**Challenges Confronting the Physics of Superconductivity in the 21st Century:**

**From Nanoscale Theories to Exascale Energy Applications**

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# Abstract

We commence by summarizing the history and physics of superconductivity beginning with the development of low temperature refrigeration and instrumentation in the first decade of the 20th century subsequently leading to the discovery of “perfect conductivity” in solid mercury at 4.2 K boiling point of liquid helium in 1911 by Gilles Holst and Kammerlingh-Onnes. Throughout the ensuing years, physicists worldwide pursued both the explanation and exploitation of this remarkable phenomenon. A major advance occurred in 1957 with the publication by Bardeen, Cooper and Schrieffer (BCS) proposing and proving the phenomenon of “superconductivity” resulted from lattice vibrations (ironically the source of electrical resistance in metals) “pairing” the electrons/holes to enable zero-dissipation transport and by the 1960s, materials had evolved that exhibited transition temperatures in the low 20 K range. However, the BCS theory appeared to rule out the possibility of substantially higher values, and and such improbabilities were rather euphemistically termed “high temperature superconductors.” Nevertheless, “HTSCs” were discovered in the family of copper oxide perovskites with Tc’s between 30-40 K in 1986 by Bednorz and Mueller which by 1989 had reached 135 K and thus operational using liquid hydrogen, nitrogen and methane as refrigerants, consequently opening a wide variety of economically viable electronic and power applications.

The major portion of this talk will review the present state of the understanding and application of high temperature superconductor materials ranging from attempts to clarify and identify pairing mechanisms on the energy scale of a few milli-electron-volts to their use to embody terra-kwh continental wide deployment within the electricity enterprise. Examples include the use of density functional theory to study the relative roles of spin-fluctuation and/or lattice vibration induced Cooper pairing to modelling the incorporation of long distance HTSC transmission cables within the same natural gas pipeline rights-of-way infrastructure now emerging worldwide.