Dear Costas, dear distinguished guests, dear colleagues and co-workers,

It is a huge pleasure for me to stand here and to outline the reasons why the Faculty of Biochemical and Chemical Engineering of TU Dortmund has proposed to the Rectorate of TU Dortmund to honour Professor Constantinos. C. (or short Costas) Pantelides with the title of Dr.-Ing. honoris causa. The faculty is extremely happy that the Rectorate approved the proposal on May 22, 2019, and that we can, in a few minutes, hand over the certificate to Professor Pantelides and celebrate with him. So, let me say a few words about Professor Costas Pantelides' career and his achievements. Professor Pantelides was born in 1959. He obtained his Bachelor degree from Imperial College London in 1981 and a Master Degree from MIT in 1983. Then he returned to Imperial College to work on his PhD under the guidance of the founder of the field of Process Systems Engineering, the late Professor Roger Sargent. He obtained the PhD in 1985 for the thesis "Symbolic and numerical techniques for the solution of large systems of nonlinear algebraic equations". The title sounds like being applied mathematics rather than chemical engineering, but the focus was on the numerical simulation of large models of chemical production processes. In contrast to the situation today, the modelling and simulation of chemical production processes, also known under the headline of "flowsheet simulation" at that time was not yet a standard technique applied day in day out in the chemical industry in process development and revamping, and with numerous software vendors offering modelling and simulation environments. The equation-based flowsheet simulation package Speed up that was developed at Imperial College by the group of Roger Sargent, including Costas Pantelides at that time was one of the pioneering developments in this domain. It was widely used in industry and taken over by AspenTech under the name of Aspen Custom Modeller. Modelling, numerical simulation, and optimization have been the core areas of the work of Costas Pantelides from 1981 on. He laid the foundations for the solution of several fundamental problems in these domains. His developments are still up to date and are in widespread use. The related papers receive numerous citations every year. One of the most important early contributions of Costas Pantelides concerns the dynamic simulation of complex processing systems, for example heat-integrated distillation columns. The dynamic modelling of such processing systems leads to so-called systems of differential and algebraic equations, in short DAEs. Two main reasons for the models be-coming DAEs are the description of the thermodynamic equilibria which leads to systems of algebraic equations which often cannot be solved explicitly, and the connection of different pieces of equipment by flows of energy and material that yield coupling equations of the individual models which again are algebraic and not differential in nature. Naively, one might think that algebraic equations are much simpler "beings" than differential equations. However, when added to differential equations, they can change the nature of the game and make the initialization and the solution of the models much more involved. A key contribution of Costas Pantelides is the so-called Pantelides algorithm for index reduction. It is based on a graph that represents the occurrence of variables in equations and determines the equations that are derived to arrive at an index 1 system which can be solved numerically in a reliable fashion. The algorithm is used since then in a large number of DAE packages and process simulators. The corresponding paper appeared in 1988 in the SIAM Journal on Scientific and Statistical Computing, and it has

been cited in papers from a broad range of fields, showing its relevance far beyond the domain of Process Systems Engineering. In the following years, Costas Pantelides, being a Lecturer and Senior Lecturer at Imperial College, together with his students made persistent contributions to three areas. Two of them concern the modelling, simulation and optimization of dynamic systems with discrete changes of inputs and states. An obvious example for such systems are batch processes in chemical and biochemical production. A batch is started at a certain point in time, it is executed step by step as described by a so-called recipe. The recipe defines different stages of the process which start and end at certain times or when certain conditions are met. The physical quantities are usually continuous from one stage to the other, but, caused by modelling abstractions, they may also jump, e.g. if the addition of a substance is considered to take place instantaneously so that the volume and the concentrations jump at a certain point in time. Adding such discrete transitions to continuous dynamic models gives rise to hybrid systems which are much harder to analyse and to simulate than purely continuous systems. In the industry, batch processes are executed one after the other or in parallel on a certain set of pieces of equipment, reactors, filters, homogenization vessels, filling stations etc., with cleaning steps in between. The different steps of the processes may also require other resources, e.g. manual actions by operators. The goal to produce certain amounts of different products until certain due dates as efficiently as possible leads to the topic of batch scheduling, i.e. to decide on the splitting of the production orders into batches, the allocation of resources to these batches, and the sequencing and timing of the operations that are needed to produce the different batches. Often intermediate products are produced and must be stored, and there may be restrictions on the storage, in terms of capacity and duration. With Emilia Kondili, Nilay Shah and Roger Sargent, Costas Pantelides developed the so-called state-task network formulation of batch production planning and scheduling problems which has become the most used formalism for the modelling and mathematical solution of scheduling problems in Process Systems Engineering. Their work included also the transformation of the STN model into a mixed-integer linear program. Costas Pantelides generalized it shortly after the first publications to the resource-task network, which treats all kinds of resources uniformly. The STN and RTN formalisms have been used broadly in the solution of planning and scheduling problems since then. As mentioned before, modelling the dynamics of batch processes leads to hybrid systems. At that time, the modelling, simulation, verification and optimization of such hybrid systems was one of the hottest areas in systems and control engineering. With Paul Barton, Costas Pantelides developed the first process simulator, called gPROMS, that can adequately represent and precisely simulate processes that exhibit such abrupt changes. To simulate such hybrid systems comes with a lot of challenges, from the definition of suitable formalisms to represent them in a general fashion to the numerical solution of switched systems of DAEs.

Thirdly, with Vassilios Vassiliadis, Costas Pantelides developed one of the first and still widely used approaches to optimize the trajectories of dynamic models of processing systems, using what is now called single shooting and control vector parametrization. One of the external evaluators of the proposal to award Costas the Dr.-Ing. h.c. degree called it the “gold standard” in this area. So until 1996, Costas Pantelides had already made a large number of lasting fundamental contributions to the discipline of process systems engineering. Consequently, he was promoted to Professor at Imperial College in 1996. He could have continued the usual path of academic life, supervising some of the best PhD students in the world, writing influential papers, travelling to conferences, being invited to plenary lectures, etc. However, his ambitions were higher. In 1997, together

with Sandro Macchietto, Nilay Shah, and Stratos Pistikopoulos, all well respected leading contributors to the field of Process Systems Engineering, he founded the company PSE Ltd. with the goal to transfer the leading-edge technologies that he and his co-founders had developed to the process industries. One of his co-founders told me that it was quite a lengthy process to get the consent of Imperial College to this endeavor. A quote from the senior management of Imperial College was “what do you know about commercialisation? You’re just a bunch of academics!” Finally, they got PSE Ltd. started in January 2007, selling licences of gPROMS being the first source of income. I remember well that at that time, we all had the hope that batch scheduling, supply chain optimisation, and systematic design of logic controllers, all part of the portfolio of the founders of PSE Ltd. and also re-search interests of the DYN group at that time were also candidates for take-up by industry. However, this turned out to happen only slowly, if at all. So PSE Ltd. focused on process modelling and simulation, starting from the modelling language, simulation engine and optimization capabilities of gPROMS. Over the more than 20 years since its foundation, PSE Ltd. has not only survived, which already would have been a success, but has grown to a company of around 180 people with offices all over the world, serving leading companies of the process industries worldwide by providing tools and support for process modelling and modelbased process development and operational excellence. PSE nowadays offers a wide range of tools, model libraries and support for process modelling, all building on equation-based rigorous modelling with the simulation engine of gPROMS as the core. It provides state-of-the-art modelling, simulation and parameter estimation capabilities, not only for standard fluid processes but also for formulated products, and specific solutions for CCS, flaring systems, wastewater treatment, systems-based pharmaceutics, and others, implementing innovative and leading edge technologies. In 2007, PSE Ltd. won the Royal Academy of Engineering’s MacRobert Award, presented by HRH Prince Philip Duke of Edinburgh. The MacRobert Award is the UK‘s most prestigious prize for innovation in engineering. It is awarded annually for the demonstration of engineering excellence and innovation with proven commercial outcomes and bene-fits to the community. Costas Pantelides first was the Technology Director of PSE, and since January 2005 he has been the Managing Director and the master mind be-hind both the development of the technology base and the growth of the company. He passionately advocates a fully rigorous, bottom-up approach to process modelling, and, based on such rigorous models, to process de-sign and optimization. I believe that it is a great vision that will gradually become true and will not be replaced - but complemented - by “machine learning” for many reasons that would take too long to outline here. PSE has continued to invest a large fraction of its income into the further development of their technologies to help industry to improve the efficiency of their plants and processes of the chemical, pharmaceutical, and bio-tech industries, fool processing, oil and gas, electric power generation, CO_2capture and utilization, etc. As researchers in engineering science, we all want to see the results of our work being applied. Not necessarily all of them, not all of them immediately, sometimes they are not mature enough, sometimes there are obstacles beyond our control, sometimes the waves of hypes and fashions go in other directions and we have to be patient. But this should be an important goal, beyond the equally important education of the engineers of tomorrow - and of their educators, and beyond enjoying the intellectual pleasure and the fame that come with great theoretical or experimental results. Applications only happen if there is a business interest or a societal interest that translates into the investment of company money or public money. Sometimes we are lucky to experience that some company, technology provider or end user, quickly picks up the results of our work. Often, however, this does

not happen, not matter how brilliant our ideas may be. Thus creating a startup to make the ideas fly is on the agenda. To create a stable, world-wide active and recognized company that successfully transfers cutting edge technology to industrial practice in my view is a great engineering achievement. It takes more than extraordinary engineering minds. Those who consider making this step quickly become aware of the many issues that one has to deal with. Starting and developing a company requires a business strategy, salesmanship, eloquence, sometimes hiding difficulties and making promises which are not easy to meet. Scientists may frown on such activities, but to transfer technology to the industry by running a successful technology-driven enterprise that continues to innovate at a fast pace has a tremendous impact, and this is what we honor Costas Pantelides also for today. His work, both in fundamental research and in technology development and commercialization, has earned Costas Pantelides numerous honors, e.g. becoming a Fellow of the Institution of Chemical Engineers in 2009 and of the Royal Academy of Engineering in 2010. In 2015 he was the second winner of the Sargent Medal of IChemE that was introduced to recognise a major contribution to research in the area of computer-aided product and process engineering. After having moved from academia to the Managing Director of an innovation-driven business, Costas Pantelides has however not left the academic world. He remained also a re-searcher on fundamental topics at Imperial College. In recent years, his interest focused on the prediction of crystal structures, where the group from Imperial College is at the forefront of the worldwide research, as documented by the successful participation in competitions and by highly cited publications. In conclusion, for more than 30 years, Professor Costas Pantelides has been one of the worldwide leading scientists in Process Systems Engineering and at the same time he has successfully established a tech-nology-driven enterprise that has developed a set of excellent tools for model-based process engineering and is recognized as a world-wide technology leader. As our external evaluators of the proposal of this honorary doctorate have concluded, his achievements in the combination of basic leading-edge engineering research and providing advanced tools and support to the process industries are unique in the world. We are very happy that we are able to honor him today with the degree of Dr.-Ingenieur honoris causa. Please join me in congratulating him.