The Path to CO_2-neutral Mobility in 2050

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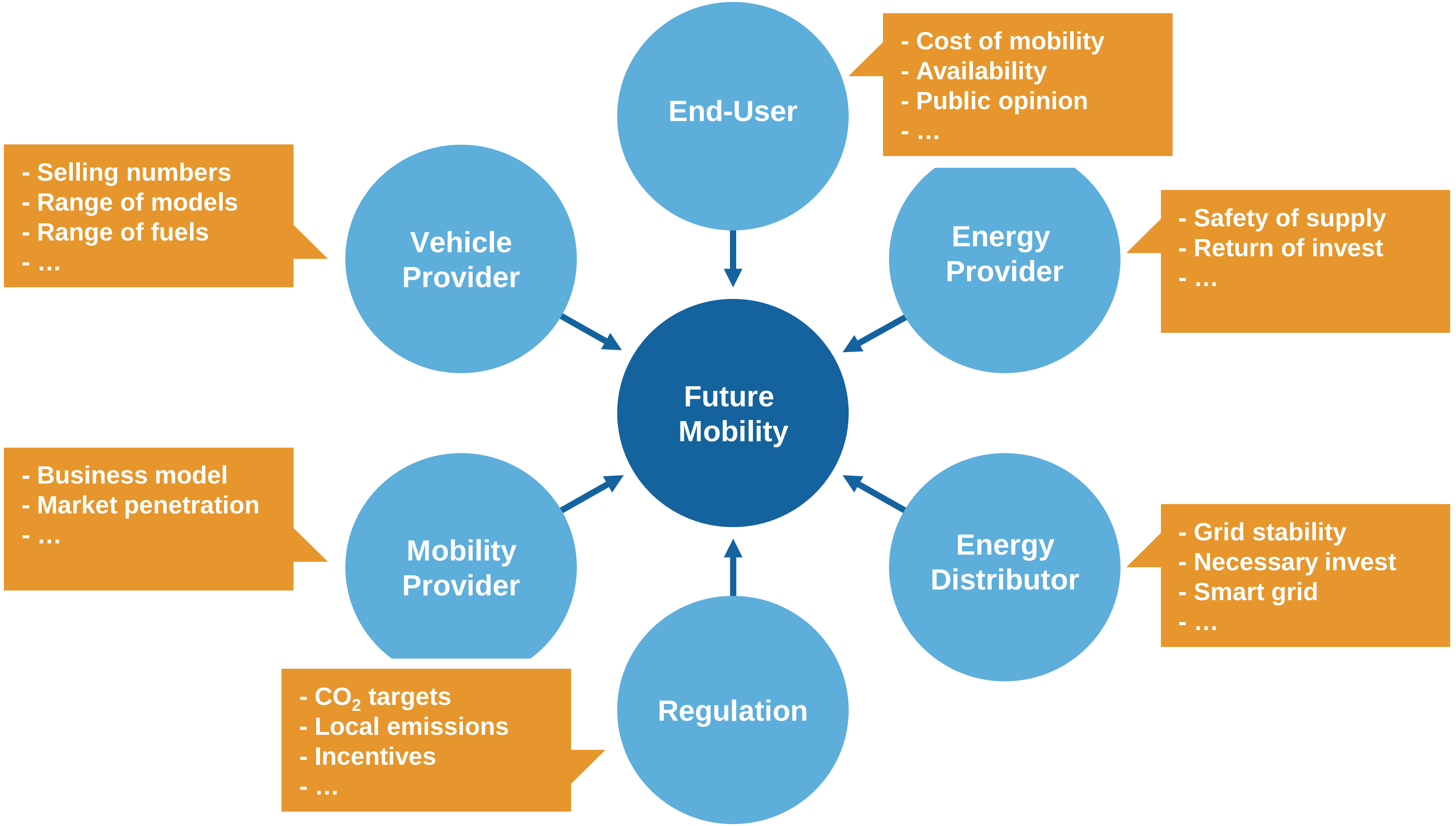
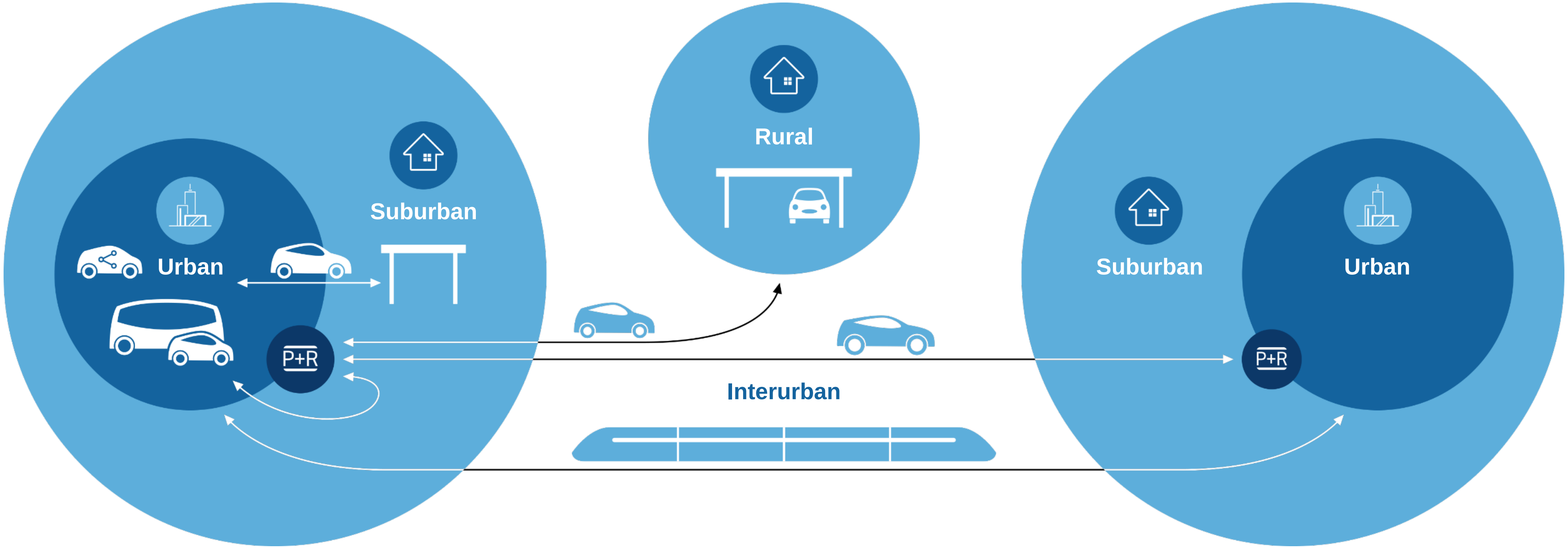
Stakeholder of Future Mobility



Ecosystems of Future Mobility



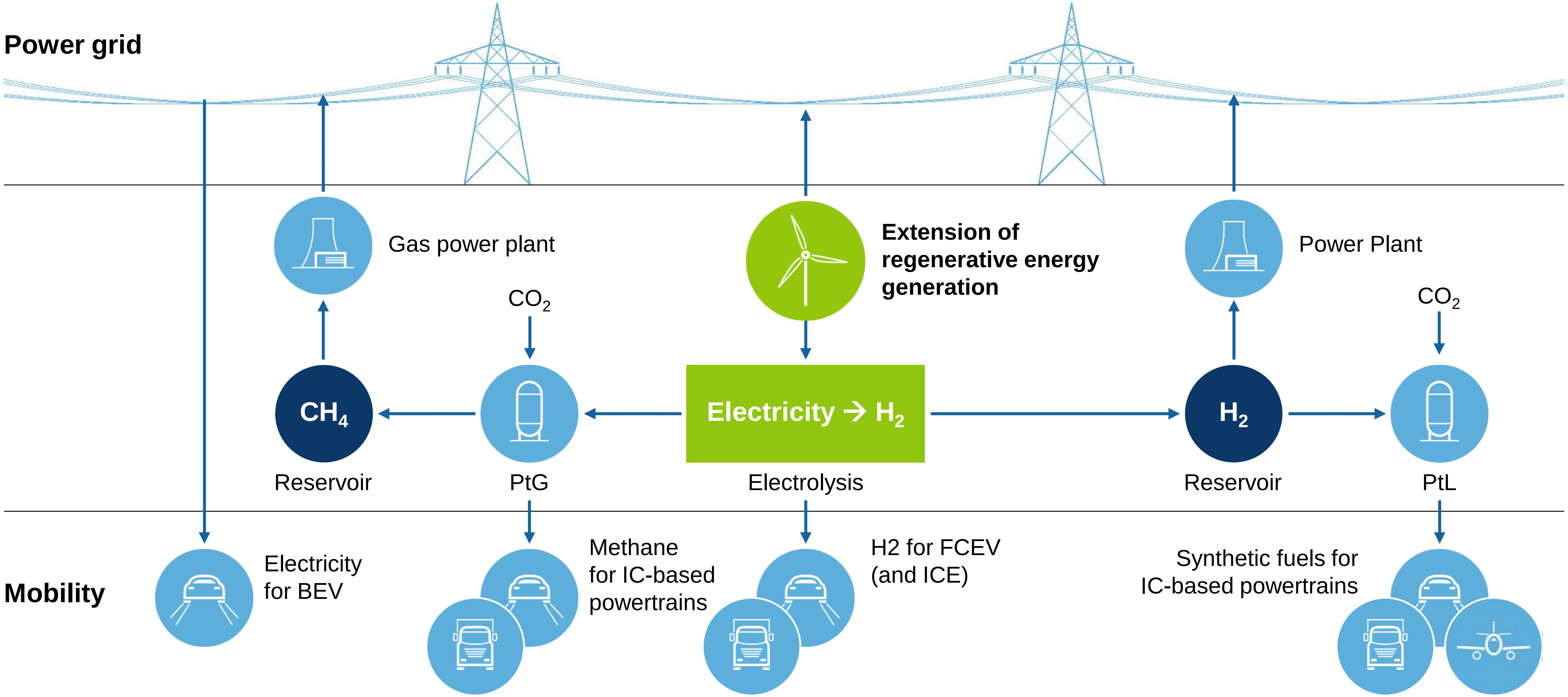
→ **Specific mobility requirements will lead to an adapted mixture of powertrain configurations**

Ecosystems of Future Mobility

Requirement	Urban	Suburban	Interurban	Rural
Form of mobility	Shared mobility; intermobility	Owned mobility; Inter-mobility at transition to urban area	Owned mobility (vs. train / plane)	Owned mobility
Sensitivity on costs	+	o	o	+
Cruising range demand	–	o	+	+
Importance local zero emission	++	o	o	–
Sensitivity on fill-up time	–	–	++	o
Availability of alternatives	++	o	o	–
Availability energy carrier	+	o	+	o

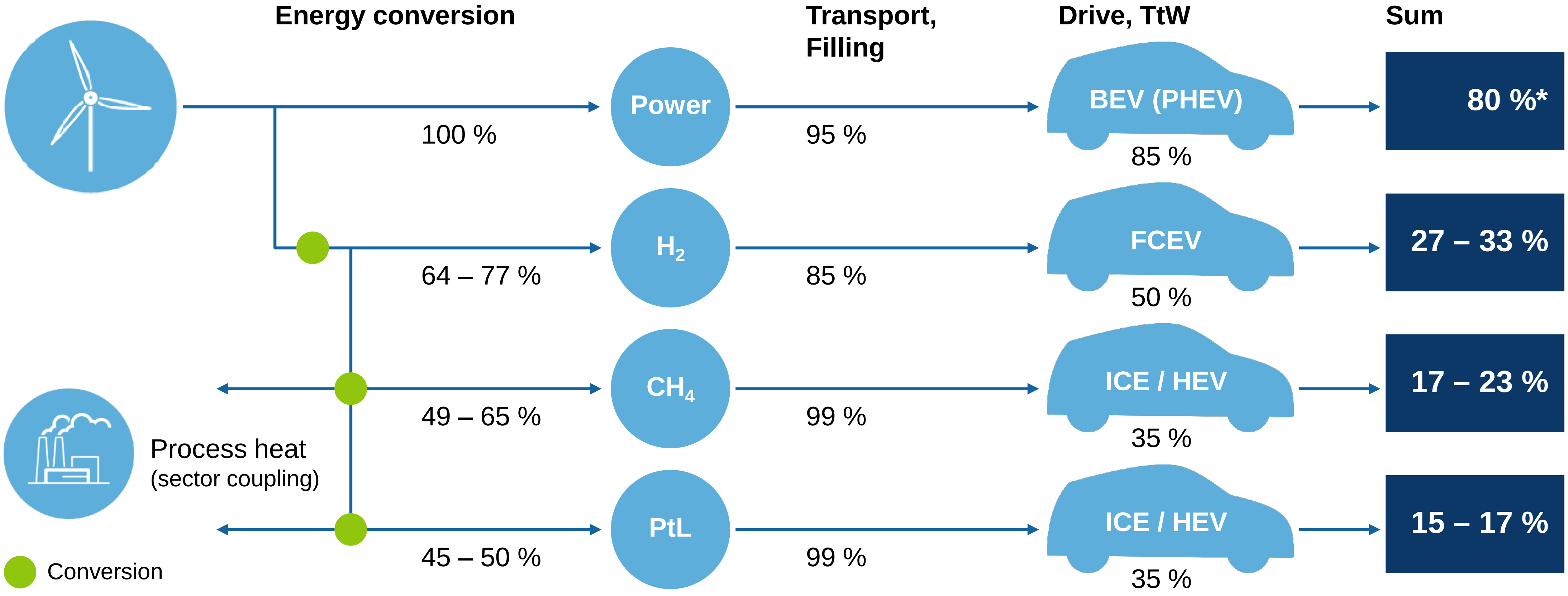
→ **No particular powertrain technology will be able to meet all requirements of the different mobility ecosystems**

Interaction of Energy- and Mobility Transition



→ **Up-scaled layout of PtX plants for mobility and transport energy supply complemented by import of energy carrier**

Competition of Technologies – Well2Wheel Efficiency

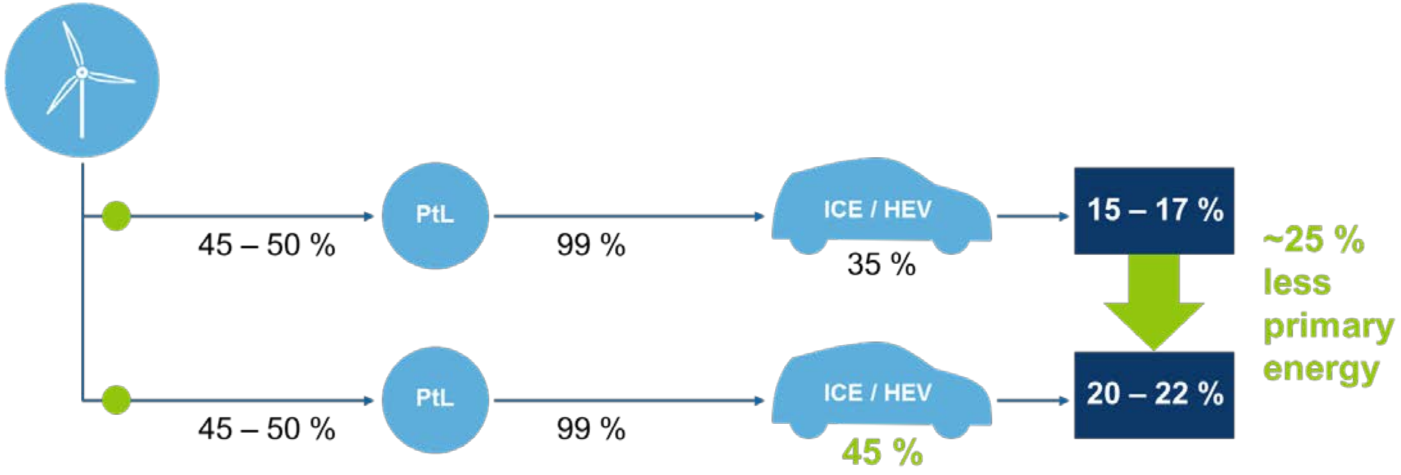


*will vary and can be much lower, depending on heating & cooling of battery, storage of electricity, etc.

- → **Direct use of electricity as most efficient way where accepted by costumer**
- → **Primary energy demand for PtL based mobility approx. 4-5 times higher than for BEV (WtW)**
- → **Efficiency of PtL can be increased if using process heat in production process (sector coupling – energy prod. trans.)**

Why to Continue the Development of Combustion Engines

- Combustion engines with e-Fuels 100% CO_2-neutral
- Internal combustion engines with e-Fuels would allow to reduce CO_2 in the existing fleet from today on (Drop In)
- High energy content – small storage volumes, big traveling range
- Easier long-term storage; better transportability
- Lower investment in infrastructure
- Impact on CO_2 not just for new mobility concepts, but even for the existing fleet from today on (drop in capability of PtX)



- Development of technology bundles to **increase ICE efficiency** in interaction with the **complete powertrain**
- Measures to achieve **local zero impact emission** to enlarge area of application

→ **Highly efficient combustion engines as precondition for future powertrains with ICE application**

From ICE with Micro Hybrid to Dedicated Hybrid ICE

WLTC Cycle Efficiency in %

today

η = 31 %
- 2200 bar FIE
- CR ~ 16
- Dual loop EGR
- CC: DOC/SDPF
- UB: SCR/ASC

η = 26 %
- 48 V Mild Hybrid
- 350 bar
- Stoichiometric
- CR ~10-12
- TWC + OPF

2023

η = 33 %
- 48V mild hybrid
- 2500 bar FIE
- VVT for „stay warm“
- CC: LNT/SCR/SDPF
- UB: SCR/ASC

η = 30 %
- HV Hybrid
- Passive PCSP
- Stoichiometric EGR
- CR~12-14
- E-catalyst + OPF
- E-Turbo + recup.
- 500 bar

2030

η = 36 %
- HV P2 Hybrid
- 3000 bar FIE
- Waste Heat Recovery
- PreTurbo: DOC/SDPF
- UB: SCR/ASC

η = 35 %
- HV Hybrid
- Active PCSP
- Homogeneous Lean (>> A/F 2, CR > 14)
- Phase change cooling
- Heated fuel injection
- E-catalyst + OPF
- Dedic. Injection Sys.

Evolution **2050**

Dedicated Hybrid SI or CI e-Fuel engine η_{WLTC}= 40 … 45 %

Engine
- Limited operating range
- Dedicated auxiliaries
- Adapted CR
- Ultra lean combustion
- Waste heat recovery
- Simplified EAT
- Zero impact emissions

Fuel
- Low aromatics, high heating value
- Lean ignitability
- Stable ignition delay
- High knock resistance

→ **Increased system efficiency by synchronized optimization of engine and hybrid powertrain**

Mobility Synthesis as a new Approach for Scenario Assessment

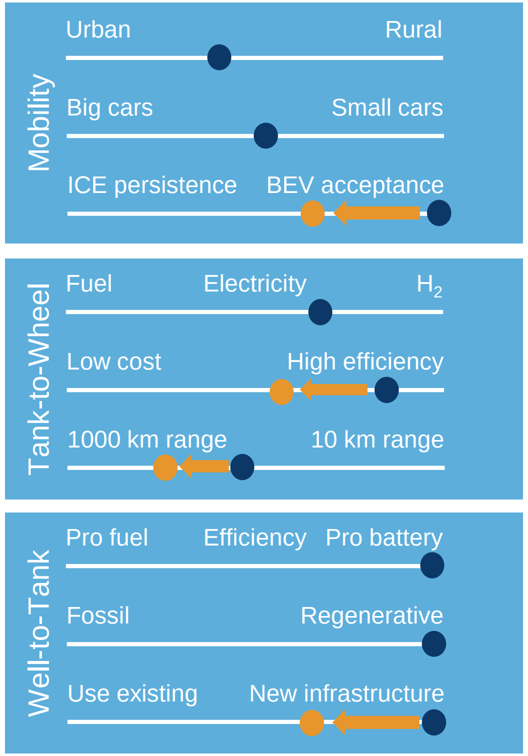
Data base

- New registrations
- CO_2 reduction potential
- Vehicle stock
- Electricity mix
- Raw material demand
- Energy carrier
- Operational profile
- Mileage
- Average fuel consumption
- Fleet emission limits

Changing trends

- Shared mobility
- Urbanization
- Ramp-up of e-mobility
- Utilization of infrastructure
- Legislation
- Potential of increasing efficiency
- Buildup of renewables

Model based scenario development



	2020	…	2050 (High BEV)	2050 (High e-fuel)
Battery electric vehicles	0.7 %	…	68 %	38 %
Fuel cell vehicles	0.02 %	…	4 %	7.4 %
Emissions based on 1990	89 % CO_2	…	7 % CO_2	7 % CO_2
Primary el. energy	1 TWh	…	219 TWh	517 TWh
Regen. Energy	41 %	…	98 %	98 %

Scenario Germany

→ **Systematic approach to evaluate the effects of the interacting factors on mobility scenarios**

→ **Possibility of technology ranking, planning of demand, etc.**

Timeline for Development of Boundary Conditions

Technology

- Development of technical solutions and feedback by costumer acceptance
- Implementation into vehicle fleet

Infrastructure

- Definition of boundary conditions
- Implementation of new infrastructure (incl. optimization of existing infrastructure)

◆ Decision cross-sectoral energy infrastructure
Grid planning Europe

Legislation

- CO_2 fleet legislation (tank-to-wheel)
- Revised legislation (well-to-wheel / LCA?)

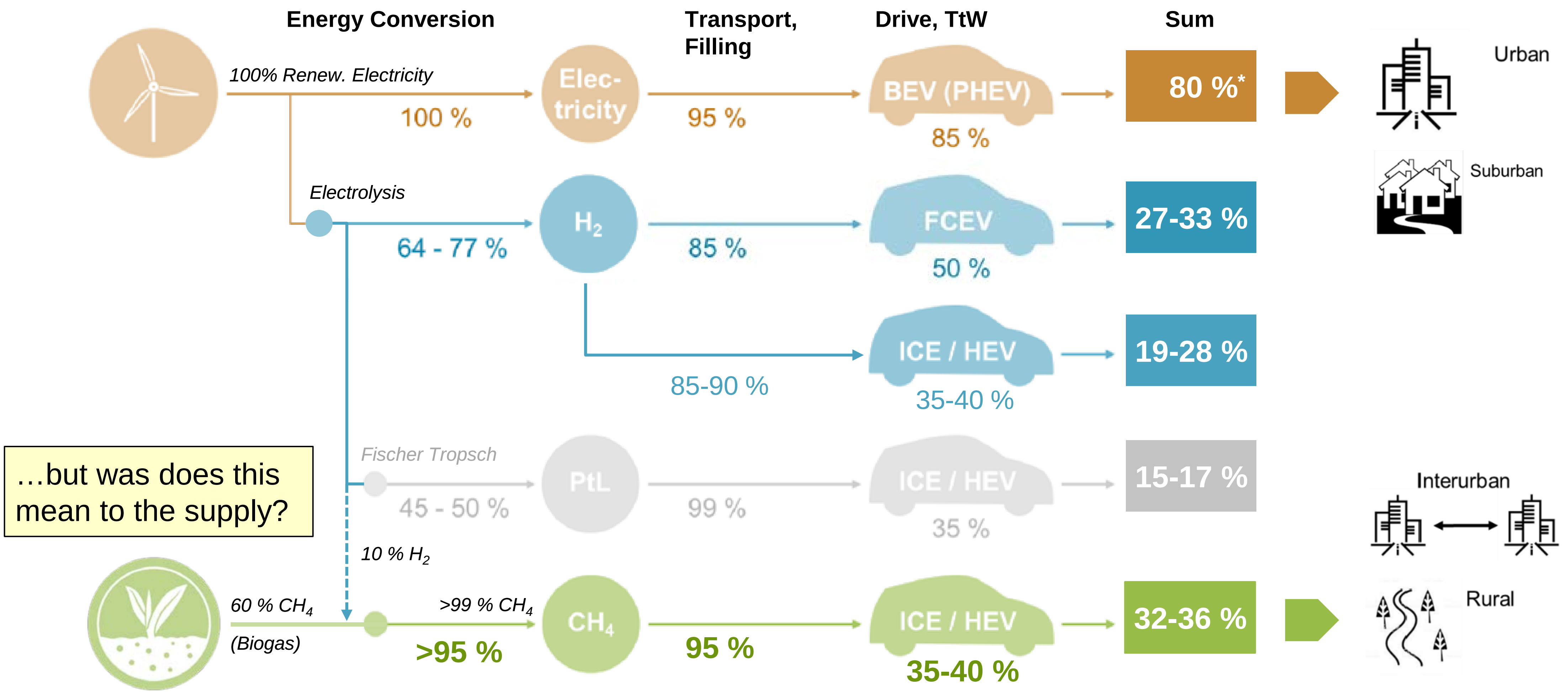
◆ Definition of balance frame CO_2 for post 2030
Taxation of PtX and electricity

2020 | 2030 | 2040 | 2050

→ **Short-term decisions necessary to meet the 2050 targets under consideration of typical implementation periods (mobility transition is just possible if an energy transition will happen upfront / in parallel)**

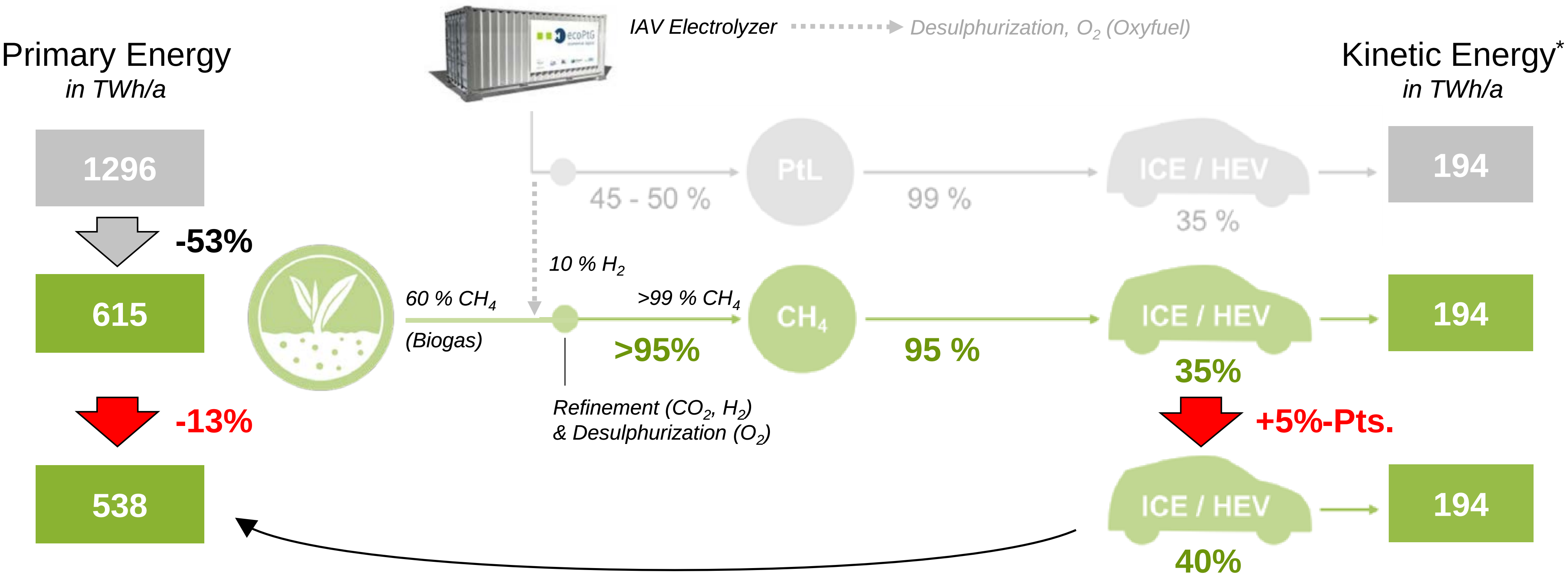
→ **What could be a short and mid term solution in order to reduce clearly the mobility based CO_2 emissions**

Additional Paths to Renewable Mobility (Well2Wheel Efficiency)



*) Will vary and can be much lower, depending on heating, cooling of battery, storage of electricity, etc.

Primary Energy Demand drives Engine Efficiency



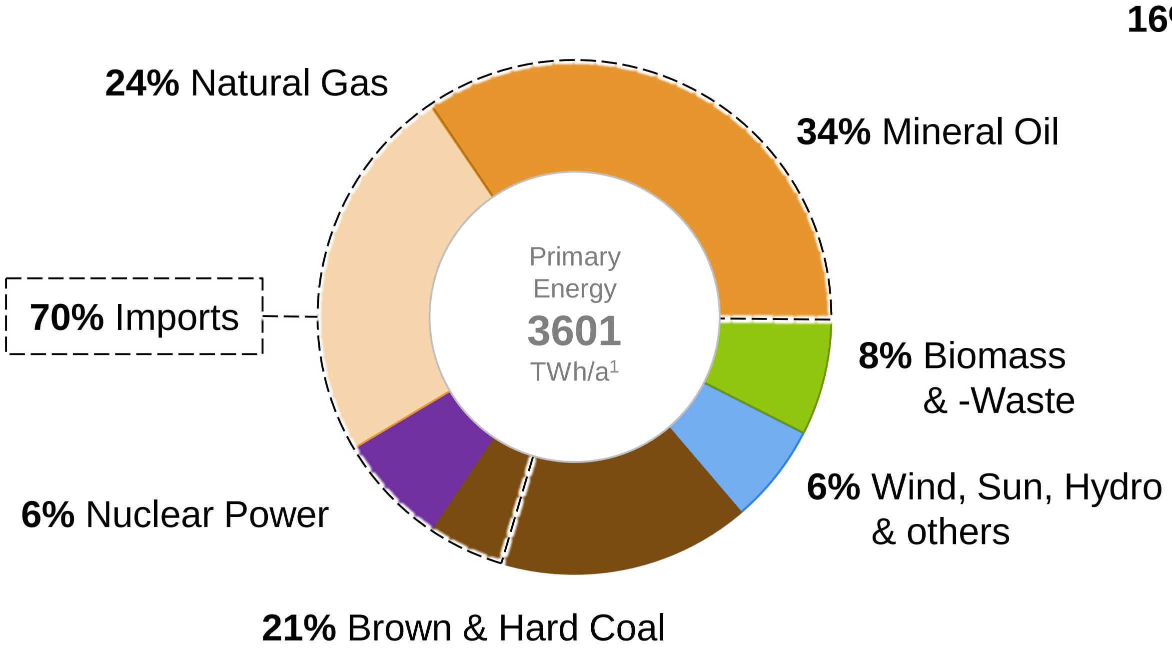
…but is there enough Biomass available for Mobility?

*) Calculated based on 30% share of Cons. Energy Germany 2017 with T2W Efficiency of 25%

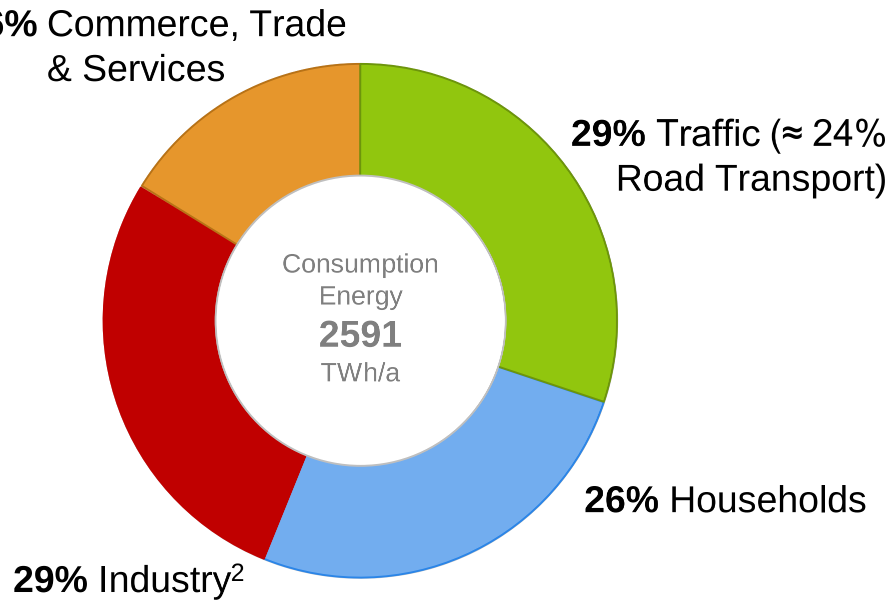
→ **Target shifts from CO_2-Emission to 1ʳʸ Energy Demand – forces ICE efficiency increase even more!**

Energy Supply and Demand in Germany Today

Germany 2018 ***Supply***



Germany 2017[3] ***Demand***

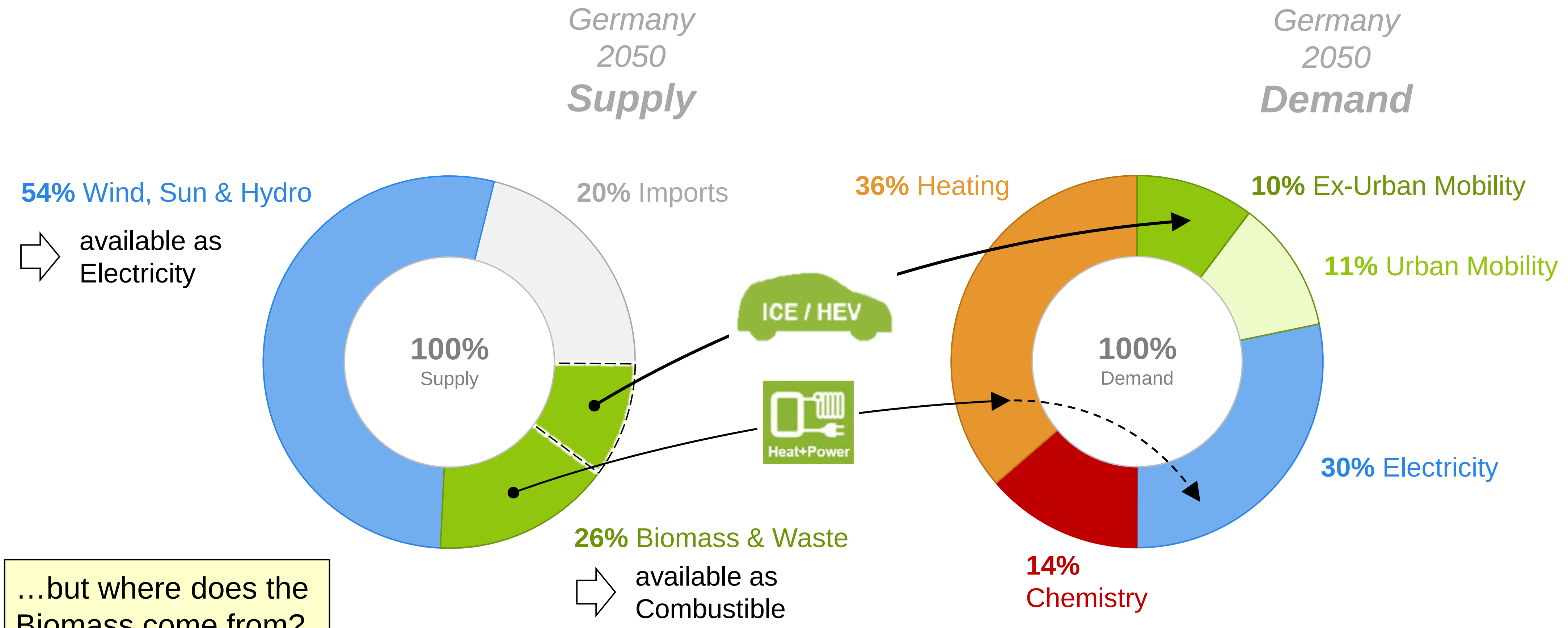


Sources: FNR 2018, BMWi 2018/19, AGEB 2018 & 2019

[1]) Equals to 12963 PJ (PJ usually used for primary energy)
[2]) Extractive and Manufacturing Industries [3]) Latest available Data Set

→ Today the energy demand for the road transport can not be fulfilled by Biomass and Bio-Waste

Energy Supply and Demand in Germany 2050

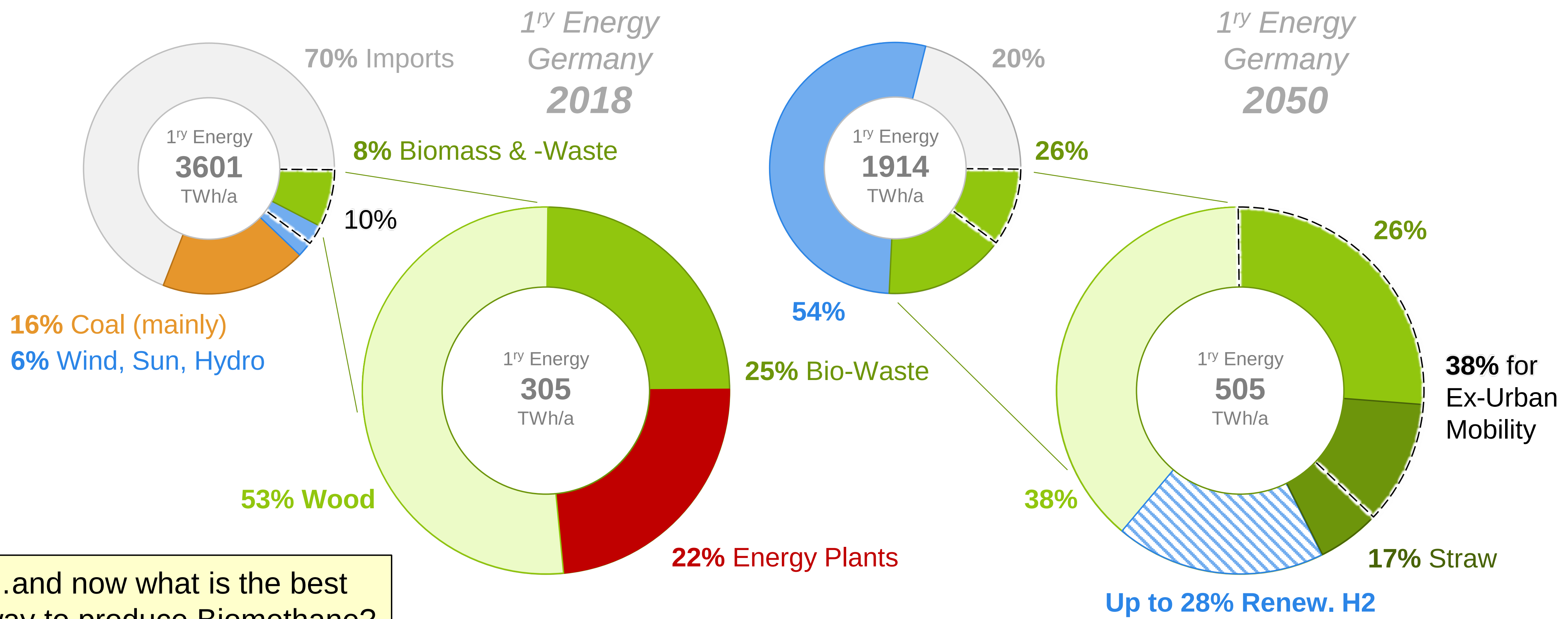


…but where does the Biomass come from?

Sources: FNR 2018, EU 2019, BMWi 2019, own calculations

→ Biomass already available as combustible for ICEs + enough available to supply ex-urban mobility

Shares of Biomass in Germany 2018 and in 2050



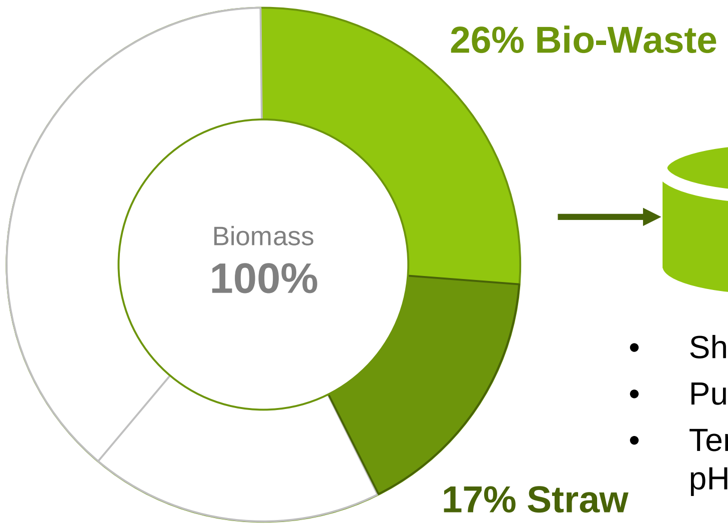
…and now what is the best way to produce Biomethane?

Sources: FNR 2018, EU 2019, "Energiekonzept 2050" Bundesregieung 2019 *, own calculations*

→ **Biomass used for Sustainable Mobility shall not compete with the Food Supply!**

Conversion Process of Biomass into Biomethane

Future Usage of Biomass



Substrate Preparation

- Shredding
- Purification
- Temperature and pH - settings

Fermentation

- Archaea Bacteria decompose the Biomass under anaerobic environment
- Result of the metabolic process is Biogas (CH_4+CO_2)

Refinement

- Desulphurization
- CO_2 Separation (e.g. Pressure Adsorption or Amine Wash)
- Integrative Methanation

Feed

- Gas Grid
- Storage capacity in Germany: 230 TWh

→ **The production of Biogas is very efficient and close to nature**

Conclusions and Urgent Things to Do

Common target of individually adapted mobility at lowest climate impact
- Politics
- Energy industry
- Fuel supply chain
- Automotive industry

Sector coupling indispensable
- Power generation
- Conversion and storage
- Grid stabilization
- Infrastructure

Development of infrastructure on European scale

Definition of regulatory boundaries necessary in short term
- Taxation of PtX and electricity
- Incentives
- Balance frame for CO_2 taxation during transient phase
- Closing of gap of CO_2 suppression costs between automotive and industry

Generation of willingness for investment in infrastructure
- Concerted action of national and European regulation authorities

Biowaste based fuels should be considered as an important part of the CO_2 neutral interurban and rural mobility

→ Open mind for all technologies targeting on CO_2 reduction – covering the complete life cycle

Thank You, and the entire Team behind this work!

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