A Proposed Method to

Electrify All Surface Modes of Transportation In the United States Using Superconducting Magnetic Energy Storage Devices

By Willard Cooper and J. William Vigrass, panel member

To the National Surface Transportation Policy and Revenue Study Commission, USDOT Bldg., L'Enfant Plaza, 400 7th St. N.W., Washington, DC, 20590, February 22, 2007.

Executive Summary: It is proposed to electrify all surface modes of transportation in the United States using Superconducting Magnetic Energy Storage devices (SMES's).

Background and Objective: This one effort will free the US from depending upon imported petroleum, will not cause global warming of and by itself, will free most urban areas of vehicle caused pollution, and will point the US toward further and safe economic growth.

At the present time, US petroleum use is as follows:

Here is a rough 2007 breakdown of where daily US oil consumption (currently about 21 million barrels/day, or 25% of world daily oil usage) in USA goes:

48%--automobiles
6%----trucking
6%----railroads
60% subtotal, surface transportation
6%----airlines
1% possibly maritime (no figure for oil use by US shipping was shown)

3%----electricity generation

30% (approx.)--petrochemicals (paint, varnish, plastics, glues, lubricants, etc.)

100% US petroleum consumption, estimated for 2007.

Buses, transit use, were not shown separately.

US Dept. of Defense uses about 2% total of US oil fuel daily (about 480,000 barrels/day), at least according to official DOD sources.

From the above approximation it appears that roughly 60% of US petroleum energy used could be replaced by electrical power, centrally generated by all means, which include nuclear, coal, oil (per above), natural gas, hydro, wind, solar and other. If coal, natural gas and oil were replaced by the other energy sources, the US would be

free from pollution and global and environmental warming caused by those forms of electrical energy generation.

Some reports indicate that the world reached a peak of petroleum production in December 2005. Since then it has been declining in the face of increased demand, especially from developing nations such as China and India. This can only mean constant increases in price. The present dip in price appears to be a short term event. There is a finite amount of petroleum. Demand is rising. Price must rise.

A. **What is superconductivity?** Superconducting materials conduct electricity with no resistance losses. Presently this can be done only at cryogenic temperatures. The word *cryogenics* literally means "the production of icy cold"; however the term is used today as a synonym for the low-temperature state. It is not well-defined at what point on the temperature scale refrigeration ends and cryogenics begins. The workers at the National Institute of Standards and Technology at Boulder, Colorado have chosen to consider the field of cryogenics as that involving temperatures below –180 °C (93.15 K). This is a logical dividing line, since the normal boiling points of the so-called permanent gases (such as helium, hydrogen, neon, nitrogen, oxygen, and normal air) lie below -180 °C while the Freon refrigerants, hydrogen sulfide, and other common refrigerants have boiling points above -180 °C.

Cryogenics is a branch of physics (or engineering) that studies the production of very low temperatures (below –150 °C, –238 °F or 123 K) and the behavior of materials at those temperatures.

As a scale of measurement, absolute zero, the total absence of heat, is defined as follows: By international agreement absolute zero is defined as precisely 0 K on the Kelvin scale, which is a thermodynamic (absolute) temperature scale, and -273.15°C on the Celsius scale. Absolute zero is also precisely equivalent to 0 °R on the Rankine scale (also a thermodynamic temperature scale), and –459.67 °F on the Fahrenheit scale.

"High temperature" superconductivity has been generally defined as taking place at above 4.5 K (liquid helium) to about 77 K, the boiling point of liquid nitrogen.

B. **What does a Superconducting Magnetic Energy Storage device do?** It can store a large amount of direct current electrical energy in a coil of superconducting wire with no loss of energy so long as temperature is maintained at cryogenic levels. Some SMES devices were developed that needed an even colder temperature, that of liquid helium, a costly process difficult to maintain. For mobile transportation use, "high temperature" superconductivity at about 65 K has been found to be most effective. The required refrigeration for liquid nitrogen to maintain 65 K to 77 K is well within cost-effective commercial state of the art.

SMES units can absorb very large amounts of energy in a short time, store it, and discharge it in a short time. No electrical energy storage device developed to date comes close to the capability of SMES units.

C. What is a SMES? Visualize a tube of say, 3 inches in diameter and about 12 feet long. Wind a continuous band of YBCO flat wire (composed of yttrium, barium and copper oxide) around it to make a solenoid type coil much like the one that powers your door chimes at home. When an electric current is applied to the wire, a magnetic field is created within the bore. Now, wrap the tube into a race track shape of about 2 feet wide by four feet long, and connect the ends of the wire together to form a continuous loop. Refrigerant would be contained within the bore. The outside of the coil would have an insulating cover. The entire coil would be placed within a double walled vessel with a vacuum between the two walls like a giant thermos bottle. You now have a SMES (if crudely described). Conventional practice has been to have an electrical connection that must penetrate the vessel to reach the coil, thereby providing a path for heat to enter. For that reason, continuous refrigeration must be applied. However, the Swedish firm ABB AB has a patent covering inductive coupling to provide means for energy to be put into or taken out of a SMES without penetrating the vessel. This method has attractive possibilities should it be developed to allow commercial use in transportation applications.

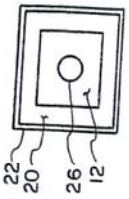

FIG. 2

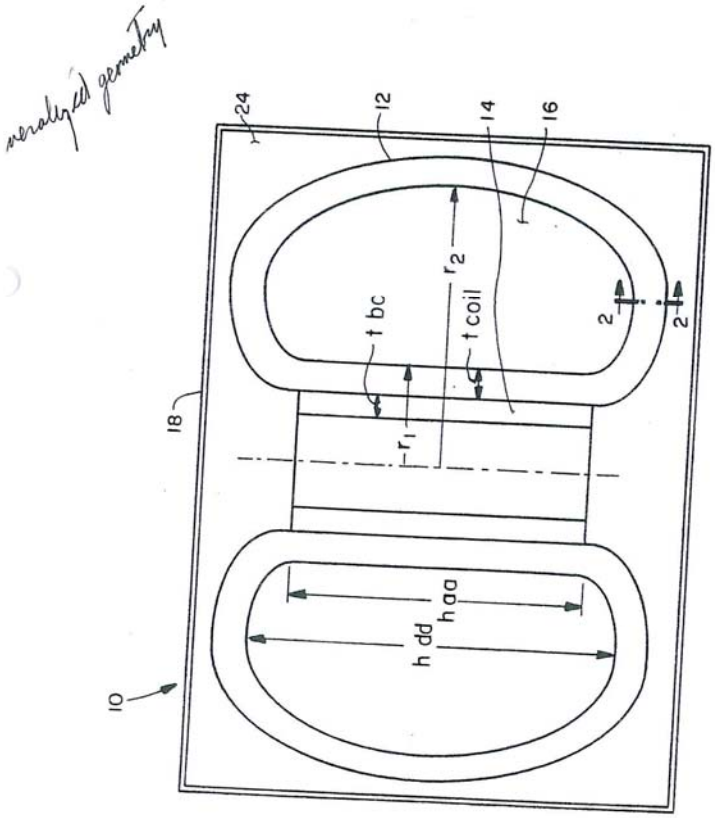

FIG. 1

This view of a Toroidal Superconducting Magnetic Energy Storage device is looking down on two "D" shaped SMES coils.

Fig. 2, Cross section A/A taken in Fig. 1 is as follows:

The magnet, 12, surrounds a central support structure or bucking column 14, made of steel or aluminum which bears a center force along the straight section of the coil. The magnet 12 is suspended in a cylindrical metal shell 18, which protects the magnet during use. The magnet is surrounded by a stabilizer structure 20, which can include aluminum with silicon fibers. Surrounding the stabilizer is a layer of electrical insulation 22, such as kaptan plastic. The magnet 12 also includes a cryogenic coolant channel 26 disposed through its center for convective cooling of the superconducting magnet. The bore of the coil 16 serves as a reservoir or storage volume for the fluid, preferably liquid helium or liquid nitrogen. The magnet is wound in a toroidal fashion such that the magnetic field is entirely contained within the bore of the magnets. The external field is very low, theoretically zero (except for electrical leads).

D. What state of development is the SMES concept in? Laboratory tests proved the concept some years ago. Some patents were issued in the early 1990's. In the recent several years, prototypical installations have occurred in Japan, Europe and the US. Considerable research and development is needed to create SMES units that can be made reliably and mass produced at a commercial economical cost.

E. What materials are used for SMES units? Materials containing yttrium, a rare earth, barium and copper oxide, have been used although other rare earths have been used. This material is called "YBCO" for short. Other rare and not so rare elements have been used that require lower temperature, but YBCO has been found to be the most effective to date because it is superconducting at 65 K, the temperature of liquid nitrogen. Identifying and developing sources of large amounts of the needed elements would be part of any research. Elements used are:

- Name: yttrium
- Symbol: Y
- Atomic number: 39
- Atomic weight: 88.90585
-
- Name: barium
- Symbol: Ba
- Atomic number: 56
- Atomic weight: 137.327

Copper oxide is a common compound, and is commercially available.

The proportions of the above substances are not shown because that information is proprietary. Other rare earths have also been used with some success.

F. How widely known is this? These developments are not widely known outside a relatively small circle of scientists. Few US academics know about it, and none have been interviewed who could be helpful in developing applications. Work has been going on in Japan, Europe and the US. Learned papers have been published under the auspices of professional societies such as the IEEE and its overseas counterparts such as the Institute of Physics, UK. These papers tend to be very technical and not easily understood by someone without knowledge of electricity and physics.

G. What is going on in the US? Two US firms have been developing the special wire (or flat tape) needed to create SMES coils. They are:

1. American Superconductor in a suburb of Boston, MA.
2. Superpower of Schenectady, NY with an installation of high temperature (65 K.) utility cables near Albany, NY. They have developed some small scale prototype coils for stationary utility use. Learned papers published by US,

Japanese and European writers have proposed different configurations and some possible commercial uses for SMES devices.

Work has been concentrated on developing means to make long lengths of superconducting tape (flat wire) so that it could be wound into coils. Progress has been made with a 9.7 mile length made (apparently by splicing shorter lengths by means not described) which would be enough to wind a superconducting cable 30 meters long.

In Japan, a 600 meter length of BSSCO, composed of bismuth, strontium, calcium, and copper oxide requiring lower temperature, had been made. Japanese firms have made several prototype applications.

All the above indicate that (1) progress has been made and (2) there is still a long way to go before commercially mass produced superconducting cable and devices can be expected. While there has been support by US Dept. of Energy and its New York State equivalent (for Superpower) for electric utility use, it appears that it is a moderate level of activity. There have been a considerable number of professional and academic papers published.

H. What are potential uses of SMES devices? They could be used to do the following:

1. Store energy generated in the off peak for use during the peak.
2. Smooth energy transmittal from one electrical system of the grid to another to avoid surges as have caused power blackouts in the recent past. There is great interest on the part of USDOE and the electric power industry on this application.
3. Superconducting coil windings have been used in generators and/or motors.
4. Superconducting wire or cable can transmit electrical energy with no losses from resistance. However some energy is used for cryogenic refrigeration.
5. SMES units can store enough power to make electrically powered vehicles useful without the severe limitations in performance and distance imposed by all known forms of batteries, ultra-capacitors or flywheels. Recharging a SMES unit could take but a few minutes.
6. **Using domestically produced electrical energy from all known forms of available energy – coal, hydro, wind, oil, natural gas and nuclear – the entire US surface transportation system could be and can be converted to electric power using on-board SMES units to store electrical energy on vehicles. An all-nuclear system would produce little global warming, no CO2 and no contaminants resulting from burning fossil fuels.**

I. What are initially attractive applications of SMES units?

1. Urban transit vehicles, buses and light rail, are attractive because they operate within a confined network where recharging stations could be conveniently located. The elimination of diesel particulates and carbon dioxide exhaust from transit vehicles within confined urban areas would be a major benefit. The SMES units can absorb braking energy that is now dissipated as heat through brake discs or resistors in rail vehicles or dispersed to other vehicles through regeneration into the third rail or overhead power line with resultant losses in transmission. With the latter, another vehicle must be relatively nearby to absorb the energy since there is no present common means of storing energy. Heavy rail rapid transit or electric commuter railroad might use SMES units at each station stop to

absorb braking energy and then use it to accelerate the train away from that station. Some experimental installations of flywheels have been used for this purpose but have not been widely adopted.

2. Commuter railroad diesel-electric or electric locomotives in start-stop service could capture much of their braking energy and use it to accelerate their train after a station stop. Diesel-electric or electric locomotives in corridor service having moderately frequent stops could also benefit. Passenger and freight locomotives in long distance service in mountainous territory could recover braking energy on downgrades. (Willard Cooper has submitted a patent application for his conceptual design of a SMES equipped locomotive.)
3. Railroad yard switching locomotives would be a first application for freight railroads since such locomotives are captive to a given yard, and could reach a recharging station easily. Some yards are in urban areas having increasingly strict emission standards and such places would be ideal first applications. Such locomotives might well be hybrids with small on-board diesel engines that could be used to move the locomotive to a charging station should it run out of stored energy. The diesel would be seldom used if the SMES system works as intended. Such locomotives could also be used for local "peddler" runs within urban areas, delivering and picking up carload freight.

Railroad and transit applications can accommodate larger and heavier SMES units than could private automobiles. Operation and maintenance is by professionals, and safe operations have always been hallmarks of operations. These would be ideal applications to develop smaller and safer SMES units.

4. Finally, highway vehicles might follow after SMES units will have been developed that can fit private automobiles and small trucks. Large trucks would be an intermediate application in which fleets would be operated by truck lines having known service parameters and careful maintenance.

Finally, the very large fleet of privately owned automobiles would be addressed after SMES development could mass produce units at a competitive cost (compared with fuel powered automobiles). Initial calculations indicate that a range of 200 or more miles is possible within the present state of the art. It is believed that this could be extended with appropriate research and development. (Willard Cooper has submitted a patent application for his conceptual design for a SMES equipped automobile.)

5. Mass produced SMES modules would have an approximate size of 2 to 4 feet wide by 4 to 6 feet long by about 8 to 12 inches thick, stacked one on top of another or vertically side by side. Windings would be reversed on adjacent SMES units to cancel out their strong magnetic fields. A key part of research would be to contain and control magnetic forces within SMES units. A SMES coil would be contained in a double walled metal vessel (probably of non-magnetic stainless steel) in which the space between the walls would be a vacuum, just like a large thermos bottle.

J. Level of Effort needed would be very large. No estimate has been made other than a guess that it would be in the millions of dollars if near-term results are desired and expected. It appears to be in the national interest to have near-term results.

K. Funding sources would have to be developed. General funds are always a possible source for R&D. Additional sources might be explored.

The electrical power industry might be invited to join as sponsors, developers and potential users because they would be primary beneficiaries of nationwide use of SMES equipped electrically powered vehicles. In-house applied research by large utilities or consortia of utilities might make use of considerable talent and knowledge that they are developing for applying SMES units to absorb surges in interconnections and to simply store off peak power for sale during peak times. They have a strong self interest.

M. Leadership is needed. Development to date has been on a relatively small scale done by private companies and some by independent research organizations with some sponsorship by the US Dept. of Energy. Their pioneering work is valuable and would be the basis for additional research and development. At present there is no entity in the US in overall charge of developing superconducting applications for mobile use.

N. US Department of Transportation could take the lead in applied research, development and engineering to use SMES units as a means of converting the entire US surface transportation network to domestically generated electric power. The Department of Energy might continue to concentrate on applying the SMES concept to electrical utility generating and distribution systems.

O. What needs to be done?

Research has been ongoing for several years for utility use sponsored in part by US Dept. of Energy, and significant progress has been made, but if the US is to become free of importing foreign petroleum the level of research and development must be greatly increased for transportation use. Given the unstable sources of much of the world's petroleum supply, and given the hostility of some of the host nations toward the US, it appears to be in the self interest of the US to give development of electrically powered surface transportation the same level of national attention as was given to the Manhattan Project of World War II. The cost may be high. The benefits will be huge. The cost of NOT doing so may well be catastrophic to the US.

A Proposed Research Program

The program most logically would be housed in the Department of Energy, but they have shown little interest in vehicle applications to date. Applied research for transportation use might better be housed in the Department of Transportation.

Some tasks that come to mind are as follows:

1. Develop modular mass produced standardized SMES units that could have widespread application in mobile transportation applications by using them in multiple, such as in series-parallel circuits to achieve the level of energy storage needed for a given application.
2. Develop quick-charge connectors to allow fast recharging of vehicles at charging stations. Develop modular charging stations that could be mass produced and distributed about the nation much like present day gasoline/diesel stations. ABB AB of Vasteras, Sweden has developed and patented a design for energy transfer between stationary power station SMES coils to the electrical grid using inductive transfer of energy. This avoids the need for a cable to penetrate the vessel containing supercooled superconducting coils and would contribute to retaining coldness within the

SMES. The inductive concept might be developed to allow wayside to vehicle transfer of electrical energy safely and quickly.

3. Develop stationary energy storage units that would store energy received during the off peak (at night) for distribution during the day.
4. Develop more efficient HVAC systems for automobiles and other vehicles that would be much more efficient that electrical resistance heating which uses energy in large quantities.
5. Develop comprehensive safety oriented design standards that would control, contain and/or quickly dissipate energy stored in SMES units in case of collision.

Strategic Needs

The US is vulnerable to any disruption in its petroleum energy supply. The US could not fight a prolonged "real" war (like WWII or Korea) without an assured supply of petroleum, and that supply is at best uncertain. Domestic transportation in the US is entirely petroleum based at the present time (except for a small amount of electric railroad in the Northeast Corridor and rail transit in some cities). Domestic transportation could come to a halt if the US's petroleum supply would be interrupted, something that our potential adversaries know very well. By using SMES based electric energy with domestic electric power generation by means other than oil, the US can be independent of oil for domestic transportation. This is a real and urgent need.

Legislation may, or may not be needed be needed to establish a federally sponsored research and development program. At the very least, some initial federal general funding would be needed to get started, pending passage of specific taxes that would be targeted toward developing this new source of energy for surface transportation of all modes.

Institutional Barriers may be anticipated. The domestic petroleum industry and the related motor vehicle industry may be expected to use their considerable influence to stifle development of SMES based transportation. This will be difficult to overcome. The strategic interest of the nation is to develop energy sources other than petroleum.

Will The Congress be up to it?

USDOT can lead the way towards energy independence.
USDOT can lead the way to reduced pollution.
USDOT CAN LEAD THE WAY TO THE FUTURE OF SURFACE TRANSPORTATION!

Acknowledgements: This paper was compiled by Bill Vigrass from information provided by Willard Cooper who in turn obtained it from several sources. Among these sources are professional and/or academic learned papers, many telephone conversations with professionals engaged in superconductivity research, and attending a number of seminars, meetings and conventions in the US and overseas. The authors of this paper do not claim to have done any original research, but Cooper has conceptualized transportation applications from information collected from several sources and submitted several applications for patents. He has had his concepts reviewed by world class researchers who agreed that what Cooper proposes is possible. A Japanese scientist, K. Sato of Sumitomo Industries, responded that Cooper's proposed vehicular application is "very viable". Cooper and Vigrass have concluded that their proposal could solve the nation's surface transportation energy problem.

Cooper's résumé is appended below. Vigrass's résumé was submitted to the Commission some time ago.

Résumé

Willard Cooper
610 Society Hill Drive
Cherry Hill, NJ 08003

Education
B. S. Temple University, 1950
Master of Government Administration, Univ. of Pennsylvania, 1951
Master of City Planning, Univ. of Pennsylvania, 1953

Employment
Cooper, Alvaré & Harkins, City Planning Consultants, 1953-1959
City of Camden, NJ, Director of Planning and Renewal, 1960-1969
Delaware River Port Authority, Camden, NJ, Director of Regional Planning and Staff Consultant for Planning 1970-1992

Recent Papers
Superconducting Wind Turbine Design with Superconducting Magnetic Energy Storage (SMES) (Patent application).
Integrated Superconducting Wind and Marine Turbine Design with SMES
Pure Electric Vehicle with SMES Energy Storage Module (Patent application)
Superconducting High-Speed Electric Train with SMES Energy Storage Modules (Patent application).
Distributed Energy Storage System for Electric Utilities Based on SMES Power Storage System
Design of a MAGLEV (Magnetic Levitation) System Using Superconducting Trapped Field Magnets for Levitation and Propulsion

Seminars and Conferences
Applied Superconductivity Bi-annual Conference, 1994 to 2006
Cryogenic Engineering Conference/International Cryogenic Materials Conference 1997-2005
Society of Automotive Engineers (SAE), Fuel Cells for Transportation Seminar
Intersociety Energy Conversion Engineering Conferences

Memberships
Society of Automotive Engineers
Cryogenic Society of America
Delaware Valley Regional Planning Commission (Thirty year member and sometimes chairman of the Transportation Planning Committee).

Miscellaneous
Registered Community Planner, State of New Jersey 1953 until retirement 1992
American Institute of Planners/American Society of Planning Officials award for "Best Planning in the United States" for 1965.

Member of the Charter Drafting Committee of the Delaware Valley Regional Planning Commission, Philadelphia, PA., 1960.

Designed the First Drive-train for a Superconducting Electric Vehicle, 1993-94, evaluated by K. Sato of Sumitomo Industries, Osaka, Japan, and found “certainly viable”. (Mr. Sato works in the field of superconducting devices.)

Prepared all applications for Urban Mass Transportation Administration funding for the PATCO Lindenwold Hi-Speed Line (owned by Delaware River Port Authority) 1970 through 1991.

WC/jwv/NatlTransp.
Résumé, Cooper, W.
02.19.07

WC/JWV/jwvNatlTranspComm
SMES. SurfaceTransp.
01.30.07 Rev. 0.
02.07.07 Rev. 1.
02.09.07 Rev. 2
02.10.07 Rev. 3
02.20.07 Rev. 4 WC.
02.21.07 Rev. 5

J. William Vigrass
1813 Cardinal Lake Drive
Cherry Hill, NJ 08003
Home tele. 1-856-428-7217
Cell phone: 1-856-816-2708
billvigrass@comcast.net Home
billvigrass@hillintl.com. Office

Willard Cooper
610 Society Hill Drive
Cherry Hill, NJ 08003
1-856-751-1411