Bioengineering Working Group Report: Analysis of Existing Strengths, Critical Gaps, and Opportunities for Collaboration

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1. Introduction

Biomedical Engineering (BME) encompasses a large number of research areas and indirectly impacts almost all biomedical research. BME is an interdisciplinary, collaborative, translational science that applies engineering principles to the study of normal biological processes for treating, repairing, or replacing impaired functions. Bioengineering, with a focus on design and analysis, and Biomaterials, with a focus on developing therapeutic or replacement materials, are established, well-funded programs at Rutgers that are housed primarily in the Departments of Biomedical Engineering, Materials Science & Engineering, Chemistry & Chemical Biology, the School of Pharmacy, and the New Jersey Center for Biomaterials. An integral part of BME research is in vivo testing which requires expertise in animal models and increasingly the use of various imaging methods to measure cell, tissue, and physiological responses to materials or other treatments. **The BME Working Group found that the largest barrier to increasing BME research productivity is a scarcity of faculty with expertise in conducting animal model research or imaging research and is exacerbated by barriers to collaborating with existing faculty.** Eliminating these barriers by investing in Tissue Regeneration and associated Imaging modalities will have an immediate impact on research productivity, a lasting impact on research funding, and dramatically increase the likelihood of translating discoveries to clinical use.

2. Analysis of BME Strengths

Publications: Between 2009 and 2014, Rutgers faculty published 1,749 manuscripts related to BME. Federal funding supported 56% of the manuscripts (985), and non-federal sources supported 32% of the manuscripts (561). Within the manuscripts supported by federal funds, 714 (41%) were supported by PHS, 561 were supported specifically by NIH extramural awards (32%), and 271 (15%) were supported by non-PHS sources. Publications and funding information were obtained from PubMed. The 1,749 publications found in PubMed were analyzed by secondary keyword searches as shown in **Table 1**.

Table 1: Analysis of BME Related Publications

BME Research Area	Pubs.	Keyword Search
Imaging	381	Imaging
Bioengineering	256	Engineering
Materials	250	Materials
Tissue Regeneration	218	(tissue, heart, or bone) and (regeneration, healing, wound, growth, or fracture)
Diagnostic	173	Diagnostic
Drug Delivery	167	Drug and (delivery or release)
Nanomedicine	157	"Nano"
Device Development	146	Device
Integration with other RBHS Strategic Research Areas		
Drug Development	411	Drug and (delivery or release or material)
Clinical Research	217	Research and (clinical or translational)
Cancer	213	Cancer
Infection and Inflammation	165	Inflammation or infection or infectious or immunity or biocompatibility
Neuroscience	285	Neuroscience or brain or nervous system
Regenerative Medicine	119	Stem cell or regeneration

Funding: An analysis of grants, awards, and contracts from 2009 till now reveals that BME has been directly or implicitly involved in $798 million of funding (**Table 2**). The BME working group submitted faculty names and keywords that were used to search internal databases for funding. Known awards from members of the working group were added to the database report. It is noted that the data are incomplete. Nevertheless, duplicate entries and clearly erroneous awards were removed. Awards were coded as being primarily associated with BME, secondarily associated with BME, or clearly associated with a complementary Working Group. Award primary and secondary BME associations were classified as shown in **Table 2** (Research Area). An award that develops new materials for tissue engineering would be coded Biomaterials as the primary association, Tissue Regeneration as the secondary, and Stem Cells and Regenerative Medicine as the complementary Working Group. Awards were sorted based on these associations to arrive at the aggregate numbers. Of the $798 million in BME related funding, $693 million were from legacy Rutgers faculty and $106 million were from legacy UMDNJ faculty. Of those funds, $298 million (37%) could be directly attributed to Biomedical Engineering (and associated fields). **Table 2** shows the distribution of the funds according to each BME research area (Direct Funding). Biomaterials, Drug Delivery,

and Engineering stand out as well-funded areas. Funds primarily associated with Biomaterials also were analyzed for secondary associations with other BME research areas (**Table 2** Biomaterials Overlap). This analysis showed that 59% (68.5/116) of Biomaterials funding was associated with developing materials for tissue regeneration.

Table 2: BME Funding ($ millions) by Research Areas and Overlapping Signature Areas Since 2009

Research Areas	Direct Funding	Biomaterials Overlap	Complementary Working Groups	BME Funding Overlap
Tissue Regeneration	16	68.5 (59%)	Clinical	5.47
Imaging	24	4.35 (4%)	Cancer	44.47
Engineering	54	1.37 (1%)	Drug Dev	49.23
Biomaterials	116	--	Neuroscience	61.84
Diagnostics	6	0 (0%)	Inflammation	4.97
Devices	8	0.05 (0%)	Stem Cells	111.08
Drug Delivery	59	3.64 (3%)	Child Health	5.55
Nanomedicine	13	4.44 (4%)	Education	13.84
RUCDR, CounterACT, & Others	502	--	Bioinformatics	365.04
Total	798	82.35 (71%)	Environmental Health	52.38

BME funding that is associated with other Working Groups was determined (**Table 2** Complementary Working Groups). Approximately 46% of the funds are associated with the Rutgers Cell and DNA Repository (RUCDR, under Bioinformatics). RUCDR is the largest repository of human cells in the country, and relies on advanced technology and imaging to handle and characterize cells, as well as convert cells to stem cells and to establish in vitro cell models of disease. Other Working Groups are well-represented, including Stem Cells & Regenerative Medicine, Drug Development, Exposure and Environmental Health, Cancer, and Education. This last area is noteworthy, as the interdisciplinary and collaborative nature of research is a hallmark of training in BME.

The funding analysis highlights the strengths of BME and important opportunities. **Clearly, Biomaterials is an established strength with significant influence on Tissue Regeneration and efforts should be made to leverage that strength.** Significant potential to support Imaging and Drug Development exists and should be leveraged by the Neuroscience, Cancer, and Drug Development Working Groups.

Patents: The intellectual property output of the BME faculty was estimated by supplying the Office of Technology Commercialization (Susan Dolci) with a list of prominent BME faculty to summarize the intellectual property (IP) output of those investigators. In the last 5 years, 645 BME-related patents were submitted. Currently, 295 are still under consideration (filled or published) and 31 patents were issued. Approximately 300 were abandoned or allowed to expire for various reasons.

Education: BME continues to play a critical role in the education mission of RBHS. The primary educational site for BME in Piscataway is the Department of Biomedical Engineering and associated joint graduate program in Biomedical Engineering at Rutgers where faculty from Rutgers-SOE, RBHS-RWJMS, and RBHS-PHARM engage in developing and implementing undergraduate and graduate courses and thesis research. A second focal site is the BME program at RBHS-NJMS that is articulated with NJIT. In the past 5 years, over $17,000,000 was awarded to Rutgers through Federal, State, and private enterprise to support diverse BME-related education programs. Federal awards from NIH, NSF, and the DoD contributed to the training of more than 1,200 undergraduate, graduate, and post-doctoral students from the Department of Biomedical Engineering, The School of Engineering, the Ernst Mario School of Pharmacy, Robert Wood Johnson Medical School, the Center for Biomaterials, and the Cancer Institute of New Jersey. Joint graduate and MD/PhD programs between GSNB and GSBS and the DPT/PhD program between SHRP and GSBS encompass a diverse faculty with broad areas of interest throughout the State of New Jersey, including Princeton University and NJIT. Biomedical engineering at RBHS also serves as the principal reservoir of highly educated and well-trained individuals to join and later lead various biotech and pharmaceutical companies in the State. BME students and trainees have used learned entrepreneurial skills to build successful start-up companies, thus contributing to the economic interests of the State of New Jersey. In summary, BME at RBHS continues to be an active participant in the future of RBHS, Rutgers University, and the State of New Jersey. Continued and expanded support can only enhance impact.

3. Comparative Analysis of Strengths in BME Research Areas

Strengths in BME research were identified based upon publication records and funding (since 2009) and were compared to identical areas at other regional and Big Ten universities by publications.

Bioengineering: Because "engineering" encompasses many fields, manuscripts that fall broadly within this category may not be associated with the engineering keyword. Thus the 256 publications (14.6% of the total) do not reflect the strength of BME at Rutgers. Bioengineering is an essential, underlying discipline that includes modeling and design analysis necessary for multiple research areas.

Imaging: The number of imaging-related papers (381/1,749 or ~22%) includes those developing methods, software, and equipment to improve imaging as well as those that used imaging technology for an experimental outcome. Improvements in imaging technology and support for existing facilities will positively impact multiple fields of research across schools, departments, and disciplines (BME, neuroscience, cancer biology, and more). Analysis of publication records, using a limited keyword search, found that Rutgers ranks 7th regionally and within the Big Ten (**Table 3**). It is worth mentioning that our 7th ranking is all the more impressive because research-dedicated human imaging facilities at Rutgers only became available about two years ago, thanks to a $1.8M Large Instrumentation NSF Grant in 2010 (Award #1039505). The growing MRI user group will significantly boost the number of imaging-related publications and grants in the coming years.

Table 3. Imaging Publications by Institution

Regional	Big Ten
Penn (1,609)	Michigan (1,544)
Pittsburgh (1,278)	Wisconsin (1,186)
Yale (1,172)	Illinois (841)
Columbia (1,070)	Northwestern (812)
Cornell (942)	Minnesota (725)
NYU (876)	Ohio State (610)
Rutgers (459)	Rutgers (459)
CUNY & SUNY (432)	Indiana (608)
U. Rochester (430)	Iowa (522)
U. Conn. (224)	Purdue (384)
Drexel (128)	Penn State (225)
Princeton (283)	Michigan State (208)
Delaware (64)	Nebraska (194)

Table 4. Materials Publications by Institution

Regional	**Big Ten**
Columbia (1,162)	Michigan (934)
Penn (647)	Northwestern (729)
Pittsburgh (606)	Wisconsin (618)
Cornell (513)	Illinois (543)
NYU (417)	Minnesota (469)
Rutgers (359)	Ohio State (403)
Yale (332)	**Rutgers (359)**
CUNY & SUNY (250)	Indiana (318)
U. Rochester (183)	Purdue (290)
U. Conn. (175)	Iowa (235)
Princeton (130)	Penn State (223)
Drexel (118)	Nebraska (160)
Delaware (106)	Michigan State (123)

Materials Research: Though ranking 6th regionally and 7th in terms of publications, Biomaterials is a clear strength within Biomedical Engineering as reflected by the number of publications (**Table 4**), the volume of funding, and the natural overlap with other primary BME areas, such as Tissue Regeneration (**Table 2**). In terms of translational medicine, biomaterials research at Rutgers is one of the greatest success stories, with several start-up companies emerging including one – TyRx – that was recently purchased by Medtronic, a global leader in the medical device industry. Biomaterials research at Rutgers is led by the New Jersey Center for Biomaterials, which has raised almost $100 million in research funding – highlighted by major awards from the NIH and DoD – and over $200 million in private capital. Leveraging the strength in Biomaterials at Rutgers with overlapping strategic areas at RBHS can elevate those fields to "best in class" while improving, the already strong, internationally recognized Biomaterials research at Rutgers.

Tissue Regeneration: A substantial number of articles (218/1,749 or ~12% of the articles retrieved) focused on tissue growth or regeneration, thus this sub-discipline represents an area of strength within BME at Rutgers. Of the articles retrieved, 39/218 studied bone and cartilage repair, 34/218 were studies of the nervous system, 34/218 studied liver regeneration, 28/218 studied the hematopoietic system, 16/218 studied skin regeneration and 7/218 studies focused on muscle growth. Improvements in the infrastructure at Rutgers that will promote and facilitate studies on Tissue Regeneration will cut across many other areas of excellence and breakthroughs in this discipline can be readily moved into the clinic. Tissue Regeneration is at the forefront of biomedical sciences and Rutgers BME has much to offer this emerging research discipline. For example, the Neuroscience Working group has chosen neural regeneration as a signature area of research. A comparative analysis of publication records, using a limited keyword search, found that Rutgers ranks 4th regionally and 6th within the Big Ten (**Table 5**).

Nanomedicine: In the last 5 years, 112 nanomedicine or nanomaterials related papers were published by Rutgers faculty. A limited key word search ("nanomedicine or nanomaterials") found that Rutgers ranked 6th regionally and 9th among Big Ten schools in this developing research field (**Table 6**).

Drug Delivery & Device Development: Faculty published 313 papers (~18% of the 1,749 papers) in the areas of drug delivery and device development. This represents a significant strength in BME and occurs

Table 5: Tissue Regeneration Pubs. by Institution	
Regional	**Big Ten**
Pittsburgh (331)	Michigan (327)
Penn (277)	Wisconsin (192)
Columbia (184)	Illinois (187)
Rutgers (133)	Northwestern (173)
Yale (130)	Ohio State (164)
Cornell (122)	**Rutgers (133)**
NYU (111)	Minnesota (103)
U. Rochester (97)	Purdue (73)
U. Conn. (85)	Indiana (70)
Drexel (77)	Iowa (51)
CUNY & SUNY (67)	Nebraska (48)
Delaware (46)	Penn State (37)
Princeton (13)	Michigan State (30)

Table 6: Nanomedicine & Nanomaterials Publications by Institution	
Regional	**Big Ten**
Columbia (377)	Northwestern (366)
Penn (181)	Illinois (300)
CUNY & SUNY (173)	Michigan (273)
Cornell (171)	Purdue (257)
Yale (128)	Wisconsin (166)
Rutgers (112)	Minnesota (152)
Pittsburgh (100)	Penn State (127)
U. Conn. (81)	Ohio State (121)
Princeton (71)	**Rutgers (112)**
U. Rochester (64)	Nebraska (89)
Drexel (62)	Iowa (51)
NYU (48)	Indiana (46)
Delaware (44)	Michigan State (40)

through collaborative efforts primarily between various pharmacy departments and Biomedical Engineering, Materials Science & Engineering, and Chemistry & Chemical Biology. Rutgers ranks 5th regionally and 4th within the Big Ten in this area based upon a limited keyword PubMed search (**Table 7**). Doubling faculty research productivity in these areas would make Rutgers Best in Class. The BME Working Group found that the most likely avenue to making Device Development, Drug Delivery, or Nanomedicine Best in Class would occur through strategic collaborations initiated by the Drug Development Working Group and augmented by investments in Tissue Regeneration and Imaging.

Table 7. Device Development & Drug Delivery Publications by Institution	
Regional	**Big Ten**
Columbia (233)	Michigan (196)
Penn (158)	Purdue (161)
Pittsburgh (125)	Illinois (130)
Yale (113)	**Rutgers (108)**
Rutgers (108)	Minnesota (105)
CUNY & SUNY (83)	Northwestern (104)
Cornell (70)	Wisconsin (104)
U. Conn. (59)	Ohio State (94)
NYU (44)	Nebraska (79)
U. Rochester (37)	Iowa (41)
Drexel (35)	Indiana (36)
Princeton (31)	Penn State (32)
Delaware (27)	Michigan State (13)

5. Impact of BME on Complementary Areas

As noted above the highly collaborative nature of BME research significantly impacts many complementary areas of research (see **Table 2**). Three areas were highlighted by the BME Working Group.

Neuroscience: Approaches developed by BME are significantly affecting neuroscience research at Rutgers. The nervous system is difficult to study in living organisms but with advances in imaging technologies, such as structural and functional MRI and multi-photon microscopy, neuroscientists have been able to glean new insights into CNS function. The capacity of the nervous system to regenerate is poor. The Neuroscience Working group has established that Rutgers is close to best in class in studies of CNS injury. Methods developed in tissue engineering are being used by Rutgers neuroscientists to promote regeneration of neurons after brain and spinal cord injuries. BME also benefits the neurosciences in drug delivery. The blood-brain-barrier, which is both a chemical and physical barrier, prevents most proteins and hydrophilic substances from gaining access to the CNS. The blood-brain barrier has long impeded treatments for multiple CNS disorders. New drug delivery methods developed by biomedical engineers can overcome the blood-brain-barrier, opening up possibilities for new treatments for a wide range of neurological and psychiatric disorders.

Regenerative Medicine: BME strength in Tissue Regeneration, as noted above, significantly overlaps with regenerative medicine. For instance, stem cell research has been an ongoing research area in Orthopaedics for over 30 years and BME was the home department for the first NSF funded IGERT training program in stem cells. Development of polymers and materials as tissue regeneration scaffolds or for drug delivery is an essential part of regenerative medicine and forms the basis of many collaborative efforts.

Education and the State Economy: The graduate and undergraduate BME engineering programs were developed in part to provide a highly trained labor force for the medical device industries of New Jersey. The education programs have been highly successful with many Rutgers BME graduates now holding senior management positions at several medical device companies.

6. Critical Gaps to becoming Best in Class

Collaboration: The analysis indicates that Rutgers has the "parts" to become Best in Class in research areas within BME (e.g., tissue regeneration). However, collaboration between these "parts" is piecemeal. A strategy to promote collaboration between the parts will create a synergistic research and educational environment. Overcoming this collaboration barrier is paramount for BME to become Best in Class.

Building Academic Collaborations: Campus geography, poor web-based information, and the expanse of Rutgers makes identifying and establishing collaborations difficult.

Building Industrial Collaborations: Despite having several Rutgers alumni in senior management positions at many medical device and biotechnology companies, collaborations between industry and many departments within Rutgers are infrequent and insufficient to sustain a meaningful research program. There are several reasons for lack of industrial collaboration. Contract negotiation is unnecessarily long and creates an adversarial rather than collaborative relationship between the potential industrial partner and Rutgers. An adversarial relationship can become problematic if new IP is developed or if the industrial partner wishes to perform additional studies. Industrial partners are unwilling to pay indirect costs of more than 25%. Given this lower level of indirect cost support, Rutgers would benefit more from long-term rather than piecemeal, short-term support. In addition, an industrial partner cannot easily find an academic collaborator at Rutgers except through a personal contact. Steps are being made to address this through ORED. Technical resources within Rutgers need to be updated to attract industrial collaborators. Finally, there is no apparent concerted effort to support Good Laboratory Practices (GLP) studies at Rutgers which would be a significant attraction to industrial collaborators. In a similar vein, a Good Manufacturing Practices (GMP) lab for producing clinical-grade drugs and test compounds would also increase industrial collaboration.

Translational Research: Where do investigators go to test their material, device, drug, or therapy in an animal model or in humans? Currently, potential collaborators are identified through publication records or personal contacts. This creates inefficiency and often leads to testing outside of Rutgers.

Faculty using Biomaterials in Tissue Regeneration Research: The funding analysis shows a clear disparity between funding for biomaterials research related to tissue regeneration ($68.5 million) versus funding directly related to tissue regeneration research ($16 million, **Table 2**). These data indicate that Rutgers lacks a sufficient number of investigators directly involved in tissue regeneration research that can test newly developed materials in appropriate animal models. Better avenues for collaboration will alleviate this problem to some extent, as discussed above. However, the number of Rutgers faculty involved in engineering (143) is considerably less than our aspirational peers (U. of Michigan, 381 engineering faculty). Additional BME faculty are needed to fill this gap and exploit the abundance of materials research as a competitive advantage.

Instrumentation and Technical Resources: Improvements in instrumentation and technical resources are needed to increase research productivity and promote collaboration. Specific improvements should include:

Access: Finding technical resources and gaining access to those resources is very challenging. Efforts to centralize "high end" equipment and to improve internet resources for identifying and scheduling use of existing instrumentation and technical resources are needed. However, centralization of resources potentially used for high-volume purposes needs to remain mindful of throughput and geographical limitations. Often instrument functionality is hidden by core facility and center names, making it virtually impossible to identify an available instrument. Instruments maintained by individual investigators are often not available for use because trained personnel are not available to perform the experiment or to teach someone how to properly use the instrument. This problem is exacerbated by compliance and regulatory roadblocks that prevent establishing cost-recovery centers to maintain the instrument or pay trained personnel.

Equipment and Instrument Maintenance, Upgrades, and Replacement: Equipment and instruments need to be maintained through service contracts and repaired, upgraded, or replaced as warranted. Failure to maintain equipment negatively impacts Rutgers ability to conduct research, teach, collaborate, and perform GLP studies. Equipment and instruments includes autoclaves and glassware washers to PET scanners and MALDI-TOF mass spectrometers. There is no apparent policy or procedures for insuring that equipment and instruments are maintained.

New Equipment, Instruments, and Resources: To be Best in Class will require using cutting-edge technology and instrumentation which means adding new capabilities to the Rutgers campus. There is no apparent policy or procedure for organizing, prioritizing, and directing the acquisition of new instruments. There is also

an apparent adversarial relationship between investigators and facility management with regards to equipment installation, most notably facility management seeking to recover facilities costs from award direct costs.

Commercializing Rutgers Technology: BME research is translational science. As such, many discoveries made by Rutgers faculty are patented. Procedures for selecting and prosecuting IP need to be improved. There is no institutional mechanism for actively moving IP to commercial development or to a point in commercial development that the IP would be licensed. The conflicts of interest policies deter faculty from pursuing IP protection or commercial development of that IP.

Regulatory and Academic Issues: The burden of increased regulatory compliance, documentation, and accountability continues to detract from faculty productivity and creates barriers to collaborations, particularly between campuses. The increase in non-tenure track faculty and the decline in tenured and tenure-track faculty have reduced the number of faculty that can effectively compete for federal awards. Joint appointments between medical and dental school faculty with core BME departments would enhance collaboration.

SHRP: Programs at SHRP, such as Rehabilitation and Movement Science and BioInformatics, have clear translational avenues to which BME-related advances can be applied. Establishing collaborations between SHRP and BME-related research is necessary for increased productivity. Recognizing this, a new dual-degree DPT-PhD program was established between the Department of Rehabilitation and Movement Science and GSBS. However, these relationships, resource sharing opportunities, and collaborations are sparse, and need to be strengthened.

RSDM: Dentistry is a natural environment for materials science, bone regeneration, tissue engineering, and related research disciplines. Currently, RSDM has a very a strong Oral Biology program focused on infectious disease. However, there are few RSDM faculty members actively pursuing research in any BME related field.

7. Opportunities to become Best in Class

Tissue Regeneration: Rutgers clearly has regional strength in tissue regeneration research. Increasing research productivity by 40 tissue regeneration publications per year would make Rutgers Best in Class regionally and within the Big Ten. Creation of a center, institute, or department focused on tissue regeneration would significantly increase the profile of Rutgers in tissue regeneration research. As noted above, RSDM is a natural environment for BME related research and a center devoted to Tissue Regeneration research could spur related research in RSDM. Joint hires could be made with appropriate departments in SoE, SAS, or RBHS to enhance collaborations and leverage the new faculty expertise in education and training.

Improving Collaborations:

BME as a Focal Point for Collaboration: Clear avenues for collaboration need to be established between the Departments of Biomedical Engineering, Materials Science & Engineering, and Chemistry & Chemical Biology, the School of Pharmacy, and the Center for Biomaterials and with other Departments, including but not limited to NJMS-Orthopaedics, NJMS-Neurosurgery, NJMS-Surgery, RWJMS-Surgery, SHRP-Rehabilitation & Movement Sciences, various Pharmacy departments, and various computer science departments. These collaborations will enable development of materials and devices for tissue regeneration, drug delivery, other biomedical applications, and better diagnostic image analysis tools.

Translation and Clinical Science: Tissue Regeneration, Imaging, Drug Delivery, and Device Development require substantial collaborative efforts between traditional BME related disciplines and clinical disciplines. Clear avenues of collaboration need to be established for these efforts to be productive.

Rutgers Study Sections: Using the NIH Study Section model, Rutgers should develop broadly defined study sections (e.g., BME, Neuroscience, Cancer, Immunology, etc.) for two purposes. First, investigators could submit their grant proposals to these study sections for critical evaluation prior to submission with the goal of increasing funding success. Second, these study sections could identify potential collaborators within Rutgers, either to help directly with the proposal or to develop an alternative, related additional future proposal. The study sections would then pass these recommendations on to the investigator and potential collaborators. Parameters for service on these Rutgers Study Sections would need to be established and enforced in order for their value to be recognized by the faculty.

Industrial Collaboration: Multiple tasks should be accomplished to improve industrial collaborations. First, a centralized, web based resource should be developed and maintained by ORED for industrial partners to find Rutgers faculty or facilities. Second, contract negotiations, COI policies, and other compliance issues need

to be streamlined and transparent. Third, Rutgers should reach out to the various biomaterials and biomedical device companies to fund endowed faculty chairs, post-doctoral fellowships, and graduate student fellowships. These contacts need to be made from the highest levels and not from Department Chairs or faculty. Investments from the biomaterials/biomedical device companies into endowed chairs and fellowships will likely increase long-term direct funding support. Fourth, procedures and monitors for GLP studies need to be developed. Fifth, investments in technology to attract federal and industrial support should be instituted.

Equipment and Instruments: An RBHS or University wide committee that receives requests for equipment maintenance, acquisition of new instruments or equipment, or installation of equipment should be formed to prioritize those requests for University purchase or support. This committee could also organize online resources for CORE facilities, available equipment, scheduling, fees, and other associated tasks. This would have a positive impact on BME research as well as all other disciplines.

The large distance between the Newark and Piscataway/New Brunswick campuses creates logistical hurdles for regular data collection at core facilities that are housed at only one campus. For example, Newark has a newly built research-dedicated MRI facility (Rutgers University Brain Imaging Center, RUBIC) funded by a large NSF instrumentation grant in 2010. To bring Rutgers to Best in Class status and to attract high-tier scientists across all of Rutgers, imaging facilities need to be upgraded and high-volume animal imaging instruments need to be available at both campus locations. For instance, digital X-ray equipment, PET/CT scanners, and a high resolution MRI are needed for animal imaging on the Newark campus, while access to clinical imaging equipment for human studies is needed on the New Brunswick campus.

Regulatory and Compliance: Faculty productivity is significantly impaired because of regulatory and compliance issues. Protocols, forms, and procedures need to be simplified so that investigators can maintain compliance using minimum effort.

Rutgers Incubator Companies: BME research generates a large amount of intellectual property (IP) but procedures for moving IP from the lab to a company do not exist and must be learned by individual faculty, which is terribly inefficient and reduces faculty academic productivity. Rutgers should establish a company that develops promising IP to that point at which the IP can be licensed to an independent company. The Rutgers-based company would be able to provide the business, regulatory, and additional scientific expertise necessary to develop a product. The MBA program at Rutgers could be leveraged to support this concept.

Education: Graduate education in BME is pivotal to moving RBHS to the top echelon of schools in biomedical sciences. Most of the top medical schools in the nation host or are closely allied with top ranked BME programs (e.g., Johns Hopkins, UCSD, U. Washington, Emory/Georgia Tech). Three areas require sustained investment to strengthen BME educational and research impact at RBHS:

Endowments: Expansion of endowments, graduate student support and fellowships to support incoming graduate students at levels that are competitive with our aspirational peer institutions.

Multi-disciplinary Programs: Investment in strategic research areas (such as, integrative cancer biology, regenerative medicine, or biomedical imaging) to support multidisciplinary research clusters via seed funding and facility upgrades will promote research productivity and accelerated time-to-graduation for PhD scientists and engineers in BME.

Student Pipeline: The number of PhD students in STEM fields allied with BME needs to be increased. Currently, Rutgers and several programs in RBHS rank toward the lower tier of Big Ten institutions in terms of PhDs graduated in engineering fields. However, BME has stood out as an exceptional outlier due to the strong brand developed by this program and the institutionalization of a large influx of federal training projects and fellowships. For example, Rutgers BME is the home to two sequential NSF IGERT programs, one of the few recipients of this honor nationwide, and continues to host the NIH Biotechnology training program as one of the longest standing sites for this prestigious T32 program. RBHS should continue to leverage this excellence and invest in joint RBHS-SOE fellowships. Prospective graduate fellows placed in a number of laboratories across RBHS will provide the much needed intellectual brainpower to fuel a vibrant pipeline of research projects that, in turn, will help to propel RBHS further in peer-rankings.