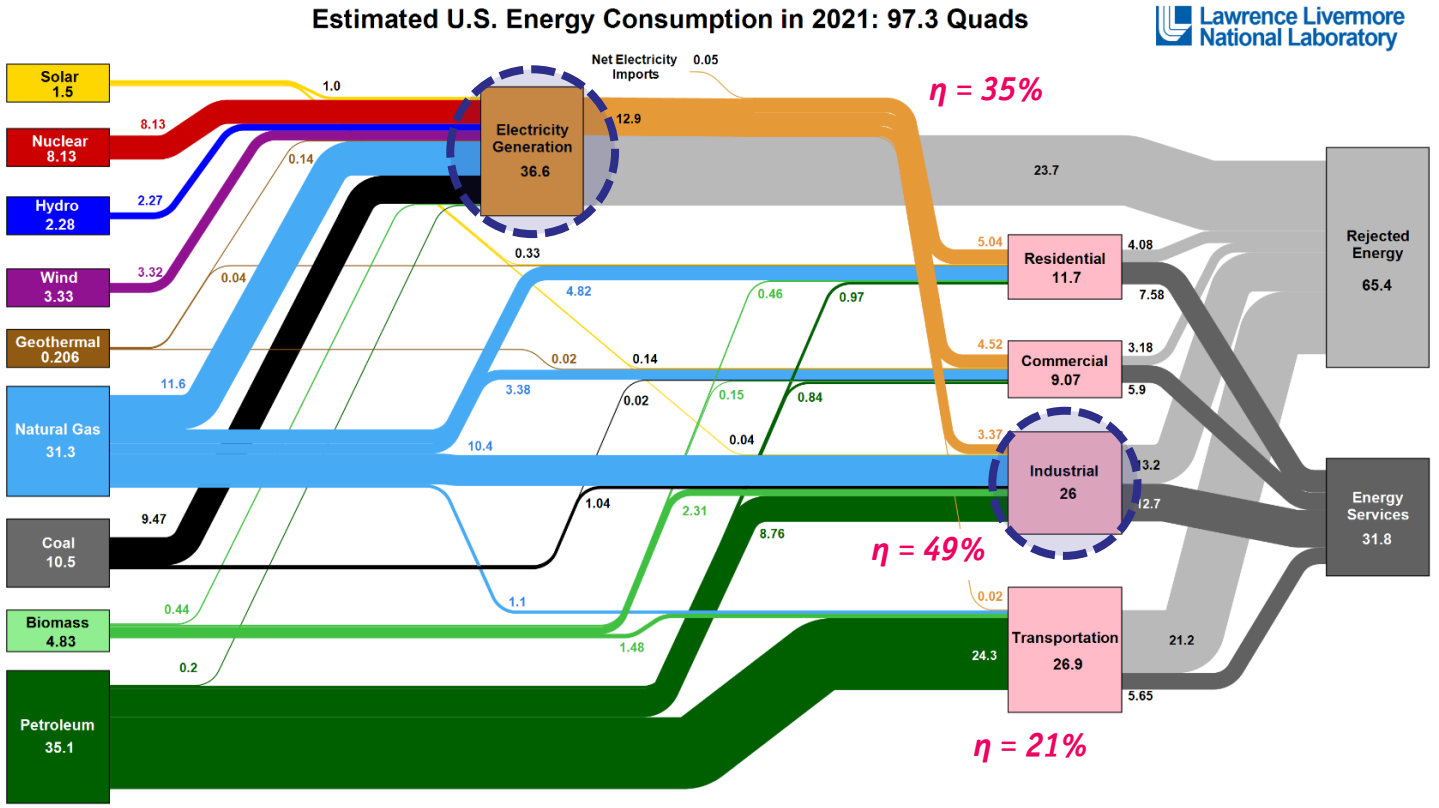
40 $GtCO_2$ →



↑ „Net-Negative" Remove Overshoot of 300 $GtCO_2$

- *50 $GtCO_2$eq Global Greenhouse Gas Emissions / Year → 280 $GtCO_2$ Budget Remaining for 1.5°C Limit*

The Challenge



Note: „Rejected Energy" includes Waste (Recoverable, e.g. Waste Heat) and Losses (e.g. Cond. Losses, Not Recoverabe)

Average Efficiency of 33% / 2x More Energy Wasted than Used (!)

Quads – Quadrillion British Thermal Units (BTUs)

1 Quad = 290TWh

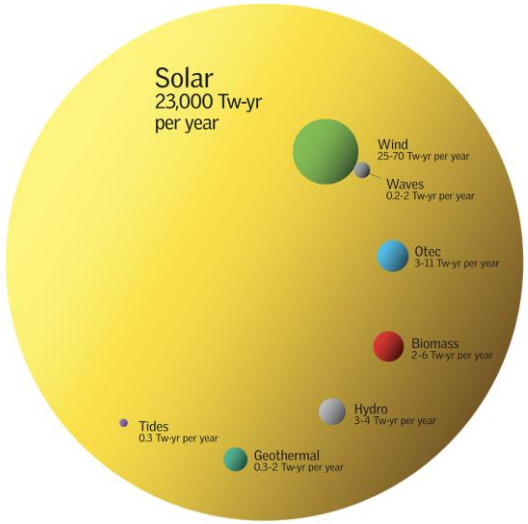
- ***Low Share of Electricity in Industry Energy Consumption***
- ***Low Efficiency of Electricity Generation / Massive Use of Natural Gas & Petroleum***

The Opportunity

(2009) 16 TW-yr — 16 Tw-yr per year — *27 TW-yr (2050)*

100% Conv. Efficiency Excl. Oceans

Renewable energy resources per year



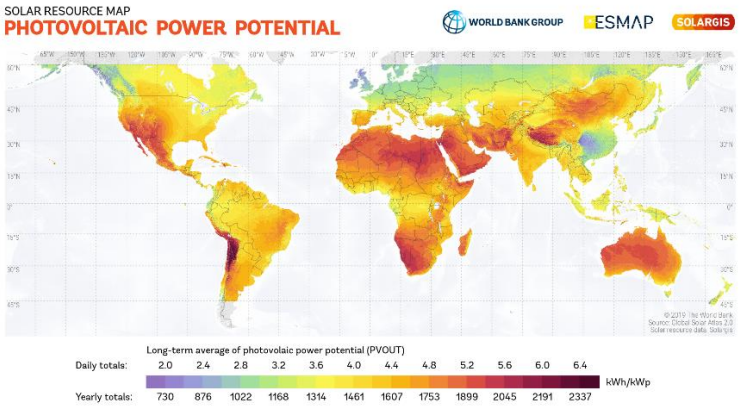
Note: Graphical Representation Assumes Spheres Not Circles

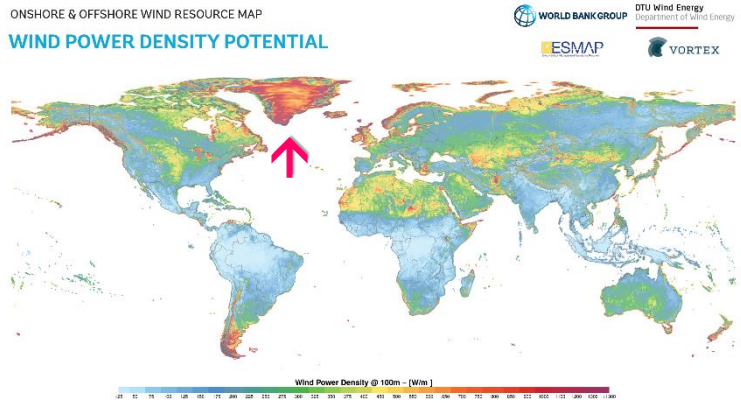
Primary Consumption:
16 TW-yr → 27 TW-yr
Final Consumption:
11 TW-yr → 15 TW-yr

Source: R. Perez et al., IEA SHC Program Solar Update (2009)

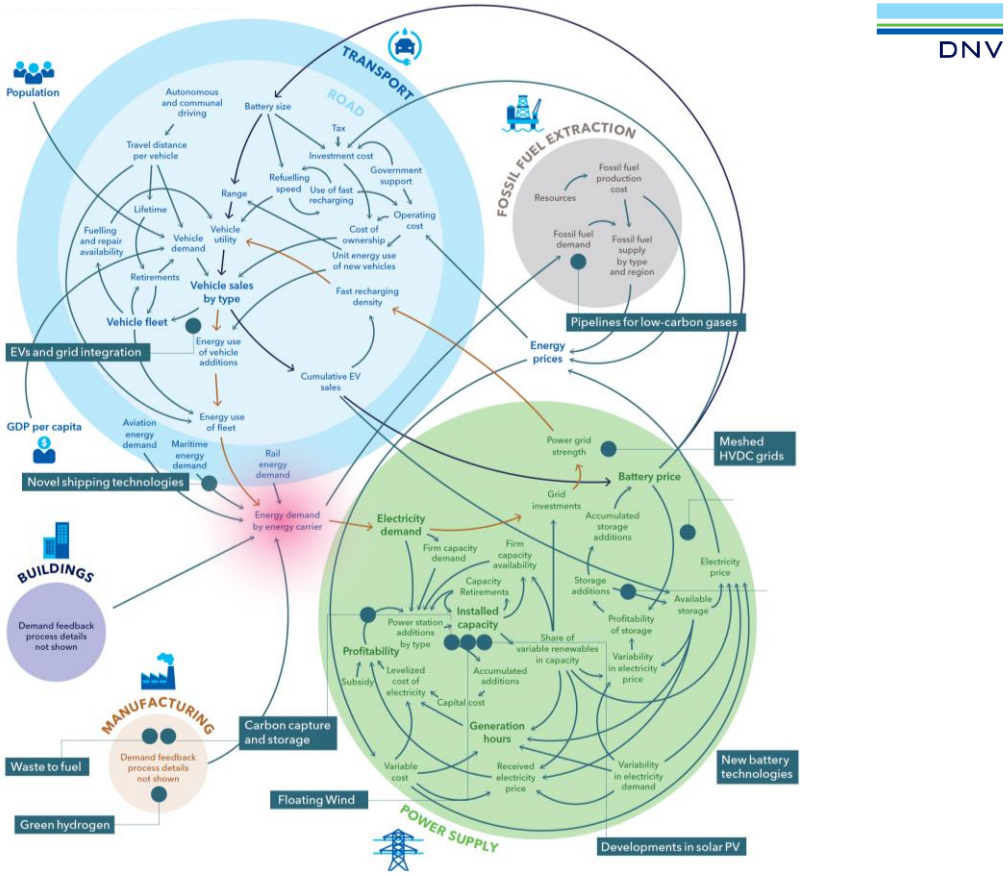
Fossil energy resources - total reserve left on earth

■ *Global Distribution of Solar & Wind Resources*





The Complexity

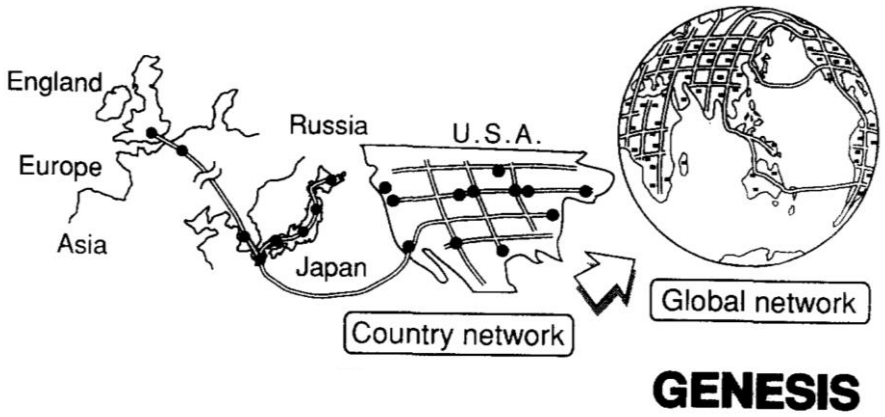


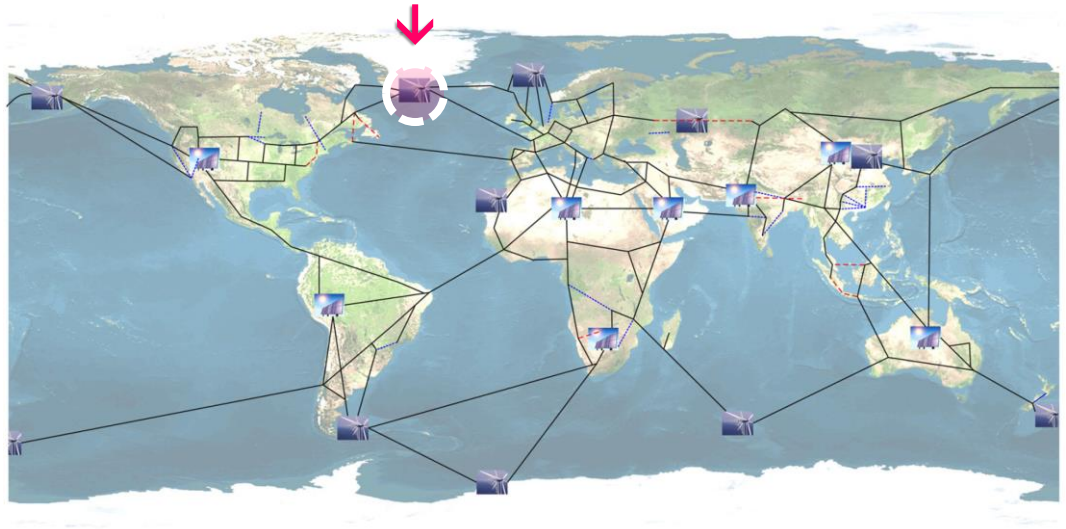
- *Example of Comprehensive Energy Transition Outlook Model*
- *Complex Coupling of Energy Systems / Technologies / Economics*

The Solution (?)

- *Global Grid / "Top-Down" Approach*

Source: Y. Kuwano / SANYO (1994)





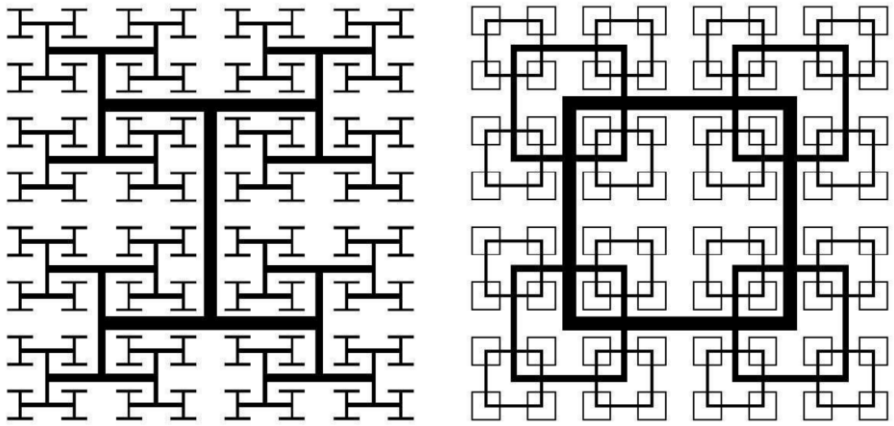
Source: G. Andersson / ETH Zurich (2013)

- *PV & Global Superconducting Grid (1994)*
- *Globally Interconnected HVDC-Network (2013)*

The Solution

- *Fractal Grid / Facilitates Integration of "Bottom-Up" Approaches*
- *20´000´000´000´000 $ (=GDP of USA) Global Electric Grid Investments Until 2050 / Decentralization & Digitization*
- *System of Independently Operable Coordinated Systems | Local Gen. & Storage | Distrib. Monitoring & Control etc.*

Source: D. Hurst et al. / Imperial College

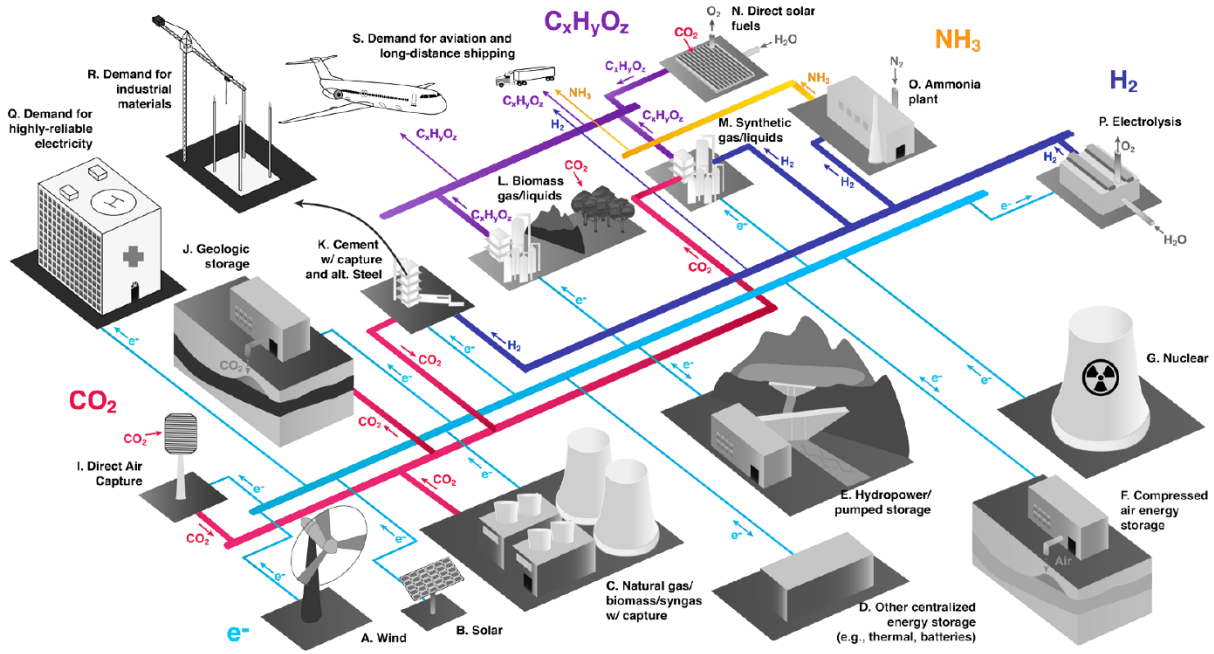


solarworx

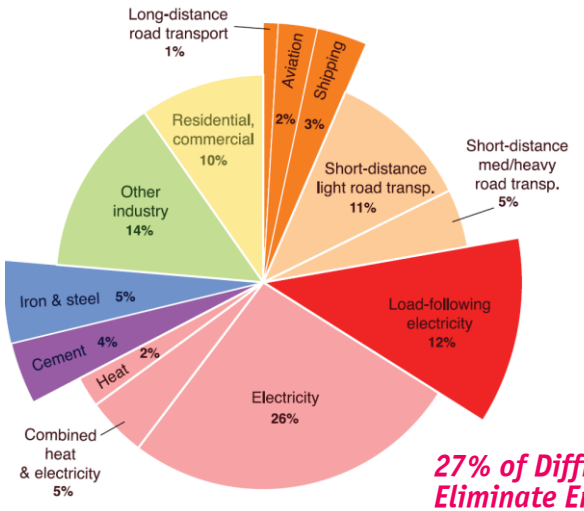
- *Load Management / Demand Response / Peak Shaving etc.*
- *Decentralized Smart 60VDC Pico-Grid in Zambia*

The Comprehensive Solution (!)

- *CO_2-Free Electricity / Electrification — Viable Pathway for Reducing Emissions !&! Costs (Long Term)*
- *E-Fuels & P2X for Long-Haul Transport / Aviation / etc. & Short Term / Seasonal Storage*



Science
S.J. Davis et al. (2018)



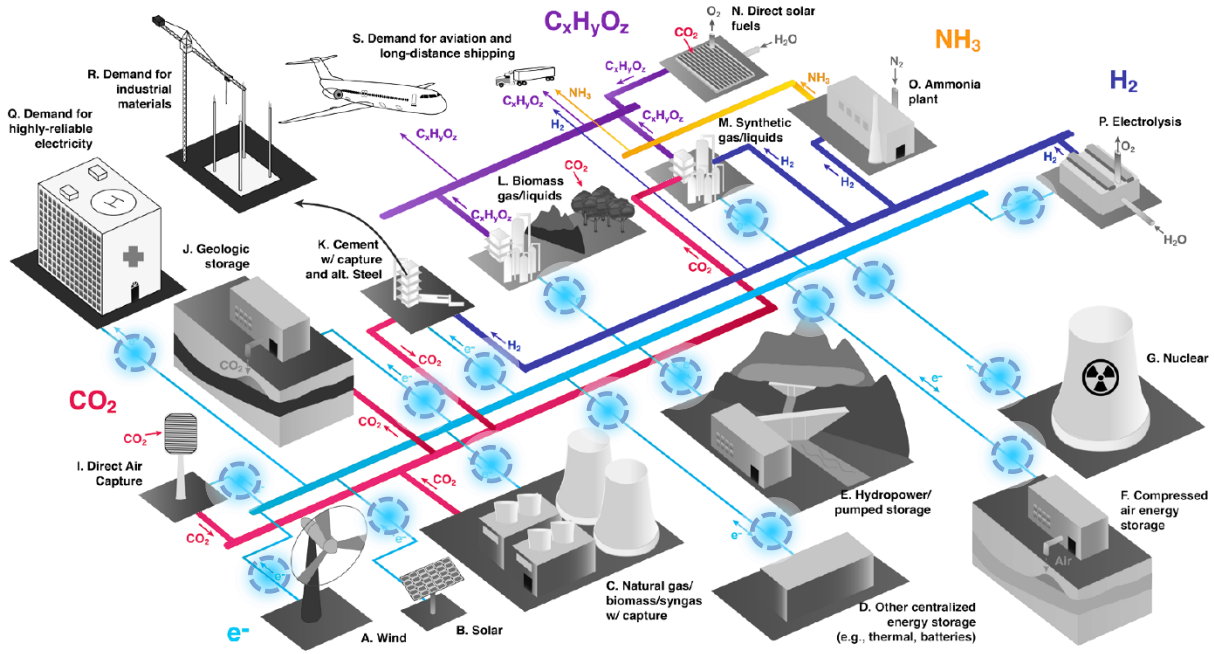
27% of Difficult-to-Eliminate Emissions

Global fossil fuel & industry emissions, 2014 (33.9 Gt CO_2)

- *Integrated Net-Zero Multi-Carrier Energy System — E-Energy | Heat & Cold (N.N.) | etc. | Storage | CO_2C&S*
- *Missing Multi-Discipl. Research on Cross-Sector Converters / Technologies / Geogr. Diversity / Economics etc.*

The Comprehensive Solution (!)

- *Power Electronics — A Key Enabler !*



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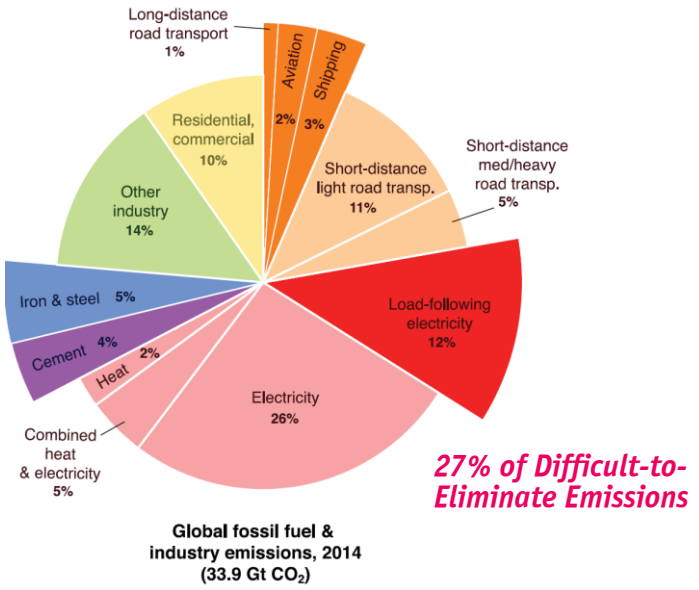
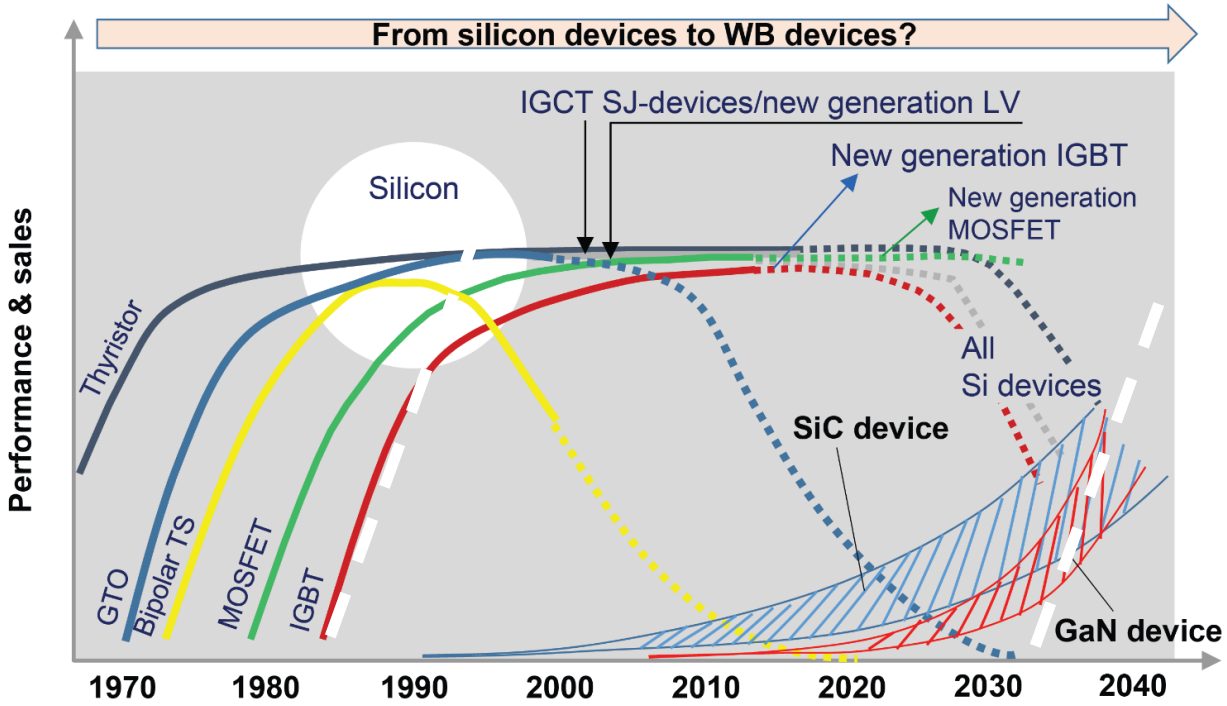


27% of Difficult-to-Eliminate Emissions

- *Ren. Gen. & Cross-Sector Conv. — Heat-Pumps / Electrolyzers / FCs / etc. → All Power Electronics Dependent !*

The Restriction

- *2050 → No Fundamentally New Concepts in 20+ Years Time Frame (!)*
- *Main Barriers to NZ-MCES Deployment are Social & Political & Institutional*

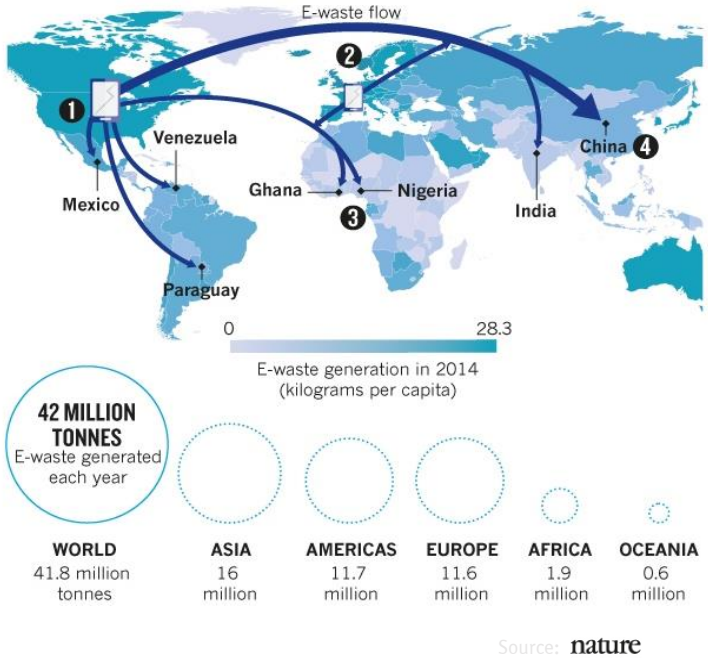


Source: ABB/ECPE
L. Lorenz et al.
Elsevier (2018)

- *E.g. 10...20 Years Introduction Phase of New Power Semiconductor Technologies*

The Elephant in the Room

- *53´000´000 Tons of Electronic Waste Produced Worldwide in 2019 → 74´000´000 Tons in 2030*
- *Increasingly Complex Constructions → No Repair or Recycling*



Source: nature

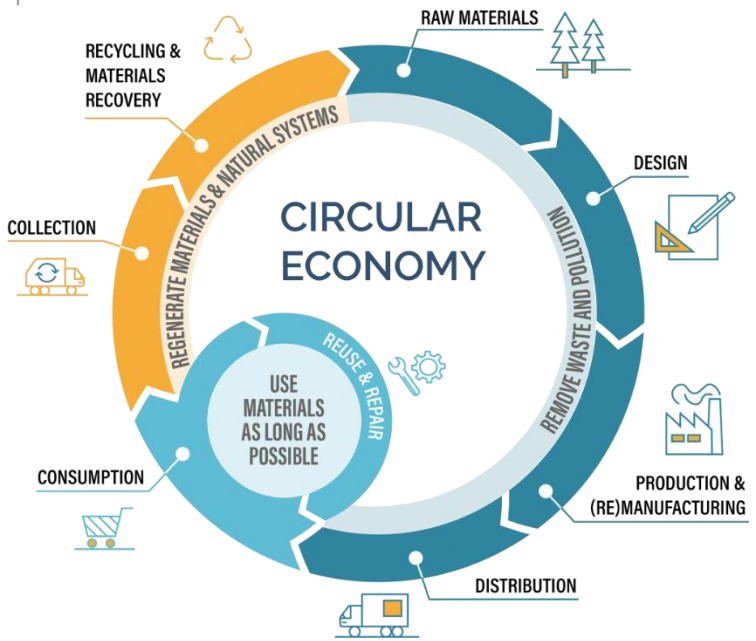
Source: Green IT Solution

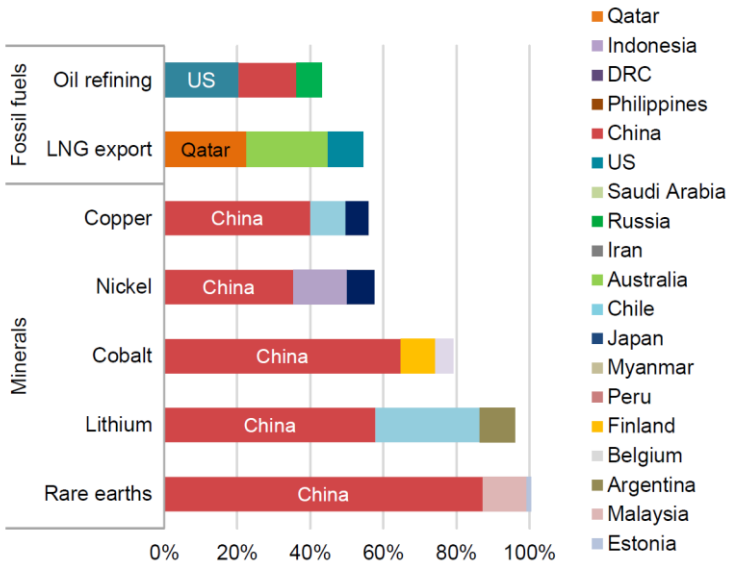
- *Growing Global E-Waste Streams → Regulations Mandatory (!)*

The Paradigm Shift

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

Source: https://circularphiladelphia.org





Share of top three producing countries, 2019

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

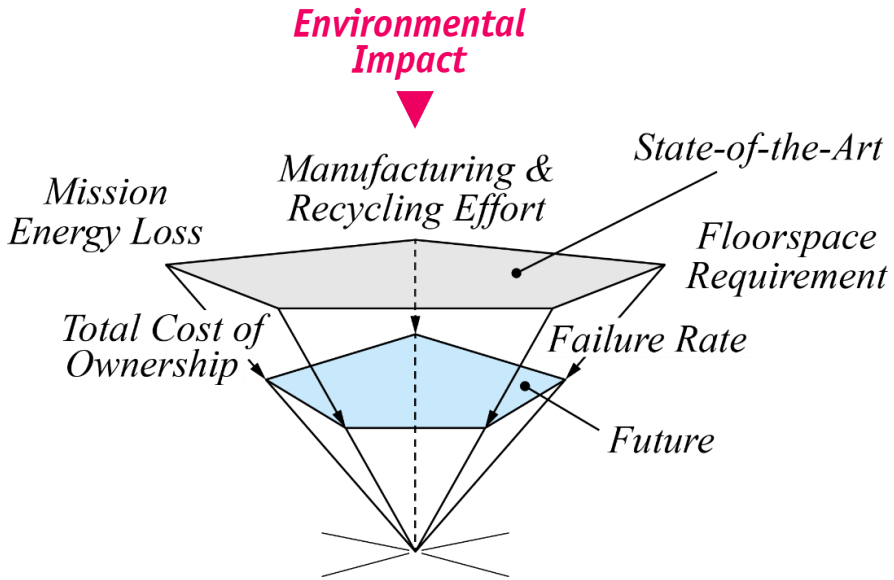
- *Geographically Concentrated Production of Many Energy Transition Critical Minerals*

The Future

- *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	[$kgCO_2eq/kW$]
— Resource Efficiency	[kg_{xx}/kW]
— Embodied Energy	[kWh/kW]
— TCO	[$/kW]
— Power Density	[kW/m^2]
— Mission Efficiency	[%]
— Failure Rate	[h^{-1}]



Thank you!

Source: P. Aylward