# THE (EVER MORE) ELECTRIC SOCIETY

## A PUSH TO THE LIMITS OF MODERN POWER ELECTRONICS

CHRISTIAN KOITZSCH

# Agenda

1. Introduction to **Bosch** and Bosch Corporate Research

2. **Trends and Drivers** of the More Electric Society

3. Examples

   a. **Automated Driving** - Fault tolerant Drives

   b. **Distributed Energy Generation** - SOFC

   c. **Electrified Powertrain** - Wide Band Gap Semiconductors

4. Future of Research **Work**



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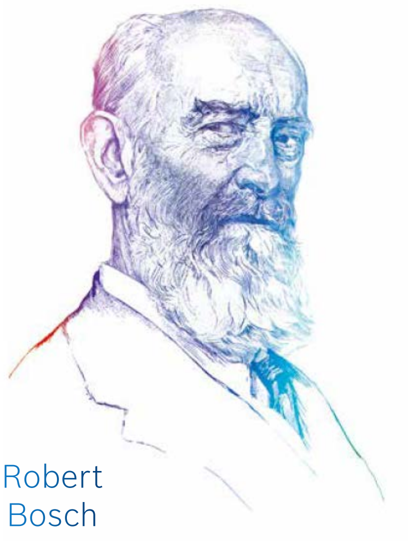
# INTRODUCTION

# BOSCH &

# BOSCH RESEARCH

# Bosch

## Invented for Life – a guiding principle deeply rooted in our origin



Robert Bosch

"Improvements in the world of technology and business should always also be beneficial for mankind"

On May 24, **1884**, aged 22, he set out from Rotterdam aboard a Dutch steamer headed for New York City. Robert Bosch found a job in an **Edison factory** manufacturing all types of electrical equipment, including arc lamps, light fixtures, remote-reading thermometers, and phonographs. But not everything went quite to plan. He experienced a **period of unemployment** before once again finding a job at the Edison Machine Works. Bosch decided to return to Germany after a year in the U.S. On his way home, he stopped off in England and spent half a year working for **Siemens** Brothers in Woolwich, on the outskirts of London.



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# Bosch Research: Figures, Facts and Locations

## Corporate Sector Research and Advance Engineering at a glance

**1,800**
highly specialized employees

**143**
PhD students in 2018

**1,722**
invention reports in 2018

**+12**
top research facilities
around the globe

**392.4** mio.€
invested in Bosch Research & Center
for Artificial Intelligence in 2018

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Research

# Bosch Research: Scientific Environment

## Connected with the best in the world

**Asia-Pacific**
50

- Indian Institute of Science
- Nanyang Techn. University
- Univ. of Tokyo
- Shanghai Jiao Tong Univ.
- Tongji Univ.

**Europe**
641

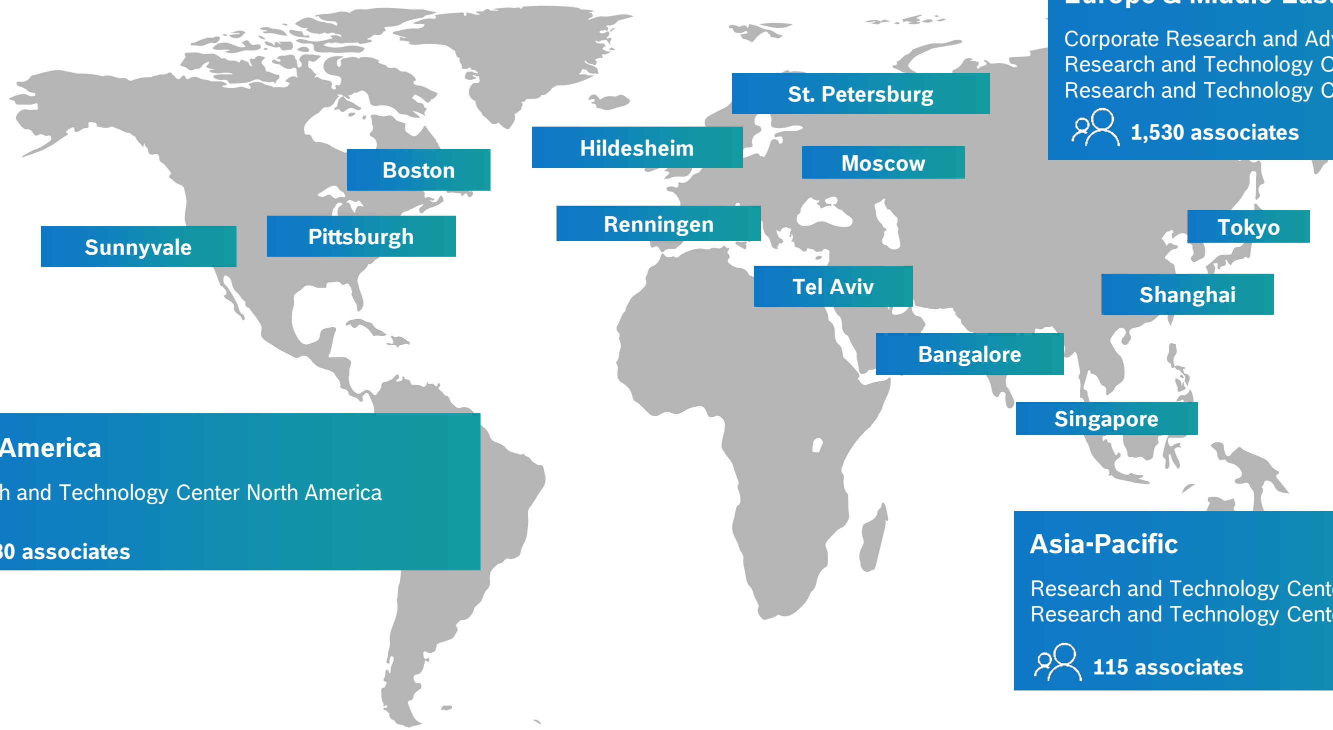
- German Aerospace Center
- Fraunhofer Society
- ETH Zürich
- KIT
- University (CWI) Amsterdam

**America**
95

- Stanford University
- Berkeley
- Univ. of Michigan
- Carnegie Mellon Univ.
- MIT

# Bosch Research: Figures, Facts and Locations

## An eye for the big picture through a global presence




**Europe & Middle East**

Corporate Research and Advance Engineering Germany
Research and Technology Office Russia
Research and Technology Center Tel Aviv

**1,530 associates**

**North America**

Research and Technology Center North America

**130 associates**

**Asia-Pacific**

Research and Technology Center India
Research and Technology Center Asia-Pacific

**115 associates**



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# Bosch Research: Figures, Facts and Locations

## Renningen Campus




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# TRENDS AND DRIVERS TOWARDS A MORE ELECTRIC SOCIETY

# Trends and Drivers towards a more Electric Society
## The Internet of Things / Ubiquitous Robotics

Autonomous Driving

I4.0 / Industrial Robotics

Consumer Electronics

**Internet of Things: Sensors + AI + Actors**



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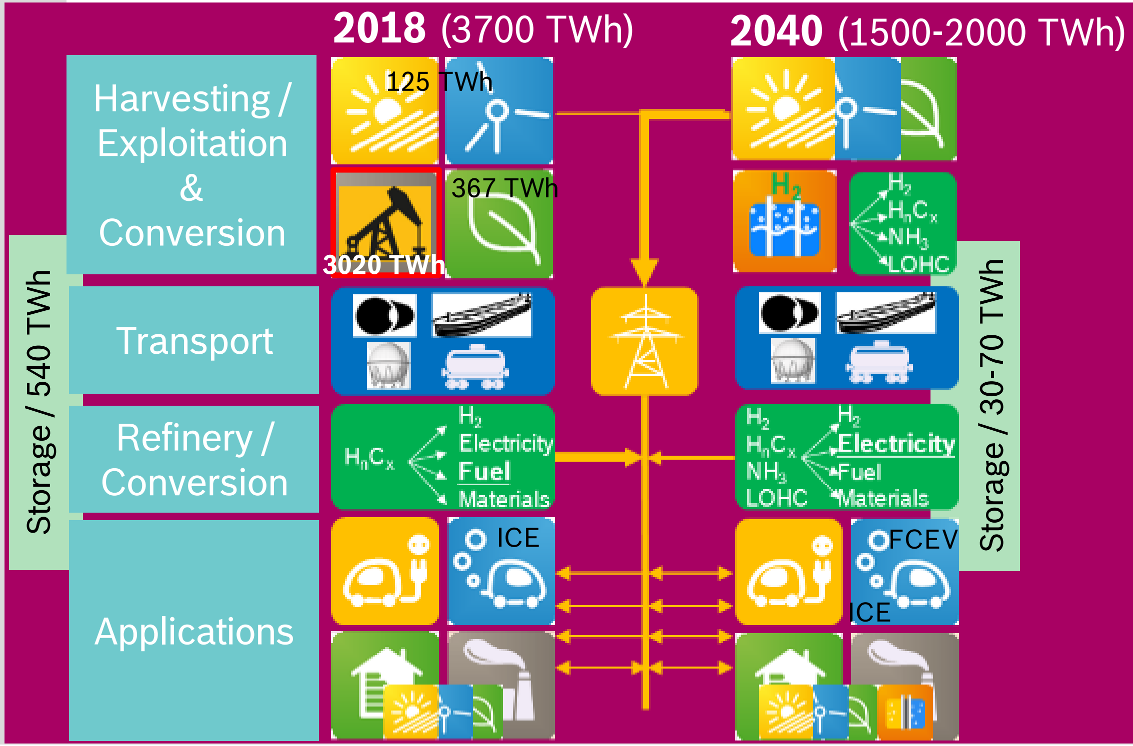
# Trends and Drivers towards a more Electric Society

## But…there is the storage problem

**New primary energy: Electricity** (PV$_{LCOE*}$: 1.5 ct/kWh (2025) within ±30° latitude)
**→ Transport & storage will require energy conversion technologies**




Use electricity from renewables directly wherever possible.

2018: Primary energy supply, transport & storage is mainly fossil. 76% primary energy imported (DE).

2025 - 2040: $CO_2$ neutral & clean energy systems:

- Trend from large to small standardized units
- Energy trading still expected (electricity, $H_2$, eFuels, …)
- Diversity in energy carriers and way of transportation for different applications
- Storage capacity (30-70 TWh for DE)





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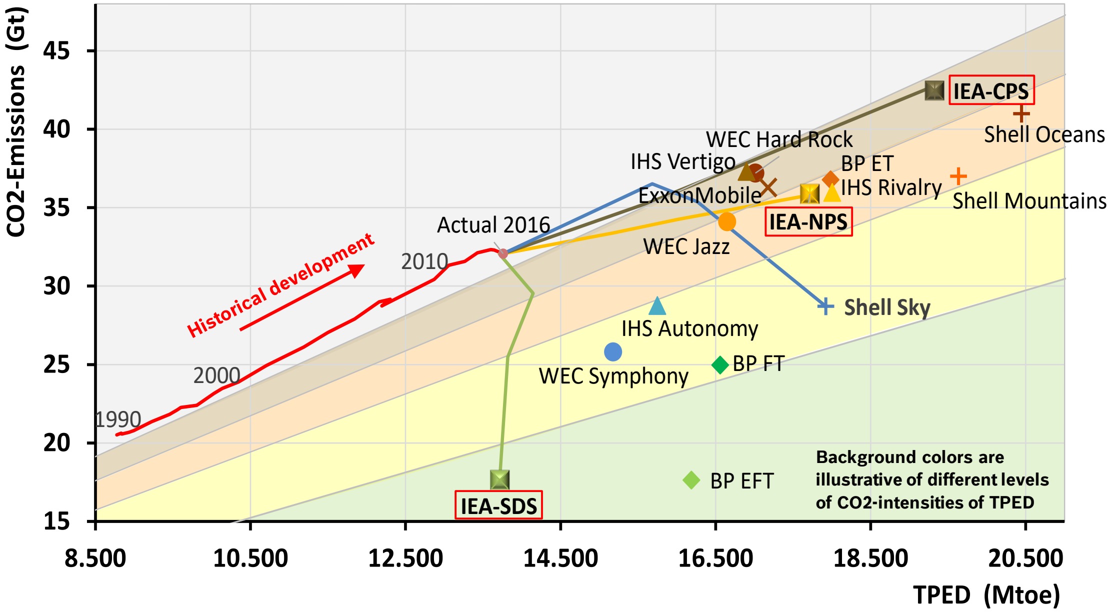
# Trends and Drivers towards a more Electric Society
## And there will be no abundancy of green energy…

**Energy-related $CO_2$ emissions vs. total energy demand in 2040**

Scenario synopsis to compare KPIs




### Findings

- KPIs clearly illustrate the differences between the scenarios available.
- Scenarios include “current policies projections”, “likely development scenarios” and “normative <2°C scenarios”, with IEA offering the full spread.
- Only normative scenarios manage to reduce $CO_2$ emissions.
- Noting how large the challenge is to reduce $CO_2$ emis-sions, a global state of "*opulence of energy*" does not seem conceivable soon.

**Globally, clean energy will stay a rare good, until mid-century at the least.**

- **Scenarios cover a wide range of developments and illustrate the enormous dimension of possible future changes.**

TPED: Total Primary Energy Demand; Mtoe: Million Tonnes of Oil Equivalent; IEA: International Energy Agency

# Trends and Drivers towards a more Electric Society

## And information is Energy…

***The Landauer Limit***

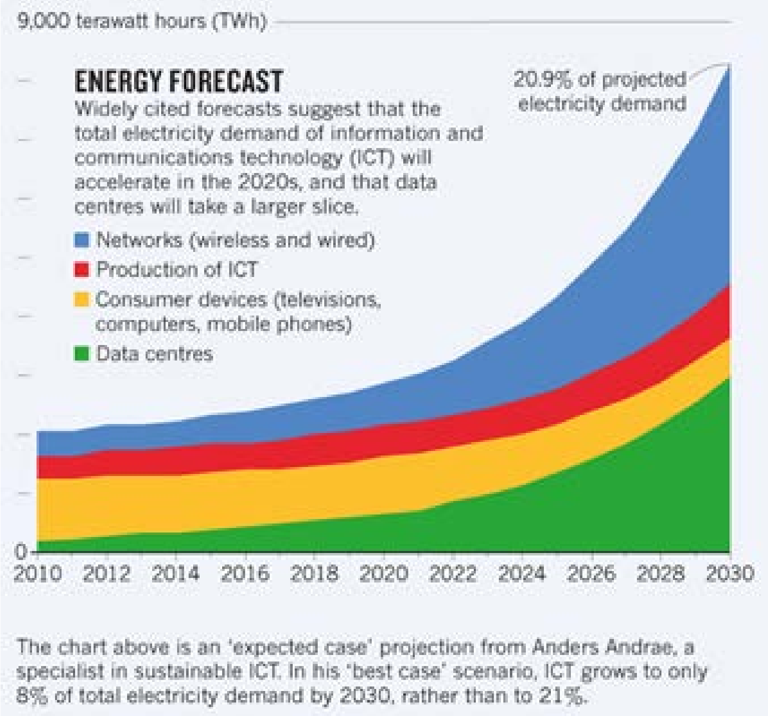
Each single bit operation in computers must use an absolute minimum amount of energy:

= 2.75 zepto-joules at room-temperature

(R. Landauer, 1961, IBM Research)

Physics: 2nd law of thermodynamics. If a system is going from a state of higher concentration to lower concentration, it gets increasingly disordered. That loss of order is called entropy, and it comes off as waste heat (in computing e.g. when a bit is erased).

**ICT could use 20.9 percent of the world's electricity consumption by 2025*.**




* Source: Nature, 12. Sept. 2018





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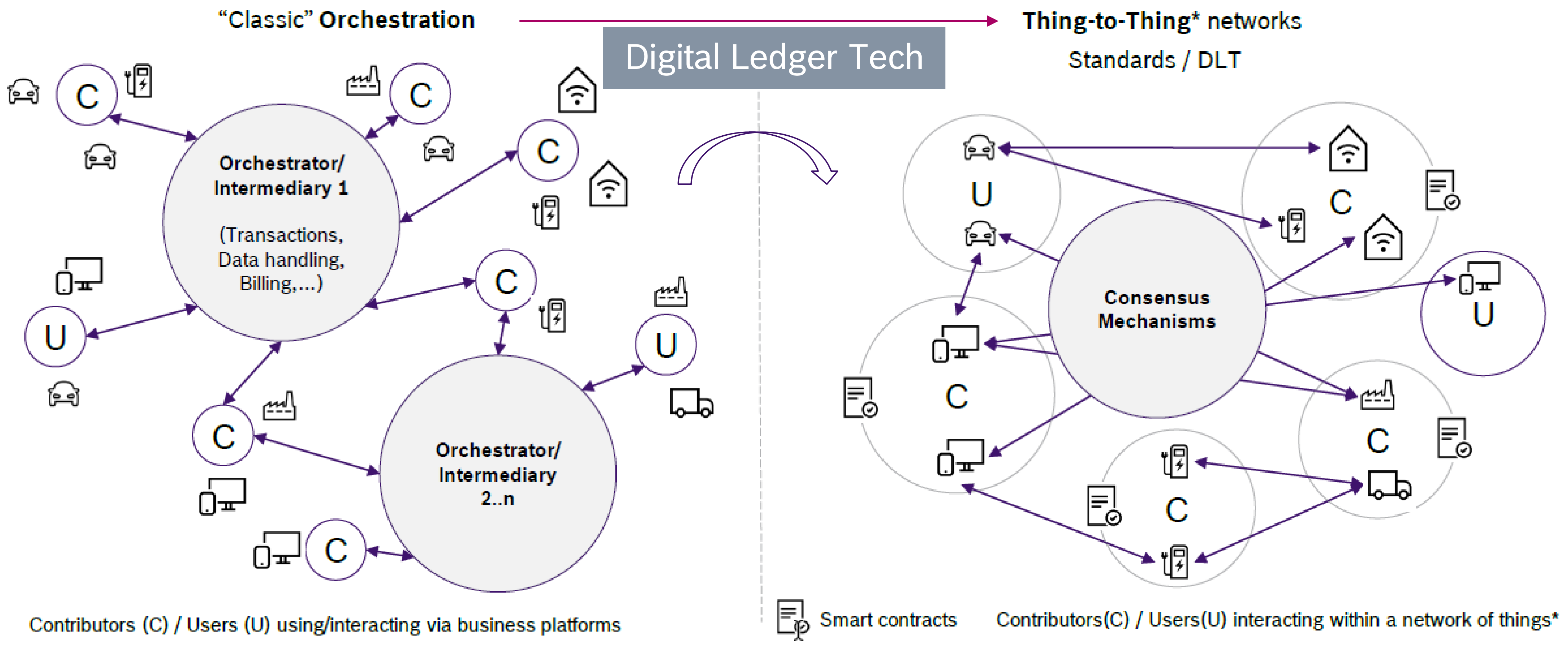
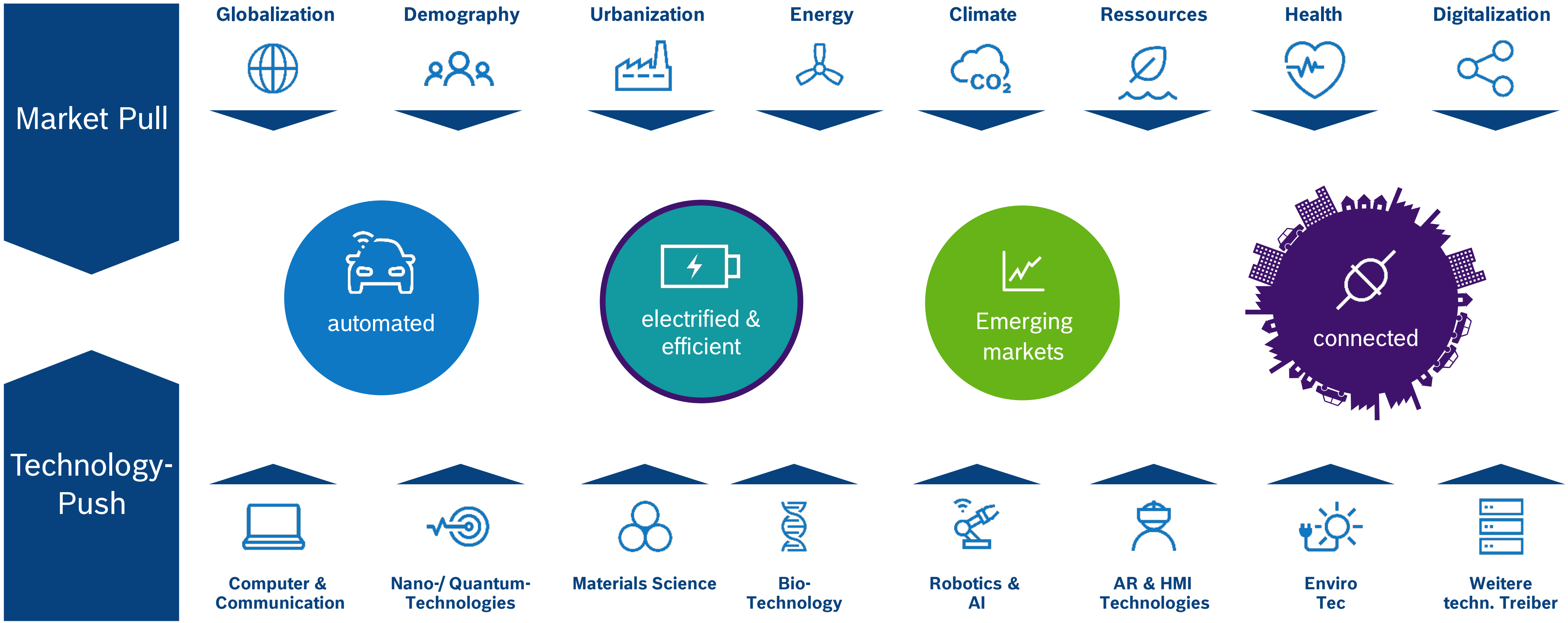
# Trends and Drivers towards a more Electric Society

## And the Economy of Things is on the horizon



# Bosch Research: Strategic Focus Points
## From Megatrends & Technologies to Strategic Focus



# RESEARCH AGENDA TOWARDS A MORE ELECTRIFIED SOCIETY

# RESEARCH EXAMPLES

# Agenda

1. *Introduction to **Bosch** and Bosch Corporate Research*

2. ***Trends and Drivers** of the More Electric Society*

3. Examples

   a. **Automated Driving** - **Fault tolerant** Drives

   b. **Distributed Energy Generation** – SOFC with **ultra reliable** electronics

   c. **Electrified Powertrain** - Wide Band Gap Semiconductors for **low losses**

4. Future of Research **Work**

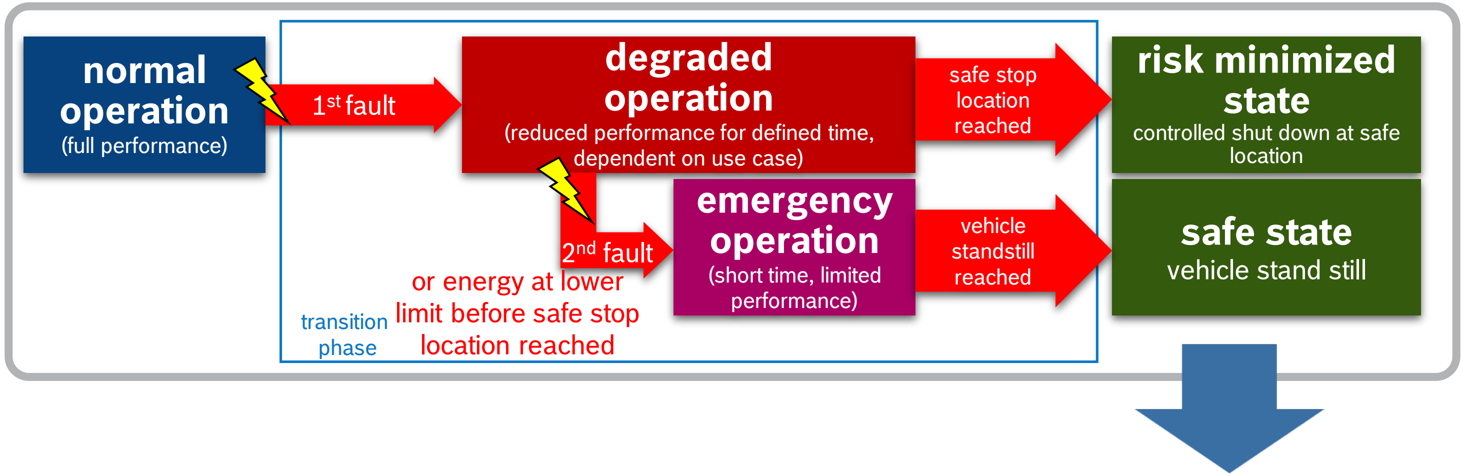
# Research Example - Fail-Degraded Powertrain
# Impact on Future Powertrain

| **Powertrain Requirements** | **Privately Owned Automated Vehicles** | **Publicly Shared Automated Vehicles** |
|---|---|---|
| Typical trips | urban & long distances | mainly urban, including limited highways |
| Purchase decision criteria | system cost & emotions | **TCO**[1)] |
| Peak power / peak Torque | as today | **reduced** |
| Mean engine speed | as today | **increased** |
| Safety requirements | as today / extended | **extended** |

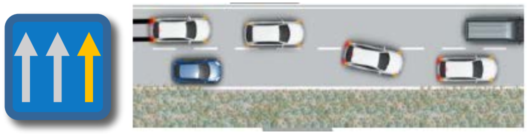
[1)] Total Cost of Ownership

# Research Example - Fail-Degraded Powertrain

## Expected Future Minimum Safe State




### Expectation towards AD based on State of the art



- **Fail-Degraded Powertrain for Safe Stop Level SSL4/5**

- **At the moment only market driven, could become regulative requirement**

Move the vehicle into a

**Risk Minimized Position**

**even after a vehicle stop on the left lane in stop & go situations.**



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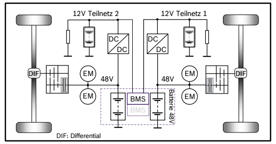
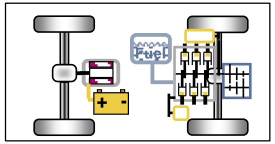
# Research Example - Fail-Degraded Powertrain

## Fail-degraded Powertrain – Solution Options

### hardware redundancy




BEV
(2x e-axle/battery)




HEV
(axle split)

### inherent redundancy

single component fault → degraded mode

- e-machine: 1 phase
- ICE: 1 component of control system
  (e.g. ign. coil)

### indirect redundancy

- predictive diagnosis & maintenance
  → fault avoided/detected early enough
- *externally by services:*
  *e.g. reserve car/automated tow car provided within "fault tolerance time"*

degree of innovation
(& development effort)

total cost (& weight, space)

<u>challenges:</u>

E/E-architecture, mainly

- redundant power net
- fall-back level for ECU failure

benefit: torque splitting → efficiency↑

**Just do it!**

<u>challenges:</u>

identify all relevant failure modes

→ extensive system analyses
→ find solution with min. add-on cost

**Rework the systems!**

<u>challenges:</u>

**Innovate the solutions!**



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# Research Example – Solid Oxide Fuel Cell

## Prototype Development

| | | Design 2016 | Design 2017 | Design 2018 |
|---|---|---|---|---|
| | | → Proof basic performance data | → Proof of concept and show case | → Demonstration in Bosch facilities |
| | |  |  |  |
| Nominal power | kW | 10.0 | 6.5 | 10.0 |
| DC efficiency | % | 57.8 | 73.0 | >73 |
| AC net efficiency | % | 48.8 | 59.2 | > 60 |
| Power density | kW/m³ | 1.3 | 2.0 | 6.9 |
| Start up time (after 12 h break) | h | not measured | 0.5 | <0.5 |

Design 2016, 2017: measured data, Design 2018: targets

Gefördert durch: Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des Deutschen Bundestages





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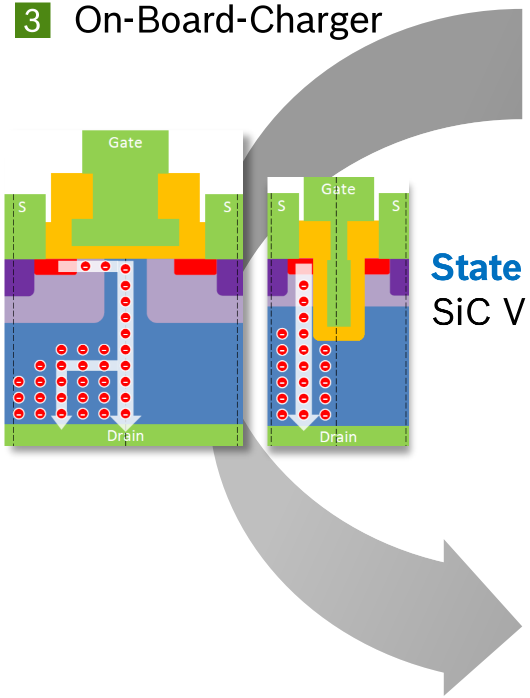
# Research Example – Power Semiconductors
## SiC@Bosch

- SiC in Bosch power electronic products for electrified power train (inverter/converter)
- Benefit of SiC:
  - Converters: enables increase in switching frequency (cost reduction passives)
  - Inverter 6% range increase SiC in WLTP cycle for 1200V devices (800V DC-Link)
- Series Production of Trench-MOSFET planned in Reutlingen Plant for 2022
- Trend: 750V (400V DC-Link) to reduce battery cost in volume market
- State of the Art: channel mobility limits cost competitiveness vs. silicon IGBT for 750V class

→ **Research on new WBG power transistor concepts „high η for competitive cost“**

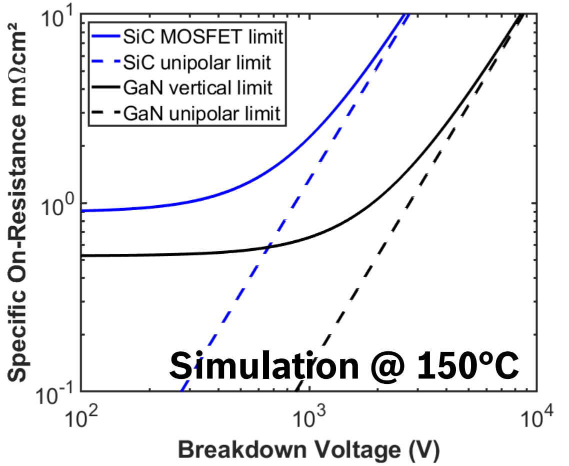
**SiC Power Transistors in:**

1 Inverter
2 DC/DC Converter
3 On-Board-Charger


**State of the art 1200V:**
SiC VD / TMOSFET

**Research on new concepts for 750V:**
advanced SiC, vertical GaN



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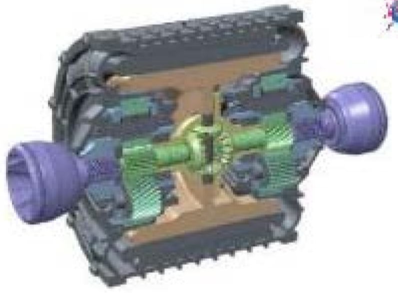
# Research Example – eAxle
## Challenging an excellent team

**Lighthouse Challenge: "World record" E-Drive w/ highest power density**

e-Machine with >1000Nm, <50 kg, <20 l as e-Drive with >500 hp



How **experts** tackle these challenges

- Combine ideas cross over physical domains & components with enabling technologies

**Ideas** for a new e-Machine & e-Drive
- High pole numbers (doubled)
- High outer diameter for high torque
- Gear integration in rotor with less rpm

New **technologies** in **manufacturing & material**
- Preformed coils
- Fully potted
- Approx. Halbach ring magnets

New **design technologies**
- Parametric models
- Multi objective optimization
- (Free shape & topology optimization)





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# THANK YOU


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