

THE DANISH NATIONAL RESEARCH FOUNDATION
2023 PUBLICATION

LASTING VALUE FROM DNRF CENTERS OF EXCELLENCE

THEME REPORTS FROM THE DANISH NATIONAL RESEARCH FOUNDATION - RESEARCHERS' PERSPECTIVES ON CONDITIONS OF RESEARCH

Close contact with its grant holders is part of the Danish National Research Foundation's DNA. Annual follow-up meetings at the sites of each grant holder are a way of supporting the ambitious research centers through continual dialogue. At the meetings, the DNRF takes the opportunity to interview the center staff about how they view the broader issues that are directly consequential to the continued well-being of research and researchers.

Themes emerging from these interviews are collected in the annual meeting publications. In this way, researchers' perspectives become available to other stakeholders in the Danish research landscape who share the ambition of promoting Danish research and innovation. The 2023 annual meeting publication is different in that it gives perspectives from former center leaders and others from former centers.

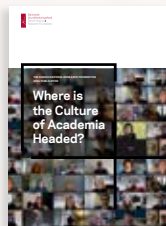
ABOUT THE DANISH NATIONAL RESEARCH FOUNDATION (DNRF)

The DNRF funds Danish basic research in all academic fields with the potential of becoming world leading. This is achieved mainly through flexible, long-term funding in the form of Centers of Excellence led by top scientists.

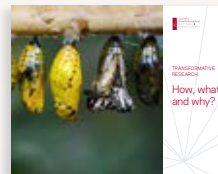
PREVIOUS THEME REPORTS



**Digitization
and FAIR data
2022**



**The Culture
of Academia
2021**



**Transformative
Research
2019**

*Editor: Morten Andreassen
August 2023*

*Danish National
Research Foundation
1057 Copenhagen K*

*T: +45 3318 1950
E: dg@dg.dk
www.dg.dk*

CONTENT

PREFACE	4
Like ripples in water	

INTRODUCTION	6
Lasting value from DNRF Centers of Excellence	

CASE 1 QUANTUM SCIENCE AND -TECHNOLOGY	16
The Danish National Research Foundation's imprint on Danish quantum science	

CASE 2 ECONOMY	28
Top economic research behind GreenREFORM and the Wage Structure Commission	

CASE 3 CATALYSIS AND POWER-TO-X	38
Capacity building for 30 years	

Preface

LIKE RIPPLES IN WATER

With this publication, we show how the long-term investment in Centers of Excellence over the past 30 years has created the basis for top-class research and breakthroughs internationally and at the same time created lasting value in society in the form of, for example, building capacity in areas that later proved to be particularly important to society. Capacity that the DNRF Centers of Excellence were, obviously, not alone in building, but their contribution is extraordinary in some fields.

The publication is based on studies of the lasting value that arose from the earliest rounds of Centers of Excellence that ceased operations over 20 years ago, as well as the conditions for the value they created.

The results provide food for thought.

First, we note that the value created by the centers is startling. It is value that over the years has spread like ripples in water and has made a decisive contribution to the fact that Denmark today belongs with the world elite in research areas such as catalysis and quantum science. Thanks to visionary researchers, we started capacity building in Denmark in a number of fields long before their prospective importance became so clear that everyone began heavily investing in the development of science and technology areas linked to the development of, for example, power-to-X and quantum computers. In a similar way, the economic researchers in early DNRF Centers

of Excellence were pioneers in the development of robust models behind economic policy and labor market policy.

These are examples that we go into in-depth in this report, but several other subject areas could be mentioned.

Second, we find that the conditions that applied to a Center of Excellence are perceived by the researchers as largely ideal and decisive for these results, also seen from a distance of 10 or 20 years. It is essentially the same conditions that apply to a DNRF Center of Excellence today, that is, trust-based and flexible long-term financing of ambitious and interdisciplinary projects.

At the same time, we find it logical and thought-provoking that the long-term societal value of the work of Centers of Excellence is so significant, given that the foundation does not demand that the results of the centers' research have immediate applications. For us, it confirms a presumption that talented basic researchers choose to work on important questions, even when the outside world cannot yet see their relevance.

The publication sheds a well-deserved light on researchers and their work – work that has contributed to society's progress to the highest degree, mostly outside the limelight.

Thanks to the The Danish Centre for Studies in Research and Research Policy at Aarhus University for contributing a thorough report on the three earliest rounds of Centers of Excellence (1993-2005), which can be found on dg.dk/en/impact. And not least thanks to the many previous center leaders and others who have contributed to the DNRF's mapping.

The report was drafted by the DNRF secretariat.

Enjoy your reading.

Søren-Peter Olesen, CEO
Morten Andreasen, senior adviser

Introduction

LASTING VALUE FROM DNRF CENTERS OF EXCELLENCE

The effects of basic research on society are often subtle and long term. Even when basic research has had transformative significance, it can be difficult to spot the contributions it makes to, for example, solving current challenges, promoting new technology or creating a basis for perhaps medical or political decisions. These contributions may have been made long before their relevance was clear to outsiders.

This means that it can be difficult for politicians to assess how they should prioritize long-term basic research or research with a focus on current needs. This also means that mapping the contributions of basic research to society requires more than a quick glance.

The Danish National Research Foundation continuously monitors the value created by its Centers of Excellence, value that grantees contribute in the form of research, talents, innovation and consultancy, among other things. But when we talk about an assessment of basic research's contribution to major technological breakthroughs or to the building of a national position of strength, even a time frame such as the ten years that make up a center's

“ *Long-term investments in high-level basic research deliver a surprising amount of value within the societal challenges of any given time, even if the researchers were never asked to do so, and even if the practical value was often unclear when the research was initiated.*

lifetime is often too short. A large part of the value created comes to light long after the foundation has stopped following the centers' activities.

This is the reason why, in the past year, the foundation has taken a closer look at the value that becomes apparent after the grants expire. We have done this in two different ways:

- **Long-term value created by the early Centers of Excellence**

First, the foundation has initiated an external research-based study of the long-term value created by the earliest Centers of Excellence. These centers ceased operations up to 20 years ago. The investigation provides insight into the achievement of goals in relation to the foundation's purpose, uncovers connections between the results and the conditions created by the Center of Excellence format and outlines opportunities for improvement. Read more below.

- **Lasting value in socially important areas: Cases**

Second, the foundation itself has looked at, how former centers within areas that are today considered to be important to society have contributed to building the necessary capacity in these areas. These cases can provide an insight into the potential of investing in the quality of research compared to funding primarily based on current societal needs. The cases were elected because of their obvious contribution to societal challenges, but they are but examples. Other Centers of Excellence have produced equally impressive results over the years, such as within bioinformatics, astrophysics or health research.

What is the role of DNRF Centers of Excellence?

The results of the analysis must, of course, be understood on the basis of the premises and purposes that apply to the specific Centers of Excellence. These centers constitute the main instrument of the Danish National Research Foundation, whose purpose is to promote research and talent at a high international level.

DNRF Centers of Excellence are established for up to 10 years, divided into two grant periods of six and four years, respectively. (Previously, grant periods were divided into 5 years plus up to another 5 years). From the start, the idea has been to award a center grant to the best researchers and research teams with the best and most demanding ideas. The success rate for the last five rounds (2012-2022) was approximately 6.4%.

[See overview of active Centers of Excellence](#)

The Center of Excellence format has proven to be an appropriate framework for outstanding research, also called excellence. In the words of the Danish Council for Research and Innovation Policy (DFiR), "Excellence in research must not only benefit the research area in question, but the entire research system - and the country. The best pull the overall research performance upwards and increase the research's influence, impact and the general culture of quality."¹ In other words, there is an expectation that excellent research manages to raise the level in a lasting way, both within and outside the given research area.

DNRF Centers of Excellence are characterized by:

- Being led by researchers who are well-regarded and have considerable experience or are deemed to be able to quickly grow into the task.
- Having relatively many years available to deliver results, that is, considerably more long-term and more in-depth work can be done than most other research grants allow.

¹ Viden i Verdensklasse – hvorfor klarer dansk forskning sig så godt?
The Danish Council for Research and Innovation Policy. The Danish Agency for Research and Innovation, 2016

- Having wide room for maneuvering, that is, the freedom to use the grant optimally, including taking advantage of the opportunities to go in new, promising directions that arise along the way.
- Fostering interdisciplinary work, since the center forms the framework for new constellations of researchers who together examine a problem across conventional subject and institutional boundaries.

It follows from the foregoing that a crucial prerequisite for the establishment of successful Centers of Excellence is the universities' ongoing development of skilled researchers, with support from Independent Research Fund Denmark and other funds that promote research at all levels.

The center construction has proven to form a framework not only for discoveries and the development of theory, but also for the development of inventions, some of which are commercially interesting, while others create value in society in other ways. The foundation finds that this actively has especially gained momentum in the last two decades. For example, in the past ten years, the centers were involved in 11% of all spinoffs from public institutions, even though they only consume approx. 0.6% of the total research budget (2012-2021). Even if taking additional funding from the universities and other funds into account, it demonstrates that the centers are very active suppliers of practical ideas, which are often further developed with support from e.g. Innovation Fund Denmark.

Ideal conditions for research

Looking back at the 20 years since some of the centers closed, former center leaders and young researchers from the earliest three rounds of Center of Excellence grants describe their time in a DNRF center as an exceptionally productive and creative period, with close to ideal conditions in which to conduct good research and to develop as a young researcher. This appears in the report that the Center for Research Analysis at Aarhus University has prepared for the Danish National Research Foundation. The study covers the first three rounds of Center of Excellence grants (1993-2005) and involves a survey, interviews and an output analysis.

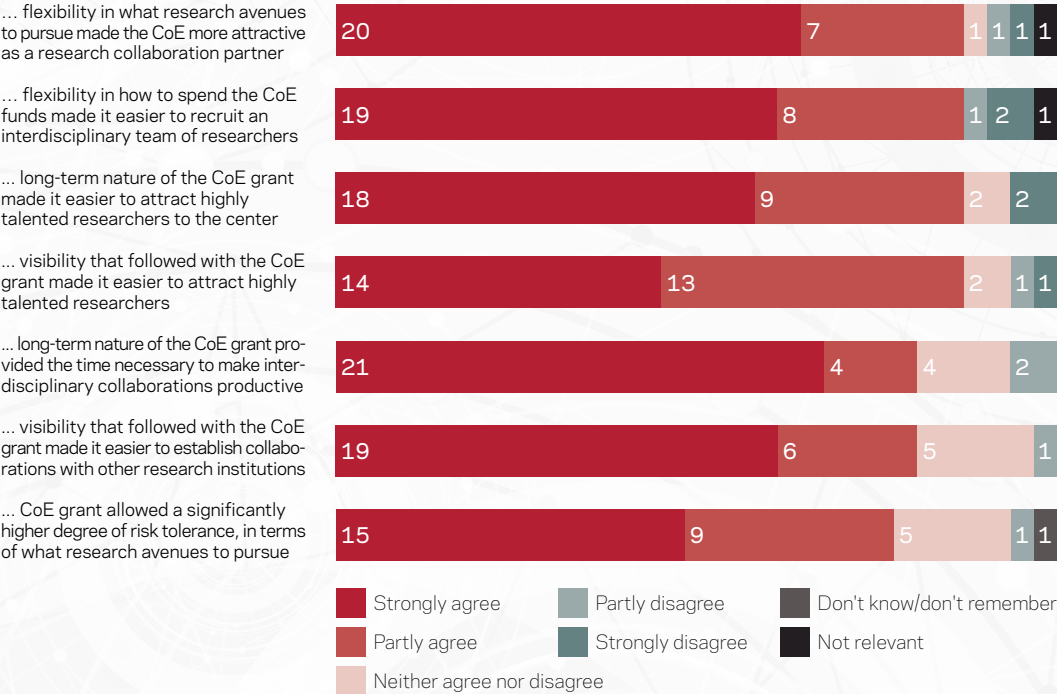
The report, which has examined the research's impact right up to the present day, shows that the academic results the centers created over the intervening period stand undiminished. Even by the most demanding definitions, some centers have been pioneers and have created breakthroughs, as well as new fields and methods that have today been adopted globally. Most famous among these is Morten Meldal, who in 2022 won the Nobel Prize for the development of so-called "click chemistry" on the basis of research in his Center of Excellence 20 years ago. Today, his discovery is used in the development of drugs and materials. The report shows that many other centers were excellent when measured in terms of breakthrough articles, citation impact or top 10 most cited articles.

According to researchers interviewed, the results can be largely attributed to characteristics of the Center of Excellence format, such as stability, visibility, flexibility and risk tolerance and the conditions this format created, such as opportunities for new collaborations and improved recruitment. These conditions promote the possibility of carrying out more demanding projects, and the researchers not least highlighted the good conditions for interdisciplinary work. The study thus indicates a clear connection between the centers' results and the conditions created by the DNRF Center of Excellence format and also emphasizes the advantages of the centers' close dialogue with the foundation. Both the format and the close dialogue are still central elements in the foundation's work.

"The flexibility made it much easier to use the funding optimally and get the best candidates. The length and size made it possible to take risks that I would not have been able to take with conventional funding"

Quote from respondent from an early Center of Excellence²

**Please indicate to what extent you agree with the following statements.
Compared to other funding that were available at the time, the ...**



Description of different conditions for research in DNRF Centers of Excellence, compared to alternative funding, from former center leaders and others.²

Although the expectations from the foundation, the universities and society in general during the period (1993-2005) were relatively narrowly focused on academic quality, approximately half of the centers answered that inventions they made are still in use in Danish companies, and a similar proportion applies to the public sector. In addition, there is the development, e.g. of new

² Alnor, Schneider and Degn (2023): Centers of Excellence from the Danish National Research Foundation 1993-2005 Report from The Danish Center for Studies in Research and Research Policy, Aarhus University.

methods or instruments that support innovation, even if they do not count in publications or innovation statistics.³

Nevertheless, there is much evidence that the most important long-term contribution of the early centers has been their production of talent. The report sheds limited light on this aspect; however, the examples described below elaborate further.

[Find the report here.](#)

Capacity building in socially important areas: Cases

Societal challenges and global crises take up a lot of the media's and politicians' agenda these days. Now that we have put the coronavirus crisis and its urgent need for action behind us, the climate crisis remains as the overriding challenge. And yet it is just one crisis among many.

Lack of knowledge is a fundamental challenge for the green transition. This applies not least in the area of energy, where the transformation of the global energy system away from fossil fuels is extremely demanding. This is the background for the extensive investments in the development of power-to-X technologies. One of the major challenges here consists of finding ways to scale up already well-known technologies, so that it is logistically and economically realistic to produce green fuels in the large quantities needed. Not least, this requires new materials that must be used as catalysts in the process. In the words of the researchers, the solution requires a look into "deep chemical space."

This presupposes one absolutely crucial thing, namely, capacity. In Denmark, we are lucky enough to have world-leading researchers in crucial research and technology areas, and Denmark is therefore prepared to take up the challenge.

³ Find further examples of methods and instrument development in Centers of Excellence within fields such as quantum science, economics and finance in the publication *[Curiosity Benefits Society](#)* (2021).

But, of course, preparedness is not all about luck and chance. The readiness is largely due to the presence of visionary researchers and to the presence of strong professional environments, built up over many years, thanks to far-sighted choices and investments at the universities and foundations. Such activities may live a quiet life for decades, far from the attention of the media and politicians—right up until a crisis arrives.

Read about the contribution by Centers of Excellence to building capacity within power-to-X (page 38)

Readiness is similarly important in the context of new technological opportunities. The quantum computer is an example of the technological and societal leaps that, in order to be successful within a relatively short time horizon, require an acceleration of technological development. Today, there is a widespread belief that it will be possible to create a quantum computer that can be used to solve very demanding calculation tasks for practical and research purposes, as there will soon be physical limits to the development of current semiconductor-based computer technology. In 2022, in fierce competition, the Niels Bohr Institute succeeded in attracting NATO's Center for Quantum Technology, showing that Denmark punches well above its weight class in this area as well. Here again, a significant part of the explanation can be found in the visionary and excellent Danish research environments that have grown up over the past decades outside the media spotlight – which meant that Denmark was qualified to participate in the competition for the NATO center and ultimately to take part in the development of the technology.

Read about the contribution by Centers of Excellence to building capacity in quantum technology (page 16)

How do Centers of Excellence contribute to solutions to societal challenges?

In other words, one cannot decide, overnight, to compete in fields such as power-to-X or quantum science, since this requires an environment that is at

the forefront and that can deliver research and talent at the top level. This raises the question of how to build such environments.

The development of such environments was the intention of the DNRF Centers of Excellence from the beginning, when the format was introduced 30 years ago. Repeated evaluations have shown that the combination of long-term funding, the often interdisciplinary and targeted organization of work with ambitious and original ideas and, not least, skilled center leaders and teams generates creative and productive environments.

The two examples already mentioned lie within current high-profile areas that also hold commercial potential. But one of the things that ensure a very high level of quality in DNRF-financed research is that the selection takes place without consideration of area. This also means that capacity is built in areas that create societal value in non-commercial ways. The Danish development of leading research within public economics, which then led to, among other things, the development of the DREAM and GreenREFORM calculation models, started with a Center of Excellence in 1993 and offers an example of permanent non-commercial value created by a center.

Read about the contribution by Centers of Excellence to building capacity within economics (page 28)

In the following, we show examples that former DNRF Centers of Excellence, despite their relatively limited consumption of research funds, have made a decisive contribution to the building of capacity and the delivery of lasting value to society in socially important areas.

The selected cases show that long-term investments in high-level basic research deliver a surprising amount of value within the societal challenges of any given time, even if the researchers were never asked to do so, and even if the practical value was often unclear when the research was initiated. It is in our view an exciting and important point in a time, when society asks everyone to contribute with solutions to current societal challenges.

The background of the slide is a complex, abstract pattern. It features numerous concentric circles of varying shades of gray, some solid and some outlined. Overlaid on these circles is a network of thin, light-gray lines that connect small, semi-transparent circular nodes. The nodes and lines are distributed across the entire frame, creating a sense of depth and connectivity, reminiscent of a molecular structure or a data network. The overall color palette is monochromatic, using various tones of gray and white.

“

Looking back at the 20 years since some of the centers closed, former center leaders and young researchers from the earliest three rounds of Center of Excellence grants describe their time in a DNRF center as an exceptionally productive and creative period, with close to ideal conditions in which to conduct good research and to develop as a young researcher.

Case 1

Quantum science and -technology

THE DANISH NATIONAL RESEARCH FOUNDATION'S IMPRINT ON DANISH QUANTUM SCIENCE

Danish quantum science stands strong in international competition, and it is an area in which discoveries will lead to a multitude of applications. This applies, for example, to energy supply, medical development, communication and, not least, the development of quantum computers; the latter a field in exponential development.

The strength of Danish quantum science is based on many years of capacity building at the Danish universities. The DNRF has contributed to this stronghold, since the foundation helped to finance the first major investments in the

“second quantum revolution” starting at the beginning of the 2000s, where the field started moving, until today, where the many activities bear witness to a field that is growing and gaining increased attention.

There are numerous examples of how the results from Danish basic research in the quantum field can now be put to further use: In 2022 NATO chose to place a new center at the University of Copenhagen for the development of quantum technology, and in 2023 the Novo Nordisk Foundation granted almost 1.5 billion DKK for a large collaborative project anchored at the University of Copenhagen for the development of Denmark’s first functional quantum computer. Innovation Fund Denmark also has plans for large investments in the area, and in June 2023 the government published a national strategy for quantum technology, which, among other things, contains a plan for research and innovation within the area and with a goal of spending at least a further DKK 1 billion over the period 2023 to 2027.

These are initiatives that stand on the shoulders of the basic research in quantum science that the DNRF has contributed to building. The first DNRF quantum center was established back in 2001. In 2009, the foundation gave grants to two new quantum centers and later the foundation funded additional centers, so that today there are seven active centers continuing the necessary broad investment in basic research within quantum science.

On the following pages, you can read more about the DNRF’s quantum centers and many of the ways in which they have contributed to bringing the quantum field to the position that it holds today. The greatest contribution from the DNRF centers is the many talented researchers who have passed on their knowledge in the Danish and foreign quantum environment, both at universities and in industry.

OTHER CENTERS AND PROGRAMS

- Centre for Quantum Mathematics, SDU (2019-) Jørgen Ellegaard Andersen
- Quantum Field Theory Center, SDU (2023-) Francesco Sannino

ATTRACTION OF HIGH-PROFILE GUEST RESEARCHERS

- Maxim Kontsevich (Fields medal 1998, Crafoord Prize 2008, Shaw Prize 2012)
- Ignacio Cirac (Franklin Medal 2010, Wolf Prize 2013)
- Nicolai Reshetikhin (DNRF Niels Bohr guest professor, 2006-2011)

INNOVATION & CONSULTANCY

BSMBench - a flexible and scalable super computer benchmark from calculation-based particle physics

Andersen-Kashaev TQFT and Andersen-Ueno isomorph with applications in topological quantum computing

Continual consultancy of the EU, ERC, US Department of Energy, and others

SPINOFF COMPANY

- Qpurpose ApS (2022-) CEO Jørgen Ellegaard Andersen

FORMER CENTERS OF EXCELLENCE:

- Center for Quantum Optics
Eugene S. Polzik (2001-2011)
- Center for Quantum Geometry of Moduli Spaces
Jørgen Ellegaard Andersen (2009-2019)
- Center for Cosmology and Particle Physics Phenomenology
Francesco Sannino (2009-2019)

LATER DNRF CENTERS OF EXCELLENCE

- Quantum Devices (2012-2023)
- Silicon Photonics for Optical Communication (2015-2025)
- Hybrid Quantum Networks (2018-2028)
- Macroscopic Quantum States (2018-2028)
- NanoPhotonics (2020-)
- Complex Quantum Systems (2020-2023)
- Polariton-driven Light-Matter Interactions (2023-)

CAPACITY BUILDING

- Education of about 113 PhDs and 81 post-docs
- Basic physics and mathematics research underpinning the development of quantum-based technology
- New courses at BSc, MSc and PhD level, within high energy physics and quantum mathematics, among others
- Buildup of physics education at SDU
- Buildup of the geometry group at AU

PRESTIGIOUS GRANTS

- Eugene S. Polzik: ERC Advanced grants (2011 og 2017)
- Jørgen Ellegaard-Andersen: ERC Synergy grant (2018); Simon Foundation Collaboration grant (2023)
- Francesco Sannino: Carlsberg Foundation Semper Arden Advance (2022)

“

The early DNRF centers have been absolutely decisive for quantum science becoming an area of competence in Denmark and for world-leading researchers to be recruited to the Danish universities within this area. The large investments we are now seeing in quantum technology and the political support and understanding that Denmark has a very strong position and can measure up to some of the strongest international environments can be directly related to some of the DNRF's forward-looking investments.

Professor Peter Lodahl, head of the Center for Hybrid Quantum Networks, University of Copenhagen

“

We did not anticipate so many new directions - Microsoft, Novo Nordisk, Innofund, ERC Synergy, Quantum Machines, QDevil - but we have certainly not lost sight of the fact that it was DNRF that got this big quantum snowball rolling.

Professor Charles Marcus, previous center leader, Center for Quantum Devices, University of Copenhagen

CENTER FOR QUANTUM OPTICS (QUANTOP)

*University of Copenhagen and Aarhus University
(2001-2011)*



Center manager Eugene S. Polzik

Co-Principal Investigators Klaus Mølmer, Michael Drewsen, Michael Budde, Jan Arlt, Joerg Helge Müller, Anders S. Sørensen, Michael Wolf

THE CENTER MANAGER

Eugene S. Polzik is a professor of physics at the Niels Bohr Institute at the University of Copenhagen. Polzik has received many national and international awards and recognition for his research over the years: in 2007 Scientific American named him among the top 50 researchers for his work on quantum teleportation. In 2020 he received the Herbert Walther Award. Polzik has also served as a member of the steering committee of the EU's quantum technology flagship launched in 2018.

THE CENTER'S RESEARCH

QUANTOP started as a Center of Excellence in 2001 at Aarhus University with research focused on quantum effects at the interface between light and matter and was the first major Nordic research center in modern quantum physics. The center has contributed to some of the decisive steps in the development of future quantum technology and has helped to put Denmark on the world map within quantum information. The forward-looking research in quantum optics and quantum information and many major scientific breakthroughs

The center has contributed to some of the decisive steps in the development of future quantum technology and has helped to put Denmark on the world map within quantum information.

have repeatedly attracted international attention, for example, when it was possible, for the first time ever, to transfer information between two small gas containers using quantum teleportation. The DNRF grant ended in 2011, but with Polzik as the leader, the center is still active thanks to several large grants from the ERC and the Villum Foundation.

TALENT

In its lifetime, the center trained 32 Ph.D.s and 31 post-docs. It also engaged in over 40 different educational activities.

Examples of new research leaders emerging from the center:

- Anders S. Sørensen
(Professor, University of Copenhagen - co-PI Hy-Q)
- Jonas S. Neergaard-Nielsen (Associate Professor, DTU - co-PI bigQ)
- Jonatan B. Brask
(Associate Professor, DTU - bigQ)
- Ulrich B. Hoff
(Senior Advisor, DTU - bigQ)
- Brian Julsgaard
(Associate Professor, AU)
- Jacob Sherson (Professor WSR, AU)

CENTER FOR QUANTUM GEOMETRY OF MODULI SPACES (QGM)

Aarhus University (2009-2019)

Center manager Jørgen Ellegaard-Andersen

Co-Principal Investigators Cristiano Spotti, Artan Sheshmani, Gergely Bérczi, Robert C. Penner, Marcel Bökstedt, Andrew Swann, Sergey Arkhipov, Henning Haahr Andersen, Alexei Venkov



THE CENTER MANAGER

Professor Jørgen Ellegaard-Andersen is a world leader in quantum mathematical research, and his groundbreaking results include the Andersen Asymptotic Faithfulness, the Andersen-Ueno isomorphism, and the Andersen-Kashaev TQFT, all of which have profound implications for topological quantum computing. He is an extremely active researcher and is among the few who have published in the three largest international mathematical journals, in addition to many other top journals, in the field of quantum

topology. He simultaneously holds an ERC-Synergy Grant and a Simons Foundation Collaboration Grant, an achievement that is unique. In 2019, he was recruited by SDU to spearhead the establishment of the Center for Quantum Mathematics, which already houses more than 30 international top researchers. He has since formed the spinoff company Qpurpose, which services a large number of Danish C25 companies by solving their most difficult optimization problems via a combination of classic HPC and quantum computing.

THE CENTER'S RESEARCH

QGM had a broad focus on expanding the mathematical basis of the quantum field theories and contributed in a pioneering way to the development of that basis using the latest advanced geometric, topological and algebraic techniques for a number of special quantum field theories. In close collaboration with international researchers, the center built up its status as an innovative and highly respected research group that delivered many groundbreaking results at the interface between mathematics and theoretical physics. The far-sighted research helped to move the understanding of quantum mathematics to a position, where it is possible to put it to use in the development of quantum software for use in areas such as finance, energy, climate and medicine.

TALENT

During the center's lifetime, it educated 54 Ph.D.s and 20 post-docs; 20 of those Ph.D.s are employed in leading positions in Danish C25 companies and 5 of them in leading positions in larger companies in England and the USA. The center developed more than 60 different educational activities and 21 master classes.

Examples of new research leaders emerging from the center:

- Cristiano Spotti
(Professor, AU, Villum YI+)
- Laura Schaposnik
(Professor, Uni. Illinois, Chicago)
- Artan Shishmani
(Full Research Fellow, Yanqi Lake Beijing Institute and Senior Member at CMSA, Harvard, Sapere Aude)
- Gergely Berczi (Lecturer, AU)
- Du Pei (associate professor, SDU, Villum YI)
- Alexander Shapiro
(Research Fellow, Uni. Edinburgh, ERC St-grant)

CENTER FOR COSMOLOGY AND PARTICLE PHYSICS PHENOMENOLOGY (CP3)

University of Southern Denmark (2009-2019)

Center leader Francesco Sannino

Co-Principal Investigators Astrid Eichhorn, Mads T. Frandsen, Chris Kouvaris, Claudio Pica, Thomas Rytrov, Martin S. Sloth, Michele Della Morte, John Bulava



THE CENTER MANAGER

Francesco Sannino is an eminent professor of physics at SDU, who in 2010 received the Elite Research Award. During the center's period of operation, he contributed to almost 400 scientific articles (many of which are top cited), and he also developed a new theory: the „Litim-Sannino theory.“ Furthermore, Sannino has also passed on his knowledge of high-energy physics to

a wide audience with great interest. In 2014, Sannino received SDU's communication award. One of many examples is „Kvante-Karina,“ an animated YouTuber who explains quantum and particle physics in easy-to-understand language. Sannino helped establish the Danish Institute for Advanced Study (DIAS) at SDU and is today head of the Quantum Field Theory Center (QTC), also at SDU.

THE CENTER'S RESEARCH

CP3 was established as a completely new research field at SDU: research in fundamental particle physics. The goal was to uncover the origin of the mass for all elementary particles. Before too long the center was internationally recognized and helped to advise the US Department of Energy, the ERC and many others. Among other things, CP3 became known for, with a different theoretical approach, creating the basis for an expansion of the standard model – the basic theory of particle physics. The center was characterized by fostering a creative space for many young researchers and played a decisive role in developing physics education at SDU, as measured by an impressive increase in student uptake for the program. The DG grant ended in 2019, but Sannino's substantial activity has contributed to several larger grants from the Carlsberg Foundation, among others.

TALENT

The center trained 27 Ph.D.s and 30 post-docs. The center contributed substantial educational activity, including 30 graduate courses.

Examples of new research leaders emerging from the center:

- Claudio Pica (Professor and Director, eScience center, SDU)
- Thomas Rytrov (Associate Professor, SDU)
- Chris Kouvaris (Professor, Natl Tec. Univ. Athens)
- Marco Nardecchia (Associate Professor, Roma La Sapeinza)
- Paolo Panci (Associate Professor, University of Pisa)
- Zhi-Wei Wang (Professor, UESTC, Chengdu China)
- Oleg Antipin (Senior Researcher, Boskovic Inst. Zagreb)
- Martin Sloth (Professor, SDU)
- Astrid Eichoorn (Professor, SDU)
- Mads T. Frandsen (Professor and Deputy Head of Department, SDU)

CURRENT CENTERS WITHIN QUANTUM RESEARCH WITH DNRF FUNDING



CENTER FOR QUANTUM DEVICES (2012-2023)

Center leader: Professor Charles Marcus, University of Copenhagen

Research vision: "To create, control, measure and protect quantum coherence and entanglement in solid-state electronic devices."



CENTER FOR SILICON PHOTONICS FOR OPTICAL COMMUNICATION (2015-2025)

Center leader: Leif Katsue Oxenløwe, DTU

Research vision: "Addresses the optical communication infrastructures of the future, in an interdisciplinary approach."



CENTER FOR HYBRID QUANTUM NETWORKS (2018-2028)

Center leader: Peter Lodahl, KU

Research vision: „The long-term perspective of the research is to enable large scale processing of quantum information over global distances."



CENTER FOR MACROSCOPIC QUANTUM STATES (2018-2028)

Center leader: Ulrik Lund Andersen, DTU

Research vision: „To radically advance our understanding of macroscopic quantum effects and to exploit these macroscopic effects for demonstrating quantum supremacy.“



CENTER FOR NANOPHOTONICS (2020-)

Center leader: Jesper Mørk, DTU

Research vision: „To perform fundamental research on light-matter interaction in semiconductor nanostructures and to apply this to realize a new generation of nanophotonic devices.“



CENTER FOR COMPLEX QUANTUM SYSTEMS (2020-2023)

Center leader: Thomas Pohl, AU

Research vision: „Develop theory and experiments to investigate, control and harness the dynamics and collective quantum states of interacting atoms and light.“



CENTER FOR POLARITON-DRIVEN LIGHT-MATTER INTERACTIONS (2023-)

Center leader: N. Asger Mortensen, SDU

Research vision: “Explore and manipulate polaritons in flatland, in engineered meta-surfaces interfacing light-emitting quantum systems or serving as light sources themselves.”

Case 2

Economy

TOP ECONOMIC RESEARCH BEHIND GREENREFORM AND THE WAGE STRUCTURE COMMISSION

In the early 1990s, economic researchers decided to develop new economic models and empirical methods to improve the basis for decision-making within economic and labor politics.

The first three Centers of Excellence in economics led not only to results that resonated internationally, but also to a significant upgrade in Danish politicians' basis for key decisions.

One center developed the foundations for the DREAM model, which became a basic analytic instrument in economic reform efforts (e.g., related to the sustainability of the welfare state). This model is currently being further developed into the GreenREFORM model, which takes into account the environmental and climate effects of policy suggestions.

Another center was a global pioneer in the use of economic register data at the population level. The data used in this center's research was, among other things, behind the work of the Wage Structure Commission.

TALENT

Around 23 PhDs and 12 postdocs, e.g.:

- David Dreyer-Lassen
- Claus Thustrup Kreiner
- Søren Leth-Petersen
- Niels Johannesen
- Michael Svarer
- Carl-Johan Dalgaard
- Mette Deding

ATTRACTION OF HIGH-PROFILE GUEST RESEARCHERS

Dale T. Mortensen (Nobel Prize 2010)
James Heckman (Nobel Prize 2000)

INNOVATION & CONSULTANCY

Dream-model applied since 1998 by the Ministry of Finance and the Danish Economic Councils

Continual consultancy and analysis for ministries

DANISH STRONGHOLDS IN RESEARCH AND EDUCATION

- New courses at BSc, MSc and PhD level, e.g., Public Economics and Integration, Production and Welfare
- New networks, e.g., DREAM-group, Economic Policy Research Network
- Danish research stronghold: Public Economics (UCPH and CBS)

FORMER CENTERS OF EXCELLENCE:

- Centre for Labour Market and Social Research
Niels Westergård-Nielsen (1993-2001)
- Economic Policy Research Unit
Peter Birch Sørensen & Søren Bo Nielsen (1993-2002)
- Centre for Applied Microeconomics
Martin Browning (2001-2007)

DANISH ECONOMIC COUNCILS, CHAIRS

- Carl-Johan Dalgaard ('20-)
- Michael Svarer ('16-'20)
- Hans Jørgen Whitta-Jacobsen ('10-'15)
- Peter Birch Sørensen ('04-'09)
- Torben M. Andersen ('01-'03)

LATER DNRF CENTERS OF EXCELLENCE

Center for Research in Econometric Analysis of Time Series (2007-2016)
Niels Haldrup
> 28 PhDs and 8 post-docs

Center for Economic Behavior and Inequality (2017 -)
Claus Thustrup Kreiner

CENTRE FOR LABOUR MARKET AND SOCIAL RESEARCH (CLS)

Aarhus University (1993-2001)

Center leader Niels Westergård-Nielsen

Co-Principal Investigators Nina Smith, Aarhus School of Business; Peter Jensen, Aarhus School of Business; Peder J. Pedersen, Aarhus University; Henning Bunzel, Aalborg University; Preben Bo Mortensen, National Center for Register-based Research; Tor Eriksson, Aarhus School of Business; Nabanita Datta Gupta, Aarhus School of Business.



THE CENTER LEADER

Niels Westergård-Nielsen, former professor at Aarhus University, now professor at Copenhagen Business School, was among the first economic researchers to work with population-level register data. This research was done in collaboration with Dale Mortensen (Nobel Prize winner in 2010), who was associated with the CLS, and who globally

promoted the unique Danish register research. Westergård-Nielsen has sat on a number of commissions and committees, including as an expert for the Wage Commission set up by the Fogh Rasmussen government in 2008-2010, where CLS contributed with data. The CLS data was also applied in the Wage Structure Commission's work, which was completed in 2023.

... among the first economic researchers to work with population-level register data.

THE CENTER'S RESEARCH

The center was founded on the basis of a long-term collaboration between labor market economists at the Department of Economics, Aarhus University and the Business School in Aarhus. The CLS worked with a wide range of topics, the majority of which were based on empirical studies of longitudinal data from public registers.

The center's work with register data from Statistics Denmark formed the basis for the calculations of countless commissions. It has moved labor market policy toward a more

evidence-based approach. The center succeeded in establishing a department of Statistics Denmark in Aarhus, which paved the way for register researchers at AU to have much better access to relevant data.

During its lifetime, the center created 11 new Ph.D. courses.

TALENT

The center trained 8 Ph.D.s, including:

- Michael Svarer
- Michael Rosholm
- Mette Deding

ECONOMIC POLICY RESEARCH UNIT (EPRU)

University of Copenhagen and CBS (1993-2002)

Center leaders Peter Birch Sørensen & Søren Bo Nielsen



Co-Principal Investigators Svend Erik Hougaard Jensen. Department of Economics, CBS; Pascalis Raimondos-Møller, Department of Economics, CBS and later University of Copenhagen; Niels Thygesen, Department of Economics, University of Copenhagen; Lars Haagen Pedersen, Department of Economics, University of Copenhagen; Henrik Jensen, Department of Economics, University of Copenhagen; Claus Thustrup Kreiner, Department of Economics, University of Copenhagen; Torben Tranæs, Department of Economics, University of Copenhagen.

THE CENTER LEADERS

Peter Birch Sørensen is a professor of economics at the University of Copenhagen. He is an International Research Fellow in the CESifo research network and a member of the Royal Danish Academy of Sciences and Letters. He was previously the chair of the Danish Economic Councils ('overvismand') of the Productivity Commission and of the Climate Council. He has served on several international committees

on public finance and has been an advisor on tax policy for the OECD, the International Monetary Fund, the EU Commission and several governments.

Søren Bo Nielsen (†) was a professor of economics at CBS and previously chair of the Danish Economic Councils. Furthermore, he worked as an economic adviser in Greenland and the Faroe Islands and for the Swedish Ministry of Finance.

THE CENTER'S RESEARCH

EPRU brought together some of the best Danish economic researchers of the time with the aim of strengthening the scientific basis for the assessment of economic policies. One of the center's main contributions was to construct a new model for calculating general economic equilibrium. The model was designed to assess the economic effects of structural economic policy choices, such as tax policy pension policy and labor market policy, and the distribution of the effect of those choices across generations. The model was also used to assess the long-term sustainability of fiscal policy from the perspective of population development.

The model, to whose development EPRU contributed, has most recently resulted in the development of the dynamic GreenREFORM model of the Danish economy. It describes

the effects of economic activity on gas emissions and other pollutants. EPRU research has also contributed to making public economics a Danish research stronghold.

TALENT

The center trained 9 Ph.D.s and 4 post-docs, including:

Carl-Johan Dalgaard (current chairman of the Economic Council)

David Dreyer Lassen (pro-rector, University of Copenhagen).

INNOVATION

The model expertise, for which EPRU created the basis, has most recently resulted in the development of the dynamic GreenREFORM model for the Danish economy. The model describes the effects of economic activity on greenhouse gas emissions and other pollutants. The OECD has highlighted this work as an example for other countries to follow.

CENTER FOR APPLIED MICROECONOMETRICS (CAM)

The University of Copenhagen (2001-2007)

Center leader Martin Browning

Co-Principal Investigators Karsten Albæk, University of Copenhagen; Mette Ejrnæs, University of Copenhagen; Hans Christian Kongsted, University of Copenhagen; Allan Würtz, Aalborg University; Michael Svarer, Aalborg University



THE CENTER LEADER

Martin Browning was a professor at the Department of Economics at the University of Copenhagen until 2006, when he became a professor at Oxford University. He continued to lead the center until 2007 and maintained an association with the Department of Economics. He is a fellow of the Econometric Society and an emeritus member of the European Economic Association. He is a resident of Denmark.

THE CENTER'S RESEARCH

CAM focused on econometrics, that is, studies of how the decisions made by individuals, households, companies, etc., under certain conditions, affect given markets. Microeconometrics has decisively improved economists' ability to come up with qualified suggestions on what happens to supply and demand when, for example, political administrations change fees and taxes. The interest in

Microeconomics has decisively improved economists' ability to come up with qualified suggestions on what happens to supply and demand when, for example, political administrations change fees and taxes.

microeconomic models in economics is large and growing.

CAM made particular use of the Danish register data, the quality of which gave the researchers the opportunity to make important contributions to internationally debated research questions.

TALENT

The center trained 11 Ph.D.s and 8 post-docs, including Mette Ejrnæs, professor at the University of Copenhagen and a member of the chairmanship of the Economic Council.

CURRENT CENTERS WITHIN ECONOMIC RESEARCH WITH DNRF FUNDING



CENTER FOR ECONOMIC BEHAVIOR AND INEQUALITY (2017-)

Center leader: Claus Thustrup Kreiner, University of Copenhagen

Research vision: „To understand what role behavior has in the formation of different outcomes across people.“

“

The early Centers of Excellence within economics have, to the highest degree, accomplished their longer-term ambition: They have improved economic research, delivered top talent and generated substantial societal value

*Søren-Peter Olesen
CEO at the DNRF*

Case 3

Catalysis and power-to-X

CAPACITY BUILDING FOR 30 YEARS

The development of green fuels is a turning point in the green transition and one of the government's four missions in the green area. Another concerns the capture and storage or conversion of greenhouse gases.

Both missions are completely dependent on the development of catalysis technologies that allow the transformation of chemical substances on a very large scale. It is a challenge that requires basic scientific research at the highest international level.

If the research is successful, Denmark can contribute decisively to solving some of the most important climate challenges and to the development of Danish companies within the green area.

The possibilities are staggering. So is the international competition.

But Denmark is well prepared to take on the competition, because over a long period of time, we have built a world-leading capacity within, among other things, catalysis. In the DNRF, developments started with the establishment of two basic research centers in 1993 and 2005, that is, long before the importance of catalysis for the green transition was clear.

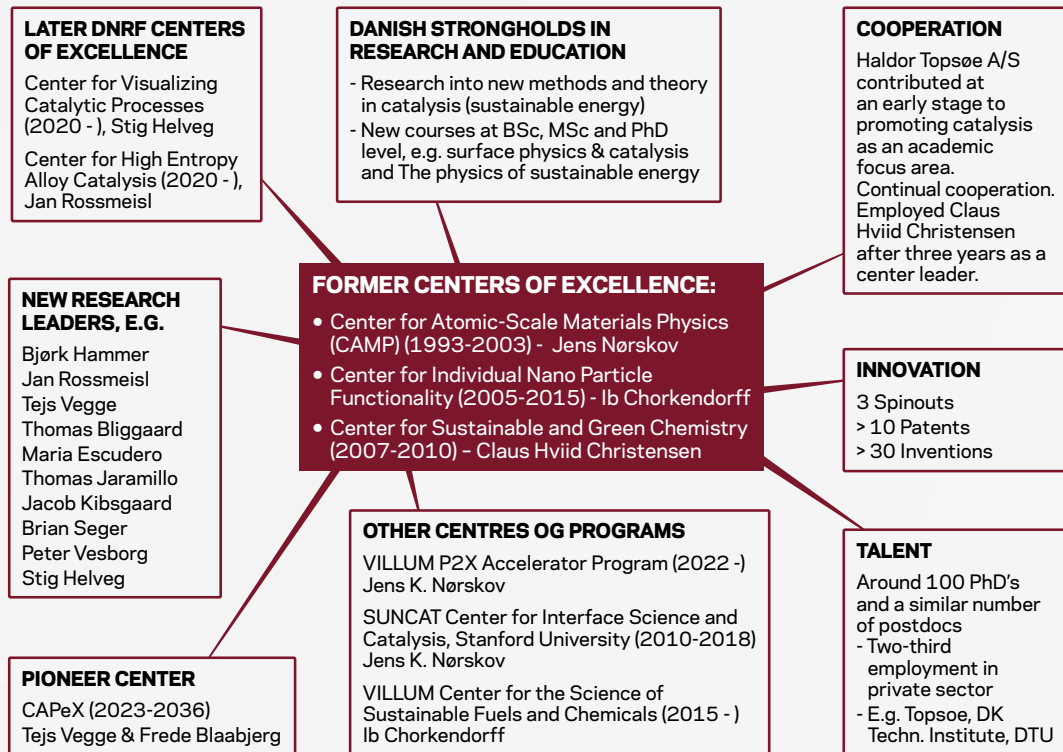
Since then, there have been two further centers, and a pioneer center with even greater ambitions has just opened.¹ The centers are led by researchers who were trained in the early centers and will train a new generation of researchers who will contribute to the green transition. A single center ceased operations after three years when the center's manager was hired by Topsøe.

However, catalysis is not just about the green transition. It is estimated that the commercial value of catalysis corresponds to 30% of the GDP of the European economies and that catalysis is involved in the creation of 80% of all consumer goods.²

Read more below about centers and researchers within catalysis, who – with funding from the DNRF – are helping to promote Denmark's role in the green transition.

¹ The establishment of the Pioneer Centers is an ambitious national undertaking initiated by the Ministry of Higher Education and Science and developed in close cooperation (and co-financing) between the Minister, the Danish National Research Foundation, the Carlsberg Foundation, the Lundbeck Foundation, the Novo Nordisk Foundation, the Villum Foundation and the universities.

² [Read more](#)



“The establishment of the Centers of Excellence CAMP and CINF has created the basis for a number of scientific breakthroughs and for the establishment of a completely new mindset within catalysis research, on which subsequent generations of experts and research leaders have built.

In addition to the cutting-edge research at the highest international level, which has led to the understanding of how the atomic structure of catalysts controls their interactions and catalytic activity, the close link between theory and experimentation at the center led to completely new ways to design and manufacture more efficient catalysts for use in the chemical industry and for the green transition, among other things.

This way of thinking, working with and communicating the understanding of catalysts and catalytic processes has since become a backbone of Danish and international catalysis research.

Tejs Vegge, Professor, Technical University of Denmark
and center leader at CAPeX Pioneer Center

CENTER FOR ATOMIC-SCALE MATERIALS PHYSICS (CAMP)

Technical University of Denmark (1993 - 2003)

Center leader Jens K. Nørskov,
Technical University of Denmark

Co-Principal Investigators Flemming Besenbacher, Aarhus University



THE CENTER MANAGER

Jens Kehlet Nørskov, a professor at DTU, is an internationally leading catalysis researcher. He has, among other things, been employed at Stanford University, USA, for eight years. Nørskov is ranked number 3 in the world in chemistry (research.com). He is now the head of the VILLUM P2X accelerator program, which aims to bring research ideas directly to the market.

THE CENTER'S RESEARCH

In CAMP, the foundations for theoretical catalysis were laid, and it was possible to design new catalysts from scratch based on a basic description at the atomic level. The research showed that the path from basic research to industrial applications can be short. As an example, CAMP had a close collaboration with Haldor Topsøe A/S, which led to the development of industrial catalysts.

CAMP has set the standard for the next generations of researchers worldwide, where some of the leading catalysis researchers were trained.

CAMP has set the standard for the next generations of researchers worldwide, where some of the leading catalysis researchers were trained. Below, only those who were trained while the center was active are mentioned; many more were trained in the following period and benefited from the expertise the center had built up.

TALENT

The center trained 51 Ph.D.s and 53 post-docs. Around half are currently employed in the private

sector and half in the public sector. These researchers were only in part directly financed by the DNRF grant, but the center formed the basis for the training of many more researchers, for example, by virtue of additional grants.

The center developed 11 new Ph.D. courses.

Examples of research leaders whose careers were launched in CAMP:

- Stig Helveg (Professor, center manager at VISION Center of Excellence, DTU)
- Jan Rossmeisl (Professor, center manager at CHEAC Center of Excellence, University of Copenhagen)
- Tejs Vegge (Professor, center manager at CAPeX pioneer center, DTU)
- Bjørk Hammer (Professor, AU)
- Thomas Bligaard (Professor, DTU)

INNOVATION

- The center took out 3 patents

CENTER FOR INDIVIDUAL NANO PARTICLE FUNCTIONALITY (CINF)

Technical University of Denmark (2005-2015)

Centerleder

Ib Chorkendorff



THE CENTER LEADER

Ib Chorkendorff is a professor of physics at DTU. Throughout his career, he has worked with all aspects of catalysis, including surface physics, classical heterogeneous catalysis, electrocatalysis and photocatalysis. He was awarded several patents and contributed to over 400 scientific articles. He is currently head of the Villum Center for the Science of Sustainable Fuels and Chemicals.

THE CENTER'S RESEARCH

The center worked with catalysis on metal surfaces, which is one of the three classical catalysis methods used for the large-scale production

of specific molecules. This focus had been cultivated at DTU since 1987 in close collaboration with Haldor Topsøe A/S, which also became a collaborative partner and important employer of candidates and young researchers from the center.

The center laid the foundation for research into new materials for catalysis, a stronghold whose critical importance has become particularly evident in the context of the need to be able to convert electricity into fuel (power-to-X) and to bind atmospheric greenhouse gases. The area is still a stronghold at DTU and has continuously secured new talent for both industry and research.

The center laid the foundation for research into new materials for catalysis

TALENT

During the life of the center, 49 Ph.D.s and a corresponding number of post-docs have been trained. Around three out of four are currently employed in the private sector and one out of four in the public sector. These researchers were only in part directly financed by the DNRF grant, but the center formed the basis for the training of many more researchers, for example, by virtue of additional grants.

The center developed several new courses within its area, including Surface Physics and Catalysis and Physics in Renewable Energy.

Examples of new research leaders:

- Maria Escudero (Professor, Catalan Institute of Nanoscience and Nanotechnology and co-PI pioneer center CAPeX)
- Thomas Jaramillo (Professor, Stanford University, and international co-PI pioneer center CAPeX)
- Peter Vesborg (Professor, DTU)
- Brian Seger (Professor, DTU and co-PI, pioneering center CAPeX)
- Jakob Kibsgaard (Professor, DTU and co-PI, pioneer center CAPeX)

INNOVATION

- Three spinoffs: HPNow, Spectro-Inlets, RenCat
- 31 inventions and 8 patents

CURRENT CENTERS WITHIN GREEN CATALYSIS WITH DG FUNDING



CENTER FOR HIGH ENTROPY ALLOY CATALYSIS (2020 -)

Center leader: Jan Rossmeisl, KU

Research vision: "Electrochemical reactions for the production of renewable and high-value chemicals where the reaction energy is provided by electricity, thus paving the way for a greener society."



CENTER FOR VISUALIZING CATALYTIC PROCESSES (2020 -)

Center leader: Stig Helveg, DTU

Research vision: „Breakthrough scientific discoveries in thermal catalysis and electrocatalysis needed to tackle the grand environmental challenges of our time.“



PIONEER CENTER FOR ACCELERATING P2X MATERIALS DISCOVERY (2023-2036)

Center leader: Tejs Vegge, DTU

Deputy center leader: Frede Blaabjerg, AaU

Research vision: „Reinvent the ways we invent new sustainable materials for P2X.“

“
My Ph.D. background in the former center CAMP has always been incredibly inspiring and defining for me. It has equipped me with a compass to pursue research that is ambitious, relevant and competent. This has been extremely fruitful in my work both in private and academic research environments, in particular, in terms of continuing to pursue the tension between experiment and theory and between different professional disciplines. And by focusing on the long-term fundamental questions, rather than the lowest hanging fruit, my work has opened the doors to the best research environments in the world, hatched a new field of research and contributed both to industrial development and to groundbreaking scientific insight.

In short, my career has confirmed me in the fact that there is not necessarily a contradictory relationship between fundamental and applied research. By insisting on making the research ambitious, relevant and competent, knowledge generation becomes useful, effective and groundbreaking in the short and long term.

*Stig Helveg, Professor, Technical University of Denmark
and center leader for VISION Center of Excellence*

LASTING VALUE FROM DNRF CENTERS OF EXCELLENCE

Even when basic research has had transformative significance, it can be difficult to spot the contributions it makes to, for example, solving current challenges, promoting new technology, or creating a basis for perhaps medical or political decisions. These contributions may have been made long before their relevance was clear to outsiders.

In the past year, the DNRF has taken a closer look at the value that becomes apparent after the grants expire.