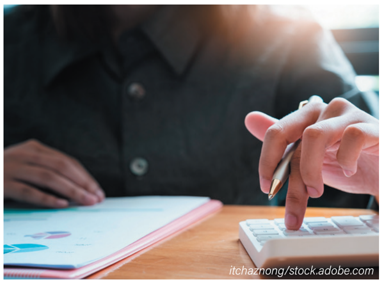
Position paper

June 2021

Technical, regulatory and social challenges for realising CO_2-neutral drive technology for cars and commercial vehicles during the coming decades



IASTEC

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Introduction

The International Scientific Association of Sustainable Drivetrain and Vehicle Technology Research, IASTEC (in the process of founding) is an international association of professors and researchers worldwide working on vehicle and drivetrain research at famous universities. The purpose of IASTEC is to promote science, research and teaching in the field of vehicle and drivetrain technology.

The members of IASTEC develop innovative vehicle concepts and systems as well as various sustainable drivetrain technologies (battery electric vehicles, fuel cell vehicles and engine technology for CO_2-neutral reFuels, which are synthetic electric power based eFuels as well as biogenic fuels, also known as bioFuels) and promote a CO_2-neutral mobility system of the future without fossil energy sources or fossil energy supply.

With this position paper, the signees address the urgent need for technological openness for propulsion technology for ground vehicles in order to reduce CO_2 emission from fossil energy sources on a global basis and fast. This position paper is directed at political decision-makers, investors, and also interested citizens.

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Summary

Due to current discussion on future mobility strategy, the scientific cooperation of vehicle and engine technology professors from Germany, Austria and Switzerland have written this position paper on technical, regulatory and social challenges inherent in the choice of passenger and commercial vehicle propulsion (and related fuel) technology for the coming decades, driven by the target of realising long-term CO_2 -neutral, sustainable mobility.

CORE MESSAGES AND CONCLUSIONS OF THIS POSITION PAPER ARE:

1.) In the near term, automotive propulsion technology must be able to achieve the highest CO_2 reduction potential quickly, so that the requirements of the Paris Climate Agreement [1] can be adhered to. At the same time, energy storage fuels and propulsion system will continue to undergo longer term development, necessitating coordination of near-term propulsion system technology with such future developments. These challenges can only be met optimally with an appropriate technology mix, adapted to each respective application [2].
2.) The promotion of battery-based electrical mobility, primarily for urban mobility, is an important component. Further valuable technological potential of this propulsion technology must be developed.
3.) Fuel cell technology is being developed further worldwide and especially in Asia. Here, too, further-reaching support of research and development in Europe will be necessary. The global hurdles that must be overcome to successfully mass produce this technology (and to create a viable and effective refueling infrastructure) remain demanding.
4.) The internal combustion engine (ICE) is an efficient energy converter at reasonable cost and has still a high potential for further improvements. The ICE is perfectly capable of exhibiting a low CO_2 footprint with the use of CO_2-neutral liquid hydrocarbon fuels (so called "reFuels") in place of petroleum based fuels [3–12].
5.) Concerns are increasing that currently elaborated CO_2 regulations of the future do not support the recommendations of the IPCC (Intergovernmental Panel of Climate Change) for fast CO_2 emission reduction in a best possible way. An unnecessary burden for the remaining CO_2 budget is expected for characteristic applications [12–15].
6.) There exists the potential for considerable CO_2 emissions reduction in the transport sector without requiring the elimination of the internal combustion engine. The point that is being missed in current regulations is that it is not the ICE that is the root cause of CO_2 emissions, but the fuels that are burnt within it. The replacement of fossil fuel based liquid hydrocarbon fuels with CO_2 neutral reFuels has the potential of significantly reducing CO_2 emissions from road transport in

a progressive way (increasing reFuels blending rate over the years), without the need to build a new infrastructure for fuel distribution and delivery. This solution could accompany and support a dedicated electric vehicle strategy and significantly improve the CO_2 reduction of transport sector.

7.) The current regulation leads to the inevitable use of PHEV or BEV, also where they neither lead to CO_2 advantages nor customer advantages. Therefore, the central demand of this position paper is to express political framework conditions unprejudiced and open to technology and to support all technology paths which can result in an effectively overall evaluated CO_2 reduction and therefore contribute a minimum CO_2-burden to the remaining budget [2, 16, 17].

8.) Mobility, transport and energy supply form the essential cornerstones of a prospering, open and resilient society. Technological competition and a cross-sector, holistic system view are decisive factors for the development of an optimum overall system [18].

Marginal conditions for sustainable mobility in the coming decades

The energy and mobility transition are inseparably linked and require great efforts.

The energy system of the future will change. With the considerable expansion of wind energy and photovoltaics, the temporally and locally needs-orientated availability of electrical energy will become more challenging. High-performance energy storage technologies must be installed [19]. Today's share of photovoltaics and wind energy in Germany of ca. 5% of primary energy requirement will increase considerably in the long-term. In 2030, approx. 70% of electrical energy will originate from renewable sources [20–22]. Worldwide 63% of power in 2019 was generated by fossil energy, 10% by nuclear energy and 26% by renewable energy like wind and solar [68].

Today, some 70% of primary energy is imported. In the future, Europe and in particular Germany will remain dependent on imported energy, however the imported energy must originate from renewable sources [23]. Therefore, one of the greatest global challenges in the coming 30 years will be the considerable expansion of the provision of regenerative energy (e.g. photovoltaics, wind energy, etc.). This enables the production of and trade with CO_2-neutral energy carriers[1]. CO_2-neutral operation by all consumers must therefore be society's objective, whereby economically viable solutions must be striven for. Moreover, the energy system will be supported by the progress in further developing battery technology. These marginal conditions decisively assume physically feasible and also affordable energy transport.

Whilst transfer of electrical energy is possible over short and medium distances, transport from of electricity from wind-rich or sun-rich areas cannot be realised in many cases, e.g. from South America, Australia, Africa or the Arabian Peninsula. Therefore, importing chemical energy carriers instead of electricity makes more sense. These can include hydrogen with volumetric energy density between 1.4 kWh/l and 2.4 kWh/l. Methanol or Fischer-Tropsch products allow a considerably higher energy density of 4 kWh/l to 9 kWh/l. Due to this high energy density, chemical energy carriers are not only preferred for vehicle use, but also for energy transport. Even if the manufacturing with CO_2-neutral processes demonstrates higher losses than is the case for electricity generation, this decoupling between the manufacturing location and use as well as the excellent storage capability offer decisive advantages. This important aspect is given too little attention both in current public discussion and within the regulatory activities.

[1] *CO_2-neutrality refers to the carbon cycle. CO_2 is taken from the air, the carbon C stored in fuel and neutrally emitted during energy implementation again as CO_2 to form a balance.*

Marginal conditions for sustainable mobility in the coming decades

All-in-all within the transport sector, in addition to the focus on drive energy needs, further requirements are decisive, namely payload, vehicle weight, handling the energy carrier, safety aspects, readiness for use, comfort and costs. Dependent on the application case, different energy carriers are needed for different mobility requirements. Electrical energy, hydrogen or CO_2-neutral synthetic fuels, reFuels, will respectively be able to meet different mobility and transport requirements optimally and CO_2-neutrally.

All paths to defossilisation will have to be used across all sectors in the future in order to ensure the success of energy transition. Here, the term decarbonisation is confusing because carbon will also have to play an important role, primarily in the energy economy and chemicals industry in the future for chemical-physical reasons. Fossil carbon must be refrained from in the long-term for energy supply!

The important principles which must be observed for the technical, regulatory and social challenges of a sustainable mobility system are expressed below.

Technical and regulatory challenges for sustainable mobility in the coming decades

THE ANALYSIS OF THE ENERGY SYSTEM AND FURTHER-REACHING MARGINAL CONDITIONS LEAD TO THE FOLLOWING CORE STATEMENTS WHEN EVALUATING THE TECHNICAL AND REGULATORY CHALLENGES:

1.) Political efforts to develop a CO_2-neutral mobility sector and its fast implementation are expressly supported by all signees of this position paper [24]. A significant CO_2 emission reduction of the car fleet must be achieved by 2030 and CO_2-neutral mobility by 2050 at the latest.

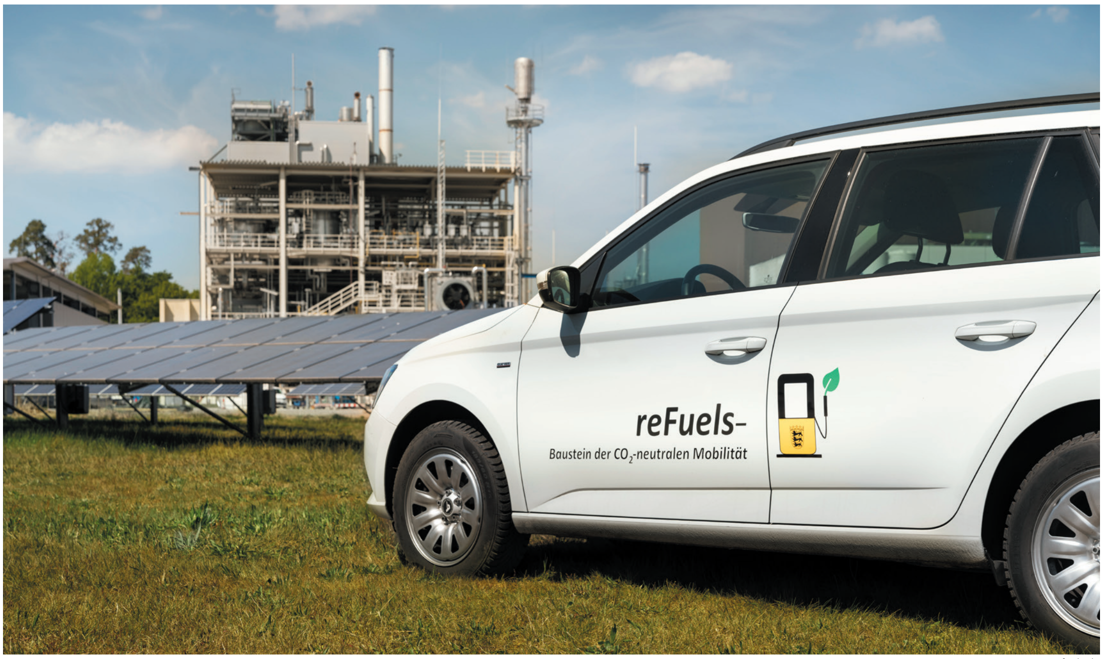
2.) Providing CO_2-neutral electrical energy throughout the year remains a great challenge for several decades.

   a. Therefore, the shift to vehicles with electrical batteries within the car market will contribute a decisive share of CO_2 emission reduction [13] in 2035 at the earliest.

   b. The realisation of energy storage options in Germany is also necessary because an excess of electrical power of 60 GW is expected in 2035 [25]. For this, both rechargeable batteries and chemical energy carriers such as H_2, methanol or Fischer-Tropsch products are possible options.

3.) However, the signees criticise that through the current separate observation of the sectors no holistic optimum reduction of CO_2 emission is achieved [26]. On the contrary, the regulation leads to singular optimisation of individual sector emission. This means that large holistic CO_2 potential remains unused, incorrect stop signals are set for technological development and important technologies are not observed. Therefore, based on the planned regulation, only battery-supported (BEV/PHEV) or H_2-driven vehicles (FCV, ICE) without CO_2 fines can be sold in the future although vehicles operated with reFuels show comparable environmental advantages [27, 69].

4.) The battery-supported mobility offers important potential for holistic CO_2reduction [14]. Important technological progress with batteries, power electronics, electrical motors and production underline the significance of this technology pillar. However, an average ten-year BEV sales rate of 20% results, for example, in a decade in a mere 5 million BEV vehicles sold, with the existence of some 40 million vehicles with a combustion engine in Germany. Therefore, a binding CO_2 quota with a genuine CO_2 reduction potential of at least 25% should be introduced in 2030. The limited availability of reFuels will initially restrict such a quota, however 30%-40% reFuels blended with fossil fuel in 2030 is not unrealistic. This would mean a reFuels quantity requirement of 13-17 million t/a for Germany [28–32]. The blending of fossil fuels with refuels results in a considerable reduction of the genuine CO_2 emission for existing vehicles and can be implemented without technical obstacles.



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5.) The CO_2 regulation existing to-date in the transport sector leads to higher environmental burdens than necessary as its contents are not coherent. Thus, the use of hydrogen in vehicles is evaluated as CO_2-neutral. On the other hand, the operation of a vehicle with CO_2-neutral reFuels from a CO_2-H_2-cycle is taken fully into account for CO_2 calculation. Contrary to this, the reconversion of CO_2-neutral reFuels and the operation of a battery vehicle with this electricity is evaluated as being CO_2-free. These regulations are not physically and scientific sound and result in increased CO_2 emission, burdening the remaining CO_2 budget according to the IPCC recommendations [33]. Faster and better CO_2 reduction is achieved via a technology-neutral approach.

6.) The further electrification of the internal combustion engine drivetrain results in eminent CO_2-reduction [34–38]. This hybrid technology enables consumption and operation advantages with a purely combustion engine-based drivetrain. Some 50% CO_2 savings combined with R33 or G40 fuel[2] can thus be depicted, nevertheless this technology cannot meet today's planned regulatory CO_2 reduction [4]. CO_2 regulation does not take this potential into account, meaning that particularly economical and cheap small cars cannot achieve the target specifications planed for the future.

7.) Latest CO_2 regulations of German legislation still hardly show any binding steps for the introduction of reFuels [39]. The total quantity of existing regulatory specifications does not meet the requirement of technological openness and still has a single-sided effect. Considering the future energy situation, the fast introduction of reFuels is indispensable. The comprehensive availability of CO_2-neutral fuels can only be depicted in accordance with the required investment security for the systems required.

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[2] Please note, that the energy and transport sector situation of Germany is often referred in this publication as intensive analysis has been accomplished for this market with comparable key messages for many other countries.

[3] R33 and G40 fuels are diesel fuel and petrol with a reduced fossil fuel share: see chapter "List of Abbreviations"

Social challenges regarding the drive portfolio for future mobility

CONSIDERABLE SOCIAL CHALLENGES ARISE DUE TO THE ENERGY AND MOBILITY TRANSITION. THE DIFFERENT ENERGY CARRIERS BATTERY, HYDROGEN AND REFUELS WILL RESPECTIVELY MAKE IMPORTANT CONTRIBUTIONS TO CO_2 REDUCTION. THE FOLLOWING CHALLENGES ARISE FROM THE CURRENTLY SINGLE-SIDED FUTURE STRATEGY:

1.) Holistic observation of the energy system and knowledge of the interdependencies are important. The advantage of BEV mobility is its favourable energy balance from the electron to the wheel. This advantage against synthetic PtX fuels (eFuels), during whose production process disadvantages arise due to conversion losses [40, 41], means on average, taking in account line loss, charge loss, thermal management operation and customer-typical average vehicle use, an approximately 2-3 times better energy utilisation when operating a battery vehicle as opposed to a modern hybrid vehicle with synthetic fuel from electrical energy [42, 43].
This efficiency benefit of the BEV can in particular be fully utilised when regeneratively generated electricity really is provided for charging [44]. As this can also only in-part be implemented in the long-term, parallel pursuit of the reFuels technology path, that is to say chemical energy storage, is necessary [18].
In order to achieve climate targets, today's fossil energy imports to Germany will have to be replaced by CO_2-neutral chemical energy carriers.
    a. Good medium-term opportunities exist in importing chemically stored energy from several different locations worldwide [45, 46]. German and European companies' technical expertise enables Europe to assume a leading role in the production and sales of chemical energy carriers in a global network [47]. This results in long-term attractive economic opportunities for European countries and companies.
    b. Particularly wind-rich and sun-rich regions can be found in-part within, but mostly outside Europe. Energy import via chemical energy carriers is the most economic means to utilise these remote energy sources in Europe. The electrical energy available from wind and photovoltaics systems in suitable regions is approx. 2-3 times higher than in Germany [46, 48–51].
    c. Important global automotive markets like China now also follow the path of chemical energy carrier reFuels. This provides an economic surroundings which Europe should certainly be part of. [52, 53]

2.) Marginal conditions arise for the future mobility system which must be observed in good time:
    a. Individual mobility today is classless and available to almost all parts of our society Europe-wide and cross-border.

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b. A high range for vehicles in the cheap market segment with batteries is not to be expected in the mid-term[3] because the battery size is decisive for the product price. Individual mobility with cheap vehicles with a high range cannot be depicted with BEVs alone.
c. The value chains for different drive systems vary. Therefore, the medium-term effects of various drive systems for production at industrial locations in Europe must be evaluated comprehensively with regard to salary structures, tax income and social security tax.
d. The introduction and further research of an H_2-driven mobility system offers a major opportunity for selected vehicle segments. Social acceptance, the resulting costs and technical challenges in particular of the fuel cell (FC) do not allow concrete predictions currently regarding start of large series production and vehicle costs.

3.) Due to the intelligent expansion of charging options at the workplace, electrical battery mobility can be extended to new groups of the population. Nevertheless, also in the long-term there will not be adequate charging opportunities for all vehicles, in particular in towns and cities. The availability of charging facilities decisively influences the market acceptance of BEV and correct operation of PHEV.

4.) In addition to the energy density, the major advantage of the reFuels is the storability of the energy carrier. This makes reFuels time-independent, meaning use and manufacturing of use reFuels from the are independent from each other. In particular in rare, but important emergency and catastrophe situations (cold, war, electricity failure), the storability of reFuels proves to be a valuable advantage.

5.) The costs of our future mobility system must be elucidated more clearly, also against the backdrop of the Covid-19 pandemic. Numerous business analyses show that manufacturing costs for CO_2-neutral reFuels of considerably under €2/l to lower than €1/l are realistic in the long-term if cheap locations are used [6, 45, 50, 61–66], in particular if the electricity generation costs are considerably lower than €0.02/kWh. These fuel costs already include the investment costs for the systems, making reFuels a significant module within an economically sustainable mobility system.

6.) The current pandemic has in particular shown the lacking resilience of the supply chains for important industrial processes and economies [67]. When evaluating the future drive portfolio, the effects of the resilience of supply chains in international alliance should be relatively significant. Moreover, the high significance of mobility available at all times and transport capacity in system-relevant area has become clear to society.

[5] For example, an estimation of the coverage of mobility requirements can be found at an estimation of the battery cost development with battery cost scenarios up to less than €80/kWh can be found at [55–60].

List of Abbreviations

BEV	Battery Electric Vehicle; electrical vehicle with battery storage without further energy storage
bioFuels	Biogenic fuels; fuel manufactured from organic or animal raw materials: the biogenic resource is limited, however 20-30% can be depicted as a valuable partial energy contribution to CO_2reduction.
BtX	Biomass to X; alternative designation for bioFuels
B7	Technical term for Diesel fuel with 7% bio Diesel share. The bio Diesel consists of organic and animal oil and fat, which is prepared by esterification in a production process. The technical term is fatty acid methyl ester FAME).
CO_2	Carbon dioxide; develops during energy release due to the oxidisation of energy carriers with a carbon component.
DIN	Deutsche Industrie Norm [German Industry Standard]
eFuels	Synthetic fuels; fuel manufactured from electrical energy which enables the storage and economical transport of sun, water and wind energy from distant regions, e.g. South America, Africa, Arabia, Australia
EN228	Abbreviation for EuroNorm EN228; defines the composition of petrol
EN590	Abbreviation for EuroNorm EN590; defines the composition of Diesel fuel
FC	Fuel cell; enables transformation, for example of hydrogen to electrical energy.
FCV	Fuel Cell Vehicle; electrical vehicle with a fuel cell to provide electrical energy
G40	Petrol which meets today's fuel specifications (EN228) and can therefore be used for all vehicles. G40 contains 60% fossil components, 10% ethanol and 30% MtG.
H_2	As the smallest chemical element, hydrogen is a possible comprehensive future fuel for FC or VM application.
Hybrid	Hybrid drives incorporate both the VM and an electrical engine and enable electrical recuperation (braking energy recovery) as well as overall system improvement via optimum regulation of electrical and combustion engine drive.
ICE	Internal Combustion Engine without or combinable with an additional electrical engine (hybrid), can be operated with fossil fuels or reFuels. Operation with reFuels allows low, holistic CO_2 emission, depending on the reFuels fuel share and reFuels production mode. VMs are viewed both with fossil and reFuels fuel with state-of-the-art technology as quasi emission-neutral due to their very low emission. The current EURO7 legislation initiative also ensures that the most stringent air quality requirements are met.
MtG	Methanol to Gasoline; from the intermediate methanol, can generate petrol
NH_3	Ammoniac; example of a possible fuel, maybe for ships' applications with CO_2-free energy transformation due to the missing carbon share of NH_3

List of Abbreviations

PHEV	Plugin Hybrid Vehicle; hybrid vehicle with a large battery storage capacity and an additional charging option for the battery
PtX	Power to X, alternative term for eFuels
reFuels	alternative term for synthetic eFuels and biogenic bioFuels An admixture, for example, of 26% reFuel B7 plus 67% fossil diesel results in Diesel fuel R33 within the current specification of EN590 with a CO_2 reduction potential >20% For petrol, an ethanol share of 20% plus a further MtG share of 20% also enables an overall CO_2 reduction potential >20%
RED 2	Renewable Energy Directive 2; implementation of specifications from Directive (EU) 2018/2001 from the European Parliament and the European Council from December 11, 2018 on the promotion of the use of energy from renewable sources for approval processes within the Federal State's emission legislation
R33	Diesel fuel which meets today's fuel specifications (EN590) and can therefore be used for all vehicles. R33 contains 67% fossil components, 7% bio Diesel share and 26% paraffinic Diesel share reFuel. S33 is equivalent to R33 but considers only synthetic Diesel via FT-path and no biomass base paraffinic Diesel
Sectors	Within the scope of the Federal Climate Protection Act, the CO_2 emission is separately recorded and evaluated for the sectors energy economy, industry, buildings, traffic, agriculture and waste and miscellaneous. Coupled processes (such as the production of a vehicle with energy-economical influence on the operation and a traffic contribution) are separated artificially by regulatory means, making holistic optimisation no longer possible.

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This positioning paper is published by the International Scientific Association of Sustainable Drivetrain and Vehicle Technology Research, IASTEC (in the process of founding).
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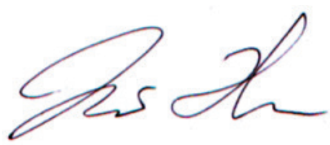

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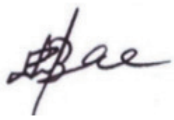

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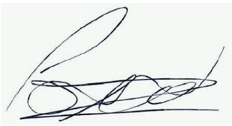

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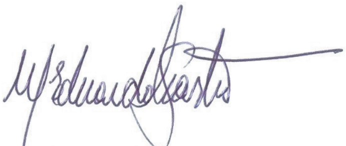

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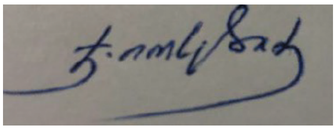

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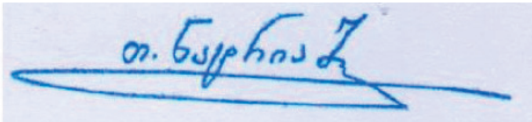

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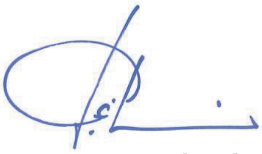

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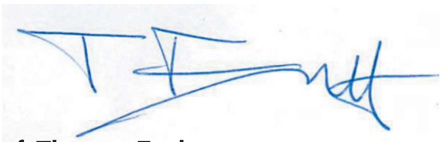

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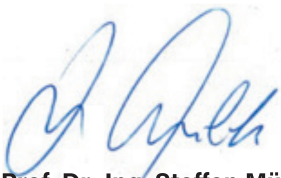

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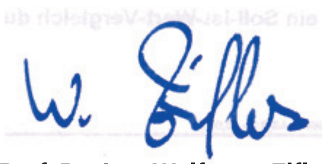

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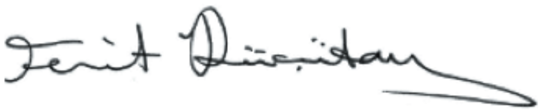

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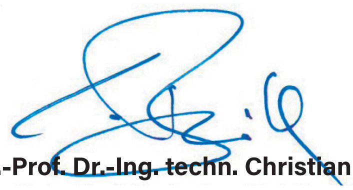

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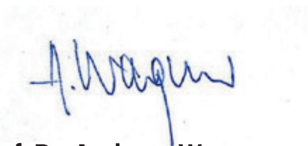

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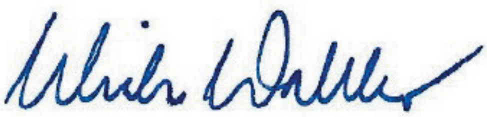

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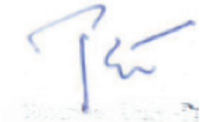

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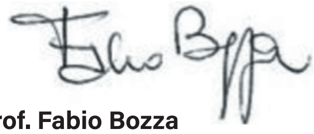

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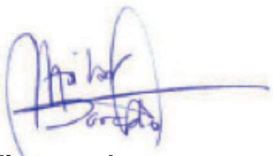

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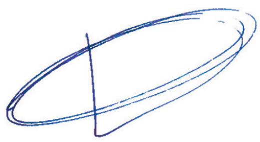

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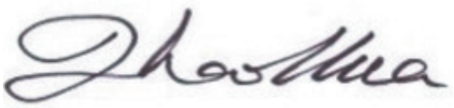

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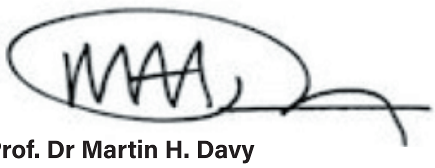

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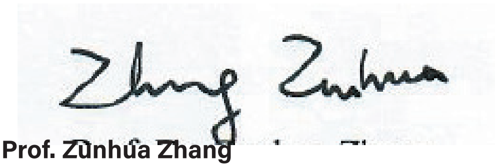

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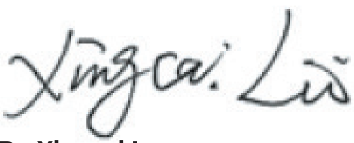

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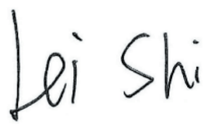

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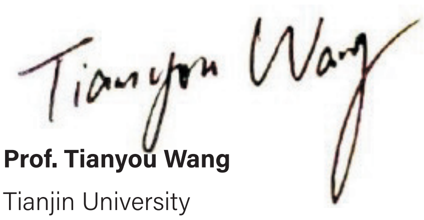

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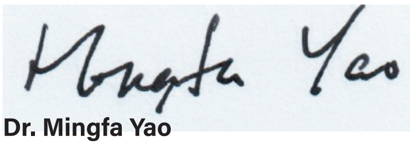

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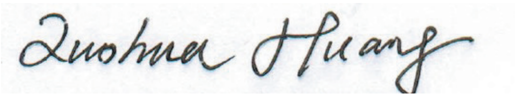

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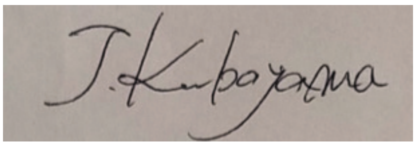

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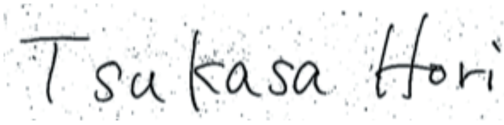

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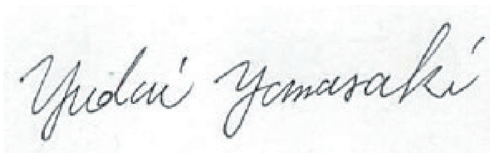

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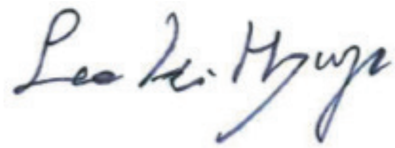

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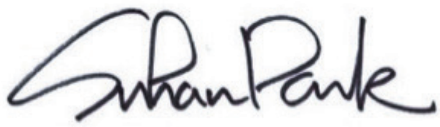

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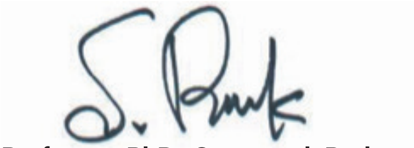

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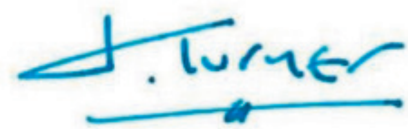

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