A report for the US National Academy of Engineering project:

A Vision for Future of Center-based Multidisciplinary Engineering Research

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A Review of International Approaches to **Center-based Multidisciplinary Engineering Research**

Preface

This paper is a report of a project reviewing international models for center-based, multidisciplinary engineering research. In particular, this study aims to identify international center features or practices which may help stimulate discussion and debate about the design and management of future NSF engineering research centers.

This brief study was carried out in support of the National Academy of Engineering (NAE) project '*A Vision for the Future of Center-Based, Multidisciplinary Engineering Research*', which was tasked with developing a vision and strategic recommendations for the future of National Science Foundation-supported center-scale, multidisciplinary engineering research.

This report is based, primarily, on 'desk research', involving a systematic review of center program documents, including: 'call for proposals', program brochures, relevant sections from the strategy documents of national science foundations and government departments, as well as (a very limited number of publically available) center program evaluation studies. The review was supplemented by a small number of interviews with funding agency program directors directors of representative individual centers.

About the Author

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Dr O'Sullivan's research agenda explores the ways science and engineering R&D is translated in new technologies, industries and economic wealth. An important research interest involves comparative analysis of the role and functions of intermediate research organisations in national innovation systems. As part of Dr O'Sullivan's research activities, he works closely with policy makers from a range of organisations. Recent policy studies have included reports for the UK Department of Business, Innovation & Skills; the UK Engineering & Physical Sciences Research Council; the UK Government Office of Science; and the Directorate of Research & Innovation at the European Commission.

Before joining the Institute for Manufacturing at Cambridge, Dr O'Sullivan was Special Advisor to the Director General of Science Foundation Ireland. At SFI, Eoin managed several university-industry initiatives including the national Centres for Science, Engineering & Technology programme. Eoin has a BSc from University College Cork and a D.Phil. (Ph.D.) from the Physics Department of Oxford University.

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1. Executive Summary

1.1 Selected Center Program Features and Practices

The following are selected features of international center programs which may prove useful in framing discussions and stimulating debate about the potential design and management of future NSF engineering research centers. The center program features and practices summarised below are outlined in more detail in Section 2.2.

1. A number of international engineering-related center programs prioritise **research and innovation challenges related to manufacturing** (including the scaling-up of emerging technologies).
2. Some manufacturing-focused center programs highlight the importance of **knowledge exchange between university research and industrial manufacturing practice** (not just corporate R&D labs).
3. Some center programs focused on innovation and commercial impact support centers' **market analysis capabilities** (to inform researchers about opportunities and barriers to commercialisation).
4. **Center grant supplements** are used by some international programs to help centers pursue emerging opportunities for translation and impact, often **integrating new industrial partners** or enhancing existing partnerships.
5. A number of recent center programs proactively encouraging **linkages between centers and other national research and innovation institutions** (e.g. public R&D institutes and national labs).
6. Most of the new (or next generation) center programs explored in this study **have longer center lifetimes** (beyond 'traditional' 5 year funding cycles with 10 year 'sunsets').
7. **The funding levels of many international center programs are growing**, and in some cases appear to be higher than that NSF Engineering Research Centers.
8. Additional **pre-proposal planning effort may lead to stronger submitted proposals** (in terms of team formation, partner commitment, and identification of integrated challenge goals).
9. **Effective pre-proposal planning can also lead to more engaged industrial partners**, as well as greater alignment of the expectations of university and industry partners
10. The design of review processes and (agency) program management activities for many international center programs are increasingly **focused on assessing the quality of 'added value' collaboration and impact**.
11. Student education and training activities within some international are putting increasing effort into **providing students with greater insight into real-world industrial environments and the variety of future career options.**
12. There is growing attention in some countries regarding the need to **train students to work in large (often multidisciplinary) teams,** including collaborating with less technical domains from the social sciences or humanities.

13. Some center programs, especially those a strong mission focus on industrial innovation impact, emphasize the **importance of industry career experience within the center management team.**
14. **Facilitating the movement of people between universities and industry** is considered an important and valuable function of many center programs.
15. Many international center programs may have **lighter annual reporting requirements**, by comparison with the ERC program.
16. Some international center programs highlight the importance of **performance metrics which are tailored to the 'impact logic' of the center** being evaluated.

1.2 High-level Observations on International Approaches & Context

The following are a set of general observations about international approaches (and policy thinking) related to the design of new center programs. These observations are intended to provide additional context to the features and practices outlined above. These observations are outlined in more detail in Section 2.1.

17. Almost every country is **asking the same questions about new center models, in the context of emerging innovation trends** and key socio-economic challenges.
18. In response to these trends and drivers, **many international agencies are 'experimenting'** with (or introducing 'course corrections') to their center models.
19. It is generally considered "too soon to tell" if new center models or practices have been successful, as there has, as yet, been **limited evaluation of the new centers**.
20. There are a **common set of trends of drivers** cited as motivation for new approaches: key socio-economic 'challenges'; innovation priorities for key emerging technologies, innovation trends (related to globalisation, open innovation, etc).
21. There is growing expectation in many countries for center programs to deliver **'impact'** (in terms of supporting the **creation of economic and/or societal value**).
22. Commonly cited 'capabilities' considered to be of growing importance for center competitiveness include: **'challenge-focused', 'flexible', and 'networked'**.
23. There are very few international center programs with a specific *multidisciplinary engineering* research mission. Most programs are open to researchers from a broad spectrum of science, engineering (and even social science) disciplines, or emerge from thematic calls (e.g. quantum technologies, advanced manufacturing, etc)
24. There are different motivations for funding 'critical mass' research centers. Some programs are more focused on **capacity-building and visibility**, others on **tackling complex (multidisciplinary) systems challenges**.
25. There is growing attention to ensuring funded centers offer **'added-value'** through real collaboration within systematically integrated research endeavors (i.e. generating outputs and outcomes which are ***"more than the sum of the parts*" offered by a set of individual PI grants**).

2. Introduction

This study is being carried out in support of the National Academy of Engineering (NAE) project '*A Vision for the Future of Center-Based, Multidisciplinary Engineering Research*'. The NAE project aims to develop a vision and strategic recommendations for the future of National Science Foundation-supported "center-scale, multidisciplinary engineering research". This paper contributes to the broader project by reviewing a selection of international models for center-based engineering research. In particular, this study aims to highlight features or practices of international center programs which may inform the discussion and stimulate debate about the future design and management of next generation NSF engineering research centers.

This report is based on a systematic 'desk research' review of documentation related to a range of international center models ('research centers of excellence', 'competence centers', etc). The categories of documents reviewed include: 'calls for proposals', program brochures, program evaluation studies, best practice guides, and relevant sections from the strategy documents of national science foundations and government departments. Recent academic literature and policy studies exploring international research center models were also reviewed. Finally, this review was supplemented by a small number of interviews with funding agency program directors, government officials and individual center directors from a number of countries.

Based on the goals of the broader National Academy study, this paper focuses on center models which have as many as possible of the following characteristics: (a) an ***engineering***-related mission focus, (b) address research challenges which require a critical mass of ***multidisciplinary*** expertise, (c) have an expectation of significant ***engagement with industry*** (and/or the broader 'innovation ecosystem'), (d) integrate both research and ***education*** within their activities, (e) focus on translation research and ***impact*** on industry or society.

An initial scoping phase of this project identified and briefly reviewed over 40 center programs (see Appendix I). Based on the criteria outlined above, a smaller number of center programs were selected for more detailed analysis and discussion. In particular, this report highlights interesting features and practices of selected center programs in the ***United Kingdom***, ***Germany***, and ***Japan***. The report also offers brief descriptions of center programs in ***China, Sweden, Canada*** *and* ***Ireland***, pointing to some further features of interest.

It was originally anticipated that a significant portion of this study would focus on capturing detailed 'effective practices' for center design and management; and that much of the analysis would involve systematic review of program evaluation studies, 'best practice' guides, reports of 'best practice'-sharing workshops, etc. It quickly transpired that such evidence did not exist or was not available in the public domain. This appears, at least in part, to be because many of the center programs were relatively new and had not yet been formally evaluated. Unfortunately, it was beyond the scope of this small study, in terms of both resources and timescale, to carry out sufficient interviews to make definitive value judgments about whether particular program models were successful or whether particular practices were especially effective.

Consequently, this review focuses on highlighting **novel or distinctive features of international programs** which may help stimulate discussion and debate about the potential design and management of future NSF engineering research centers.

The rest of this chapter contains sections with observations related to the following themes:

- **The innovation system *contexts* of international center programs**. In particular, section 2.1 includes observations about: key drivers of change, prioritised mission goals and functions, linkages to other innovation actors, relevant contextual information about approaches to education, funding, etc. This section also includes discussion on the challenges of effectively comparing international center programs, as well as some cautions about how transferable any practices might be to the U.S.A.
- **Features and practices of international center models.** In particular, section 2.2 includes observations on novel or distinctive features of international programs which may help inform discussion and provoke debate about the potential design and management of future NSF multidisciplinary engineering research centers. Some of the features identified appear to be part of a general trend in center design, others are unique but were considered promising enough to highlight.

The following chapters contain summaries of selected center programs – including more detailed 'case study' information about distinctive features or practices of center models in the following countries:

- **United Kingdom**
- **Germany**
- **Japan**

The final chapter contains shorter summaries (with 'headline' observations) regarding selected center programs in the following countries:

- **China, Sweden, Canada, and Ireland.**

A list of the over 40 center programs reviewed as part of this study is provided in Appendix I.

Related reading

Further information can be found in other related policy studies and academic reviews (which compare research center models in different countries), including the following:

- **Koschatzky, K., Stahlecker, T. (Ed.s), 2016.** *Public-private partnerships in research and innovation: Trends and international perspectives.* Fraunhofer Verlag.
- **OECD, 2014.** *Promoting Research Excellence: New Approaches to Funding.* Organisation for Economic Cooperation and Development.

  [See, in particular, Chapter 3. *Research excellence initiatives and centres of excellence* and country case studies, Chapters 6-10]
- **Boardman, C., Gray, D.O., Rivers, D. (Ed.s), 2013.** *Cooperative Research Centers and Technical Innovation: Government Policies, Industry Strategies and Organizational Dynamics.* Springer.
- **Lal, B., Boardman, C., Deshmukh Towery, N., Link, J., 2007.** *Designing the Next Generation of NSF Engineering Research Centers: Insights from Worldwide Practice.* A report for the National Science Foundation by the Science and Technology Policy Institute, Washington DC.

2.1 High-level Observations on International Approaches and Context

The following are a set of general observations about international approaches to the design of new center programs. These observations are intended to provide additional context to the center program features and practices outlined in the following section (2.2). Some of the observations outlined below highlight some of the challenges of effectively comparing international center programs, as well as imply some level of caution regarding how transferable any practices might be to the United States.

- **Almost every country is asking the same questions about new center models**, **in the context of emerging innovation trends and key socio-economic challenges**: Overall, the information gathered in this review suggests that international research agency officials are confronting the same questions as this NAE study, in terms of what future center models should look like in the face of trends and drivers shaping research priorities and innovation systems.

- **This is a time of 'experimentation' with center models and innovation programs:** A repeated theme that emerged from interviews with center program officials was that, in response to the innovation-related trends and drivers, many agencies have been 'experimenting' with new center models (in terms of new missions, functions or practices, etc), as well as introducing 'course corrections' to existing models.

- **"Too soon to tell" – there has been limited evaluation of the success of new center models and practices:** One of the consequences such recent 'experimentation' – many programs are <3 years old (e.g. UK Manufacturing Hubs, German Research Campuses, Japanese Centers of Innovation, Chinese Manufacturing Innovation Centers, etc) – is that there has not yet been any formal evaluation of programs.

- **There are few substantial and systematic attempts to capture center 'best practices'**. Even for the most recent incarnations of more established center models, there appear to be very few formal attempts to capture 'best practices' (or, at least, there are few that are in the public domain), cf the ERC Association *Best Practices Model*[1]. This makes it more challenging to compare, contrast[2], and make relative value judgements on, particular practices of international center programs.

- **There are very few international center programs with a specific <u>multidisciplinary engineering research</u> mission:** Few programs which are truly analogous to the NSF Engineering Research Center program. Most international center programs are open

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[1] It may be worth noting that a number of experts interviewed for this study suggested that ERC Association Directors' Meetings and the online *Best Practices Manual* were still probably 'best in class' internationally; and not only considered an inspiration, but also a valuable resource.

[2] It may also be worth noting in this context, that several of those interviewed raised the idea of a potential international workshop or forum for agency officials to share their experiences and "experiments" with new center models and practices.

to researchers from most or all of the disciplines the research agency funds, typically cover a broad spectrum of science, engineering (and even social science) disciplines. In this context, it is harder to extract *engineering-specific* lessons, potential future visions and effective practices from these programs.

- **There are different motivations for funding 'critical mass' research centers: Critical mass for capacity-building and visibility** *versus* **critical mass for tackling complex systems challenges:** It should also be noted that many national center programs (especially those in emerging innovation economies) are primarily designed for **'*capacity-building*'**, i.e. focusing talent, resources and infrastructure in particular areas of potential strength with a view to further enhancing research professionalism, international competitiveness and visibility.

  This contrasts with the focus of this study, i.e. center programs which are primarily designed to support ***'added value' impact*** by assembling a critical mass of complementary multidisciplinary expertise to ***tackle research challenges of significant scale and complexity*** that couldn't be tackled effectively by with individual PI grants (cf NSF ERCs).

- **There are a common set of trends of drivers cited as motivation for new center programs or functions:** A number of key trends, drivers and emerging innovation priorities are repeatedly highlighted in many international center program documents (or related funding agency strategies). Broad categories of trends and drivers influencing the design of international center programs include:
  - *Growing socio-economic 'challenges'* influencing the wellbeing of citizens, but also offering opportunities for new technology-based markets of tomorrow, for example: aging population, resource efficiency and sustainability, climate change, security, urbanisation and future cities, mobility, etc.
  - *Emerging technologies*, and their promise for new industries and new sources of economic competitiveness, for example: quantum technologies, advanced functional materials, synthetic biology, advanced manufacturing technologies, internet of things/cyber-physical systems, etc.
  - *Innovation trends* affecting future competitiveness of national innovation systems, for example: (a) Increasing quality and competitiveness of international research; (b) increasing globalisation of corporate R&D; (c) acceleration of technological innovation / product lifecycles; (d) increasing urgency in competition to scale-up / industrialise emerging technologies.

- **Increased expectation on centers to have 'impact', in terms of supporting the creation of economic and/or societal value:** Many international center program call documents (and related documents[3]) are increasingly emphasizing economic impact, societal value and national importance. Increased competition and the pace of technological change appear to be creating ever greater urgency to translate

[3] For example, some research funding agency strategies and 'delivery plans' articulate the role of center programs in contributing to particular agency mission goals or impact targets related to economic and social grand challenges.

research outputs into real products and services – to more efficiently demonstrate technical feasibility and 'manufacturability' of novel technologies and engineered systems – or to offer solutions to industrial or societal challenges, such as those outlined above.

Challenge-led research: The terms 'challenge-led research' and 'research grand challenges' are increasingly used in center program documents and related agency strategies. The term 'challenge-led' is, however, defined variously - sometimes just referring to broad thematic socio-economic areas (e.g. climate change, aging, etc) and sometimes referring to quite specific industry needs-driven 'stretch goals'.

A number of center directors interviewed as part of this study, highlighted the implications of 'challenge-led' research for identifying suitable performance indicators and metrics of success. By contrast with more basic 'technology push' research where numbers of papers and patents may offer some proxy (however crude) for the generation of new knowledge, the success of challenge-led research is better judged in terms of how well the new knowledge generated addresses the challenges (or helps meet critical stretch goals on the way to a solution). For challenge-led research, it may be even less appropriate to have '*cookie cutter*' or '*one-size-fits-all*' approach to key performance indicators.

- **There appears to be some emerging consensus on broad "qualities" that future university-industry research centers should have: Challenge-focused, flexible, and networked.** A repeated theme in the initial set of interviews carried out for this study was that, in order to support the future competitiveness of national innovation systems, many future centre-based engineering research activities will need to be ever more:
    - *Challenge-focused* (in terms of a greater fraction of centers addressing industrial 'needs pull' challenges, rather than just tackling 'science push' opportunities);
    - *Agile and adaptable* (in terms of addressing opportunities and barriers to translation, scale-up, and industrialisation)
    - *Networked and aligned* (in terms of collaborating with and leveraging the complementary capabilities and resources of other national, regional and international innovation actors).

- **There is significant consensus about the 'added-value' centers can offer, in principle, through *real* collaboration within integrated research endeavors:** As discussed above, many center programs do not explicitly require systematic collaboration around a large and complex research challenge. More generally, however, most center program competitions do not highlight clear demonstration of the potential added value (i.e. collaborations delivering '*whole is greater than the sum of the parts*' impact) within calls for proposals. A number of experts interviewed in the initial scoping phase of this study suggested that centers achieving significant added-value, based on systematic collaboration and truly integrated research endeavors, was extremely rare.

2.2 Selected Center Program Features and Practices

This section summarises observations on novel or distinctive features of international programs identified in the course of this study. It is hoped that some of the approaches highlighted here may help frame discussions and stimulate debate about the potential design and management of future NSF engineering research centers (and similar programs).

- **A number of international engineering-related center programs prioritise research and innovation challenges related to manufacturing (including the scaling-up of emerging technologies).** Examples of international manufacturing-focused engineering research centres include: the UK *Centres for Innovative Manufacturing* and *Future Manufacturing Hubs* programs, as well as the Chinese *Manufacturing Innovation Centers*[4]. Several centers funded under the German *Research Campus* initiative adopt a '**research factory' model**, creating collaborative environments where new technologies and processes can be tested in realistic environments. A common thread in these and other programs is the importance of knowledge exchange between university research and industrial manufacturing practice (i.e not just between universities and the R&D labs of firms).

  It may be worth noting that such initiatives strongly reflect aspects of the recommendation for *Manufacturing Centers of Excellence* in the 2014 PCAST report on Advanced Manufacturing. In particular, the report recommend consideration of creating collaborative university-industry lab-based research activities '***focusing on earlier-stage technologies responding to particular manufacturing challenges, either advancing manufacturing technologies or challenges of scaling-up novel materials technologies... often working closely or sharing facilities with research institutes addressing later stage technology R&D'.*** The PCAST report goes on to suggest that NSF ERC program may be well placed to address challenges of this type.

- **Some international programs expect funded centers to possess (or have access to) market analysis capabilities** to support the identification and evaluation of the commercial potential across a range of potential end-uses. In this context, a number of engineering-focused centers (for example those funded under the UK *Innovation & Knowledge* Centres program) have engaged with Business Schools, market analyst firms and management researchers in engineering departments to support these capabilities. A number of those interviewed as part of this study highlighted the value of 'engineering-friendly' management tools, such as technology roadmapping, to develop research strategies relevant to future market opportunities

- **Several international center programs offer supplementary grants which can be used to support the integration of new partners.** In particular, supplementary funding mechanisms appear to have the potential to facilitate the addition of new industrial partnerships based around translational research project opportunities which have emerged in the course of the initial research agenda. For example, the

[4] Although the Chinese Manufacturing Innovation Centers are perhaps more closely analogous to US National Manufacturing Innovation Institutes, they reflect a common theme related to the prioritisation of multi-disciplinary engineering R&D activities addressing manufacturing or scale-up challenges. It is worth noting the new Chinese program's emphasis on *strategic alliances* (including universities) to address *generic* industrial technology innovation challenges.

German *Collaborative Research Centres* program, has a '*Transfer Projects*' mechanism which provides a platform for researchers[5] to test results obtained through more basic research under more realistic industrial conditions or to develop prototypes or demonstrators. This is done through joint research carried out with industrial 'application partners'.

Science Foundation Ireland runs an initiative – the '*SFI Spokes Programme*' – which is designed to facilitate the addition of new industrial and academic partners and projects to a SFI Research Centre. This allows centers to expand and develop in line with new priorities and opportunities. A key emphasis in this program is on ensuring centers are **flexible and adaptable to opportunity**, while retaining their ability to carry out high quality research of industrial relevance (which is necessary to support a center's longer term sustainability).

- **A number of recent center programs appear to be proactively encouraging center linkages to other national research and innovation institutions:** Several international center programs, for example UK *Centres for Innovative Manufacturing* explicitly require that funded centers "*work collegiately with other... critical mass activities (e.g. Hubs, Centres)*" and to "*take a leadership role in the national innovation landscape, influencing and working with other stakeholders in the innovation chain... particularly... the [intermediate R&D institute] Catapult network*[6]*, to ensure acceleration of impact"*. Similarly, programs, such as the German *Research Campus* initiative are specifically designed to bring university researchers together with public research institutes[7] and industry together in critical mass joint research endeavours. It may be worth noting that some newer programs, e.g. the Japanese Centers of Innovtion, which don't *explicitly* encourage such linkages of this type, have funded many centers with strong connections of this type.

  The emphasis on such linkages often appears in programs with a particular 'grand challenge' focus, where the capabilities and infrastructure to address a challenge may be distributed across a wider range of innovation actors.

- **The funding levels of a number of international center programs are growing, and in some cases appear to be higher than that NSF Engineering Research Centers.** While, at first glance, the funding for NSF Engineering Research Centers may appear to be comparable to (or even slightly larger than) many international center programs, this may be misleading in many cases. Although there is significant variation in funding and resource allocation for individual NSF ERCs (and international comparators), many ERCs have cost items that international center models do not. For example, international faculty typically have 12 month salaries, so center grants budgets do not contain any 'summer salaries'. For some

[5] It is worth noting that although the 'Transfer Project' mechanism is open to centers across a range of scientific and engineering disciplines, the vast majority of transfer projects have been awarded to engineering-related research domains.

[6] UK Catapult centers are, perhaps, most closely analogous to US National Manufacturing Innovation Institutes.

[7] A number of Fraunhofer Institutes are, in particular, partners in Research Campus initiatives, but other national labs and institutes are also involved.

international centers, PhD students working on center projects typically have funding from other sources (e.g. individual PhD studentships). Furthermore, several international programs have supplementary grant mechanisms (see above) which can raise the funding level of a center over time, beyond the original award size. Many center programs do not receive a budget for education and outreach, even though they may be significantly involved in such activities funded from other sources and managed through dedicated university or department programs.

Another significant factor influencing the viability or competitiveness of center funding is the scope of their technology innovation efforts from basic research to final system pre-deployment development and validation. This can have significant consequences for budget, with later stage system integration and demonstration of manufacturability - activities which can require more expensive equipment and facilities – typically being more expensive. By comparison with some international (*university-based)* programs, some NSF ERCs go higher up the 'technology readiness level' scale. In this context, comparing the funding levels of NSF ERCs with center programs which are constrained to earlier stage 'proof of principle' (or proof of feasibility) engineering research may be misleading.

A view expressed by a number of interviewees during the course of this study was that the appropriate 'critical mass' funding level of a center was, in part, a function of the nature and the complexity of the challenges being addressed. In particular, it was suggested that some of the most interesting and important future multi-disciplinary engineering research opportunities are increasingly likely to be **complex systems challenges and/or require significant demonstration, scale-up and test-bed facilities.** And, as a consequence, center funding levels may have to grow to reflect this.

Although it is beyond the scope of this project to carry out a careful audit of center budgets, there appears to be a danger that – despite the headline budget numbers - NSF center funding levels may in fact be lower than their international comparators in many cases. There may be merit in carrying out more careful 'benchmarking' analysis of this issue, in particular paying attention to budget composition, comparison of the funding levels per faculty Investigator (or per project), and comparison of funding levels for centers addressing higher TRL research endeavours.

- **Most of the new (or next generation) center programs explored in this study have longer center life cycles.** Although many international center programs have traditionally been funded for similar lifetimes to NSF centers – i.e. 5 years (with the potential for a further 5 year funding period) – several programs have recently extended the center lifetimes. For example: the recent UK *Future Manufacturing Hubs* have a 7 year life time; *Science Foundation Ireland Research Centres* have gone from a 5 to 6 year life cycle; German *Collaborative Research Centres* can now be funded for up to 12 years (made up of 4 year funding periods).

  UK *Knowledge & Innovation Centres (IKCs)* are granted funding for an initial period of five years, but where a technology domain has demonstrated exceptional promise during this period, the funders may be prepared to support an IKC in that technology domain for a further period, renewed in tranches, **based on an assessment of the needs and growth prospects of the emergent industry.**

A number of those interviewed in the course of this study highlighted the importance of longer center lifetimes for 'challenge-led' research, where **multidisciplinary teams may take longer to learn how to work together; and where new 'tools' and resources to address to challenge make have to be developed as part of the center endeavour**.

Interviewees also suggested that it may take longer than 5 years to effectively nurture early career talent. It was also pointed out that longer lifetimes offered the potential to have several cohorts of PhD students go through the center (rather than, as was often the case with 4-5 year center grants, just having one single intake of PhD students in year 1).

Many international center programs have two funding cycles before 'sunset'. There are instances of models where, for the first lifecycle, there is funding for both a 'core' research management activities (which helps lead and coordinate joint research efforts and outreach) and a set research projects, but then, for the second cycle, only funds the 'core' coordination activities (as well as demonstration and communication efforts). The expectation is that if truly collaborative behaviour has been 'catalysed' by the original grant, then individual PIs will continue to engage in the center if a core 'coordination' function exists to support the engagement.

- **There is significant consensus across many international programs that effective pre-proposal planning can lead to stronger proposals (in terms of team formation, commitment, and identifying integrated challenge goals).** More careful and systematic pre-proposal planning is occasionally encouraged or facilitated by the funding agency, but is increasingly emerging 'bottom up' as a community best practice, whereby networks of collaborators and their key stakeholders arrange their own national workshops or technology roadmapping exercises to facilitate center proposal and partnership development.

  In particular, it was suggested that structured exercises designed to support proposal development can help ensure **more effective identification (and refinement) of collective research goals, better design of integrating 'demonstrators'** and eliciting more detailed commitment from industrial partners.

  More structured and inclusive **pre-proposal development exercises can also support more effective team formation** by more clearly identifying capability and expertise gaps, more clearly revealing the complementary capabilities of potential team members, and creating awareness among potential team members (or collaborators) of individual expectations regarding project outputs and impact.

  A number of interviewees highlighted the value of more systematic and substantial pre-proposal planning in ensuring real collaboration. In particular, it was suggested that such planning ensures a stronger 'social contract' commitment from individual researchers to work on projects addressing collective goals. This approach both empowers the director to insist on genuine and substantial collaboration (rather than PIs retreating into silos once funding has been allocated), but also makes it clear that the director's authority only exists in the context of leading a research endeavour based on a clear shared vision. An important part of ensuring buy-in into more detailed planning is transparency on how goals can be changed, priorities can be adapted, and under what circumstances projects can be closed down.

- **Effective pre-proposal planning can also lead to more engaged industrial partners, as well as greater alignment of the expectations of university and industry partners:** As outlined above systematic pre-proposal co-development of research plans can ensure more effective identification of collective research goals. Some of those interviewed as part of this study, further suggested that (especially for those centers with a stronger focus on industrial innovation impact), close pre-proposal co-development with industrial partners can improve the design of research integrating 'demonstrators'. In particular, demonstrators can be designed to create knowledge outputs that can be more readily absorbed by firms; and which have better accounted for any barriers to translation into real-world environments and practice.

  There are interesting examples of how **pre-proposal planning can be facilitated formally by funding agencies**, for example through thematic calls which are part of broader initiatives involving community workshops, 'roadmapping exercises', etc. For example, the *UK Quantum Technologies Hubs* center competition was framed in terms of national strategy development efforts. Similarly, proposals for the Japanese Centers of Innovation program competition had to demonstrate how they would contribute to detailed national '*visions*'.

- **The design of review processes and (agency) program management activities for some new center programs are increasingly focused on assessing the quality of 'added value' collaboration and impact.** A repeated theme throughout the initial set of interviews carried out for this study was the challenge of ensuring that center researchers engaged in **systematic collaboration and integrated research endeavors** which could achieve real **'added value'** (i.e. '*whole is greater than the sum of the parts'* outcomes beyond that which could be achieved by individual PIs).

  Several interviewees highlighted that these essential qualities – of systematic collaboration and added value impact – required not only an appropriate center 'model', but crucially demanded **effective agency review processes and program management practices** that could reveal and encourage truly collaborative behavior. Some reviewers pointed to some of the practices outlined above in this context, in particular: (a) the value of pre-proposal planning in delivering more substantial collaborative research proposals which could be scrutinized in more detail; (b) the potential for supplementary grants to incentivize collaborative behaviour and impact; (c) the opportunities to use mid-term reviews to ensure appropriate levels of collaboration (and not just count conventional research outputs).

- **Student education and training activities within some international are putting increasing effort into giving students greater insight into real-world industrial environments and the variety of future career options.** This review of international center program documentation did not reveal any program-wide education or training practices which were especially distinctive or novel. While some experts interviewed as part of this study could identify centers doing high quality education and training, they were hesitant about claiming these practices were especially 'innovative' or necessarily transferable. Most of the education activities raised by interviewees related to center contributions to curriculum development (introducing new content related to the center's mission focus) implemented through normal departmental teaching processes. Other activities that were highlighted, e.g. research experiences of undergraduates, internatonal research experiences of students, etc, are well known within the US ERC system.

One area where there may be a more distinctive emphasis with education and training activities, especially within centers with a strong industrial impact focus, is **increasing effort into giving students greater insight into real-world industrial environments** and the **variety of future career options**. For example: Efforts to create awareness of the types of potential academic and non-academic careers that are open to doctoral graduates, in particular highlighting areas that are less well known to their students (graduate or undergraduate); facilitate student experiences of more industrially relevant work through engagement with nearby public R&D institutes; having regular 'site visits' to the operations of leading edge-companies.

Another area that was highlighted by a number of interviewees, albeit in terms of identifying an area which needed attention rather than particular best practices, was **training students to work in large teams, in particular multidisciplinary teams** (including working with less technical domains from the social sciences).

It is important to note, by way of context, that many countries do not have a US-style 'graduate school' system. Consequently other programmatic initiatives have been put in place by government agencies to develop aspects of graduate school-like experience in important emerging science and engineering domains (for example, UK Centres for Doctoral Training/Doctoral Training Centres, German Excellence Initiative 'Graduate Schools', etc). This means, in several countries, there that there is a different 'division of labor' regarding student education and training between 'research centers' and 'doctoral training centers' (or similar).

- **Some center programs, especially those a strong mission focus on industrial innovation impact, emphasize the importance of industry career experience within the center management team.** Some programs, such as the Japanese *Centers of Innovation* program require the centers have COI Project Leader (responsible for supervising the overall management of COI site and its R&D activities) that comes from industry. Other programs have an expectation that centers will have operations managers with professional industry management experience (especially in coordinating large complex technical projects) or industrial partnership managers with industry and university career experience, who can help align university and industry cultures and expectations.

- **Facilitating the movement of people between universities and industry is considered an important and valuable function of center programs.** The value of movement of people between university and industry, in terms of helping develop a culture and mutual awareness which facilitates the translation of center knowledge, was a theme that emerged regularly in interviewees carried out for this study. Although this concept is, of course, already well understood, international centers continue to 'experiment' with new ways of appropriately enabling or facilitating this movement. Examples of mechanism to support movement of people that were identified in the course of this study include: industrial 'Professors of Practice', university-'embedded' industry researchers (or even embedded labs), and student placements in industry. As with other international practices discussed in this section, interviewees were reluctant to point to particular activities as exemplars of 'innovative' practice or as 'best practices' which were necessarily transferable.

- **Many international center programs may have lighter annual reporting requirements (relative to the ERC program).** Although there is significant variation in practice from program to program in terms of reporting on progress, a number of international center directors interviewed as part of this study quickly volunteered that their **annual reporting requirements and mid-term reviews are not too onerous.** It was suggested that mid-terms reviews were often designed, at least in part, to constructively support center strategy development and help communication with current and future industry partners. It was also suggested that mid-term reviews can be helpful in terms of (re-)empowering center directors and reminding individual project leaders that they are part of a larger collaborative research endeavour. It was also suggested by some of those interviewed that **management information tools and IT systems were reducing the burden of annual reporting,** making it easier to collect and collate journal articles, conference papers, patents, etc; and gather information about outreach and impact activities, etc.

- **Some international center programs highlight the importance of performance metrics which are tailored to the 'impact logic' of the center being evaluated.** This is nicely expressed in a recent impact evaluation survey report for the Swedish VINN Excellence Centres program [Anaya-Carlsson & Lundberg, 2014]:

  > "*…it is important to keep in mind that objectives and conditions are different for the Centres and this affects the activity level, direction and results of the centres activities. All in all, the different conditions may result in the Centres need to create their own impact logic, namely to clarify how they contribute to the achievement of their specific short and long-term objectives that are found at the programme level. Some caution should therefore be exercised before drawing conclusions on the basis of comparisons between Centres. For example, generating patents is not an objective for some Centres because the participating partner/sectors do not have this as part of their business logic*".

- **Some international center programs are experimenting with novel impact metrics:** The impact metrics and evaluation criteria used by different international center programs are not always available in the public domain. It was beyond the scope of this study to systematically track down a comprehensive list of such metrics. International efforts to supplement traditional lists of output metrics include **additional categories, such as "*number of company 'assists'*" and "*number of 'demonstrators' produced*".**

  It may be worth noting that some international programs funded centers the freedom to track and report additional **novel metrics which they believe are helpful indicators of progress** towards their overarching objectives (i.e. novel metrics which are not specified in official reporting forms, but identified by the centers themselves).

3. United Kingdom

In this section, some basic information on selected centres from the United Kingdom (including features and practices referred to in Section 2 of this report) is provided. In particular, the following programs are briefly summarised:

- **Future Manufacturing Hubs**
- **Centres for Innovative Manufacturing**
- **Innovation & Knowledge Centres**

Based on the review of recent UK center programs summarised in this section, features or practices which may be worth reflecting on (whether for adoption, adaption or simply awareness regarding how international competitors operate), include the following:

- The prioritisation of **research & innovation challenges related to manufacturing** (including the scaling-up of emerging technologies)
- A trend towards **longer center life times**
- More focused **thematic** calls for some center competitions (e.g. advanced manufacturing, quantum technologies, etc)
- Programs which require funded centers to have **market analysis capabilities**
- Programs which encourage center **engagement with other innovation actors** (e.g. national R&D institutes, national labs, business schools, etc)

It should be noted that the models discussed in this section co-exist with a range of other center and institute models in the UK innovation 'ecosytem'. Other engineering-related center programs in the UK include further thematic **'hub' models**, such as those for 'quantum technologies' and the 'digital economy'. As discussed in Section 2, there are also centers focused on graduate education, the **Centres for Doctoral Training** funded by the Engineering & Physical Sciences Research Council. Other important engineering research actors include the institutes of the so-called ***Catapult* network** (cf US National Network for Manufacturing Innovation Institutes or German Fraunhofer Institutes), which carry out applied engineering-related R&D in areas such as: high value manufacturing, satellite applications, offshore renewable energy, digital economy, transport systems, and energy systems. Links to further information on all of the UK programs mentioned here are given at the end of this chapter.

3.1 Future Manufacturing Hubs

Future Manufacturing Hubs are center-based, multi-disciplinary, engineering research centers funded by the UK's Engineering & Physical Sciences Research Council. The 'Hubs' are designed to address major, long-term challenges facing the UK's manufacturing industries, and capture opportunities from emerging research. In particular, Future Manufacturing Hubs are expected to perform the following functions:

- Carry out innovative research in engineering and physical sciences, related to challenges in commercialising and industrialising early stage technology research.
- Carry out multidisciplinary research, strong engagement with relevant manufacturing industries
- Address major, long term challenges facing manufacturing industries, as well as future industrial opportunities from emerging research areas

- Engage strongly with industry to enhance knowledge exchange between universities and industry, and deliver significant impact
- Take a leadership role in the national innovation landscape, influencing and working with other public R&D actors (including Innovate UK[8] & the Catapult network[9])
- Take a leadership role within the relevant national network of researchers and innovators, including through outreach activities, etc)
- Work collegiately with other Manufacturing the Future critical mass activities (e.g. Hubs, Centres, Programmes)

Research Council funding for each Hub is up to **£10M (~US$13M) over seven years.** The core Hub activity should be based in a single location, with other institutions or groups acting as 'spokes', inputting specific expertise in areas that complement those from the lead institution. The first two manufacturing research Hubs were launched in 2015, with EPSRC's £20M investment leveraging £14M from the universities and a further £58 million from industry. The first two funded Hubs were:

- The EPSRC Manufacturing Hub in Future Liquid Metal Engineering (Brunel University)
- The EPSRC National Hub in High Value Photonic Manufacturing (U. Southampton).

3.2 Centres for Innovative Manufacturing

Centres for Innovative Manufacturing (CIMs) are center-based, multi-disciplinary, engineering research centers funded by the UK's Engineering & Physical Sciences Research Council. They are a precursor model to the Future Manufacturing Hubs discussed above[10]. CIMs address research topics and challenges enabling the commercial development of the key discoveries in university manufacturing research. Some CIMs investigate production technologies and how they scale-up, such as additive manufacturing and automation, others carry out manufacturing research related to future products in areas of importance to the UK economy, such as composite materials, food and pharmaceuticals. As with manufacturing Hubs, CIMs are expected to engage with the relevant national community of interest, and draw in the knowledge of the best people in each community.

The focus of the CIM program was to support the best researchers the best environment to carry out important manufacturing research and facilitate them to connect up with the best research talent and other stakeholders from around the country. There are currently (June 2016) 16 active EPSRC CIMs carrying out research and education activities in the following technology and application domains: Advanced composites; Industrial Sustainability; Emergent Macromolecular Therapies; Medical Devices; Photonics; Large-Area Electronics;

[8] **InnovateUK** is the United Kingdom's Innovation Agency. InnovateUK works with firms and university partners to de-risk, enable and support innovation, thereby putting companies in a stronger position to attract investment and facilitating access to investors, collaborators, customers and export markets. InnovateUK funds research in universities through a number of mechanisms, including its collaborative R&D grants program. InnovateUK also jointly funds research programs with other agencies, including the Innovation & Knowledge Centres described later in this section. InnovateUK typically funds research activities between Technology Readiness Levels 4 and 6.

[9] **Catapult centres** are applied R&D organisations set up by InnovateUK to promote research and innovation through business-led collaboration between scientists, engineers and market opportunities. Catapult centres are comparable to US National Manufacturing Innovation Institutes or German Fraunhofer Institutes.

[10] It is not clear whether Future Manufacturing Hubs will entirely replace the Centres for Innovative Manufacturing program, after the current generation of CIMs 'graduate'.

Liquid Metal Engineering; Intelligent Automation; Additive Manufacturing; Advanced Metrology; Food; Continuous Manufacturing and Crystallisation; Laser-based Production Processes; Regenerative Medicine; Through-life Engineering Services; Ultra Precision

3.3 Innovation and Knowledge Centres (IKCs)

The prime objective of an Innovation & Knowledge Centre is to "accelerate and promote business exploitation of an emerging research and technology field in a strategically important area. It is a nucleating point for the emergence of a new industry". The IKC program is run jointly by Innovate UK and the UK Research Councils. Individual centers are **funded by a different combination of agencies**, depending on the thematic focus of the center.

IKCs are based in a university they are led by an expert entrepreneurial team. While continuing to advance the research agenda, they create impact by enhancing wealth generation of the businesses with which they work.
IKCs are expected to possess or have direct access to:-

- Core capabilities in the domain(s) of the chosen science and technology – a shared environment to enhance collaboration, and leading to the creation of critical mass.
- Flexible capabilities in companion and enabling technologies that might be needed to remove barriers to innovation and make systems work
- **Market analysis, and market development, capability to evaluate the commercial potential across a range of potential end-uses**
- Facility & equipment fit for purpose - to enable operational activities; **to produce technology demonstrators; with access for third parties**
- **Ability to dynamically respond to business needs**
- Professional management of knowledge and intellectual assets, including both internally and externally owned intellectual property.

An IKC is granted funding for an initial period of five years, but when a technology domain reveals exceptional promise, the funding agencies may support a center for a further period, renewed in tranches. **The decision to fund an IKC in a particular technology domain beyond its original 5 year funding cycle will be made on an assessment of the needs and growth prospects of the emergent industry.** The decision to award any extension of this type will, of course, also be conditional upon the success of the center's performance against established metrics.

It is worth noting that the IKC program documentation repeatedly highlights the importance of having **a wide range of collaborations** in order to meet the program objectives. Such collaborations include partnerships with industry, with academia, and with other bodies that are important in the space (such as in standard development bodies, national metrology labs, regulatory bodies, Government Departments, public Research Institutes and Research & Technology Organisations). IKCs are also expected to collaborate with and contribute to the missions of other centers (including Catapults and Centres for Doctoral Training). The IKC will be cognizant of the wider science and industry ecosystems, and **possess knowledge of road mapping activities** and a vision for the development of the future industry(s).

Recently funded engineering-related IKCs (jointly funded with the Engineering & Physical Sciences Research Council) include:

- Cambridge Information and Knowledge Centre: Advanced Manufacturing Technologies for Photonics and Electronics (University of Cambridge)
- Ultra Precision and Structured Surfaces (University of Cranfield)
- Centre for Secure Information Technologies (Queen's University Belfast)
- Medical Technologies (University of Leeds)
- Centre for Smart Infrastructure and Construction (University of Cambridge)

Further information

- **EPSRC, 2014.** *Future Manufacturing Research Hubs 2016.* Call for outline proposals document. Engineering & Physical Sciences Research Council: https://www.epsrc.ac.uk/files/funding/calls/2014/futuremanufacturingresearchhubs
- **EPSRC, 2015.** *EPSRC Centres for Innovative Manufacturing.* Brochure: https://www.epsrc.ac.uk/newsevents/pubs/cimbrochure/
- **EPSRC, 2012.** *EPSRC Centres for Innovative Manufacturing – Call for Proposals 2012:* https://www.epsrc.ac.uk/funding/calls/centresforinnovativemanufacturing/
- **CIM program pages** on the EPSRC website: https://www.epsrc.ac.uk/research/centres/innovativemanufacturing/
- **IKC program page** on the EPSRC website: https://www.epsrc.ac.uk/innovation/business/opportunities/ikcs/
- **Catapult network page** on the InnovateUK website: https://www.catapult.org.uk/
- **Centres for Doctoral Training page** on the EPSRC website: https://www.epsrc.ac.uk/skills/students/centres/

4. Germany

In this section, some preliminary basic information on selected centres from Germany (including features and practices referenced in Section 2 of this report) is provided. In particular, the following programs are briefly summarised:

- **Collaborative Research Centres**
- **Research Campuses**

Based on a review of recent German center programs summarised in this section (and others), selected features or practices which may be worth reflecting on (whether for adoption, adaption or simply knowing how international competitors have chosen to operate), include the following:

- Most of the new (or next generation) center programs explored in this study have **longer center lifetimes.**
- **Supplementary grants which can support the integration of new partners**.
- There are strong **linkages between university-based engineering research centers and national research and innovation institutions** (notably Fraunhofer Institutes)
- Attention to manufacturing-related challenges and creating collaborative spaces where **new technologies/processes can be tested in realistic environments**.

4.1 Collaborative Research Centres (CRC)

The Collaborative Research Centres program is run by the German Research Council (Deutche Forschungsgemeinschaft, DFG). CRCs are long-term university-based research centers, established for **up to 12 years (made up of 4 year funding periods)**, in which researchers work together within a multidisciplinary research programme. CRCs are designed to support researchers tackle innovative, challenging, complex and long-term research undertakings through the cooperation, coordination and concentration of researchers, infrastructure and resources.

CRCs are open to a broad range of disciplines. Of the currently funded CRCs, only about **17% are in the engineering sciences**, although a sizeable fraction of centers in the natural sciences (and some in the life sciences) have significant contributions from engineering-related researchers. Last year the DFG introduced key changes to the CRC program, in particular: In order to introduce more flexibility, a previous requirement for local (departmental) concentration of researchers was replaced by the requirement of concentration at the host universities. The participation of external projects is facilitated within well-defined rules. The evaluation process for CRCs was strengthened to better assess the added value of a CRC as a whole, with review criteria focusing on: research, people, research profile of the universities, and support structures.

The DFG currently funds 249 Collaborative Research Centres (CRC) with a total of €649 million for 2016. This accounts for approximately 21% of the DFG's total budget. Typical engineering-related CRCs receive funding levels ranging from €1.5M (US$1.7M) to nearly €3M (US$3.4M), with an **average of about €2.2M (US$2.5M) per year**.

One interesting feature of the CRC program is the **'Transfer Projects' mechanism** which provides a platform for researchers to test results obtained through more basic research under more realistic industrial conditions or to develop prototypes or demonstrators. This is done through joint research carried out with industrial 'application partners'. Transfer Projects are designed to improve feedback loops between applied research and more fundamental research. Proposals can be submitted at any time during a CRC's funding period. An individual transfer project can be funded for up to 4 years. The majority of transfer projects have been awarded to engineering-related.

Although education and outreach is regularly carried out by CRC team members, this typically happens without direct funding from a CRC budget. In particular, there are significant efforts related to outreach to schools, engagement of women in science and engineering; as well as contributions to undergraduate/graduate student teaching modules.

It is worth noting that a significant fraction of PIs applying for CRC grants solicit their own unofficial but often extremely rigorous peer reviewing of draft proposals before formal submission. The application process itself requires a very significant amount of detail for both the preliminary proposal and full proposal process. One interviewee estimated that preliminary proposals can be over 100 pages long and full pages over 400 pages.
In the context of engineering-related CRCs, significant importance is placed on **'demonstrators' as a focus for synergies, facilitates transfer and impact**.

As discussed above, CRCs are now funded for up to 12 years (made up of 4 year funding periods). There is a strong sense that centres, especially entirely new centres (not built on previous critical mass investments) **need longer than 5 years to build up activities, grow trust, refine collective agenda**.

CRC experts interviewed as part of the initial scoping phase of this study, highlighted the vital role played by centre directors – a good director being a critical success factor in ensuring focus on a collective vision and ensuring added value and impact. The interviewees also highlighted growing awareness of the vulnerability of centre sustainability if the Director leaves or retires. There has been, therefore, increasing attention to the issue of sustainability and resilience in this context; and **the importance of succession planning and the empowerment of senior staff who can share management responsibilities**.

4.2 Research Campus: Public-private Partnerships for Innovation

The German *Research Campus* initiative is funded by the German Federal Ministry for Research and Education (BMBF) and is designed to bring together researchers from **universities, public research institutes (in particular Fraunhofer Institutes) and companies** to work together **"under one roof"**. They Research Campus partners work together on areas of research that **are characterised by great complexity, a high level of risk** associated with the research, or special potential for leaps in innovation. The research themes currently covered by the initiative range from mobility and energy-supply to manufacturing technologies to common diseases, but there is a significant multi-disciplinary engineering research component in most of them. Research campuses also pursue complementary goals such as the training of young scientists in specific graduate schools or the training of staff at the companies involved. Some research campuses collaborate further in international research networks or standardisation bodies.

A number of Research Campuses take the form of ***'research factories'* – collaborative environments where new technologies and processes can be tested in realistic environments – in particular, the results of design and engineering research can be immediately tested in more realistic industry-like environments - creating direct feedback loops between academic theory and manufacturing practice**. For example:

- **ARENA2036** (Active Research Environment for the Next Generation of Automobiles), Stuttgart which explore versatile production of the future for function-integrated lightweight materials for automotive vehicles;
- **Digital Photonic Production**, Aachen which brings together RWTH Aachen, the Fraunhofer-Gesellschaft and industry to investigate new approaches to the use of light as a manufacturing tool (especially for transport, energy, health, and ICT);
- **Open hybrid LABfactory**, Wolfsburg, which carries out research on mass production and manufacturing technologies for economically and environmentally sustainable production of hybrid lightweight components, covering the entire value chain (from conceptual design to hybrid production processes through to recycling).

Research Campus centres receive funding of **up to €2M (~US$2.25M) per year for a period of up to 15 years**. The funding initiative is aimed at medium to long-term, sustainable cooperation between partners which can continue to exist independently even after the funding ceases. A prerequisite for the funding is the introduction of personal contributions from the partners involved in the form of personnel, infrastructure or financial resources. These contributions support the sustainable securing of the overall financing of a research campus. In addition, the BMBF supports the implementation of specific projects at research campuses in application-oriented basic research.

Further information:

- **DFG, 2010.** *Monitoring des Förderprogramms Sonderforschungsbereiche.*: www.dfg.de/download/pdf/dfg_im_profil/geschaeftsstelle/publikationen/dfg_monitoring_sfb_2010.pdf
- **DFG, 2012.** *From Theory to Practice: Transfer Projects in Collaborative Research Centres link Research with Applications.* DFG InfoBrief 1.12: www.dfg.de/en/research_funding/programmes/coordinated_programmes/collaborative_research_centres/
- **CRC program pages** on the DFG website: www.dfg.de/en/research_funding/programmes/coordinated_programmes/collaborative_research_centres/
- **Research Campus program pages** on the BMBF website: *www.bmbf.de/de/forschungscampus-oeffentlich-private-partnerschaft-fuer-innovationen-562.html*
- **BMBF, 2014.** *Forschungscampus – öffentlich-private Partnerschaft für Innovationen. Program brochure:* www.bmbf.de/pub/Forschungscampus_2014_bf.pdf

5. Japan

In this section, information on selected centre programs from Japan is provided. The chapter focuses on the **Centers of Innovation (COI) program** of the Japan Science & Technology Agency (highlighting features and practices referenced in Section 2 of this report), but also offers brief contextual information about other '**centers of excellence' programs, public R&D institutes,** and **innovation programs**.

Based on the review of recent Japanese center programs summarised in this section, features or practices which may be worth reflecting on (whether for adoption, adaption or simply knowing how international competitors have chosen to operate), include:

- Program calls with **thematic socio-economic goals** (identified by 'backcasting')
- Active shaping of individual center agendas by programmatic 'visionary teams'
- Significant efforts to engage with the **social sciences and humanities**
- Center project **leaders from industry**
- The use of **development awards** to nurture COI proposals considered promising but not yet competitive – i.e. so-called 'COI Trials'

The programs discussed below operate in the context of the recent (5th) *Basic Plan for Science & Technology* which highlights: R&D addressing **socio-economic challenges**, developing **collaborative and entrepreneurial mindsets**, increasing **international collaboration,** and the role of public R&D **institutes as innovation hubs.** It is worth noting that there has been **significant growth in industrial R&D investment in Japanese universities**[11] in recent years.

5.1 Centers of Innovation Program

Although the Centers of Innovation program is a relatively new program (the first solicitation was in 2013) and has not yet been evaluated, it merits attention for a number reasons: It has a number of **similarities with the NSF's ERC program** (in terms of scale, attention to research translation[12], and integration of multidisciplinary effort), but also has very different features reflecting recent reforms of the Japanese R&D funding system, with a shift from '*science and technology-push*' to more **'*needs-pull*'** policies.

The Centres of Innovation program is designed to address complex multidisciplinary R&D **challenges of industrial and/or societal importance**, which cannot be solved by industry or academia alone. In particular, COIs are expected to make radical innovations in thematic areas associated with **"visions" of a future ideal society**. These visions, the COI mission goals for contributing to these visions, and the R&D plans to deliver on them, are developed using a **'backcasting'**[13] approach (see below). As part of this process many of the funded

[11] The 2013 MEXT survey of industry partnerships with Japanese universities showed record levels of investment (with growth of ~JPN¥6.7B)

[12] The program invests in integrated research endeavours requiring "fundamental technology research", "enabling technology development", and "system integration". These categories of R&D are drawn directly from the **'3-plane' model of the NSF ERC program**. Attention is focused on supporting research 'culture change' towards greater engagement between traditionally more 'siloed' categories of R&D activity.

[13] In this context, 'backcasting' refers to an approach whereby the COI mission goals and associated R&D agenda are developed by working backwards from a vision of a future ideal society.

centers end up including significant multidisciplinary engineering activities as part of their research endeavours to support the delivery on these visions.

The COI program is managed by the Japan Science & Technology Agency (JST) on behalf of the Ministry of Education, Culture, Sports, Science and Technology (MEXT). The program was launched in 2013 and is one the main funding programs under the broader MEXT initiative '*Center of Innovation Science and Technology based Radical Innovation and Entrepreneurship Program*' (COI STREAM).The 'visions' which determine the socio-economic goals addressed by the centers are developed by the COI STREAM Governing Committee supported by 'Visionary Teams' made up of leading academics and industrialists.

The current set of 'visions' is:

- **Vision 1 - Smart Life Care, Ageless Society:** Secure sustainability as a country advanced in its aging population and declining birth rate
- **Vision 2 - Smart Japan:** Create a living environment with a high quality of life as a prosperous and reputable country
- **Vision 3 - Active Sustainability:** Establish a sustainable society with vitality

Key features and practices of the COI program include:

- **'Top-down' shaping of COI design:** The COI STREAM 'Visionary Teams' appointed for each vision play a significant role in shaping the design of COI sites, including soliciting COI proposals; as well as being responsible for COI evaluation.
- **COI funding levels**: Funding for individual COI sites can be up to a maximum of JPN¥ 1B / year **(up to ~US$ 9.8M / year)**, *including overhead expenses*[14].
- **COI site lifecyles:** COIs can be funded for up to 9 years, after which they are expected to be self-sustaining. Graduated COIs are expected to continue to carry out R&D for radical innovation (rather than become self-sustaining via contract R&D).
- **Co-location:** Funded center activities take place at a COI site ('innovation platform') where university and firm researchers can carry out R&D together '***under one roof***'.
- **Engagement along R&D journey:** COIs are expected to work across the spectrum of R&D activities from 'fundamental technology research', and 'enabling technology development', to 'system integration' (**cf NSF ERC '3-plane' model**)
- **Multidisciplinarity:** COIs are expected to develop a multidisciplinary research agendas appropriate to the goals identified as part of the socio-economic 'vision'
- **Engagement with the social sciences:** COIs are expected to develop collaborations with social science and humanities researchers, where appropriate to mission goals
- **Project Leaders from industry**: Each COI has one Project Leader from industry responsible for the overall management of COI sites and R&D activities
- **High level engagement by host universities**: The contract for a COI is between JST and the President of the host University. The President is expected to participate in site visits and actively engage in ensuring a supportive environment for the COI site.
- **Development awards:** As part of the 2013 COI solicitation, MEXT also funded 14 so-called 'COI Trials' (COI-Ts). Each COI-T can be funded up to JPN¥ 100M / year **(up to ~US$ 0.98M / year)**. The COI-Ts were based on promising COI proposals which

[14] As discussed elsewhere in this report, care should be taken when directly comparing funding levels of international programs. In this case the JST quoted figures for the maximum annual funding for COIs *includes overheads*. Most other center programs summarized in this report quote maximum *direct cost* funding levels.

received good evaluations, but were not considered competitive. COI-Ts may have opportunities to be selected as full COI sites in the next solicitation round.

Examples of funded centers with a strong multidisciplinary engineering activity include:

- The *Center for* ***Coherent Photon Technology*** (University of Tokyo)
- The *Center of* ***Kansei-oriented Digital Fabrication*** (Keio University)
- The COI for ***Next-generation Infrastructure systems*** (Kanazawa Inst. of Technology)
- The COI for ***Unobtrusive Sensing and Daily Health Screening*** (Tohoku University)

5.2 Complementary Research Institutes, Centers of Excellence, and Innovation Programs

In order to place the COI program described above in greater context and offer further examples of center-like features and practices from Japan, the following section briefly describes some other 'centers of excellence', major research institutes and recent initiatives addressing multidisciplinary engineering research, including:

- **COE:** Global Centres of Excellence Program
- **WPI:** World Premier International Research Centres Initiative
- **AIST:** The National Institute of Advanced Industrial Science and Technology
- **RIKEN:** The Institute of Physical and Chemical Research
- **ImPACT:** The 'Impulse Paradigm Change through disruptive technologies' program

Capacity-building Centers of Excellence

Although there have been other recent 'critical mass' center programs in Japan (e.g. the 21st Century Centres of Excellence Program and World Premier International Research Centres Initiative), and some of these have invested in multidisciplinary engineering-related research, the programs themselves have broader remit than engineering and are primarily focused on '***capacity building***'[15] – i.e. focusing talent, resources and infrastructure in particular areas of potential strength with a view to further enhancing research professionalism, international competitiveness, visibility and connectedness. For example:

- **The Global Centres of Excellence**: As part of a government policy to reform the university system, the Global Centres of Excellence program was established by the Japan Society for the Promotion of Science in 2007. A key goal of the Global COE program was to enhance the education and research functions of **graduate schools**, with the aim of fostering highly creative young researchers who will go on to become world leaders in their research domains.
- **World Premier International Research Centres Initiative (WPI):** The WPI program is run by the Japan Society for the Promotion of Science and was launched in 2007 by MEXT with the goal of building **'globally visible' research centers** with research activities of a "global elite" standard. Particular attention was given to developing environments that were attractive enough to attract elite international researchers; and to develop **international connections and collaborations** with other elite research universities. The centers were given a high degree of autonomy, allowing them to introduce novel models for effective research operation and administration.

[15] This contrasts with the focus of this study, i.e. center programs which are primarily designed to support ***'added value' impact*** by assembling a critical mass of complementary multidisciplinary expertise to ***tackle research challenges of significant scale and complexity*** that couldn't be tackled effectively by with individual PI grants (cf NSF ERCs).

Public research institutes

When considering the features or practices of Japanese research center programs, especially those focused on multidisciplinary engineering R&D in collaboration with industry, it should be borne in mind that Japan has a national innovation system with well established and very large public research institutes, including some which have a long history of carrying out industry-relevant engineering research as part of their missions.

- **The National Institute of Advanced Industrial Science and Technology (AIST)** focuses on technology R&D of relevance to to Japanese industry and society; and on **'bridging the gap' between promising innovative technological ideas and commercialization**. AIST is one of the largest public research organizations in Japan, with a budget of almost ~¥99B (**US$990M**) and staff of about 2000 researchers (not including post docs, visiting researchers or technical staff) working at 10 research bases across the country, each with 'priority fields' in multidisciplinary engineering-related domains. In the context of ongoing policy attention to **internationalisation**, AIST has been proactively **building a global network** – recently signing memoranda of understanding with 30 major research institutes around the world.
- **RIKEN:** The Institute of Physical and Chemical Research is another a large research institute in Japan with about 3000 scientists on seven campuses across Japan and an annual budget of ~¥90B (**US$900M**). Although it originally was more focused on research in areas such as physics and chemistry, it has now got major activities in **multidisciplinary engineering R&D domains** such as medical devices, engineering, high-performance computing and computational science, and ranging from basic research to practical applications.

Innovation programs

It is worth noting that in addition to the COI program, there have been a range of recent innovation programs and initiatives focused on translational impact, and which have significant investment in multidisciplinary engineering R&D within their portfolios. Although these programs are not specifically *engineering* center programs, they have some functions which are similar in purpose and practice. One of the most high profile recent programs is the 'Impulse Paradigm Change through disruptive technologies' (ImPACT) program:

- **Impulse Paradigm Change through Disruptive Technologies** program: The ImPACT program, launched by the Cabinet Office Council for Science, Technology and Innovation in 2014 and managed by JST, is designed to encourage high-risk, high-impact R&D. ImPACT is often explained as a 'civilian DARPA', not least because of the key role played by Program Managers (cf DARPA program directors). ImPACT Program Managers are given significant budget and authority to set ambitious targets for societal and industrial change; and to select the group of researchers with the capabilities to deliver on high-risk, high-impact R&D aimed at achieving the necessary disruptive innovation. ImPACT has a 5 year budget of JPN¥ 55B (~US$0.54B) and is currently running 16 programmes, under the following themes:
    - Releasing manufacturing capability constraints in resources and innovation: **"Japan-style value creation for the new century"**.
    - Realizing an ecologically sound society and innovative energy conservation lifestyles: **"Living in harmony with the world"**.
    - Realizing a highly advanced functional society that surpasses the information networked society: **"Smart community that links people with society"**.

- Providing world's most comfortable living environment for an aging society with declining birthrate: **“Realize healthy and comfortable lives for all”**.
- Controlling the impact / minimizing damage from hazards and natural disasters: **“Realize a resilience that is keenly felt by every individual”**.

In keeping with ImPACT’s focus on professional R&D program management, the program provides detailed guidance for program managers on good management, challenge identification and team formation [ImPACT, 2014]

Further information:

- **Centre of Innovation program pages** on the JST website: https://www.jst.go.jp/tt/EN/platform/coi.html
- **JST, 2014.** *Center of Innovation (COI) Program.* Program brochure, Japanese Science & Technology Agency: http://www.jst.go.jp/coi/etc/brochure_EN.pdf
- **OECD (2014),** *Chapter 7. Japanese experience with centres of excellence*, in *Promoting Research Excellence: New Approaches to Funding*, pp. 165-186. OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264207462-10-en
- **JST, 2016.** *Impulsing Paradigm Change through Disruptive Technologies Program.* Program brochure, Japanese Science & Technology Agency: http://www.jst.go.jp/impact/download/data/ImPACT_p_en.pdf
- **ImPACT, 2014.** Impulsing Paradigm Change through Disruptive Technologies Program (ImPACT) Program Manager Application Guideline: *https://impact.jst.go.jp/koubo/pm/applicationprocedure_en.pdf*
- Basic Policy for Management of the Impulsing Paradigm Change through Disruptive Technologies (ImPACT) Program: *http://www8.cao.go.jp/cstp/sentan/kakushintekikenkyu/basicpolicy.pdf*

6. Other selected countries

In this section, information on centre programs from a number of selected countries[16] is briefly presented. This section highlights themes of interest which have repeatedly emerged throughout the course of this study, but also some noteworthy center program features or practices not revealed in the more detailed case studies.

In particular, the following national programs are briefly summarised (together with some additional contextual information):

- **China:** National Manufacturing Innovation Centers
- **Sweden:** VINN Excellence Centres
- **Canada:** Networks of Centres of Excellence
- **Ireland:** SFI Research Centres

[16] The material presented in the following section is almost entirely based on 'desk research' reviews of program documents available online (supplemented with information from evaluation reports, agency strategy documents, and external studies, where possible). Time, resource and access constraints meant there was less opportunity for gathering interview-based information than there was for some of the programs described in earlier sections. Nevertheless, efforts were made to interview at least one researcher, program director or policy official, familiar with each program.

6.1 China: National Manuacturing Innovation Centers

China has a very large number of 'critical mass' engineering R&D activities funded by different agencies through a variety of programs, e.g.: National Engineering Research Centers, National Engineering Technology Research Centers, National Key Laboratories, etc. Some programs funded by different organisations, e.g. Engineering Research Centers (supported by the Ministry of Science & Technology) and National Engineering Center (supported by National Development and Reform Commission) appear to have very similar functions and missions. The most recent center model, however the **National Manuacturing Innovation Centers program**, has some interesting features relevant to this study and is discussed in more detail below.

Although many of the older center models have been cited as comparators to NSF ERCs in previous reviews of international university-industry engineering research center models, there are a number of distinct differences. For example, most of these centers have worked at higher technology readiness levels than the university-based centers discussed elsewhere in this report. Although many are hosted by universities, many other (even within the same program) are not. More than half of National Key Laboratories are based in Universities, but only about a third of National Engineering Research Centers are based in universities, and even fewer National Engineering Technology Research Centers. Most of these centers do not appear to have a fixed life time.

It should also be noted that, by comparison with other countries, center program documentation and data (with key facts and figures about center funding, specific mission goals, etc) is not readily available in the public domain. This review did not identify any publically available evaluation reports or best practice studies.

National Manufacturing Innovation Centers: The recent national strategy '***Made in China 2025***'[17] recommended the creation of 15 'National Manufacturing Innovation Centers' by 2020, and a further 40 by 2025. Background documents and interviews with Chinese experts suggest that '*Made in China 2025*' was significantly inspired by Germany's 'Industry 4.0' strategy, the new National Manufacturing Innovation Centers are significantly based on the model for the institutes of the US National Network for Manufacturing Innovation.

By contrast with some established programs (e.g. National Engineering Research Centers) outlined above, the National Manufacturing Innovation Centers build on recent Chinese policies related to *implementation measures on promoting structure and development (SAITI),* which explores new models of the industrial innovation via strategic alliances.

It should be noted that this is still an *extremely* new program - the first national manufacturing innovation center only launched in July 2016. That center was the National Power Battery Innovation Center. The center's mission is to accelerate the industrialization of innovative battery technologies and enhance the competitiveness of China's power battery industry, not only through R&D, but also by providing testing services, pilot-scale experiments, and industry support services.

Although this review was unable to identify many details about the National Manufacturing Innovation Centers (e.g. it was not possible to get verifiable information on the planned

[17] http://www.gov.cn/zhengce/content/2015-05/19/content_9784.htm

budgets, scale, longevity, or KPIs for the program), nevertheless, the program design does appear to reflect important themes that have also arisen in a number of other countries, in particular:

- Attention to **manufacturing scale-up**, in particular building a critical mass of multidisciplinary engineering R&D capabilities to **accelerate the industrialisation of key 'generic industrial technologies'**
- Efforts to deploy a greater range of scientific and technological resources to address industry-relevant engineering R&D challenges by building stronger linkages and **alliances between universities and firms, but also public research institutes**
- Although the program is still very new, there are some suggestions that the centers will have significant **flexibility and freedom to experiment with organisational models** for effective industry-academia-research cooperation

Further information:

This report is based, primarily, on a review of (English language) documents available online. By comparison with other countries, Chinese center program documentation and data (with key facts and figures about center funding, specific mission goals, etc) is not as readily available in the public domain. This review did not identify any publically available evaluation reports or best practice studies.

Additional information on the Chinese research and innovation system of centers, as well as recent policy developments, can be found in the following:

- **Chinese State Council, 2015.** *Government issues project guidance to boost manufacturing.* Press release, August 2016: http://english.gov.cn/policies/latest_releases/2016/08/22/content_281475423253219.htm
- **Chinese State Council, 2015.** *Made in China 2025.* Press release, May 2015 [Chinese language only] *http://www.gov.cn/zhengce/content/2015-05/19/content_9784.htm*
- **Guo, R., 2013.** *Key Players and the Nature of their Interactions in Chinese STI Resource and Budgetary Allocations.* Policy Brief, STI No. 9. A report by the *Study of Innovation and Technology in China* (SITC) project of the University of California Institute on Global Conflict and Cooperation.
- **Springut, M., Schlaikjer, S., Chen, D., 2011.** *China's Program for Science and Technology Modernization: Implications for American Competitiveness.* A report for the US-China Economic and Security Review Commission.
- **Chen, K., Kenney, M. 2006.** *Universities/Research Institutes and Regional Innovation Systems.* World Development, 35 (6), pp. 1056–1074.
- **Wu, W., Zhou, Y., 2012.** *The third mission stalled? Universities in China's technological progress.* Journal of Technology Transfer, 37, pp. 812–827

6.2 Sweden: VINN Excellence Centres

The VINN Excellence Center programme, fun by the VINNOVA innovation agency, supports collaboration between universities, research institutes and firms (as well as other public sector stakeholders) with a focus on enabling participating companies to be better connected to and better able to take advantage of new knowledge and new technologies emerging from the public research base. In this context, there centers have an important mission to help build networks and communities necessary to address needs-driven research, in particular strengthening linkages between university research and other actors.

Unlike many of the other center programs discussed in this report, which have a much broader scope in terms of eligible scientific research domains, the majority of the centers have research agendas which are focus on multidisciplinary engineering research challenges (i.e. the are more comparably thematically to NSF ERCs). Also similar to the NSF ERC program, is the VINN Excellence Center program emphasis on the 'added value' that can be created by carrying out the research in an integrated center activity (i.e. how the 'whole is greater than the sum of the parts' of the set of individual PI projects).

The VINN Excellence Centres program has a strong emphasis on basis and applied multidisciplinary research related to 'needs driven' industry challenges (and opportunities). Center activities should ensure that the outputs they generate in terms of new knowledge and new technological developments are in a format that industry can effectively absorb, in order to effectively development products, processes and services. The first cohort of 19 VINN Excellence Centers were launched in 2005-2006 in 9 universities with funding of up to 10 years. Around 100 firms, public R&D institutes and other stakeholders are contributing as centre partners and together with VINNOVA and the host universities made a total investment of SEK4.5B (~US$540M) over the 10 years. VINNOVA itself invested up to SEK63M (~US$7.5M) in each VINN Excellence Center, so there is significant leveraging of stakeholder funds[18]. VINNOVA's ambition is to establish a further 25 VINN Excellence Centers for a further 10 year period.

Some interesting features and practices of the VINN Excellence Centre include:

- **International connectedness and visibility:** As with many of the other center programs in smaller countries, there is stronger focus on the international dimension of the centres' missions. In particular, there appears to be greater requirement for (and effort put into) developing international connectedness, visibility, and recruitment (staff, students, post docs).
- **Engagement with public research institutes:** As seen in other countries with established public R&D institutes (and other Research & Technology Organisations), Excellence Centers play a greater role in networking with these organisations, allowing them to more easily draw on research institutes' complementary expertise, where necessary, to address industry needs-driven challenges.
- **Collaboration between research/graduate schools and private sectors:** As discussed elsewhere in this study, most other countries do not have a US-style formal 'graduate school' system. New center models are, therefore, being developed

[18] Although the program has several similarities to the NSF ERC program, the industry needs drive research agenda (and the role of industry partners in shaping the agenda) and the level of 'gearing' of agency funds with private sector cost-share may suggest some similarities with the NSF I/UCRC program.

alongside other programmatic initiatives to develop aspects of grad school-like experience in important emerging science and engineering domains. There is potential for Excellence Centers to help connect existing or new research schools to industry, and support the development of courses that address issues to do with innovation, commercialisation and industry collaboration.

- **Evaluation reports:** The VINN Excellence Center program is one of the few that have evaluation reports publically available online. Although these reports are largely a collection of individual site review reports, they reviews are carried out systematically and the reports offer some general observations about effective practices. Although many of the highlighted practices well known to NSF center community (e.g. the importance of 'added value', importance of a strong director, etc), the evaluation reports offer interesting information and insights.
- **Networking function:** The network-building aspects of Excellence Centers' missions, appears to extend beyond just connecting academics and industry, but also adds value by connecting firms which have shared interests in a particular domain.
- **Performance impact survey:** VINNOVA has surveyed Excellence Centers, following up on annual status reporting, as part of efforts to more comprehensively understand the overall program's impact; and potentially identify any 'course corrections' for the program. The most recent survey [Anaya-Carlsson & Lundberg, 2014] highlights the cross comparison challenges impact metrics, stating:

> "*…it is important to keep in mind that objectives and conditions are different for the Centres and this affects the activity level, direction and results of the centres activities. All in all, the different conditions may result in the Centres need to create their own impact logic, namely to clarify how they contribute to the achievement of their specific short and long-term objectives that are found at the programme level. Some caution should therefore be exercised before drawing conclusions on the basis of comparisons between Centres. For example, generating patents is not an objective for some Centres because the participating partner/sectors do not have this as part of their business logic*".

Further details:

- **Programme webpage:** www.vinnova.se/en/Our-acitivities/Innovativeness-of-specific-target-groups/Individuals-and-Innovation-Milieus/VINN-Excellence-Center/
- **O´Kane, M., et al., 2016.** *Third Evaluation of VINN Excellence Centres*: www.vinnova.se/en/Publications-and-events/Publications/Products/Third-Evaluation-of-VINN-Excellence-Centres/
- **Anaya-Carlsson, K., Lundberg, M., 2014.** *Results from 18 VINN Excellence Centres reported in 2012: Compilation of the survey results:* http://www.vinnova.se/en/Publications-and-events/Publications/Products/Results-from-18-VINN-Excellence-Centres-reported-in-2012/
- **List of current centres**: www.vinnova.se/en/Results/Starka-forsknings-och-innovationsmiljoer/Strong-research-and-innovation-milieus---VINN-Excellence-Center/
- **Lidgard, A., Lundberg, M., 2010.** *Center of Attention.* Public Service Review: European Union: issue 19

6.3 Canada: Networks of Centers of Excellence

Networks of Centers of Excellence (NCE) is a joint initiative of the Canadian Natural Sciences and Engineering Research Council, the Social Sciences and Humanities Research Council, the Canadian Institutes of Health Research, Industry Canada and Health Canada. The NCE initiative offers a **suite of programs** designed to facilitate the mobilisation of a critical mass of leading Canadian R&D and entrepreneurial actors around key research and innovation challenges of importance to the economy and society.

The suite of NCE programs include:

- **Networks of Centres of Excellence (NCE):** The main NCE program is focused on mobilising multi-disciplinary research communities and resources from across Canada to address key innovation challenges of importance to the Canadian economy and society. NCEs can engage a large number of partners from multiple academic institutions and various public and private-sector organizations[19] depending on the nature of the innovation challenges they are addressing. Although primarily research networks, NCEs also engage in training activities to supply the next generation of skilled workers in areas relevant to their innovation domain. NCE's vary in size and scope, but the NCE program offers the following statistical averages for networks funded to date: Average Award over 15 year Network Life = ~ CA$54M (~US£40M); Average Contributions over Network Life: ~ CA$35M (~US£27M); Average number of Researchers per Network per Network Lifecycle: ~ 220; Average number of Institutions per Network per Year: ~ 30
- **Centres of Excellence for Commercialization and Research (CECR):** CECRs are a not-for-profit corporations which assemble clusters of research expertise with key industrial actors. CECR is designed to share knowledge, expertise and resources to accelerate the translation of novel technologies into real products (and services). Although CECRs are normally created by universities, they can also be formed by research institutes, colleges or firms). In particular, a key purpose (and expected impact factor) of CECRs is to stimulate new commercialization activities that would probably not otherwise have taken place. The CECR program invests funding of CA$30M **(~US$23M) per year**. CECR investments are leveraged by the program's cost-sharing requirements. CECRs also attract other funding, including FDI and venture capital to translate and scale-up new technologies to market
- **Business-Led Networks of Centres of Excellence (BL-NCE)**: BL-NCEs are led by not-for-profit consortia from the private sector. The BL-NCE program addresses major industrial research & innovation challenges by engaging with universities, research organizations and private sector firms. The program's partnership model gives parity to academic and private-sector partners. Cost-sharing requirements mean that >50% of a BL-NCE's R&D costs are funded by network partners. One of the most striking features of the BL-NCE program is that it permits networks to fund private sector partners directly, so they can conduct research at their own facilities. The BL-NCE program receives funding of CA$12M **(~US$9.5M) per year**.

Interesting practices/features of the Networks of Centers of Excellence include:

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[19] In 2013-14, NCE activities involved the participation of over 1,900 public and private sector organizations in Canada and abroad).

- **Distributed networks:** As reflected in its title, this program adopts a "distributed network model" to link groups of researchers at universities distributed across Canada, with industrial and other partners, to collaborate on common research problems. The emphasis of networking being in no small part a response to Canada's large land area and widely distributed population.
- **Longevity of funding:** NCEs have relatively long lifetimes. NCEs can have up to **15 years of funding** (in up to three potential funding cycles of five years)
- **Research at industry partner facilities:** As discussed above, the BL-NCE program allows networks to fund private sector partner BL-NCE projects at their facilities
- **Attention to international visibility and connectedness:** Similar, to trends in other countries, the NCE program places a particular emphasis ncrease Canada's international visibility and reputation as a leader by attracting world-class collaborations, and developing partnerships with international organisation counterparts, when applicable
- **Strong communications efforts:** As befits a distributed network model (of centers of excellence), there is significant attention paid to intra-network communications. Although it was beyond the scope of this study to evaluate the communications processes of particular NCEs, this programs practices may merit further study.
- **Quality of program documentation:** The NCE program host an impressive collection of program guides, best practices manuals for governance, etc. There appears to be significant transparency of process with, for example, performance measurement strategies are laid out in detail.
- **Sharing of best practices:** Following the NCE competition, the NCE Secretariat hosts best practices sessions to bring together newly funded networks. Group discussion focuses on topics essential to the NCE program. Participants in the session may also pose questions to guest speakers representing active, successful networks regarding things such as lessons learned, good governance practices developed, and how to manage conflict of interest.

Further information

- Program webpage: www.nce-rce.gc.ca/Programs-Programmes/NCE-RCE/Index_eng.asp
- List of currently funded networks: www.nce-rce.gc.ca/NetworksCentres-CentresReseaux/NCE-RCE_eng.asp
- Audit of the Networks of Centres of Excellence programme: www.nserc-crsng.gc.ca/_doc/Reports-Rapports/Audits-Verifications/AuditNCEProgram_e.pdf
- Program webpage: www.nce-rce.gc.ca/Programs-Programmes/BLNCE-RCEE/Index_eng.asp
- List of currently funded networks: www.nce-rce.gc.ca/NetworksCentres-CentresReseaux/BLNCE-RCEE_eng.asp
- Program webpage: www.nce-rce.gc.ca/NetworksCentres-CentresReseaux/CECR-CECR_eng.asp
- NCE, 2016. Best Practices for Governance and Operations. Centres of Excellence for Commercialization and Research (CECR). Networks of Centres of Excellence (NCE), Canada: www.nce-rce.gc.ca/_docs/BestPractices-PratiquesExemplaires/CECR_eng.pdf

6.4 Ireland

Science Foundation Ireland's **Research Centres Programme** funds university-based 'critical mass' research centers carrying out science and engineering research with the potential to impact the Irish economy and society. Centres address research challenges where the complexity of the research agenda **requires the "*advantages of scope, scale, dynamism, synergy, duration, equipment, and facilities that a centre can provide*"**. In this context, the centers have significant similarities to NSF ERCs. This is not altogether surprising given key elements of the predecessor program, **the *Centers for Science, Engineering & Technology (CSET)*, were closely modelled on aspects of NSF center models, including ERCs**.

SFI Research Centers do, however, have some distinctive interesting features and practices:

- **Attractors of Foreign Direct Investment:** The SFI Research Centers program documentation explicitly highlights the potential and value of attracting large foreign direct investment (FDI), in particular via corporate R&D laboratories. Although somewhat ad hoc, there is a strong tradition of Center teams and funding agency officials working closely with the national inward investment agency to support efforts to attract FDI.
- **Supplementary 'spoke' grants**: Science Foundation Ireland runs a so-called 'spokes' competition whereby centers can apply for further funding to address new opportunities. In particular, the program is designed to be **responsive and flexible to opportunities to add new industrial partners**
- **Funding levels and duration:** Centers are funded for 6 yearrs with up to €5M/year in direct costs (**~US$5.7M / year)**. This investment is up to 70% of the expected overall Research Centre budget. SFI expects a minimum cost share contribution of 30% must be secured from industry, at least one-third in cash.
- **Mission focus on economic impact:** The center program explicitly links center impact goals to Ireland's recent national innovation strategy ('*Innovation 2020: Ireland's Strategy for Research and Development, Science and Technology*', DJEI, 2015), which identifies particular areas of strategic opportunity for Ireland, including 14 National Research Priority areas and six broad enterprise themes (ICT, manufacturing & materials, heath & medical, food, energy, and services & business processes)

It may be worth noting that, echoing a theme that has emerged in a number of the country case studies in this report, the *Innovation 2020* strategy highlighted a perceived **need for higher 'technology readiness level' research** that addressed **technology development and prototype demonstration** not being adequately met by the current configuration of centres.

SFI Research Centres co-exist in the Irish national innovation system with a number of other public R&D actors. There are 15 '**Technology Centres**' which carry out market-focussed strategic R&D based on collaborative research agendas designed and led by industry. The Technology Centres are jointly supported by the economic development agencies Enterprise Ireland (focused on indigenous firms) and IDA Ireland (focused on multinational enterprises) with the aim of allowing Irish companies and multinationals to work together in these centres with Irish researchers. A typical Technology Center receives ~€1M **(~US$1.1M) per**

year over a **5 year lifecycle** with continued funding dependent on a range of industrial impact metrics.

In addition to SFI Research Centres and EI/IDA Technology Centres, there are also a small number of **public R&D institutes** addressing specific sectors, including the ICT engineering-focused Tyndall National Institute and the bioengineering/biopharma-focused National Institute for Bioprocessing Research & Training (NIBRT).

A recent report by the Technopolis consulting group for the Irish government [Technopolis, 2015] assessed opportunities to further enhance the ***'market-focused research centre capacity'*** of Ireland's innovation system. A key message of this report focused on a perceived "*substantial demand for* ***middle [technology readiness level] research, and for short-term applied and contract research*** *in Ireland*" to complement the earlier proof-of-concept/-feasibility collaborative research carried out by SFI research centers. In particular, the report pointed to a number of European countries' networks of Research & Technology Organisations (e.g. Fraunhofer, IMEC, etc) which offer technology validation and testing services, pilot line/scale-up facilities, contract R&D and technical consultancy services. In this context, the Technopolis analysis of the Irish research center system reflects policy themes observed in many strategy documents reviewed in this study – i.e. attention to the complementary functions and linkages between university-based multi-disciplinary (TRL 2-3) 'technology push' engineering research and 'market pull' demonstration and scale-up (TRL 4-6) R&D institutes. The Technopolis report also suggests that many of the current market-focused centers are **not of a scale and critical mass to be internationally competitive**.

Further information:

- **DJEI, 2015.** Directory of Research Centres and Technology Centres, 2015: http://www.knowledgetransferireland.com/About_KTI/Reports-Publications/Directory-of-Research-Centres-and-Technology-Centres-2015.pdf
- **SFI Research Centre Program webpage**: www.sfi.ie/funding/funding-calls/open-calls/sfi-research-centres-programme-2016.html
- **SFI Research Centre Program brochure** on currently funded centers: www.sfi.ie/assets/media/files/downloads/Investments/2015%20RC%20Leaflets/Combined.pdf
- **SFI Research Centre Program 'Call for proposals'** (2016): www.sfi.ie/assets/media/files/downloads/Funding/Funding%20Calls/centres/Research%20Centres%20Programme%20Call%202016.pdf
- **Technopolis, 2015.** *Roadmap for the further development of market-focused research centres in Ireland.* A report for the Department of Jobs, Enterprise and Innovation, Government of Ireland by the Technopolis Group. https://www.djei.ie/en/Publications/Publication-files/Strengthening-Irelands-Market-Focused-Research-Centre-Landscape.pdf
- **Technology Centres program page** on the Enterprise Ireland website: https://www.enterprise-ireland.com/en/research-innovation/companies/collaborate-with-companies-research-institutes/technology-centres.html

7. Documentary Sources

The following sources have been used to gather information on the international center models reviewed in this study.

- **BMBF, 2014.** *Forschungscampus – öffentlich-private Partnerschaft für Innovationen.*

- **De Barros, F.B., 2014.** *Australia Case Study: Centres of Excellence as a Tool for Capacity Building.* Programme on Innovation, Higher Education and Research for Development (IHERD), Organisation for Economic Cooperation & Development (OECD).

- **CSTI, 2015.** *Report on The 5th Science and Technology Basic Plan.* Council for Science, Technology and Innovation, Cabinet Office, Government of Japan.

- **DFG, 2010.** *Stellungnahme zu den Programmen Sonderforschungsbereiche und Forschungszentren der Deutschen Forschungsgemeinschaft.*

- **DFG, 2010.** *Monitoring des Förderprogramms Sonderforschungsbereiche.*

- **DFG, 2013.** *Excellence Initiative at a Glance: The Programme by the German Federal and State Governments to Promote Top-level Research at Universities.* A Deutsche Forschungsgemeinschaft brochure summarising investments from 2012–2017.

- **DJEI, 2015.** *Innovation 2020. Excellence, Talent, Impact: Ireland's Strategy for Research and Development, Science and Technology*. A report for the Department of Jobs, Enterprise and Innovation, Government of Ireland.

- **EPSRC, 2012.** *EPSRC Centres for Innovative Manufacturing – Call for Proposals 2012*

- **EPSRC, 2014.** *EPSRC Centres for Innovative Manufacturing.* Brochure.

- **EPSRC, 2015.** *Future Manufacturing Research Hubs 2016.* Call for outline proposals document. Engineering & Physical Sciences Research Council.

- **Forschungsunion Wirtschaft – Wissenschaft, 2013**. *Prosperity through research – What tasks lie ahead for Germany?* An Industry-Science Research Alliance Prospect Study.

- **Geyer, A. 2014.** *The German Excellence Initiative.* In Chapter 6, *Promoting Research Excellence: New Approaches to Funding,* OECD.

- **Haliwell, J.E., 2013.** *Canada Case Study: Centres of Excellence as a Tool for Capacity Building.* Programme on Innovation, Higher Education and Research for Development (IHERD), OECD.

- **Hartmann, D. 2009.** *Increasing Australia's level of international research collaboration via the CRC Program.* Cooperative Research Centres Association.

- **Hellstrom, T., 2014.** *Centres of Excellence as a Tool for Capacity Building.* Draft synthesis report, Programme on Innovation, Higher Education and Research for Development, OECD.

- **Koschatsky, K., et al., 2015.** *Public-private Partnerships in Research and Innovation: Case Studies from Australia, Austria, Sweden and the United States.* Working Papers Firms and Region, No. R2/2015, Fraunhofer Innovation Systems Institute.
- **Hepburn, N., Wolfe, D.A., 2014.** *Technology and Innovation Centres: Lessons from Germany, the UK and the USA.*
- **IDA/STPI, 2007.** *Designing the Next Generation of NSF Engineering Research Centers: Insights from Worldwide Practice.* Science and Technology Policy Institute
- **Imboden, 2016.** *Internationale Expertenkommission zur Evaluation der Exzellenzinitiative* [German language only].
- **Innovate UK, 2015.** *Innovate UK Delivery Plan, Financial Year 2015/16.*
- **Kobayashi, S., Saitoh, Y., 2014.** *Japanese experience with centres of excellence.* In Chapter 7, *Promoting Research Excellence: New Approaches to Funding,* OECD.
- **Koschatzky, K., et al., 2015**. *Public Private Partnerships in Research and Innovation: Case studies from Australia, Austria, Sweden and the United States.* Working Papers Firms and Regions, No. R2/2015. Fraunhofer ISI.
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- **NCE, 2016.** *Best Practices for Governance and Operations. Centres of Excellence for Commercialization and Research (CECR).* Networks of Centres of Excellence (NCE), Canada.
- ***NIFU, 2012.*** *Centres of Excellence in the Nordic countries: A comparative study of research excellence policy and excellence centre schemes in Denmark, Finland, Norway and Sweden.* Working Paper 4/2012. Nordic Institute for Studies in Innovation, Research and Education (NIFU).
- **NRF, 2013.** *Research Centres of Excellence. Brochure.* National Research Foundation, Singapore.
- **OECD, 2014.** *Promoting Research Excellence: New Approaches to Funding.* Organisation for Economic Cooperation & Development (OECD).
- **OECD/RIHR, 2014.** *Research excellence initiatives and centres of excellence.* In Chapter 3, *Promoting Research Excellence: New Approaches to Funding,* OECD.
- **Schiermeier, Q., 2016.** *Germany's science hubs win in major research revamp: Research clusters emerge as the big success of Germany's Excellence Initiative — despite its focus on elite institutes.* Nature magazine, news article: 02 February 2016:
- **SNSF, 2014.** *The National Centres of Competence in Research NCCRs: Research in networks.* Swiss National Science Foundation.
- **SNSF, 2016.** *Guide 2016: National Centres of Competence in Research.* Swiss National Science Foundation.

- **Technopolis, 2012.** *Research Centres in Ireland: Funding Models, Oversight Mechanisms and Vision of a Future Research Centre Landscape.* An independent report to Forfás.

- **Technopolis, 2015.** *Roadmap for the further development of market-focused research centres in Ireland.* Department of Jobs, Enterprise and Innovation, Government of Ireland.

- **Um, M.-J., 2013.** *Korea Case Study: Centres of Excellence as a Tool for Capacity Building.* Programme on Innovation, Higher Education and Research for Development (IHERD), OECD.

- **Vogel, G., 2016.** *Germany’s excellence program gets good grades.* Science magazine, 29 January, 2016. AAAS.

Appendix I: Long list of international programs

1. Centres for Innovative Manufacturing (EPSRC, UK)
2. Centres for Doctoral Training (EPSRC, UK)
3. Innovation & Knowledge Centres (InnovateUK, UK)
4. Manufacturing Hubs (EPSRC, UK)
5. Quantum Technology Hubs (EPSRC, UK)
6. Collaborative Research Centres (DFG, Germany)
7. DFG Research Centres (DFG, Germany)
8. Clusters of Excellence (DFG, Germany)
9. Forschungscampus (BMBF, Germany)
10. Networks of Centres of Excellence (NCE, Canada)
11. Business-led Networks of Centres of Excellence (NCE, Canada)
12. Centres of Excellence for Commercialization and Research (NCE, Canada)
13. SFI Research Centres (SFI, Ireland)
14. Technology Centres (Enterprise Ireland, Ireland)
15. Strategic Centres for Science, Technology and Innovation (Tekes, Finland)
16. VINN Excellence Centres (VINNOVA, Sweden)
17. Berzelii Centres (VINNOVA / SRC, Sweden)
18. National Centres of Competence in Research (SNF, Switzerland)
19. 21st Century Centres of Excellence (JSPS, Japan)
20. Global Centres of Excellence (JSPS, Japan)
21. World Premier International Research Center Initiative (JSPS, Japan)
22. Center of Innovation (COI) Program (JST, Japan)
23. Cooperative Research Centres (AusIndustry)
24. ARC Research Centres (ARC, Australia)
25. Research Centres of Excellence (NRF, Singapore)
26. Corp Lab@University Scheme (NRF, Singapore)
27. COMET: Competence Centres for Excellent Technologies (FFG, Austria)
28. National Manufacturing Innovation Centers (China)
29. Chinese National Engineering Research Centers (China)
30. National Key Labs (China)
31. State Key Labs (China)
32. National Development and Research Commission Centers (China)
33. Natural Science Foundation of China centers (China)
34. CSIR National Laboratories (CSIR, India)
35. Impacting Research Innovation and Technology program (DST, India)
36. Israeli Centers of Research Excellence (ISF, Israel)
37. Centres for Research-based Innovation (Research Councils of Norway, Norway)
38. Norwegian Centres of Excellence Scheme (Research Councils of Norway, Norway)
39. Advanced Research Center Program (Korea)
40. Brain Korea 21st century (BK21) Program (Korea)