Nano and functional material solutions for applications in energy sector

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1. Materials and future energy system

- Sustainable power generation is needed for the mitigation of global warming caused by greenhouse gas emissions.
- Advanced materials are needed to improve the efficiency and durability of renewable energy technologies like biofuels, wind and solar.
- The intermittency and distributed nature of the renewables is balanced by smart grids and energy storage.
- Electric and hybrid drive drains will be applied in cars and industrial vehicles.
- Carbon capture and storage (CCS) is needed for future fossil power plants.
- Material requirements by generation 4 nuclear fission and nuclear fusion concepts are most challenging.
- Advanced materials and devices are needed for the production, storage, distribution and conversion of hydrogen, the ultimate clean fuel.
2. VTT competence

- VTT strength is combination of material and processing know how to application and condition monitoring know how.
- VTT offering comprises the whole value chain.
- VTT has leading specialists e.g. in the fields of bio energy, wind energy and nuclear energy.
- VTT is following the international developments through extensive networking both within the scientific community and leading industrial companies.
3. Bottom Up or Top Down Approaches

**Bottom Up**
- Development of materials and processing techniques followed by application in the energy sector.
- Production of nanostructured materials and coatings, e.g. polymers, sol-gel, HVOF.
- Printed electronics, e.g. OLED, solar cells, batteries and fuel cells.
- Embedded sensors.
- Smart materials and composites based on SMAs, piezo ceramics, magneto and electro rheological liquids and elastomers.
- Vibration and noise control.
- Tribology.
- Material and process modelling.

**Top Down**
- Erosion, corrosion, wear and fatigue monitoring of materials in harsh environments (chemical, thermal, pressure, friction, radiation).
- Tailored materials, coatings and concepts are developed for biomass and oxyfuel combustion and gasification.
- Light weight, high strength and low activation structural materials for wind power, boilers and nuclear energy.
- Nanomaterials are developed for batteries, capacitors, fuel cells and thermoelectrics.
- Embedded sensors are developed for wind power and internal combustion engines.
- Modelling, monitoring and evaluation of material performance in all the applications.
4. Research facilities and equipment

- Powder processing laboratory for synthesis, grinding, agglomeration, heat treatment and analysis of metal, ceramic and polymer powders for further processing.
- Plastics and composite processing and polymer modification laboratory.
- HVOF spray, DirectWrite.
- Gas phase synthesis of nanoparticles.
- Corrosion, environmentally assisted cracking, erosion and fatigue testing.
- Autoclave platform for determining materials properties under realistic service environments and loading conditions (LWR, SCWR, H2S)
- In-line probes for high temperature corrosion monitoring and fouling detection
- Mechanical and microstructural characterization (i.e. SEM/EDS, AFM, SIMSS, FEG-STEM)
- Fuel cell and battery testing equipment.
- ICE, CFB and vehicle testing laboratories.
- World class production environment for printed intelligence (PrintoCent).
- Centre for Micro and Nanotechnology (MICRONOVA).
Case 1: Gas phase synthesis of metallic nanopowders

- **Need**
  - Economical synthesis technique for industrial scale production of metallic nanopowders
  - High efficiency materials for energy storage applications
  - Materials for printable electrodes and current collectors

- **Development steps**
  - Two processes for continuous production of metallic nanoparticles
  - Particle coating with metals, metal oxides, graphite and polymers
  - Online monitoring and control of the production
  - Scaling up the facilities

- **Results**
  - High purity and oxidation resistance of the powders
  - Patented nanoparticle production techniques based on CVS and physical vapor nucleation (WO0714445A and FI20096162)
  - Patented nanoparticle coating by carbon, metals and metal oxides (WO11073514A, FI20096317, WO11098665A and FI20105126A)
  - Application in silicon based Li-ion cells, printed batteries and solar cells

- **Customers**
  - OM Group, Nokia, SAFT Batteries and Varta microbatteries
Case 2: Organic Solar Cells

- **Need**
  - Roll-to-roll production of organic solar cell modules
  - Cost effective manufacturing methods
  - Power conversion efficiency more than 5%

- **Development steps**
  - Suitable printing techniques for solar cell structures
  - Novel module architectures
  - Stable and efficient photoactive materials
  - Printable electrodes
  - Optimized processing conditions
  - Fully roll-to-roll printed solar cells

- **Results**
  - Large area printing of photoactive materials
  - Printed organic solar cells with high power conversion efficiency
  - Modeling of optical and electrical phenomena occurring in bulk heterojunction solar cell structures

\[ \eta = 2.8 \% \]

\[ V_{oc} = 0.6 \text{ V} \]
\[ I_{sc} = 7.9 \text{ mA/cm}^2 \]
\[ FF = 0.57 \]
\[ A = 18 \text{ mm}^2 \]
Case 3: Noise control

- **Need**
  - Reduced noise levels give competitive advantage in all kinds of machinery.
  - Vibration damping improve the durability and can increase, e.g. rotational speed of machines or quality of the product.

- **Development steps**
  - Modelling of structures and noise sources.
  - Noise measurements at customer sites.
  - Development of active and passive materials and structures for noise control.
  - Application to customer cases.
  - Performance verification.

- **Results**
  - Passive materials with a loss factor above 1.
  - Technology transfer to an industry partner.
  - Trade mark registration ELASTE by Noisetek Oy.
  - 15 dB noise reduction in the inspection doors of a large diesel engine.
Case 4: Stainless steel coating for fuel cells

- **Need**
  - Electrically conductive corrosion protection coatings are needed for PEM fuel cells in order to reduce the cost and volume of the PEMFC stacks.
  - Cost effective test methods are needed for screening of the candidate coatings.

- **Development steps**
  - Selection of candidate coatings based on a literature review.
  - Deposition of CrN by alternative methods (PVD, ALD, electrodeposition).
  - Development of in-situ monitoring method, the multisinglecell.
  - Optimization of the coating process based on the screening results.
  - Stack testing.
  - Cost assessment.

- **Results**
  - CrN/Cr2N on AISI 316 L tested in a commercial PEMFC stack.
  - Cost reduction by replacing PVD by cheaper coating process.
Case 5: Coating development for fireside protection

- **Need**
  - Radically improved new material solutions for surfaces under highly demanding service conditions at temperatures of 500-700 °C using highly corrosive fuels enabling higher service temperatures and increased efficiency
  - Allow different strategies for material design:
    - Tube: creep properties and costs – Coatings: corrosion and erosion at high T
    - E.g. new compositions outside the alloy solubility limits allowing extremely high alloying contents and sophisticated and tailored material properties.

- **Development steps**
  - Exploiting modeling approaches in material development and alloy design of new innovative materials to e.g. prevent active corrosion in tubing
  - Optimization of the complete manufacturing chain from powder to coating
  - Laboratory and Plant scale testing and demonstration

- **Results**
  - Compared to uncoated, radical increase in lifetime of tubing in erosion-corrosion environment in biomass burning plants up to 500 °C has been demonstrated at a customer site.
  - The benefits from the use of supersaturated alloys are achieved through the improved diffusion of the oxide forming component, which allows the formation of a more resistant oxide layer acting as the chlorine barrier.
  - It was also already demonstrated at the initial testing stage that the chlorine corrosion through active oxidation mechanism can be efficiently hindered by using the new concept of the multilayer alloy design.

- **Protective Fe-based amorphous arc-sprayed coating after deposition testing. Only thin sulphur, sodium and potassium containing layer on the surface.**

- **Trial from the power plant to demonstrate coating suffering no oxidation under the deposit layer.**
Case 6: Thermoelectric Energy Recovery and Refrigeration

- **Need**
  - Thermoelectric energy recovery is “green technology” that utilizes waste heat to produce energy – for distributed power, autonomous sensors and wireless, etc.
  - Thermoelectric cooling enhances the lifetime of thermally loaded components, and can be utilized in consumer appliances
  - Efficient thermoelectric materials can be used in advanced sensors
  - New materials and manufacturing technologies need to be developed to enhance the cost efficiency and power density of thermoelectric systems.

- **Development steps**
  - Tailoring of heavily doped semiconductors for enhanced performance.
  - Development and testing of new consolidation methods
  - Metrology with national and international partners
  - Thermo-mechanical-electrical modeling of thermoelectric generators and refrigerators with partners
  - Demonstrators and peripherals development for energy conversion and cooling
  - Demonstrators measurement and evaluation with international partners
  - Piloting

- **Results**
  - New light weight materials with high figure of merit for energy
  - New manufacturing methods
  - New optimized low cost modules and peripherals for energy harvesting and refrigeration
Case 7: Adaptive wind turbine blade

- **Need**
  - Load reduction on large wind turbine blades.
  - Vibration damping.
  - Blade adaption to wind speed variations.

- **Development steps**
  - Modelling and design of composite structure with embedded SMA wires.
  - Lamination of the structure with embedded wires.
  - Control system for the adaptive structure.
  - Performance verification in a wind tunnel.

- **Results**
  - 1 m prototype blade successfully designed and operated.
  - The lift force was doubled after activation in a wind tunnel.
  - Only a small part of a large blade need to be adaptive.
Case 8: Nuclear fusion materials

- **Need**
  - Materials and manufacturing technologies pay a key role in development towards fusion power plants, e.g., ITER, W-7X, DEMO and PROTOTYPE.
  - Radiation damage resistance, ductility, low activation and lifetime are critical issues in material development as well as multi-material components.

- **Development steps**
  - Model and characterize materials and define design parameters
  - Innovative material characterizing methods in fusion relevant environments

- **Results**
  - Fracture mechanical and radiation damage evaluation of bimetallic CuCrZr alloy and 316L(N) stainless steel joints
  - Innovative pneumatic loading devices for tensile and creep fatigue testing under neutron radiation
  - Viability of powder hot isostatic pressing method in manufacturing of First Wall components
Case 9: Material performance and evaluation

- **Need**
  - Technoeconomic and safe life of critical components
  - Operational condition and ageing
  - Repairability of damaged or ageing parts

- **Development steps**
  - Materials degradation mechanisms and modelling
  - Service performance and applicability; simulation and verification
  - Monitoring technologies and diagnostics

- **Examples**
  - Creep (and creep-crack) simulation of materials with defects
  - Ultrasonic evaluation of dissimilar metal welds by Phased Array technology
  - Electrochemical evaluation and modelling of metal-oxide-water interactions
VTT creates business from technology