

# Next Frontiers in Power Electronics

**Johann W. Kolar et al.**



Swiss Federal Institute of Technology (ETH) Zurich  
Power Electronic Systems Laboratory  
[www.pes.ee.ethz.ch](http://www.pes.ee.ethz.ch)

*June 25, 2024*



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## Outline



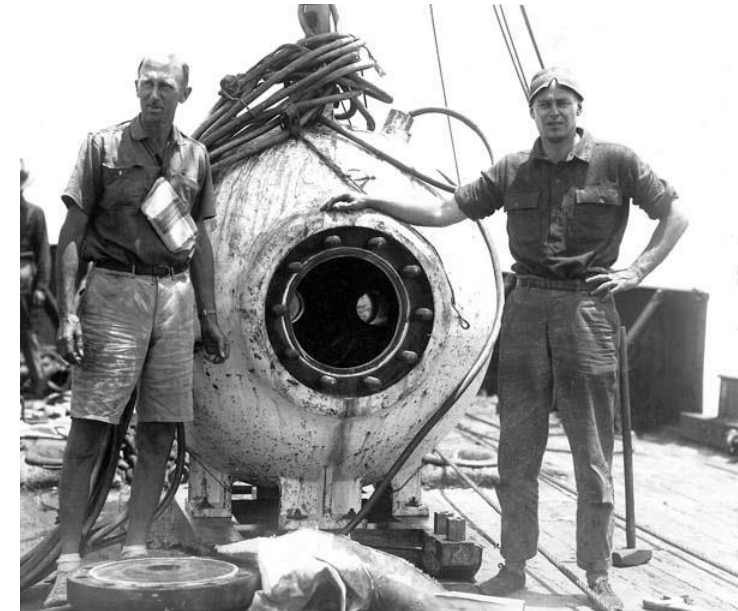
- ▶ *Introduction*
- ▶ *Mastering the Deep*
- ▶ *Taking Actions for a Healthy Planet*
- ▶ *Unlocking the High Frontier*
- ▶ *Conclusions*

### Acknowledgment

Florian Krismer  
David Menzi

# The Human Desire for Exploration

- *Vikings Blown Off Course Discovered America in 986 AD*
- *Record-Breaking 3'028 Feet Dive of Ch. Beebe & O. Barton in 1934*
- *Exploration is Fundamental to Human Success and Driven by Curiosity &/or Thirst for Fertile Land & Profit etc.*



- *Today Most Explorers Making Fundamental Discoveries are Scientists*

## *Mastering the Deep*

*Deep-Sea E-HyDrones  
Subsea Resident AUVs*



# Classification of Underwater Vehicles

- **ROV** — *Remotely Operated Underwater Vehicle* | *Connected to Surface Vessel via Umbilical*
- **AUV** — *Autonomous Underwater Vehicle*

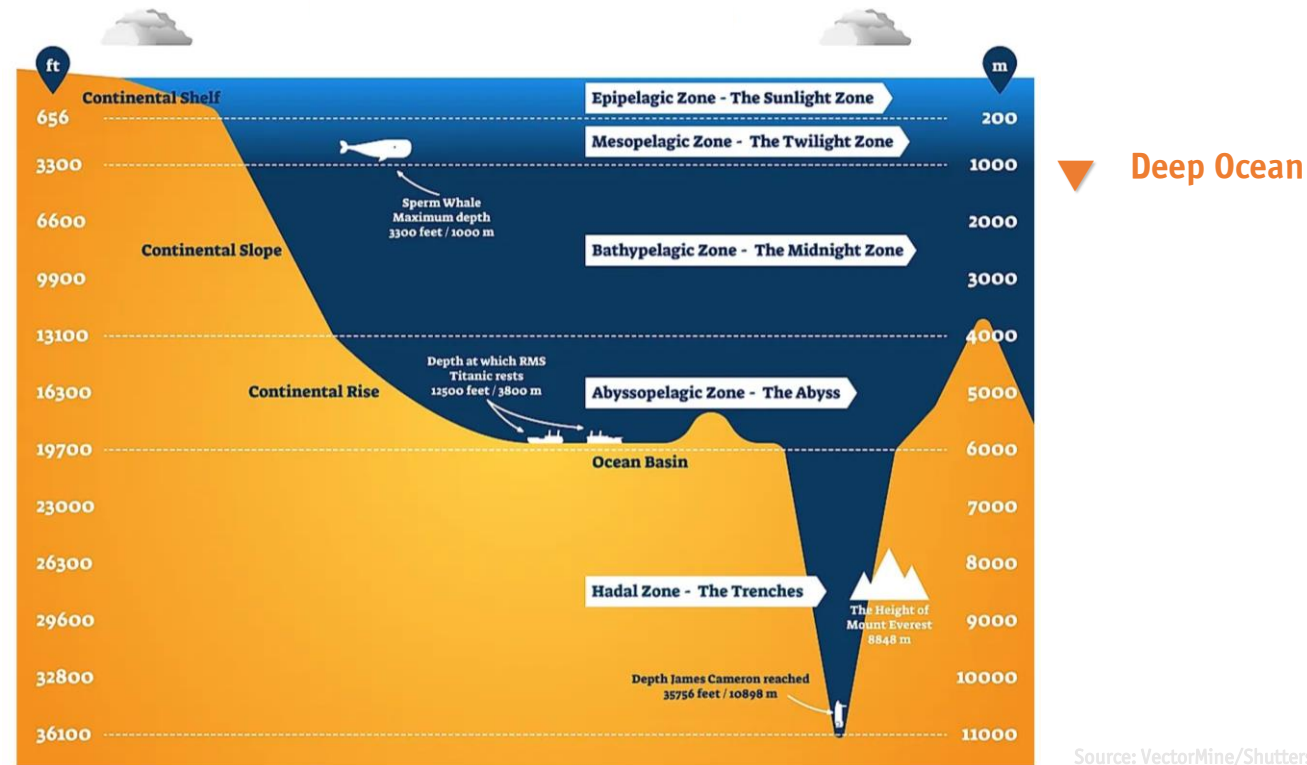


Source:  
 SCHMIDT  
OCEAN  
INSTITUTE

- **Oceans Cover 71% of Earth's Surface** | **5% Explored**
- **Global Annual ROV Market** — **\$3.5 Billion in 2020 / 11.5% CAGR in 2021...2026**
- **74% Increase in AUV Demand in 2022**

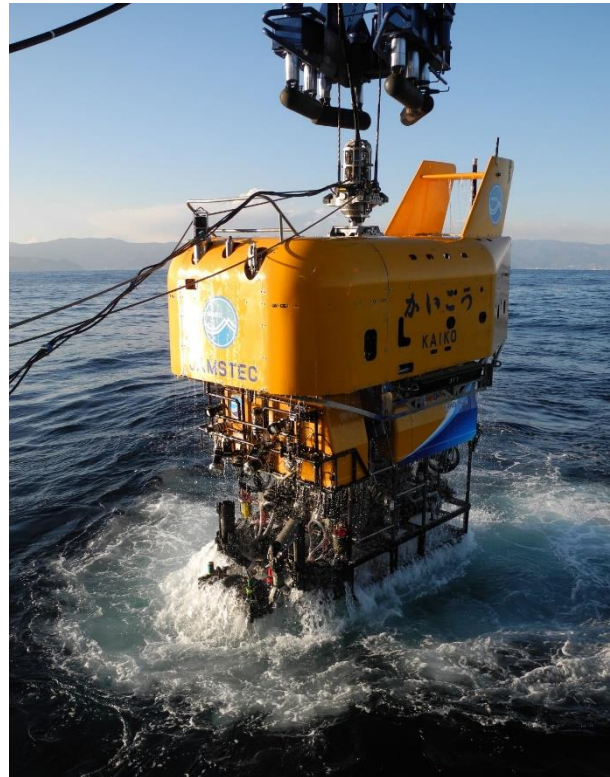
# Scientific Exploration of Ocean Depths – 1/2

- *Surveys of Submarine Volcanoes / Hydrothermal Vents / Subduction Zones*
- *Collection of Seabed Sediments / Microorganisms*

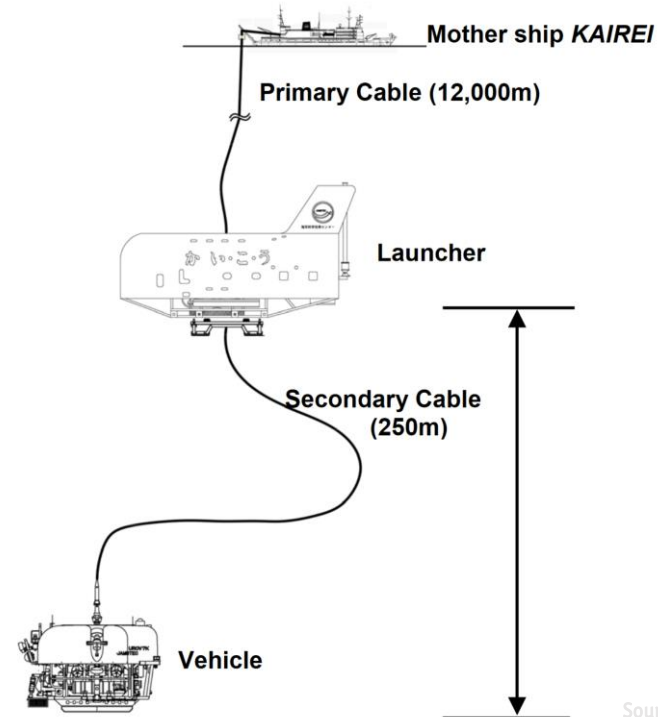


- *5 Zones / Deepest Location → “The Challenger Deep” @ 11’034m (≈ 4°C) | 3’700m in Average*

# Scientific Exploration of Ocean Depths – 2/2



Source: 



Source: Murashima et al, 2005

- Full Ocean Depth ROV Kaiko / JAMSTEC (Launcher & Vehicle) → 10'911m / Lost During a Typhoon
- New 11'000m-Class ROV (ABISMO — Automatic Bottom Inspection and Sampling Mobile)



# Blue Economy

- *Economic Sectors Related to Exploitation / Preservation / Regeneration of Marine Environment*
- *Established Sectors — Maritime Transp. | Ship Buildg | Fishing | Off-Shore Oil & Gas | Coastal Tourism | etc.*



Source: EU Science Hub

- *Highlighted Emerging Activities — Floating Off-Shore Wind & Solar Energy | Wave & Tidal Energy | Robotics etc.*
- *Important Role in the EU's Transition Towards a Carbon-Neutral / Circular / Biodiverse Economy*

# Floating Off-Shore Wind Power Plants

- *80% of Off-Shore Wind Energy Available in Deep Waters*
- *Higher & More Consistent Wind Speeds / Lower Environmental Impact*



Source: Josh Bauer / NREL

- *Floating Support Structures for Seabed Depths > 60m — Seabed Connection Through Mooring Cables*
- *3 Basic Types — Tower-Like Spar Buoy | Semi-Submersible | Tension Leg (Mooring Cables Under Tension)*

# Floating Off-Shore Solar Plants

- *10x Growth of Solar Power to 5 TW Mandatory for Closing the Emission Gap*
- *Dense Population / Land Shortage → Utility-Scale Solar Projects on Inland Waters and in Oceans*
- *Potential Combination of Off-Shore Wind & Off-Shore Solar Infrastructures*



Source: [www.rechargenews.com](http://www.rechargenews.com)

- *Higher Sun Irradiance @ Sea & Lower Temperature / Higher Efficiency*
- *Destructive Wind & Wave Forces → Membrane-Type Flexible Circular Platforms w/ Buoyancy Rings*
- *Potentially Lower Cost of Off-Shore Solar Compared to Off-Shore Wind — 2x Higher GWh/km<sup>2</sup>*

# Off-Shore Green-H<sub>2</sub> Production

- *Energy Transport via Molecules / Hydrogen Avoids High \$\$\$ of HVDC Cables / Systems*
- *Decline of Oil & Gas Production → Repurposing of Offshore Assets / Platforms, Pipelines etc.*

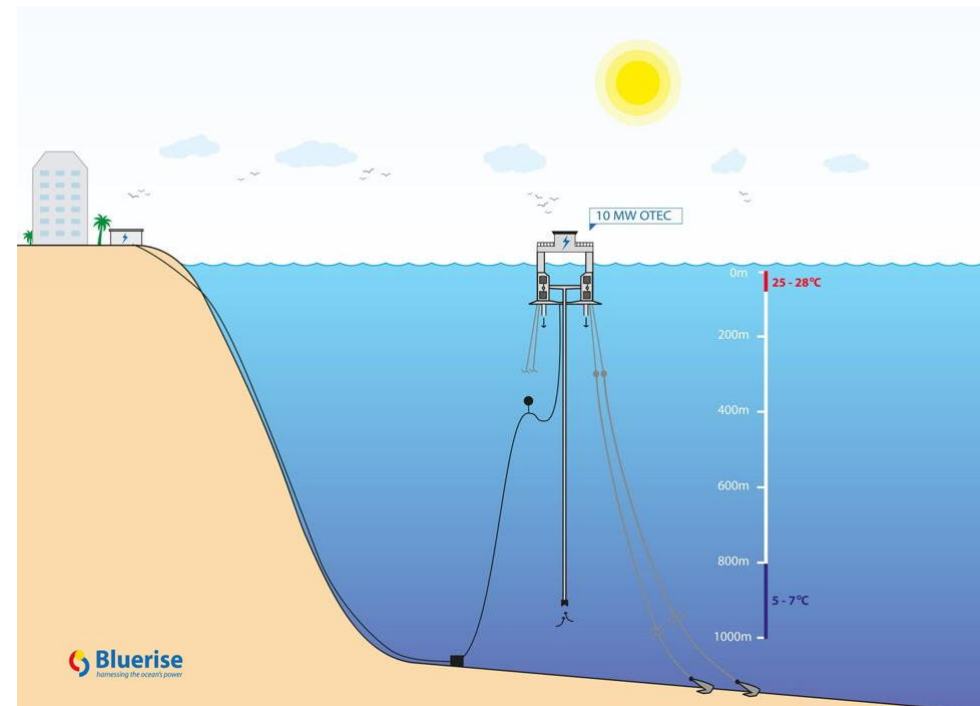
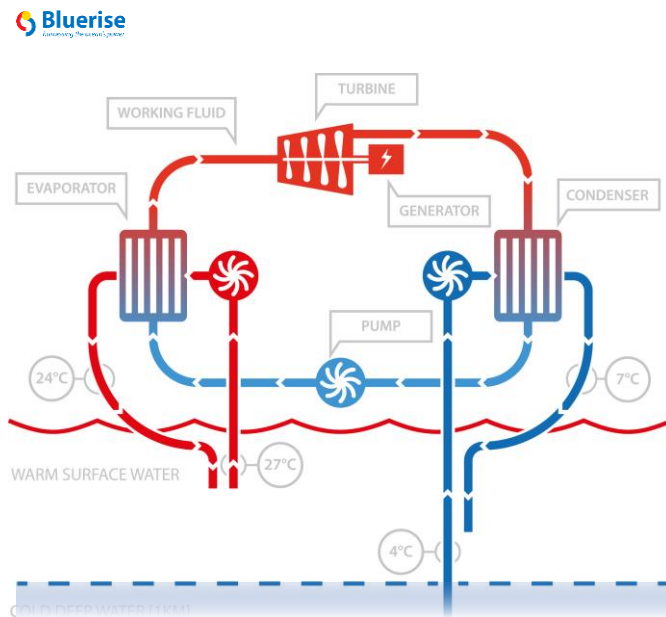


Source:  
<https://tractebel-engie.com>

- *P2G → Desalinated H<sub>2</sub>O Electrolyzers on Off-Shore Platforms Converting Wind Energy to “Green Hydrogen”*
- *60-80% Conversion Efficiency / Multi-GW Scale / Interconnection of Neighboring Countries*

# Ocean Thermal Energy Conversion

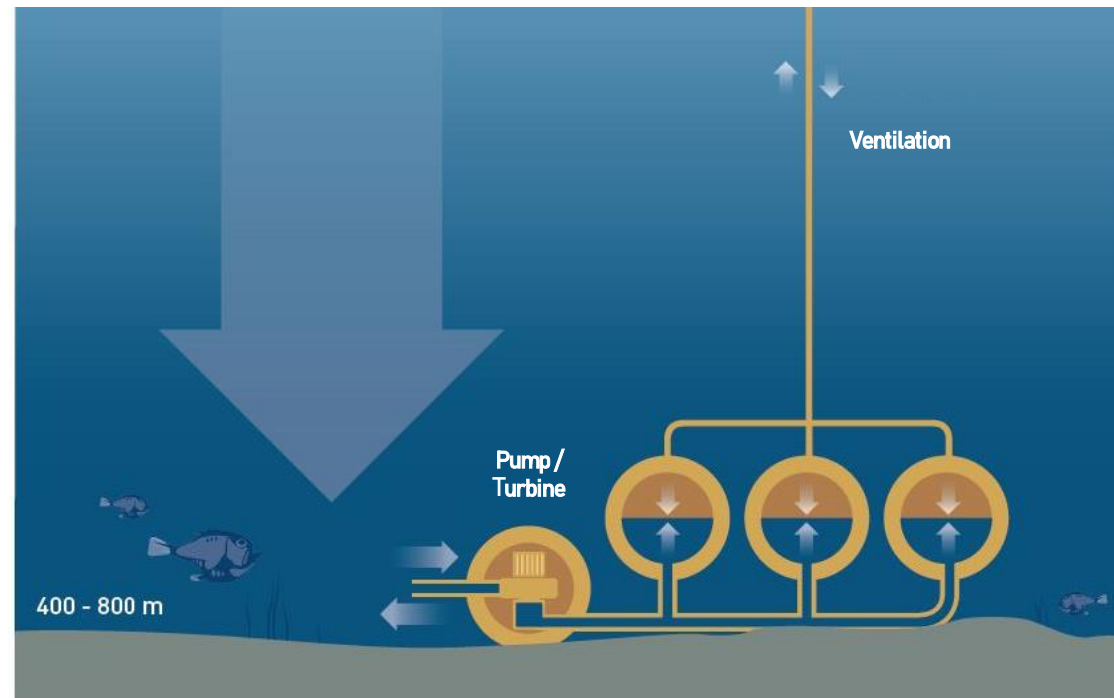
- **Temperature Difference in Oceans Utilized for 24/7 (!) Electricity Generation**
- **25°C Surface Water Vaporizes Low Boiling Point Ammonia – Expanding Vapor Drives Turbine**
- **Vapor @ Turbine Output Condensed by 5°C Seawater Pumped from -1000m**



- **10MW OTEC Pilot Planned in Southern China by Lockheed Martin & Reignwood Group**
- **Solar Energy Absorbed by 23 Million Square Miles = 250 Billion Barrels of Oil = 200x Entire US Energy / Day**

# Subsea Pumped Hydro Storage

- *GWh-Scale 10MWh-Modular / Scalable Storage @ Seabed Exploiting the High Deep-Sea Pressure*
- *Off-Shore Installation Near Wind Farms / Floating Solar Farms / Tidal & Wave Energy Systems etc.*

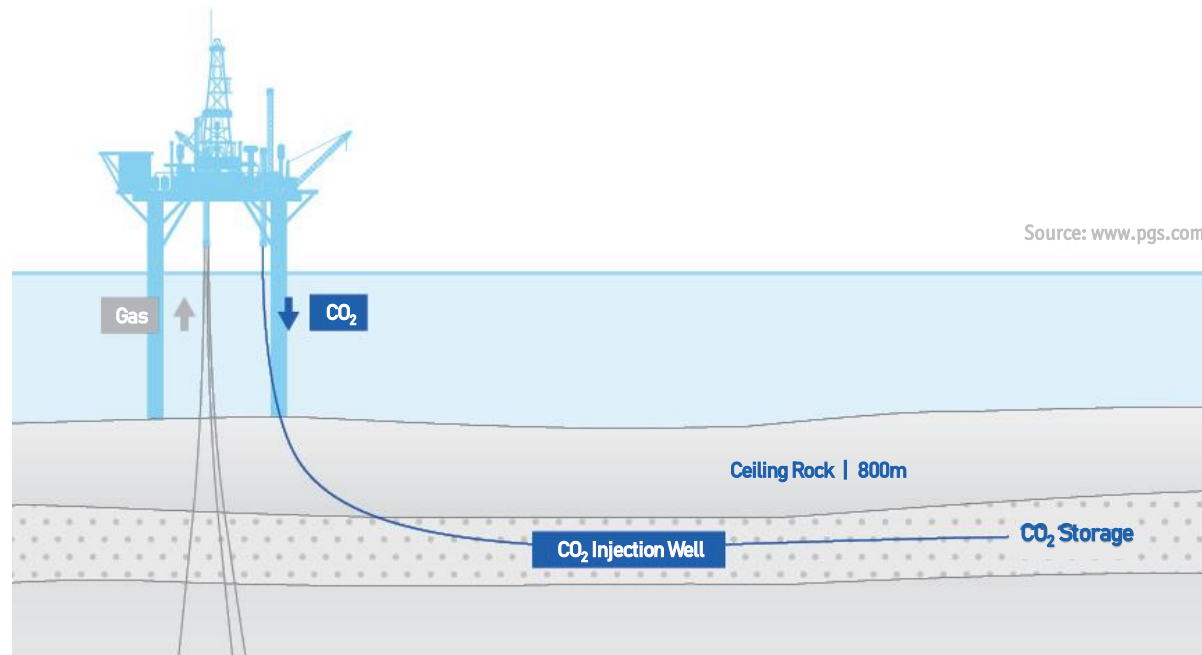


Source: SINTEF

- *Charging* → *Pumping Water from Low-Pressure Rigid Reservoir Into High Pressure Environment*
- *Discharging* → *High Pressure Environment Pushes Water Into Reservoir / Drives Turbine*

# Off-Shore CO<sub>2</sub> Storage

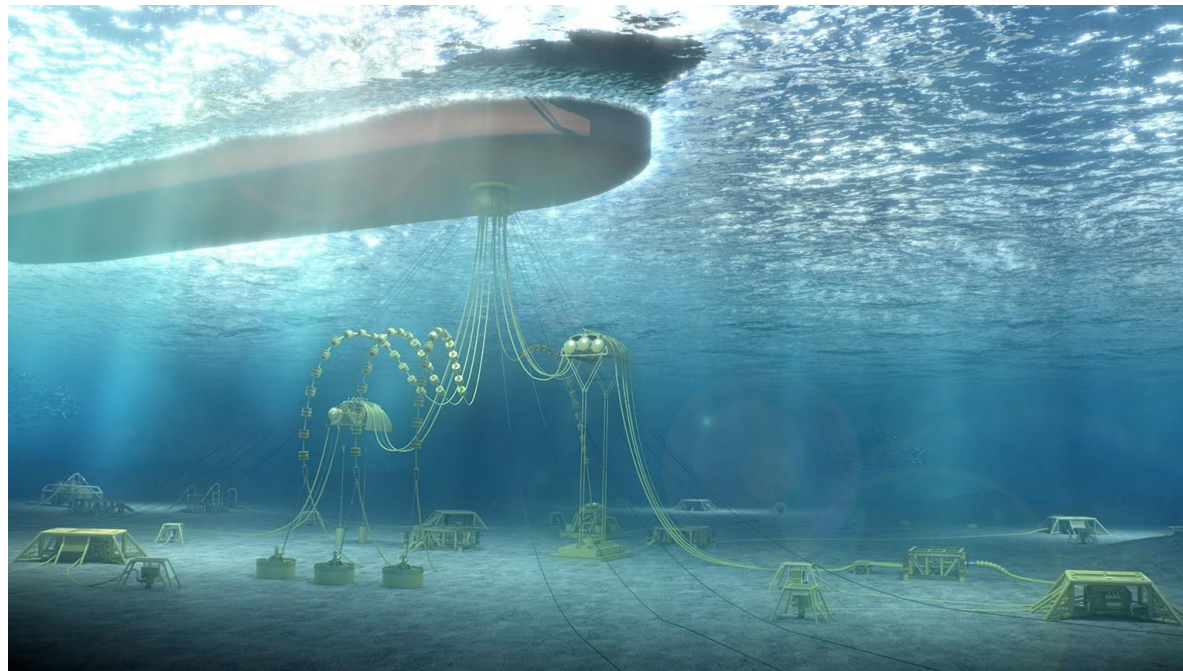
- *CO<sub>2</sub> Capture & Storage (CCS) → Main Element of the Energy Transition to a Low Carbon Future*
- *Future Industrial CCS Value Chain → CO<sub>2</sub> Transported by Ships & Stored in Off-Shore Formations*



- *World's 1<sup>st</sup> Off-Shore CCS Plant in Operation since 1996 in Sleipner Natural Gas Field (Equinor = Statoil)*
- *Norwegian CO<sub>2</sub> Tax Introduced 1991 → CO<sub>2</sub> Contained in Natural Gas Re-Injected Into Porous Sandstone*

# Subsea Industry / Autonomous Factories

- *Deep-Sea Oil & Gas Extraction / Processing — No Platforms / Lower \$\$\$ | Deep-Sea Mining*
- *Lower Environmental Impact of Natural Gas Compared to Coal → “Golden Age of Gas”*



Source: [www.ocean-5.com](http://www.ocean-5.com)

- *Hydraulic Wells → High Eff. All-Electric Wells → No High Pressure Equipm. / No Pipe Leaking / Lower \$\$\$*
- *Long Distance DC Power Transmission (600km, 100MW, 3000m) → Pumps etc. Located @ Seabed*



# Seabed Interventions – 1/2

- *Burial of Subsea Pipelines and Cables*
- *Jet Trenching ROVs | Ploughs | Mechanical Trenchers — x 1000m Operation Depth*



Source:  
**DEEPOCEAN**

- *World's Most Powerful Trencher (T3200 / 2.4MW / DeepOcean)*

## Seabed Interventions – 2/2

- *Burial of Subsea Pipelines and Cables*
- *Jet Trenching ROVs | Ploughs | Mechanical Trenchers — x 1000m Operation Depth*

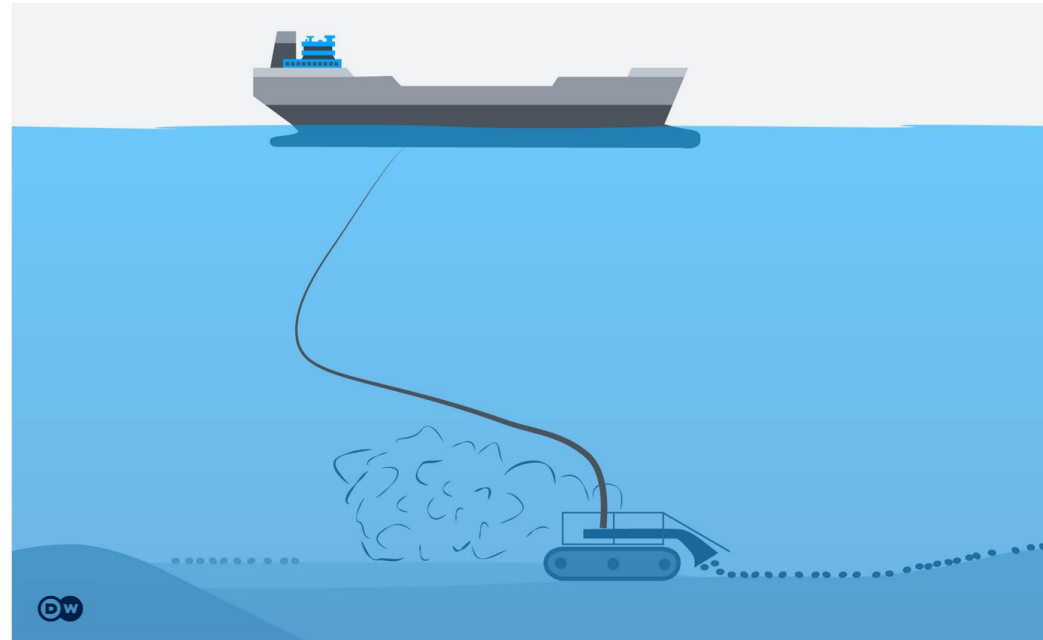


Source:  
DEEPOCEAN

- *World's Most Powerful Trencher (T3200 / 2.4MW / DeepOcean)*

# Deep-Sea Mining Vehicles – 1/2

- *Suction of Polymetallic Nodules (Mn, Co, Cu, etc.) @ Seabed (4000...6000m)*
- *Subsea Crushers & Pumps for Transportation of the Minerals to Supporting Vessel*



Source: [www.hydrographica.org](http://www.hydrographica.org)

- *Potential Serious Threat to Global Oceans (!)*

## Deep-Sea Mining Vehicles – 2/2

- *Suction of Polymetallic Nodules (Mn, Co, Cu, etc.) @ Seabed (4000...6000m)*
- *Subsea Crushers & Pumps for Transportation of the Minerals to Supporting Vessel*

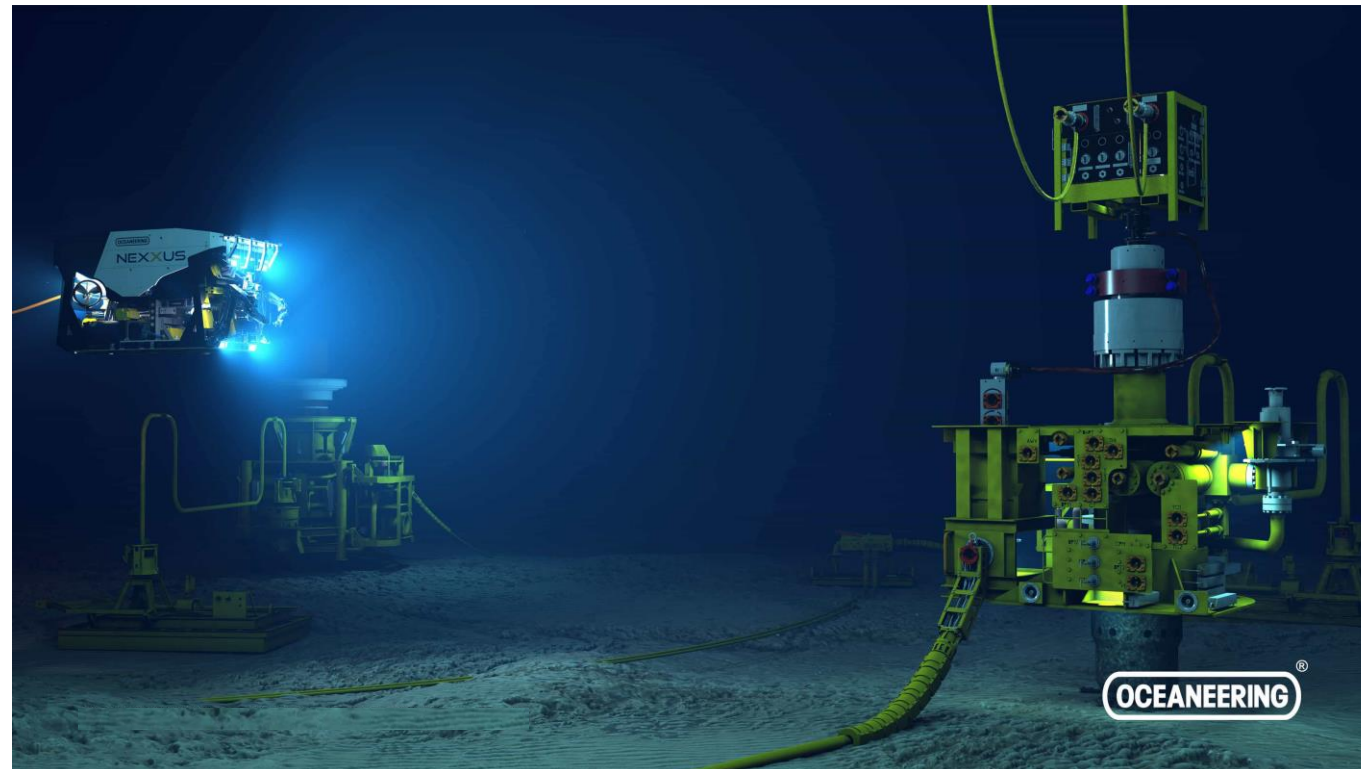


Source:  GSR

- *Patania II 25t Robot "Nodule Collector" (Tested @ 4500 m)*

# Subsea IMR — Inspection / Maintenance / Repair

- *Complex / Inaccessible Subsea Infrastructures* → *Inspections & Interventions*
- *Oil & Gas Industry* → *Well & Infrastructure Diagnostics | Remediation of Damaged Wells etc.*

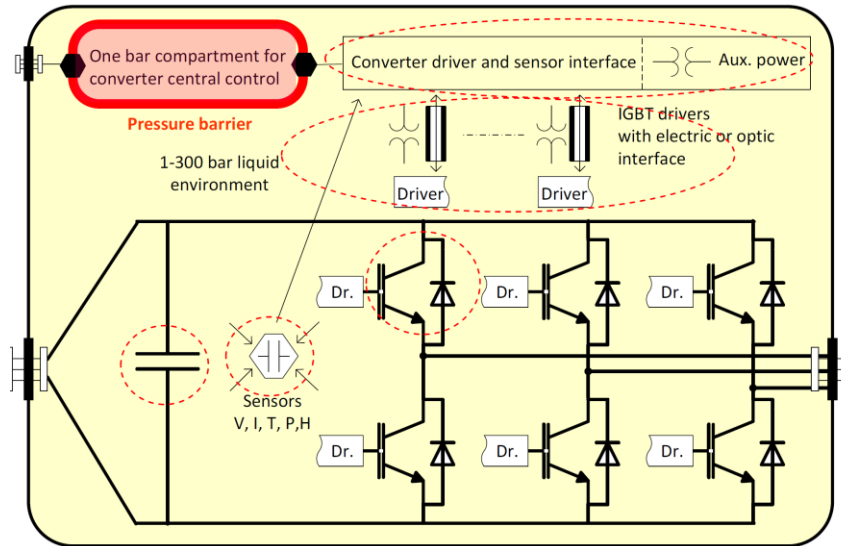


- *Operation Depths > 2500m*

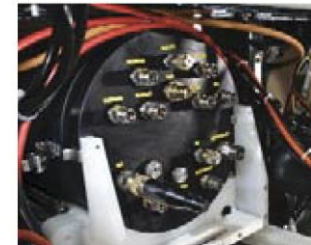
# Remark Electronics Pressure Housings

- Air or Gas Filled Components → Would implode in Large Depths (e.g. 6000m → 600bar)
- One-Atmosphere Housings → Maintain Constant Inside Pressure / Cylindrical or Spherical Shape
- Pressure Balanced Housings → Int. ≈ Ext. Pressure / Oil Filled – No Voids / Not Shape (Cooling) Restricted !

Source: M. Hernes  
SINTEF



Source: SAAB



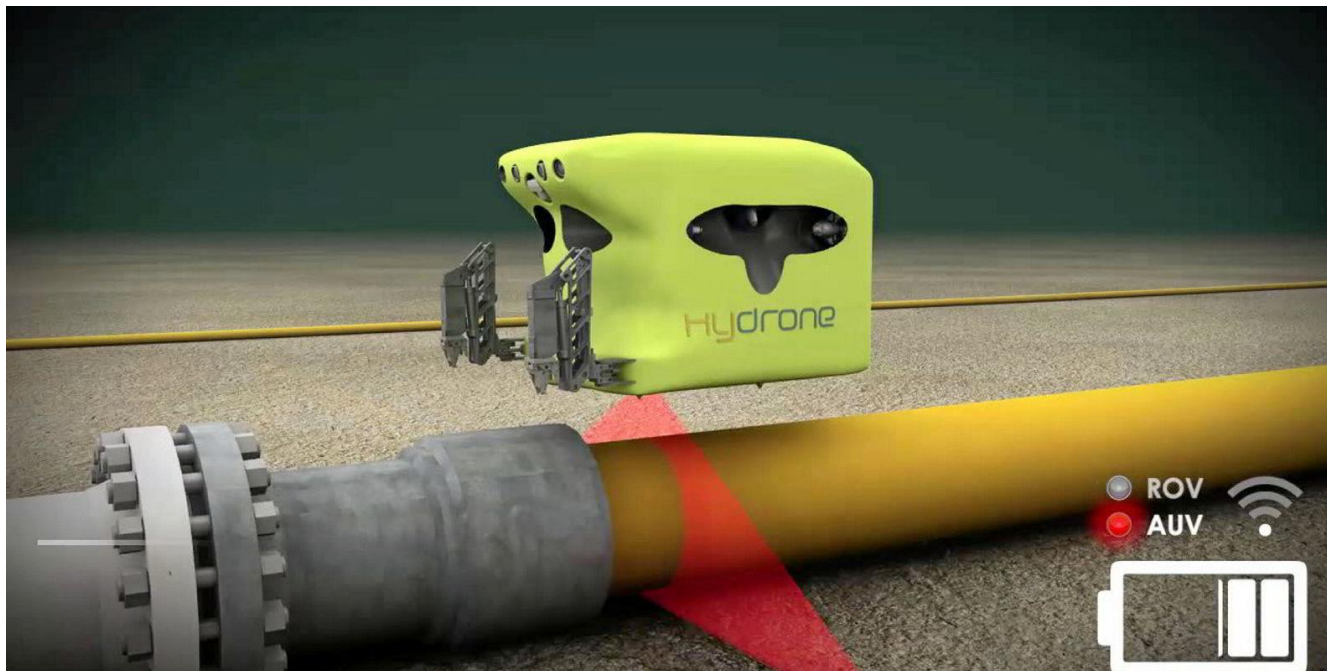
Electronics Compartment of Saeye Jaguar



- Research on Pressure-Tolerant Power Electronic Components (300bar) @ SINTEF
- IGBTs → Sw. Behavior Unaffected / Chip Interface Needs to be Protected from Surrounding Liquid
- Pressure Affects BH-Curve of Magnetic Cores & Impairs Self-Healing of PP Film Cap. → Voltage Derating

# Autonomous Underwater Vehicles — AUV

- *Self-Powered & Self-Guided → No Tether or Line to Crewed or Uncrewed Surface Ship / Lower Mission \$\$\$ etc.*
- *Mission Range & Duration Limited by Onboard Battery Capacity*

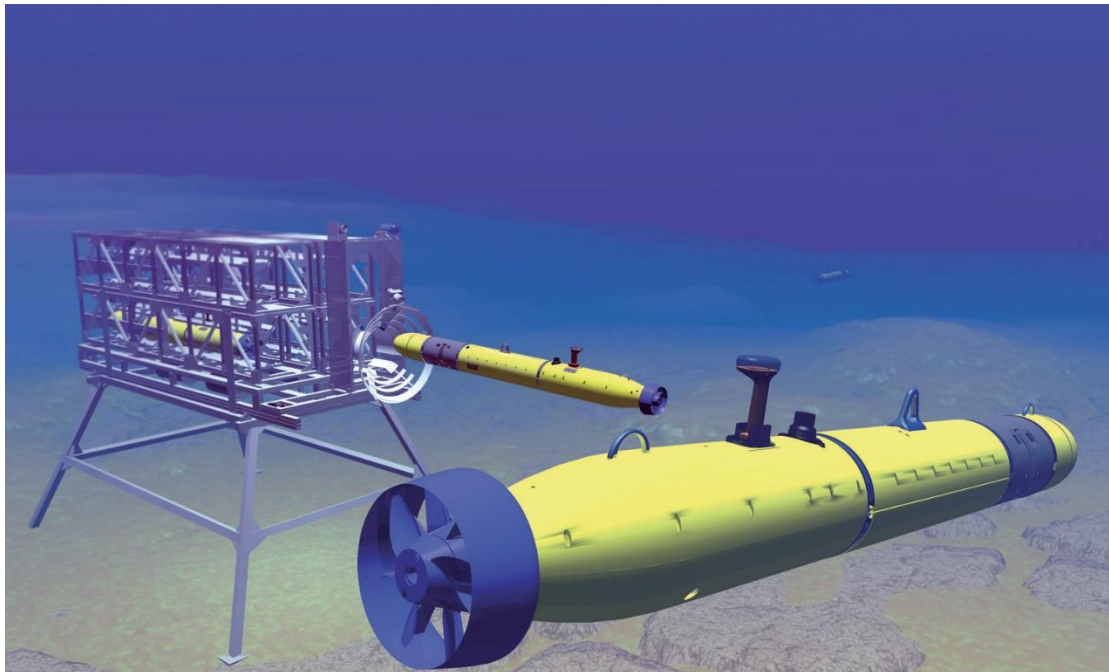


Source:  SAIPEM

- *Seabed Docking Station for Battery Recharge / Mission Download & Data Offload → Enables Subsea Residency*
- *Local Power Generation & Surface Communication | Unmanned Surface Vehicle for Launch & Recovery*

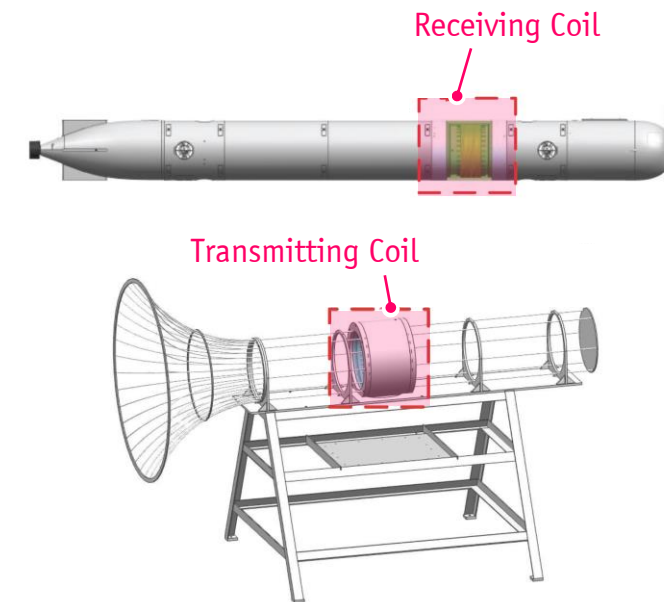
# Wireless AUV Charging — Resonant IPT

- *Co-Axial Arrangement of High-Q Coils Operating in Resonance / Relatively Large Misalignment Tolerance*
- *Funnel-Shaped Recovery Cage — Entry Cone & Docking Tube*



Source: www.oedigital.com

Source: Peizhou Liu et al., 2022

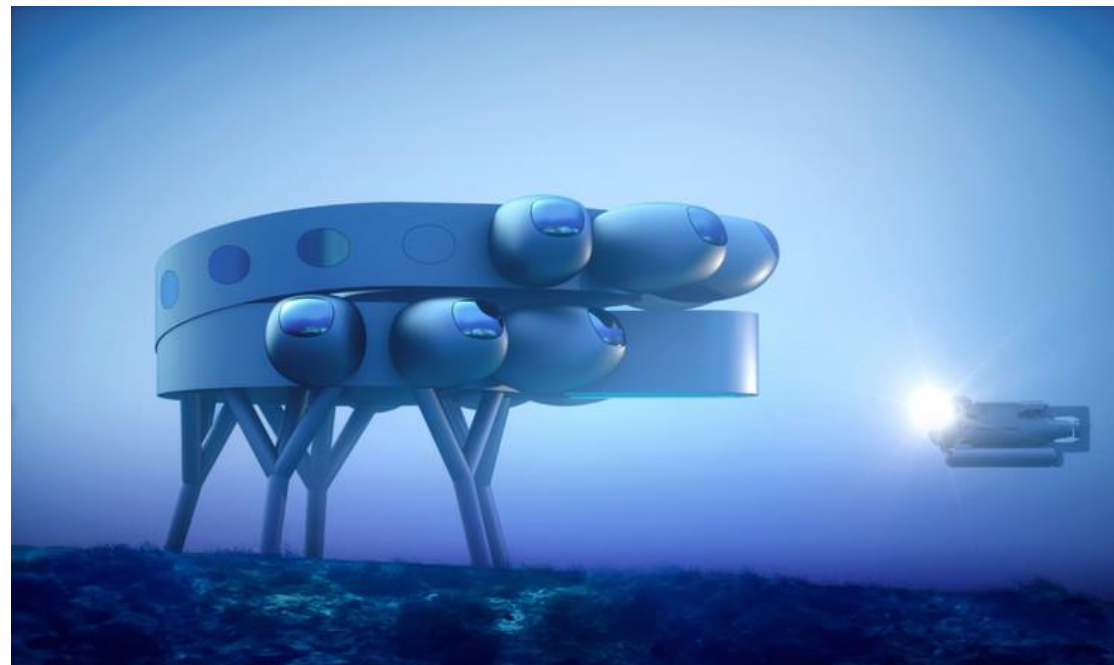


- *Ferrite Elements for Magn. Flux Shaping → Red. Field/EMI Inside the AUV & Red. Eddy Curr. in AUV Metal Hull*
- *Coil Geometry Adapted to Physical AUV Structure → Limited Interoperability*



# Future Underwater Habitats

- *Underwater Version of the International Space Station*
- *Discovery of New Species of Marine Life / Aquacultures / Understanding Climate Change Effects*

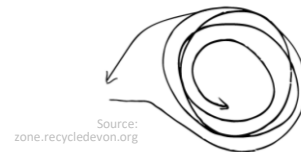


Source:  
ArchDaily/  
Protheus

- *PROTEUS — First in a Network of Future Underwater Habitats*

## *Taking Actions for a Healthy Planet*

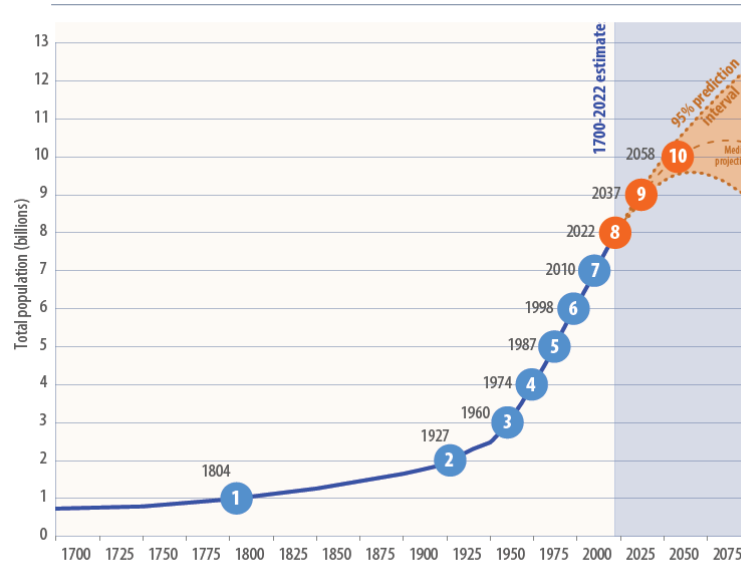
*Decarbonization*  
*Circular Economy*



# The Challenge 1/2

- **Growth of World Population & Growth of Energy Use per Capita**
- **1980 — 4.4 Billion |  $\approx 10$  TW.yr  $\rightarrow$  2022 —  $\approx 8$  Billion | 20.4 TW.yr**

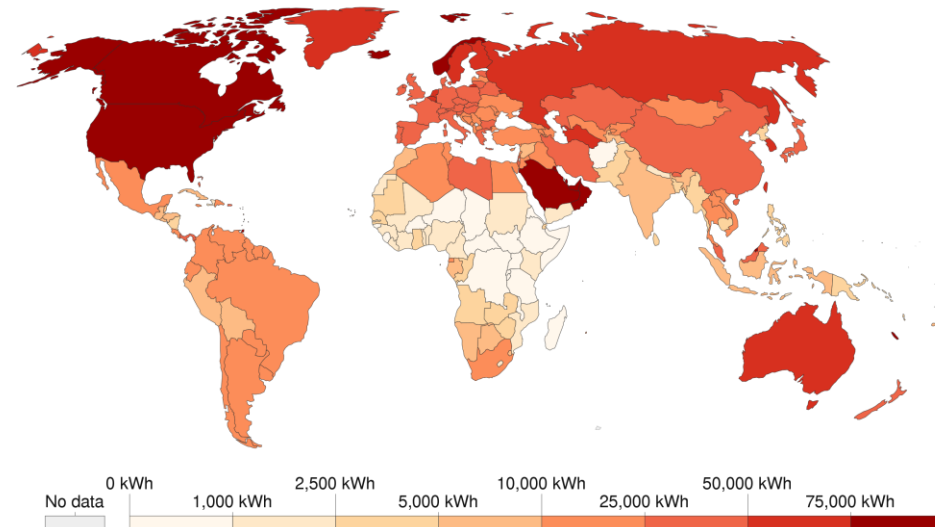
**Global population size: estimates for 1700-2022 and projections for 2022-2100**



Source: United Nations, DESA, Population Division (2022). World Population Prospects 2022.

**Energy use per person, 2021**

Energy use not only includes electricity, but also other areas of consumption including transport, heating and cooking.



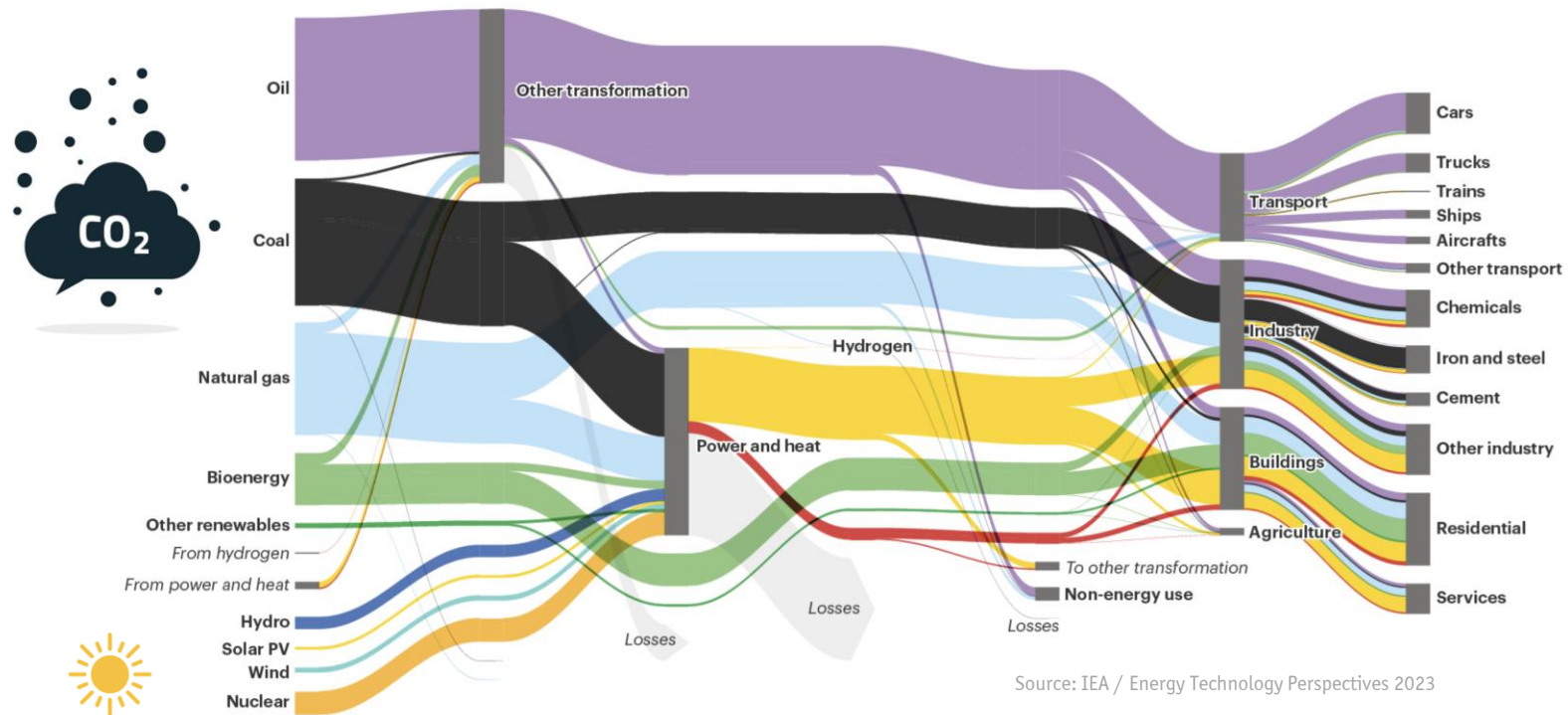
Source: Our World in Data based on BP & Shift Data Portal

Note: Energy refers to primary energy – the energy input before the transformation to forms of energy for end-use (such as electricity or petrol for transport).

- **2022 Global Energy Consumption per Capita — 22'400 kWh avg. | 2.6 kW avg. (2.3 kW avg. in 1980)**

# The Challenge 2/2

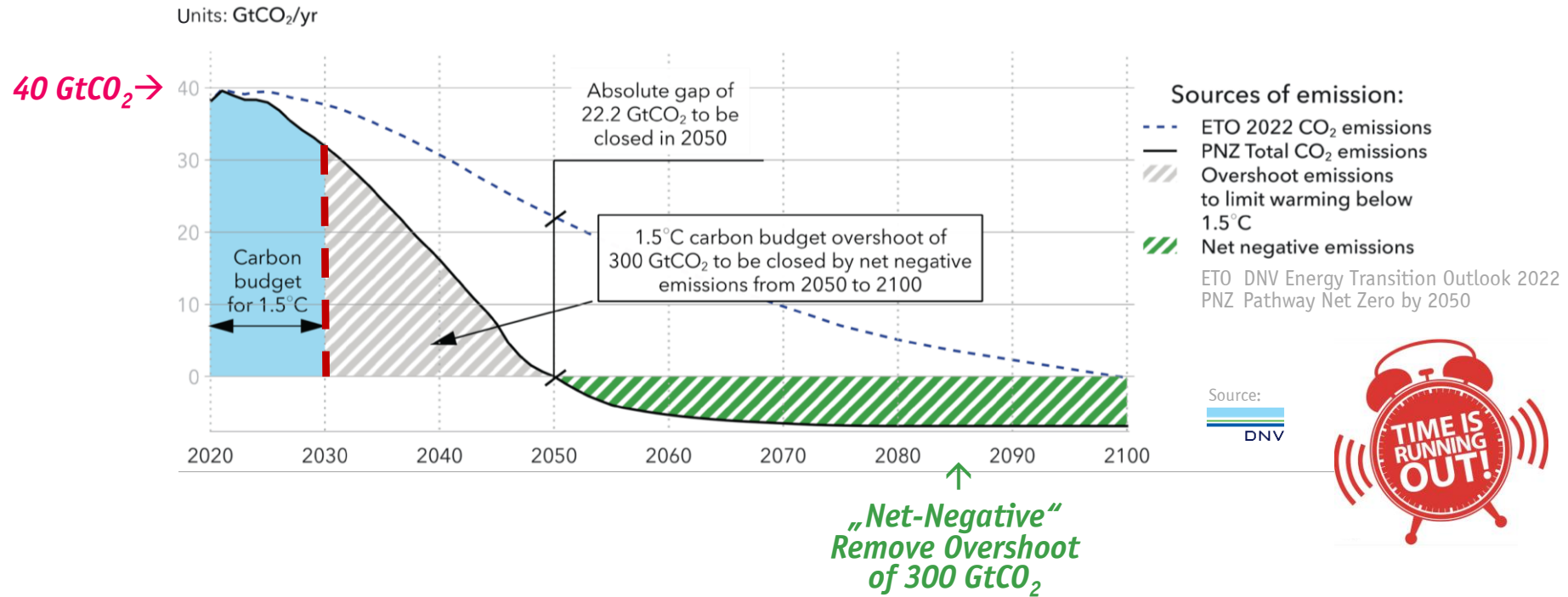
- Coal & Oil Powered the 1<sup>st</sup> Industrial Revolution (1750) / Enabled Mechanization



- Global Energy Flows — 2021
- World Economy Still Heavily Depends on Fossil Fuels (!)

# Decarbonization / Defossilization

- **“Net-Zero” Emissions by 2050 & Gap to be Closed**
- **50 GtCO<sub>2eq</sub> Global Greenhouse Gas Emissions / Year → 280 GtCO<sub>2</sub> Budget Left for 1.5°C Limit**

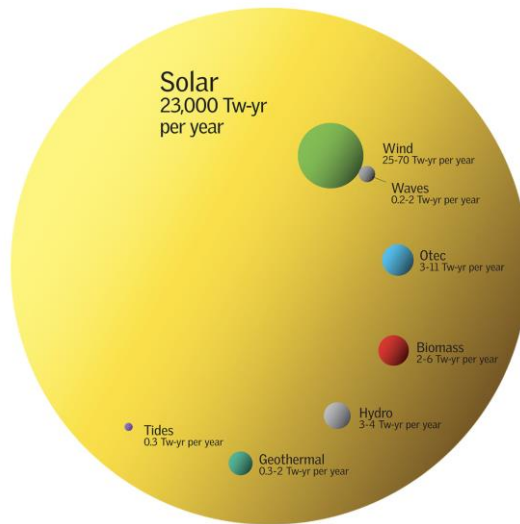


- **Challenge of Stepping Back from Oil & Gas**
- **Human History — Transition from Lower to Higher Energy Density Fuel — Wood → Coal → Oil & Gas**

# The Opportunity

(2009) 16 TW-yr  16 TW-yr per year  27 TW-yr (2050)

Renewable energy resources per year



100% Conv. Efficiency  
Excl. Oceans

Note: Graphical Representation Assumes Spheres Not Circles

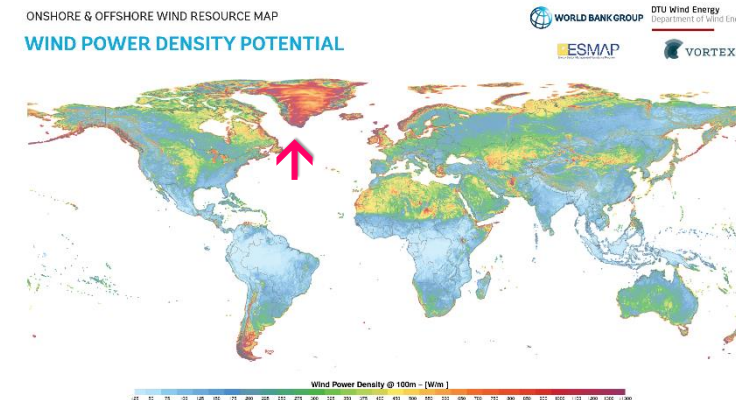
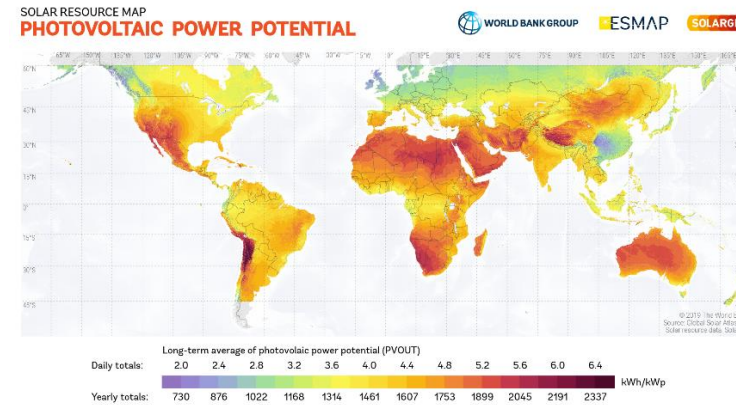
Primary Consumption: 16 TW-yr → 27 TW-yr  
Final Consumption: 11 TW-yr → 15 TW-yr

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

Fossil energy resources - total reserve left on earth

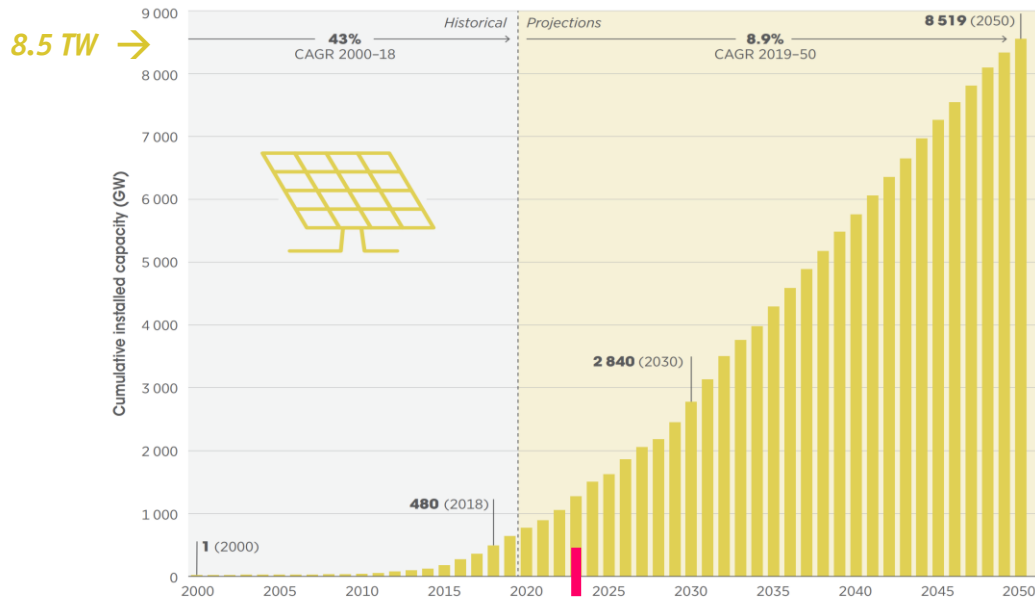


## Global Distribution of Solar & Wind Resources



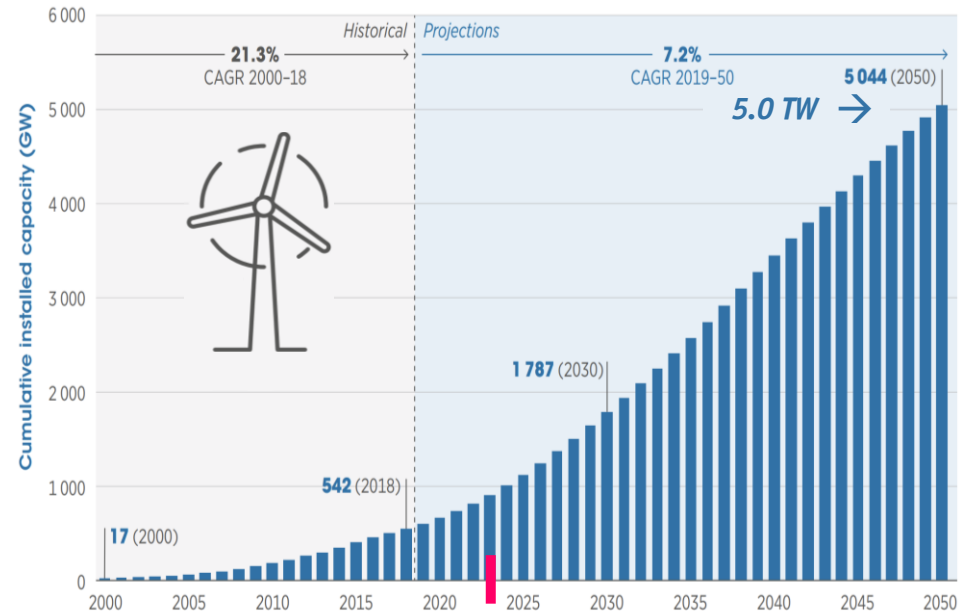
# The Approach

- 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 → 8500 GW

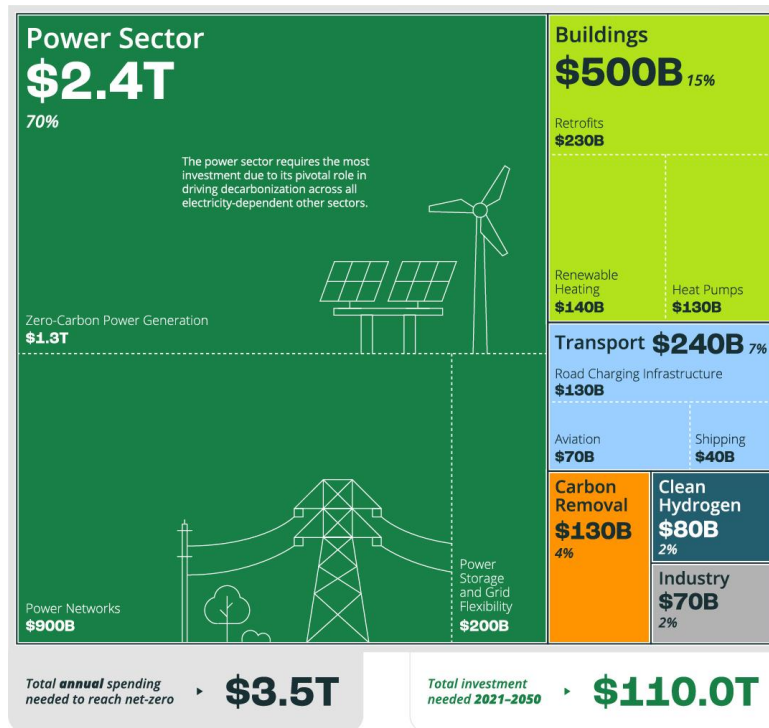


Source: Historical values based on IRENA's renewable capacity statistics (IRENA, 2019d) and future projections based on IRENA analysis (IRENA, 2019a).

- CAGR of  $\approx 7\%$  up to 2050 → 5000 GW

# The Costs

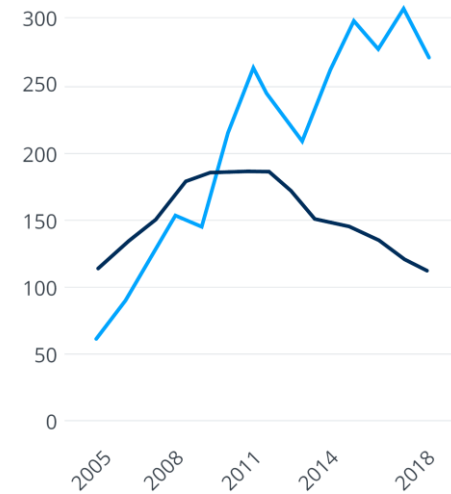
- **Net-Zero by 2050 — 3.5 Trillion USD ( $3.5 \cdot 10^{12}$  USD) Annual Investment (Globally btw. 2021-2050)**
- **Total 110 Trillion USD until 2050 / Decarbonized Electricity Serves as Catalyst for All Other Sectors**



Decarbonization Channel  
A VISUAL CAPITALIST BRAND

## Renewables vs. fossil fuels

Global investments in billion US-dollars



■ Renewable fuels

■ Fossil fuels

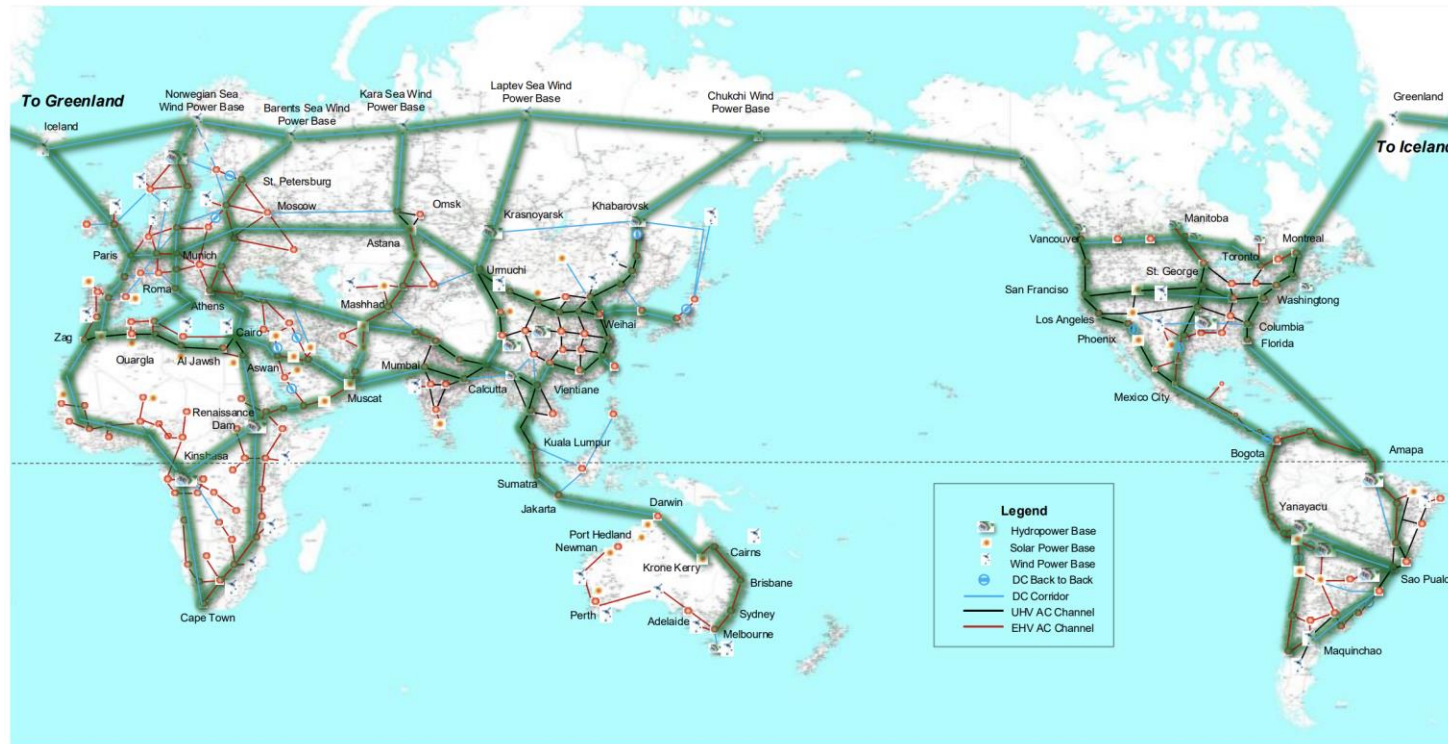
Source: International Energy Agency, UN Environment, BloombergNEF, Frankfurt School

- **3.5 Trillion USD are  $\approx 3\%$  of the World GDP /  $\approx 13\%$  of the USA GDP (2023)**
- **2.4 Trillion USD World Defense Expenditures (2023)**



# Remark The Global Solution (?)

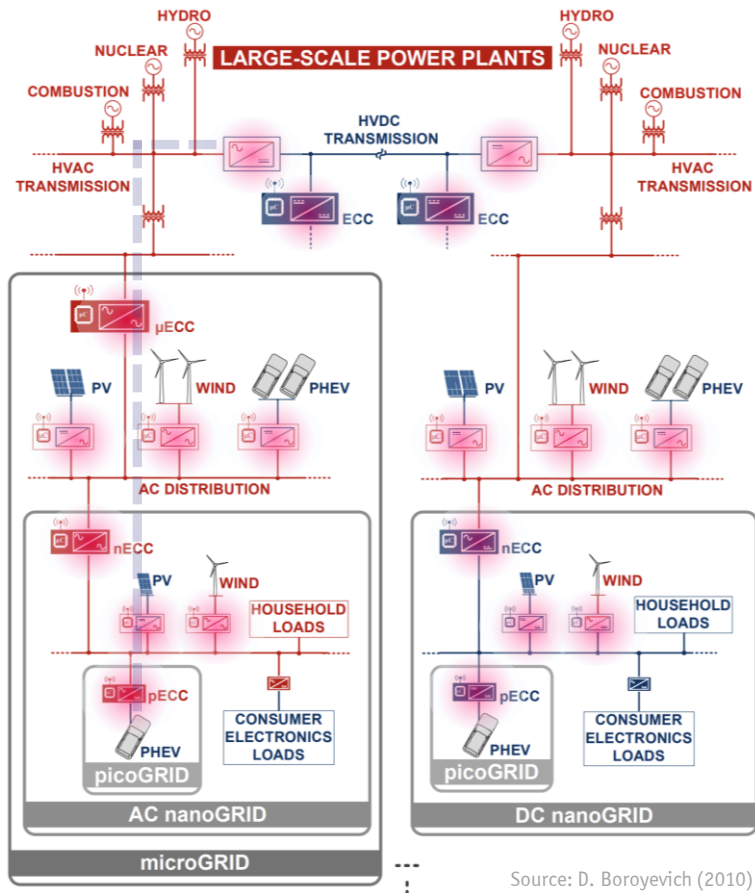
- *“Super/Mega/Overlay Grid”-Concepts Proposed since 1950s — GENESIS (1994), DESERTEC (2003), etc.*
- *UHVDC Trans-Continental or Multi-National Supply & Trade of Clean Electricity*



Source: GEIDCO 2018

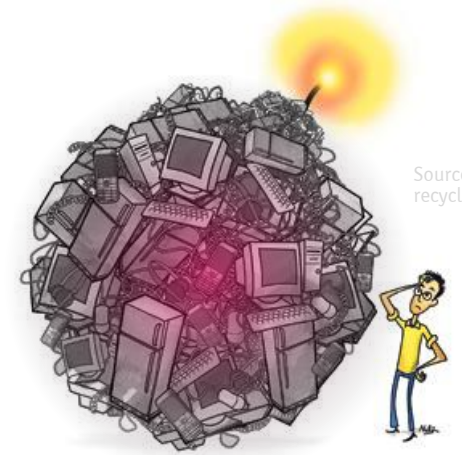
- *Example of the “Global Energy Interconnection Backbone Grid” (GEIDCO) Proposed by China in 2015*

# The in the Room



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



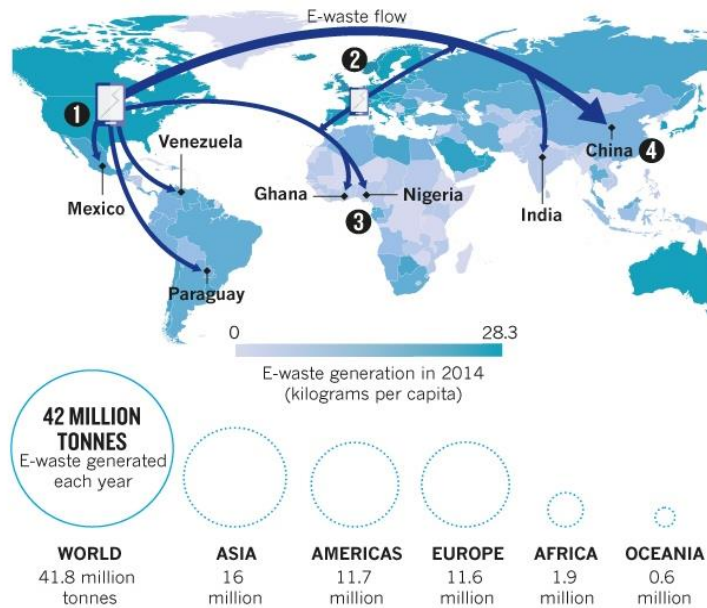
Source: www.e-waste-recyclers.co.in

- 5'000 GW<sub>eq</sub> = 5'000'000'000 kW<sub>eq</sub> of E-Waste / Year (!)
- 10'000'000'000 \$ of Potential Value

# The in the Room

- 52'000'000 Tons of Electronic Waste Produced Worldwide in 2021 → 74'000'000 Tons in 2030
- Increasingly Complex Constructions → No Repair or Recycling

Source:  Green IT Solution



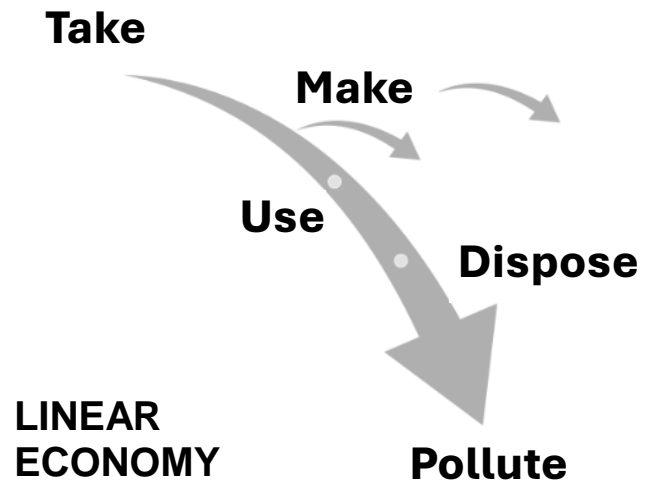
Source: nature



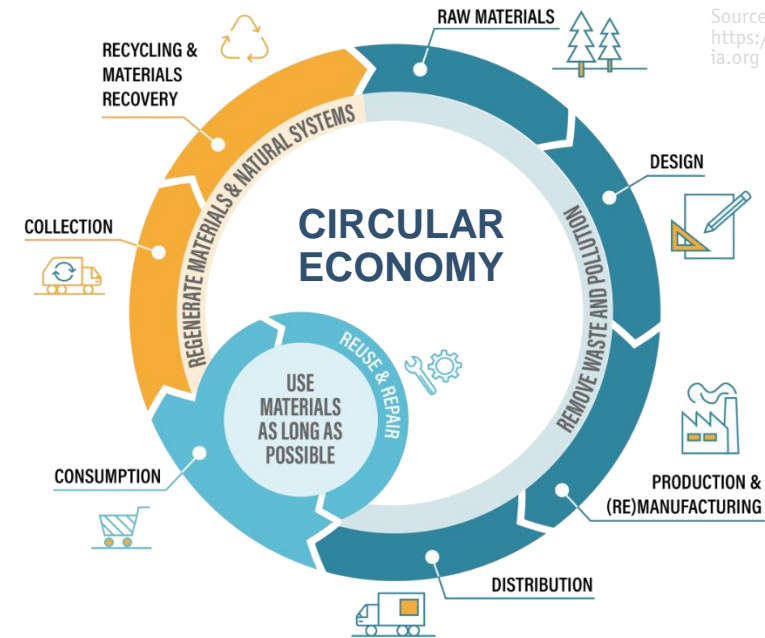
- Growing Global E-Waste Streams → Regulations Mandatory (!)

# The Paradigm Shift

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



Source: CC 3.0 Catherine Weetman 2016

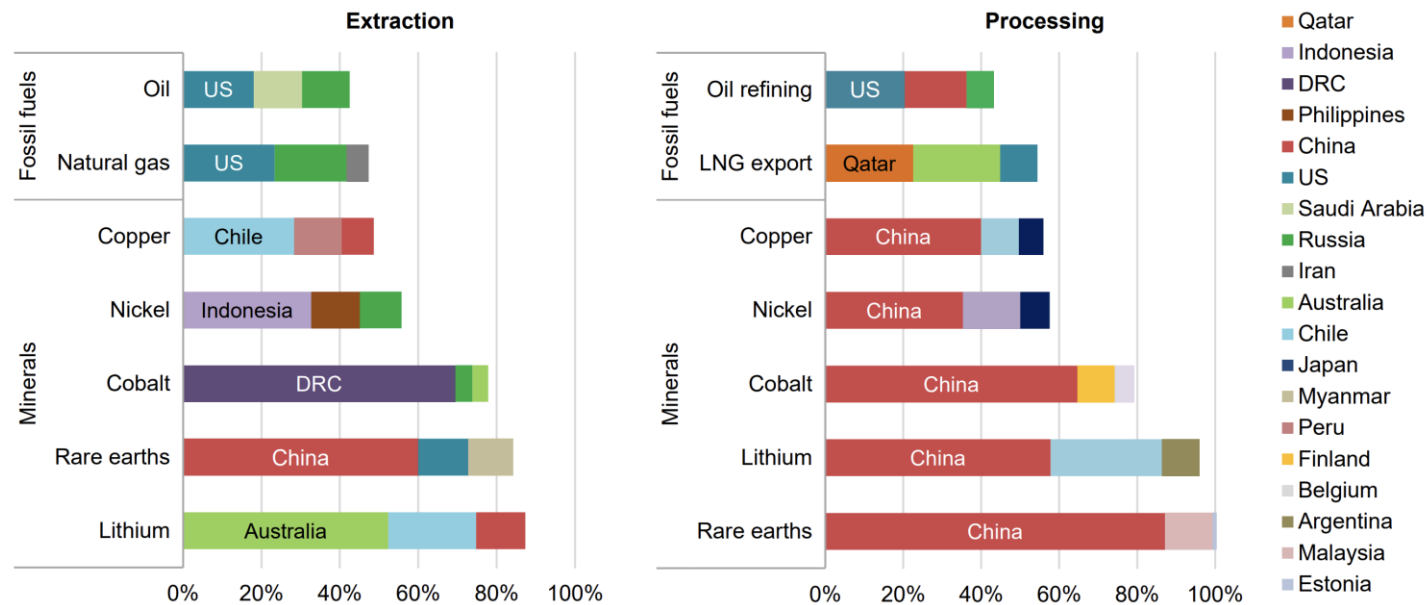


Source: <https://circularphiladelphia.org>

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

# Critical Minerals

## ■ Production of Selected Minerals Critical for the Clean Energy Transition



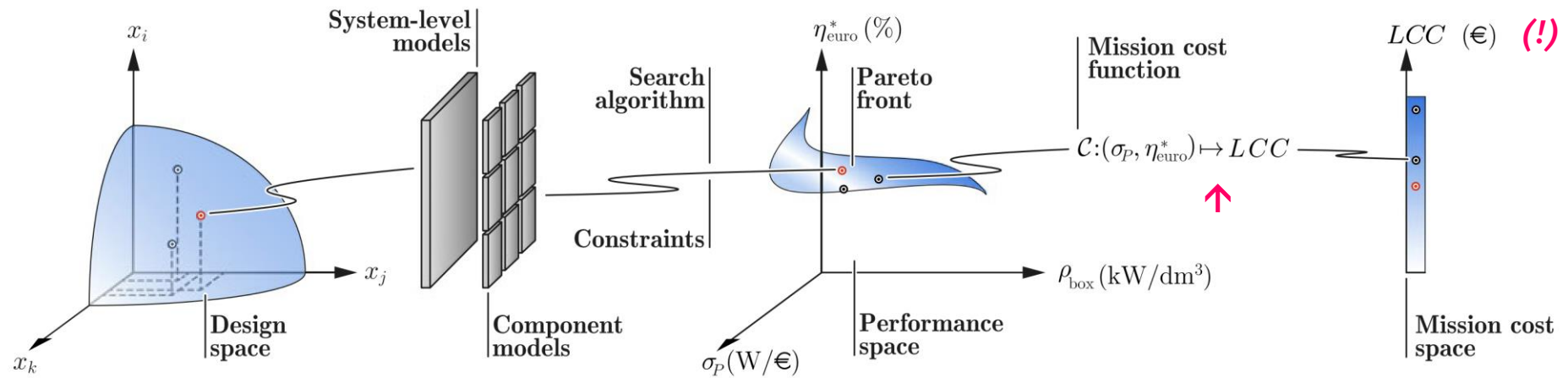
Source: IEA / The Role of Critical Minerals in Clean Energy Transitions (2021)

Shares of top three producing countries, 2019

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

# Multi-Objective Optimization

- *Typ. Performance Indices* — Efficiency  $\eta$  [%] | Power Density  $\rho$  [kW/dm<sup>3</sup>] | Rel. Cost  $\sigma$  [kW/\$]
- *Consideration of Specific Operating Points OR Mission Profile*

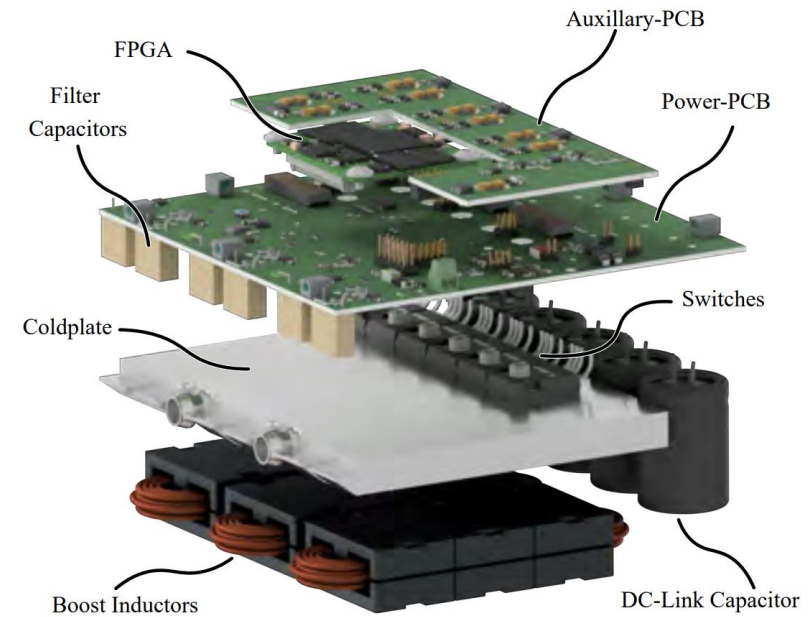
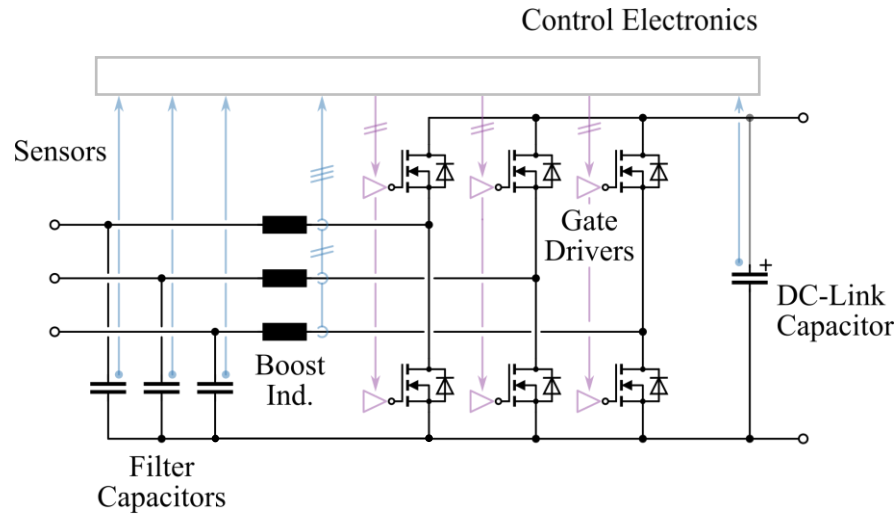


- *Mission Profile* — Power Loss  $\rightarrow$  Energy Loss / Life-Cycle Cost (!)

# Example — Three-Phase AC/DC PEBB

- **Key Power Electronics Building Block (PEBB) for Three-Phase PFC Rectifiers & Inverters**

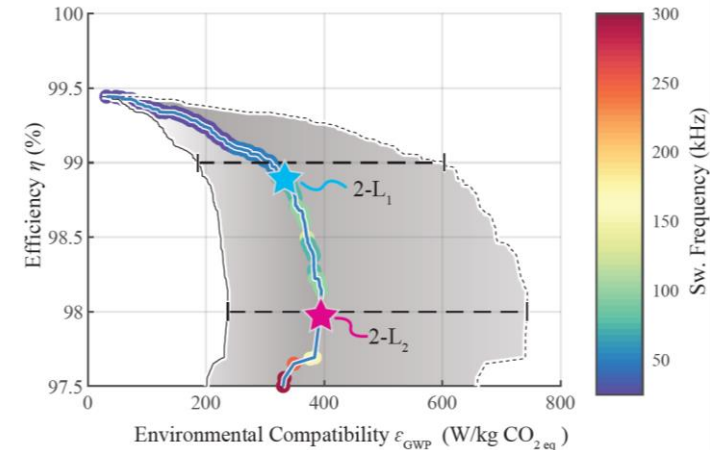
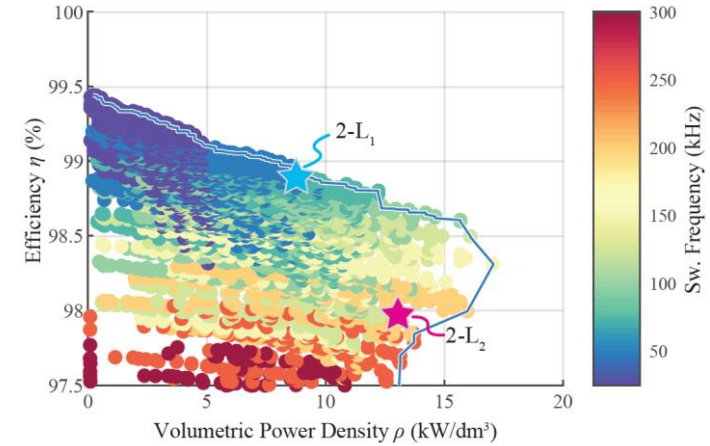
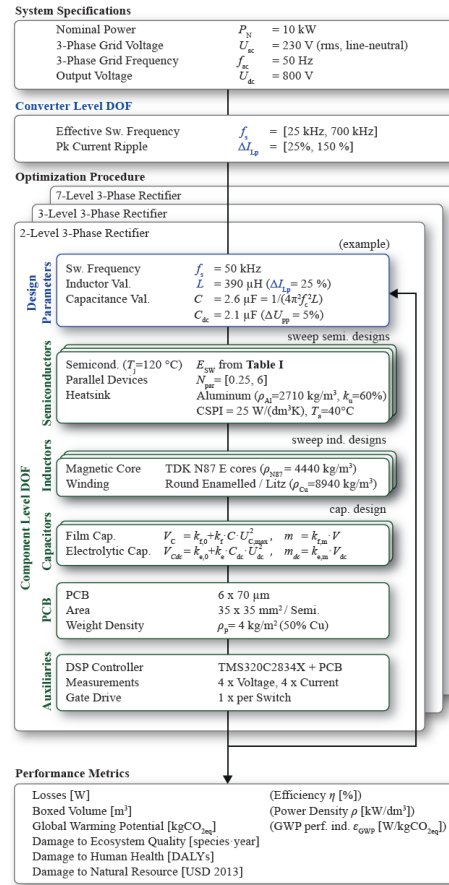
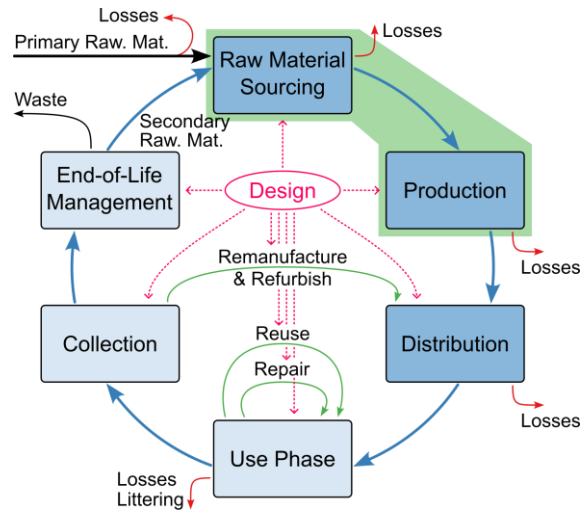
10 kW  
 400 V<sub>AC</sub> Mains  
 800 V<sub>DC</sub> Output  
 1200 V SiC



- **Main Components Considered (Losses, Volume, CO<sub>2eq</sub>)**
- **Power Trans., Heat Sink, Boost Ind., DC-Link Cap., Filter Cap., Gate Drivers, Sensors, Contr. Electr., PCBs**

# Multi-Objective Optimization incl. Env. Impacts

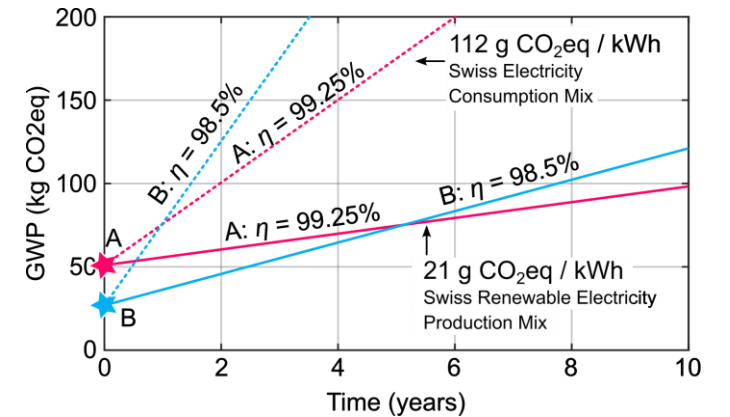
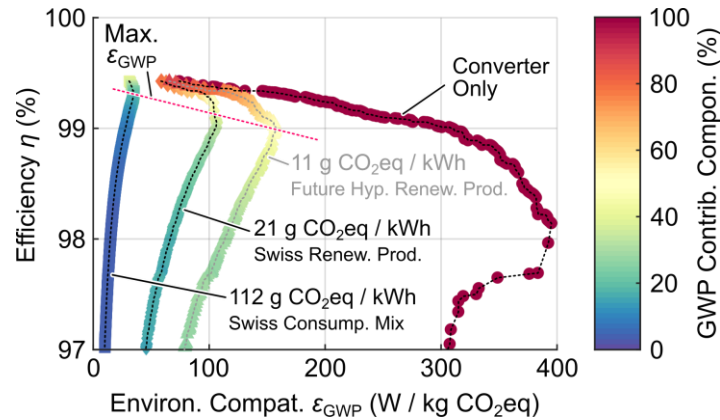
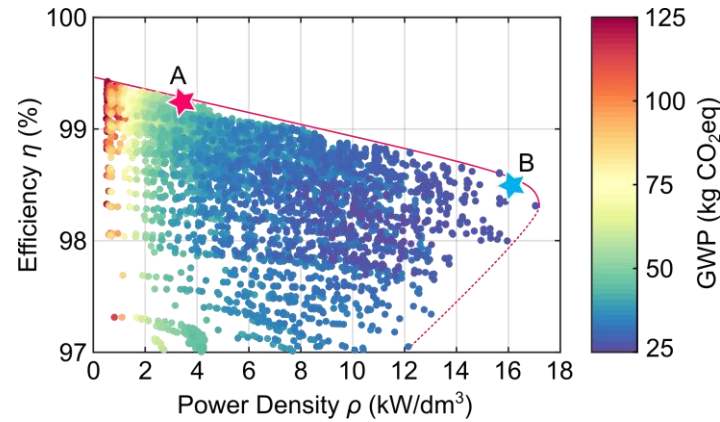
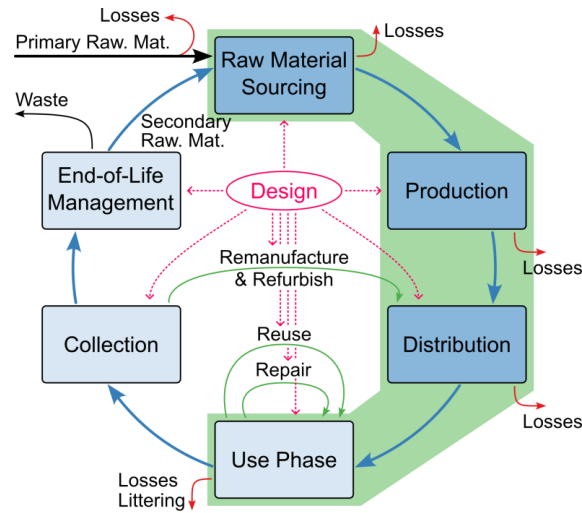
- Efficiency vs. Env. Compatibility / Carbon Footprint [W/kg CO<sub>2eq</sub>]
- Limited Data Availability / Quality — High Uncertainties





# Multi-Objective Optimization incl. Use Phase

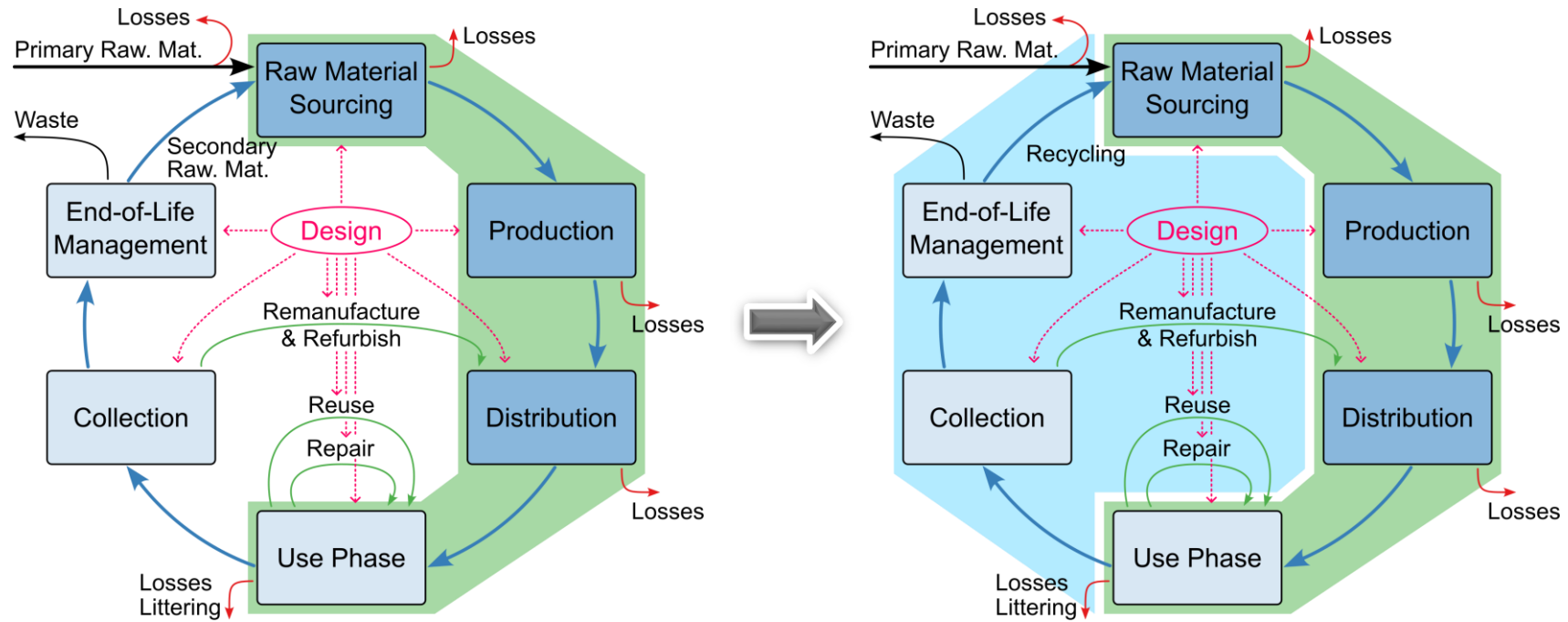
- *Design Considers Use Phase / Aims for Best Life-Cycle Performance*
- *Analogy to Total Cost of Ownership (TCO) Considerations*



- *Life-Cycle Carbon Footprint Strongly Depends on Electricity Mix & Mission Profile / Usage Intensity*

# “Closing the Loop”

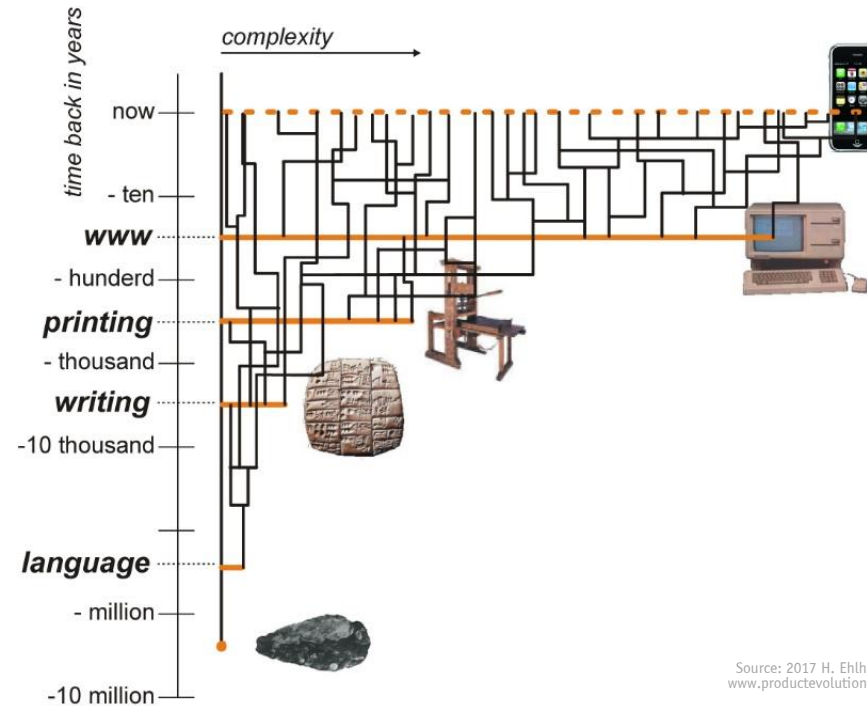
- “4R” Included Into the Design Process — Repair | Reuse | Refurbish | Recycle



- *Life-Cycle Cost Perspective Potentially Advantageous for Suppliers & Customers*
- *Quantification of Repairability / Reusability / etc. Still to be Clarified*

# The Complexity Challenge

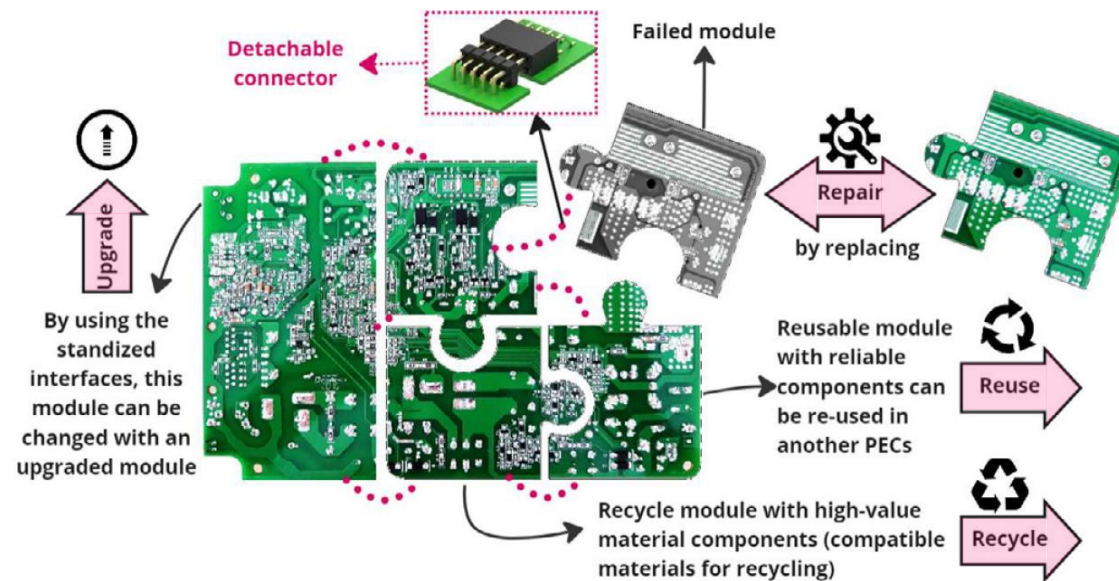
- Technological Innovation — Increasing Level of Complexity & Diversity of Modern Products
- Exp. Accelerating Technological Advancement (R. Kurzweil)



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

# Modularity — Facilitating Upgrade | Reuse | Repair

- *Modular Design Considering Ease of Disassembly | Maintainability | Upgradability | Reusability | etc.*
- *Grouping of Components Determined by Reliability Level & Expected Lifetime / Level of Reusability or Recyclability*

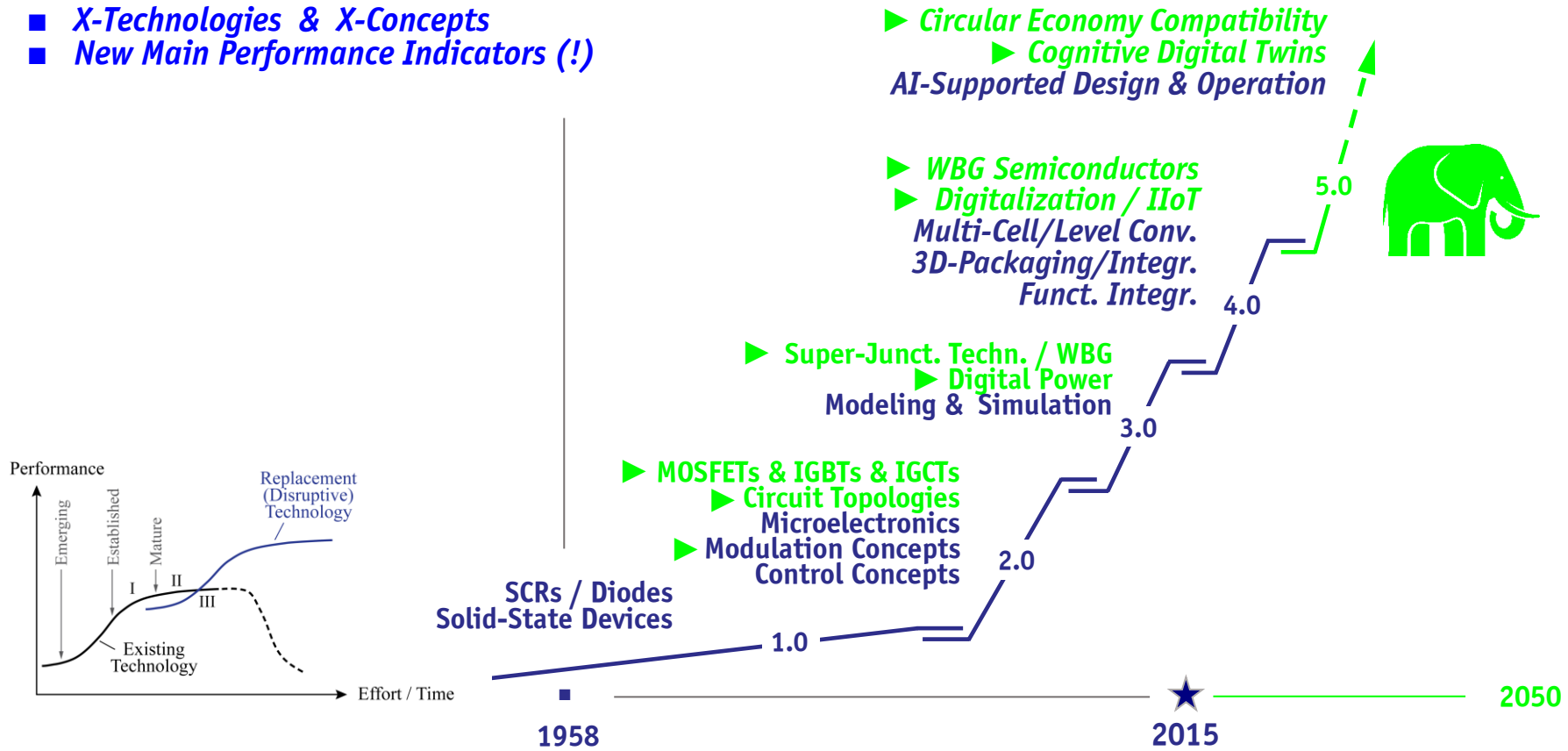


université BORDEAUX GRENoble INP

- **FAIRPHONE** — Modular | Manually Replaceable Parts | 100% Recycl. of Sold Products | Fairtrade Materials
- *Standardized Interfaces / Mechanically Separable Connections*
- *Leveraging Economies of Scale to Compensate Interface Costs*

# Power Electronics 5.0

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



## *Unlocking the High Frontier*

*Launch Systems  
Space Colonies*



# Space — An “Unexplored Ocean” to be Navigated

- **Global Space Race** — *Demonstration of Technology Leadership | Military Interests | Resources*
- **Mining the Moon** — *Helium-3 | Rare Earth Elements | Platinum | etc. & Ice (Life Support & Propellant)*
- **Satellite Network** — *Communication | Navigation | Military Operations*

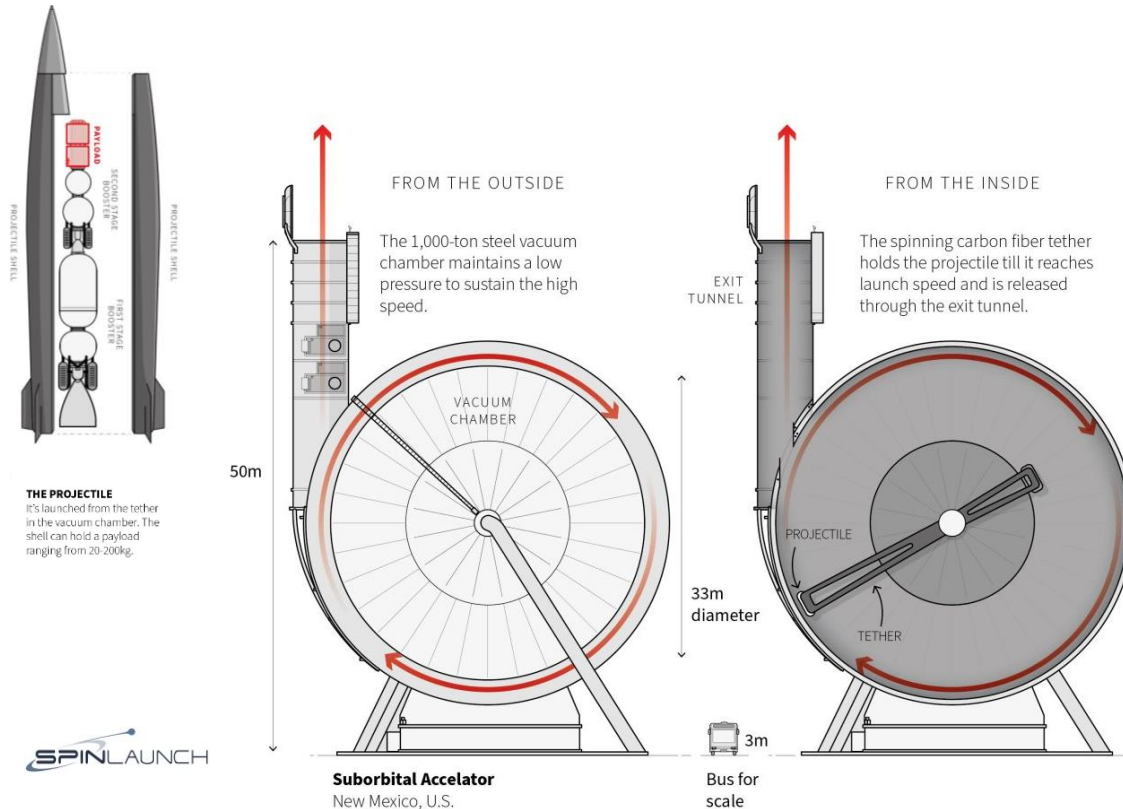


Source: 

- **NASA** — *Artemis Program — Land Humans @ Lunar South Pole by 2026*
- **ESA** — *Planning to Send a Lunar Lander to the Moon’s South Pole / Construct “Lunarville”*
- **CNSA** — *China | Crewed Moon Landing by 2030*

# Launching Satellites w/o Rockets

- **Traditional Fuel-Based Rocket Launching — Up to \$ 100'000/Pound (\$ 2000/Pound w/ SpaceX)**
- **SpinLaunch Uses Electrical Slingshot to Catapult a Spacecraft into Orbit**



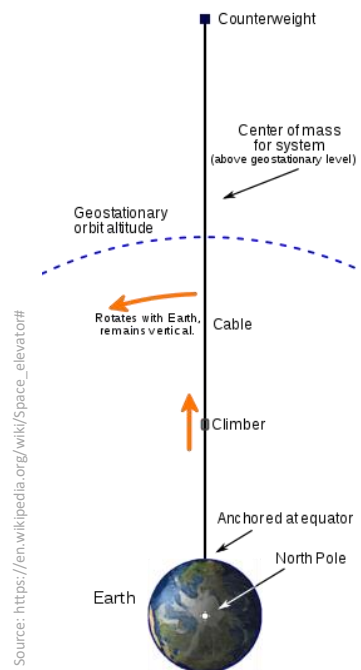
- **Payload (up to 200kg) in Reusable Launch Vehicle | 1.5h Acceleration in Vacuum Centrifuge up to 8000km/h**
- **Released Through Hypersonic Header | 10'000g Take-Off | Ignition of Small Rocket Engine in 60km Altitude**



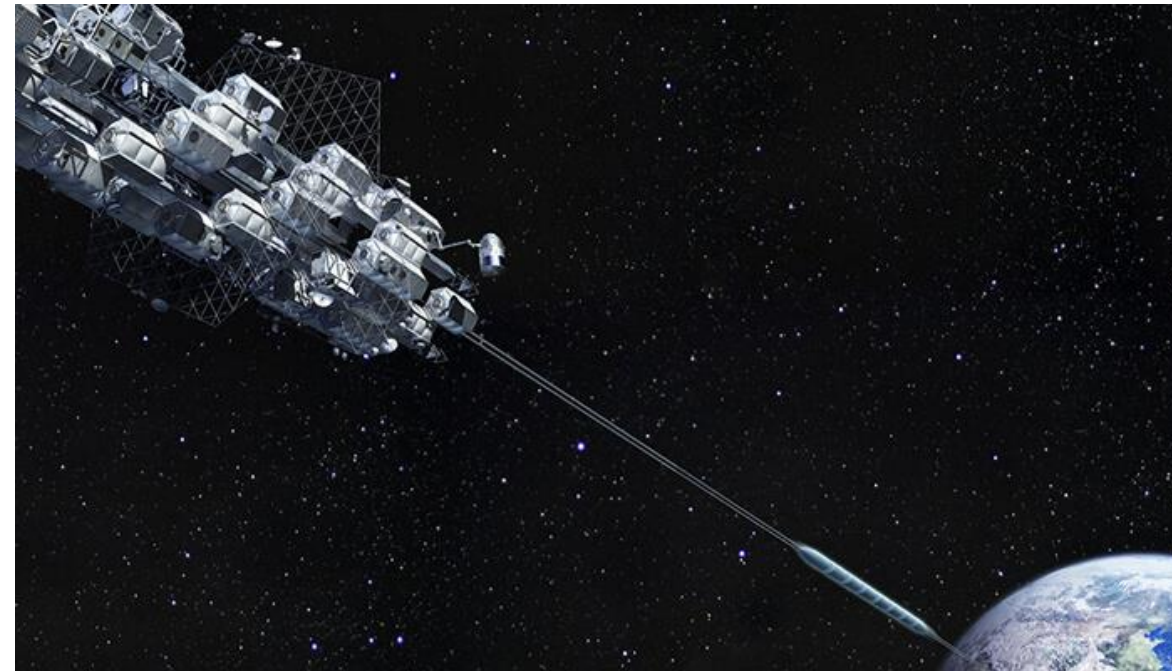
# Space Elevator

- *“Cosmic Railway”/ Space Elevator Envisioned by to Y. Artsutanov as Alternative to Rockets in 1960*
- *By 2050 — 100t Electric Climber | 96'000km Carbon Nanotube Tether | 400m Diameter Floating Earth Port*

Space Elevator



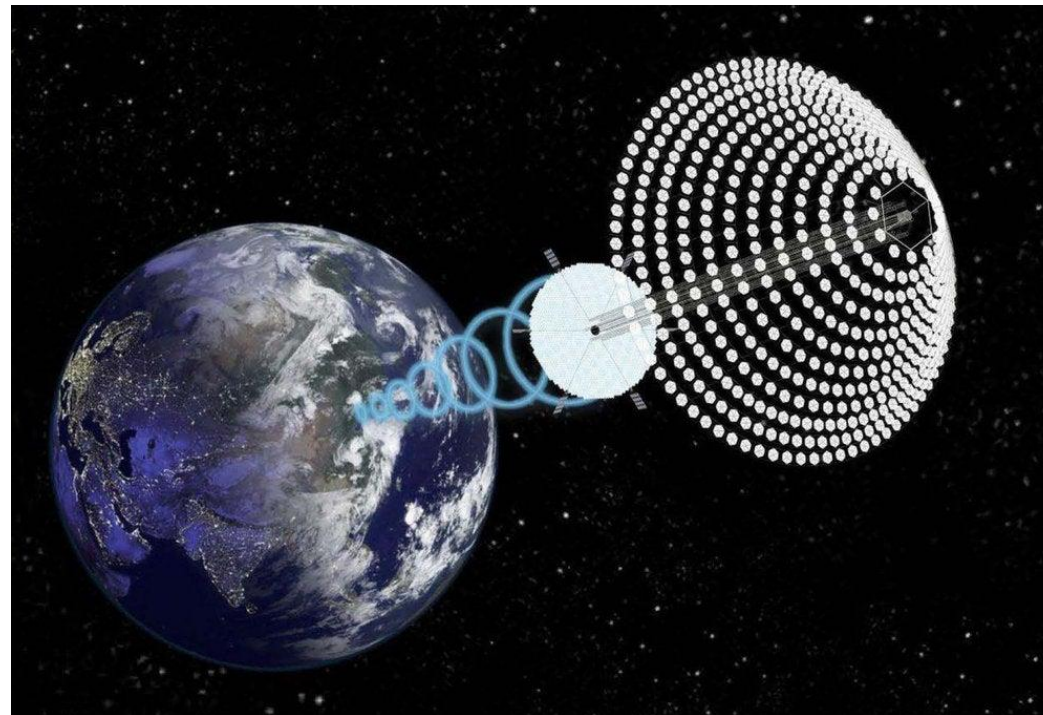
Source: Obayashi Corporation



- *Upward Centrifugal Force on 12'500t Counter-Weight & Gravity Acting on Lower End Keep Tether Under Tension*
- *Balanced Forces at Geostationary Equatorial Orbit (GEO) — Orbit Station at Height of 36'000km*

# Beaming Solar Power from Space

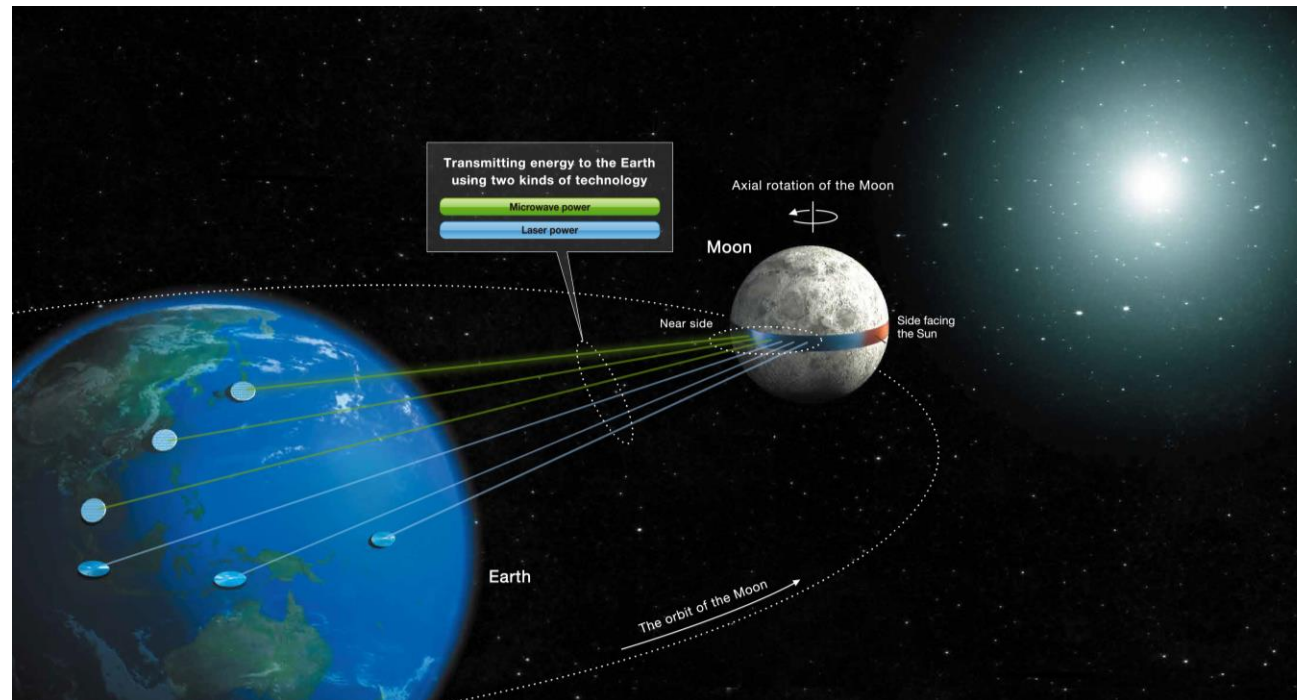
- *Solar Power Harvested in Space | Converted to Microwaves | Sent to Earth-Based Receiving Stations*
- *Advantage of Permanent Availability of Energy Regardless of Weather or Time of Day – No Storage (!)*



- *Several International Programs (ESA, JAXA, NASA, CNSA, etc.)*
- *Caltech — Space Solar Power Prototype Launched into Orbit in 2023*
- *Demonstration of Ability to Beam Detectable Power to Earth*

# Beaming Solar Energy from the Moon 1/2

- *The "LUNAR RING" — Belt of Solar Cells Around Lunar Equator / 11'000km Length / 400km Width*
- *Continuous (!) Electric Power Beamed to the Earth Using 20km Diameter Antennas / 20GHz*



- *Construction Start Planned for 2035 by Shimizu Corporation, Japan*
- *30 Years Multi-Phase Project / Utiliz. of Lunar Resources / Install. w/ Remotely Contr. Robots*

## Beaming Solar Energy from the Moon 2/2

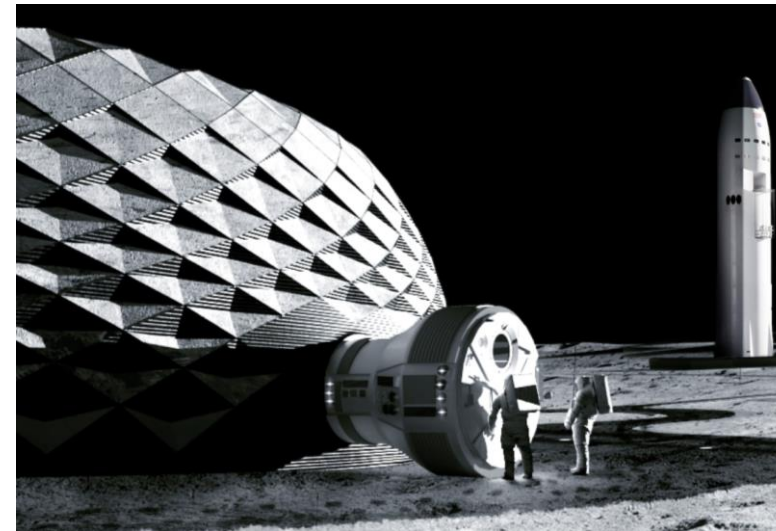
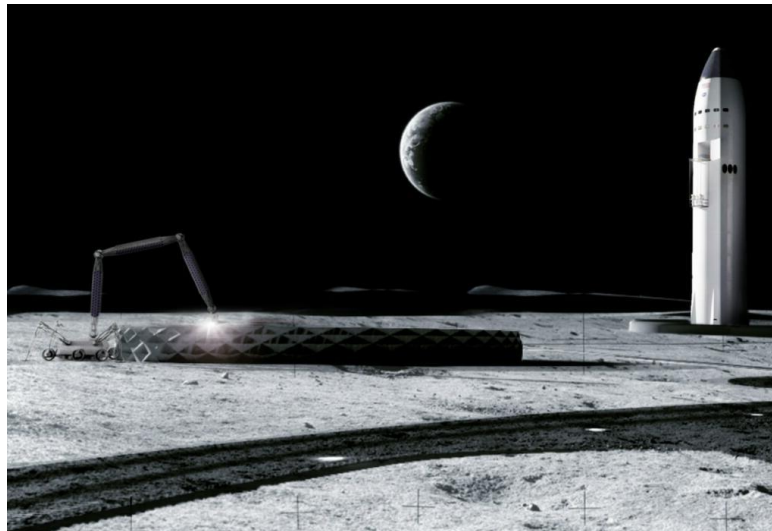
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- *30 Years Multi-Phase Project / Utiliz. of Lunar Resources / Install. w/ Remotely Contr. Robots*

## 3D-Printing of Lunar Habitats

- *Lunar Regolith Processed Into Building Material — Local 3D-Printing of Habitats*
- *Extreme Temp. Swings of 120°C ... -220°C & Frequent Strikes by Micrometeorites*
- *No Protective Magnetic Shield / Ionizing Radiation from Sun & Deep Space*

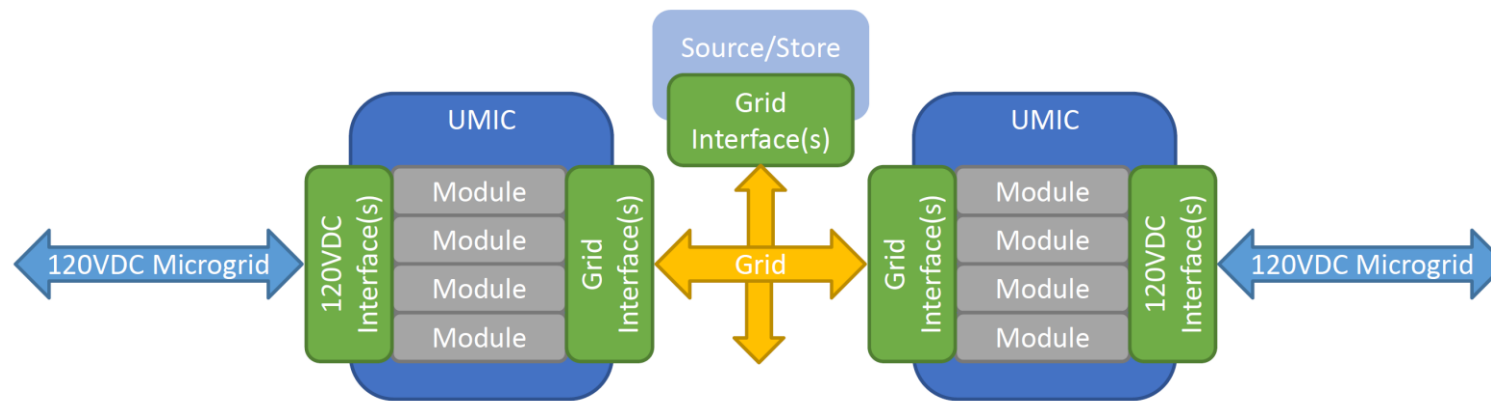


Source: **ikon**

- *Regenerative Closed-Loop Life Support Systems | Wireless Connections to El. Power System*
- *NASA "LunaGrid"— km-Range MV Transmission btw  $\mu$ -Grids w/ Solar Power Gen. & Storage & Loads*

# Lunar Power Distribution

- 28 Days Rot. / 2 Weeks of Darkness — Lunar Base Placed @ South Pole for Continuous Sunlight
- Tether-Based MV Grid for Connecting Isolated Microgrids Comprising Generation-Storage-Loads
- Power Beaming for Robotic Exploration of Craters & WPT Rover Charging Outposts



- Example of Univ. Modular Microgrid Definition & Interface Conv. for Planetary Surfaces – UMIC/UMIPS
- Bidir. Converter Interface btw Transmission Voltage (typ. 1.5 kV<sub>DC</sub>) & Prim. Distribution Voltage (120V<sub>DC</sub>)
- Power Levels btw. 100+ kW for In-Situ Resource Utiliz. / Mining - 50...100 kW / Habitat - 1...5 kW / Rover

# Lunar Cruiser

- *Contribution of JAXA (Japanese Aerospace Exploration Agency) & Toyota to NASA Artemis Program*
- *Pressurized Vehicle | 13 m<sup>3</sup> Living Space for 2 ... 4 Astronauts | 10'000 km Range*



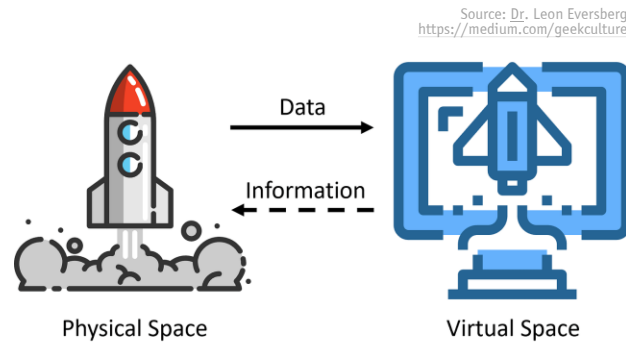
- *10 Tons | 6 m x 5.2 m x 3.8 m | Metal Tires*
- *Fuel-Cell EV Technologies (Lunar Nights) | H<sub>2</sub>O Electrolysis System (Mitsubishi) for H<sub>2</sub> Production*





# The Future of Education & Engineering

- **Digital Twin (DT)** — **Comprehensive Physical and Virtual Description of a System** — IIoT / Industry 4.0
- **Cognitive DT (CDT)** — **Cognitive Capabilities / Autonomy / Continuous Evolvement / Full Lifecycle Coverage**

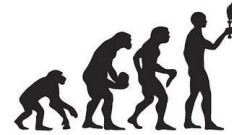
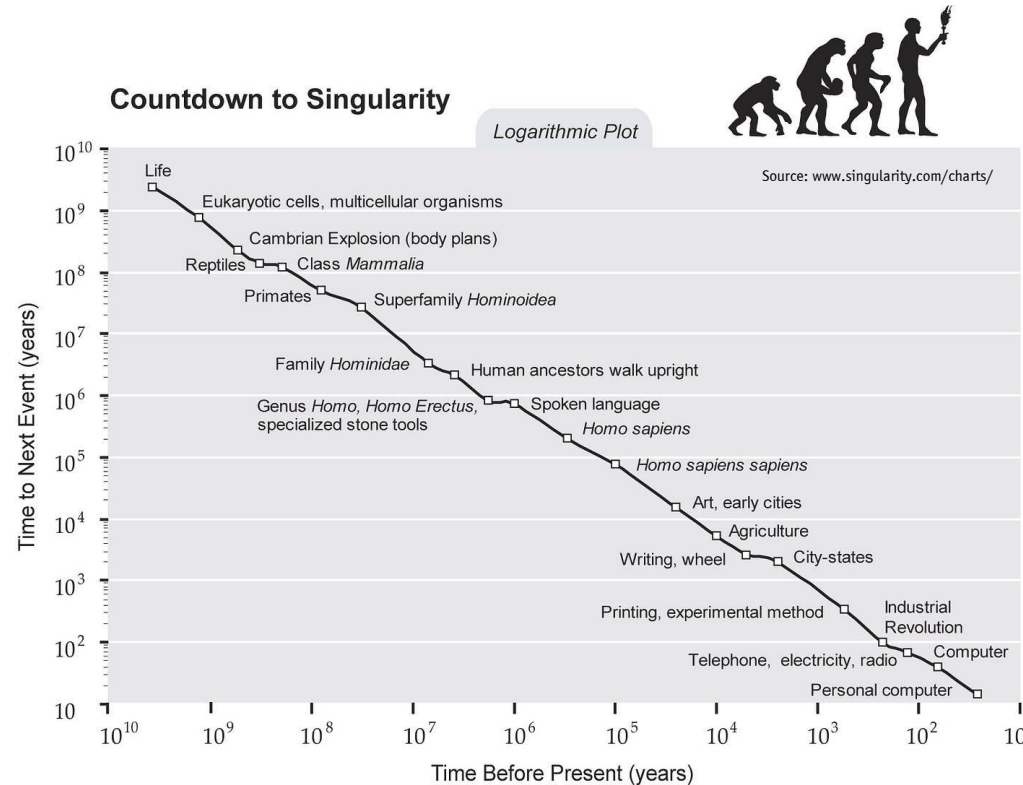


Source: [www.twi-global.com](http://www.twi-global.com)

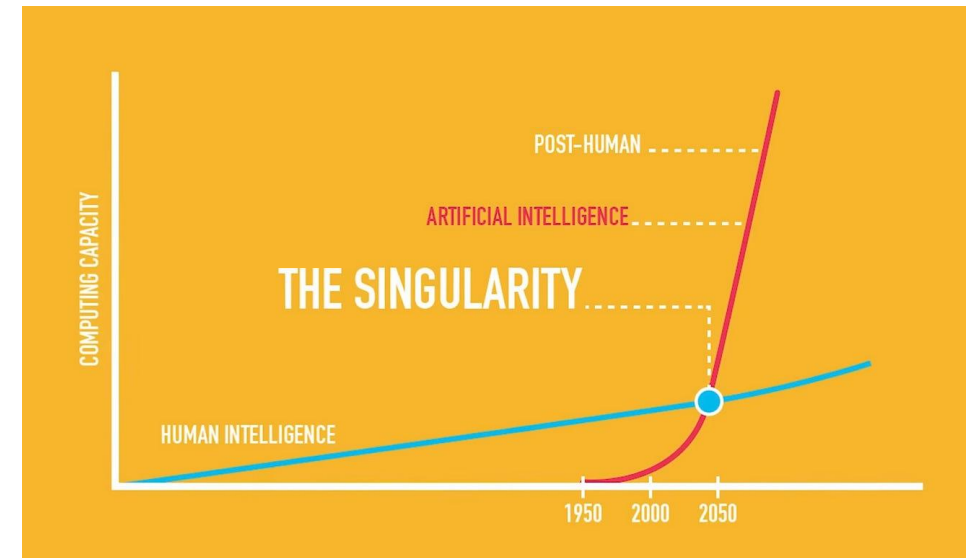
- **Students Grow Their (!) CDT Throughout College & Academia**
- **CDT Retains Record of Learned & Add. Acquired Knowledge / Knows Anything-Anytime-Anywhere / Is Immortal (!)**
- **Personalized Generative AI Assistance** — **Potentially Disrupting Engineering & Education on All Levels**

# Countdown to Technological Singularity

- **Each Generation Builds on Previously Achieved Results — Accelerating Exponential Growth of Technologies**
- **Documented by Biological & Technological Evolution Milestones — «The Singularity is Near», Ray Kurzweil, 2005**



Source: <https://getgetner.com/uploads/futurist.jpg>

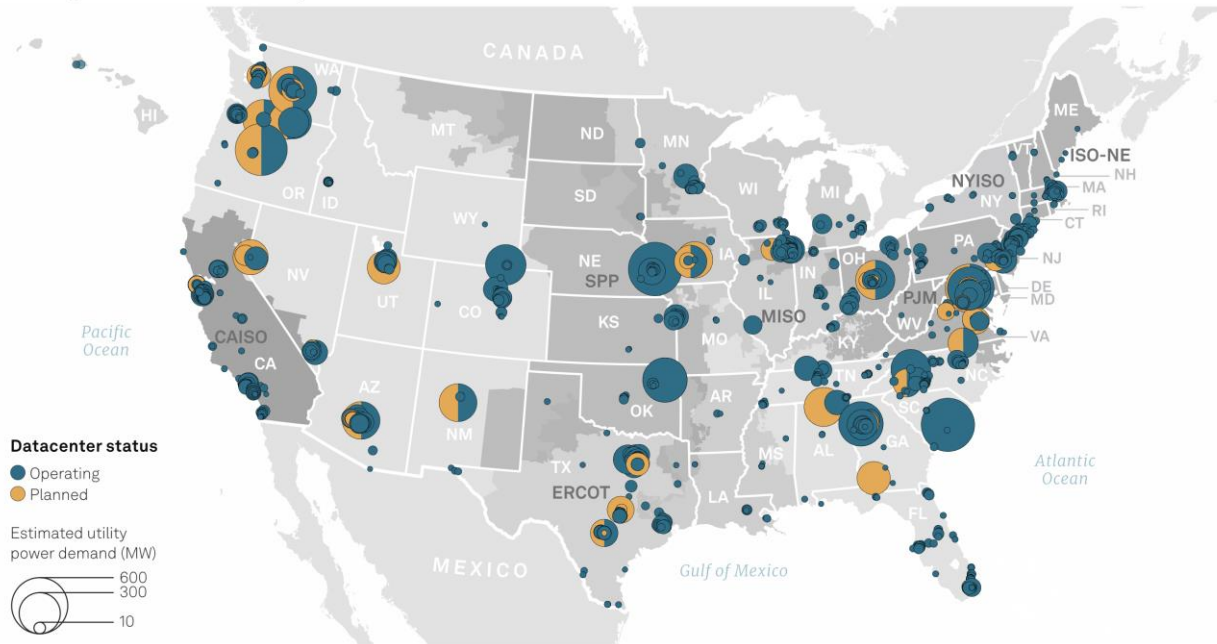


- **Singularity (2045) — AI-Based Creation of a Self-Aware Machine Intelligence Capable of Recursive Self-Improvement**
- **Uncontrollable / Irreversible Technological Growth — Potential Massive Social & Geo-Political Consequences (!)**

# Remark Future Gigawatt-Scale Datacenters

- **Explosion of AI — « Hyperscale » Datacenters Evolving into « Exascale »**
- **Gigawatt Power Levels Despite High Power Usage Effectiveness (PUE)**

AI is expected to drive more power demand from datacenters



Sources: S&P Global Market Intelligence; 451 Research; S&P Global Commodity Insights

- **Plans for 2.5 ... 6 Gigawatt Campuses Co-Located w/ Nuclear Power Facilities —**  **BALANCING ENERGY LANCUM**
- **Collaboration w/ Utilities — Datacenters as Responsive Loads for Balancing Solar & Wind Power**

# Shut Down Skepticism (!)

- *We Need Visions & Utopian Dreams — GREAT Challenges Require GREAT Answers !*



Shoot for the  
\* \* \* \* \*  
\* \* **MOON** \* \* \* \* \*  
\* \* \* \* \*  
EVEN IF YOU MISS  
\* \* \* \* \*  
\* \* you'll still land  
\* \* \* \* \*  
AMONG THE \* \* \* \* \*  
\* \* \* \* \*  
\* \* \* \* \* **STARS** \* \* \* \* \*

Source: www.redbubble.com

- *The Dream of Yesterday is the Hope of Today and the Reality of Tomorrow (R. Goddard)*

**Thank you!**



Source:  
[www.terencemaury.com](http://www.terencemaury.com)