



Role of Technology in Energy Efficiency — Past & Future

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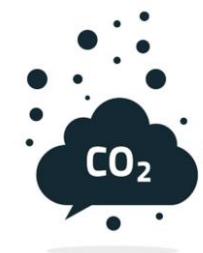
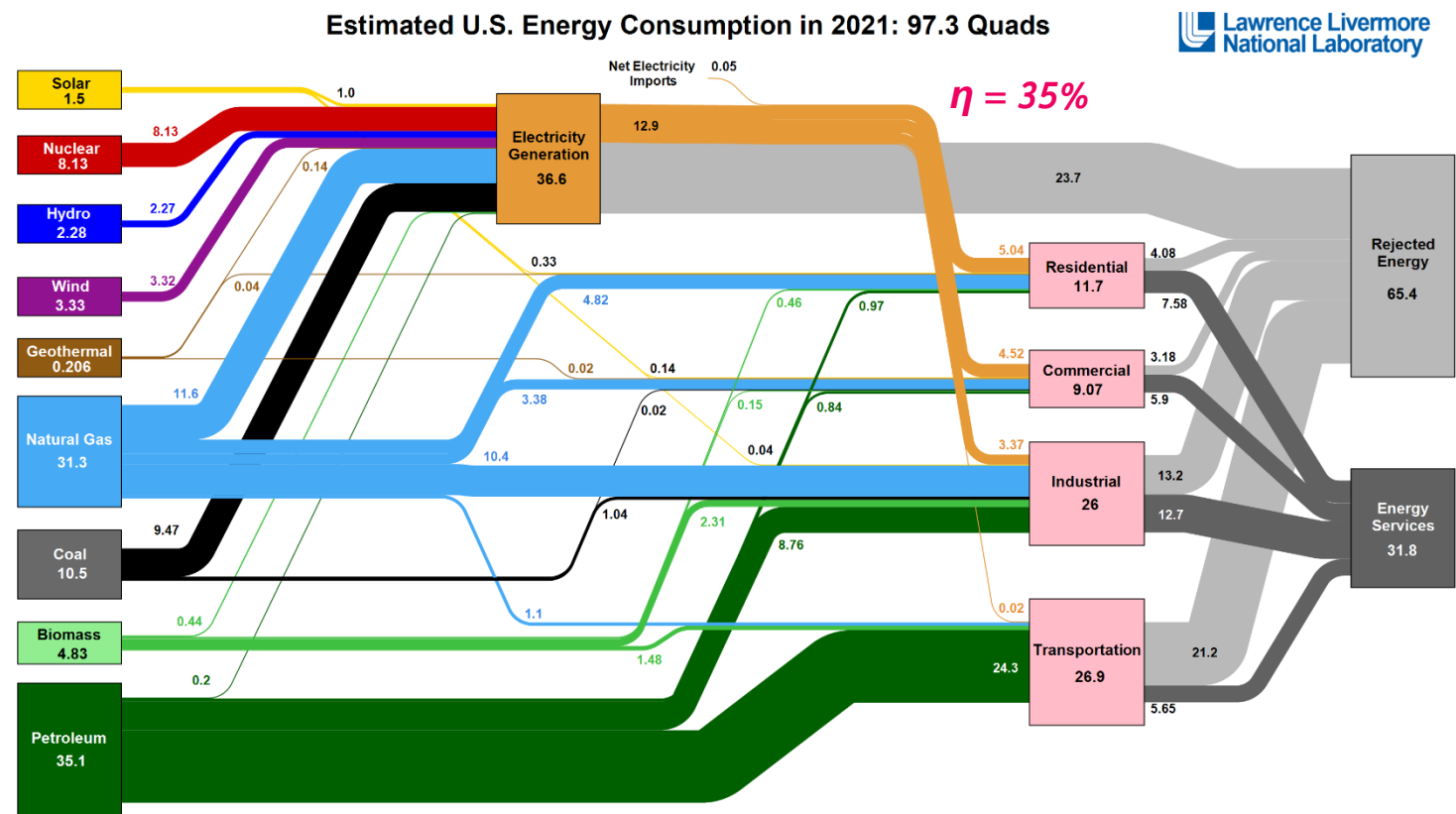
Outline



- ▶ *Introduction*
- ▶ *Power Electronics*
- ▶ *Battery Storage*
- ▶ *Digitalization*
- ▶ *Conclusions / Remarks*

Acknowledgement
Dr. Jonas E. Huber

U.S. Energy Resources | Areas of Use | Losses



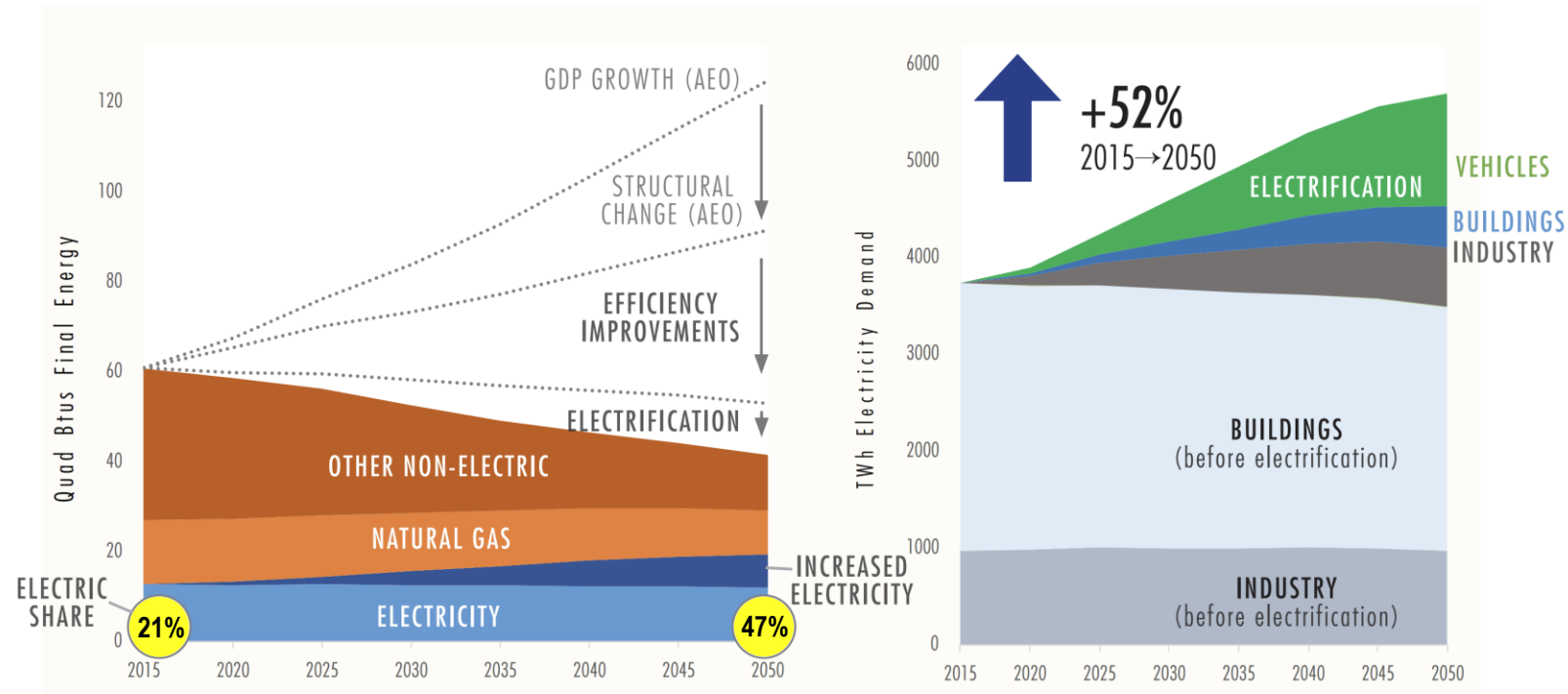
**Average
Efficiency
of 33% / More
Energy Wasted
than Used (!)**

Quads –
Quadrillion
British Thermal
Units (BTUs)

■ End Use Efficiency — Industry $\eta = 49\%$ (!) | Transportation $\eta = 21\%$

U.S. Forecasted Electricity Use

Source: **EPRI** U.S. National Electrification Assessment 2018



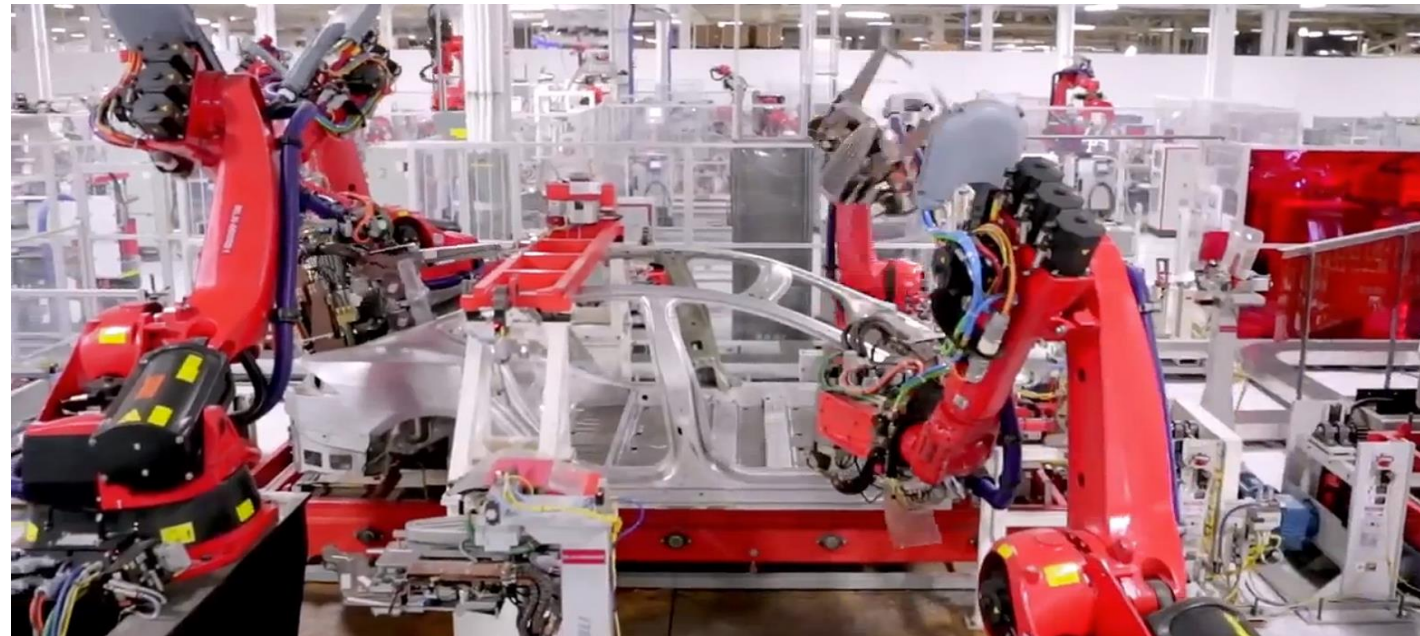
- **“Transformation” Scenario** → **Increase of Electricity Share to 47% (!)**

Industrial Use of Electric Energy

- *Variable Speed Drives / Robotics*
- *Material Machining / Processing – Drilling, Milling etc.*
- *Data Processing / Communication*
- *Compressors / Pumps / Fans*
- *Lighting*
- *etc., etc.*

.... Everywhere !

Source:  TESLA MOTORS



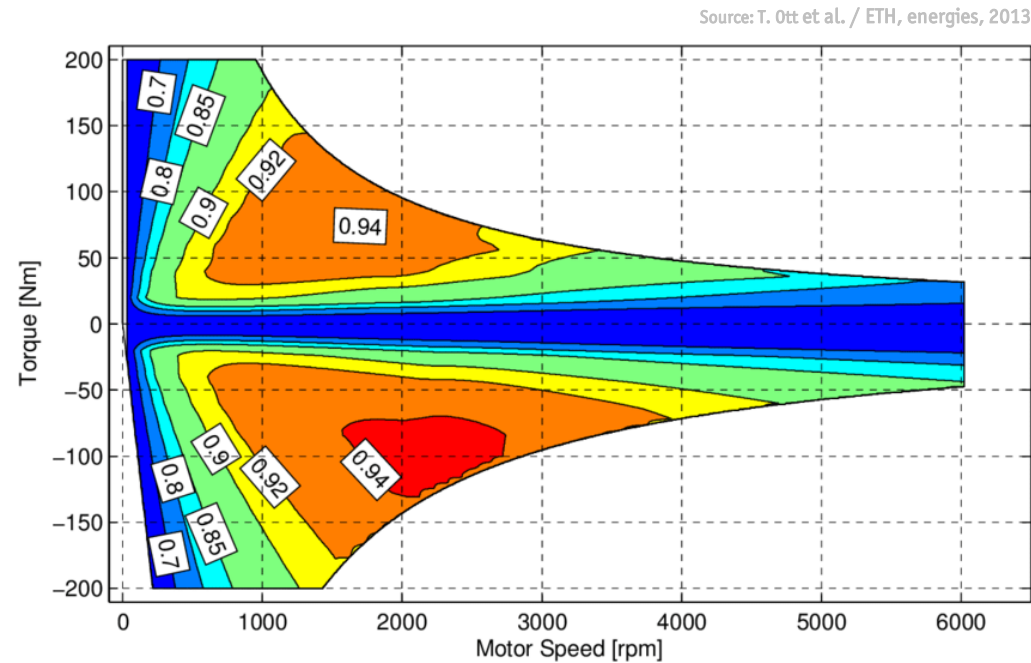
X-Technology #1



***El. Motors / El. Lighting / ...
Power Electronics***

Electromechanical Energy Conversion (1)

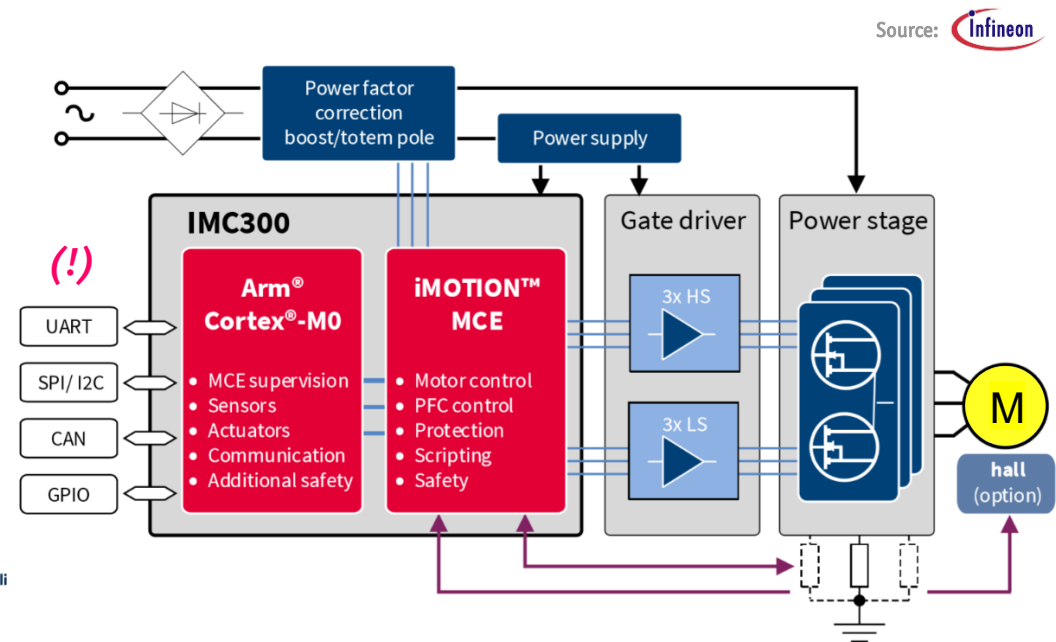
- 30...40% of Global Electricity Consumption — Largest Single-Energy End Use
- 40% of All Electric Energy Used Powers Industry
- 65% Share of Electric Motors



- IEC 60034-2-3 (2020)
- High Eff. Motor/ Generator Operation | *Electronic Control & System Optimiz. Mandatory for High Eff. (!)*

Electromechanical Energy Conversion (2)

- 30...40% of Global Electricity Consumption — Largest Single-Energy End Use
- 40% of All Electric Energy Used Powers Industry
- 65% Share of Electric Motors

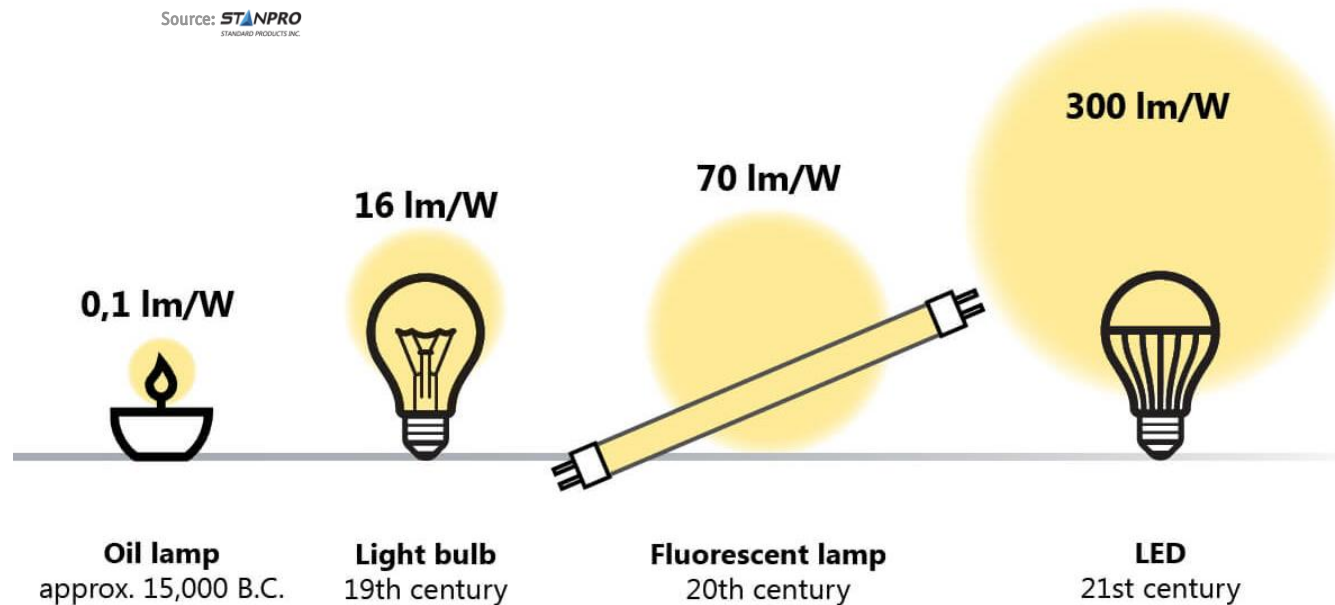


- IEC 60034-2-3 (2020)
- High Eff. Motor/ Generator Operation | Electronic Control & System Optimiz. Mandatory for High Eff. (!)

Efficient Lighting Evolution (1)

- 15...20% of Worldwide Energy Consumption Used for Lighting
- Power Electronics Mains Interface of Fluorescent Lamps & LEDs

Source: STANPRO
STANDARD PRODUCTS INC.



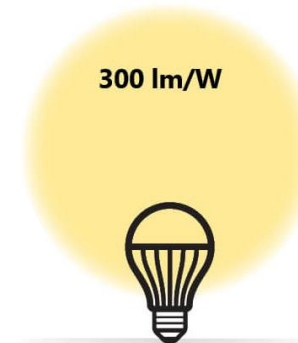
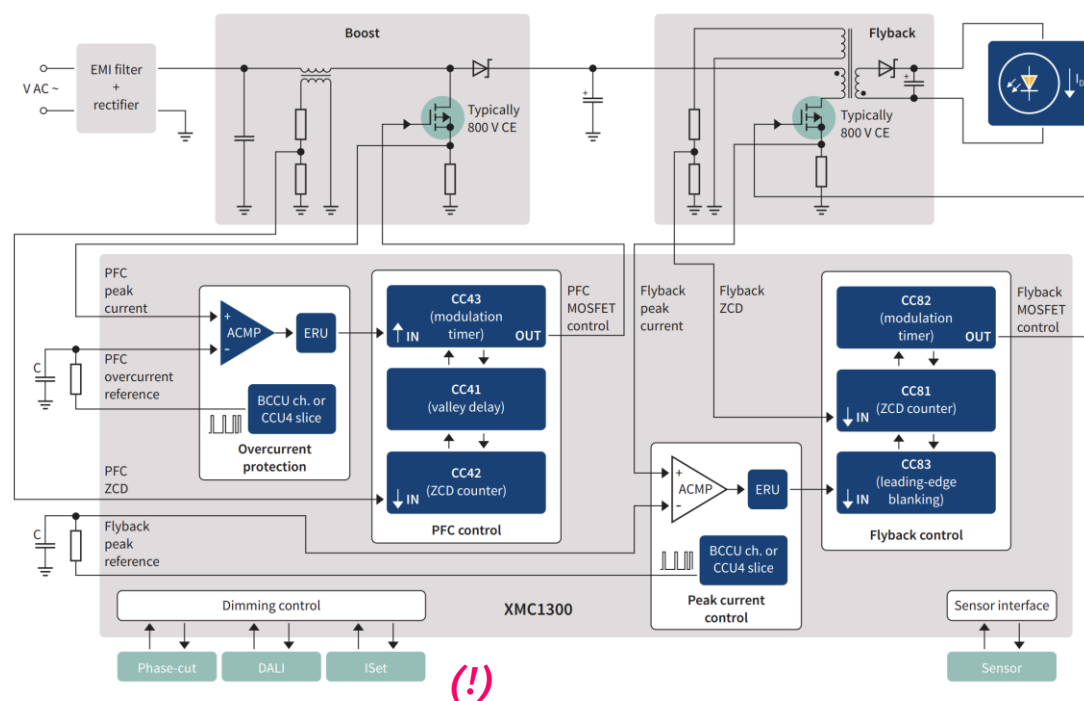
Source: Hera



- SMART & Human-Centric Intelligent Lighting — Dimming | Flex. Color Mixing | Presence Detection

Efficient Lighting Evolution (2)

- 15...20% of Worldwide Energy Consumption Used for Lighting
- Power Electronics Mains Interface of Fluorescent Lamps & LEDs



Source: **STANPRO**
STANDARD PRODUCTS INC.

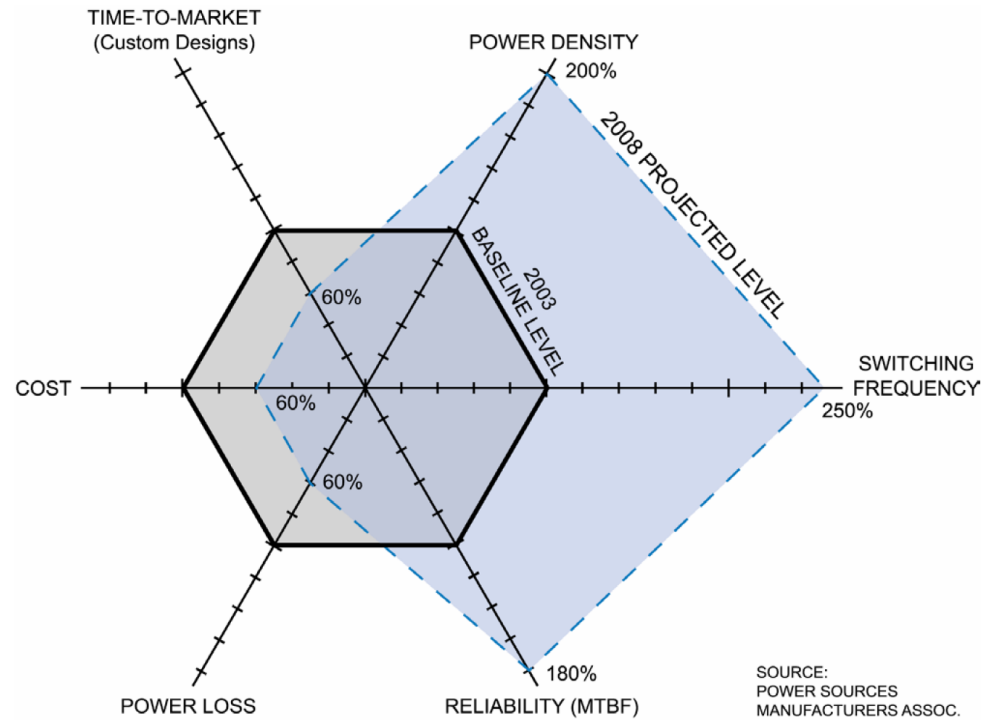


Source: **Infineon**

- SMART & Human-Centric Intelligent Lighting — Dimming | Flex. Color Mixing | Presence Detection

Power Electronics Roadmap

- Costs
- Costs
- Costs
- Robustness
- Power Density
- Efficiency
- Life-Cycle Costs









- Objectives / KPIs Dependent on Application Area

Power Supply Efficiency Categories

- **80 PLUS Voluntary Computer PSUs Certification Introduced in 2004**
- **Min. Efficiencies @ 20% | 50% | 100% & PF > 0.9 @ Rated Power**

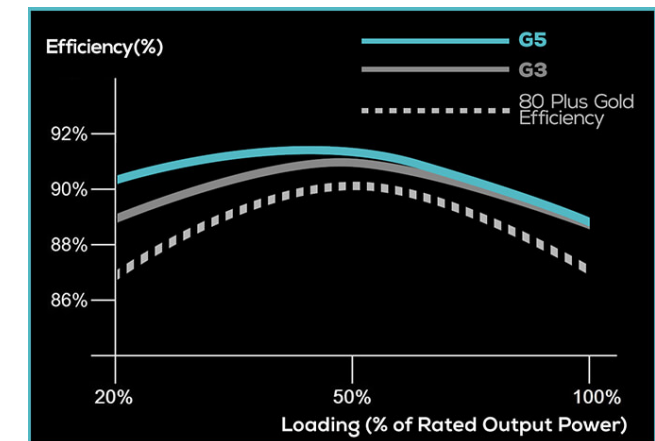
Source: *msi*

							
Efficiency	Loading	80 Plus	80 Plus Bronze	80 Plus Silver	80Plus Gold	80 Plus Platinum	80 Plus Titanium
	10%	-	-	-	-	-	90%
	20%	80%	82%	85%	87%	90%	92% / PF 0.95
	50%	80%	85% / PF 0.9	88% / PF 0.9	90% / PF 0.9	92% / PF 0.95	94%
	100%	80% / PF 0.9	82%	85%	87%	89%	90%

Source: 



Source: *EVGA*

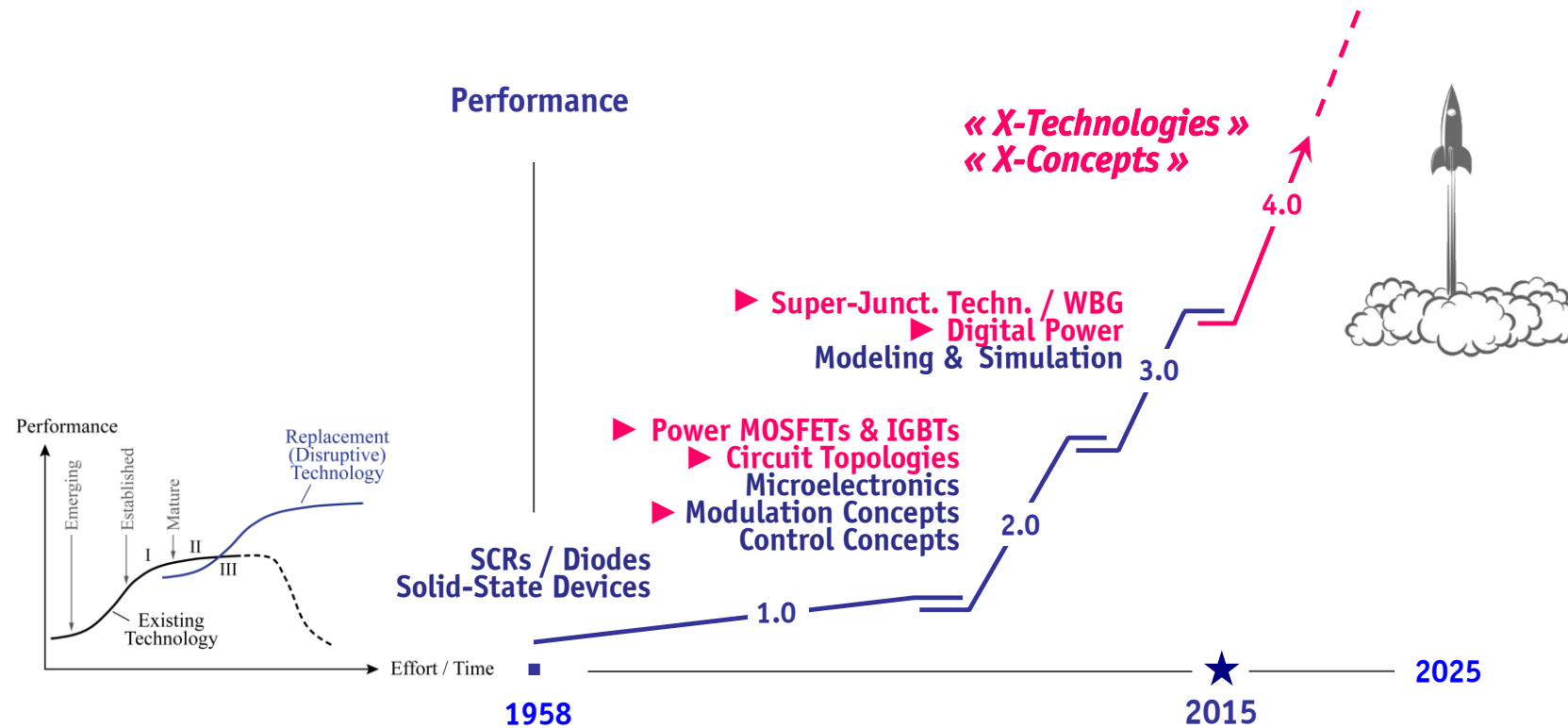


- **No Efficiency Targets @ Very Low Load / Standby (!) → “One Watt Initiative” of IEA (2010)**



Power Electronics S-Curve

- « X-Concepts » → Full Utilization of Basic Scaling Laws & X-Technologies
- « X-Technologies » / “Moon-Shot” Technologies



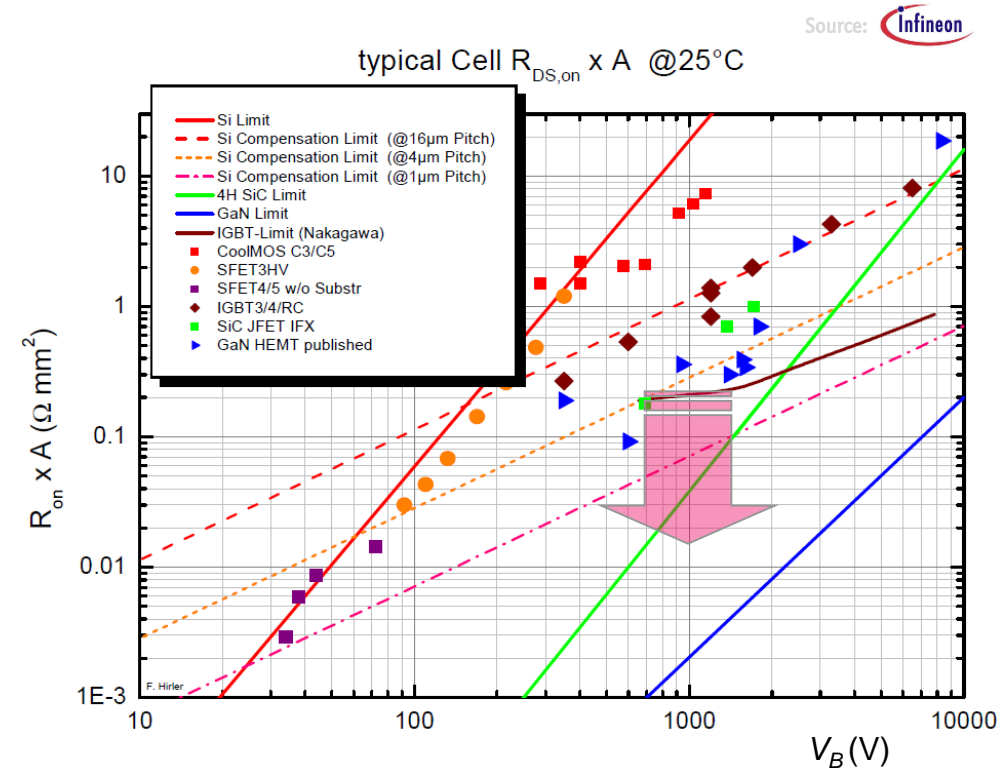
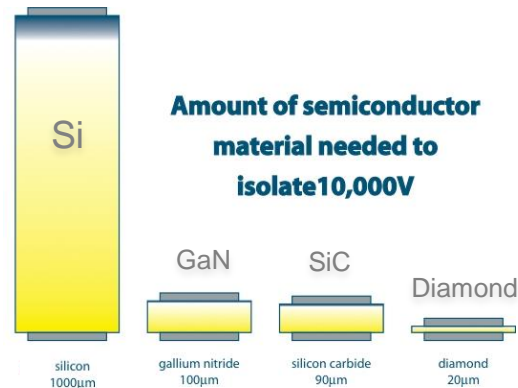
Disruptive Technology

- **SiC MOSFETs / GaN HEMTs**
- **Low Conduction Losses**
- **High Efficiency**

Source:  www.evincetechtechnology.com

$$R_{on}^* = \frac{4V_B^2}{\epsilon\mu_n E_C^3} \leftarrow$$

$$R_{on,SiC}^* \approx \frac{1}{300} R_{on,Si}^*$$



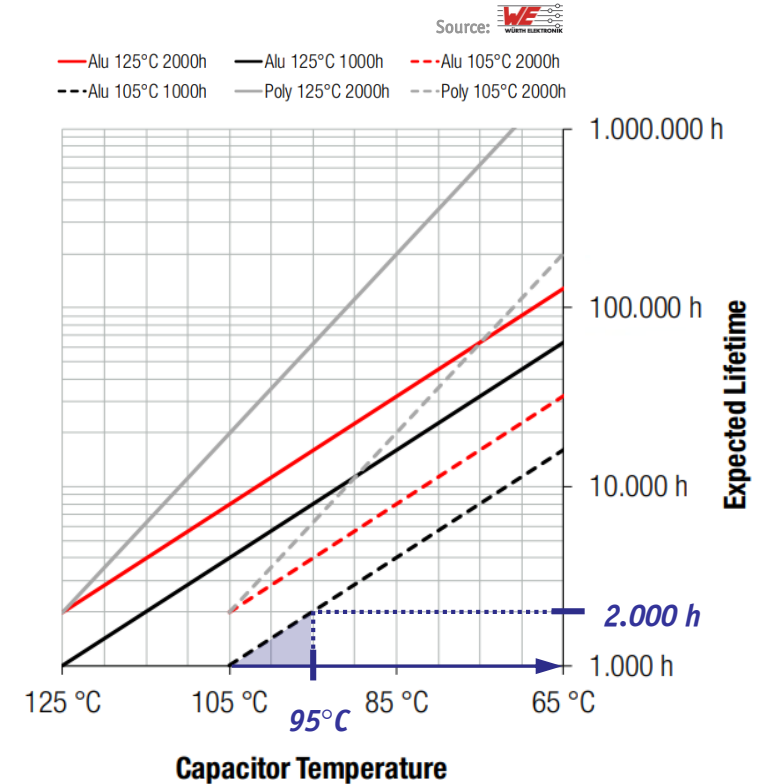
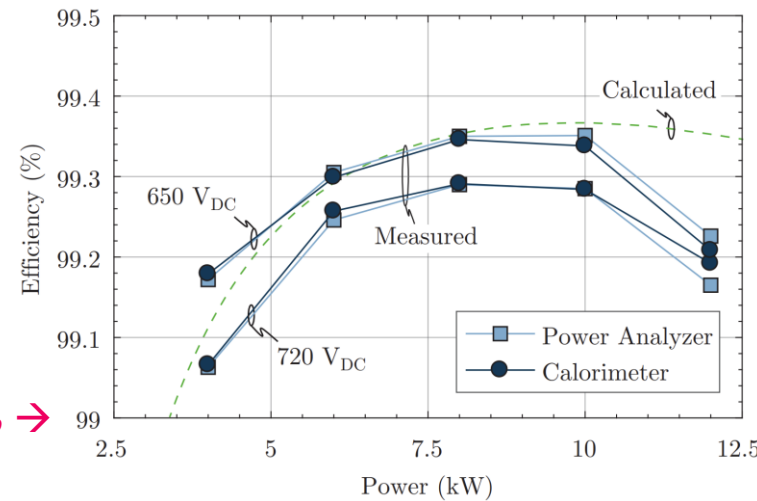
- **High Voltage Unipolar (!) Devices** → **Excellent Sw. Performance / High Power Density**

Efficiency / Lifetime — Power Density

- High Efficiency → Low Operating Costs & Extended Lifetime
- Forced → Natural Convection Cooling → No Maintenance
- Operation in High Temperature Environments



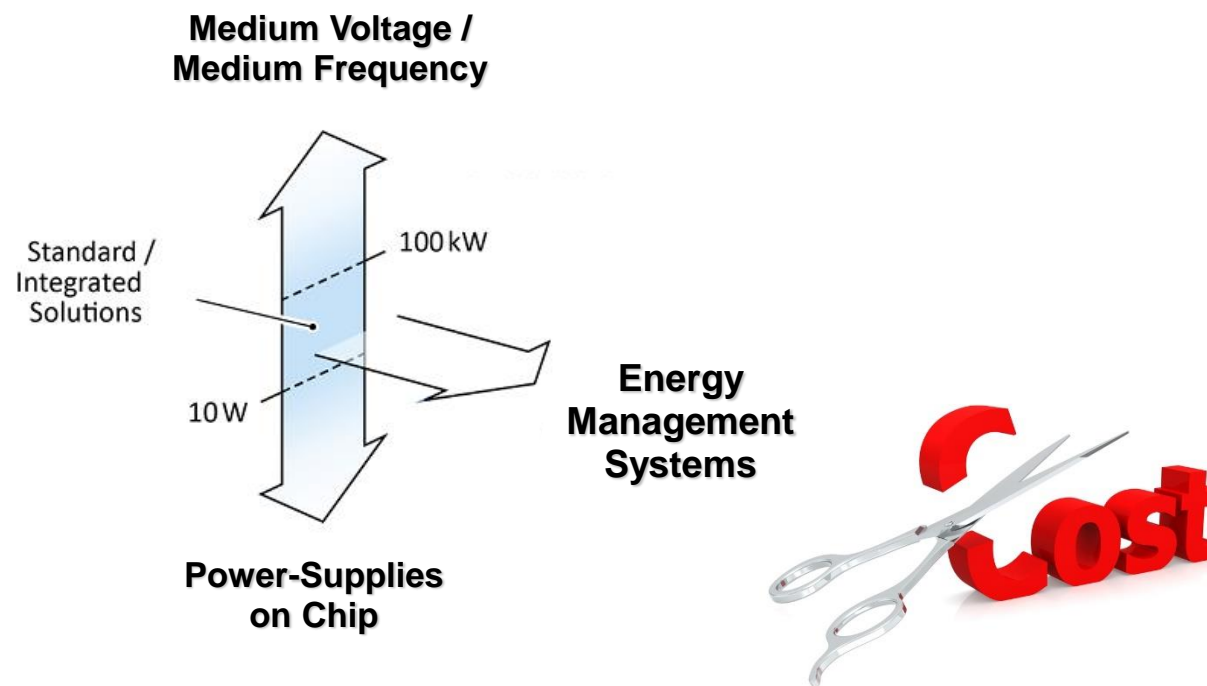
99% →



- Low Cond. & Sw. Losses of SiC / GaN → Extreme Compactness @ Very High Efficiencies

Power → “Energy” Electronics

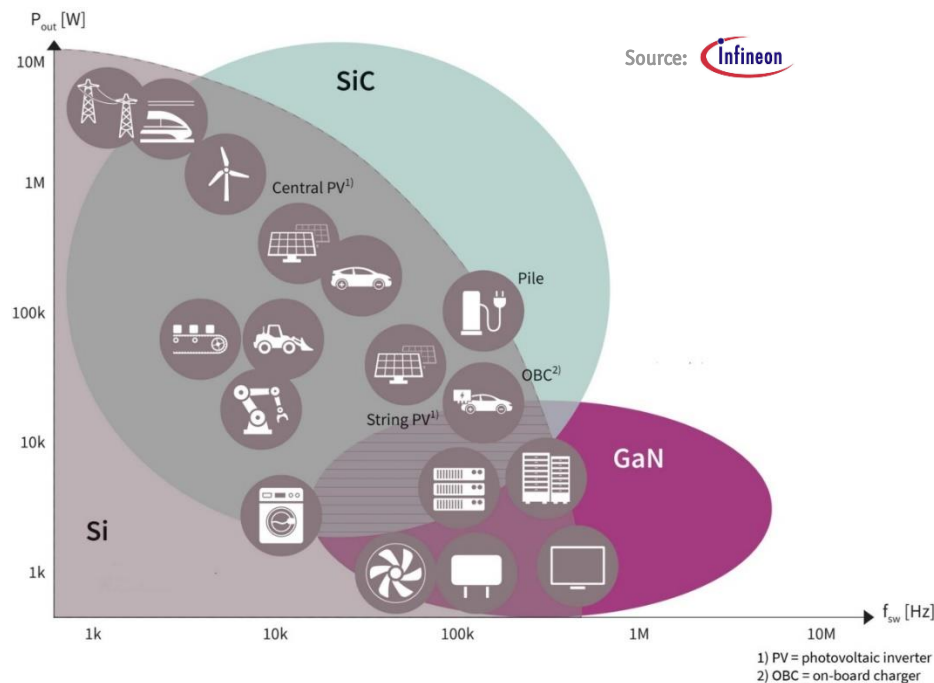
- *Converter* → *System*
- *Time* → *Life Cycle*



- *There is Plenty of Room @ the Top | There is Plenty of Room @ the Bottom*

Power Electronics — Business Volume

- **Clean Energy Transition** → **“All-Electric” Society**
- **5.2% CAGR** / Compound Annual Growth Rate – 2021 - 2030



PRECEDENCE
RESEARCH

POWER ELECTRONICS MARKET SIZE, 2020 TO 2030 (USD BILLION)



- **Global Megatrends / Drivers** → **Sustainable Mobility | Renewable Energy | Industry Automation | etc.**

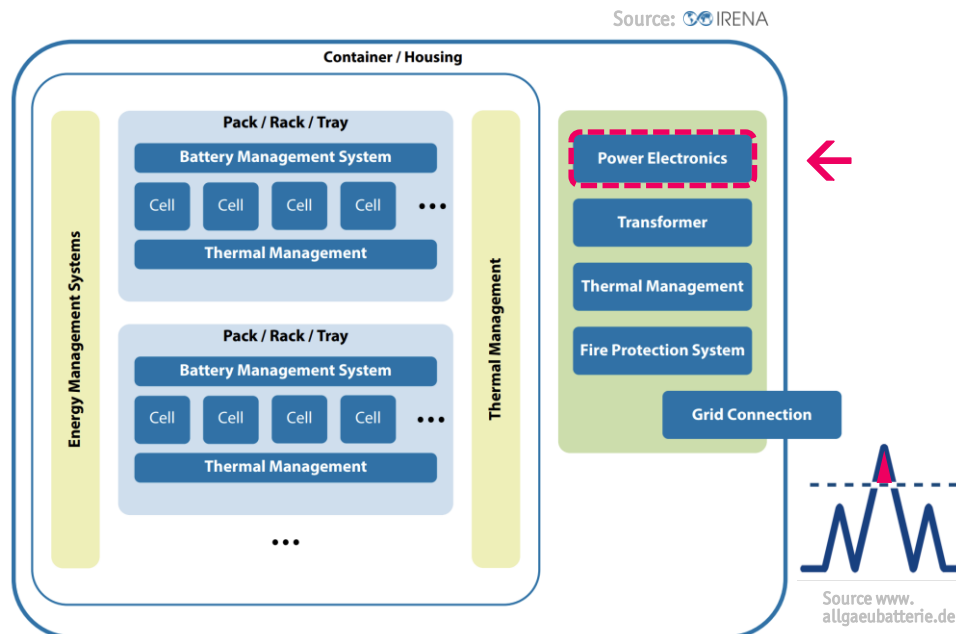
X-Technology #2



Electric Energy Storage

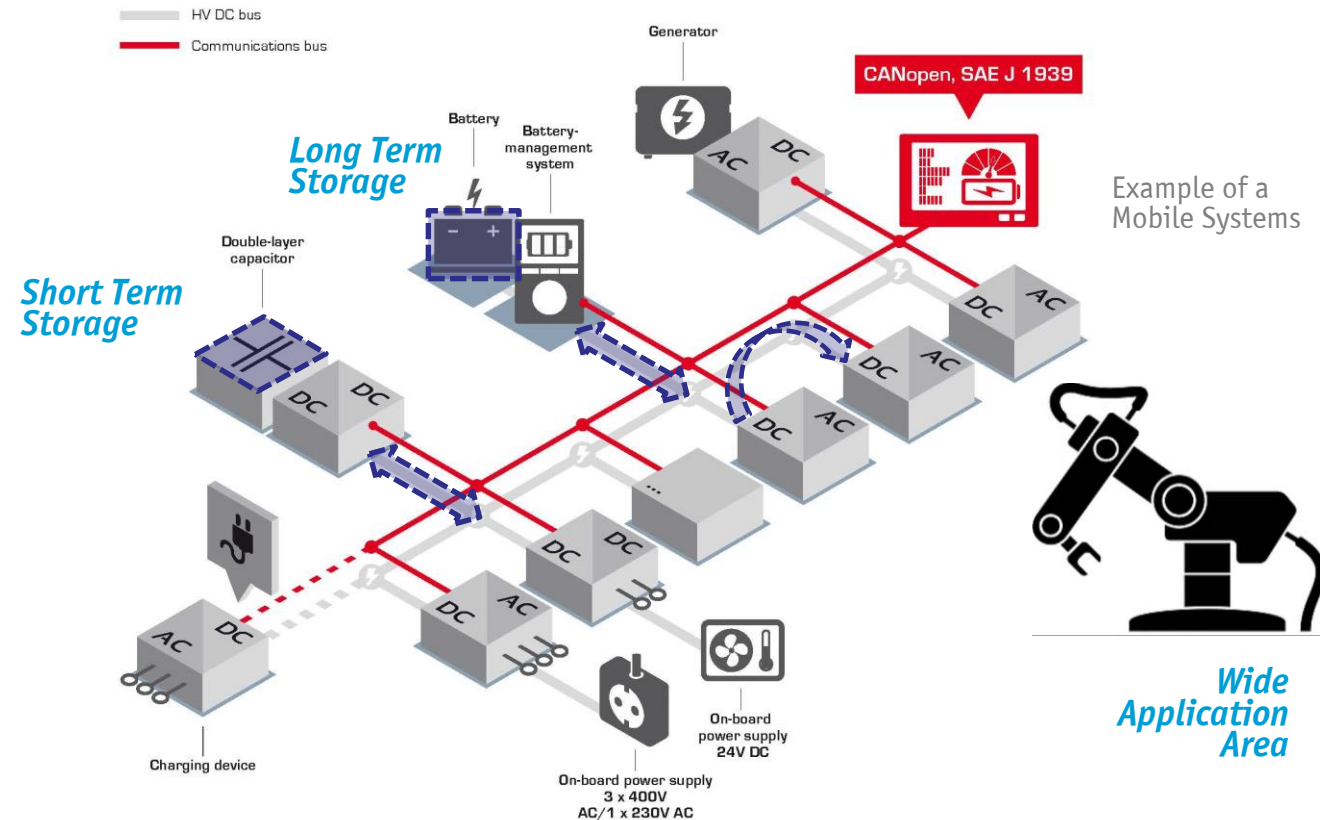
Power / Energy Management

- *Local Battery Storage & Power Electronics for **Decoupling of Load / Generation & Supply***
- ***"Mission Efficiency" Optimization** | Peak Load Shaving | UPS | Ancillary Grid Services*



- *Utilized Storage Technology Dependent on **Timescale & Power / Energy Demand***
- *Learning Curve of Battery Technology Driven by Automotive Applications (**10'000 GWh in 2030**)*

Energy Management — DC Micro-/Nanogrids



- **Renewable Energy Integration**
- **"Networked"** — Bidir. Flow/Exchange of Energy & Signals/Data | Distrib. Autonom. Cntrl & Protect.
- **Hybrid Power Solutions** — Combin. of Electric / Hydraulic / etc. Systems | Continuous Opt. & Diagnosis

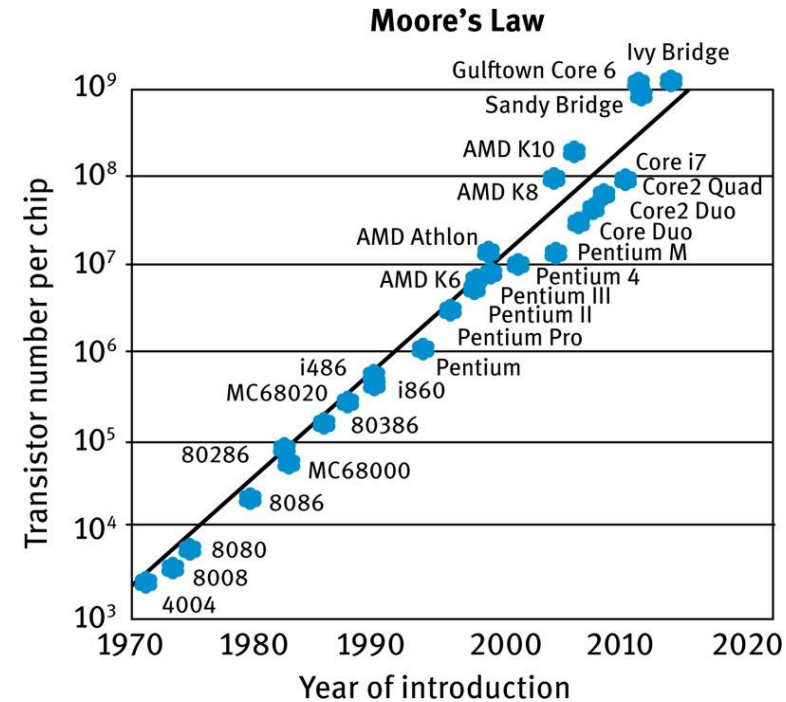
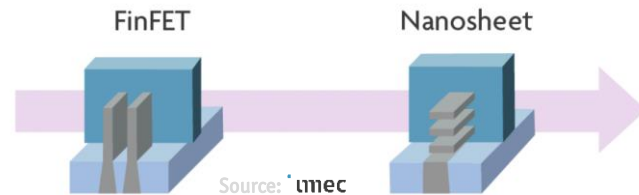
X-Technology #3



Digitalization / IIoT

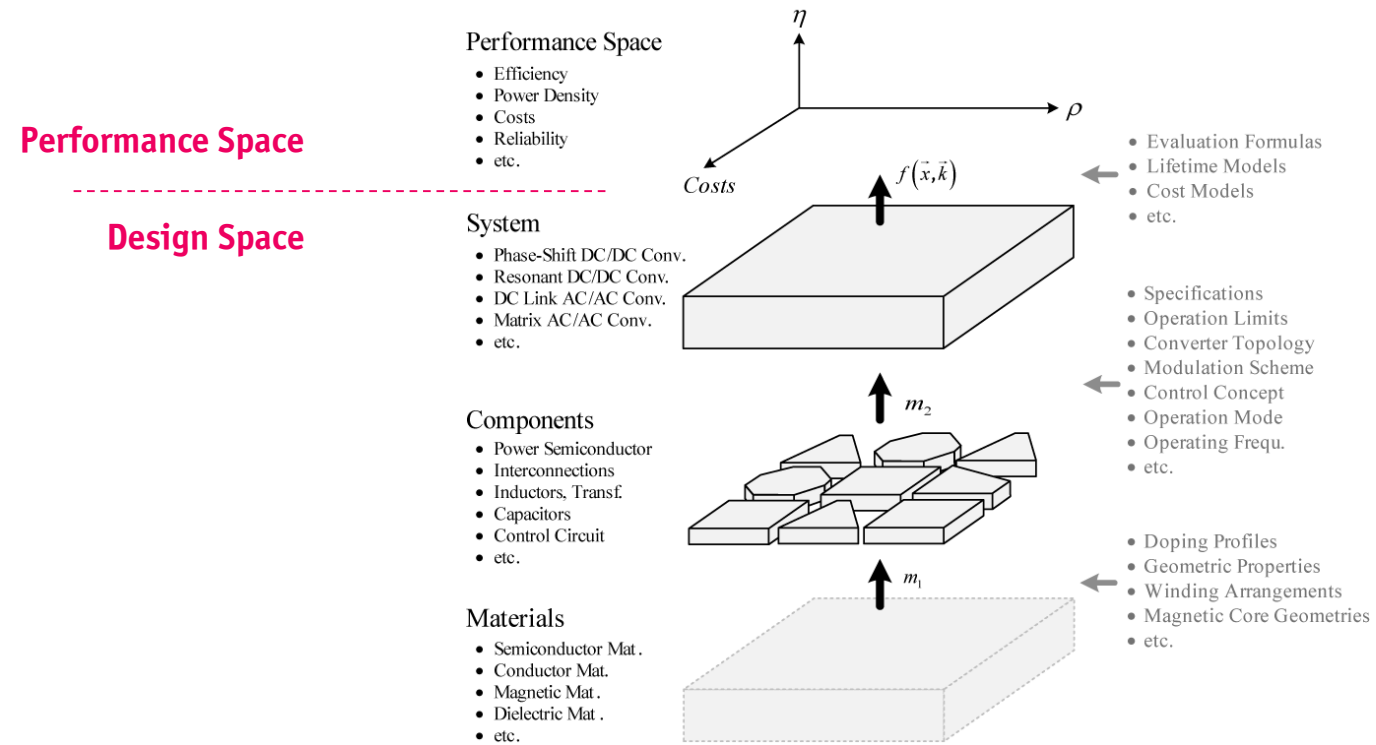
Digital Signal & Data Processing

- **Exponentially Improving uC / Storage Technology (!)**
- **Extreme Levels of Density (nm-Nodes) / Processing Speed**
- **Continuous Relative Cost Reduction**



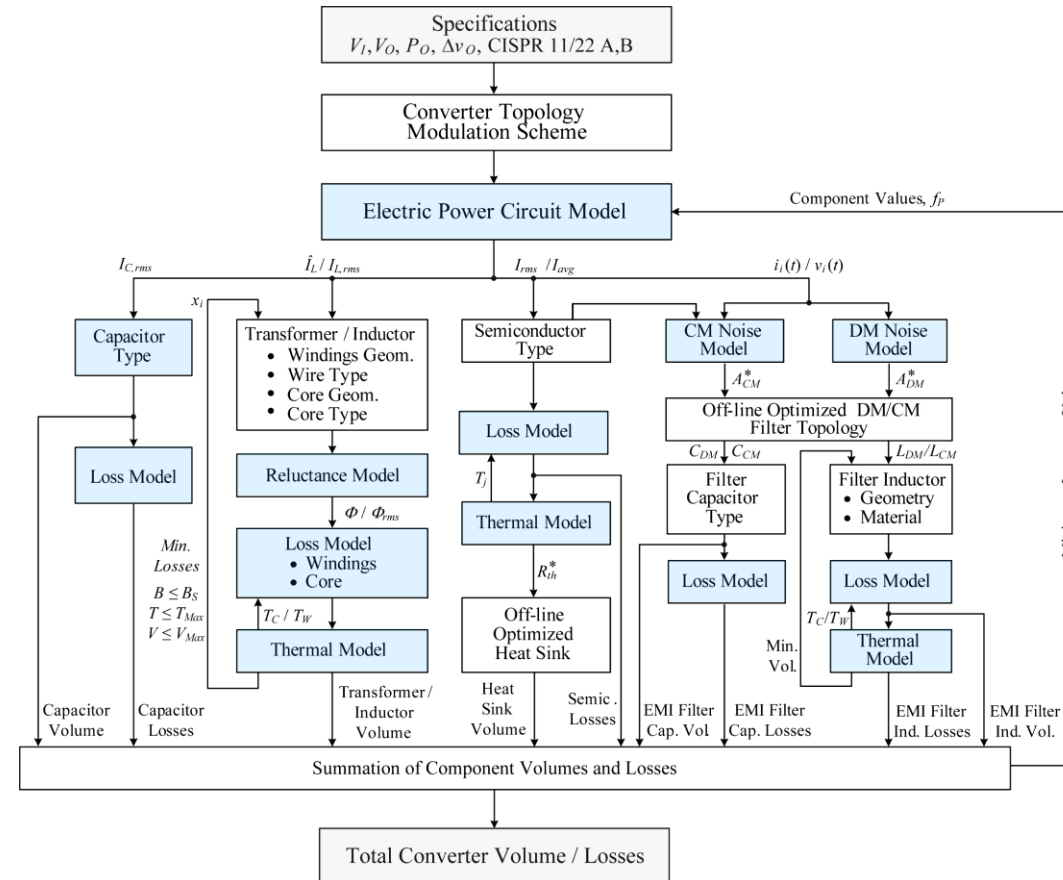
- **Distributed Intelligence**
- **Fully Digital Control of Complex Systems – AI-Based Design / Digital Twins / Industrial IoT (IIoT)**

Virtual Prototyping



■ Mapping of “Design Space” into System “Performance Space”

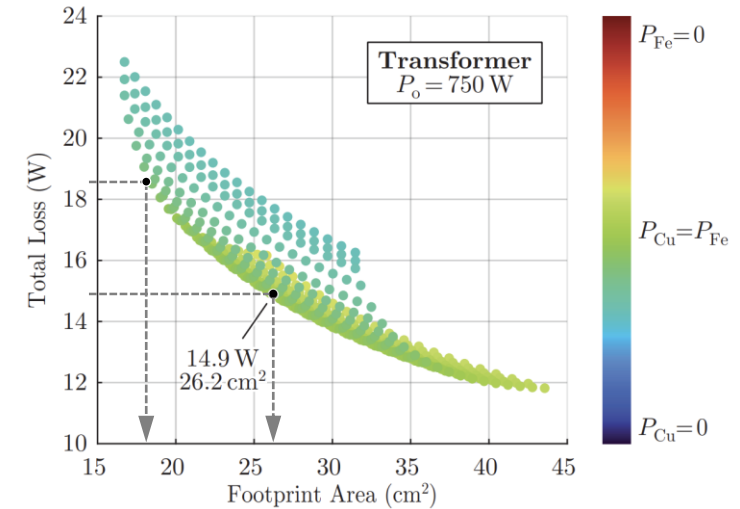
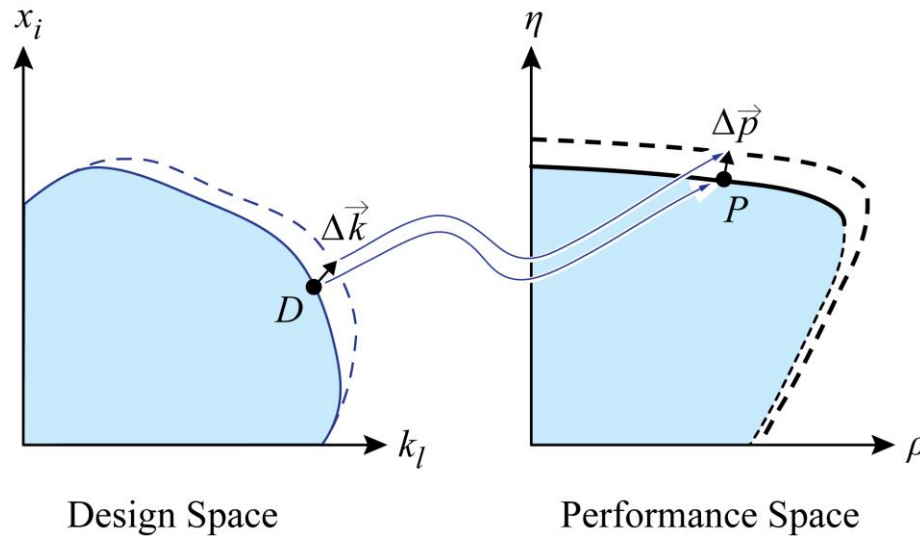
Multi-Objective Optimization



- “Digital Twin”
- Multi-Objective Optimization → Best Utilization of All Degrees of Freedom (!)

Automated Design

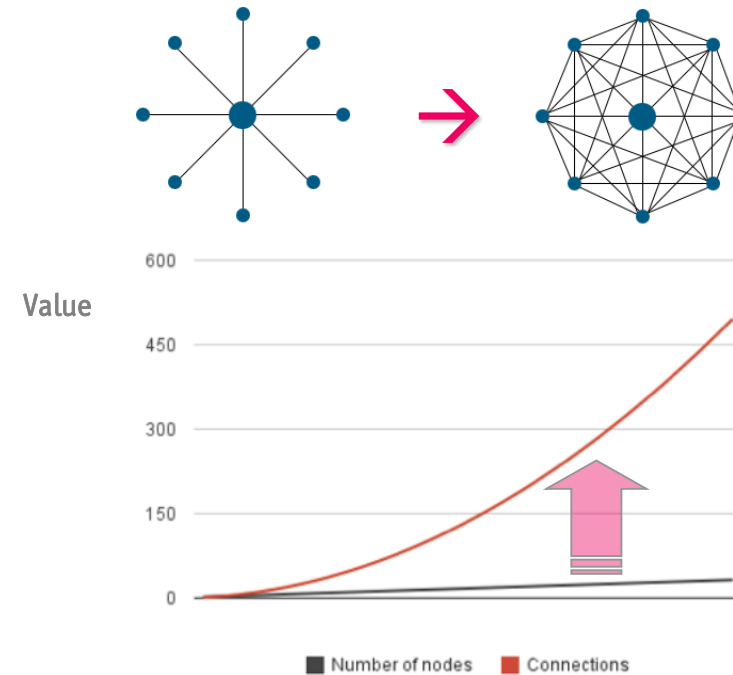
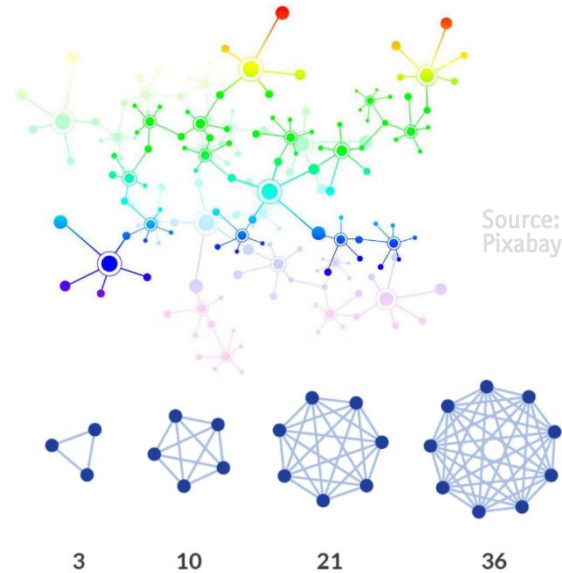
- *Multi-Objective Optimization* → *Identifies Absolute Performance Limits*



- *Clarifies Performance Sensitivity to Technology Improvements* → *Trade-Off Analysis*

Connected → Networked

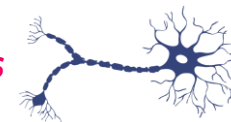
- Moving from Hub-Based Concept to **Community Concept** Increases Potential Network Value Over-Proportional ($\sim n(n-1)$ or $\sim n \log(n)$)



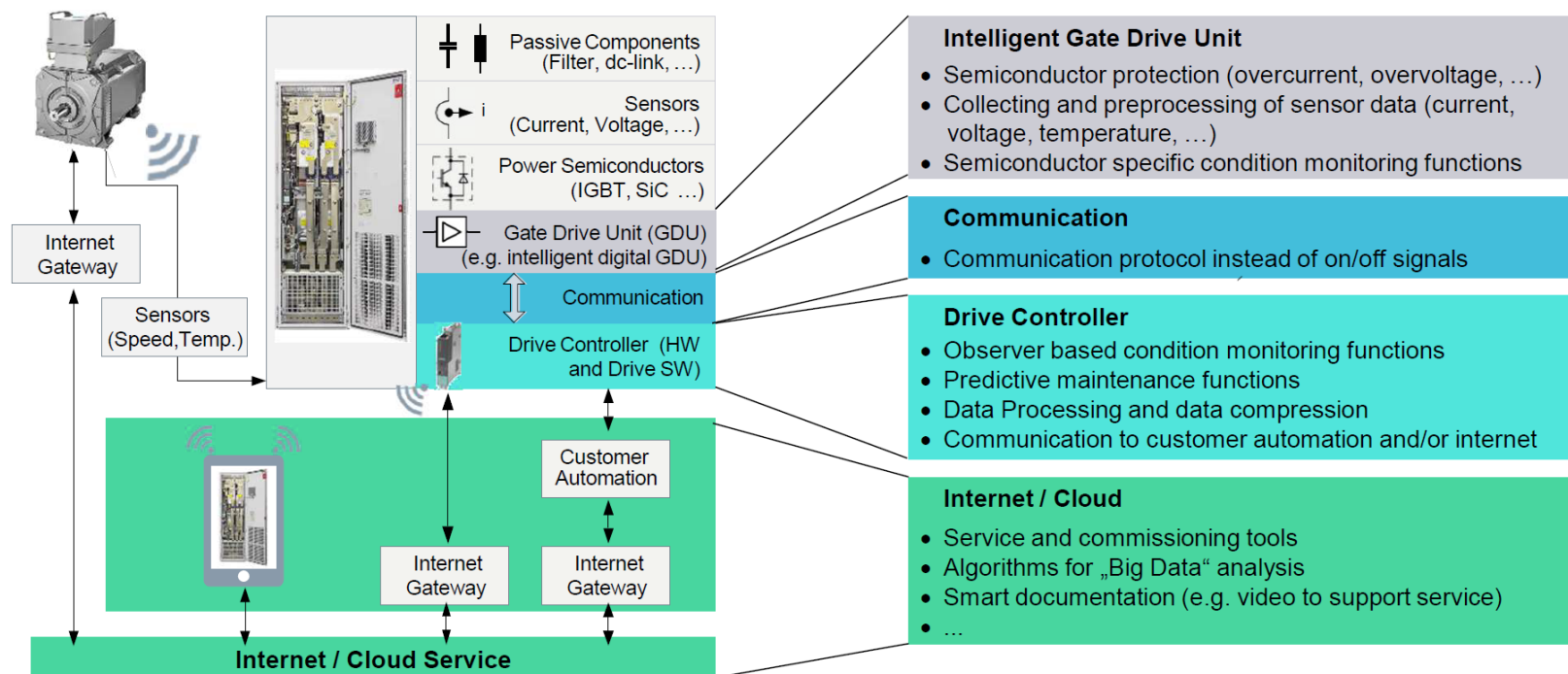
- Metcalf's Law
- Automated Design / Digital Control / Digital Twin

Smart Inverter Concept

■ “Cognitive” Power Electronics / Converter Systems



Source: R. Sommer
SIEMENS



■ Component — Converter — System — Application Level — IIoT



Energy 4.0 — Innovation Potential

Conceptually only Bounded by

- *Imagination / Vision*
- *Material Properties*
- *Laws of Physics*



... No Need to Wait !

Side Conditions

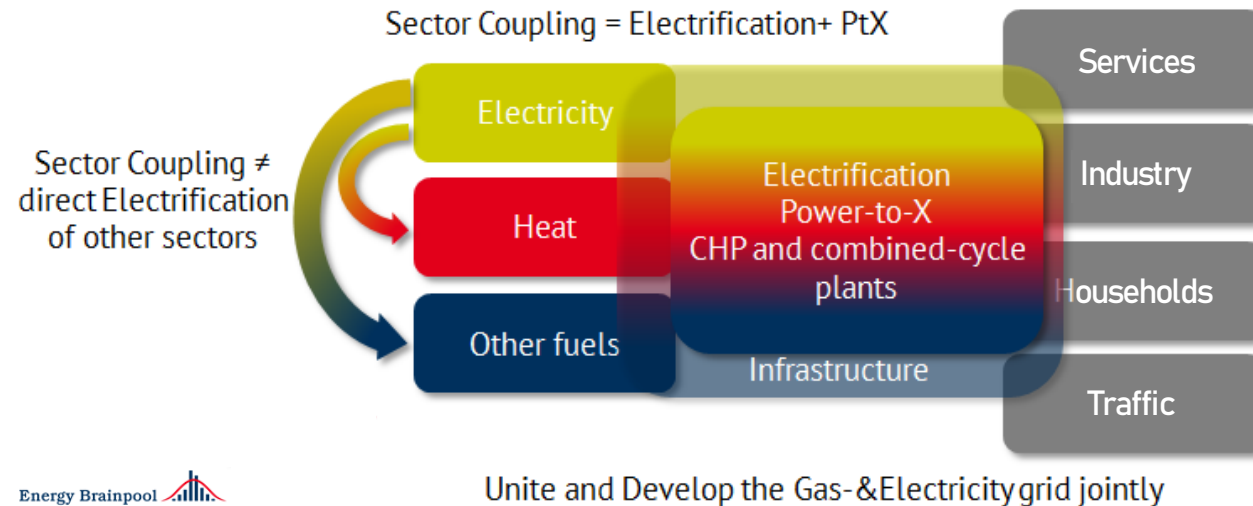
- *TCO / Payback*
- *Regulations*
- *Resources*
- *Education / Research*
- *Sustainability / LCA*

Key Technologies

- *Power Electronics*
- *Energy Storage*
- *Digitalization*
- *Sector Coupling*

Remark Sector Coupling

- *Integration of Main Energy Sectors — Electricity | Heat/Cold | Fuels & Generation | Consumption | Storage*
- *Full & Max. Eff. Utilization of Intermittent Renewable El. Sources → “All-Electric” | “Net-Zero”*

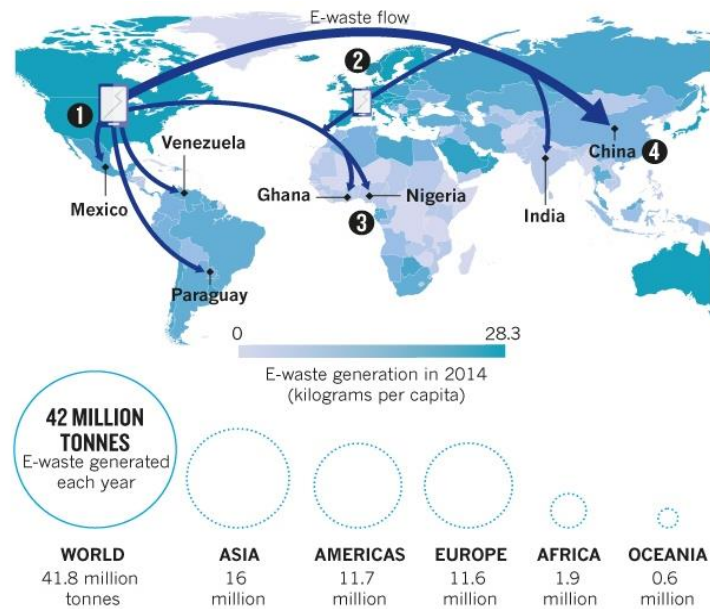


- *Electric Power-to-X / Hydrogen | Inertia of Thermal Processes | Combined Heat & Power | etc.*
- *Therm. Insulation of Buildings is Most \$\$\$-Effective to Improve Energy Efficiency (vs. Transp. & Ind.)*

Remark Increasing E-Waste Problem

- 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:
Green IT
Solution



Source: nature

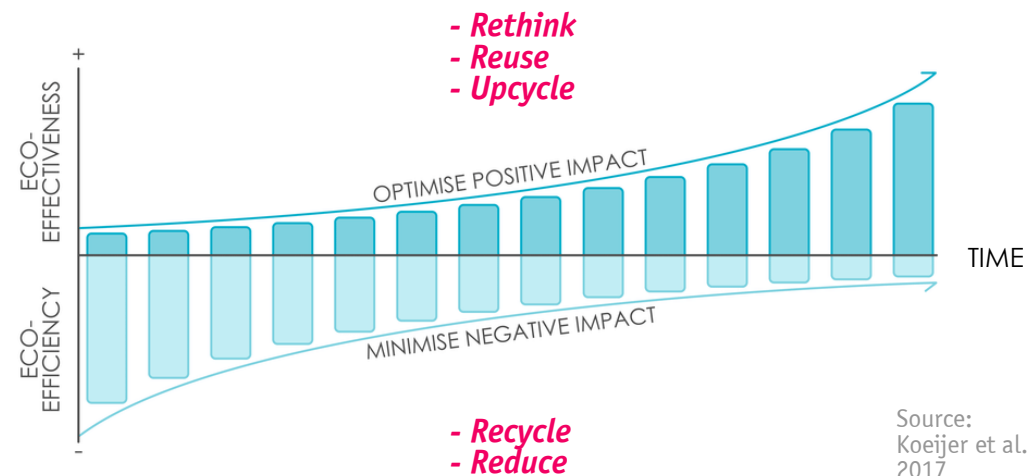
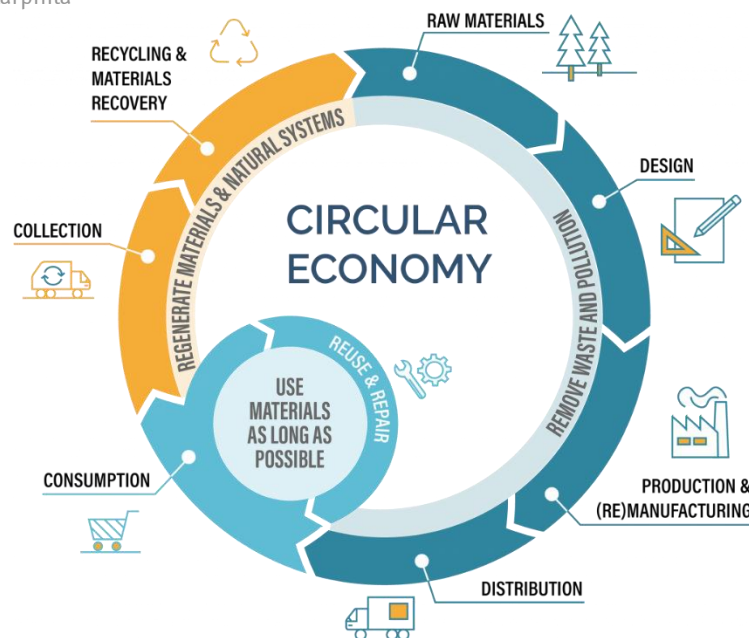


- Growing Global E-Waste Streams → Upcoming Regulations

Remark Cradle-to-Cradle

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

Source:
<https://circularphila.delphia.org>

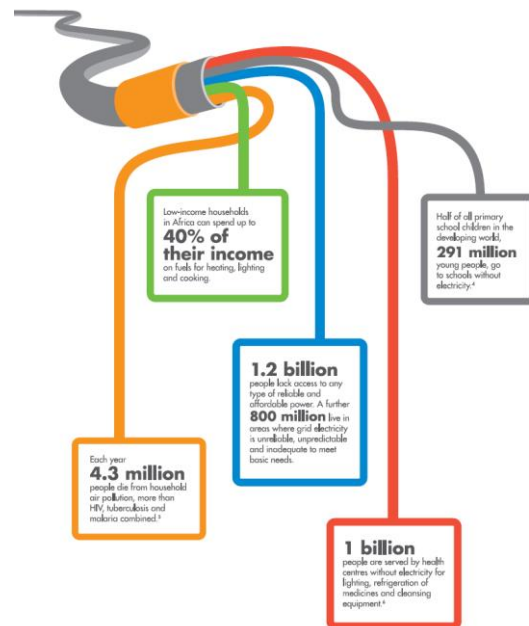


Source:
Koeijer et al.
2017

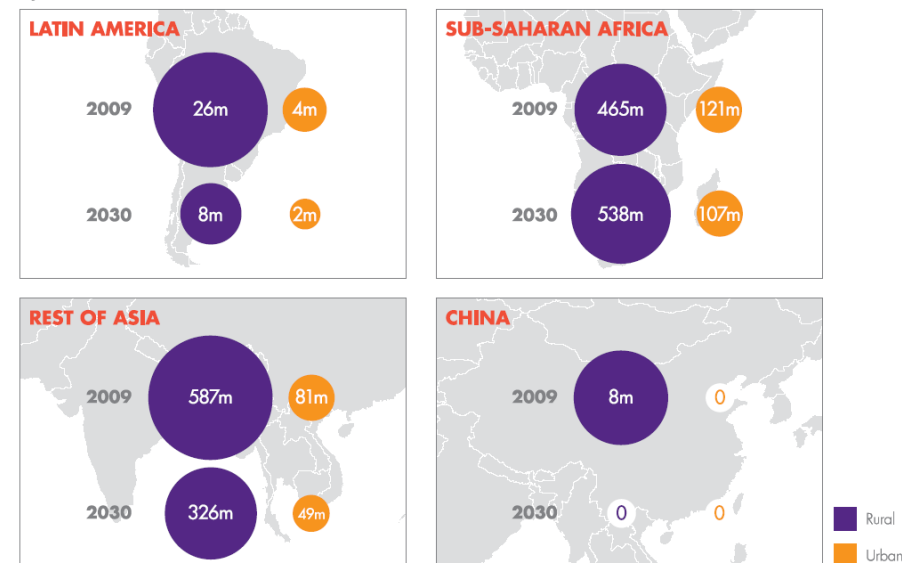
- **Decoupling of Economic Growth & Use of Resources**

Remark Bottom-of-the-Pyramid

- **2 Billion People** are Lacking Access to Clean Energy
- **Urgent Need for Rural Electrification**



The number of people without access to electricity



Over 1 billion people will still be without access to electricity in 2030

Source: IEA, Dalberg Analysts, IFC

- **2 US\$ / Household / Month (!)** for 2 LED Lights & Mobile-Phone Charging

Thank you!

