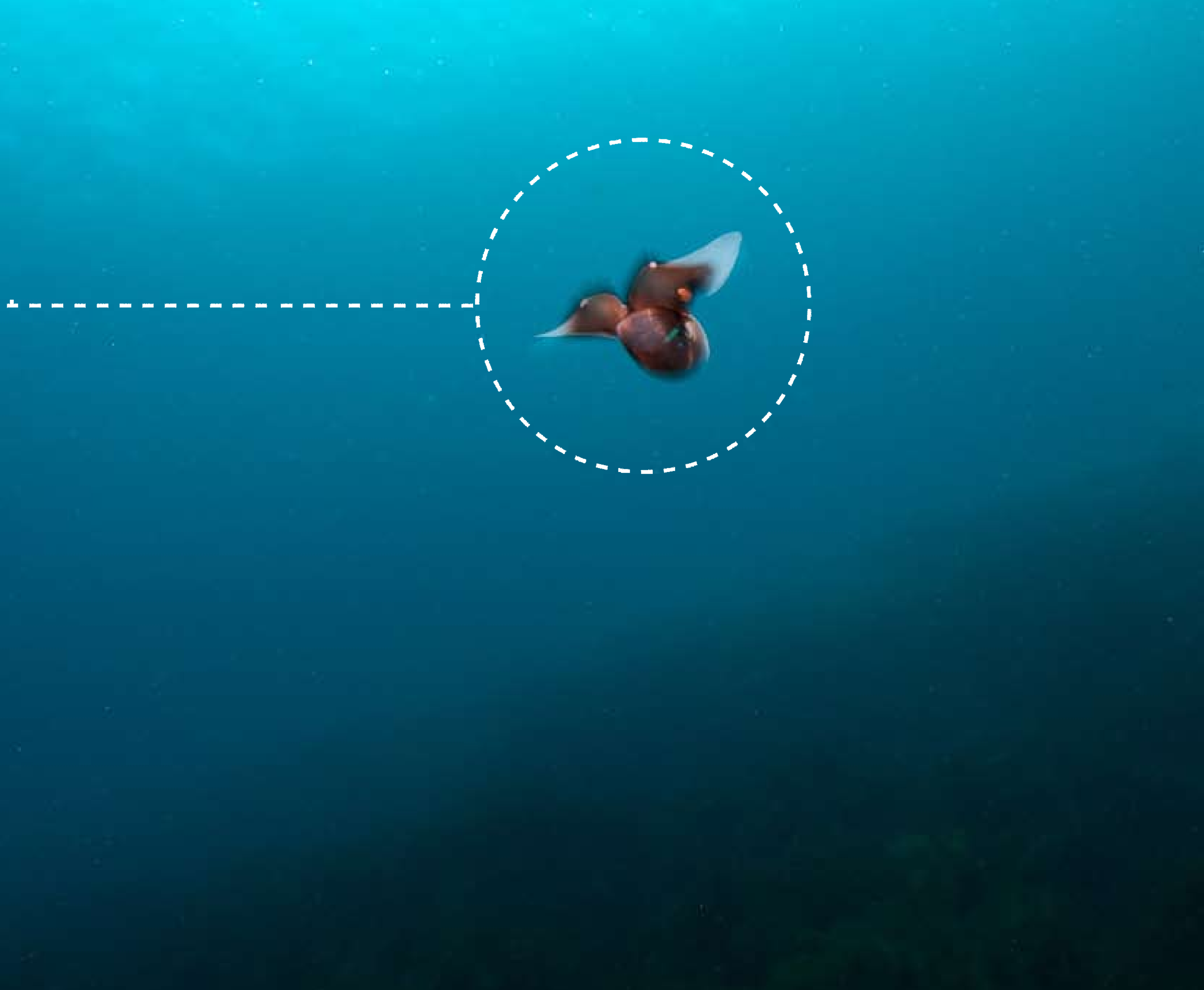
Strategic Research Area
NTNU Marine Coastal Development

Science Plan 2020 – Vision and Strategic Research Agenda



NTNU
Norwegian University of Science and Technology

NTNU MCD. 2009. Science plan 2020. Vision and Strategic Research Agenda. October 2009. (www.ntnu.no/marine)
Front page foto: The pteropod Limacina helicina in Norwegian coastal waters (photo: Geir Johnsen)
Illustrations: Maria – www.mariaberge.com.
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Introduction

Since our forbears first settled along our barren coasts, exploitation of the bountiful ocean has been vital for the livelihood of the Norwegian people. In the last century the Marine and Maritime Industries became the cornerstone of the welfare of the nation. Assessment studies have shown that these industries also have substantial potentials for the future.

The main sectors of marine industries are:

- Seafood producers, e.g., fisheries, aquaculture, and processing industries
- Oil and gas producers, e.g., offshore exploitation and shore based supply and processing industries
- Maritime industries, e.g., shipbuilding, engineering industries, and international shipping

Our coastal communities have been a hotbed for the continuous innovation processes that have developed, transformed and expanded the activities from basic fishing and marine transport activities into a comprehensive and internationally competitive industrial cluster that now includes offshore oil exploitation and aquaculture. It is due to the well developed industrial culture of these coastal communities that Norway is maintaining a leading position in the marine world. More than 60% of the export value of Norway originates from the marine sector. We have also a strong international position in marine research. The further development of the marine sector, where most of the real values of the nation are created, is obviously very important for our coastal communities as well as for the nation. An important future challenge is to be able to continue producing food and energy from the ocean while maintaining our pure and unpolluted marine environment.

The challenges we are facing are becoming more and more complex and future solutions will be more knowledge intensive. The current pressures of increasing international competition and globalisation have caused major adaptive actions and restructuring processes in the marine sector, displaying a flexibility that bodes well for the future. One of the major challenges for our nation is to establish the boundary conditions needed for an overall sustainable development in the marine field. To achieve this, our society needs major involvement and contributions from the knowledge sector.

A recent foresight study of the seafood sector concluded that knowledge was paramount for future development in all scenario examined. Knowledge was a main driver and a pre-condition of industrial innovation and competitive ability in a scenario where Norway became a world leading producer and exporter of seafood, equipments, services, and competence over the entire value chain of the seafood sector. On the other hand, in the scenario where we failed to take advantages of our strong marine traditions, as the innovation capabilities of the coastal communities disintegrated in the globalized stock market economy, knowledge was still important to reduce the negative consequences for industries, society and economy.

The future is about producing food and energy from the ocean while maintaining our pure an unpolluted marine environment

1) Strategic basis

The Norwegian University of Science and Technology (NTNU) is a university with a broad academic scope. It has been given the national responsibility for graduate engineering education in Norway. NTNU's research has an international focus and can be characterized by being at the leading edge in specific areas of technology, with a broad disciplinary scope and an interdisciplinary approach.

The strategic plan *"NTNU 2020 – Internationally outstanding"* emphasize that the main tasks of NTNU are *to develop and maintain knowledge in interaction with society, to develop the competence of candidates through research based education of high quality, and to renew society and contribute to value creation and welfare standards of the society.* The value base of NTNU is *to be Creative, Constructive, and Critical, with innovations in research and society and the search for sustainable solutions of national and international challenges as important elements.*

Upon the most recent reorganisation of the university in 1995, the Norwegian Parliament emphasized in its mandate to NTNU that a holistic and multidisciplinary perspective is paramount for dealing with the comprehensive future challenges of mankind. With its broad range of scientific disciplines, NTNU were particularly challenged to establish arenas and support processes for facilitation of interdisciplinary research and education. It was anticipated that the answer of the complex questions of the future must be searched for through interactions across the classical disciplines. As a means for developing interdisciplinary research, NTNU has selected six thematic interdisciplinary strategic areas, of which Marine and Maritime Research is one area.

The Strategic Focus Areas were established within sectors of particular importance for the Norwegian society and economy in year 2000. The Strategic Focus Area "Marine and Maritime Research" (NTNU Marine) has two main pillars:

1. Centre for Ships and Ocean Structures (CeSOS), Centre of Excellence, funded by the Research Council of Norway and NTNU
2. NTNU Marine Coastal Development (NTNU MCD)

The present Science Plan presents a vision and an overall Research Agenda 2020 worked out by the consortium forming NTNU MCD and their SINTEF counterparts. It describes vision and overall objective, the consortium, the prioritized thematic research areas, selected multidisciplinary priorities, infrastructure needs, and main strategic goals for the interdisciplinary research activities planned for the next 12 years (2008-20).

A main role of NTNU MCD is to stimulate interactions between social sciences, humanities, natural sciences, and engineering sciences. Acknowledging the fundamental values of NTNU, a primary guiding principle will be to search for solutions which are socially, environmentally, economically and energy-wise sustainable. A second principle is system thinking, with integration of knowledge from the individual disciplines. A third principle is to prioritize, beside the fundamental aspects of research, also innovation and research with impact for society and industry.

It is our creed, that innovation through cooperation across disciplines requires strong disciplines. Cooperation is not to overshadow the perspectives and responsibilities the individual disciplines, but to generate interaction between inquisitive people who primarily take care of and develop their own discipline.

A second main role of NTNU MCD is to act as facilitator for developing and deepening the strategic cooperation with SINTEF. NTNU and SINTEF has developed a common strategy; with the vision to

A primary principle is to search for solutions which are socially, environmentally, economically and energy-wise sustainable.

A second principle is system thinking, with integration of knowledge from the individual disciplines

A third principle is to prioritize, beside the fundamental aspects of research, also innovation and research with impact for society and industry become internationally outstanding together (*"NTNU and SINTEF – Internationally outstanding together, 2006-2010"*). SINTEF Fisheries and Aquaculture is, on behalf of the SINTEF Group, the appointed strategic partner of NTNU MCD.

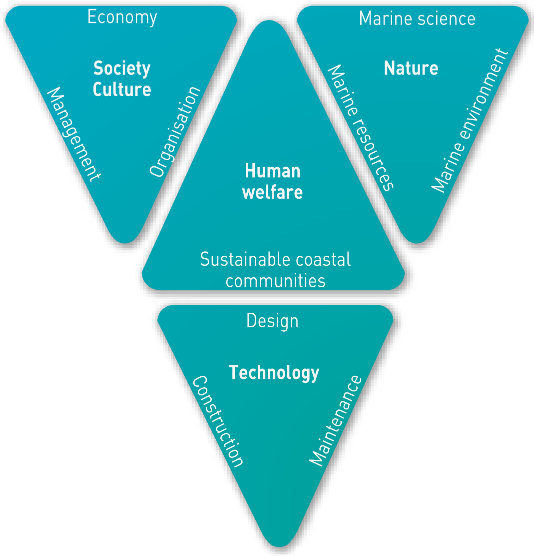


FIGURE 1
Disciplines and perspectives forming a platform for the multidisciplinary, holistic approach of NTNU MCD and SINTEF counterparts

With their broad range of scientific disciplines, NTNU and SINTEF together represent an over-critical mass and an interdisciplinary broadness in research and education in the marine field which cannot easily be matched by other universities or institutes. The scientific strategic basis for interdisciplinary interaction in research and education of the NTNU-SINTEF partnership rest on the following main disciplinary pillars, also illustrated in Figure 1:

- Humanities and social science
- Marine natural science
- Marine engineering science

The space encompassed by these three pillars forms the framework of the research and education potentials. An ultimate challenge is to contribute to sustainable coastal communities which base their welfare on a sustainable exploitation of living and non-living marine resources in a wide sense. Technology is man's tools for managing, protecting, and exploiting nature for the benefits of society. Technology is therefore paramount for our future welfare.

With their broad range of scientific disciplines, NTNU and SINTEF together represent mass and interdisciplinary broadness in marine research and education which cannot easily be matched by many other institutions

2) Main scientific domains and consortia

The marine research activity of NTNU MCD is organised within three main interacting domains along the value chain which all have specific needs for research infrastructure (Figure 2). SFF-CeSOS and SFI-CREATE are mentioned as associated partners, but their activity is to the degree needed integrated in the overall research agenda. The main scientific domains are:

- **Ocean Space Research – Methodological and technological development for research on living and non-living resources**
  This domain includes marine research with a major focus on methodological and technological systems for research on utilisation and conservation of marine living and non-living resources. Research topics cover technological, scientific and societal aspects, and there is a main focus of developing new instrumentation and systems and to use these widely for scientific purposes in many disciplines.
- **Fisheries and Aquaculture – Science, engineering and societal research**
  The domain involves aquaculture and fisheries research, including harvesting of non-fish marine biomass. Aquaculture has a main focus on marine aquaculture, in particular engineering aspects of different production systems, the sustainability of those production systems, and the fundamental natural scientific and engineering disciplines of aquaculture engineering. Fisheries research has a main focus on fishing technology and sustainable fisheries with a broad societal perspective.
- **Marine Resource Processing – Sustainable Marine Resource Processing and Technology**
  The domain includes important downstream aspects of marine resources, including fish, other animals, macroalgae and genetic marine resources. Important issues are raw materials and their quality and treatments, process engineering, energy chain studies, including super-cooling and super-freezing, marine biotechnology, advanced industrial applications of biopolymers and other products, seafood design issues, and management of sea food value chain.

The NTNU and SINTEF consortium involve participation from 6 faculties at NTNU and 7 SINTEF institutes (Figure 3). SINTEF Fisheries and Aquaculture is, on behalf of the SINTEF Group, the appointed strategic counterpart to the NTNU MCD Consortium.

Some departments/institutes have a main activity within the marine field, others are involved with minor activities. Main competence and activity of the NTNU departments are shown in Table 1 and Enclosure Table 1.

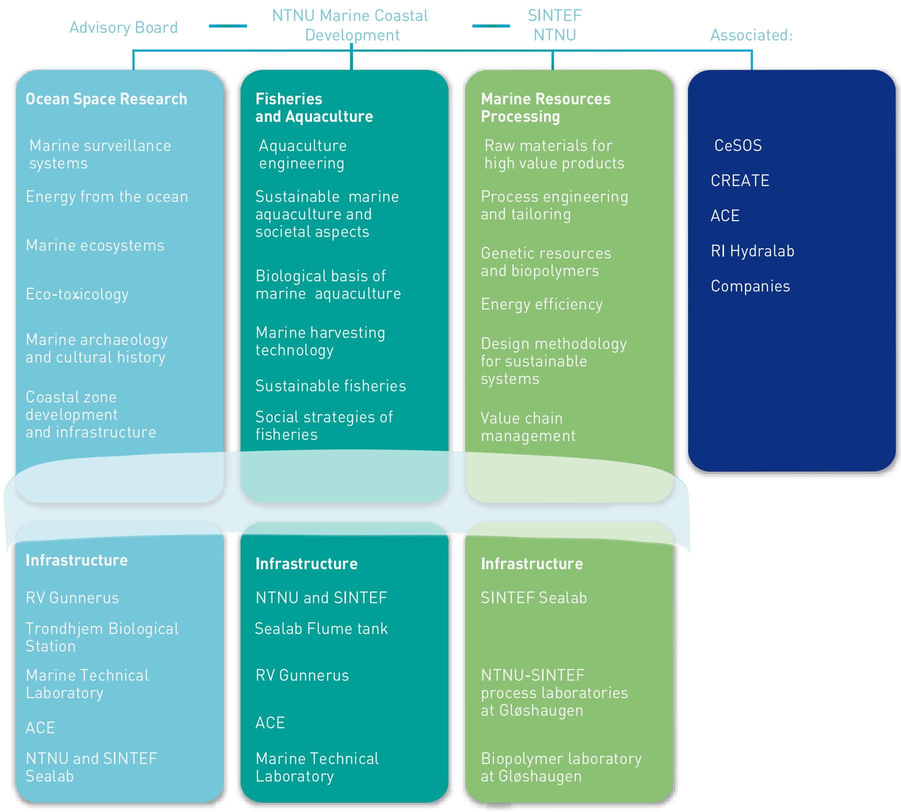


FIGURE 2
Scientific domains of NTNU MCD and SINTEF counterparts with main research topics and important infrastructure illustrated. CeSOS (Centre of Excellence for Ships and Ocean Structures, Centre) and CREATE (Centre for Research-based innovation in Aquaculture Technology) are closely related, although independent, associated partners.

FIGURE 3
NTNU Departments and SINTEF Institutes that are taking part in the cooperation.

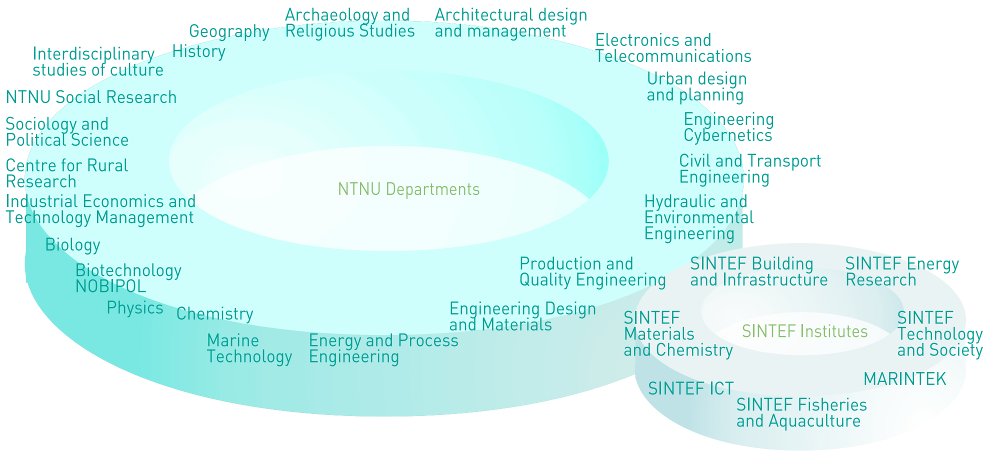


TABLE 1
Main competence and experience of relevant NTNU Departments.

NTNU DEPARTMENT	MAIN EXPERTISE
History and Classical Studies	Fisheries and aquaculture history
Archaeology and Religious Studies	Marine archaeology, maritime history, cultural heritage
Interdisciplinary Studies of Culture	Cultural perspectives of coastal communities
Geography	Coastal geography, societies
Sociology and Political Science	Fisheries politics, risk evaluations
Industrial Economics and Technology Management	Value chain management
NTNU Social Research, Studio Apertura	Organization studies, work processes and management in aquaculture
Centre for Rural Research	Regional policies, regional development, coastal communities, resource use/management, coastal industries
Architectural Design and Management	Harbour architecture
Urban Design and Planning	Ecological based planning of coastal land use
Biology	Marine biology, biological oceanography, aquaculture, eco-toxicology, coastal ecology, behaviour
Biotechnology	Marine biopolymers, biochemistry, chemical engineering, processing, marine biotechnology
Chemistry	Trace metal chemistry, metal pollution
Physics	Marine optics
Marine Technology	Marine constructions, marine systems and operations, fisheries and aquaculture technology
CeSOS	Centre of Excellence for Ships and Ocean Structures
Hydraulic and Environmental Engineering	Water processing technologies
Civil and Transport Engineering	Coastal engineering, infrastructure, geotechnique
Production and Quality Engineering	Food technology and manufacturing
Energy and Process Engineering	Processing engineering, energy and value chain management
Engineering Design and Materials	Design methodologies, sustainability and simulation. Structural integrity, metal forming and composites, collaborative engineering
Mathematical Sciences	Bio-modelling, statistics
Engineering Cybernetics	Aquaculture and fisheries cybernetics, instrumentation, telemetry
Electronics and Telecommunications,	Acoustics, underwater communication
Museum of Natural History and Archaeology	Marine archaeology, maritime history, cultural heritage, marine biodiversity

4) Vision, objectives and main strategy

The overall vision of NTNU Marine Coastal Development is:

- **Excellence in research and higher education supporting sustainable coastal development**

The ultimate objective of the thematic focus areas is to improve the quality and recognition of NTNU research and higher education. The long-term objective of NTNU MCD, complying with *"NTNU 2020 – Internationally outstanding"* and *"NTNU and SINTEF – Internationally outstanding together, 2006-2010"*, is the following:

- **To improve the quality, relevance, and impact of the marine related research at NTNU as a basis for higher education and innovation furthering sustainability and welfare of coastal communities**

As the national university of science and technology, NTNU should play a leading role in developing sustainable marine-related activities that secure and maintain our marine industries role as a front runner in the marine world. This depends on more than excellence in science and technology; solutions must also be politically, culturally, economically and environmentally sustainable. Research should consider all aspects of sustainability, and should encompass both long-term and short-term perspectives.

The general strategy for reaching the objective of the strategic focus area is to facilitate research cooperation in NTNU within and across disciplines. Specific overall strategies for complying with *"NTNU 2020 – Internationally outstanding"* and *"NTNU and SINTEF – Internationally outstanding together, 2006-2010"*, is the following:

- Continue to support the development of key marine disciplines and facilitate research cooperation across disciplines within the scientific domains
- Support and facilitate research that result in a higher number of peer reviewed publications and higher international recognition – an increase in the number of PhD students is a general measure for achieving this.
- Develop closer research cooperation and interaction with SINTEF counterparts to make NTNU and SINTEF attractive partners for industry and the public sector.
- Support the establishment of Gemini centres as a means to develop stronger research cooperation between stable research groups and thereby foster excellence in research.
- Establish and maintain modern and relevant infrastructure and instrumentation, in own laboratories and together with SINTEF, and make that infrastructure broadly available for scientists within the research domains
- Establish regional, national, and international networks for communication and cooperation in research and education with universities, institutes, companies, and public authorities
- Work continuously to revise and improve master and doctoral education programmes, with particular focus on international master education and establishing PhD schools within the marine domain

One important challenge for NTNU is the establishment of viable multidisciplinary research groups that can efficiently respond to the complexity of the most vital long term challenges facing our nation. SINTEF institutes are, to a great extent, multidisciplinary arenas. A more intimate cooperation may support the process of developing such arenas in NTNU as well. Multidisciplinary research arenas are also a means to facilitate the transfer of relevant experience and technology developed in other industries to the marine field. In this context, interaction with research arenas dealing with the oil industry, relevant process industries, the ICT industries, equipment industries, the medical industries as well as the service and consultancy sectors, may become an important source for cross-fertilization.

The ultimate objective is to improve NTNU research and recognition in marine research and higher education

The ultimate strategic means is to facilitate research cooperation within and across disciplines and to do that by diverse means together with SINTEF

5) Research agenda 2020

The following section describes briefly the backdrop for present marine research, including some general research challenges facing us within the scientific domains given priority (Figure 2). It also describes the consortia that will be involved in the interdisciplinary research activities, and the overall research agenda and strategic goals of the work.

5.1 Ocean Space Research – Methodological and technological development for research on living and non-living resources

5.1.1 Background

From the dawn of civilisation, seafarers have always been intrigued by the mysteries of the oceans. The ocean has triggered people's fantasies and has been both a benevolent friend and a dangerous foe. Perceptions of the ocean have been reflected in multitudes of cultural manifestations, religious as well as profane. Traces of this have been found in our ancient coastal rock carvings. However, the technology to really explore the sub sea world has become available only in recent years. Ocean space is the "last frontier" of mankind on our blue planet. It is a major challenge to learn more about the potential of the ocean, its living and non-living resources and its functioning and interaction with the terrestrial biosphere and the global climate. The observation and sampling techniques that are now becoming available are based on contemporary achievements in marine technology, information and communication technologies, and on a growing fundamental knowledge of the ocean and its ecosystems.

It is a major challenge to learn more about the ocean, its living and non-living resources and its functioning and interaction with the terrestrial biosphere and the global climate

Among the available equipment are improved sensors for detection of physical, chemical and biological environments, a variety of stationary, mobile and autonomous platforms to carry those sensors. Equally important is a variety of sub-sea devices and communication technology for transferring data from *in situ* positions to other sub water installations, floating buoys, or to satellites that transfer signals back to the laboratory. Progress is made developing advanced acoustic transducers, video cameras, improved oxygen sensors, and detection systems for ocean colour. Platforms for carrying sensor systems are continuously improved, such as remotely operated vehicles (ROV), autonomous underwater vehicles (AUV, gliders etc) relying on subsea navigation and communication systems. Different types of stationary platforms for monitoring water masses or the sea floor are becoming available, in addition to buoys, research vessels, airplanes, and satellites. Marine communication systems for sub water and air communication may transfer information in between platforms and between platforms and the laboratory.

Advanced technological equipment is currently used for many purposes that include both commercial, management related, and scientific activities. An increasing number of scientific disciplines benefit from such new methods, many of which are just in their infancy. Physical, chemical, and biological oceanographers may for example use high-tech instrumentation for studies of climate change, structure and function of marine ecosystems, detection and quantification of marine resources, bio-prospection of genetic resources, and harmful algal blooms. Ocean circulation may be monitored as well as habitats of the sea floor. Ocean modellers are deriving data sets for validation of their models. Marine technologists may monitor the environment for and the condition of marine sub sea installations, such as systems for renewable energy production and oil and gas exploration. Geologist and geochemists will be able to collect detailed information about sea floor bathometry and geology, and marine archaeologists may undertake underwater research and documentation of our maritime history and activities of ancient coastal communities, which are also indirect proxies for climate change.

A further improvement in the technology to explore the sea will affect all sectors of the society, directly or indirectly. Better knowledge will aid decision making, for example in the question of human impact on climate change. This is an issue that influences our national economy and technology developments in most sectors. It affects community planning, and ultimately employment and human welfare. An advanced marine technology is already of paramount importance for the management and exploitation of living and non-living marine resources, and new opportunities will be emerging for producers of advanced marine instrumentation.

5.1.2 Consortium of Ocean Space Research

NTNU and SINTEF together possess a very comprehensive generic base of competence that may contribute to the further development of technology for exploration of the ocean space (Figure 4). This includes marine natural science and engineering disciplines with a potential for contributing to advancement of technology and methods for operation, surveillance, and communication. Other

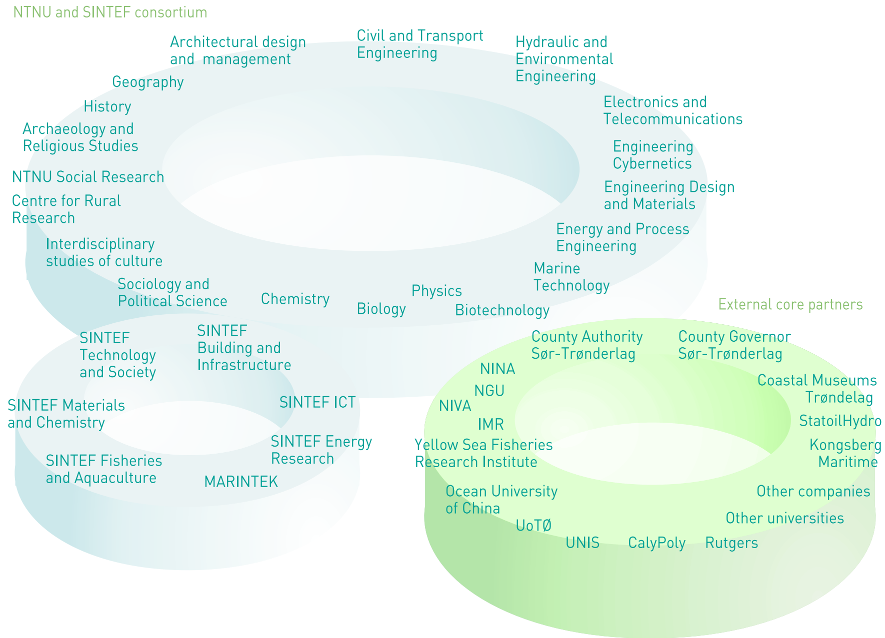


FIGURE 4
Consortia involved in the Ocean Space Research domain (OSR-consortium)

research groups, within a broad range of disciplines, are potential users of new technology, contributing to the enhancement of environmental, cultural, and societal research. These include oceanographers, biologists, biochemist, environmental scientists, geochemists, and marine archaeologists. Social sciences and disciplines of the humanities contribute to link development in technology and science to societal aspects and history.

External core partners of NTNU and SINTEF (Figure 4) are in some way related to one or more partners in the NTNU-SINTEF partnership. Figure 4 is regrettably not complete; new partners are welcome, and will be included upon mutual agreement. NGU has a specific and complementary position; NTNU and SINTEF have no comparable marine geological activity. This is also the case for NINA, which has major complementary research activities in the marine domain. Institute of Marine Research, The University of Tromsø and the University of Svalbard have signed institutional agreements with NTNU and/or SINTEF. The County representation forms a link to the public sector, which has been strongly involved in developing the marine sector of the region.

5.1.3 Research agenda 2020 – Ocean SpaceResearch

The ultimate focus of the Ocean Space Research domain will be on the opportunities and challenges that will become increasingly important as our exploitation of living and non-living recourses in the Northern Seas are increasing. This also include production of renewable energy.

Challenges will involve technological developments for marine exploration and operation, for studies of interactions and impacts on marine ecosystems, marine environment, and society. A future exploration and exploitation of living and non-living recourses in Northern Seas will require highly advanced technology for research and surveil-

RV Gunnerus on duty in the Trondheim fjord (photo: Leif Magne Sunde)

Use of Autonomous Underwater Vehicles (AUV) for surveillance of the marine ecosystem (photo Geir Johnsen) lance. Advanced instrumentation systems and specialised research platforms will be of paramount importance. The research activities of the Ocean Space Research domain involve the following main research topics:

- Marine surveillance and communication systems
- Energy from the ocean
- Marine ecosystems
- Eco-toxicology
- Marine archaeology and cultural history
- Coastal zone development and infrastructure

Marine surveillance and communication systems involve development of advanced instrumentation systems for exploration and exploitation of living and non-living marine resources including gene resources. All research topics within the domain will, to some extent, contribute to the development of both the methodology and of the operational systems.

Challenges will involve technological developments for marine exploration and operation, for studies of interactions and impacts on marine ecosystems, marine environment, and society

The instrumentation systems includes technology for ecosystem studies, environmental impact studies, deep sea research, ocean acidification, monitoring and mapping of living and non-living resources, climate change research, bio-prospecting of genetic resources, studies of our marine cultural heritage, geochemical and geological studies, and development of methods and technology for extracting renewable energy from the ocean.

The methodological systems include sub-sea installations and a wide range of smaller stationary or mobile platforms (e.g., ships, satellites, ROV, AUV, gliders, landers, stationary systems). The sensor technologies include acoustics, bio-optics/spectral analysis, and image analysing systems. Sub-sea navigation and communication technology and networks are particular challenges. The instrumentation systems represent a methodological platform for description of the real sub-sea world. 3D modelling (e.g., hydrodynamic, ecological, and ocean space modelling) and visualisation can contribute to describe the state of a virtual world.

Energy from the ocean – It is a major marine challenge of our time to establish production systems for renewable, CO_2 neutral energy from the ocean. Members of the OSR-consortium will address marine technical, environmental, marine biological and societal aspects of such developments, in cooperation with the NTNU Energy Focus Area which will take care of the technological aspect of the energy production systems. The focus will be renewable energy production based on waves, tides, and wind, with a main focus on offshore windmill power plants and large scale seaweed production for bio-energy, optionally associated to the mill constructions. Seaweed biomass can provide raw material for marine lipids and polymers, the remaining biomass may be used for bio-fuel.

Kelp forest dominated by Alaria esculenta (photo: Geir Johnsen)

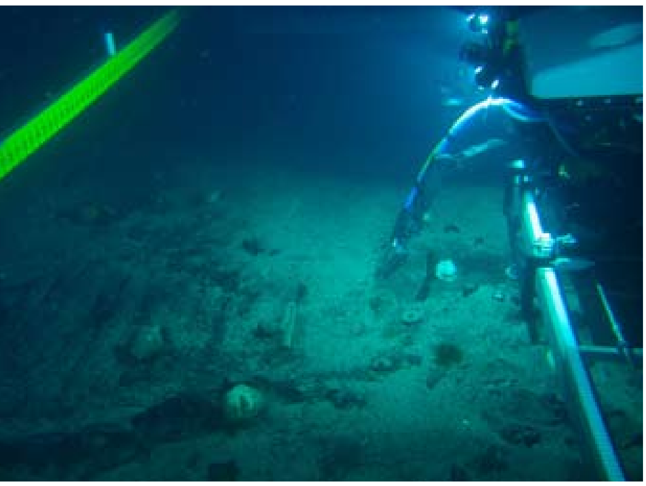
Colourful anemone in the Trondheim fjord (photo: Nils Tokle)

Marine ecosystems – Knowledge on diversity, genetic resources, and biology and ecology of marine ecosystems is fundamental for their sustainable exploitation and management. Energy production, be it from petroleum or renewable marine resources, as well as harvesting, will affect the marine ecosystem. Members of the OSR-consortium will contribute to the understandings of such interactions. Such knowledge is also important for combining offshore culture of seaweed and renewable energy production and for the testing and development of marine surveillance and communication systems. Members will also contribute to studies of climate change, ocean acidification, and search for new genetic resources useful for mankind – blue biotechnology. Marine surveillance and communication systems are essential for ecosystem research, and the studies will contribute to the further development of such systems.

Eco-toxicology – The ecosystems of the Northern Seas are particularly subjected to exposure from persistent toxic compounds. This may occur through atmospheric transport and precipitation in the Polar Regions, or through ocean current transport of pollution to high latitudes. Local human activities, like oil and gas exploitation might be another type of source. Such exposures, ranging from hazard from blow-outs and oil spill to long-term exposures of toxic compounds to organisms and food webs represent a multitude of challenges. Environmental toxins are a potential threat for the marine and coastal environment and for marine living resources, including food safety. Members of the OSR-consortium will contribute to a further understanding and mitigation of these problems.

Marine archaeology and cultural history – Our marine cultural heritage embraces our maritime history and the activities of our coastal ancestors from the Stone Age until the present. Over the centuries, human interaction with the ocean has been the basis for the development of coastal settlements and communities, a dependency that still continues. Among the research challenges are studies, with a long-term comparative perspective, of maritime culture and communities from geographically, climatically and culturally different regions. Members of the OSR-consortium will contribute to a further understanding of our maritime history. Marine acoustic systems and underwater remote vehicles like ROV and sonars are important tools for this research, and the studies will contribute to the further development and use of such systems.

Cuckoo wrasse (Labrus bimaculatus) as part of the Norwegian fauna (photo Nils Tokle)



Marine archaeological investigations at the Ormen Lange gas field (photo: Marek Jasinski)

Coastal zone development and infrastructure – Marine and maritime industries depend on space in the coastal zone, and future development and expansion of these activities will to en increasing extent create conflicts with other users and stakeholders. Marine and terrestrial wildlife reserves, recreation and tourism represent stakeholders trying to restrict industrial expansion. The welfare of coastal communities depends on the ability to strike a sound balance between exploitation and protection. Our current legislation requires efficient means and models for coastal planning and resource utilisation. This is a multidisciplinary, major challenge for our society. Factors involved are coastal environment and ecosystems, coastal communities and their activities, socio-economic factors, and aspects of coastal engineering, including harbour infrastructure and architecture. New collaborative engineering approaches can enable rapid access to global expertise and e.g. remote diagnostics even at small satellite sites/offices in coastal areas with strict environmental regulations. Members of the OSR-consortium will contribute to a further holistic understanding of coastal zone development and infrastructure.

5.1.4 Strategic goals 2020 – Ocean Space Research

The following strategic goals are defined for the Ocean Space Research domain for the period 2008-20:

- Develop the Trondheimsfjord and the coastal regions off Trøndelag into an Ocean Space Research Laboratory, a methodological R&D platform that is easily accessible for all partners, and then implement the plans within 2010
- Establish over time a cross-disciplinary research group with multiple users and technology providers in the Marine Surveillance and Communication domain
- Establish a Gemini centre within this domain before 2013
- Establish active and sustained cooperation and joint project activity with the Energy Focus Area to develop technology for extracting renewable energy from the ocean
- Consider the establishment of other cross disciplinary Gemini centres, for instance within

The Ocean Space Research Laboratory is an integrated research platform for interdisciplinary research and development related to ocean space

Eco-toxicology, or other research areas of the domain (within 2012)
- Establish a broad network of cooperating companies involved in marine instrumentation and operation in the marine field and take actions to organise these developments in a SFI within 2020
- Increase the research activity in externally funded and cross-disciplinary research projects
- Establish a study in "Marine Surveillance and Sub-sea Communication Systems and Installations" within the Coastal Marine Development Master Programme

5.1.5 Infrastructure – The Ocean Space Research Laboratory (OSR-Laboratory)

The planned OSR-Laboratory is an integrated research platform for interdisciplinary research and development related to the ocean space. It includes the main infrastructural facilities of the OSR-consortium, and it is the major research arena and means to develop cooperation between disciplines and institutions. A main agenda is to make the infrastructure of individual partner's easily available for the entire consortium, forming an integrated infrastructure for research and higher education within the domain. All core partners may include their components to the integrated facility. The OSR-Laboratory will include for example the following infrastructure components:

- Databases, describing for example biological, geological, historical, and socio-economic data for the fjord and coastal region off Trøndelag
- Bathymetric maps, geology and habitats
- Maps of cultural heritage of the seafloor
- 3D ecological model for fjord and the coastal region off Trøndelag
- Satellite and buoy-based sea surface monitoring abilities.
- R&D facility for sub-sea communication networks
- Trondhjem Biological Station, with outdoor sea-water basin, research laboratories for biological research and space for facilities for R&D on marine operations and marine surveillance and communication systems
- FF Gunnerus, an advanced and well equipped research vessel
- Marine Technology Laboratories, Tyholt (Model Tanks, Ocean Lab, Cybernetics Lab)
- ACE Testing facility of marine constructions, Valsneset, Bjugn

5.2 Fisheries and Aquaculture – Science, engineering and societal research

5.2.1 Background

A paradigm shift for global marine fisheries took place around 1990 when global fisheries yields levelled off. Before that, the global total marine harvest, including both captured and cultured production, had increased steadily by 1.5-2 % per year since 1950, mainly because of increased yields in fisheries. It is most surprising that marine aquaculture during the last 15 years has contributed to the same annual increase in total harvest as experienced before 1990. This clear trend, derived from FAO-statistics, indicates that future increases of seafood production must come from mariculture.

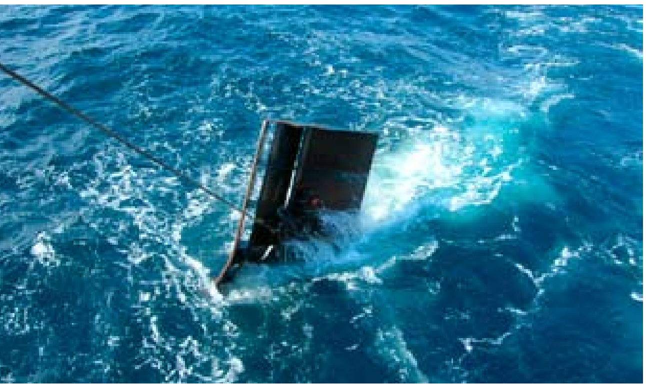
Aquaculture. The future development of marine aquaculture is facing substantial obstacles. We can not, without major efforts, expect aquaculture to develop in the same way as agriculture did during the green revolution 4-5 decades ago, driven by an increased availability of cheap fertilisers. We are still harvesting a main fraction of the raw material that is used for fish feed from marine resources. However, these feed resources are gradually becoming less available for fish feed, as they are more and more being consumed directly by humans. The use of agricultural feed resources in aquaculture has been increasing in recent years. Such use of human food resources for feeding animals will not be sustainable in a longer time perspective. This has become clear through the pronounced increase in prices of many agricultural products in 2008. Availability of "new" marine resources, or similar marine sources for fish feed, may postpone a possible "feed-crisis" in mariculture.

The global mariculture production will continue to grow, but the availability of bio-resources for fish feed will affect the composition of cultured species. Marine plants and herbivore animal species, like tilapia and species of shellfish, will become most important if marine feed resources become severely constrained. Europe is the leading continent in finfish cultivation, with carnivores like salmon, sea bass, and sea bream as the most important species. A reduced availability of fish feed of marine origin may therefore hit Europe harder than many other regions. A changing structure in global aquaculture due to lack of suitable marine feed may affect European coastal communities, because it may impede the possibility of creating a competitive aquaculture industry and related employment in Europe.

Limited space for mariculture in coastal waters and a growing environmental concern among public and authorities, expressed through the EU water directive, are at present major constraints on mariculture. The production technologies will most likely, because of these external drivers, continue to cluster into two already established technological concepts:

1) **Cage culture,** further developed towards use in fairly exposed coastal systems, or ultimately developed for operation under real offshore conditions.

2) **Land or shore based culture,** with reuse of water, emission control of wastes, and optimised energy cycling as key functions. It is not likely that other major concepts like pond culture or sea ranching will become more important in Europe during the first decades.



Fisheries gear used in Norwegian trawling (photo: Harald Ellingsen)

Marine juveniles will like today be produced in indoor hatcheries and nurseries, but the production will be further improved and automated. For all types of culture, there is a continuous drive for more cost efficient technologies and better predictability. The future prospects of marine aquaculture are strongly linked to political and social objectives. The complete picture with limited feed resources, a strong need for technological innovation, critical costumers, limited space for production, a stronger environmental concern, and the ongoing process of globalisation calls for a broad social and human perspective in R&D. A sustainable development of aquaculture in coastal waters is important for creating new employment opportunities. Many coastal communities are under heavy pressure throughout Europe. Aquaculture and seafood is also paramount for human nutrition and health.

The complete picture with limited feed resources, a strong need for technological innovation, critical costumers, limited space for production, a stronger environmental concern, and the ongoing process of globalisation calls for a broad social and human perspective in R&D

Fisheries. Over the last century, technology development has been the driving force in changing fisheries from a nearly artisanal fishing and gathering of food, to a large-scale industrial activity. Although the technological development has improved the efficiency within most of the world fishing fleets, fundamental problems such as overexploitation, poor selectivity of fishing gear, large post harvest losses and poor utilisation of by-products are not solved. In addition, the working conditions onboard fishing vessels are generally poor and fishermen are more exposed to fatalities than workers in most other occupations. High risk of accidents affects new recruitment and creates economic problems as well, such as high social cost of accidents, the loss of skilled labour, and high insurance costs.

Harvesting, processing and distribution of seafood products are also energy-intensive activities. Fish capture is energy demanding and there is much evidence indicating increased fuel consumption in fishing in resent years. This is surprising, considering the massive technological development. One would expect that improved engines, advanced fish finding equipment, fishing gear that is more efficient, as well as improved control systems would lead to improved energy efficiency. The increasing energy prices cause serious economic problems to important sectors of the industry. In terms of sustainability, it may well be asked, if the development so far has contributed in a positive direction.

Salmon sea cages in the Mid-Norwegian area (photo: Yngvar Olsen)

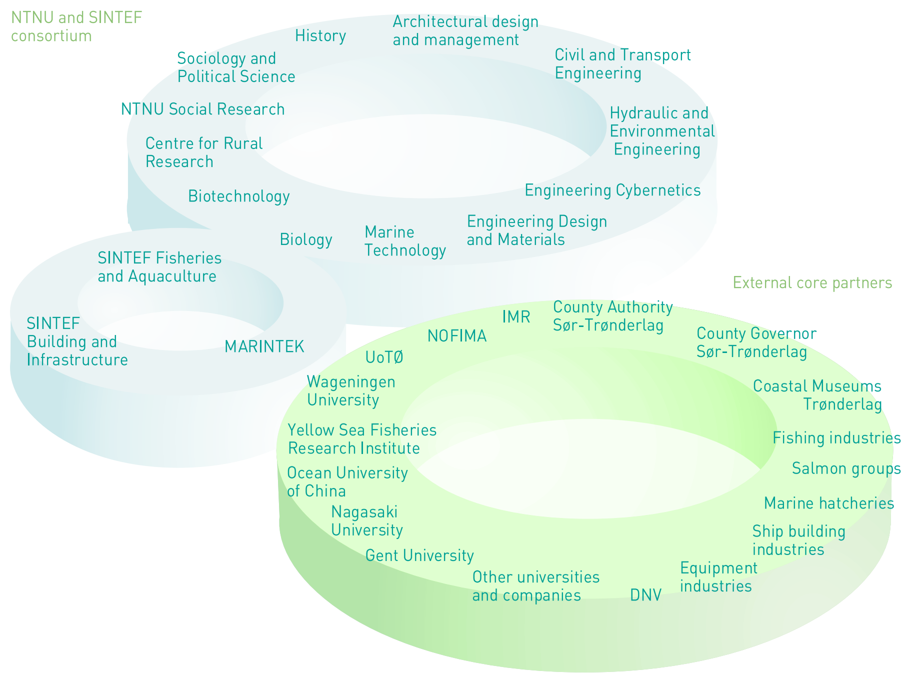


FIGURE 5
Consortium involved in the Fisheries and Aquaculture domain (AF-consortium)

A paradigm shift, however, can be seen in the seafood consumers' attitudes to the environmental impact of seafood production. Future developments may be driven by the consumer awareness of the need for sustainable development and product documentation revealing any environmental impact.

Most commercial fish species are fully utilized or exploited above safe biological limits, and the supply of captured wild fish cannot be expected to increase in the future. FAO however states that the global demand for fish will increase. This will result in a general increase of the value of captured fish, and increased utilization of the capture fish directly for human consumption. The use of such fish for industrial purposes will be reduced, leaving less fishmeal and oil for aquaculture feed. The handling and storing requirements of fish for human consumption are different from those required by the fish oil and meal industries. Consequently, the fishing vessel of the future must be designed to take better care of the catch than what is often the case today.

As mentioned above, environmental impacts from the fisheries are not only a matter of interest for the authorities, but are also increasingly focused by the public. Increased pressure from strong consumer groups and retailer organisations is thus expected in the direction of a more environmentally sustainable food production chain. This also includes requirements with respect to documentation. Introduction of environmental product labels combined with requirements for traceability and safety of foods is expected. The development of mutually accepted criteria for sustainability will be important in the future.

5.2.2 Consortia involved

NTNU has, together with SINTEF, the diversity of engineering disciplines and the scientific competence in biosciences needed to become a world leading university actor in aquaculture engineering (Figure 5). These include the engineering disciplines that are crucial for a further development of both open ocean cage systems and land based recycling systems, and to make these industries more sustainable and competitive. A focus on aquaculture engineering requires a strong fundament of biological competence on larval and adult organisms in culture, and NTNU has a well-organised research group working with fundamental and more applied aspects of marine aquaculture. Marine juvenile technologies have been a long-term research focus of that group.

In future fisheries, questions related to environmental and ethical issues are expected to be important areas of concern. These include responsible catching, combating of illegal fishing and unintended mortality, energy use, sea floor disturbance, and societal impacts are expected to attract attention. The distribution and logistic chain must further secure that the fish food is brought to the marked in an optimal way. NTNU, SINTEF and the core consortium partners have the competence needed to play an important role in the development of competence, technology and concepts needed to meet these challenges.

The external core partners are in some way related to one or more partners in the NTNU-SINTEF partnership and will be taken up according to an open policy. The list of core partners is dynamic and incomplete.

5.2.3 Research agenda 2020 – Aquaculture

Aquaculture research will have a main focus on marine aquaculture, in particular engineering aspects of different production systems, the sustainability of those production systems, and the fundamental natural scientific and engineering disciplines of marine aquaculture and aquaculture engineering. Aquaculture is becoming a mature industry, and it is the belief of the AF-consortium that Norway can play a major international role in knowledge generation and management as well as in supporting industries and services, which both have large international potentials. An overall approach of the research will be to take full advantage of knowledge, development and progress made in other sciences and industries, as for instance in offshore oil industry, relevant process industries, human medicine, and agriculture (Figure 6).

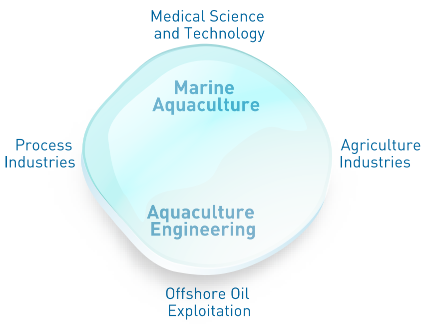


FIGURE 6 *A general strategy for developing marine aquaculture is to fully take advantage of the knowledge and technology developed and implemented for other relevant industries.*

The research activity within the Aquaculture domain involves the following main research topics:

- **Aquaculture engineering**
- **Sustainable marine aquaculture and societal aspects**
- **Biological basis of marine aquaculture**

Aquaculture engineering – The research is generally aquaculture system oriented, with major concern on equipments, systems, instrumentation, automation, management, animal welfare, and environmental aspects and impacts.

Hatchery and nursery – Hatchery aquaculture systems (HAS) has been designed and operated more or less in the same way for more than 20 years world wide, although with better protocols, routines and improved production results over the years. An ultimate vision of members of the AF-consortium is to contribute to the establishment of the next generation juvenile technology for marine fish, with a production technology which is widely automated and cost efficient. The future HAS is highly specialized, automated, and intensified as compared with today. Live feed will still be used in the very early stages and separate fed plants produce that live fed, calling for an advancement in technology.

An ultimate vision is to contribute to the next generation hatchery and nursery technology which is widely automated and cost efficient

Cage and open ocean mariculture – Major driving forces like environmental concern, legislation, cost efficiency, and limited space in coastal waters drives production in cage aquaculture systems (CAS) towards more exposed locations in the western world, and ultimately towards open ocean or offshore locations. Going offshore with CAS is a major challenge of marine and maritime engineering, including mooring, constructions, maintenance of CAS using ROV and advanced tools, security, logistics, fouling, and welfare of the cultured organisms, be it fish, shellfish, or macroalgae. It is a vision of the AF-consortium that CAS will grow bigger, become localized more in large clusters, and in more exposed waters. There will also be a stronger focus on environmental interaction and of generating added value of feed investments through combined production of other organisms based on wastes generated by salmon CAS (IMTA, see below).

Aquaculture engineering is defined as a branch of agricultural engineering that studies aquatic species cultured and the production systems used in their culture (Wikipedia)

Major research efforts on sea based aquaculture in NTNU and SINTEF is presently mainly undertaken and coordinated in SFI-CREATE/SFF-CeSOS. Representatives of the AF-consortium will address complementary research of CAS in close cooperation with CREATE/CeSOS, including environmental impacts.

Aquaculture research will have a main focus on aquaculture engineering of production systems, the sustainability of these systems, and the fundamental biological sciences of aquaculture engineering

Aquaculture system engineering will, according to a core premises, only be successful if undertaken in concert with the best available biological knowledge on the cultured organism and their developmental stages

Recycling aquaculture – A second line of development drives production into land based systems with reuse of water and energy, with controlled waste management, or recycling aquaculture systems (RAS). Water quality is paramount in aquaculture, and developments must consider aspects of microbial state and water processing engineering. It is the vision of the members of the AF-consortium that all future production of juveniles will be undertaken in RAS, and that some species will be produced in RAS through the whole life cycle. The consortium will address the further development of recycling engineering, with a focus on microbial processes, energy use, and animal welfare. Technological measures to prevent disease will be developed using alternative approaches from other industrial sectors.

All aquaculture systems – More efforts into equipments, automation and implementation of control systems is a main challenge for all production systems in the young aquaculture industry, and the needs are particularly clear in the juvenile industry. Members of the AF-consortium will address fundamental and practical research aspects of introducing modern cybernetic methods of model based control systems and implement these methods in broad cooperation with other disciplines. Other AF-members will develop sophisticated methods of telemetry for research and for aquaculture production.

Sustainable marine aquaculture and societal aspects – The sustainability of marine aquaculture encompasses economic, animal health and welfare, societal, public perception, and environmental aspects, and a holistic perspective is paramount. Aquaculture will increasingly become an important industry for value creation in coastal communities, and is important for regional development. Members of the AF consortium have the vision that Norway will remain a major seafood actor on the global scene, and that this industry will be both sustainable and broadly recognized in the public domain.
A proper waste management of CAS, in concert with the vision of an "Ecosystem based management of aquaculture", requires a more holistic understanding of environmental interactions of aquaculture. The benthic impacts of aquaculture is rather well understood and managed, the pelagic impacts is unclear, lacking a scientific concept as well as adequate monitoring methods. Members of the AF-consortia will work to obtain the knowledge needed to fulfill the vision of an ecosystem based management of aquaculture in marine waters.

Integrated multi-trophic aquaculture (IMTA) is one means to obtain added value from feed investments while meanwhile reducing environmental impacts of wastes from aquaculture systems. AF-members will make efforts to identify economically feasible food chains for IMTA and technology to exploit the potentials of creating added value of feed investments in CAS and RAS production. The organisms of these food webs in question include macroalgae, shellfish, crustaceans, and other high prized organisms, with fish and feed wastes as the major drivers.

Biological basis of marine aquaculture – Fundamental knowledge on biology and requirements of cultured species are essential for a successful R&D on rearing technologies. A main focus will be on production technology for early stages of marine species (hatchery and nursery) and on fundamental biological issues important for marine aquaculture engineering of adult stages of finfish, shellfish and crustaceans.

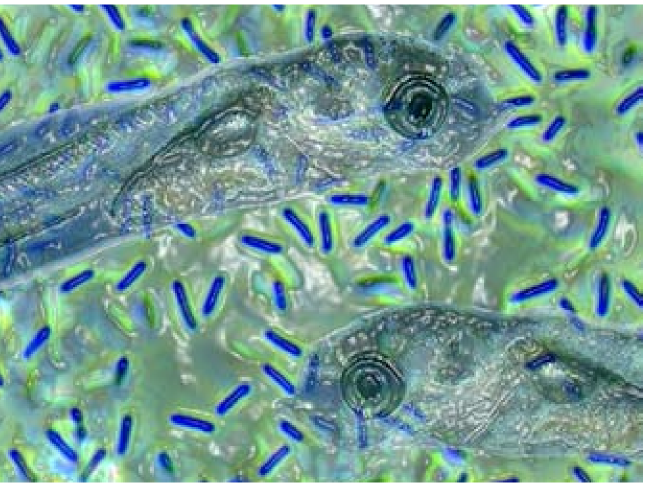
Early stages – Interactions between nutritional and microbial factors in larval rearing, driven by the physical regimes and rearing protocols are main fundamental challenges that need to be addressed to obtain a more controlled larval production, and automation is needed to stabilize and control the larval food web and to reduce costs. The interactions between larvae and natural bacteria are not well understood, and the nutritional requirements of cold water larval species are still inadequate. The new methodology of functional genomics and NMR are very important diagnostic tools needed to bring science and production technologies of fish juveniles forward.

Adult stages – The biological research agenda for older stages will be closely related to R&D needs for developing cage aquaculture systems (CAS) and recycling aquaculture systems (RAS), and their process control systems. Members of the AF-consortium will accordingly address challenges of biological research that are instrumental for developing aquaculture system, including process control and automation. Aquaculture system engineering will, according to a core premises, only be successful if undertaken in concert with the best available biological knowledge on the cultured organisms and their developmental stages.

5.2.4 Research agenda 2020 – Fisheries

Improvements of fishing technology and resource management have been important cornerstones in fisheries. The new paradigm of stagnating catches calls for an alternative approach to the management of fisheries by integrating technology management, and to future development of fisheries resources and value creation. The global trend of over-fishing calls for political processes to counteract potential problems. Both stagnation and new technology have major societal impacts and call for revised well-considered strategies for obtaining added value from fisheries and maintaining sustainable coastal communities.

Cod larva feeding on Artemia nauplii (photo: Tora Bardal)



Control of the environmental microbial community is a crucial factor in the survival of marine fish larvae (photo: Karina Playfoot)

A holistic approach to these issues is urgently required. A major goal of the work at NTNU is to promote active multi-disciplinary problem-solving research involving close interaction among engineering, natural science, and social sciences, and that this holistic approach is reflected in higher education in NTNU. The research activity within the Fisheries domain involves the following main research activities:

- **Marine harvesting technology**
- **Sustainable fisheries**
- **Social strategies of fisheries**

Marine harvesting technology – *Low energy catching technology* – The economic viability of large parts of the fishing fleet both in Norway and abroad is threatened by increased energy costs caused by high fuel prices and low energy efficiency. The high energy consumption and subsequent emissions of CO_2, NOx and other harmful substances also have political implications, as Norway has endorsed international agreements aiming at reducing the climate effects and environmental pollution. This calls for new vessel and machinery concepts designed for low energy consumption and/or use of alternative energy carriers such as LNG or hydrogen.

Improved fishing gear – Environmentally friendly and efficient fishing gear is continuously called for. Priority should be given to the development of new gear types that reduce unwanted mortality, ghost fishing, energy consumption and other impacts such as sea floor disturbances.

On board catch handling – The quality of the catch is highly dependent on the fishing gear itself, as well on the handling of the gear and the fish when the catch is taken on board. To improve catch quality, research should focus on the construction of the gear itself, as well as the way the gear is operated. Towing speed, as well as towing and soaking time, are important catch quality parameters. In addition, methods for handling and transferring the catch to the vessel, and procedures and methods for pre-processing and onboard storage should be improved.

Flexible logistic- and distribution systems – The catch should be brought to the market quickly and efficiently without any quality deterioration. The loca-

The new paradigm of stagnating catches calls for an alternative approach to the management of fisheries by integrating technology management. Both stagnation and new technology have major societal impacts and call for revised, well-considered strategies for obtaining added value from fisheries and in maintaining sustainable coastal communities tion of catching, the identity of the vessel, of the transport vehicles and of the processing plants should be traceable, as well as the methods for on board storage, methods of production, processing and distribution. This calls for improved systems and methods for distribution of high quality seafood such as ultra fresh fish, including efficient post harvest routines and advanced traceability systems.

Sustainable fisheries – Improved fisheries sustainability and reduced environmental impacts depend on technology development, improved industrial structures, as well as better management strategies. The burdens and responsibility placed on fisheries management will increase substantially. Improvements in the effectiveness of systems for documentation, verification and traceability of catches is needed as the basis for a transparent product data information system keeping track of the catch from the fishing gear to the consumers table. This will be the core of the future food safety and security system. A side effect of an efficient tracing system would be a reduction of illegal fishing, as the system will prevent access of illegal fish to the market. Such a system will define the standards for the activities throughout the seafood industry in general.

Catch registration and monitoring – Continuous/online registration of location, size and composition of catches is a prerequisite for traceability as well as an essential basis for efficient future management and utilisation of our fish stocks. To enable fisheries management to exploit fish stocks at safe levels, improved systems for registration of the catch volume, location and composition are needed. In addition, there is a need for monitoring the fishing fleets efficiently, keeping track of vessel positions, and preventing illegal fishing. A system for fishing fleet capacity monitoring should be developed and implemented along with efforts to develop better regulatory policies for curbing fleet capacity expansion.

Management strategies – Management of existing and new fisheries is becoming a critical area for research as the sustainability of the commercial fisheries of the world is threatened in numerous ways. Attempts at managing technology in order to restrict catching capacity, have not been very successful in the past. Management and regulatory policies have led to unintended sub-optimized technical solutions such as expensive paragraph vessels with poor working conditions and high fuel consumption. Research in the field of technology management should focus on restricting catching capacity while facilitating development of environmentally friendly, economically viable vessels with improved safety and working conditions.

To deal with the multifaceted issue of sustainability, fisheries- and coastal management may need a wider scope for their objectives. To foster sustainability there is probably a need for addressing topics in addition to the much needed concern with marine ecology and the state of our commercial fish stock. A related issue worth consideration might be task of investigating the possibilities for increasing the total yield from the food web by harvesting at all trophic levels in a balanced and sustainable way. The present system for allocation of quotas is to a certain degree indirectly dealing with social issues such as the welfare of coastal communities. A future management system should have more pronounced responsibilities in this arena. Management regimes that build trust, cooperation and compliance among stakeholders must established or improved at both national and international levels.

Technological development and industry structure – In spite of management efforts to reduce the catching capacity of the Norwegian fishing fleet, the capacity has increased in recent years. The same situation is found in most segments of industrial fisheries all over the world. As the number of fishing vessels in operation has been reduced, the total catching capacity has increased. The various management measures for capacity reduction, such as reduction of the number of vessels, have been neutralized and even counteracted by technological development. Management strategies seem to have been based on the assumption that technology is a static factor in the management equations. A better understanding of how technology, as a dynamic element, influences on the overall capacity of the fishing fleet over time, should be developed as a basis for technology management in fisheries. Important tool would be simulation models and the use of operational analysis methods. Studies of coastal communities and societal impacts as a consequence of various strategies should be included.

Documentation of sustainability – There is a general consensus that the fishing industry of the future will have to adhere to the principles of sustainability. This will be important due to international and governmental legislation, pressures from NGOs and from the general public. In this respect, customer preferences in the food markets play an important role. Both governments and the seafood industry will need new and improved methods for analysing seafood production activities with respect to environmental impacts. This is a prerequisite for both verification of the present situation and for improvement in methods and technology. It is imperative that such new methods for measuring impact and the development of suitable indicators for verification of sustainability have a scientific basis and get international authorisation.

Social strategies of fisheries – Transitions within the fisheries sector have had and will have major consequences for Norway as well as others. Technology, market and marketing demands, regulations for production, consumer demands and expectations, increased energy prices and environmental constraints all impact fishers, their industry and their community. Maintaining a competitive position in fisheries requires understanding and managing change in ways that sustain the community of fishers as well as rationalizing the fishing industry and protecting the resource.

Safety and working conditions – Fisheries must be sustainable with respect to their ability to attract and keep a labour force. Working conditions and hazard levels on board fishing vessels are outside the acceptable limits, especially for the smaller vessel segments. Both new vessel concepts and new operational procedures are needed, including establishment and monitoring of statistics.

Grading bigeye herring on board of the coastal fishing vessel 'Trønderkari' (photo: Harald Ellingsen)

International management – The past half century has witnessed a remarkable growth in international law, organizations, norms and management regimes. International efforts to produce sustainable fisheries have had mixed results, but have now developed momentum. Transitions in fisheries along with the projected increasing prices of food and fuel and the tightening of the resource base, however, suggest that international institutions, including fisheries regimes, will suffer increased pressure in the future. Research into the construction and maintenance of robust international institutions and the security issues that may arise in the near future is vital.

Cultural transitions and immigration – Coastal communities are changing rapidly as new workers take the place of exiting ethnic Norwegians. This will create social challenges as well as management issues and transform the "typical" coastal community. Research to preserve cultural heritage as well as to ease the adjustment to new conditions is highly desirable.

Stakeholder involvement – Successful management requires stakeholder input as well as cooperation, but also raises problems of economic, energy and technological efficiency. Research should focus how technological solutions can be mixed with social management to produce fisheries that are sustainable along many dimensions.

5.2.5 Strategic goals 2020 – Aquaculture and Fisheries

The following strategic goals are defined for the Aquaculture and Fisheries domain for the period up to 2020:

- Establish within 2010 a multidisciplinary Gemini centre, or centres, addressing the major aspects and challenges of marine aquaculture engineering, and contribute to a development which can make this group among the world 5 strongest research groups in aquaculture engineering within 2020
- Coordinate initiatives and research efforts with the NTNU-SINTEF centres of excellence CREATE/CeSOS, and facilitate the incorporation of their core activity and teaching capabilities after termination beyond 2012-15.
- Take positions in and use the European Aquaculture Technology Platform (EATP) as a vehicle for getting the research agenda of the aquaculture consortia implemented in calls in EU framework programmes
- Establish within 2010 a multidisciplinary research group, and optionally a Gemini centre, addressing the major technical, scientific and societal aspects and challenges of sustainable fisheries
- Establish, in close cooperation with SINTEF, routines and conditions for use of the SeaLab laboratories for research and higher education in aquaculture and fisheries as a joint and economically sustainable research platform for all NTNU actors
- Take, together with SINTEF, a major ownership and responsibility for developing and exploiting the ACE testing facility for aquaculture constructions at Valsneset, and do that together with the Strategic Focus Area for energy research

5.2.6 Infrastructure – Fisheries and Aquaculture

Excellence in research requires a modern and efficient research infrastructure that is available for all core partners. It is a general strategic goal to operate key infrastructure together with SINTEF. The main infrastructure of the Aquaculture and Fisheries domain is:

- **NTNU and SINTEF Sealab** – The research laboratories of SINTEF Fisheries and Aquaculture and NTNU, situated in the harbor area of Trondheim.
- **Flume tank** – Testing facility for fishing gear and aquaculture systems, SINTEF Fisheries and Aquaculture in Hirtshals, Denmark.
- **RV Gunnerus** – The research vessel of NTNU, for research on fishing technology and ROV operations of aquaculture.
- **ACE** – Open ocean testing facility of aquaculture constructions and systems, with or without organisms present. The facility is applicable also for other constructions, for example for open ocean wind mills.

- **Marine Technical Laboratory** – Ocean basin, towing tanks and cybernetic laboratory at NTNU-SINTEF, Tyholt, for advanced testing of constructions and systems.
- **Trondhjem Biological Station** – Outdoor basin at TBS, the property of NTNU, testing facility for IMTA, including mussel and macroalgae research.

5.3 Marine Resource Processing – Sustainable Marine Resource Processing and Technology

5.3.1 Background

The marine food producing industry transforms raw materials from renewable food resources to products of high nutritional value, popular and highly appreciated worldwide. This production is important for the coastal communities and the economy of Norway. The industry must improve its image of being sustainable, in the sense of full utilisation of the harvested raw materials, minimal environmental impact as well as efficient use of energy. Increased environmental awareness and food safety demands from customers, combined with the long term objectives of free trade of WTO, will result in new challenges. The global trend in food processing is moving towards value added products and diversity.

High quality fresh seafood distribution requires low and stable temperatures in processing and distribution. More efficient chilling in processing plants, better design of rooms and display units and improved refrigeration and temperature control systems are required. Recent development in RFID sensor technology (Radio Frequency Identification) combined with modelling of quality decay can serve as a basis for cold chain improvements. When developing new automatic processing methods and technologies, hygienic design of equipment and production facilities, good cleaning and disinfection procedures, and control of factors that influence the air flow patterns around the product, are essential to ensure the microbial quality of food products.

The competitive power of this industry demands high efficiency in all segments of the production. This means that a higher degree of automation and flexibility is needed. Few production lines are designed based on effective material flow and there is a need for development of almost fully automated processing lines. Fish fillets pose stringent demands on equipment such as gripping tools, as they are non-rigid, have natural geometric variations, and are wet and slippery. There are variations in quality from fish to fish as well as seasonal variations. Fish are also perishable products that require strict hygienic handling. A major challenge facing the food industry is to increase efficiency of production and at the same time maintain or improve product quality. Consequently, rapid sensor techniques are increasingly being applied in the entire production and retail lines for quality control, and for optimised utilisation of raw materials, with due regard to its variations.

Understanding and quantifying thermo-physical processes in seafood during processing is of outmost value for optimal design of cooling equipment and packing system for different marine products. Effective and flexible processes that preserve premium product quality must be designed and basic data for calculation of processing time and temperature, air/gas flow, refrigeration load must be found.

There is a development towards clean, high-tech and automated processing factories, the energy systems are, however, still quite unsophisticated. Being investment intensive and not directly linked to raw material cost and product price, executives are often tempted to use cheap technical solutions disregarding high costs of operation. In addition to the industry's low energy competence, large variations and uncertainty in raw material supply has resulted in excessive investments in high capacity production lines and refrigeration systems of low energy efficiency. Facing rising production costs, including increasing electrical energy prices, in combination with uncertain marked access and product prices, there is an expectation of increase in the ongoing restructuring of the industry towards fewer and bigger companies. The alternative is specialization and closer cooperation between existing companies. In time, this might increase the industry's recognition of the need for competence improvement in general and particularly within the field of systems- and energy management.

Marine macromolecules of significant commercial value are found in marine algae (alginates), shrimp/crabs (chitin and chitosans), as by-products from fisheries and aquaculture (fish gelatins, protein hydrolysates and glycosaminoglycans) and as marine lipids. Beside biomass and macromolecules, the genetic resources of the oceans, and in particular those of the deep oceans, are catching increased attention. Marine, or "blue", biotechnology is probably only in its beginning and may serve humans with novel products or sources for human wellbeing and industrial applications, e.g. bio-materials, chemicals and pharmaceuticals.

Another opportunity lies in the large amount of seaweed that is landed in Norway. Annually, approximately 160 000 metric tons is harvested with the kelp *Laminaria hyperborea* being the dominant species. It is used for the production of alginates, a biopolymer used in several hundred different applications ranging from the production of welding rods to pharmaceuticals. There is, however, also a small but significant non-utilized fraction of marine phospholipids that could be extracted. The main scientific and engineering challenge in this context is that in order to be able to get hold of this important component, the manufacturing process for alginate will have to be modified. Furthermore, the signifi-

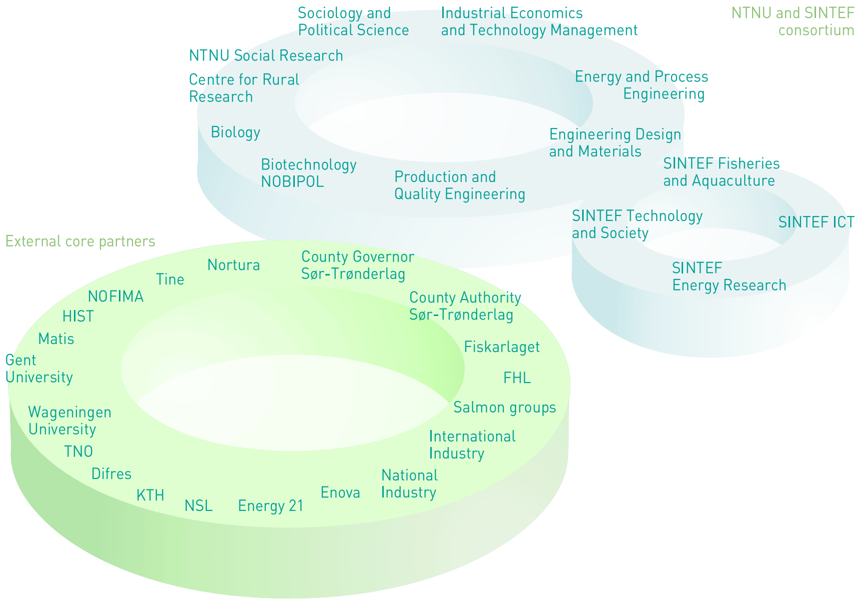


FIGURE 7
Consortium involved in Marine Resource Processing domain (MRP-consortium)

cant amount of leftovers from the alginate production has the potential for use as bio-gas rather than being treated as waste as it is today.

5.3.2 Consortium involved

NTNU and SINTEF have the broad range of engineering, natural science, and social science disciplines needed to address the questions of processing of marine resources and their industrial applications all through the production value chain. The resources include fish, other marine animals, marine macroalgae, and particularly the various biopolymers of marine macroalgae which are widely used for advanced industrial applications. The activity in the MRP-consortium is comprehensive and broad, involving many research groups and departments (Figure 7). The NTNU-SINTEF consortium is closely related to that of the KMB project "Competitive Food processing of Norway" which consists of 15 partners.

Core partners are in some ways related to one or more partners in the NTNU-SINTEF partnership and may join the consortium in accordance with our open door policy. The list of core partners is dynamic and incomplete.

5.3.3 Research agenda – Marine Resource Processing

A main future focus is to address and solve the main technological challenges needed to realize and secure important consumer benefits and to achieve an internationally competitive marine resource processing industry in Norway

The vision of the consortium is to remain a leading contributor in research and higher education for a knowledge based and sustainable utilization of marine resources and a sustainable tenfold value increase of harvested resources. The work will involve close interactions between engineering, natural science, and social sciences, and securing that this holistic approach is reflected in higher NTNU education. Politically and scientifically, the main two challenges in the area of marine resources are i) an increased added-value of the resources already brought on shore, and ii) utilization of until now unexploited marine organisms and resources. In case i) the focus is on increased utilization of by-products, by-catch and the search for new (not utilized) components within landed resources, whereas in case ii) the focus is either on new organisms for bulk commodities, such as marine lipids and proteins, or on the search for new (micro-) organisms with biochemical specialty components of high value ("bio-prospecting"). The research activity within the Marine Resource Processing domain involves the following main research topics:

- **Raw materials for high value products**
- **Processing engineering and tailoring**
- **Genetic resources and biopolymers**
- **Energy efficiency**
- **Design methodology for sustainable systems**
- **Value chain management**

Raw materials for high value products – The focus in this area is to study the biochemical changes in product quality due to processing and storage conditions, from harvesting to the market. To improve the quality and stability of fish and fish products, there is a need for better knowledge and understanding of raw material properties and the changes that takes place in the raw material in the different processing steps during the whole process chain from catch to consumer. This understanding is also necessary in order to develop new and improved processing and preservation methods so that the best processing conditions can be chosen based on the raw material properties. There is a need for research on better conservation and processing methods to increase the utilization of by-

Successful research in the field of marine or blue biotechnology will require the involvement of a wide range of research disciplines

products and amount used for human consumption. In order to utilize a higher proportion of the marine lipids and proteins, more knowledge is needed on processing methods to extract the interesting fractions/biomolecules. The processes developed should be able to handle variations on the basis of season, habitat and species and should be designed so that the valuable health properties is preserved and products with and acceptable stability is obtained.

Processing engineering and tailoring – The processing of the fish starts directly after catching or slaughtering. It can even start when the cultured or wild fish is taken alive from the net cage and transported by ships to the slaughtering factory. Important activity will be the research around new and improved technology, machinery and equipment for efficient and ethical transfer, handling/slaughtering of wild and farmed fish from sea to processing line including development of new concepts for efficient fish processing with the focus on automation.

Processes like chilling, freezing, thawing, tempering, storage, transport, and for some products also drying, are of importance

Chilling and gentle handling will be among the important factors for the quality at the time the product is presented to the consumer. In this chain of processing, handling and transport, the time and the temperature level will influence the final quality. Processes like chilling, freezing, thawing, tempering, storage, transport, and for some products also drying, are of importance. The need for fundamental research is linked to the understanding of heat and mass transfer in the food and other parameter for modelling of processes and systems. There is a need for more intimate knowledge of parameters like thermal conductivity, specific heat, thermal diffusivity, density, water activity, absorption isotherms, and drying kinetics. Such knowledge is essential for modelling and simulation of processing systems.

The basic understanding of processes during phase changes in the freezing stage and phase changes like glassy state at low temperatures are of importance. To improve the quality for the end user, processes like super chilling and super freezing in combination with highly developed new thawing processes, are needed. The cold chain has to adapt to the temperature level of the super chilled products with a minimum of temperature variations. Thawing of fish is more difficult than freezing due to the temperature difference and the thermal properties of the fish. To have the full effect of super freezing of fish, it is of importance to develop new understanding of the thawing process and new equipment. There is a requirement for making tailored process design adapted to the industries' needs.

A large quantity of the wild fish is dried outdoor or indoor and exported. Use of heat pump systems will improve the quality. The knowledge of drying kinetics and basic understanding of the product will give possibilities for improved and new products. Drying technology based on heat pumps can also give new possibilities developing other products from the marine area. The system has demonstrated that it is possible to dry bioactive components and store these for a long period with a high level of recovery after re-hydration.

Catch and by-catch is separated on board of the vessel (photo: Harald Ellingsen)

Super chilling of salmon as a more efficient conservation method (photo: Tom Nordtvedt)

The families of biopolymers have a large potential as functional biomaterials for the medical, pharmaceutical and food industries

Genetic resources and biopolymers – The activity includes marine genetic resources and products derived from marine organisms, biosynthesis of biopolymers, biopolymer chemistry and biological properties, biopolymer engineering, and industrial applications. The extreme or specific environmental conditions of the oceans, e.g. in temperature, pressure, salt content, pH, chemical composition, and the enormous biodiversity of these ecosystems offer multiple opportunities for bio-prospecting, exploitation and use of microbes, algae and animals and their physiological performance and genes. Successful research in this new field of marine or blue biotechnology will require the involvement of a wide range of research disciplines, such as molecular physiology and biochemistry, genomics and proteomics, bioinformatics, nanotechnology, aquaculture, environmental bioremediation and biotechnology.

Marine macro algae as a source for 3rd generation bio-fuels? (photo: Karl Tangen)

The families of biopolymers have a large potential as functional biomaterials for the medical, pharmaceutical and food industries. Marine red algae represent as yet an unexploited marine resource in Norway and their distribution and utilization deserves to be highlighted, including their potential in high cost markets (e.g., agars, carrageenans). Members of the MRC-consortium will continue their efforts in advanced studies of marine polymers, and also contribute to identify suitable applications of macroalgae culture based on aquaculture wastes (IMTA).

Energy efficiency – Refrigeration systems in the fish processing industry are often over-dimensioned. They run inefficiently on part-load most of the time, with high energy costs. Introducing carbon dioxide (CO_2) as a refrigerant will improve the energy efficiency, due to its favourable thermo-physical properties. CO_2 has relatively high energy density, and the systems can therefore be made more compact, environmental footprints can be reduced, and energy can be saved. The fish processing industry is known to have a relatively large demand for high temperature water for cleaning and other purposes. The CO_2 system can easily be used to produce high temperature tap water (80-90oC) without supplementary heater. Many refrigeration systems in the food industry today use HCFC-22 as refrigerant. According to European legislation, import of HCFC-22 is forbidden from January 1st 2010.

Design methodology for sustainable systems – The process of developing successful products, services and industrial solutions today requires collaboration in multidisciplinary teams, and the sparse population in some coastal areas imply limited access to critical competencies. In addition, Design Theory and Methodology has not kept up with the current trends of open innovation networks and the emerg-

A key to achieve holistic and dynamic management is to utilize all available information, also cross company, when designing the value chain. New control models should include these perspectives ing collaborative aspects of design. As a result, many aspects of design are typically governed by serendipity rather than structured methods, and this reduces design performance. There is a need for new collaborative engineering and innovation approaches supported by collaboration technologies and management and leadership principles; better adapted to specific coastal challenges and contexts.

Value chain management – Marine value chains need to be more dynamic in adapting to customer needs by being faster, more cost efficient and more focused on value creation. More dynamic and agile enterprise control models, which also ensure safe and high quality products, have to be developed. A key to achieve holistic and dynamic management is to utilize all available information, also cross company, when designing the value chain. New control models should include these perspectives. Today supply chain planning is normally done without regarding information from the production process and from the traceability system. New optimization and simulation methodology utilizing the huge source of information now available; from the traceability system, online sensor technology and other new technologies, should be developed. There is also a need for new research on decision support tools managing the inherent uncertainty in sea food catching, production, sales and distribution. This will apply to all planning levels in the value chain; online, operational, tactical and strategic.

5.3.4 Strategic goals 2020 – Marine Resource Processing

The following strategic goals are defined for the Marine Resource Processing domain for the period up to 2020:

- Establish a centre for advanced analysis of marine raw materials and products
- Take positions in and use the European Technology Platforms (i.e., EATiP and Food for life) as vehicles for getting the research agenda of the marine resource consortium implemented in calls in EU framework programmes
- Further develop and continue the Gemini center of technology for environmental friendly and energy efficient processes for use in the fish and food industry and distribution
- Establish, together with SINTEF, a major research program – CREATIV – for technologies for efficient industrial energy use and advanced processing, including automation of value added marine products
- Implement new methods of advanced decision support systems from other industrial sectors into the marine food value chain

5.3.5 Infrastructure – Marine Resource Processing

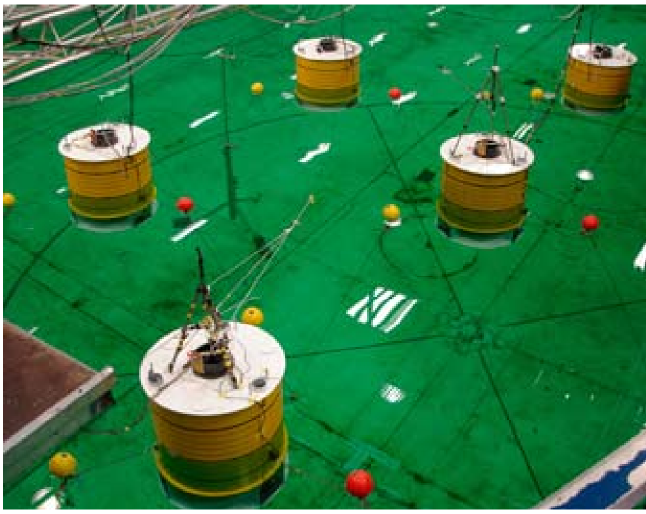
Excellence in research requires a modern and efficient research infrastructure that is available for all core partners. It is a general strategic goal to operate key infrastructure together with SINTEF. The main infrastructure of the Marine Resource Processing domain is:

- Refrigeration Laboratory - Pilot plant laboratory of SINTEF Energy and NTNU at Gløshaugen
- Food Engineering Laboratory – Pilot plant laboratory of SINTEF Energy and NTNU at Gløshaugen
- Dewatering R&D Laboratory – Pilot plant laboratory of SINTEF Energy and NTNU at Gløshaugen
- Process laboratory at Sealab - Process laboratory for marine resources at SINTEF Fisheries and Aquaculture at SINTEF Sealab
- Biopolymer laboratory – Chemical-Physical laboratory for biopolymer research at Gløshaugen, NTNU and SINTEF Chemistry and Materials.

5.4 Main cross-domain research targets (CD-targets)

The following cross-domain research targets will have a particular focus of the NTNU and SINTEF consortia of the scientific domains in the period up to 2020 (Figure 8):

CD1 – Renewable energy from the ocean – Production of renewable energy from the ocean is one, although still not economically feasible, option for



Development and testing of wave energy convertors (photo: Brian Linfoot)

energy producing in the decades to come. Current climate policies are main drivers of this development, and economically, environmentally, and socially acceptable offshore windmills or other systems extracting energy from the ocean are obvious options for Norway. The NTNU Energy Focus Area and NTNU MCD with SINTEF counterparts will together explore energy systems which produce electricity and seaweed biomass for bio-energy from the ocean.

We are mainly exploiting organisms on "wolf" and "eaters of wolfs" levels in the marine food web, but there is public, scientific, and political resistance against a change in management practise which implies to harvest further down in the food web

The perspectives of NTNU MCD in this cooperation are related to the common R&D infrastructure, the environmental interactions of energy production, and the potential for the large-scale cultivation of seaweed for bio-energy and industrial raw material associated with moored energy installations. Seaweed biomass can be used as a source of marine lipids for fish feed and for biopolymer extraction, and the remaining biomass can be used for energy/bio-fuel production. The current utilization of harvested seaweed biomass utilizes biopolymers only; the industry will take advantage of a new production process for biopolymers/lipids and a sustainable use of their waste material (Domains: Ocean Space Research, Fisheries and Aquaculture, and Marine Resource Processing).

CD2 – New marine bio-resources for aquaculture – There is a general demand for marine resources world wide, be it for direct human consumption or for aquaculture feed. Resources of significant magnitude are only available at low level of the food web. Although we are mainly exploiting organisms on "wolf" and "eaters of wolfs" levels of the marine as compared to the terrestrial food web, there is public, scientific, and political resistance against a change in management practise for marine resources which implies harvesting further down in the food web. Significant resources available are Antarctic krill, Red feed, and macroalgae (seaweed, cf. CD1), and macroalgae as well as microalgae can also be cultured. A production of marine-type biomass (with marine lipids), that can sustain the needs of aquaculture over a long time perspective can only be based on transgenic plants or microorganisms produced based on a waste resources from human activities such as methane. A capable microorganism must be found in the sea, where methane is a common resource for microbial growth and where new genetic resources are available. Marine genetic resources will probably become more and more important for feeding humans, and will be among the bio-resources explored (Domains: Ocean Space Research, Fisheries and Aquaculture, and Marine Resource Processing).

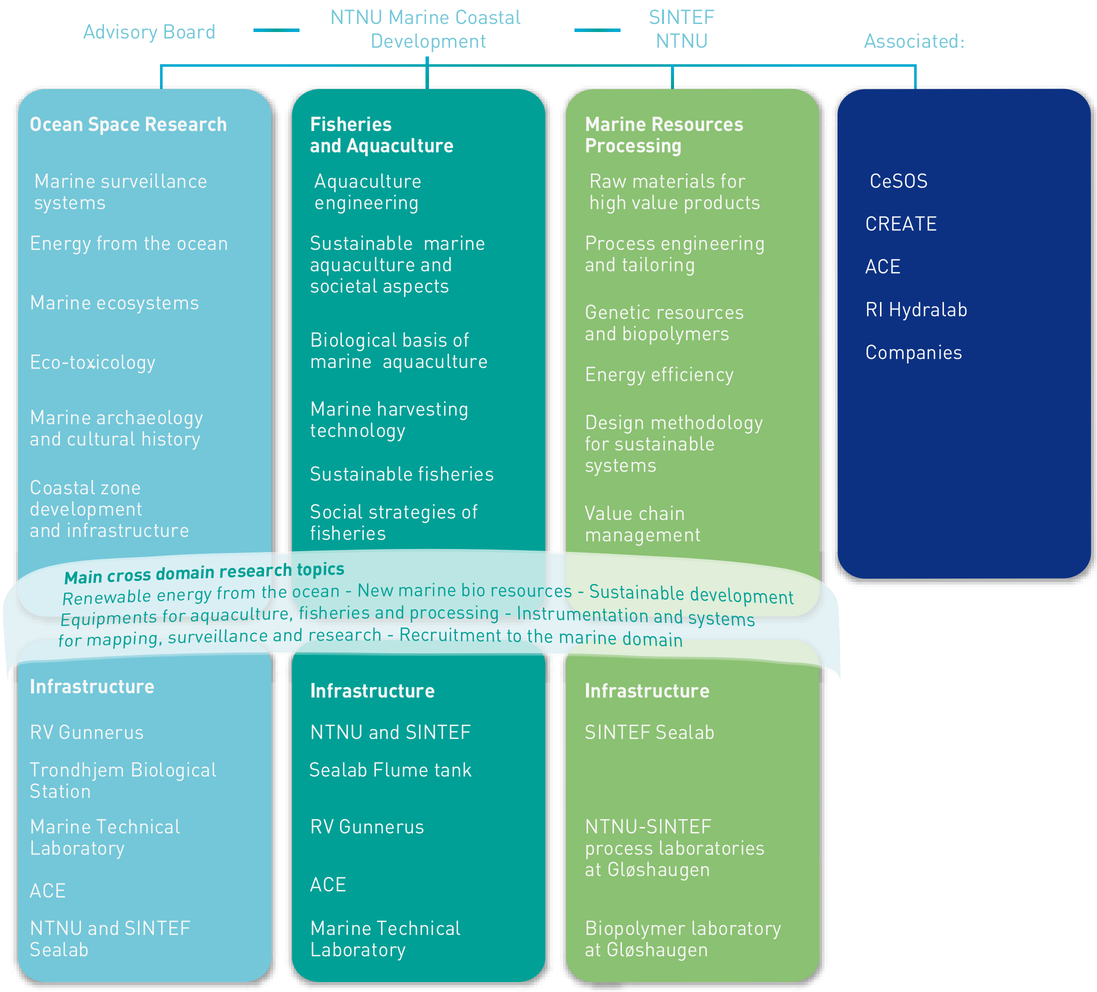
CD3 – Sustainable development – There is a general consensus that the utilisation of living and non-living marine resources in the future will have to adhere to the principles of sustainability. An increased focus on environmental impacts of industrial activities is gaining momentum among the public, consumer organizations, retailers, NGOs, and authorities. In the marine field, climate change and greenhouse gases, over-fishing and environmental impacts of fisheries and aquaculture, along with the socioeconomic impacts of globalization are among the burning issues. The overall vision is to accept only development and activities that are environmentally sustainable, and then to secure that the development is sustainable in a societal and economic sense, with an efficient use of non-living and living resources. Among the challenges is the public environmental debate in which there are few reference points for determining what an environmental friendly fishery- and aquaculture industry is like. Those environmental requirements are not always easy to define, and for most consumer segments, it is almost impossible to examine the scientific basis, if any, for existing environmental labels. New methods for more comprehensive and transparent environmental analysis and assessments of seafood production, based on science, are therefore needed. (Domains: Ocean Space Research, Fisheries and Aquaculture, and Marine Resource Processing).

CD4 – Equipment for aquaculture, fisheries and processing – Norway is one of the few countries which have an industrial structure combined with research activities that can form basis for development and supply of equipments for the international fisheries and aquaculture industry. Equipments for sustainable harvesting (vessel, machinery, gear etc.), aquaculture production (e.g., cages, feeding systems, and control systems) and processing (optimized processing plants) has to be developed. The main challenges are to handle the expected growth in fish and shellfish production for human consumption and at the same time meet customer demands for environmentally sound and sustainable production processes. The international economic potential of such products may be higher than that for biomass production. Being among the leading European institutions in the field, NTNU and SINTEF can make unique and major contributions to this development (Domains: Fisheries and Aquaculture and Marine Resource Processing).

CD5 – Instrumentation and systems for mapping, surveillance and research – The rapid development of information and communication technology (ICT), has opened up new possibilities for observing, managing, and monitoring marine systems and our exploitation of marine recourses in a wide sense.

Sustainable exploitation of living and non-living marine resources in Northern Seas, be it of fossil fuels, renewable energy or fish stocks, requires major efforts in the field of exploration technology and long-term intensive monitoring. Traceability in fisheries and its value chain and automation in aquaculture require ICT aided means to become efficient. The concept of distributed data acquisition via an advanced infrastructure demands the adop-

FIGURE 8
Main scientific domains, infrastructural means and cross-domain research targets of the consortium in the period to 2020.



> *There is a major potential of developing technological systems solutions for the marine value chain, in particular for the Ocean Space Research domain.*

tion of technology and methods originally developed for other purposes, particularly in sensor and communications technology. New sensor, advanced platforms, and instrumentation system technologies have revolutionized the potential for gathering high-quality data from a much broader spectrum of platforms. There is a major potential of developing technological systems solutions for the marine value chain, in particular for the Ocean Space Research domain. Among the important issues are methods and models for optimal model-based data collection and data assimilation and integrated networks for telecommunications both on and beneath the sea surface. New sensor technology and sensor networks are needed for detecting and monitoring living and non-living resources, environmental state monitoring as well as pollution assessment. New methods for measuring parameters for fish and plankton, collecting data for physical, biological and chemical oceanography, and measuring other environmental parameter are important issues. (Domains: Ocean Space Research, Fisheries and Aquaculture, and Marine Resource Processing).

CD6 – Recruitment to the marine domain – The sector of higher education is currently under heavy pressure. There is an increased focus today on quality and excellence, driven by international competition and increasing student mobility. There is also a requirement for continuous improvement and adaption in higher education to fill the needs of society and industry without compromising quality. These needs call for more dynamic attitudes in higher education. Key issues are internationalisation, a relentless focus on quality, sustained interactions with the employers of our students, and a continuous focus on improving courses and study programmes for Master and PhD students (Domains: Ocean Space Research, Fisheries and Aquaculture, and Marine Resource Processing).

6) Higher education

6.1 Master education

An international cross-faculty master program "Marine Coastal Development" is established and offered beside other relevant master programmes given by the departments. The four study directions of the programme are:

- Aquaculture
- Fisheries and marine resources
- Marine biology and biochemistry
- Marine environmental technology

The participating departments and faculties are responsible for the master and doctoral education programmes and members of the NTNU MCD consortium is responsible for the quality of the courses given. The students take their common obligatory courses during the first semester, among them courses established to bring disciplines together and to develop a common language for the students.

The agenda for 2020 for the master education at NTNU within the domains is to:

- Include other appropriate study directions in the program, including processing, engineering, aquaculture cybernetics/ICT, and social science/humanities
- Further develop courses themes and their contents to improve quality and relevance of the educated msc-candidates
- Recruit international students to the master programme, among others by Erasmus Mundus participation.
- Involve SINTEF employee more strongly in the master education

The overall strategic goals 2020 are to have:

- All major NTNU departments/disciplines in the marine domains become involved in the MCD master programme
- SINTEF contribute to >25% of the teaching in master courses and thesis work

6.2 PhD education

PhD students will be admitted and educated in the established programmes of the faculties/departments. The cross-disciplinary perspective of the candidates will be ensured by advisor networks and joint arenas for the students.

The agenda for 2020 for the PhD education at NTNU within the marine domains is to:

- Explore the possibility to establish PhD schools for students of the marine domain
- Offer attractive doctoral courses and give doctoral students access to broad networks of external and internal advisors within the consortium and its partners
- Recruit PhD students with funding from other countries

The ultimate strategic goals for 2020 are to:

- Establish PhD schools for all students of the marine domain at NTNU
- Increase the number of PhD students within the marine domain from 122 in 2007 (ca 30-35 per year) to 220 in 2020 (ca 50-60 per year). Department of Marine Technology and CeSOS educated 73% of the candidates in 2007

Marine Master students on a cruise at Svalbard (photo: Geir Johnsen)

7) Overall strategic goals

Overall strategic goals of NTNU MCD for 2020 are:

- Contribute to the overall visions of NTNU to become internationally outstanding within specific areas of the marine domain within 2020; to be among the ten leading natural science and technology universities in Europe and among the 1% best universities in the world that offer a broad technological scope
- Contribute to the overall strategy of becoming internationally outstanding together with SINTEF within the marine domain, measured based on the numbers of Gemini-centres established and the numbers of joint major strategic research programmes generated and funded
- All the major NTNU departments in the consortium has at least one SINTEF employee in Professor II position
- NTNU Professors from all core departments within the marine domains are in positions as advisors in their related SINTEF institute

Left: Freshly harvested copepods (Calanus finmarchicus)

Right: The fishing community Mausundvær in Mid-Norway

RV Gunnerus: a highly equipped platform for marine studies in the Mid-Norwegian area

Enclosure: A reviewof human capabilities and activities of NTNU partners in the marine domains

NTNU Department	Main expertise	Professors Associate Professors	Other scien-tists, Post docs	Phd students	Msc students	Technical staff
History and Classical Studies	Fisheries and aquaculture history	2			4	
Archaeology and Religious Studies	Marine archaeology, maritime history, and cultural heritage	2				
Interdisciplinary Studies of Culture	Cultural perspectives of coastal communities	1				
Sociology and Political Science	Fisheries politics, risk evaluations	2		1		
Geography	Coastal geography, societies	2				
Industrial Economics and Technology Management	Value chain management	1		1		
NTNU Social Research, Studio Apertura	Organization studies, work processes and management in aquaculture	1	2			
Centre for Rural Research	Regional policies, regional development, coastal communities, resource use/manage-ment, coastal industries	2	2			
Architectural Design and Management	Harbor architecture	3				
Urban Design and Planning	Ecological based planning of coastal land use	1				
Biology	Marine biology, biological oceanography, aquaculture, eco-toxicology, coastal ecology, behaviour	13	7	10	37	7
Biotechnology	Marine biopolymers, biochemistry, chemical engineering, processing, marine biotechnology	5	3	8	5	1
Chemistry	Trace metal chemistry, metal pollution	1				
Physics	Marine optics	1				
Marine Technology	Marine constructions, marine systems and operations, fisheries and aquaculture technology	26	6	37	77	13
CeSOS	Centre of Excellence for Ships and Ocean Structures	6	17	42		
Hydraulic and Environ-mental Engineering	Water processing technologies	4				
Civil and Transport Engineering	Coastal engineering, infrastructure, geotechnique	7	5	14		1
Production and Quality Engineering	Food technology and manufacturing	1		1	1	
Energy and Process Engineering	Processing engineering, energy and value chain management	2	1	2		2
Engineering Design and Materials	Design methodologies, sustainability and simulation, structural integrity, metal forming and composites, collaborative engineering	10		1	2	
Mathematical sciences	Bio-modelling, statistics	1				
Engineering Cybernetics	Aquaculture and fisheries cybernetics, instrumentation, telemetry	2	2	4	7	1
Electronics and Telecommunications	Acoustics, underwater communication	4	4	2	4	
Museum of Natural History and Archaeology	Marine archaeology, maritime history, cultural heritage, marine biodiversity	1	3			2

Professors/Associate Professors *reflect the number of permanent employee who contributes at least partly to research and education within the marine domain.* ***Post doctors*** *reflects numbers who have at least 50% position in NTNU within the marine domain in 2007.* ***PhD students*** *reflect the numbers present in at least one month of 2007; some may defend their thesis that year.*

NTNU

The Norwegian University of Science and Technology (NTNU) in Trondheim represents academic eminence in technology and the natural sciences as well as in other academic disciplines ranging from the social sciences, the arts, medicine, architecture and the fine arts. Cross-disciplinary cooperation results in ideas no one else has thought of, and creative solutions that change our daily lives.

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