Professor Amit Goyal
SUNY Distinguished Professor & SUNY Empire Innovation professor
State University of New York (SUNY) at Buffalo
USA

中国科学院北京纳米能源与系统研究所
Beijing Institute of Nanoenergy and Nanosystems,Chinese Academy of Sciences

Georgia Institute of Technology

Date: November 12th, 2021

The "Albert Einstein" World Award of Science
The World Cultural Council

Re: Nomination of Prof. Amit Goyal for the 2022 "Albert Einstein" World Award of Science

Dear 2022 Members of the World Cultural Council Interdisciplinary Committee:

It is my distinct pleasure to nominate of Prof. Amit Goyal for the 2022 "Albert Einstein" World Award of Science. I am the recipient of the 2019 "Albert Einstein" World Award of Science. I would like to nominate Prof. Amit Goyal specifically for "*Pioneering research and transformative contributions to the field of applied high temperature superconductivity, including fundamental scientific advances and technical innovations enabling large-scale applications of these novel materials world-wide with truly significant societal impact*".

The *Nobel Prize* winning discovery of high-temperature superconductivity (HTS) by Bednorz and Müller in 1986 triggered an enormous flurry of research and development world-wide, sparked by the tremendous technological and energy-related potential of these materials, slated to be in many tens of Billions of dollars per year at full penetration and maturity. However, in order for all these large-scale applications to be realized, one needed *kilometer-long, flexible superconducting wires that carried millions of Amps of current per unit cross-section and at a cost similar to the cost of plain copper wire*. Since grain boundaries with misorientations larger than 4° were barriers to supercurrent flow, essentially mile-long, single-crystal wires were needed to be fabricated at a price/performance metric of standard copper wire that one can buy at the hardware store. This seemingly *impossible* technical challenge quickly became the **1st *holy-grail* in the field of applied HTS world-wide**.

Prof. Goyal's inventions, provide the *only* known routes to fabricate and address this *holy-grail* and realize such single-crystal-like high temperature superconducting wires at a performance/price metric potentially comparable or superior to copper wire. The first of these was the *Rolling-Assisted-Biaxially-Textured-Substrates (RABiTS) technology* for fabrication of mile-long, single-crystal-like HTS wire. Dr. Goyal's invention and subsequent innovations R&D led to the development and commercialization of this RABiTS technology world-wide. The RABiTS process uses scalable, thermomechanical, routes to fabricate single-crystal-like substrates upon which epitaxial deposition of buffer and device layers is performed. Since this invention, Dr. Goyal has made numerous additional inventions to truly make the RABiTS approach practical for commercial scale-up. American Superconductor Corporation (AMSC), the leading manufacturer of high temperature superconducting wire world-wide, chose to terminate production of the powder-in-tube (1st generation high temperature superconducting wire upon which the company was established), licensed the 2nd generation RABiTS technology, and established a factory for manufacturing high temperature superconducting wire based on the process. AMSC has filled some the world's largest orders of millions of meters HTS Amperium wire – AMSC's proprietary second-generation, high-temperature superconducting wire, based on the RABiTS process. Dr. Goyal has received numerous awards for this technology, including an *R&D100 Award* in 1999 and has over 60 issued patents related to all aspects of this technology.

The second technology he developed was the *LMOe ($LaMnO_3$)-enabled IBAD-MgO HTS wire technology*. He and his group invented the key LMOe layer which enables scaling-up and fabrication of Km-long HTS wires using the IBAD process to realize single-crystal-like wires. The LMOe buffer layer innovation was a critical technology crucial for scale-up of this second and only other key method to fabricate such high-performance, single-crystal-like HTS wires. Working closely with SuperPower, the second largest manufacturer of high temperature superconducting wire in the United States, Dr. Goyal and his collaborators at ORNL established a $RMnO_3$, $R_{1-x}A_xMnO_3$, buffer layer technology on IBAD MgO; wherein R includes an element selected from the group consisting of La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, and Y, and A includes an element selected from the group consisting of Be, Mg, Ca, Sr, Ba, and Ra (US Patent 6,764,770). Deposition of RMnO3, R1−xAxMnO3, are very robust buffer layers chemically and structurally and it is possible to deposit them at very high rates using reactive sputtering; thereby making the IBAD-MgO process scalable to long-lengths. Of these buffer possibilities, the $LaMnO_3$ (LMO) buffer technology (called LMOe-Enabled, IBAD-MgO wire) has become the most widely used composition, followed by La-Sr-Mn-O buffer technology. SuperPower Inc. has licensed this transformative technology based on this macro-invention and is now fabricating kilometer-long wires based on this process. Dr. Goyal and other team members, including those from SuperPower, received an *R&D100 Award* for this technology in 2007.

Once, mile-long, single-crystal-like wires were fabricated using the technologies described above, the *second HTS Grand Challenge* or the ***2nd holy-grail*** **in the field of applied superconductivity** emerged. This was the need to dramatically improve the performance of wires in high-applied magnetic fields since most large-scale applications of HTS materials were in high-applied magnetic fields.. It was shown elegantly that this could ideally be accomplished using heavy-ion irradiation that penetrated the superconductor and produced amorphous, non-superconducting, nanoscale damage tracks at nanoscale spacing, which dramatically improved properties. These non-superconducting, nanocolumns at nanoscale spacings "pinned" the magnetic flux (also nanoscale and at nanoscale spacings) which enhanced the current carrying ability of the superconductor in high-applied magnetic fields. The challenge in the field or ***2nd holy-grail*** **in the field of applied superconductivity** was to accomplish such a modification without using the heavy-ion irradiation which was impractical to scale-up, was prohibitively expensive, and also rendered the metallic layers in the wire radioactive. Prof. Goyal invented and developed nanoscale, non-superconducting vortex-pinning columns via a low-cost, phase-separation and strain-induced self-assembly technology. This *Phase-Separation and Strain-Driven Self-Assembly process* is the only way to practically realize nanocolumns of non-superconducting materials at nanoscale spacings to realize optimal magnetic flux-pinning in the temperature regime for applications (20K-77K) in high-applied magnetic fields *without adding cost* and without using heavy-ion radiation. The *world's highest performance HTS wires* in high-applied magnetic fields are enabled by this *truly remarkable nanoengineering and nanotechnology innovation*. This is one of the few *scaled-up, high-technology applications of nanotechnology*.

An additional challenge in the field was the need to transition from a tape-like geometry to "round wire" in order to be easily bent and twisted for reducing energy losses in alternating current applications. This was *another holy-grail* in the field. Dr. Goyal developed a new process to fabricate single-crystal, "round" wire via epitaxial growth of the yttrium-barium-copper oxide-type superconductor on Structural, Single-Crystal, Faceted, Fibers (SSIFFS™) of aluminum oxide. Presently, this discovery represents the primary route to fabrication of a "round" high temperature superconducting wire for operation at liquid N_2 temperatures. This macro-invention is also referred to as 3rd generation high temperature superconducting wire technology (US Patents 8,481,460 and 8,227,082). Goyal received an *R&D100 Award* for this technology in 2009.

Essentially ALL HTS companies in the US (American Superconductor, SuperPower, MetOx) and world-wide employ one of Dr. Goyal's innovations mentioned above to fabricate kilometer-long, single-crystal-like, high-performance HTS wires. The technology of self-assembly to create nanoscale defects is also being employed world-wide.

The RABiTS process invented by him is presently being scaled-up by the two largest companies in the HTS world - American Superconductor Corporation (the largest HTS company in the USA), by BASF/Deutsche Nanoschicht GmbH in Germany. The LMOe-enabled HTS wire is being scaled-up by SuperPower and MetOx in the US; SuNAM in South Korea; SuperOx in Russia and Japan; Fujikura in Japan; and Shanghai Superconductor Technology and Shanghai Creative Superconductor in China. Many of these companies are also using the strain-driven, self-assembly technology for producing nanoscale columnar defects in these HTS wires.

These HTS wires are enabling all kinds of large-scale applications which could have a multi-billion dollar societal impact. Only some of these are very briefly summarized below:

a) **Nuclear Fusion**: The HTS wires allow very high magnetic fields to be reached and this can contain the nuclear plasma so that companies like Commonwealth Fusion Systems were recently incorporated to realize *commercial fusion*. Commercial fusion has been a human dream for decades and is only now close to being realized due to these HTS wires. See – https://www.cnbc.com/2021/09/08/fusion-gets-closer-with-successful-test-of-new-kind-of-magnet.html. This reports on the fabrication of a 20 Tesla magnet using HTS wires (fabricated using technology described previously) that will essentially enable commercial nuclear fusion. This may indeed solve the world's energy problems in an environmentally-friendly manner and one could envisage a nuclear fusion as part of the electric grid.

b) **Transmission of Electrical Power:** AC and DC cables for transmitting large amounts of power. More electricity is lost in the transmitting power in the Unites States than is consumed in the entire continent of Africa! Superconducting transmission cables have zero losses and can carry very large amount of electric power. While there have been many superconducting cable installations around the world, see link for a recent new one Chicago - https://www.nexans.com/newsroom/news/details/2021/09/2021-09-02-pr-nexans-installs-and-commissions-superconducting-cable-for-chicago-resilient-electric-grid-project.html. The superconducting cable is also smart and provides for a resilient electric grid. A nice and detailed YouTube video on this cable technology can be viewed here - https://www.youtube.com/watch?v=D3BSJ4HNMCg. This AC cable in Chicago is made using HTS wire supplied by AMSC which fabricates HTS wire using the RABiTS technology. Similarly, DC cables are for long-distance transmission of very large amounts of power. They are expected to be used for transmitting the DC power generated by renewables such as large solar or wind installations to where the power will actually be consumed. For example, in the United States (US), Solar and Wind installations are in central US and power demand is highest along the west and east coast.

c) **Improving Energy Efficiency:** HTS motors, transformers, fault-current limiters, etc. Fault-current limiters are essential for the electric power grid world-wide and HTS fault current limiters are a niche technology. Here is a video of AMSC's HTS fault current limiters made using the RABiTS-based HTS wires.

d) **Energy Generation:** HTS generators including those in off-shore wind turbines. Here is a link to the installation of superconducting wind generator - https://www.evwind.es/2019/11/22/first-superconducting-wind-energy-generator-successfully-tested/71971. Superconducting wind generators can produce twice the power of conventional wind generators.

e) **Defense Applications:** All-electric ships and planes. Here is a video of an HTS motor by AMSC made using RABiTS HTS wire for a Navy application - https://www.powermag.com/superconductor-motor-for-navy-passes-full-power-test/.

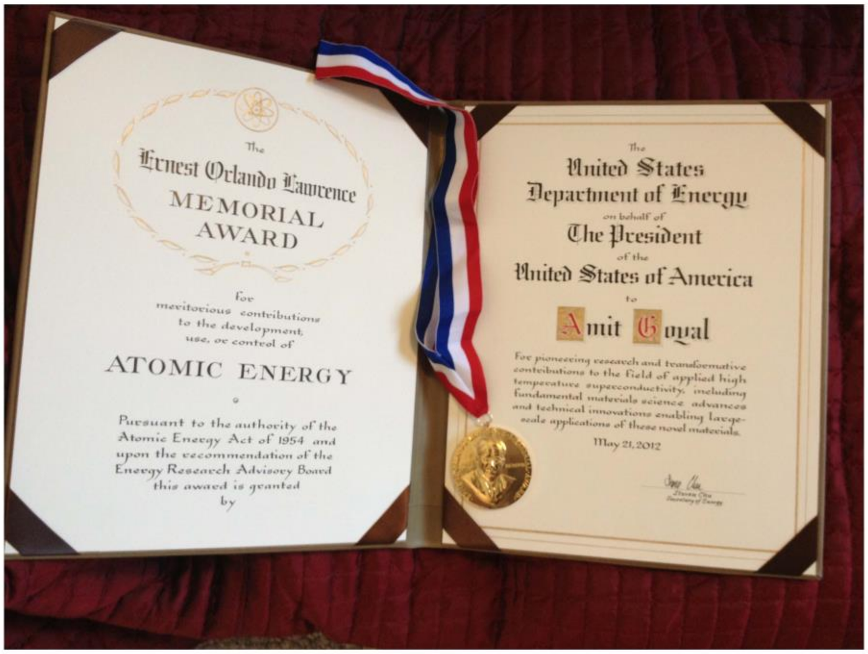
For his numerous contributions to help realize the vision of the 1987 Nobel Prize in Physics for High-Temperature Superconductors, Prof. Goyal was inducted into the highly prestigious *United States National Academy of Engineering* for his contributions to the field of applied high-temperature superconductivity and was cited for "*materials science advances and contributions enabling commercialization of high-temperature superconducting* *materials*". He has received 10 R&D100 awards. Given by the R&D100 magazine, the R&D100 awards are widely regarded as the "*Oscars for innovation*". In addition, he was also named by R&D Magazine as the *2010 Innovator of the Year* for his collective innovations to the field of high-temperature superconductors enabling their commercialization.

He is presently a *SUNY Distinguished Professor* and a *SUNY Empire Innovation Professor* at the University at Buffalo (UB). He was the *Founding Director* (from January 2015 to July 2021) of the *internally-funded*, Research and Education in Energy, Environment and Water (RENEW) Institute, a unique, multidisciplinary institute spanning seven schools and colleges at the UB and dedicated to research and education on globally pressing problems in energy, environment and water. One of the most expansive initiatives launched by UB or SUNY-Buffalo in recent years, RENEW (Research and Education in eNergy, Environment and Water) is a multidisciplinary institute that harnesses the expertise of more than 100 faculty members across seven schools and colleges and had 19 additional faculty lines to add new faculty. During his 6.5 yr term as Founding Director, he hired 15 multidisciplinary faculty and 4 senior scientists; and during his term as Director, the RENEW Institute directly or indirectly contributed to over 600 publications and over 400 presentations and garnering of over $50 Million in external funds in the important areas of Energy, Environment and Water. The Institute is now poised to have a transformational impact. For his contributions in establishing the RENEW Institute, he was awarded the *UB President's Medal*, first presented in 1990, recognizes "*Outstanding scholarly or artistic achievements, humanitarian acts, contributions of time or treasure, exemplary leadership or any other major contribution to the development of the University at Buffalo and the quality of life in the UB community*." This is highest recognition given at the university.

He is now founding a new, "*externally-funded*" research center of excellence funded by the Department of Energy Conservation titled - Initiative for Plastics Recycling & Innovation, at the University at Buffalo (UB) as Founding Director. This is an externally-funded, multidisciplinary initiative at a funding level of $1,500,000.00/yr for 6 years to address the critical problem of Plastics Recycling that has critical implications for climate change and impact.

Previously he was *Corporate Fellow and a Battelle Distinguished Inventor* at ORNL and also the *Chair of the Corporate Fellows Council* at ORNL. He has authored or co-authored over 360 publications. He has written over 45 invited papers and book chapters, and has also co-edited six books on high temperature superconductors. He has given over 25 plenary or keynote presentations and ~ 200 invited presentations in national and international conferences. An analysis of citations and papers published between 1998-2008 in the field of high-temperature superconductivity listed the top 20 authors worldwide in terms of total number of citations and total number of published papers (http://sciencewatch.com/ana/st/hts/authors/); *Dr. Goyal was the most cited author on this list world-wide* (total of 1988 authors) and *had the highest number of papers* (published in this timeframe for the United States). Dr. Goyal has 88 issued patents comprising 70 US patents and 18 international patents. In addition, he has over 20 US and International patents pending. *Most of his 88 issued patents have been licensed to companies whose products are making significant* *societal impact*.

In 2011, he was awarded the prestigious E. O. Lawrence Award from the United States Department of Energy (USDOE) for "Energy Science & Innovation". ***The E. O. Lawrence award is a highly prestigious award given on behalf of the President of the United States by the US Department of Energy Secretary.*** This award in the inaugural category of Energy Science and Innovation recognizes transformative accomplishments related to USDOE's investments in "use inspired" scientific research to develop new understanding, methodologies and materials required to advance, promote, and enable energy innovation. The Ernest Orlando Lawrence Award was established in 1959 in honor of the Nobel winning scientist who helped elevate American physics to world leadership. He was also invited by U. S. Department of Energy Secretary Steven Chu to give the *first ever* science lecture at the Department of Energy based on his work that led to the E. O. Lawrence Award. Dr. Goyal was introduced by Secretary Chu before his lecture. This talk is on YouTube and can be viewed on *science cinema* at the link - https://www.osti.gov/sciencecinema/biblio/1043697. A recent interview by Superconductor Week, a leading publication in the field of superconductivity summarizes Prof. Goyal's personal scientific and technological innovations - https://www.superconductorweek.com/2021/04/13/an-interview-with-amit-goyal/.



In 2012, he was awarded the prestigious World Technology Award in the Category of "Materials". The prestigious World Technology Awards are presented by the World Technology Network (WTN) in association with Time, Fortune, CNN, Science/AAAS and MIT's Technology Review Magazine with a stated goal to recognize "individuals and companies for innovations of the greatest long-term significance" in their respective fields.

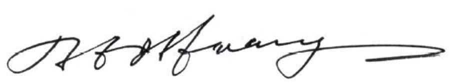
For his inventions and transformative contributions to the field of HTS, Dr. Goyal was selected by ***R&D Magazine* as the *2010 Innovator of the Year*** for transformative contributions to this field of high-temperature superconductors. He was honored for his pioneering research contributions to both the fundamental materials science and for innovations that allow for transition of scientific discoveries from the laboratory to the marketplace. Previous awardees of the *R&D Magazine's* Innovator of the Year Award include Larry Page (co-founder of Google), Elon Musk (lnventor of PayPal, Tesla Motors), and Dean Kaman (inventor of the Segway).

His scientific and technological contributions have had a *major and profound transformational impact* on the field of HTS. The influence of his work is felt not only in America, but world-wide. National programs on high temperature superconductivity in Japan, Korea, Germany, the United Kingdom, Spain, Italy, France, Belgium, China, etc. are using his methods, discoveries, and inventions to fabricate long-lengths of high-performance superconducting wire for large-scale applications of HTS. His work has *transformed* the field of Applied Superconductivity and today all companies world-wide fabricating high-performance superconducting (HTS) wires use atleast one of his innovations to fabricate the high-performance HTS wires. Large-scale applications high temperature superconductors are in many Billions of dollars.

Dr. Goyal's innovations are now realizing the vision for societal benefits that led to the flurry of excitement, leading to the Nobel Prize in Physics in 1987 for discovery of HTS materials. His innovative research is slated to bring true benefit and well-being to mankind with the numerous applications with major societal impact with potential for true benefit and well-being to mankind. He is ideally suited to receive the 2022 "Albert Einstein" World Award of Science.

Please do not hesitate to contact me for any further information.

Best regards.



Zhong Lin (Z.L.) Wang, PhD
Hightower Chair in Materials Science and Engineering
Regents' Professor
Georgia-Tech. University

Director and Chief Scientist
Beijing Institute of Nanoenergy and Nanosystems Chinese
Academy of Sciences
E-mail: zlwang@binn.cas.cn or zhong.wang@mse.gatech.edu
Personal website: http://www.nanoscience.gatech.edu

North Carolina State University is a land-
Grant university and a constituent institution
Of The University of North Carolina

College of Engineering
Department of Materials Science
and Engineering

NC STATE UNIVERSITY

Prof. Jagdish (Jay) Narayan
John Fan Family Distinguished
Chair Professor
Materials Science and
Engineering Department
Campus Box 7907
Raleigh, NC 27695-7907

919.515.7874 (phone)
919.515.7724 (fax)
J_NARAYAN@ncsu.edu
http://www.mse.ncsu.edu/

Date: November 9th, 2021

To: The "Albert Einstein" World Award of Science Committee

Re: Nomination of Prof. Amit Goyal for The "Albert Einstein" World Award of Science

Dear "Albert Einstein" World Award of Science Committee:

It is indeed a distinct pleasure to provide the strongest support for the nomination of Dr. Amit Goyal for the "Albert Einstein" World Award of Science. I have known Dr. Goyal for over two decades and am familiar with his leading work in the area of applied high temperature superconductors. The "Albert Einstein" World Award of Science recognizes scientific and technological research and development that has the potential for true benefit and well-being to mankind. Dr. Goyal's work in the area of applied superconductivity epitomizes this goal as elaborated below.

Motivated by the vision of the 1987 Nobel Prize in Physics for the discovery of high-temperature superconductivity by Bednorz and Müller in 1986 and the enormous, envisioned potential applications of these materials, Dr. Goyal's career has been driven by the *singular goal* to make the numerous envisioned applications of high-temperature superconductors a reality. His research has been defined by solving whatever *obstacles or fundamental challenges* presented themselves along the way to reach this goal. This has required him to *develop expertise and specialize in different scientific areas and adapt information from other areas* to solve fundamental problems that emerged along the way. Once a particular fundamental challenge was solved he moved onwards and addressed the next obstacle in the path of achieving the ultimate goal.

The ultimate goal of his research was to realize fabrication of high-performance, flexible superconducting wires for all the envisioned large-scale applications of high-temperature superconductors (HTS). Based on his leading and defining fundamental research on properties and characteristics of interconnected grain boundary networks in all classes of polycrystalline HTS materials, he concluded that the performance of polycrystalline superconductors was directly related to percolative current flow through low-angle, GB networks and that to realize truly high-performance HTS wires needed for all large-scale applications, essentially single-crystal, flexible, mile-long HTS wires were needed. He did this work on studying characteristics of interconnected grain boundary networks by adapting a fledgling electron microscopy technique at the time called Electron Backscatter Kikuchi Diffraction (EBKD). His work on HTS materials using this technique was also one of the first significant and impactful use of this technique to gain knowledge on a fundamental problem.

The 1987 Nobel Prize in Physics created enormous excitement globally and resulted in initiation of significant research and development activities world-wide, motivated by the numerous potential applications of these materials, which were slated to be in many tens of Billions $.

For all these large-scale applications to be realized, one needed mile-long, flexible superconducting wires that carried extremely high supercurrents and the wire had to be made at a cost that was similar to the cost of plain copper wire, a seemingly *impossible goal scientifically*. *Dr. Goyal's research over that last two and a half decades has been focused on addressing this specific goal and his research and innovations have led to highly promising approaches to fabricate high-performance HTS wires to enable widespread commercialization world-wide*. His work has addressed key fundamental issues and grand challenges in applied superconductivity.

His research and innovations solved the seemingly impossible goal of fabricating "*single-crystal, flexible superconducting HTS wires by the mile*" which were required for having high-performance HTS wire that could carry millions of Amps of supercurrent per unit cross-section. Dr. Goyal's innovations provide the *only* known routes to fabricate and realize long-lengths of single-crystal-like high temperature superconducting wires at a performance/price metric potentially comparable or superior to copper wire. The first of these inventions is the *Rolling-Assisted-Biaxially-Textured Substrates (RABiTS)* process for making large-area, flexible, near single-crystal substrates. The RABiTS process uses scalable, thermomechanical, routes to fabricate single-crystal-like substrates upon which epitaxial deposition of buffer and device layers is performed. American Superconductor Corporation (AMSC) located in Massachusetts, the leading manufacturer of high temperature superconducting wire world-wide, chose to terminate production of its 1st generation, powder-in-tube based superconducting wire (high temperature superconducting wire upon which the company was established), licensed the RABiTS technology, and established a factory for manufacturing high temperature superconducting wire based solely on the process. Another technology that can realize a long single-crystal-like wire is the Ion-Beam-Assisted-Deposition (IBAD) process invented in Japan and further developed at Stanford, Los Alamos National Laboratory, and SuperPower Inc. Working closely with SuperPower (located in New York), the second largest manufacturer of high temperature superconducting wire in the United States, Dr. Goyal's research established a buffer technology that enables this process to become practically scalable. This is the LMOe-enabled, IBAD MgO technology. SuperPower Inc. has licensed this *transformative* technology based on Goyal's innovations and is now fabricating kilometer-long wires routinely based on this process for diverse large-scale device applications.

Another major issue in the field of HTS was to significantly enhance the vortex-pinning or flux-pinning for applications in high-applied magnetic fields. It was shown elegantly that this could ideally be accomplished using heavy-ion irradiation which produced amorphous, nanoscale damage tracks at nanoscale spacing, which dramatically improved properties. However, the challenge in the field was to accomplish such a modification without using the heavy-ion irradiation which was impractical to scale-up. Dr. Goyal developed a practical scalable process which accomplished this using strain-driven, 3D self-assembly of non-superconducting, nanoscale oxides during HTS film growth to essentially achieve an identical microstructural modification. This process dramatically improved properties of high temperature superconducting wires, especially in high-applied magnetic fields. This technology is now being used world-wide to fabricate the highest performance, high-temperature superconducting wires enabled via self-assembly of non-superconducting columnar nanostructures.

His research related to fabricating "*high-performance, single-crystal, flexible superconducting HTS wires by the mile*" required adaption of knowledge from numerous fields:

- *Ceramics:* HTS materials are ceramics and classic properties of ceramics such as brittleness and cracking had to be dealt with in making long, flexible wires.
- *Crystallographic texture development:* His research went deep into this field and he created for the very first time, essentially single-crystal-like metallic foils with no high-angle grain boundaries using thermomechanical processing and dictating the as-rolled texture and then the annealed texture.
- *Metallurgy:* He adapted roll-to-roll rolling techniques to create metallic foils and also advanced how the teste rolling operations had to be performed.
- *Electron microscopy:* As mentioned previously, he first used the relatively new electron microscopy technique, Electron Backscatter Kikuchi Diffraction (EBKD), to study grain boundary networks in polycrystalline superconductors. He also extensively applied this technique to study grain boundaries in the textured metallic foils, and on heteroepitaxial buffers layers and superconductor layers on them. He used a combination of scanning transmission electron microscopy and Secondary Ion Mass Spectrometry (SIMS) to study diffusion of impurities from the metallic substrate to the superconductor and from the superconductor to the metallic substrate to optimize thickness of all layers.
- *Heteroepitaxial thin-film growth:* He adapted thin-film deposition using chemical solution deposition, physical vapor deposition (using laser ablation, e-beam evaporation and sputtering) and chemical vapor deposition techniques to create heteroepitaxial multilayered substrates and hetero-epitaxial superconductors on these multilayered substrates. He developed innovative new ways to realize heteroepitaxy of multicomponent oxides on highly reactive metal and allow tapes.
- *High-temperature, roll-to-roll deposition of heteroepitaxial layers:* High-temperature, roll-to-roll, heteroepitaxial deposition had never been done or demonstrated in the past for any material. Even in the Silicon Valley, all applications were developed for room-temperature roll-to-roll depositions on a moving web. These applications were for low-tech applications such as beer bottle labels. He had to adapt existing knowledge of thin-film deposition, mechanical deformation of flexible metallic webs at high-temperature and engineering aspects to prevent pre- or post- deposition on the web to realize high-quality, heteroepitaxial deposition by the mile.
- *Chemical engineering:* Principles of chemical engineering were adapted for deposition chamber design particularly for chemical vapor deposition.
- *Chemistry:* Standard chemistry sol-gel techniques were adapted for fabrication of los-cost layers such as heteroepitaxial buffers layers and superconductor layers.
- *Electrical Engineering:* To measure transport properties of superconductors, standard electrical engineering techniques were adapted to measure critical current densities of HTS materials as a function of magnetic field (0-10T), magnetic field orientation (0-360°) and measurement temperature (from 90K – 42.K). Electrical engineering also guided the development of metallic substrates with low AC losses and combined with metallurgy and rolling techniques (mechanical engineering) lead to the creation of crystallographically textured, non-magnetic NiW tapes or substrates for growth of superconductors.

- *Nanotechnology:* Multilayered substrates comprised of several buffer layers on metallic tapes had buffer layers which were all in tens of nanometers. So, development of the right buffer stack involved dealing extensively with nanotechnology. He also developed the technique and process of strain-driven self-assembly to realize a nanoscale modification of the superconductor into non-superconducting columns at nanoscale spacing separated by nanoscale dimensions for optimizing the current carrying ability of HTS wires in applied magnetic fields.
- *Solid-state and condensed matter physics:* This field forms the central basis of all work in the area of high-temperature superconductors. From supercurrent transport across individual grain boundaries to assemblage of grain-boundaries to vortex-pinning within a grain, all of this forms the basis of the work related to superconductors.

ALL companies in the US and around the world are presently using atleast one of Dr. Goyal's innovations to fabricate long-lengths of high-performance superconducting wires for large-scale applications. These include (1) *Commercial nuclear fusion enabled by HTS wires* which allowed very high-field magnets to contain the plasma to small volumes. It could truly solve the world's energy problem in a sustainable and environmentally friendly way; (2) *Superconducting generators enabled by HTS wires* in off-shore wind-turbines allow for almost twice the power generation compared to non-HTS turbines and will have major impact in renewable energy generation; (3) *Superconducting magnetic energy storage systems (SMES) enabled by HTS wires* allows storing large amounts of energy; (4) *Superconducting transmission cables enabled by HTS wires* allow for efficiently transmitting large amount of power. Maybe essential in large power usage areas to transmit power from where it is generated to where it is consumed; (5) *HTS high-field magnets enabled by HTS wires* have all kinds of other societal applications from MRI to NMR to fundamental physics; (6) *The electric power grid has many applications (motors, transformers, fault-current limiters) that are enabled by HTS wires* and (7) drive-trains for *all-electric ships and planes enabled by HTS wires*.

The fabrication of these high-performance HTS wires is now making possible to realize *nuclear fusion* since much higher fields can be generated to contain the plasma for fusion. This also results in a much smaller and orders of magnitude cheaper fusion reactor than the International Thermonuclear Experimental Reactor (ITER) project comprising 35 nations and costing over many tens of Billion's of dollars (https://www.iter.org). A company funded by leading investors Jeff Bezos, Bill Gates, Mark Zuckerberg, etc. and spun out from MIT, is demonstrating fabrication of such small and cheap fusion reactors (https://cfs.energy) that are enabled by these HTS wires. Once this demonstration is done, these reactors could potentially address the worlds energy needs in a renewable manner.

Each of the above listed HTS applications is expected to be in many Billions of dollars when fully matured. For each of these applications, long-lengths of high-performance superconducting wire are essential and these are *being made using one or more of Dr. Goyal's innovations.*

In 2011, he was awarded the prestigious *E. O. Lawrence Award* from the United States Department of Energy (USDOE) in the inaugural category of "*Energy Science & Innovation*". The E. O. Lawrence award is a highly prestigious award given on behalf of the *President of the United States* by the *US Department of Energy Secretary*. This award in the inaugural category of Energy Science and Innovation recognizes transformative accomplishments related to USDOE's investments in "use inspired" scientific research to develop new understanding, methodologies and materials required to advance, promote, and enable energy innovation.

He is regarded a leader in this field of applied HTS world-wide and his work has provided the US with global prestige and leadership. He founded the RENEW Institute at the University at Buffalo which is developing solutions to the environmental issues, pollution, clean water, global climate change, renewable energy and sustainable development and served as its Director from 2015-2021. For his contributions, he was awarded, the University's President's Medal in 2019. The UB President's Medal, recognizes "*outstanding scholarly or artistic achievements, humanitarian acts, contributions of time or treasure, exemplary leadership or any other major contribution to the development of the University at Buffalo and the quality of life in the UB community*." He is now founding an externally-funded, research center of excellence at a funding level of $1,500,000.00/yr for 6 years to address the critical world-wide problem of Plastics Recycling that has critical implications for climate change and societal impact.

Dr. Goyal was inducted into the National Academy of Engineering in 2018, cited for "*materials science advances and contributions enabling commercialization of high-temperature superconducting materials*".

In closing, Dr. Goyal is *ideally* suited for the "Albert Einstein" World Award of Science. His work has been *transformative* to the HTS field and his work is making and slated to make significant societal impact.

Best regards.

Prof. Jagdish Narayan
NAE, NAI, INAS
The John C. C. Fan Family Distinguished Chair in Materials Science
ORNL Distinguished Visiting Scientist and Director
NSF Center for Advanced Materials and Smart Structures
Department of Materials Science and Engineering
EB I, Suite 3030, Centennial Campus
North Carolina State University
Raleigh, NC 27695-7907.
T: (919) 515-7874; Fax: (919) 515-7642; E-mail: J_NARAYAN@NCSU.EDU

University at Buffalo
Department of Chemical and Biological Engineering
School of Engineering and Applied Sciences

Thomas Thundat, SUNY Empire Innovation Professor
Department of Chemical & Biological Engineering
School of Engineering & Applied Sciences
310 Furnas Hall
Buffalo, NY 14260-4200

Voice: (716) 645-3209
Fax: (716) 645-3822
Email: tgthunda@buffalo.edu

Nov. 09, 2021

The "Albert Einstein" World Award of Science
The World Cultural Council

Re: Nomination of Prof. Amit Goyal for the "Albert Einstein" World Award of Science, 2022

Dear Members of the World Cultural Council Interdisciplinary Committee:

I am delighted to support the nomination of Prof. Amit Goyal for the "Albert Einstein" World Award of Science. I have known Prof. Goyal since the early nineties when we were both at the Oak Ridge National Laboratory. His research has addressed key scientific challenges in the field of high-temperature superconductors and his innovations and technologies have enabled world-wide development and commercialization of large-scale, high-temperature superconductors applications.

His professional career has been devoted to establishing a fundamental understanding of scientific issues dictating or limiting the performance of high-temperature superconductors (HTS) and subsequently finding practical, innovative solutions which allow overcoming these limitations to enable realization of large-scale, commercial applications of these novel materials. He has made numerous important contributions to the materials science aspects of high temperature superconductors that have *altered* and *transformed* the research and development in this field. His work can be characterized as highly creative and innovative and which has continually challenged the HTS field with new ideas and concepts. A unique characteristic of his contributions is that he has worked at the *intersection of science and technology*. There are many aspects of his work that are very *fundamental* in nature, yet many that are very *applied* in nature. Over the years, he has tackled complicated problems in diverse areas such as *ceramics, metallurgy, solid-state and condensed-matter physics, electron microscopy, crystallographic texture development, heteroepitaxial thin-film growth, high-temperature roll-to-roll deposition, nanotechnology and various topics in electrical, chemical and mechanical engineering*.

The discovery of high-temperature superconductivity (HTS) by Bednorz and Müller in 1986 generated enormous excitement and research and development world-wide on these materials due to the tremendous potential applications of these materials and how they could change the world we live in. It resulted in a Nobel Prize in Physics in 1987. For all these large-scale applications, mile-long, flexible superconducting wires that that can carry millions of Amps of current per unit cross-section were needed. Moreover, there wires had to fabricated at a cost similar to that of plain copper wire that is available everywhere. Since mile-long wires are invariably polycrystalline, meaning they have many many grains, the properties of the junctions of these grains were important. It was determined that grain boundaries with misorientations larger than 4° were barriers to supercurrent flow, essentially mile-long, single-crystal wires were needed to be fabricated at a price/performance metric of standard copper wire. This seemingly impossible technical challenge quickly became the 1st grand challenge in the field of applied HTS world-wide. Dr. Goyal's multidisciplinary research over that last three decades has been focused on addressing this central issue and his fundamental research and resulting innovations have led to highly promising approaches to fabricate such a wire to enable widespread commercialization world-wide. Dr. Goyal's innovations are now helping realize the vision for societal benefits that led to the flurry of excitement, leading to the Nobel Prize in Physics in 1987 for discovery of HTS materials (*the theory of HTS materials is still not known and hence applications significantly motivated the 1987 Nobel*).

Dr. Goyal's early work focused on advanced ceramic-based, melt-processing of the ceramic superconductors to fabricate high-performance materials. Subsequently his focus shifted towards determining the *current-limiting mechanisms* in various classes of high temperature superconducting, polycrystalline materials that were being considered as prospects for fabricating long-lengths of flexible high temperature superconducting wires. He applied a new advanced electron-microscopy technique in the early nineties called Electron Backscatter Kikuchi Diffraction to study grain boundary (GB) character of GB networks to learn about percolative current flow in polycrystalline HTS materials. This was the first advanced application of this new microscopy technique. His research findings in each of the materials examined, namely, melt-processed wires, powder-in-tube tapes, and thick films on flexible tapes, had a *profound* influence on the field. Contrary to the widely held hypothesis that the grain boundaries in some of these materials were special and not weak-linked, Dr. Goyal's work showed that this was not the case. The best superconducting properties in each class of materials could be explained via percolative current flow through low-angle, GB networks. Since there was no obvious method to control the types of GB's that formed in these materials, none of the existing processes were deemed possible for fabricating long-lengths of high-performance high temperature superconducting wires. Hence, the need for biaxial (and triaxial) texture or "*single-crystal by the mile*" was identified. It became clear that essentially mile-long, single-crystal-like, wires needed to be fabricated from the brittle high-temperature superconducting materials in order to meet the performance requirements for all large-scale applications. In addition, this had to be done using a method that could approach the price/performance metric of standard copper wire in the hardware store. This was a seemingly *impossible goal* since the largest single-crystal grown by man is Si and it is only 18" in dia. and 1.5 long. In addition, it takes a long time to grow this Si crystal and it is a very expensive process. This technical challenge quickly became the ***first grand challenge*** in the field of applied HTS.

Dr. Goyal then proceeded to look at how crystallographic texture in polycrystalline materials affects grain boundary character of GB networks in polycrystalline materials. His studies determined that a significant biaxial or triaxial crystallographic texture was necessary to obtain a high-fraction of percolatively connected low-angle boundaries that did not act as barriers to supercurrent flow. It was determined that crystallographic textures as sharp as 5 degrees in all three crystallographic directions were needed. Dr. Goyal then proceeded to conduct experiments to determine if such a texture could be achieved by thermomechanical (involving rolling and annealing) processing as this had the potential to be cheap and scalable. Inspired by the aluminum foil in the kitchen, Dr. Goyal began experiments on metals such as Ni and Cu. He discovered that there was a whole distinct, 100-yr old, global field of "crystallographic texture" but which had never demonstrated such sharp and clean crystallographic textures with texture-modeling indicating that this may be impossible to achieve. Dr. Goyal building on the past work from the texture field with additional innovations demonstrated that such textures can indeed be obtained by thermomechanical processing in large-area substrates (few ft. x mile-long).

Having achieved the above success his attention shifted to translating this sharp crystallographic texture to the superconductor. HTS materials were brittle ceramics and they could not be thermo-mechanically processed like metals and alloys. So, he started experiments on heteroepitaxial growth of buffer layers and then the superconductor on the single-crystal-like, flexible metal tapes. This led him to the field of thin-film growth and heteroepitaxy. No one had ever grown heteroepitaxial oxides on reactive metal tapes due to severe reactions. He developed methods to do so at temperature and oxygen partial regimes wherein reaction with the metal tapes was not thermodynamically favorable and the desired oxide buffer was stable. His work showed that cube-on-cube heteroepitaxy of buffer oxides and eventually the oxide ceramic superconductor was indeed possible to achieve on the metal tapes. Once the HTS layer formed hetero-epitaxially on the single-crystal-like, buffered, flexible metal tapes, they resulted in HTS tapes having primarily low-angle, GB's and they had high critical current densities in Millions Amps per unit cross-section. He named this process *Rolling-Assisted-Biaxially-Textured-Superconductors (RABITS)*. He explored thin-film deposition using both chemistry and chemical-engineering-based and physics-based routes including chemical solution deposition, physical vapor deposition (laser ablation, e-beam evaporation and sputtering) and chemical vapor deposition techniques. After the initial demonstration, Dr. Goyal used the concepts of mechanical engineering and metallurgy to make the metallic tapes stronger while still retaining the texture and being single-crystal-like. He used solid-state physics and electrical engineering concepts to reduce AC losses from the metal tape leading to development of Ni-W alloys for substrates.

Once the above laboratory demonstration of a possible route to fabricate was done, the task was to actually scale it all up. There were significant challenges in realizing hetero-epitaxial deposition by the mile since this had to be done at high temperatures (600-800°C) and there are many issues related to unwanted deposition on tapes before they entered the deposition zone and when they exited the deposition zone, deformation of the metal web, interdiffusion between various multi-layer stacks on the tapes, etc. Looking to the Silicon Valley, it was hoped that it would be able to provide the answers for scale-up. Unfortunately, roll-to-roll, heteroepitaxial deposition was never done or demonstrated in the Silicon Valley nor were any systems ever built for roll-to-roll depositions at high temperatures. All of these systems and technology associated with it had to be developed from scratch.

While Dr. Goyal invented and developed the RABiTS process, some researchers in Japan invented a technique called ion-beam-assisted-deposition (IBAD) which relied on the use of ion-assist during deposition to texture YSZ layers on untextured metal alloys. Further work at Stanford University showed when IBAD MgO layers were deposited this could be done more quickly and only a very thin-layer was needed. Various national laboratories (Los Alamos, etc.) around the world demonstrated roll-to-roll scale-up of this technology. However, the MgO layer needed a heteroepitaxial, perovskite buffer layer that could be deposited at high-rates and was robust from a diffusion perspective and limited diffusion of detrimental elements to contaminate the HTS layer. Dr. Goyal's work and that of his colleagues at the Oak Ridge National Laboratory established a $RMnO_3$, $R_{1-x}A_xMnO_3$, buffer layer technology on IBAD MgO (US Patent 6,764,770). $RMnO_3$, $R_{1-x}A_xMnO_3$, are very robust buffer layers chemically and structurally and it is possible to deposit them at very high rates using reactive sputtering; thereby making the IBAD-MgO process scalable to long-lengths. Of these buffer possibilities, the $LaMnO_3$ (LMO) buffer technology (called LMOe-Enabled, IBAD-MgO wire) has become the most widely used composition, followed by La-Sr-Mn-O buffer technology. *The RABiTS and the LMOe-Enabled, IBAD-MgO are the only routes used by all wire manufacturers around the world to fabricate long-lengths of high-performance HTS wires and Dr. Goyal has received a R&D100 award for both techniques*.

Once fabrication of single-crystal-like, flexible, high-performance superconducting wires was realized, the emphasis in the field shifted to improving the vortex-pinning for the many large-scale, HTS-related applications in high-applied, magnetic fields. It was determined that the ideal defect structures needed in the mile-long, superconducting wires were created when heavy-ions are bombarded into the superconductor which creates nanoscale, amorphous, non-superconducing damage tracks at nanoscale spacing. This defect structure was found ideal for pinning the vortex lattice in high-applied magnetic fields. However, heavy-ion irradiation could not be used to create such a microstructure in mile long wires due to prohibitively high-cost and complexity of scale-up, and also because this would render the metal substrate in the wires radioactive. Hence, the ***second grand challenge*** in the field of applied superconductivity became creation of this microstructure in the long wires, but without adding any significant cost! Dr. Goyal's invention of the creation of nanoscale, non-superconducting, columnar defects at nanoscale spacing via the method of *phase-separation and strain-induced self-assembly* during formation of the superconducting wires provided an elegant solution to this difficult problem. *Today, the world's highest performance HTS wires in high-applied field applications are being enabled by his innovations*.

Dr. Goyal's macro-inventions, or platform technologies mentioned above (RABiTS, LMOe-Enabled, IBAD-MgO and nanoscale self-assembly of nanocolumns), provide the *only known routes* to fabricate and realize single-crystal-like, high-temperature superconducting wires with very high performance and at a performance/price metric potentially comparable or superior to copper wire. *Essentially ALL companies around the world fabricating long-lengths of high-performance, superconducting wires use one or more of Dr. Goyal's inventions/technologies to fabricate this wire*. These HTS wires are now enabling all kinds of large-scale applications world-wide. Some of these are mentioned below:

a) Nuclear Fusion**:** The commercial HTS wires fabricated by companies listed above allow very high fields and thus create high-field magnets to contain the plasma so that companies like Commonwealth Fusion Systems were recently incorporated to realize commercial fusion. This is enabling practical nuclear fusion and could truly solve the world's energy problem in a sustainable and environmentally friendly way.
References:
- https://sites.nationalacademies.org/cs/groups/bpasite/documents/webpage/bpa_185099.pdf
- https://www.psfc.mit.edu/files/psfc/imce/research/topics/sparc/MITSPARCbrochure.pdf

- https://cfs.energy/technology/

b) Power Transmission**:** Superconducting cables enabled by HTS wires allow efficiently transmitting large amount of power. There are many HTS cable installations. Some references are provided below:

- https://www.energy.gov/sites/prod/files/oeprod/DocumentsandMedia/cable_overview2.pdf
- http://www.superpower-inc.com/content/hts-transmission-cable
- https://www.nexans.us/eservice/US-en_US/navigatepub_158895_-34926/Nexans_to_provide_superconducting_cables_for_urban.html;
- Japan - https://iopscience.iop.org/article/10.1088/1742-6596/1293/1/012066/pdf;
- China - https://www.sciencedirect.com/science/article/abs/pii/S0011227520301223

Long-distance transmission of power using DC Superconducting cables is now becoming a reality, connecting renewables produced power from areas where sun-power and wind-power are best to areas where the consumption is highest. See for example, what Supernode is doing in connecting Europe with DC Superconducting cables - https://supernode.energy. All of these cables will be powered by HTS wires mde using the technologies elaborated on before.

c) Energy Generation**:** Superconducting generators enabled by HTS wires in off-shore wind-turbines allow for almost twice the power generation compared to non-HTS turbines.

- **HTS Generators:** https://www.amsc.com/wp-content/uploads/HTSGen_Bro_0312_forweb.pdf
- **HTS Wind Turbines:** https://www.amsc.com/windtec/turbine-designs/

d) Energy Efficiency**:** HTS motors, transformers, fault-current limiters, etc.

- HTS motors: https://indico.cern.ch/event/760666/contributions/3390601/attachments/1880202/3099643/Navy_Motors-20190715.pdf
- **HTS transformers:** https://www.slideshare.net/ARGHASAHA4/hts-transformer
- **HTS fault-current limiters:** https://www.amsc.com/gridtec/fault-current-limiters/

e) Energy Storage**:** Superconducting magnetic energy storage systems (SMES) enabled by HTS wires allow storing large amounts of energy.

Reference: http://www.superpower-inc.com/content/superconducting-magnetic-energy-storage-smes

f) Medical**:** High-field NMR and open MRI machines operating at higher temperatures.

- NMR: https://pubs.acs.org/doi/abs/10.1021/acs.oprd.0c00125#
- MRI: https://www.sciencedirect.com/science/article/pii/S2211379717310434

g) Physics**:** HTS high-field magnets enabled by HTS wires have all kinds of other societal applications from MRI to NMR to fundamental physics.
High-field HTS magnets: http://www.superpower-inc.com/content/high-field-magnets

h) Defense: There are numerous defense applications of high-temperature superconductors.

- Navy applications: From ship propulsion to ship degaussing. See - https://www.afcea.org/content/american-superconductor-supplying-navy-high-temperature-degaussing-system. All-electric ships are being developed by the Navy wherein all key components of the electric grid are enabled using superconducting devices made using HTS wires.
- Air-force applications: Electric propulsion is being developed and explored using cryogenic/superconducting technologies. See for example – the ASCEND program at Airbus (https://www.airbus.com/newsroom/stories/ascend-cryogenics-superconductivity-for-aircraft-explained.html) and the CABLES program at ARPA-E for fully-electrical aviation (https://www.greencar-congress.com/2021/02/20210227-cables.html).

Prof. Goyal is a *SUNY Distinguished Professor* and a *SUNY Empire Innovation Professor* at SUNY-Buffalo and an *Emeritus Corporate Fellow* at Oak Ridge National Laboratory. He received the prestigious *E. O. Lawrence Award* from the United States Department of Energy (USDOE) for "*Energy Science & Innovation*". This is a highly prestigious award given on behalf of the *President of the United States* by the *US Department of Energy Secretary*. He is a recipient of the *R&D Magazine as the 2010 Innovator-of-the-Year* and has received *ten R&D 100 awards*, widely recognized as *Oscars of Innovation*. He has over 360 publications and 88 patents most of which are licensed. A member of the *National Academy of Engineering*, he is a Fellow of 10 diverse scientific societies including - IEEE, MRS, APS, ACERS, ASM, NAI and AAAS.

Dr. Goyal's work ***truly epitomizes*** the "Albert Einstein" World Award of Science goal of recognizing *world-leading scientific and technological research and development* which has significant *societal benefits and impact*.

Sincerely,

Thomas Thundat Ph.D.,
SUNY Empire Innovation Professor,
Department of Chemical and Biological Engineering,
University at Buffalo, The State University of New York
Fellow, NAI, IEEE, AAAS, APS, ECS, ASME, SPIE, AIMBE
Canada Excellence Research Chair Laureate

Resume

Prof. Amit Goyal, Ph.D, MBA
Member, National Academy of Engineering (NAE)
Member, National Materials & Manufacturing Board (NMMB)
SUNY Distinguished Professor
SUNY Empire Innovation Professor
Founding Director (10/2021-date), Initiative for Plastics Recycling & Innovation, SUNY-Buffalo
Founding Director (1/2015-7/2021), The RENEW Institute, SUNY-Buffalo
Emeritus Corporate Fellow, Oak Ridge National Laboratory
Fellow - NAI, AAAS, MRS, APS, IEEE, ASM, ACERS, IOP, WTN, WIF
Email: agoyal@buffalo.edu; Ph. No.: (716) 645-5920

Grounds for nominating the candidate: The Nobel Prize for the discovery of high-temperature superconductors was given in the excitement of the numerous potential, large-scale applications of these novel materials. However, it was quickly realized in the field that in order for any large-scale application to be realized significant progress needed to be made in fabricating mile-long, flexible, superconducting wires which can carry millions of Amperes of supercurrent per unit cross-section. From a technical perspective, this meant that essentially single-crystal, flexible wires had to be fabricated from the brittle, high-temperature superconducting ceramics. An additional requirement was that these wires meet the price/performance metric of standard copper wires that can be bought in a hardware store. This seemingly impossible task became the ***first holy-grail*** in the field. Dr. Goyal's innovations have provided elegant solutions to fabricating such superconducting wires using scalable processes. These methods are now being used world-wide for fabrication of high-performance superconducting wires.

Once fabrication of single-crystal-like, flexible, high-performance superconducting wires was realized, the emphasis in the field shifted to improving the vortex-pinning for the many large-scale, superconductor-related applications in high-applied magnetic fields. It was determined that the ideal defect structures needed in the mile-long superconducting wires were created when heavy-ions are bombarded into the superconductor which creates nanoscale, amorphous, non-superconducing damage tracks at nanoscale spacing. This defect structure was found ideal for pinning the vortex lattice in high-applied magnetic fields. However, heavy-ion irradiation could not be used to create such a microstructure in mile long wires due to prohibitively high-cost and complexity of scale-up, and also because this would render the metal substrate in the wires radioactive. Hence, the ***second holy-grail*** in the superconductor field became creation of this microstructure in the long wires, but without adding any significant cost! Dr. Goyal's invention of the creation of nanoscale, non-superconducting, columnar defects at nanoscale spacing via the method of phase-separation and strain-induced self-assembly during formation of the superconducting wires provided an elegant solution to this difficult problem. Today, the world's highest performance superconducting wires in high-applied field applications are being enabled by his innovations.

An additional requirement for some applications is low ac-losses in alternating applied magnetic fields. To realize this, ideally a "round" single crystal superconducting wire was needed, whereas the processes being scaled up world-wide were tape or flat geometry conductors. This then became the ***third holy-grail*** in the field. Dr. Goyal's inventions provide the only way to fabricate such a "round", flexible, single-crystal wire based on a process he invented.

The technologies he has invented and developed to fabricate high-performance superconducting wires are being used world-wide to fabricate long-lengths of superconducting wires for a *whole range of large-scale, societal applications with the potential for true benefit and well-being to mankind*. These applications as detailed in this nomination include – *Energy Generation*: Commercial nuclear fusion enabled for the first time and off-shore wind turbines with superconducting motors for twice the power generation; *Energy Storage*: Superconducting magnetic energy storage systems (SMES); *Energy Efficiency*: Superconducting motors, transformers, fault-current limiters, etc.; *Energy or Power Transmission*: Superconducting cables enabled by HTS wires allow efficiently transmitting large amount of power; *Medical Applications*: High-field NMR and open MRI machines operating at higher temperatures; *Defense*: All-electric planes and All-electric ships. Dr. Goyal's vision and persistence to address the seemingly insurmountable scientific barriers to realize or enable such wires is *evidence of extraordinary achievement*. Since all large-scale applications of high-temperature superconductors are environmentally friendly, enabling HTS applications not only enable the economic prosperity but also improves the environment and addresses climate-change issues.

Publications/Patents: Dr. Goyal has developed clean energy technologies for over two decades. He has authored more than ***360 technical publications*** and has ***88 issued patents*** comprising 70 US and 18 International patents, most of which are licensed. ***He was the most cited author worldwide in the field of high-temperature superconductivity from 1999-2009***. Over the years, he has received *over $50M in research funding related to his personal research*.

Key Awards and Honors:

He has received numerous accolades including the presidential level ***DOE's E. O. Lawrence Award*** in the inaugural category of ***Energy Science & Innovation***. The US Department of Energy (DOE) Secretary on behalf of the *President of the United States* bestows the award. Dr. Goyal was the only Lawrence Award Winner that was invited by then DOE Secretary, Steven Chu to give the *first-ever science lecture* at USDOE (http://www.osti.gov/sciencecinema/biblio/1043697). A recent interview in 2021 by Superconductor Week, a leading publication in my field summarizes my personal scientific and technological innovations - https://www.superconductorweek.com/2021/04/13/an-interview-with-amit-goyal/.

Other key honors include: ***TEN R&D 100 awards* which are widely regarded as the *"Oscars for Innovation*"** over the years (in 2017, 2016, 2013, 2012, 2011, two in 2010, 2009, 2007, 1999); *Three National Federal Laboratory Consortium (FLC) Awards* for *Technology Transfer signifying passion for innovation and translation to industry*; the *2012 World Technology Award* in the category of "Materials"; *2010 R&D 100 Magazine's Innovator of the Year Award*; *2010 Distinguished Alumnus Award* from the Indian Institute of Technology; the *2008 Nano50™ Innovator Award*; the *2007 Pride of India Gold Award*; *University of Rochester's Distinguished Scholar Medal in 2007*; the *U.S. Department of Energy Exceptional Accomplishment Award* in 2005; the *UT-Battelle Inventor-of-the-Year Awards* in 2005 and 1999; the *2005 Global Indus Technovator Award*; in *2001 the Energy-100 Award* for the finest 100 scientific accomplishments of the U.S. Department of Energy since it opened its doors in 1977; the *Massachusetts Institute of Technology's Technical Review TR100 Award*; and the *Lockheed-Martin NOVA Award for technical achievement* in 1999.

He is a Member of the ***National Academy of Engineering (NAE)***. He has been elected Fellow of ten professional societies: and the *National Academy of Inventors (NAI),* the *American Association for Advancement of Science* (AAAS), the *Materials Research Society* (MRS), the *American Physical Society* (APS), *Institute of Electrical and Electronics Engineers* (IEEE), the *World Innovation Foundation* (WIF), the *American Society of Metals* (ASM), the *Institute of Physics* (IOP), the *American Ceramic Society* (ACERS) and the *World Technology Network* (WTN).

He was appointed to the National Academies, ***National Materials & Manufacturing Board (NMMB)*** in 2020. He was invited to join the *National Academies Committee* on – "***Advising NSF on its Efforts to Achieve the Nation's Vision for the Materials Genome Initiative (DMREF)***,". Most recently, he was invited to serve on a National Academies, NMMB committee on developing the ***US Smart Manufacturing Plan***, a congressional mandated study by the Dept. of Energy (DOE) Secretary in partnership with the National Academies. He serves on the ***National Academies Panel*** for reviewing the NIST Materials Measurement Laboratory, the ***National Academies Panel*** on reviewing the U.S. Army Research Laboratory in the area of Materials Science, and is a member of the ***National Academies Intelligence Science and Technology Experts Group***.

Prof. Amit Goyal

SUNY *Distinguished* Professor & *Empire Innovation* Professor
State University of New York (SUNY) at Buffalo
112 Cooke Hall, Buffalo, New York 14214
Phone: (716) 645-5920; Email: agoyal@buffalo.edu

A. Professional Preparation

Institution	Location	Major Area	Degree	Year
University of Rochester	Rochester, NY, USA	Materials Science & Eng.	Ph.D.	1991
University of Rochester	Rochester, NY, USA	Mech. & Aerospace Eng.	MS	1988
Indian Institute of Technology	Kharagpur, India	Metallurgical Eng.	B. Tech.	1986

B. Appointments

2015-Present **SUNY *Distinguished* Professor[1] & SUNY *Empire Innovation* Professor[2]**
2021-Present **Founding Director**, ***Initiative for Plastics Recycling & Innovation***, University at Buffalo (UB) (October 2021- to date)
2018-Present **Director**, ***Laboratory for Heteroepitaxial Growth of Functional Materials & Devices***, University at Buffalo
2015-7/2021 **Founding Director**, ***The Research and Education in eNergy, Environment and Water (RENEW) Institute***, University at Buffalo (UB), Buffalo, NY
2015-Present **Emeritus Corporate Fellow**, Oak Ridge National Laboratory (ORNL), TN
2010-Present **President & CEO**, *TapeSolar Inc*., a private-equity funded, solar company, TN
2010-Present **President & CEO**, *TexMat LLC*., an IP holding & consulting company
2010-2014 **Chair**, **Corporate Fellows Council**, UT-Battelle/Oak Ridge National Laboratory (ORNL)
2003-2014 **Corporate Fellow & Distinguished Scientist**, UT-Battelle/ORNL

C. Management / Administrative Experience

- **Founding Director, *Initiative for Plastics Recycling & Innovation*,** University at Buffalo (UB) (October 2021- to date): An ***externally-funded***, multidisciplinary initiative at $1,500,000.00/yr for 6 years. Funding for first three years of $4,500,000.00 is in place. Funded by the New York Department of Environmental Conservation (NYDEC). Involves 8 multidisciplinary faculty from School of Engineering & Applied Sciences (SEAS), College of Arts & Sciences (CAS) and School of Management (SOM).
- **Founding Director, *The RENEW (Research & Education in Energy, Environment & Water) Institute***, University at Buffalo (UB) (January 2015-July 2021): One of the most expansive ***internally-funded*** initiatives launched by UB or SUNY-Buffalo in recent years, RENEW (Research and Education in eNergy, Environment and Water) is a multidisciplinary initiative that harnesses the expertise of more than 100 faculty members across seven schools and colleges. During my term as Director, the Institute had the following accomplishments:
  - Attracted and hired, ***19 multidisciplinary faculty*** with specific area of expertise targeted to fill scientific/technical gaps identified during the Institute's strategic planning across the seven schools and colleges.
  - Assisted with development of over ***400 external research grant proposals***, and enabled research resulting in ***over 600 publications and over 400 presentations***.
  - Resulted in garnering ***over $50 Million in external funds***.

[1] This system-wide rank (across 64 campuses) of *SUNY Distinguished Professor* is an order above full professorship at UB or SUNY-Buffalo and is considered the highest rank of professor in the SUNY system. The *SUNY Distinguished Professorship* is conferred upon faculty having achieved national or international prominence and a distinguished reputation.
[2] The *SUNY Empire Innovation Professor* Program is designed to attract exceptionally distinguished faculty to the State of New York.

    - Established ***cutting-edge, 21st century, RENEW Shared Instrumentation Laboratories***.
    - RENEW Institute faculty developed ***over 50 new, multidisciplinary educational courses in energy, environment and water.***
- **Chair, Corporate Fellows Council, Oak Ridge National Laboratory** (2009-2014): As Chair of the Corporate Fellows Council, advised ORNL senior management / leadership on specific scientific and technological issues and opportunities, served as a channel for communication between ORNL scientific and technical staff and senior management and articulated ideas and concerns of the scientific and technical staff regarding objectives and directions of the Laboratory.
- **President & CEO and Financial Head (2010-date):** Senior administrator of two companies (TapeSolar Inc. and TexMat LLC) and responsible for all administrative and financial functions. Experience with entrepreneurship and startup of new entities.

D. National Impact: (Via service on National Academy of Science, Engineering and Medicine (NASEM) Committees)

- **Member, National Materials & Manufacturing Board (NMMB) (December 2020- to date):** The NMMB combines the charges of two preexisting boards: The National Materials Advisory Board and the Board on Manufacturing and Engineering Design. Its mission is to provide objective, independent assessments of the current state of materials and manufacturing research, including at the atomic, molecular, and nanoscales. It's also charged with assessing the applications of new and existing materials in innovative ways, including pilot-scale and large-scale manufacturing, the design of new devices and disposal of materials.
- **Member, NASEM Committee on – Advising NSF on its Efforts to Achieve the Nation's Vision for the Materials Genome Initiative (DMREF) (July 2021- date):** This committee will examine the impact of the National Science Foundation's program "Designing Materials to Revolutionize and Engineer Our Future" (DMREF) with the goal of furthering the nation's vision for the Materials Genome Initiative (MGI). It will evaluate the program's goals, progress, and scientific accomplishments within the context of similar efforts both within the U.S. and abroad.
- **Member, NASEM Committee on – Developing the US Smart Manufacturing Plan**, a ***Congressional Mandated*** study by the Dept. of Energy (DOE) Secretary in partnership with the National Academies (October 2021- date)**:** DOE to develop a National Plan, in consultation with the National Academies, for smart manufacturing technology development and deployment to improve the productivity and energy efficiency of the manufacturing sector of the United States, as per the language set forth in The Energy Act of 2020, Sec. 6006 on pages 1113 and 1115.
- **Member, NASEM Panel for reviewing the NIST Materials Measurement Laboratory**.
- **Member, NASEM Panel for reviewing the U.S. Army Research Laboratory** in the area of Materials Science.
- **Member, National Academies Intelligence Science and Technology Experts Group**.

E. Publications - Summary

- ***45 invited book chapters and publications***.
- **Over *360 publications in national and international journals*** in a wide selection of journals including Science, Nature Communications, Nature Magazine's Scientific Reports, Philosophical Magazine, etc.
- An independent analysis of the field of high-temperature superconductors conducted by ***Thompson-Reuters's Essential Science Indicators (ESI)*** and ScienceWatch.com, which tracks global trends and performance in research, ***ranked Dr. Amit Goyal No. 1 worldwide in the total number of citations during the decade*** (1999-2009). A recent interview with Amit is posted on ScienceWatch (http://archive.sciencewatch.com/ana/st/hts/09maySTHTSGoya1/).
- **Total number of citations = over 19,821; H-index = 68; i10 = 347.**

F. Patents - Summary

- ***Over 150 patent applications and/or invention disclosures*** filed.
- ***88 issued patents*** (***70 US and 18 International patents***). A majority of these issued patents have been licensed during the course of the last two decades.
- ***Additional patents pending.***

G. Editorial Boards and Advisory Boards (Selected)

- **Member, *Board of Reviewing Editors, PNAS Nexus***, a National Academy journal with a focus on multidisciplinary engineering sciences, since October, 2021.
- **Member, *Editorial Board, Nature Magazine's Scientific Reports***, since April 2015.
- **Member, *External Advisory Board***, Texas Center for Superconductivity at the University of Houston (TcSUH), since 2021.
- **Member, *University-wide SUNY Honorary Degree Advisory Committee***, since 2021.
- **Member, *External Advisory Board***, Materials Science Program, University of Rochester.
- **Member, *Board of Governors for the New York Sea Grant***, since August 2015.

H. Awards of Excellence (Selected)

- Inducted into ***National Academy of Engineering*** (2018): Elected Member of the National Academy of Engineering, USA for "*For materials science advances and contributions enabling commercialization of high-temperature superconducting materials*." Election to the National Academy of Engineering is among the highest professional distinctions accorded to an engineer/scientist.
- ***DOE's E. O. Lawrence Award*** for "*Energy Science & Innovation*" (2011). The E. O. Lawrence award is awarded on behalf of the ***President of the United States*** by the ***US Department of Energy Secretary*** to outstanding scientists. This inaugural award in the category of Energy Science and Innovation recognizes transformative accomplishments related to DOE's investments in "use inspired" scientific research to develop new understanding, methodologies and materials required to advance, promote, and enable energy innovation.
- ***R&D100 Magazine's "Innovator of the Year" Award*** (2010): The "*Innovator of the Year*" Award is given for collective lifetime contributions. Among past recipients of this honor are Larry Page (co-founder of Google), Elon Musk (lnventor of PayPal, Tesla) and Dean Kaman (inventor of the Segway). Widely recognized as the "*Oscars of invention*", the R&D100 awards are given to the most innovative products developed in any field world-wide in that calendar year.
- ***Ten R&D100 Awards*** *(2017, 2016, 2013, 2012, 2011, 2010 (two awards), 2009, 2007, 1999)*
- ***Three National Federal Laboratory Consortium Awards*** for Excellence in Technology Transfer
- **DOE's *Energy-100 Award*** for the finest 100 scientific accomplishments of the U.S. Department of Energy since it opened its doors in 1977
- ***World Technology Award*** in the category of "Materials" (2012)
- ***ORNL Inventor-of-the-Year Award*** (2006 and 1999)
- ***Massachusetts Institute of Technology's Technical Review TR100 Award*** (1999)
- ***Lockheed-Martin NOVA Award*** for technical achievement (1999)
- **Fellow of Ten Professional Societies**: National Academy of Inventors (NAI); Materials Research Society (MRS); American Association for Advancement of Science (AAAS); American Physical Society (APS); World Innovation Foundation (WIF); American Society of Metals (ASM); Institute of Physics (IOP); American Ceramic Society (ACERS) and World Technology Network (WTN).
- ***"Pride of India" Gold Award*** (2007): Bestowed by the *Indian Ambassador* to the USA.
- ***Global Indus Technovator Award*** by MIT (2005)
- ***Distinguished Alumnus Award*** from the Indian Institute of Technology (IIT), India (2007).
- ***Rochester Distinguished Scholar Medal*** (2005) from the University of Rochester , NY.
- ***President's Medal*** (highest award at university), SUNY-Buffalo, 2019.

List of 10 Significant Publications

1. "*High Critical Current Density Superconducting Tapes By Epitaxial Deposition of YBCO Thick Films on Biaxially Textured Metals*", **A. Goyal**, D. P. Norton et al., ***Appl. Phys. Lett.***, vol. 69, No. 12, Sept. 16, 1996. (*cited 1184 times*)

2. "Epitaxial YBCO on Biaxially Textured Nickel (001): An Approach to Superconducting Tapes with high Critical Current Density", D. P. Norton, **A. Goyal** et al., ***Science***, 274, 755-757, 1996. (*cited 899 times*)

3. "*Irradiation-free, columnar defects comprised of self-assembled nanodots and nanorods resulting in strongly enhanced flux-pinning in $YBa_2Cu_3O_{7-\delta}$ films*," **A. Goyal** et al., ***Supercond. Sci. Tech***., 18 (2005) 1533-1538. (*cited 478 times*)

4. "*High Performance High-T_c Superconducting Wires*," S. Kang, **A. Goyal** et al., ***Science***, vol. 311, pgs. 1911-1914, March 31st issue, 2006. (*cited 483 times*)

5. "*The RABiTS Approach: Using Rolling-Assisted Biaxially Textured Substrates for High-Performance YBCO Superconductors*," **A. Goyal**, M. Paranthaman and U. Schoop, invited paper, ***MRS Bulletin***, Vol. 29, No.8, pp. 533-542, August 2004. (*cited 273 times*)

6. "*Conductors with Controlled Grain Boundaries: An Approach to the Next Generation, High Temperature Superconducting Wire*," **A. Goyal**, D. P. Norton et al., ***J. of Materials Research***, vol. 12, pgs. 2924-2940, 1997. (*cited 213 times*)

7. "*Epitaxial Superconductors on Rolling Assisted Biaxially Textured Superconductors (RABiTS): A Route Towards High Critical Current Density Wire*", **A. Goyal** et al., ***Applied Superconductivity, commemorating the 10th anniversary of HTS***, vol. 4, pgs. 403-429, 1997. (*cited 162 times*)

8. "*Texture Formation and Grain Boundary Networks in Rolling Assisted Biaxially Textured Substrates (RABiTS) and in Epitaxial YBCO Films on such Substrates*", **A. Goyal**, et al., ***Micron***, 30, 463-478, 1999. (*cited 109 times*)

9. "*Engineering NanoColumnar Defect Configurations for Optimized Vortex Pinning in High Temperature Superconducting Nanocomposite Film-based Wires*," S. H. Wee, Y. Zuez, C. Cantoni and **A. Goyal**, ***Nature Magazine's Scientific Reports***, 3, Article number: 2310 (2013). (*cited 69 times*)

10. "*Strain-Modulated Self-Assembly in Nanostructured, Complex Oxide Films via Spontaneous Phase Separation and Ordering Mechanism*," S. H. Wee, Y. Gao, Y. L. Zuev, K. L. More, J. Meng and **A. Goyal**, ***Advanced Functional Materials***, doi: 10.1002/adfm.201202101, 2012. (*cited 33 times*)

Publications Summary: Has published over 360 publications in national and international journals and conference proceedings in a wide selection of journals including Science, Nature Communications, Nature Magazine's Scientific Reports, Philosophical Magazne, Applied Physics Letters, Energy & Environmental Science, Physical Review B, Phyics Review Letters, Physica C, Superconductor Science & Technology, Applied Superconductivity, Journal of Materials Research, Journal of Applied Physics, Science and Journal of Minerals, Metals & Materials, Cryogenics, Ultramicroscopy, Journal of American Ceramic Society, IEEE Transactions in Applied Superconductivity, Japanese Journal of Applied Physics, MRS Bulletin, Scripta Metallurgica, Materials Letters, Journal of Electronic Materials, Chemistry of Materials, Journal of Materials Science & Engineering, Materials Science Forum, Journal of Superconductivity and Nanomaterials.

An independent analysis of the field of high-temperature superconductors conducted by Thompson-Reuters's Essential Science Indicators (ESI) and ScienceWatch.com, which tracks global trends and performance in research, Dr. Amit Goyal ranks ***no. 1 worldwide in the total number of citations*** during the last decade (1999-2009). He also ranks ***no. 4 worldwide in the total number of papers*** published in same timeframe (this is still the highest number of papers by anyone outside of Japan). A recent interview with Amit is posted on ScienceWatch (http://archive.sciencewatch.com/ana/st/hts/09maySTHTSGoya1/). The analysis, conducted by ScienceWatch.com ranked authors, institutions, and countries worldwide by no. of citations, no. of papers, and average citations per paper.

Total number of citations = 19, 836
H-Index = 69
I10-index = 349

List of Publications	

1. **“**Combinatorial synthesis of heteroepitaxial multi-functional thin films with *high-throughput, in-situ, chemical, and structural* characterization,” Eun Ju Moon and Amit Goyal, To be published in **Nature Magazine’s Scientific Reports**, 2021.
2. “Single-Crystal-like, epitaxial GaAs thin film on flexible metal substrate for optoelectronic applications,” Gokul Radhakrishnan, Kyunghoon Kim, Ravi Droopad and Amit Goyal, Submitted to **Nature Magazine’s Scientific Reports**, 2021.
3. “Single-Crystal-like, epitaxial Ge Film Growth on cm-sized, biaxially-textured, Fe-based Substrates,” Kyunghoon Kim, Gokul Radhakrishnan, Ravi Droopad and Amit Goyal, Submitted to **Nature Magazine’s Scientific Reports**, 2021.
4. “Epitaxial Growth of Superconductors on Single-Crystal, Structural, Faceted Fibers (SSIFFS): A New Approach Towards Low-AC Loss Wire”, A. Goyal, S. H. Wee and Y. Zuev, In preparation, Will be submitted to **Science**, 2021.
5. “Dynamic Behavior of Reversible Oxygen Migration in Irradiated-Annealed High Temperature Superconducting Wires,” Yi Zhang, M. W. Rupich, Vyacheslav Solovyov, Qiang Li, Amit Goyal, **Nature Magazine’s Scientific Reports**, volume 10, Article number: 14848, 2020.
6. “Structural, band and electrical characterization of β-$(Al_{0.19}Ga_{0.81})_2O_3$ films grown by Molecular Beam Epitaxy on Sn doped β-Ga_2O_3 substrate,” A. Vaidya1, J. Sarkar, Y. Zhang, L. Lubecki, J. Wallace, J. Poplawsky, K. Sasaki, A. Kuramata, T. Masui, A. Goyal, J. Gardella, B. Mazumder and U Singisetti, **Journal of Applied Physics**, 126 (2019) 095702.
7. “Probing the Irradiation Defects in Enhanced 2G High Temperature Superconducting Wire”, Yi Zhang, M. W. Rupich, Vyacheslav Solovyov, Qiang Li, Amit Goyal, **Microscopy & Microanalysis 2019**, 25 (S2) (2019) 1614.
8. “Dynamic Oxygen Motion in Irradiated-Annealed High Temperature Superconducting Wire”, Yi Zhang, M. W. Rupich, Vyacheslav Solovyov, Qiang Li, Amit Goyal, **Microscopy & Microanalysis 2019**, 25 (S2) (2019) 1616.
9. “Probing Single Mn atom in doped MoS_2 Monolayer”, Yi Zhang, Chuan Zhao, Hao Zeng, Amit Goyal, To be published in the **Proceedings of Microscopy & Microanalysis 2019**, Portland, Oregon, Aug. 4^{th}-8^{th}, 2019.
10. “Optimal, Nanodefect Configurations via Strain-Mediated Assembly for Optimized Vortex-Pinning in Superconducting Wires from 4.2K-77K”, A Goyal and S. H. Wee, **Journal of Physics**, 871 (2018) 012039.
11. “Heteroepitaxy of large grain Ge film on cube-textured Ni(001) foils through CaF_2 buffer layer,” Chen, Liang, Xie, Weiyu, Wang, Gwo-Ching, Bhat, Ishwara, Zhang, Shengbai, Goyal, Amit, Lu, Toh-Ming, **Thin Solid Films**, Vol: 603, Pages: 428-434, 2015.
12. “Heteroepitaxial Cu_2O on inexpensive, scalable, single-crystal-like metallic substrates: A potential route towards non-toxic, earth-abundant solar cells,” S. H. Wee, P. Huang, J. K. Lee and A. Goyal, **Nature Magazine’s Scientific Reports**, Scientific Reports 5, Article number: 16272, doi:10.1038/srep16272 (2015).
13. “Heteroepitaxy of Ge on Cube-Textured Ni(001) Foils Through CaF_2 Buffer Layer;” Chen, L., Lu, Z.-H., Lu, T.-M., Bhat, I., Zhang, S.B., Goyal, A., Zhang, L.H., Kisslinger, K. and Wang, G.-C., **MRS Advances**, pp. 1–6. doi: 10.1557/adv.2016.517, 2015.
14. “Epitaxial growth of Ba_2YNbO_6 films on biaxially-textured Ni-W substrates as a multifunctional single buffer layer for high Jc epitaxial YBCO film,” S. H. Wee; C. Cantoni and and A Goyal, **MRS Comunications**, Volume 5, Issue 3, pp. 533-538, 2015.
15. “Robust critical current density in applied magnetic fields in 5μm thick, $SmBa_2Cu_3O_{7-\delta}$ based superconducting wires,” A O Ijaduola, F List, H-S Kim, S-S

Oh and A Goyal, **Physica C: Superconductivity and its Applications**, Volume 517, Pages 1–4, 2015.

16. "Ultra-High Performance, High-Temperature Superconducting Wires via Cost-effective, Scalable, Co-evaporation Process", Ho-Sup Kim, Sang-Soo Oh, Hong-Soo Ha, Dojun Youm, Seung-Hyun Moon, Jungho Kim, Shi Xue Dou, Yoon-Uk Heo, Sung-Hoon Wee and A. Goyal, **Nature Magazine's Scientific Reports**, 4, Article number:4744doi:10.1038/srep04744, 2014.
17. "Engineering NanoColumnar Defect Configurations for Optimized Vortex Pinning in High Temperature Superconducting Nanocomposite Film-based Wires," S. H. Wee, Y. Zuez, C. Cantoni and A. Goyal, **Nature Magazine's Scientific Reports**, 3, Article number: 2310 (2013).
18. "Robust superconducting $FeSe_{0.5}Te_{0.5}$ coated conductors at 30 tesla," Weidong Si, Su Jung Han, Xiaoya Shi, Steven N. Ehrlich, J. Jaroszynski, Amit Goyal, and Qiang Li, **Nature Communications**, 4, Article number: 1347, 2013, doi:10.1038/ncomms2337.
19. "Orientational domains in metalorganic chemical vapor deposited CdTe(111) film on cube-textured Ni," G. C. Wang, L.H. Zhang, Kim Kisslinger, C. Gaire, A. Goyal, I. Bhat and T.-M. Lu, **Thin Solid Films**, 531 (2013) 217–221.
20. "Frontiers in Thin Film Epitaxy and Nanostructured Materials," J. Narayan, J. Schwartz, A. Goyal, H. Y. Wang, S. H. Jin and X. Z. Liao, **J. of Mater. Res**., 28 (2013) 1625-1625.
21. "Strain-Modulated Self-Assembly in Nanostructured, Complex Oxide Films via Spontaneous Phase Separation and Ordering Mechanism," S. H. Wee, Y. Gao, Y. L. Zuev, K. L. More, J. Meng and A. Goyal, **Advanced Functional Materials**, doi: 10.1002/adfm.201202101, 2012.
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25. C. Gaire, S. Rao, M. Riley, L. Chen, A. Goyal, S. Lee, I. Bhat, T. M. Lu, and G. C. Wang, "Epitaxial growth of CdTe thin film on biaxially textured Ni substrate," **Thin Solid Films**, 520 (2012) 1862-1865.
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28. "Structural engineering of epitaxial, self-assembled ferromagnetic cobalt/yttria-stabilized zirconia nanocomposites for ultrahigh-density storage media," J. Shin, A. Goyal, C. Cantoni, J. W. Sinclair, and J. R. Thompson, **NanoTechnology**, 23, Article No. 155602, 2011.
29. "Triangular Graphene Grain Growth on Cube-textured Cu Substrates," J. Liu, J. Wu, C. M. Edwards, C. L. Berrie, D. Moore, Z. Chen, V. A. Maroni, M. Paranthaman, and A. Goyal, **Advanced Functional Materials**, 21 (2011) 3868-3874.
30. "Strain-driven Oxygen Deficiency in Self-assembled, Nanostructured, Composite

Oxide Films," C. Cantoni, Y. F. Gao, S. H. Wee, E. D. Specht, J. Gazquez, J. Y. Meng, S. J. Pennycook and A. Goyal, **ACS Nano**, 2011, 5 (6), pp 4783–4789.

31. "Polarization manipulation via orientation control in heteroepitaxial BiFeO3 thin films on biaxially textured, flexible metallic tapes," J. Shin, A. Goyal, S. Jesse, and L. Heatherly, **Appl. Phys. Exp**., Vol.: 4, Issue: 2, Article Number: 021501, DOI: 10.1143/APEX.4.021501, 2011.

32. "Formation of Stacking Faults and Their Correlation with Flux Pinning and Critical Current Density in Sm-doped YBa2Cu3O7-x Films," S. H. Wee, E. D. Specht, C. Cantoni, Y. L. Zuev, V. Maroni, W. Wong-Ng, G. Liu, T. J. Haugan, and A. Goyal, **Phys. Rev. B**, 83, 224520 (2011).

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34. "Formation of Self-Assembled, Double-Perovskite, Ba2YNbO6 Nanocolumns and Their Contribution to Flux-Pinning and Jc in Nb-Doped YBa2Cu3O7-δ Films," S. H. Wee, A. Goyal, Y. L. Zuev, C. Cantoni, V. Selvamanickam, and E. D. Specht, **Appl. Phys. Exp**., 3 (2010) 023101.

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36. "Multifunctional, phase separated, BaTiO3+CoFe2O4 cap buffer layers for improved flux-pinning in YBa2Cu3O7−δ based coated conductors," S. H. Wee, J. Shin, C. Cantoni, Y. L. Zuev, S. Cook, and A. Goyal, **Supercond. Sci. Technol**. 23 (2010) 014007.

37. "Enhanced flux pinning in MOCVD-YBCO films through Zr additions: systematic feasibility studies," T. Aytug, M. Paranthaman, E. D. Specht, Y. Zhang, K. Kim, Y. L. Zuev, C. Cantoni, A. Goyal, D. K. Christen, V. A. Maroni, Y. Chen and V. Selvamanickam, **Supercond. Sci. Technol**., 23 014005, 2010.

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41. "Enhanced and uniform in-field performance in long (Gd, Y)-Ba-Cu-O tapes with zirconium doping fabricated by metal-organic chemical vapor deposition," V. Selvamanickam, A. Guevara, Y. Zhang, I. Kesgin, Y. Xie, G. Carota, Y. Chen, J. Dackow, Y. Zhang, Y. Zuev, C. Cantoni, A. Goyal, J. Coulter, L. Civale, **Supercond. Sci. & Tech**., 23 (2010), Article Number 014014.

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Metal-Oxides: Fundamentals and Applications in Electronics and Energy" by Springer, 2010, edited by S. Ramanathan, Harvard University.

44. "Phase-Separated, Epitaxial, Nanostructured LaMnO3+MgO Composite Cap Layer Films for Propagation of Pinning Defects in YBa2Cu3O7-x Coated Conductors," S. H. Wee, J. Shin, C. Cantoni, H. M. Meyer, S. Cook, Y. L. Zuev, E. D. Specht, X. M. Xiong, M. P. Paranthaman, V. Selvamanikcam, A. Goyal, **Appl. Phys. Exp**., 2 (2009) 063008.

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63. "Epitaxial (La, Sr)TiO_3 on textured Ni-W as a conductive buffer architecture for high temperature superconducting coated conductor," Kim K, Norton DP, Christen DK, Cantoni C, Aytug T, Goyal A, **Physica C**, 468 (2008) 961-967.

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List of Invited Publications

1. **Invited Overview Chapter** in Handbook of Superconducting Materials**,** titled "*HTS conductor processing techniques*", 2017.
2. **Invited Overview Chapter** in second edition of handbook titled "*Nanotechnologies to enable high-performance superconductors for energy applications*", published by Wiley-VCH, 2013, edited by J. Garcia, Spain.
3. **Invited Book Chapter** for book titled "*Interfaces in Electronic Materials*" published by Francis Dodds of Woodhead Publishing, 2011.
4. **Invited Overview Chapter** in handbook titled "*Nanotechnology for the Energy Challenge*", published by Wiley-VCH, 2009, edited by J. Garcia, Spain.
5. **Invited Overview Chapter** in book titled "*Thin Film Metal-Oxides: Fundamentals and Applications in Electronics and Energy*" published by Springer, 2009, edited by S. Ramanathan, Harvard University.
6. **Invited Overview Chapter** in book titled "CSD of Functional Oxide Thin Films", To be published by Wiley-VCH, 2009, edited by T. Schneller, R. Waser and D. Payne.
7. **Invited Paper**, titled "Multifunctional, phase-separated, BaTiO3+CoFe2O4 cap buffer layers for improved flux-pinning in YBa2Cu3O7-δ based coated conductors," to be published in special issue of Superconductor Science & Technology, 2009.
8. **Invited Paper**, titled "Enhanced and Uniform in-Field Performance in Long (Gd,Y)-Ba-Cu-O Tapes with Zirconium Doping Fabricated by Metal Organic Chemical Vapor Deposition," to be published in special issue of Superconductor Science & Technology, 2009.
9. **Invited Paper**, titled "Effects on Jc of Pining Center Morphology for Multiple-in-Line-Damage in Coated Conductor and Bulk, Melt-Textured HTS," to be published in special issue of Physica C, 2009.
10. **Invited Paper**, titled "Magnetic field orientation dependence of flux pinning in (Gd,Y)Ba2Cu3O7-x coated conductor with tilted lattice and nanostructures," to be published in special issue of Physica C, 2009.
11. **Invited paper**, titled "Enhanced flux pinning in MOCVD-YBCO films through Zr-additions: Systematic feasibility studies," to be published in special issue of Physica C, 2009.
12. **Invited Overview Chapter** in Encylopedia of Materials: Science and Technology (EMSAT) on the RABiTS technology. 2007 Elsevier Ltd. All rights reserved.

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Publications-Summary	• **45 invited book chapters and publications**. • **<u>Over 360 publications in national and international journals and conference proceedings</u>** in a wide selection of journals including Science, Nature Communications, Nature Magazine's Scientific Reports, Philosophical Magazine, Applied Physics Letters, Energy & Environmental Science, Physical Review B, Physics Review Letters, Physica C, Superconductor Science & Technology, Applied Superconductivity, Journal of Materials Research, Journal of Applied Physics, Science and Journal of Minerals, Metals & Materials, Cryogenics, Ultramicroscopy, Journal of American Ceramic Society, IEEE Transactions in Applied Superconductivity, Japanese Journal of Applied Physics, MRS Bulletin, Scripta Metallurgica, Materials Letters, Journal of Electronic Materials, Chemistry of Materials, Journal of Materials Science & Engineering, Materials Science Forum, Journal of Superconductivity and Nanomaterials. • **<u>Over 8000 citations from first author and second author publications alone</u>**. • **<u>Total number of citations = over 19,836. (Google Scholar)</u>.** • **<u>H-index = 69</u> <u>(Google Scholar)</u>.** • **<u>i10 = 349 (Google Scholar)</u>.** • In an independent analysis of the field of high-temperature superconductors conducted by Thompson-Reuters's Essential Science Indicators (ESI) and ScienceWatch.com, which tracks global trends and performance in research, ***ranked Dr. Amit Goyal No. 1 worldwide in the total number of citations during the last decade (1999-2009).*** He also ranks no. 4 worldwide in the total number of papers published in same timeframe (this is still the highest number of papers by anyone outside of Japan). A recent interview with Amit is posted on ScienceWatch (http://archive.sciencewatch.com/ana/st/hts/09maySTHTSGoya1/). The analysis, conducted by ScienceWatch.com ranked authors, institutions, and countries worldwide by no. of citations, no. of papers, and average citations per paper.

Published or issued Patents - Summary	• **Over 150 patent applications and/or invention disclosures filed.** • <u>**88 issued patents**</u> (70 US and 18 International patents). • <u>**70 US patents issued to date**</u>: US Patent Nos. 5, 739, 086; 5, 741, 377; 5, 846, 912; 5, 898, 020; 5, 964, 966; 5, 958, 599; 5, 968, 877; 6, 077, 344; 6, 106, 615; 6, 114, 287; 6, 150, 034; 6, 156, 376; 6, 151, 610; 6, 159, 610; 6, 180, 570; 6, 235, 402; 6, 261, 704; 6, 270, 908; 6, 331. 199; 6,375,768; 6, 399, 154; 6, 451, 450; 6, 447, 714; 6, 440, 211; 6, 468, 591, 6, 486, 100; 6, 599, 346; 6, 602, 313, 6, 607, 313; 6, 607, 838; 6, 607, 839; 6, 610, 413; 6, 610, 414; 6, 635, 097; 6, 645, 313; 6, 663, 976; 6, 670, 308; 6, 675, 229; 6, 716, 795; 6, 740, 421; 6, 764, 770; 6, 784, 139; 6, 790, 253; 6, 797, 030; 6, 846, 344; 6, 782, 988; 6, 890, 369; 6, 902, 600; 7, 087, 113; 7, 258, 928; 7, 510 997; 7, 683, 010; 7, 879 161; 7, 906, 229; 7, 919, 435; 8, 034, 745; 8, 119, 571; 8, 178, 221; 8, 210, 420; 8, 227, 082; 8,424,745; 8,481,460; 8, 518, 526; 8, 536, 098; 8, 685, 549; 8, 748, 349; 8, 748, 350; 8, 795, 854; 8, 987, 736, 8, 993, 092. • <u>**18 international patents issued to date:**</u> Australian Patent No. 8349510, Australian Patent No. 713982, Canadian Patent No. 2,217,822**,** Japanese Patent No. 03601830, European Region Patent No. EP 0830218, South Korea Patent No. 418279, Switzerland Patent No. 0830218, Germany Patent No. 0830218, Spain Patent No. 0830218, France Patent No. 0830218, Great Britain Patent No. 0830218, Italy Patent No. 0830218, Sweden Patent No. 0830218, Hong Kong Patent HK 1150093, Chinese Patent CN101981699, Chinese Patent CN1132585 and Indian Patent 310761. • ***A majority of these issued patents have been licensed during the course of the last two decades.*** • ***Over 5 US patents presently pending***. • ***Over 5 International patents pending***. • This is the <u>*highest*</u> number of issued US patents for any employee in the Battelle system (<u>http://www.battelle.org/careers/battelle/about.stm</u>). Battelle serves the U.S. Department of Energy in the management of four leading-edge national laboratories – Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), Brookhaven National Laboratory (BNL) and National Renewable Energy Laboratory (NREL).

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