ALBERTA INNOVATES CASBE NSERC PROGRAM

DETAILED PRIORITY EMERGING TECHNOLOGIES THAT COULD BE USED BY ALBERTA ACADEMIC RESEARCHERS TO HELP ALBERTA SMEs TO DIVERSIFY THEIR TECHNOLOGICAL PRODUCTS

Proposed Projects must support the goals of the Alberta Innovates CASBE NSERC program and use emerging technologies priority areas within the targeted areas defined in detail below.

- Information and communications technologies
- Advanced materials & manufacturing technologies

Information and communications technologies (ICT) Priority areas

Context

The overall objective for proposals in the information and communications technologies (ICT) target area is to empower and protect individuals, organizations, and society by leveraging ICT at scale. Indeed, many research challenges in the ICT area are focused on enabling humans to access the benefits latent in systems and data at scale while ensuring privacy and data security. Individuals can be empowered by utilizing data to improve their health, reduce environmental impact, increase personal productivity, and enhance social interactions. Private and public organizations can use data analytics to enhance context awareness, leading to better decision-making. Innovative ICT helps societies to create successful economies while minimizing environmental impacts. Information is at the heart of these opportunities; however, information needs to be protected as well as responsibly and securely shared to gain the anticipated societal benefits.

Systems and data at scale require dealing with increasing data volume and velocity, data validity and veracity, and network and system diversity and complexity. Six research topics in ICT have been identified in support of this common thrust. Transformative research on communication networks and services is required to satisfy future bandwidth, energy, and service needs. The Internet of Things (IoT) will allow unprecedented and fine-grained awareness of the surroundings but will require overcoming communications and data-fusion challenges. Advanced data management, artificial intelligence and analysis techniques will allow humans and organizations to make better decisions on crucial social and/or economic issues. Cybersecurity is required to protect the confidentiality, privacy, integrity and availability of data and the systems over which it travels. Rethinking human interactions with digital media will improve the usability and usefulness of access to overwhelming amounts of information. Quantum computing is the next frontier of ICT, enabling improvements in sensor sensitivity and computational power by many orders of magnitude.

Priority areas

1. Communications networks and services

Transformative research on software-defined networks: Future communication networks need to be scalable, flexible, agile, secure, and cost-effective to offer an array of end-to-end communication services and applications that meet the requirements of big data, cloud computing, mobility and IoT.

Software-defined networks will scale by control and adaptive management and will handle changing demand and resources to achieve energy and resource efficiency and sustainability. Orchestration of services built on cloud computing and virtualized resources will support a dynamic applications environment. Architectures and methods will scale by enabling end-to-end connectivity spanning heterogeneous networks, including wired and wireless segments. They will deliver quality of experience and real-time and bandwidth-intensive applications and tolerate transient disconnection. Wireless networks will scale by exploiting dynamic spectrum to provide higher bandwidth, with reliability and low power, leveraging future radiofrequency and millimeter wave. Heterogeneous radio networks will interoperate to support services in IoT and 5G networks and to replace existing wired access, as well as new satellite and airborne networks. Wireline networks will be transformed by software-defined network elements (switches, routers, appliances) and virtualized network functions that will leverage scalable photonic and electronic technologies.

2. Internet of Things (IoT)/Machine-to-machine systems

Scaling IoT infrastructure: The next-generation IoT has the potential to change the way people and systems live in a world of massive and disparate data sources, and to provide opportunities for connectivity at different scales. It needs to include advanced communications with a wide range of low-power, low-cost, software-enabled devices. It should accommodate stationary, autonomous, and wearable elements, in robust self-reconfiguring arrangements.

Integration, analysis, and consumption of sensor data: Next-generation IoT systems need to operate in real or near-real time in a context of extreme data diversity and volumes. Information architectures and standards are needed to enable the reliable fusion of sensor data of disparate types from the full spectrum of data sources. The resulting systems must support the efficient extraction and rendering of relevant information to allow timely decisions and actions by users and systems, while enforcing appropriate requirements for data authentication and verification.

3. Advanced data management and analytics

Management, analytics, and information extraction of data at scale: The volume, velocity, variety, and veracity of data demand new approaches to the management of that data. New analytical methods, including the ability to predict, optimize and anonymize at scale—in real or near-real time—are required to derive useful information from the data. Information needs to be extracted from a spectrum of data sources, such as numeric, textual, image, audio, and video data, as well as social interactions and personal data.

Analytics for decision-making: Data at scale need to be analyzed to enable decision-making by people, applications, machines, and systems. This includes interactive visualizations, query systems and other analytics that allow decision participants (human or software) to dialogue with the data and the analytics to arrive at a decision that is accurate and effective.

Artificial intelligence and machine learning: There are a need to develop artificial intelligence/machine learning capacity and develop opportunities to optimize artificial intelligence/machine learning use for application and digital transformation across one or multiple sectors.

4. Cybersecurity

Secure authentication and authorization at scale: New and improved methods to authenticate the identities of people, sensors, processes, and systems, and to authorize access to services and information, will mitigate a fundamental weakness exploited by many cyber-attacks. Useable, effective, and scalable security interfaces and protocols are required. With increasing amounts of data, progress in this area will aid data security and privacy.

Quantitative approaches to cybersecurity: Quantitative approaches to cybersecurity will facilitate the application of data analytics and other metric-based approaches to protecting information and systems. The development of ontologies, behavioral and mathematical models, analytics, metrics, patterns, use cases and datasets will further the understanding, detection and prevention of both existing and new cyber threats—such as those being driven through the emergence of personal informatics, the IoT and quantum computing.

Advanced threat detection and defense systems: Advanced threats that are difficult to detect and defend against include moving and polymorphic targets that change over time, "low and slow" attacks and targeted attacks, which avoid detection by simple alert-based systems, in an ever-increasingly complex network of participants and targets. Advanced threat detection and defense systems will require coordination and correlation across different points in time and data sources and will leverage analytics and other approaches such as polymorphic defense.

5. Human interaction with digital media

Designing effortless interactions: Interactions must become invisible and engaging, as well as transparently indicate data quality. *Invisibility:* Sensors and intelligence that make the interface disappear can address challenges of wear ability, minimization of mental load and actionable feedback. *Engagement*: Gamification, for example, can sustain motivation for challenges such as health, sustainable practices, and people-centric security. *Transparency of data quality:* In the face of noisy data, information display should convey data uncertainty at a cognitively acceptable level. Application examples include novel interaction techniques; interactions for special groups, places, and contexts; collection and collation of personal data for personal use; living in information spaces; and augmented reality and virtual environments.

Effective tools for creating and populating physical and virtual objects and spaces: For designers ranging from professionals to hobbyists, software tools are needed to support maker and do-it-yourself cultures, to facilitate seamless transition between physical and virtual worlds and objects, and to leverage interactive modelling and animation. Design tools must support practices including sharing and collaboration, iterative prototyping, and stages of creative inception, refinement, and deployment. Individuals and groups require tools for customization of interfaces to specific use cases, demographics, context, and individual preferences, with as little training as possible. Individuals need tools to deploy their own approaches to information management. Designers of varying expertise need tools to create virtual and augmented environments, and to build social information spaces.

6. Quantum computing

Exploitation of quantum devices: The challenge involves exploiting quantum engineering for improved performance and efficiency of useful devices. In particular, it includes development of quantum devices and applications that use multiple qubits, entanglement and quantum algorithms for sensors, actuators and communication systems that outperform their classical counterparts. Examples include deploying and improving navigation tools; quantum sensors for chemistry, magnetic fields, electron transport and photon detection; quantum actuators for interconversion of information (spin/charge/photon/phonon); and quantum communication for physics-based information security. The challenge is to develop devices and applications that can be deployed with near-term impact to areas such as medicine, environmental monitoring, materials and chemical characterization, security, improved nanofabrication, and metrology.

Special-purpose quantum processors: A quantum computer is the ultimate quantum device and has broad applications, from breaking classical security protocols to machine learning. The challenge is to realize special-purpose quantum computers and in particular to deliver a well-working processor of 100 qubits. Examples include one optimized for running quantum simulations of materials and another for testing the robustness of quantum error correcting methods. These two building blocks are essential to the continued development of yet more complex and capable quantum processors. In addition to new hardware devices, the challenge includes new algorithms for quantum computing, particularly for small, noisy processors.

Advanced materials and manufacturing technologies (AMM) Priority areas

Context

The overall objective for proposals in the Advanced materials & manufacturing technologies target area is to lead to innovations and improvements in both the manufacturing process as well the products produced. The overarching research thrust for all proposals must be to expand knowledge of the interactions between the material/part behavior, machines, and the final product performance. Proposals in this area must address these through a combination of science-based modelling and experimentation. This involves the integration of mathematical models of processes, materials, products, and machines across manufacturing operations.

Priority areas

1. Automation (including robotics)

The goal of research proposed under this topic is to design innovative machines and their efficient utilization to improve quality and productivity in manufacturing, transportation, or farms through experimentally proven science-based digital models.

Design: Projects under this Research Topic should focus on design and digitally model intelligent, modular, reconfigurable, and multi-functional machines that are easy to adapt to products. The following areas are specifically targeted: develop and model modular kinematic arrangements of the multi-axis machines, robots and material-handling devices; develop and integrate novel smart sensors, actuators, robots and devices; multi-body dynamics and vibration modelling of machines; computer control modelling of multi-axis, multi-functional machines; digital modelling of physical interaction between machine structure, computer controller and processes.

Utilization of machines: Projects under this Research Topic should focus on developing methods and instruments to improve the productivity, accuracy, operation and safety of manufacturing, transportation or farms with the following target areas: integration of smart devices to machines, robots and assembly systems; human-machine/robot interaction; digital modelling of the manufacturing process physics for predictive process planning; on-line calibration and adaptive adjustment of digital models with sensory feedback; sensor-fused monitoring and adaptive control of processes; on-line and off-line part and machine metrology; energy-efficient and/or environmentally friendly manufacturing, transportation or farm processes; development of methods to improve safety in the manufacturing, transportation or farm environment.

2. Lightweight materials and technologies

Lightweight product design, assembly and use: Projects should focus on the development of innovative materials, material structures, designs and manufacturing methods, including fabrication technologies, that are needed to create lightweight multi-material products and assemblies of equivalent or superior performance in use and for maximum life-cycle energy efficiency. Projects that address component- level product development or system-level approaches will be considered. Specifically, projects are to address optimization for manufacturing (material and machine) built on a framework of integrated computational materials engineering (ICME), linking structure/process/property relationships to accelerate and enhance future product and process design. In the development of lightweight products and assemblies, care should be given to identify potential integration issues and formulate possible mitigation strategies.

3. Additive manufacturing

Projects in this area must integrate innovative solutions from more than one of the described research topics.

Process stability, monitoring and control: This research topic focuses on the development of the next generation of additive manufacturing technologies, integrating in-process monitoring, sensing and close-loop control strategies that allow for simultaneous improvement in manufacturing speed, repeatability and product consistency. Included in this challenge are hardware and algorithms adapted to process dynamics encountered during additive manufacturing processing and the response of the deposited material.

Development of tailored materials for additive manufacturing: This research topic focuses on the improvement and development of new additive manufacturing-specific categories of materials with adapted printability, allowing for new additive manufacturing opportunities, improved deposition quality/utilization (including recyclability and re-use) and response to post-processing operations. These will lead to superior process sustainability, part quality and performance.

Design for additive manufacturing: This Research Topic focuses on the development of integrated computation and design methodologies linking additive manufacturing process characteristics, part functionality, component and feature geometries, topology and internal structure optimization, and adaptive slicing strategies, to fully capture the novel disruptive potential of additive manufacturing.

4. Nanotechnology

Design and synthesis of nanomaterials: Projects should focus on the understanding of structural/functional properties and self-assembly characteristics that enable the synthesis of functional hierarchical 3D systems. Advantages of the material at the nanoscale and the impact of dimensionality on product properties of interest must be demonstrated. Emerging nanomaterials of interest include hybrid materials such as graphene, quantum dots, metal oxides, polymer-nanocomposites and their assemblies, based on Earth-abundant and Earth-friendly materials. A theoretical understanding, based on science-based modelling, of how these materials can be designed and integrated into manufactured products must be provided.

Scalability of synthesis and deposition/manufacturing processes: Projects in this research topic must focus on novel, efficient and sustainable manufacturing techniques for mass production of nanomaterials. Techniques to realize mass production on scales required for their integration into manufacturing processes or products, using either top-down or bottom-up processes, must be demonstrated. Clean manufacturing techniques, such as those using Earth-abundant and Earth-friendly materials, green solvents, or solvent-free techniques, are encouraged. Reproducibility of the production process and engineering scale-up is required to produce high-quality nanomaterials, addressing safety aspects in handling and use. Modelling of the process and key parameters are required to demonstrate scalability.

5. Quantum materials

Scalability and manufacturing of graphene or graphene-like materials: Projects in this area must address the mass production of graphene or graphene-like materials. Graphene, the two-dimensional atomic crystal, possesses superior physical properties that include extreme mechanical strength, exceptionally high electronic and thermal conductivities, and impermeability to any gas. The laboratory process of mechanical exfoliation of graphene is simple and cheap for small graphene sheets; however, a major challenge is to mass-produce graphene sheets (both small and large) with the same outstanding performance as those created in laboratories. Manufacturing of several new two-dimensional materials that have many of the properties of graphene is also important for future applications. These include a single layer of silicon (silicene), germanium (germanene) and black phosphorus (phosphorene) or other similarly structured materials.

Integration of graphene or graphene-like materials into devices: Projects should address the possible applications of small and large graphene (or similar materials) sheets and projects in the area of integration into future devices. For example, the small sheets of these materials could be used in composites, functional coatings, batteries, and supercapacitors. Large graphene films could be used in touch panels; low-cost photovoltaic devices; next-generation flexible, wearable electronics and optoelectronics; high-frequency transistors; photodetectors; optical modulators; energy generation and storage; sensors; and bio applications. The films of silicene and germanene could be directly integrated into the current electronics industry, once the hurdles of manufacturing these materials on a large scale are resolved. A single layer of black phosphorus is promising for novel applications in nanoelectronics and nanophotonics.