NSLS-II

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High Level Description of NSLS-II

Highly optimized x-ray synchrotron delivering:
• extremely high brightness and flux
• very small beams with exceptional beam stability
• suite of advanced instruments, optics, & detectors

Together, these:
• provide outstanding performance and flexibility from the far-IR to the very hard x-ray regions to support diverse scientific needs
• enable the study of materials properties and functions with unprecedented spatial (~ 1 nm) and energy (~ 0.1 meV) resolutions and sensitivity (single atom)
What Research will NSLS-II Enable?

Structure & properties/functions

Observe fundamental material properties with nanometer-scale resolution and atomic sensitivity

- Physical, chemical, electronic, and magnetic structure of nanoparticles, nanotubes, and nanowires, e.g., new electronic materials that scale beyond silicon
- Designer catalysts, e.g., in-situ changes in local geometric, chemical, and electronic structure of active catalytic site in real-time and under real reaction conditions

Self-assembly

Understand how to create large-scale, hierarchical structures from nanometer-scale building blocks

- Interactions between nanoscale building blocks
- Kinetics of nanoscale assembly
- Structure of hierarchical materials from nanometers to microns
- Mechanisms of directed assembly (by templating or external fields)
- Molecular interactions in nano-confined environments

Emergent behavior

Probe nanometer-scale materials that display emergent behavior

- Direct 3D imaging of domain structures and dynamics, e.g., in random field magnets and spin glasses
- Colossal magnetoresistance for high-sensitivity magnetic sensors or high-density information storage
- Dynamics of charge and spin stripes in high temperature superconductors

Molecular Electronics

Nanocatalysis

Charge and spin stripes in complex oxides
Project Scope

Accelerator Systems
• Storage Ring (~ ½ mile in circumference)
• Linac and Booster Injection System

Conventional Facilities
• Ring Building w/ Operations Center and service buildings (~ 341k gsf)
• Laboratory/Office Buildings (LOBs) to house beamline staff & users (~71k gsf)
• Reuse of existing NSLS office/lab space for NSLS-II staff

Experimental Facilities
• Initial suite of 6 insertion device beamlines and instruments
• Capable of hosting at least 58 beamlines

R&D
• Advanced optics for achieving 1 nm and 0.1 meV
• Nanopositioning and mirror metrology
NSLS-II Design

Design Parameters
- 3 GeV, 500 mA, top-off injection
- Circumference 791.5 m
- 30 cell, Double Bend Achromat
  - 15 long straights (9.3 m)
  - 15 short straights (6.6 m)

Novel design features:
- damping wigglers
- soft bend magnets
- three pole wigglers
- large gap IR dipoles

Ultra-low emittance
- $\varepsilon_x, \varepsilon_y = 0.6, 0.008 \text{ nm-rad}$
- Diffraction limited in vertical at 10 keV

Pulse Length (rms) $\sim 15 \text{ psec}$
NSLS-II Performance

Very broad spectral coverage
  Far-IR through very hard x-rays

Very high brightness
  \( > 10^{21} \text{ p/s/0.1}\%/\text{mm}^2/\text{mrad}^2 \) from \( \sim 2 \text{ keV} \) to \( \sim 10 \text{ keV} \)

Very high flux
  \( > 5 \times 10^{15} \text{ ph/s/0.1}\%\text{bw} \) from \( \sim 500 \text{ eV} \) to \( \sim 10 \text{ keV} \)

Very small beam size
  \( \sigma_y = 2.6 \ \mu\text{m}, \sigma_x = 28 \ \mu\text{m} \)
  \( \sigma'_y = 3.2 \ \mu\text{rad}, \sigma'_x = 19 \ \mu\text{rad} \)

Top-off operation
  Current stability better than 1%
NSLS-II Beamlines

19 straight sections for undulator beamlines
   • Fifteen 6.6 m long low-β and four 9.3 m long high-β
   • Highest brightness sources from UV to hard x-ray

8 straight sections for damping wiggler beamlines
   • Each 9.3 m long high-β
   • Broadband high flux sources from UV to hard x-ray

27 BM ports for IR, UV and Soft X-rays beamlines
   • Up to 15 of these can have three pole wigglers for hard x-rays

4 Large Gap BM ports for far-IR beamlines

At least 58 beamlines
More by canting multiple IDs per straight
Multiple hutches/beamline are also possible

For comparison, NSLS has 65 operating beamlines
Radiation Sources: Brightness

EPU45 SXU
45 mm, L=4.0 m, $K_{\text{max}}=4.33$

EPU100 VUV undulator
100 mm, L=4 m, $K_{\text{max}}=14.0$

U20 IVU
20 mm, L=3.0 m, $K_{\text{max}}=1.81$

U14 SCU
14 mm, L=2.0 m, $K_{\text{max}}=2.2$

DW100 damping wiggler,
B=1.8 T, 100 mm,
L=7 m, $K=16.8$

W60 SCW,
B=6.0 T, 60 mm,
L=1.0 m, $K=33.6$

25 m radius bend,
B=0.4 T, $E_c=2.39$ keV

3-pole wiggler,
B=1.0 T, $E_c=5.98$ keV

Brightness [photons/sec/0.1%bw/mm²/mrad²]

Photon Energy [eV]
Radiation Sources: Flux

(Flux per horizontal milliradian for broadband sources)
Radiation Sources: Infra-Red

Standard gap BMs provide excellent mid and near IR sources
Large gap (90 mm) BMs provide excellent far-IR sources
Rendering of NSLS-II
Laboratory Office Buildings

- Three in base scope (22,800 sf each) – Each serves six sectors
  - 72 offices w/ conference space, interaction areas, lavs, showers
  - 6 labs – optimized for shared use
  - Shipping/Receiving/Storage area & chemical storage area
  - Future addition of 2 more LOB’s as facilities builds out
- Egress provided for personnel and large items at each LOB
  - Loading area with exterior roll-up door
  - Double-door from each lab onto the experimental floor
  - Rolling access to all beamline areas
Experimental Floor

- Designed to minimize sources and propagation of vibrations
- Long beamlines will have hutches outside the experimental hall
NSLS-II Strawman Beamline Distribution

Possible distribution among beamline categories (and compared to existing NSLS)

<table>
<thead>
<tr>
<th>Type</th>
<th>NSLS-II</th>
<th></th>
<th>NSLS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IDs</td>
<td>BMs</td>
<td>Total</td>
<td>IDs</td>
</tr>
<tr>
<td>IR/UV/Soft X-ray Spectroscopy</td>
<td>1</td>
<td>8</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>X-ray Spectroscopy</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Soft Matter/Biophysics Scattering</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Hard Matter/Strongly Correlated Scattering</td>
<td>7</td>
<td>1</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Powder/single crystal/high P/optics</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Imaging/micro-probe</td>
<td>3</td>
<td>8</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Macromolecular Crystallography</td>
<td>6</td>
<td>3</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>30</td>
<td>29</td>
<td>59</td>
<td>13</td>
</tr>
</tbody>
</table>

N.B. NSLS-II distribution includes some canting (principally, damping wigglers) and also leaves 3 straights unassigned.
# Beamline Acquisition Strategy

<table>
<thead>
<tr>
<th><strong>FUNDING</strong></th>
<th><strong>BEAMLINES</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>NSLS-II Project</td>
<td>6 insertion device beamlines to be built by construction project as initial suite for physical sciences</td>
</tr>
<tr>
<td>NSLS-II Early Operations</td>
<td>~ 20 bending magnet beamlines transferred from NSLS to NSLS-II</td>
</tr>
<tr>
<td>DOE-BES MIE*</td>
<td>~ 16 insertion device beamlines for DOE-BES relevant missions</td>
</tr>
<tr>
<td>Non-DOE sources</td>
<td>~ 5 Insertion device beamlines and ~ 11 bending magnet beamlines for non-DOE-BES missions</td>
</tr>
</tbody>
</table>

* MIE = Major Item of Equipment
Project Beamlines

Goal: To provide a minimum suite of insertion device beamlines to meet physical science needs that both exploit the unique capabilities of the NSLS-II source and provide work horse instruments for large user capacity.

• The beamlines are:
  • Nanoprobe (1 nm)
  • Inelastic x-ray scattering (0.1 meV)
  • Soft x-ray coherent scattering and imaging
  • Hard x-ray coherent scattering and SAXS
  • Powder diffraction (damping wiggler source)
  • EXAFS (damping wiggler source)
Phased Transition to NSLS-II Operations

Transition from NSLS to NSLS-II

• Continue operations of NSLS until NSLS-II operational (CD-4)
• NSLS and NSLS-II staff merge to operate NSLS-II

Beneficial Occupancy of Experimental Floor (Feb 2012)

• Enables early operations funding
• Use early operations funding to transfer selected NSLS beamlines to NSLS-II to ensure significant capacity at start of operations
• Primarily techniques with high demand, high productivity
• Mainly occupy 3-pole wigglers and soft-bends
• Expect to transfer about 20 beamlines, accommodating > 1300 users/yr

Early Project Completion (June 2014) / CD-4 (June 2015)

• Start of Full Operations
• All commissioning goals have been achieved
Joint Photon Sciences Institute (JPSI)

- A new initiative in photon sciences to leverage the unique capabilities and internal science programs of NSLS-II
- Brings together interdisciplinary teams in collaborative projects, forging synergistic relationships that enable new science
- Incubator of high risk techniques & applications, requiring broad array of expertise and supporting technology
- New York State is providing $30 million for the JPSI building

Mission:
- Develop and enhance scientific programs that best utilize NSLS-II
- Develop enabling technologies to support JPSI programs
- Serve as a gateway for NSLS-II
- Educate and train the next generation of leaders in synchrotron research
User Community Input on NSLS-II

- High pressure
- High magnetic fields
- Hydrogen Storage
- Biomatters
- Pharmaceuticals
- Nanoprobes
- Biomedical Imaging
- Detectors
- Powder Diffraction
- Environmental Sciences
- Soft Matter
- Grazing incidence SAXS
- EXAFS
- Macromolecular Crystallography
- Advanced optical systems and metrology
NSLS-II Advisory Committees

- Project Advisory Committee
- Experimental Facilities Advisory Committee
- Accelerator Systems Advisory Committee
- Conventional Facilities Advisory Committee
NSLS-II User Workshop (July 17-18, 2007)

More than 450 attendees from 130 different institutions

OSTP: John Marburger
DOE: Pat Dehmer (BES)
       Pedro Montano (BES)
       Susan Gregurick (BER)
NIH: Charles Edmonds (NIGMS)
     Alan McLaughlin (NIBIB)
     Michael Marron (NCRR)
     Amy Swain (NCRR)
NSF: Guebre Tessema

Pat Dehmer announcing the award of CD-1

John Marburger addressing the audience
NSLS-II User Workshop

First Day Plenary Session

• Described conceptual design and status of project
• Highlight talks on physical and life sciences and user access models
• Described process for beamline development at NSLS-II
• Described Joint Photon Sciences Institute
• Described plans for transitioning from NSLS to NSLS-II

Second Day Breakout Sessions

Technique-based Sessions

• Hard x-ray Nanoprobe
• Soft Coherent Scattering and Imaging
• Powder Diffraction
• Macromolecular Crystallography
• Liquid Interfaces
• Inelastic X-ray Scattering
• Hard Coherent and XPCS/SAXS
• XAFS
• Bio-SAXS
• Photoemission Spectroscopy

Science-based Sessions

• Life Sciences
• Catalysis
• Environmental Science
• High-Pressure
• Strongly Correlated Electrons
• Magnetism
• Radiometry and Metrology
• Soft Condensed Matter
Upcoming Strategic Planning & Beamline Workshops

Technique-Based Workshops
• XPCS and Microbeam SAXS  Jan. 10-11
• X-Ray Absorption Spectroscopy  Jan. 16
• Powder Diffraction  Jan. 17-18
• Soft X-Ray Scattering  Feb. 4
• Inelastic X-Ray Scattering  Feb. 7-8
• Nanoprobe Beamline  Feb. 15

Scientific Strategic Planning Workshops
• Life Sciences  Jan. 15-16
• Materials Science and Engineering  Jan. 17-18
• Earth and Environmental Sciences  Jan. 22-23
• Chemical and Energy Sciences  Feb. 1
• Hard Condensed Matter and Materials Physics  Feb. 5-6
• Soft and Biomolecular Materials  Feb. 11-12
Key Milestones

Aug 2005  CD-0, Approve Mission Need                                        (Complete)
Oct 2006   Complete EA/FONSI                                             (Complete)
Nov 2006   Complete Conceptual Design Report, Preliminary Baseline      (Complete)
Dec 2006   Review, Preliminary Baseline                                 (Complete)
Jul 2007   CD-1, Approve Alternative Selection and Cost Range           (Complete)
Oct 2007   Complete Preliminary Design Report, Performance Baseline     (Complete)
Nov 2007   Review, Performance Baseline                                (Complete)
Dec 2007   CD-2, Approve Performance Baseline                            (Complete)
Oct 2008   Begin Site Prep                                              
Jan 2009   CD-3, Approve Start of Construction                          
Jun 2009   Issue Ring Building Notice to Proceed                        
Mar 2010   Contract Award for Booster System                           
Feb 2011   Ring Building Pentant #1 Beneficial Occupancy               
Feb 2012   Beneficial Occupancy of Experimental Floor, Start of Early Operations Funding 
Aug 2013   Conventional Facilities Construction Complete               
Oct 2013   Start Accelerator Commissioning                              
Jun 2014   Early Project Completion; Ring Available to Beamlines       
Jan 2015   CD-4, Project Completion                                     

## NSLS-II Cost Baseline ($M)

<table>
<thead>
<tr>
<th>Category</th>
<th>Amount ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Management</td>
<td>53</td>
</tr>
<tr>
<td>Accelerator Systems</td>
<td>242</td>
</tr>
<tr>
<td>Conventional Facilities</td>
<td>241</td>
</tr>
<tr>
<td>Experimental Facilities</td>
<td>73</td>
</tr>
<tr>
<td><strong>Total Construction Cost Baseline</strong></td>
<td>609</td>
</tr>
<tr>
<td>Contingency (30% of Constr. Cost Baseline)</td>
<td>183</td>
</tr>
<tr>
<td><strong>Total Estimated Costs (TEC)</strong></td>
<td>792</td>
</tr>
<tr>
<td>R&amp;D and Conceptual Design</td>
<td>60</td>
</tr>
<tr>
<td>Pre-Operations</td>
<td>50</td>
</tr>
<tr>
<td>Contingency (20% of Pre-ops)</td>
<td>10</td>
</tr>
<tr>
<td><strong>Other Project Costs (OPC)</strong></td>
<td>120</td>
</tr>
<tr>
<td><strong>Total Project Costs (TPC)</strong></td>
<td>$912</td>
</tr>
</tbody>
</table>
Funding Profile with Operations & MIE

TPC = $912M   TEC = $792M (including 30% contingency)

Estimated operating staff:
- 235 FTEs w/ no beamlines
- 550 FTEs w/ 57 beamlines

Note: Operations & MIE funding are not part of TPC
Summary

• Novel design w/ outstanding performance and flexibility from the far-IR to the very hard x-ray. A range of sources matched to various scientific needs.

• Baseline scope provides substantial experimental capability

• Have plan for transition from NSLS and reuse of experimental and conventional facilities from NSLS

• Community is fully engaged in optimizing overall facility utilization