To: **Eric Barron, President**
Nicholas P. Jones, Executive Vice President and Provost
David Gray, Senior Vice President for Finance & Business
Neil Sharkey, Vice President for Research
Ford Stryker, Associate Vice President for the Office of Physical Plant
From: **RCCI Executive Committee**
RCCI Data Centers Working Group
Matt Decker, Interim Vice Provost for Information Technology
Mark Saussure, Director of Data Centers
Cc. **Jenni Evans, Interim Director, Institute for Cyberscience**
Re: **The Data Center Is Already Fully Subscribed**
Date: **29 June 2016**

Data Center Power Needs: Executive Summary

In 2015, Penn State began the construction of a new Data Center building on Tower Road. This followed a planning period and various analyses, including the October 2013 “Report of the Research Data and Computing Committee” which projected that research power usage (including server closets) would be 6 MW by 2017. Ultimately, the Tower Road facility construction project began with a planned initial capacity of 1.75 MW ("Phase 1") for IT equipment, with 1 MW of this reserved for research. At opening (August 1, 2016), the data hall will have been built out so that 60% of this power is expected to be usable on Day 1. ICS-ACI is planning deployment of equipment into the Tower Road Data Center as soon as it becomes available for hosting and colocation. **Based on firm plans for expansions and firm commitments for research, the available power capacity of the Tower Road Data Center even with 100% buildout will be fully utilized by Spring 2017, with significant demand still unmet.**

In particular, with the installation of new equipment for ICS-ACI phase 3.0 and incoming grants, ICS-ACI will be using 800 kW of power of the 1 MW designated for research by January 2017. This leaves the Tower Road facility with little capacity to meet any additional computing needs until the next phase of the Data Center is built. ICS-ACI projects general usage of 1.1 MW by April 2017 and 1.4 MW by April 2018 if growth remains steady (this estimate may be too low, as recent ICS-ACI rate restructuring may increase growth, and it excludes any new arrangements with co-hires and startup support). We expect significant demand from other funded projects including the Advanced Biological Research Lab (ABRL), which could potentially require tens of thousands of additional compute cores as well as significant amounts of storage. We project that even with an accelerated build of Data Center phase 2, we face a serious power shortfall by early- to mid- 2017. This inadequate capacity will halt ICS-ACI expansion, including the marketing and allocation of compute capabilities to prospective faculty hires, and will prevent the relocation of any existing equipment from data closets scattered throughout campus into the data centers, one of the key strategic drivers of the Data Center project. Thus, **it is crystal clear that Penn State must urgently move to increase Data Center power capacity.** It is particularly urgent to act quickly because of the long lead time necessary for additional capacity to become available. Even with immediate expansion, we may be in a position where we have to turn away new computational research activity until a 4 MW phase 2 expansion is completed. We are already delaying onboarding for interested ACI customers due to the schedule of equipment deployment, which is limited by power availability.

As a result of our analysis, we recommend the following:

1) Immediately finish the 100% build out of Phase 1 for the Tower Road Data Center;
2) Immediately execute the recently designed Phase 1B expansion at Tower Road to add an additional 400kW of power;
3) Immediately start the design and renovation of the Computer Building to create a stop gap of approximately 600kW tier 1 and 150kW of tier 3 power availability (a net addition of 200kW for research);
4) Immediately start the programming, design and construction of Phase 2 for the Tower Road Data Center while reviewing current stakeholder requirements (research, low density and administrative computing projections); we recommend adding *at least* 4 MW in phase 2;
5) Along with building the full phase 2, immediately construct the full building shell that would allow us to expand rapidly and cost-effectively beyond the +4 MW level; this will yield economies of scale and prepare us for rapid buildout in the future, allowing us to respond quickly both to realized demand, and to new developments in research and infrastructure;
6) In the slightly longer term, explore what will happen when we need to exceed the 8MW that was initially discussed for the Tower Road site.

DATA CENTER FACTS, FIGURES, PROJECTIONS, AND ANALYSIS

Projected Usage

We have separated usage figures into two categories: *Committed* and *Projected*. *Committed* usage covers systems that must be accommodated (Hershey, Enterprise), where budget approval has been granted (ICS-ACI Phases 1-3), where major grants have been received (MRI/Cyberlamp/Rutgers), or where campus research groups (NCCISE) have known funds to make a significant additional "buy" in ICS-ACI. *Projected* capacity includes normal ICS-ACI growth, Advanced Biological Research Lab projections, faculty co-hires and startups, ARL, and server consolidation (server consolidation is included as *projected* rather than *committed* because initial capacity cannot accommodate it). We suspect that these figures are underestimates of demand. ICS-ACI is already being forced to delay customer onboarding because it does not have the capacity in its systems, and recent price cuts may lead to an acceleration of demand. The demonstrated success and value of the data center and ICS-ACI will generate more demand. **Finally, these estimates do NOT include ANY power demands that would emerge from major national funding opportunities Penn State is currently planning to pursue** including those from the NTIS (Department of Commerce), the NSF Campus CyberInfrastructure initiative, or the NSF/NIH joint RFP on big data. These are three multimillion dollar grant programs. Penn State's recent cyberinfrastructure investments make us potential players in these grant competitions. Currently, however, we will have to turn away these opportunities.

Committed

Hershey (8/2016)	200 kW
Enterprise (Network, research storage, mission critical) (8/2016)	550 kW
ICS-ACI Phase 1.0-2.0 (8/2016)	500kW
ICS-ACI MRI/Cyberlamp (Start date 8/1/16, Complete 11/2016)	100 kW
ICS-ACI Phase 3.0, Rutgers, LionX integration (Completion 1/2017)[1]	200 kW
Lion-X system (decommissioning possible but not scheduled)[2]	200 kW
NCCISE[3]	24 kW
	1774 kW

Projected[4]

ICS-ACI Phase 4.0 (est. 4/2017)[5]	300 kW
ICS-ACI Phase 5.0 (est. 4/2018)[6]	300 kW
ICS co-hires and startups (3 co-hires in AY 16-17 search, to start 8/2017)[7]	375 kW
ICS co-hires and startups (3 co-hires in AY 17-18 search, to start 8/2018)	375 kW
ARL unclassified[8]	50 kW

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[1] ACI Phase 1-3 includes the recent major DOE grant, and a significant new hire recruited with a commitment to 5000 cores. These phases encompass 3 rows @ 200 kW. All ICS-ACI is Tier 1 power. Total ACI cores at end of ACI phase 3.0 are expected to equal 24,240.

[2] Lion-X was developed and deployed under the former RCC. Discussions about decommissioning have begun, but these systems are still fully subscribed and in use. Researchers using Lion-X would have to relocate to new systems, and some believe that the cluster is faster for some applications than the newer ACI systems. While this is likely due to optimization issues, rapid decommissioning would leave a big research hole, and an eventual phase out of these systems is anticipated.

[3] We understand that the NCCISE team is now planning to delay a separate equipment purchase and instead subscribe to ICS-ACI. Their planned purchase of 24kW is noted because it will add that additional demand to ICS-ACI.

[4] Exact equipment mix, quantity and dates will be dependent on faculty governance input, demand from reduced rates, and uptake of GPU systems.

[5] 1 row @ 300 kW (increased wattage due to anticipated increased rack density). Total ACI cores at conclusion of ACI phase 4.0 = 36,000

[6] 1 row @ 300 kW. Total ACI cores at conclusion of ACI phase 5.0 = 48,000

[7] 3 faculty x 5000 cores each (on par with ICS lead hire in 2015-2016) @ 25W per core (wattage per core may vary somewhat with needs; this figure includes power required for related storage, cooling, and other non-CPU demands, and is based on the average ICS-ACI usage for general expansion in phases 4 and 5 of 300 kW for 12,000 cores each).

[8] From discussion with Matt Decker, Applied Research Lab CIO: ARL currently has 50 kW of unclassified research systems housed in inadequate conditions with unreliable power configurations. It has no available power left, but still has power demands (ex: a researcher presented a project that would need 35,000 cores, or approximately 875 kW, but was told there was not capacity for such a project). ARL could move these unclassified systems to the Data Center as soon as space is available, freeing capacity within ARL for more sensitive work.

Advanced Biological Research Lab Phase 1 (10/2017)[9]	1000 kW
Advanced Biological Research Lab Phase 2 (10/2018)	1100 kW
Server closet consolidation, 2018 (physical systems to be moved)[10]	269 kW
Server closet consolidation, 2018 (virtualized systems to be combined)[11]	167 kW
	3136 kW
Total (2016)	1724 kW
Total (2017)	3024 kW
Total (2018)	4860 Kw

Projected Capacity

Tower Road Data Center, 60% at Day 1 (8/2016)	1050 kW
Add: Tower Road 100% Buildout (11/2016)	700 kW
Add: Tower Road 1B (4/2017)	400 kW
Add: Computer Building Renovation for research (4/2017)	600 kW
Add: Tower Road Phase 2, 4 MW (8/2018 if approved immediately)	4000 kW
Total (2016)	1750 kW

[9] The ABRL is currently in the planning stages. Interest, buy-in, and collaboration with other institutions is well under way. It is amassing considerable funding: $10m from the DoD; $5m from Homeland Security. It is a partner in a $185m grant application, and has several applications made and planned in the $10m range and others in the $1-5m range. Depending on how the project evolves, short-term to long-term needs range from 50 kW to 750kW. There is also a huge storage need for various ABRL projects, on the order of several petabytes of storage capacity for genomic data. For projection purposes, we divide 750kW of possible demand over 3 years from mid-2017 to mid-2018. One estimate we heard was for 1.1MW before the end of the decade.

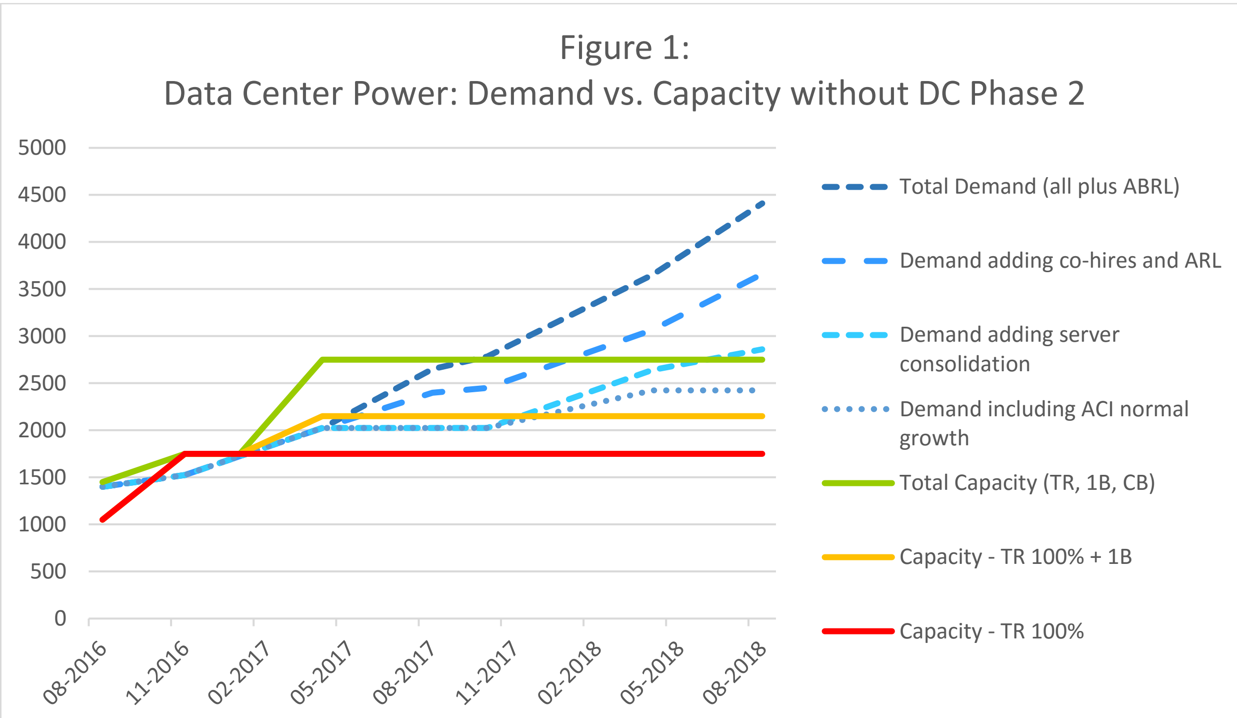
[10] For consolidation, we started with the 769 kW (from our 2014 survey) estimated to reside in UP server/computer rooms. We believe that this number is an underestimate of distributed usage – the 2013 Research Committee Report reported somewhat higher figures for just the few units it investigated. Following discussions with John Whatley (Tek Systems), Mark Saussure, and Mark Campbell, we assume a consolidation ratio of 65%, meaning that 65% of that 769 kW can be converted into virtual machines. This leaves 269 kW of power that will need to be migrated in physical form into Data Center facilities in order to close down existing computer rooms.

[11] When we remove equipment from server closets and move the applications onto virtualized systems, the virtual hosting system will itself still consume power. Without system-by-system assessment of current equipment use, we cannot have a full answer on the power utilization estimate for the virtual infrastructure needed to migrate the other 65%. But if we assume a 3 to 1 conversion (we can consolidate 3 servers into 1), this would be 167 kW required for virtual hosting systems. Unfortunately, we suspect this is an overestimate of how much we can consolidate, because many IT units have already performed significant virtualization. For example, EMS reports that has already virtualized nearly everything it can in its server rooms (40 racks, approximately 10% of the total of all campus server rooms). 3 to 1 is optimistic; if it is really 2 to 1, then we need 334 kW rather than 167 for virtual hosting.

Total (2017)	2750 kW
Total (2018)	6750 kW

Shortfall: Capacity – Usage

Figure 1 graphs multiple demand vs. capacity scenarios concerning power using the above figures.



In Figure 1, solid lines represent available power, while dotted/dashed lines represent demand.

- The lowest Red line represents Tower Road at 100% build out;
- The orange solid line represents Tower Road at 100% build out plus phase 1B;
- The yellow-green solid line represents Total Capacity after 100% build out, phase 1B, plus Computer Building renovation;
- The light blue dotted line represents ACI demand only;
- The light blue dashed line represents ACI plus demands for server room consolidation;
- The medium blue dashed line represents ACI, server rooms, co-hires, and known ARL demand;
- The dark blue dashed line represents total demand including ACI, server rooms, co-hires, ARL, and projected ABRL demand.

Even with *Committed* usage only, the Tower Road Data Center will need 1774kW of power by January 2017, but will have only 1750kW. Tower Road will then be short for ACI Phase 4, server consolidation, and all other new research activity. If Tower Road Phase 1B is constructed, it would likely be completed in April 2017, allowing ACI Phase 4; usage would be 2024kW of 2150kW capacity (94%). Computer

Building renovation can only happen after equipment is moved to Tower Road; renovation would expand power available in the computer building from 400kW to 600kW, providing a total of 2750kW total capacity (this assumes moving or decommissioning all legacy equipment out from the computer building, which could demand 200kW more). This potentially allows ICS-ACI Phase 5 for a total usage of 2324/2750kW. This then leaves only 326 kW for server relocation (estimated at 436 kW), ABRL (estimated at perhaps 2100kW by 2018), additional major grants expected, co-hires and startup packages, or unexpected ACI growth deriving from reduced pricing.

Supply will remain above demand through mid-2017 only if we immediately execute phase 1B and the computer building renovation. As ABRL (and other initiatives) start to consume power, demand will again outstrip supply, with the timing of the inevitable shortfall dependent on when computing nodes must be deployed. Meeting this demand will require Data Center phase 2.

We believe these new projections to be accurate, much as the predictions of the 2013 research report have been generally accurate so far. We know that demand will not go down. If we are already near capacity, then we will be unable properly to house anything new that comes in, or to achieve our strategic goal of shutting down server rooms across campus, improve physical security of computing equipment, improve compliance, and ensure network integrity. **Note that these projections do NOT include any out of the ordinary national grants or contracts, but only those that would occur with ICS co-hiring or would fit within baseline ACI growth.** Success in any major grant or contract initiative is not identified here, although we expect such success now that researchers can leverage the core ICS-ACI facility. These projections are also conservative in that (as noted in the 2013 research report) there is significant latent demand around campus: that is, demand such that if researchers had additional capacity available, they would use it. The 2013 report estimated latent demand reaching 75,000 to 150,000 cores in 5 years (i.e., by 2018). If we expand to satisfy this latent demand, the increment over planned ICS-ACI expansions would require an additional 600-2500 additional kW.

We do recognize that that power usage per compute core is likely to drop over time, and that this may help the situation. Recent models of core chips and GPUs (graphics processing units) deliver more compute power than their predecessors. While gains in CPU power efficiency have slowed, reduction in power demand by GPUs may yield significant savings in particular equipment. One risk could be that we will overbuild capacity. However, GPUs represent a small part of the overall ACI configuration, and we can perhaps imagine reductions in power usage of 10-20% over time. This will help give some breathing space in power, but even when new technology offers the promise of less power consumption, that technology will take time to be phased in, and we need to face current demand with current configurations. End products compatible with existing equipment must be developed by ACI vendors, and then installed gradually through the ongoing lifecycle replacement process. We also suspect that as power and cluster capacity is available, usage will increase, more than offsetting this power savings, as researchers have formulated significant research problems that require much more capacity than we have. Finally, in addition to power, physical space (white space) is necessary. There are potentially complicated interrelationships between technology improvements, scheduling improvements, cloud bursting, power consumption, natural increases in demand for computing, and unnatural increases in demand due to changes that spark sudden new interests and ideas. It is possible that things will turn out better than we expect, worse than we expect, or perhaps we will be just about right. In any case we will not know how those play out with certainty for several years, or more. Right now, we do know that planned and projected power usage will outpace supply in short order. We also know that we are behind peer institutions in available HPC capacity, and that our researchers have the research questions and grant applications ready that will use additional capacity quickly.

Recommendation Details

Following immediate full build out (recommendation point 1), the phase 1B Tower Road expansion (recommendation point 2) can add an extra 400kW for research use to Tower Road, with minimal reconfiguration needed. In parallel, 400 kW could be vacated from the Computer Building and an extra 200 kW added after renovation to make a total of 600kW available for research use in that facility (recommendation point 3). Executing this option will hold us over through ACI Phase 3, while providing additional capacity in the Computer Building to start transitioning local resources into central facilities. Computer Building renovation is NOT a long-term solution. It will simply give us a touch of head room in power while we execute one of the options below.

The best long-term option is to accelerate the construction of planned future phases at Tower Road. The ultimate capacity of that building should be reconsidered and ideally revised upward to 6 MW, based on usage projections. Building only 2 MW immediately risks another shortfall very soon, and so we recommend executing a 4MW expansion immediately (point 4) to avoid having to come back in 1-3 years and ask for 2MW more. We believe 4MW will last us 3-6 years, at which point we can execute additional expansions in the second building as needed. This projection emerges from our reported power numbers from a 2014 survey, our knowledge of changes in the last 2 years, and our projections for the future of ICS-ACI and related HPC projects that have recently been awarded or are soon expected. If anything, adding 4MW might not last as long as we hope. And so as part of this recommendation, **we also recommend full buildout of the expanded data center shell while phase 2 power is being built, leaving vacant space inside into which racks, and power, can be added much more quickly than if we have to put up a new building.** We anticipate with the shell built, we could add a MW of power in a year, as opposed to a two+ year construction process.

An inferior option is to build the next planned building at Tower Road but only execute 2MW immediately, an option sketched out in earlier planning documents. The advantage of a 2 MW option is that it would cost less in the immediate moment (although it is likely to be just a small saving). The disadvantage of this option is that we would likely need to return to the Board and request another expansion in 1-3 years. Projections for power usage are such that we do not believe an additional 2MW will give us sufficient power for growth even in the two-year time frame. If we execute this option and then find it is immediately inadequate, there will be a perception that we were not forward-thinking.

Because of the long lead time for additional capacity to become available, taking immediate action on these recommendations is vital. We recommend taking as many initial steps as possible (e.g., development of specific blueprints and timelines, obtaining initial permits or other approvals as possible, identification of specific milestones as triggers, ordering long-lead-time equipment) well in advance of filling available capacity. We know that the additional capacity will be needed. Early investment to ensure speed later is well worth any small possibility that expansion plans will be delayed, because the downside to delaying computing capacity when it is needed is significant. As a byproduct of engaging in this (2016) planning process, **we recognize the need for initiating a regular annual projection process for calculating anticipated computing power requirements that makes informed projections of demand for the next 3-5 years. RCCI will henceforth do this annually.** With continuing rapid technological developments, 5 year projections will undoubtedly be revised. But we will be in a far better position to make informed decisions if we have a systematic process, and a track record of estimates vs. actual usage patterns. We also suggest exploring options to help overcome the (we believe) inevitable shortfall we will face, and working with vendors who may be able to import ready-made solutions that can help with speed and responsiveness.

History and Previous Projections

In 2015, Penn State began the construction of a new Data Center building on Tower Road. This followed a planning period and various analyses, including the October 2013 "Report of the Research Data and Computing Committee." Prior to the 2013 report, the Data Center planning was for a facility with 1 MW total power available, including 0.5 reserved for research. That report made several key points:

1) The 2013 report projected that Penn State could need 6 MW capacity for research computing and data storage by 2017 (including existing data servers).
2) The 2013 report recommended that the Tower Road Data Center be constructed with a Day 1 capacity (then projected as 2017) of 4 MW (total), with 3 MW reserved for research.
3) Recognizing both the uncertainty of projections and a projected gap in capacity until expansions could be constructed, the 2013 report recommended that plans for the data center design include options for rapid and repeated expansion, for example in increments of 1 MW per year.
4) The 2013 report recommended that Penn State explore a variety of options to serve unmet capacity needs in the near term, including third-party hosting of servers, a spatially distributed solution on campus through container data center designs, and/or upgrades to existing server rooms.
5) The 2013 report noted that the average power capacity of 13 peer institutions *in 2013* was 3.5 MW.

Ultimately, the Tower Road facility construction project began with a planned initial capacity of 1.75 MW ("Phase 1"). At opening, the interior will have been built out so that 60% of capacity is expected to be usable on Day 1.

We have reviewed the recommendations from the 2013 committee report. We find that the growth in research computing during the past 3 years is consistent with the growth projected in 2013. Therefore, it should come as no surprise that the available power in the Tower Road Data Center and the construction of a data center smaller than those at our peer institutions will soon be inadequate to meet research computing needs.

Growth and the Consequences of Inadequate Capacity

We anticipate four drivers of growth in advanced research computing needs:

(1) The inevitable expansion of capacity in ICS-ACI to meet the increased demand for advanced research computing for existing faculty in fields which have a tradition of high-end computing to remain competitive in fields such as physical sciences, engineering, and computational science;
(2) the strategic expansion of capacity in ICS-ACI to meet the increased demand for research computing capabilities for existing faculty in fields where research computing and data storage

are growing exponentially, as they embrace the potential of data science, "Big Data", "Big Simulations" and "Big Models" to revolutionize their fields (e.g., life sciences, social sciences, digital humanities);

(3) predictable commitments by the Institute for Cyberscience to provide research computing and storage as a part of startup packages to attract faculty as part of the ICS cluster hiring initiative; and

(4) foreseeable, sudden increases in needed capacity, as Penn State researchers attract sizable external funding for advanced CyberInfrastructure and CyberScience research. For example, based on proposals submitted during the 2015/16 academic year, we have received a significant award for CyberLamp (NSF Major Research Instrumentation) and anticipate support for the Advanced Biological Research Laboratory. We also anticipate major proposals in NSF, NIH, and NTIS; these are only the currently known opportunities that researchers are likely to pursue.

All four of these drivers are signs of success for the University's research mission; we want to encourage further growth. Inadequate capacity for research computing will correspondingly constrain the growth of research at Penn State by limiting the ability of our faculty to compete for federal grants for large scale computing resources, interfering with Penn State's ability to recruit faculty with substantial research computing needs, and undermining the Institute for CyberScience's ability to contribute to the University's strategic plan. Inadequate capacity will also prevent the relocation of existing equipment from less efficient "data closets" scattered throughout campus into the data centers, one of the key strategic goals of the Data Center project. Thus, it is crystal clear that **Penn State must urgently move to increase capacity for research computing beyond Phase 1.**

Options Discussed

As the basis for this report, we considered several expansion opportunities:

1. **Data Center 100% buildout:** Expand rack space and bring Tower Road to its full 1.75 MW usable capacity from the initial 60%, completion by October/November 2016 if “go” order is given ASAP. **We recommend giving the “go” order ASAP.**
    - Option 1 (100% buildout) is a no brainer. While Tower Road was initially built out to 60% of capacity to allow for some phased growth, we clearly need to make use of all of the capacity in Tower Road. Equipment will be ready to make use of that space as soon as it is complete.

2. **Data Center Phase 1B**: +400 MW capacity, approximately 6 month timeline. This is a recently developed option. It would rearrange and repurpose some space in Tower Road and eke out some additional power from the generators.] **We recommend proceeding with this option ASAP.**
    - Pros
        - Makes even better use of the space and power capacity with Tower Road.
        - Medium time line, so relatively quick option for expanding research capacity.
    - Cons
        - None other than that it doesn’t solve the whole shortfall.

3. **Computer building renovation**: +200MW capacity, potentially 2-3 months timeline after equipment is moved to Tower Road (moving some equipment out is a prerequisite for doing the renovations.) This renovation (adding chiller, UPS, and structural capacity) gains +200kW of research capacity in a short time of the Computer Building, expanding its capacity to support research computing equipment from 400W to a total of 600W. **We recommend proceeding with this option ASAP.**
   - Pros
     - Improves conditions within the computer building, strenthening security and reliability until the facility is repurposed (if it ever is).
     - Quickest option for expanding research capacity.
     - Potentially allows the computer building to be used longer-term as a medium-security facility for faculty research clusters (and other equipment).
   - Cons
     - Invests money in an existing facility rather than in a new one. However, while one goal of the data center project is to be able to repurpose facilities, the Computer Building among the highest quality existing spaces and is likely to be the last data center to be closed. Regardless of this potential investment, the building could not be repurposed yet because of anticipated demand. Since the Computer Building will have to remain operational for several years, it would be better to maximize the use of this space and have the equipment that is located there in a safe and more reliable room than in its precarious state there now.

4. **Full Expansion via Data Center Phase 2**: The Tower Road footprint was planned to be expandable; on paper expansion was to be +2 MW in phase 2, and up to +4 MW in phase 3. The cost should be somewhat less than the initial phase 1, given the site preparation that has already been done, experience with the process, the number of key decisions that have already been made, and omitting office space in Phase 2. There is at least a 17-19 month timeline from board approval to availability, and time for design and board approval must be added, so in rough terms there is a 2 year timeline for this option. We urgently need Data Center phase 2. If it is to be available in summer 2018, that requires a "go" to be given in summer 2016—i.e., *now*. This adds the most capacity. **We recommend an immediate +4 MW expansion.** We need immediately to set as many steps in motion as possible in order to minimize the time to get Phase 2 built and made operational.
   - Pros
     - Most additional power
     - Only option that adds enough capacity to give us the ability to expand research computing and pursuit of major computing grants.
     - No issues of implementation/linking to the current data center as with the hypothetical Phase 1A (below); no user impact due to testing; maintains needed flex space and redundancy of data center Phase 1.
   - Cons
     - +4 may still not be enough capacity for research computing needs beyond 2018, and would leave only limited capacity for consolidation of distributed equipment in campus server rooms.

- It is still not practical for Phase 2 to be ready in time to meet projected demand, leading to a predicted unmet need for research computing capacity in late 2017/early 2018. No other solution fixes this problem either.

5. **Building the maximum shell as part of Data Center Phase 2.** The slowest part of data center expansion lies in building construction. Along with building phase 2, **we recommend immediately constructing an expanded building shell.** While it may take 2 years to build and commission a data center building plus power and networking, if the shell is built, adding power capacity to that shell may take only a year. Having a structure within which we can expand will allow us to expand rapidly and cost-effectively as needed in the future. We will only have to build this shell once, and so we gain economies of scale for the building part of construction. Most importantly, having the shell allows rapid buildout in the future in response to demand.

6. **Data Center Phase 3:** Add additional capacity. We need to be prepared to expand past whatever level we decide now. We believe it would be prudent to understand the maximum power consumption possible at the Tower Road site, given the necessity to draw from different substations if we stick with local utility providers, or our ability to deploy different kinds of generation technology cost-effectively if we hit higher levels of power usage.

7. **Data Center Phase 1A**: Not recommended. Phase 1A was an early option to add +1MW capacity with a 10-12 month timeline from order to availability. This option has significant risks and downsides including eating up all flex space, adding water cooling with an attendant physical reliability/security concern, and potentially significant user impacts due to integration of new systems with production systems in use. We recommend that this be held in reserve only as a future emergency option.

8. **Re-use of Other Facilities.** We have recommended renovating and expanding the Computer Building. Would planned reuse of some of the other larger computer spaces help with the major capacity crunch for research computing? In a word, no. With Tower Road full, we are unlikely to be able to move equipment out of many other spaces quickly. If spaces are not emptied, they cannot be reused, and so this does not solve the space crunch at Tower Road. If the expanded Computer Building has vacant space, the RCCI Data Center Working Group has suggested that it be used for individual faculty research clusters. While we want to encourage faculty to move to use ICS-ACI equipment, there will be some need for researchers with specialized needs to purchase equipment separately. We need a home for that equipment. Putting faculty equipment into a separate physical facility (such as the Computer Building) where it is more easily accessible provides a way to provide researchers more flexible equipment access than the Tower Road security protocols might allow. Further use of other spaces is at best merely part of a stopgap solution, but should be considered on a case-by-case basis. Huck has some cyber-enabled space in the MSC that could be some help.