SUST Roadmap for Superconductors in the Environment

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Over two years ago the editorial staff of the journal Superconductivity Science and Technology discussed having a dedicated issue that would describe superconductivity based applications that would have a positive environmental effect. This could be a superconducting application in a new technology area or the replacement of an existing technology that has a significant environmental impact.

The format and contents of the issue went through several iterations before the final version, which was published in September 2013. The issue is available online at http://iopscience.iop.org/0953-2048/26/11/113001/article
Issue Contents*

- Water purification by superconducting high gradient magnetic separation
- Long-distance dc transmission of green power
- Superconducting magnetic energy storage
- Development of Superconducting Maglev and promotion of Chuo Shinkansen
- HTS Maglev and future evacuated tube transportation
- Development of a megawatt-class superconducting motor for ship propulsion
- Terahertz imaging for environmental applications
- Future technological needs to study naturally occurring magnetic fields in the Earth and near-space environments
- UXO detection using SQUIDs—no one gets left behind
- Superconducting technology for energy efficient high-end computing

* Note, not all discussed herein
Issue authors and editors

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Water Purification

- Quality of life is related to the availability of fresh water.
- Nearly half of the 7 billion people on the earth do not consistently have a proper drinking water.
- About 2.5% of the water on the earth is fresh, but only 0.008% is easily available for human use.
- Only a small fraction of water used for any human purpose is satisfactory for reuse.
- One way to improve local water quality is to use a wastewater purification system based on a magnetic separation process.
Water Use and Population

- Graph showing population growth over time from 1800 to 2100, with lines for estimated, U.N. high, U.N. medium, U.N. low, and actual population.
- Bar chart for water consumption in the world from 1950 to 2025, with categories for domestic, industrial, and agriculture water.

UN World population Prospects 2012
From Wikipedia
Water Purification

- The force on a magnetic particle is proportional to its volume, its magnetic moment and the field gradient:

\[ F = V \cdot m \cdot \nabla B \]

- \( m \) is nearly constant for ferromagnetic materials
- \( m \propto B \) for diamagnetic and paramagnetic materials

- Magnetic separation has been used in mining operation for nearly a century and a half.

- Magnetic separation can be based on use of:
  - Low Field  Ferromagnetic particles that have been treated to adsorb or absorb specific materials: the process is referred to as seeding
  - High Field  Pollutants that are Paramagnetic or Diamagnetic.
Water Purification

• High-gradient magnet separation (HGMS) is already used in paper factories, river water purification, geothermal water treatment, and purification of landfill and agricultural leachates.

• The goal is to establish a standard system that can process several hundred tons of waste water per day.

• This is enough water for a small community including some industrial capability. One issue is to assure that the system will purify the water independent of its source, be it waste water, ground water or river water.

• To be effective in third world countries, the system would be small, rugged, reliable, and require minimum maintenance.
• A simplified SMES system.
Energy storage is an adjunct to electric power production and use. Future use will be associated with renewables.

In 2010 California passed Assembly Bill 2514 requiring all utilities have some energy storage capability.

On Oct 17 the California Public Utility Commission set storage goals for the three major utilities in the state.
  - 1325 MW by 2020.

Today energy storage is mostly in the form of pumped hydro. But several other technologies exist; and advanced storage systems using batteries are used for many applications.

SMES may fit into some niche markets.
• SMES characteristics
  – Power and energy capacities are independent
  – Rapid response
  – High cost storage ⇒ not ideal for long term backup
  – Efficiency high for short term storage
  – May be combined with longer term storage options
  – Requires significant magnetic field $E/V \propto B^2$
  – ⇒ Superconductors at low temperatures
• HTS SMES status
  – Mostly R&D
  – Some demonstrations /prototypes
  – South Korean SMES systems shown in the figure
    upper 600 kJ BSCCO solenoid
    lower 2.5 MJ GdBCO toroid
    \( T_{op} \sim 14 \text{ K} \) conduction cooled
  – Future may be combined with liquid hydrogen storage for fuel cell power system.
Superconducting Maglev

- **Chronology and Worldwide Activities**
  - Initial concept 1934 electromagnetic suspension—Germany
  - LTS concept 1966 — HTS 1990s
  - Shanghai Transrapid 30 km < 8 minutes $8$ one way
  - Brazil LRV Cobra — Germany SupraTrans
  - China SuperMaglev — Japan Chou Shinkansen

- **Issues**
  - $F_{\text{air}} \propto v^2$  
    Suggests use of evacuated tubes
  - $\text{Noise} \propto \begin{cases} v^7 & \text{if } v < 120 \text{km/h} \\ v^8 & \text{if } v > 120 \text{km/h} \end{cases}$
  - Standard is 75 dB, but near 90 dB at 400 km/h
  - Cost and number of passengers
Superconducting Maglev

- The Tokaido Shinkansen Tokyo to Osaka
  - Initial (1962) and current target (2012) is 1 h each way.
  - 515 km @ 270 km/h takes 2.5 h each way
  - 143 million passengers per year
  - 84 % of market vs. 16 % for air travel
  - Shinkansen produces $< 1/10$ as much $CO_2$ as Air

- Superconducting levitation may reach the 1 h goal
  - Tests Started at the Yamanshi Test track in 1997.
  - Achieved 581 km/h — Passing trains 1026 km/h
  - Projected SC Maglev Chou Shinkansen
  - Chou Shinkansen will produce $< 1/3$ as much $CO_2$ as Air
Superconducting Ship Propulsion

- Maritime transport is a major producer of $CO_2$
- January 2013 new regulations
  - EEDI Energy Efficiency Design Index
  - SEEMP Ship Energy Efficiency Management Plan
  - $CO_2$ emissions must be reduced to 70% of present levels by 2025
- HTS based propulsion systems
  - High efficiency (~98%) helps address new standards
  - High torque per unit volume allows pod based system
  - Many systems under development today
Superconducting Ship Propulsion

1 MW prototype motor  SUST Roadmap page 20
Superconducting Ship Propulsion

Siemens Schottel Propulsor from Wikipedia
Squids as Sensitive UXO Detectors

- UXO (Unexploded Ordinance) or MEC (Munitions and Explosives of Concern)
- 10 to 15% of all ordinance that has been deployed remains unexploded in the environment
- UXO from munitions testing and bombed areas present a major environmental challenge
  - Thousands of UXOs from WWII are found each year.
  - Nearly 40,000 km² in the US are contaminated
- Nearly 1000 people killed each year in Afghanistan.
- The standard for civilian use of areas where UXO may be present is a 99.9% confidence level that all have been detected and removed.
Squids as Sensitive UXO Detectors

- A major issue is discrimination of UXO from non hazardous items, such as shrapnel or other metallic debris.
- Removal of non hazardous materials amounts to 75% of the remediation costs (several billion $/yr), which is mainly the cost of digging and removing objects.
- Various techniques are available, depending on the type of ordinance to be located and the environment:
  - Land vs. marine; small vs. large; ferrous vs. non ferrous
  - Magnetic; electromagnetic (time or frequency domain)
  - Eddy currents cause secondary fields that reflect conductivity
Squids as Sensitive UXO Detectors

Various Ordinance SUST Roadmap page 28

Magnetic variation caused by some ordinance
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Squids as Sensitive UXO Detectors

CSIRO tensor gradiometer  SUST Roadmap page 30
What was not included

• Fusion Power sources, e.g., ITER
• Short superconducting cables
• Generators for Wind Power
• Superconducting Power System components
• Magnetic Resonance Imaging
• Particle accelerators