# Report from the Underground Capabilities Working Group

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# Why Underground Facilities Working Group?

- Underground facilities and capabilities essential to support experiments that are central to the world-wide and U.S. scientific program
  - Direct dark matter experiments
  - Neutrinoless double-beta decay ($0\nu\beta\beta$) experiments
  - Atmospheric, long-baseline, reactor, solar, supernova…. neutrino experiments
  - Proton decay
  - Connections to astrophysics, nuclear science, earth science and detectors for non-proliferation

# Underground Capabilities - Working Groups

- NAF1 – on underground facilities to support very large detectors for neutrino physics, proton decay and other science requiring detectors of the multi-kiloton scale.
  - NAF1 conveners: K. Heeger (Wisconsin), K. Scholberg (Duke), H. Sobel (Irvine)
- NAF2 – on underground facilities for dark matter experiments, neutrinoless double beta decay experiments, underground accelerators for nuclear astrophysics or other physics, low background assay of materials and related topics.
  - NAF2 conveners: P. Cushman (Minnesota), J. Klein (Pennsylvania), M. Witherell (Santa Barbara)
- Underground facilities in support of instrumentation development in both working groups
  - Conveners, contact with Instrumentation: P. Cushman (Minnesota), M. Gilchriese (LBNL)
- Neutrinos and society
  - Convener is A. Bernstein (LLNL), potential connections with underground capabilities. Primarily detectors for non-proliferation monitoring and geo-antineutrino detection.

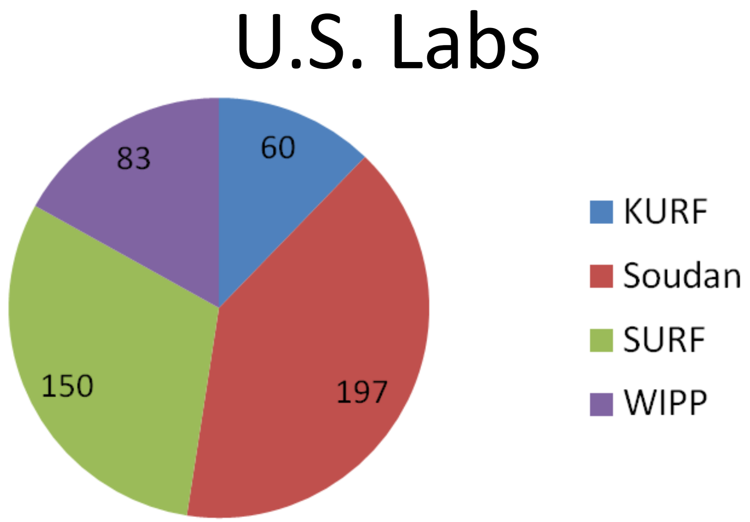
Emphasis on future facilities and capabilities

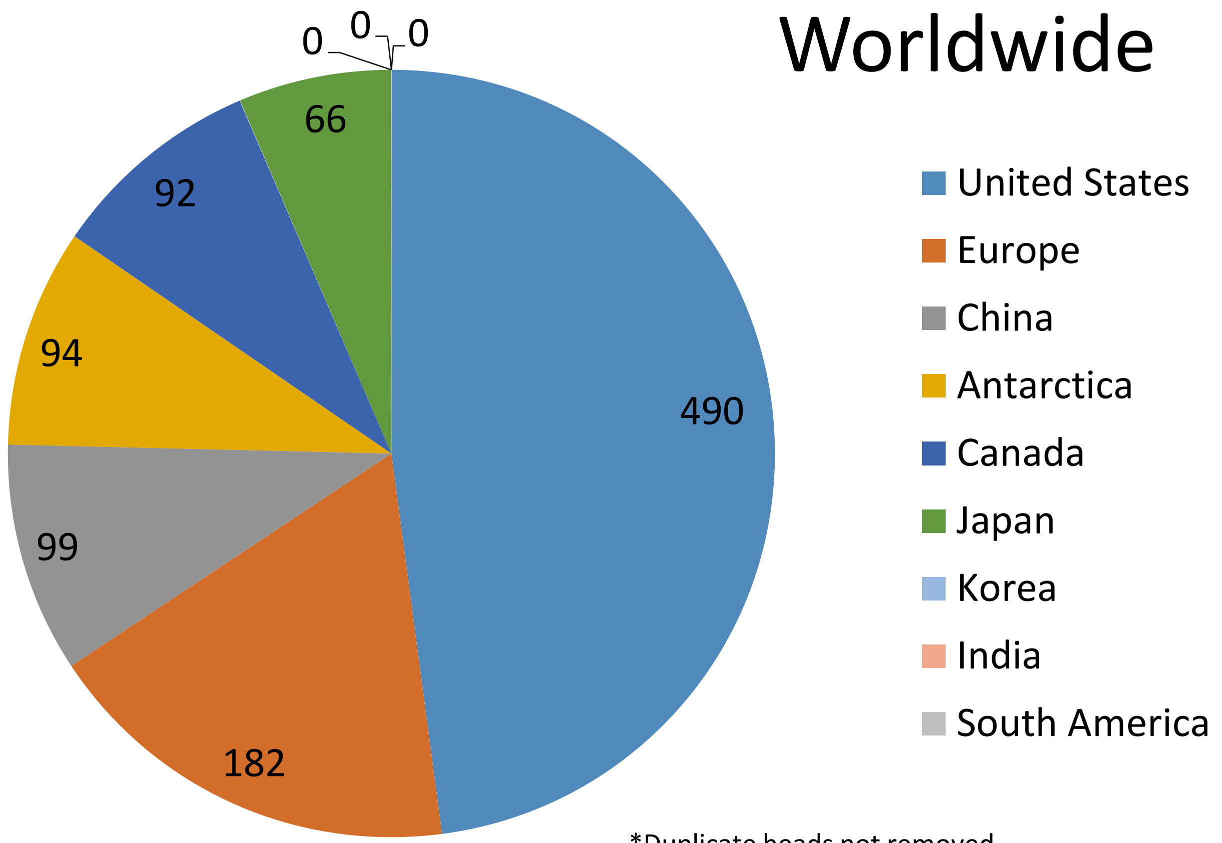
# Introduction

- No technical showstoppers to creating and outfitting underground (or ice) space for what is realistically proposed for the next 10-20 years. Too soon to say beyond.
- Existing and proposed/planned underground (or ice) facilities, roughly 20
  - United States: KURF, Soudan, SURF (including LBNE), WIPP, Fairport mine(former IMB)
  - Canada: SNOLAB
  - South America: ANDES
  - China: CJPL and extension, JUNO
  - Korea: Y2L and extension, RENO-50
  - Russia: Baksan
  - United Kingdom: Boulby
  - Finland: CUPP
  - Italy: LNGS
  - France: Modane and extension
  - Spain: LSC
  - Other Europe: perhaps associated with EU SNS
  - Japan: Kamioka (including Super-K and Hyper-K)
  - India: INO
  - Antarctica: including future extensions

# U.S. Scientists Underground

- Count of current U.S. heads (only)* at underground facilities, including Antarctica. Roughly 1,000 U.S. heads.
- Future: 30-50% growth(no hard estimate)

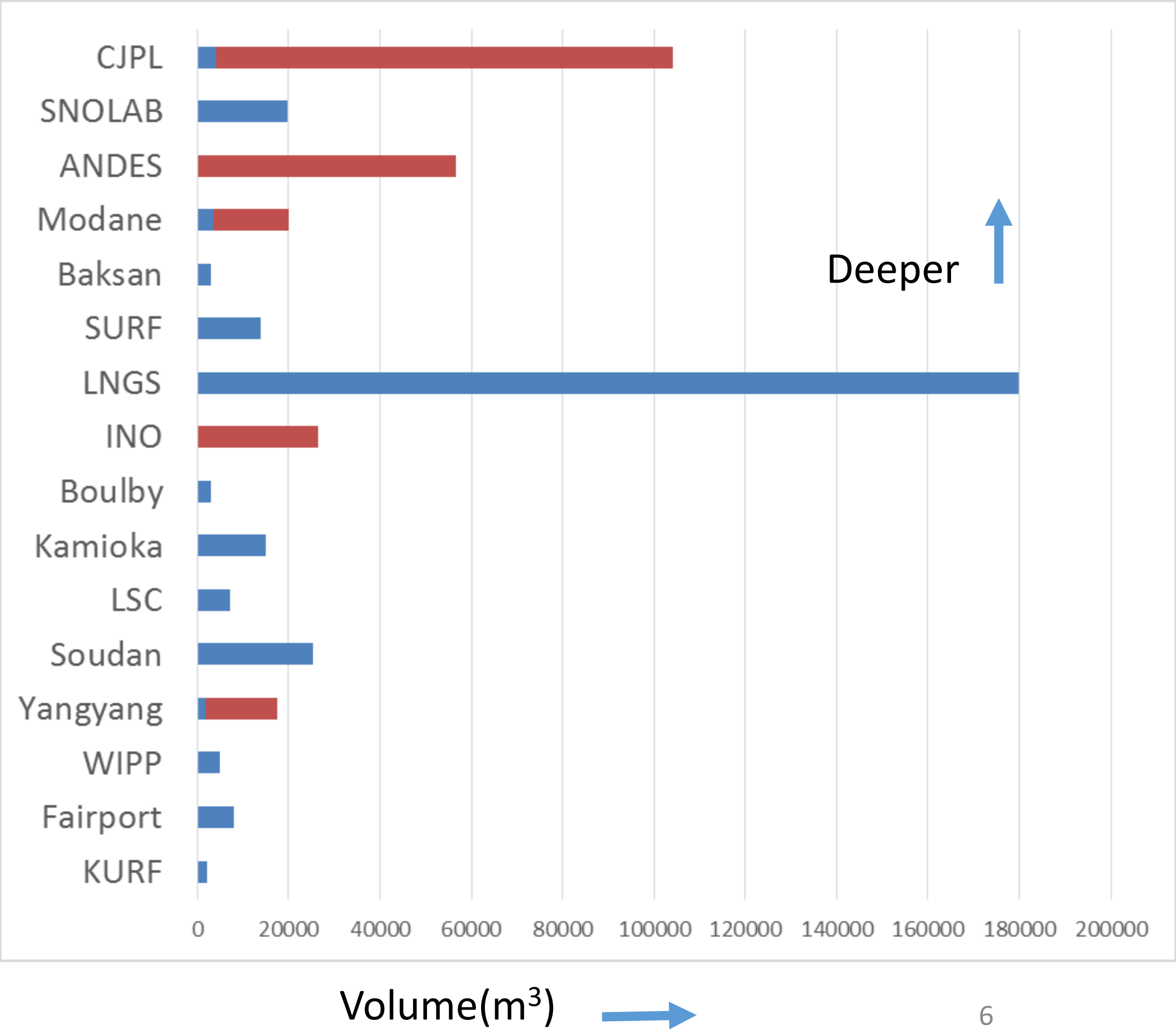



*Duplicate heads not removed

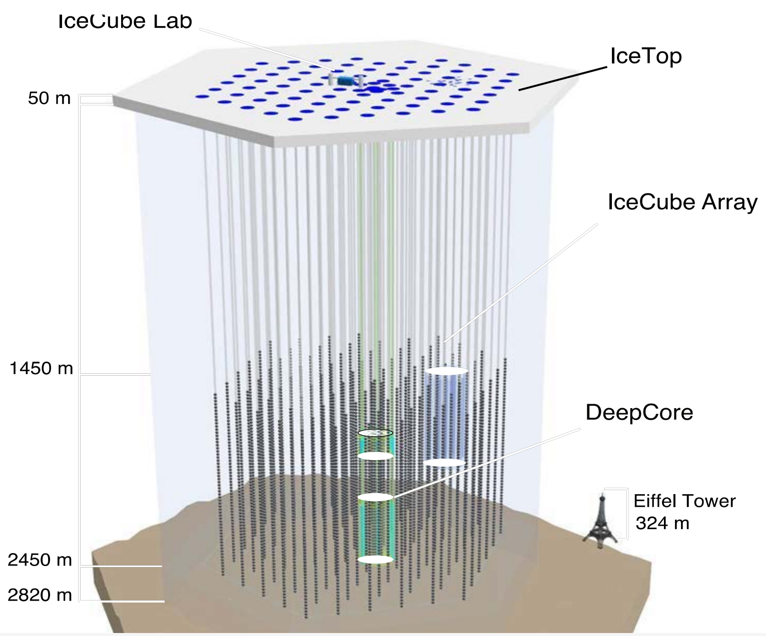
# Summary of "General Purpose" Underground Labs

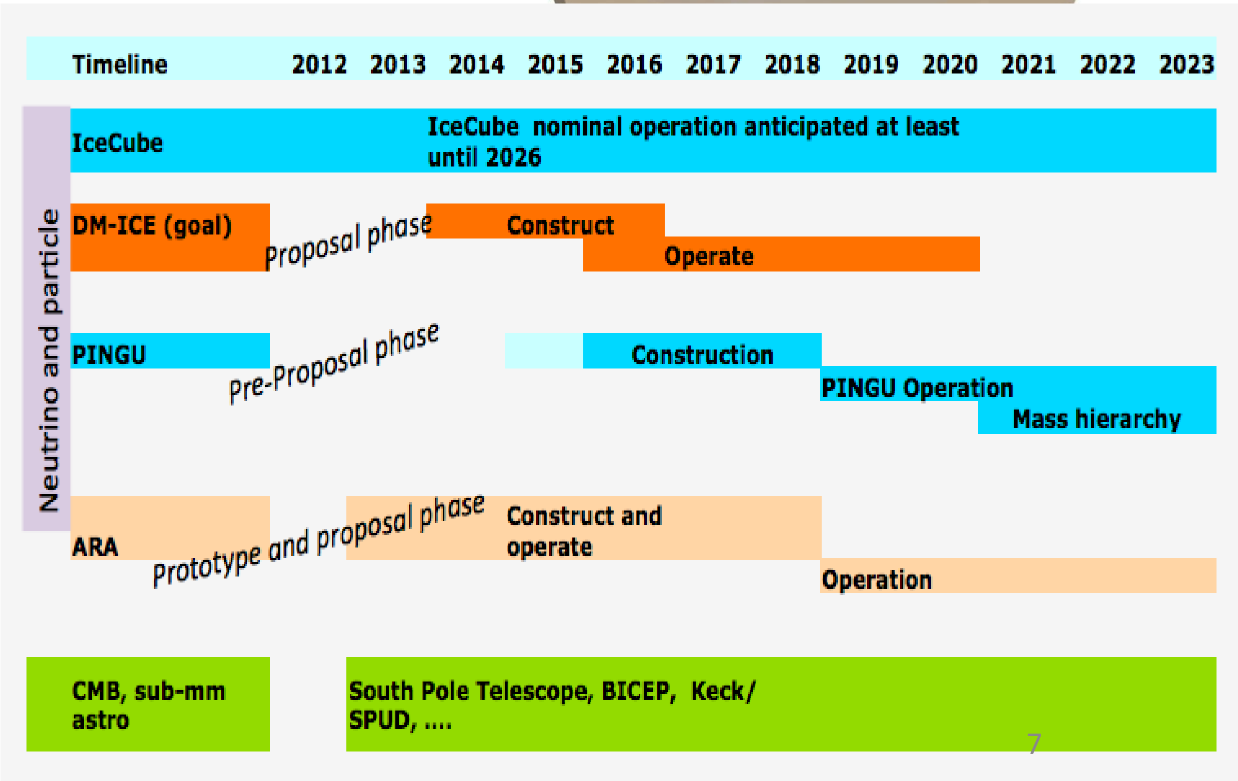
- Significant expansion completed in last ~ 3 years(CJPL, LSC, SNOLAB, SURF). Experiments now taking advantage.
- Significant additional expansion planned outside U.S. Also repurposing at LNGS without CERN ν beam.
- Comparison of current(blue) and future(red) proposed volumes
- Fairport, INO, Kamioka, SURF do not include space for very large neutrino detectors
- If all realized, "general purpose" underground space worldwide would about double by end of decade.



# Antarctica

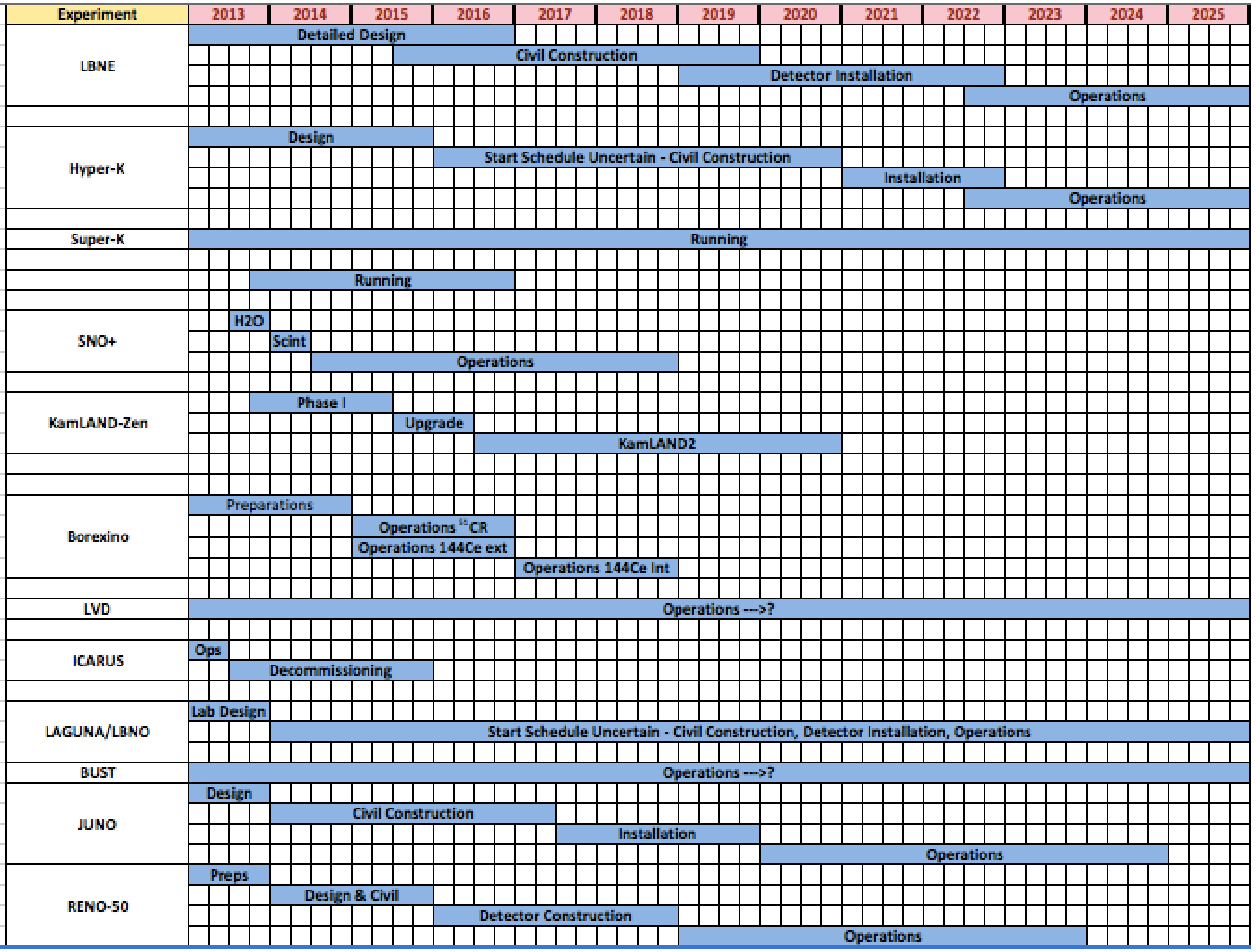
- Unique, U.S. led facility. Only Southern Hemisphere site so far.
- Dark matter, neutrino program, including operation and proposals for future experiments
- Synergy with astronomy/cosmology
- Future plans
  - Continue operation of IceCube well into 2020's
  - DM experiments proposed
  - $\nu$ experiments proposed



# Summary – Mostly Neutrino Underground

2025




| | | Proton decay | Long baseline ν | Supernova ν | Atmospheric ν | Reactor ν | Geoneutrino ν | Astrophysical ν | Solar ν | Non-proliferation ν |
|---|---|---|---|---|---|---|---|---|---|---|
| SNO+ | Canada | X | | X | | X | X | | X | |
| JUNO | China | | | X | | X | X | | | |
| CUPP | Finland | X | X | X | X | | X | | X | |
| INO | India | | | | X | | | | | |
| Kamland | Japan | | | X | | X | X | | | |
| Super-K/T2K | Japan | X | X | X | X | | | | X | |
| Hyper-K | Japan | X | X | X | X | | | | X | |
| RENO50 | Korea | | | X | | X | X | | | |
| Antarctica(various) | South Pole | | | X | X | | | X | | |
| LBNE(underground) | USA | X | X | X | X | | | | | |
| Soudan(MINOS+, etc) | USA | | X | | X | | | | | |
| WATCHMAN | USA | | | X | | | | | | X |

New, proposed

# Underground Capability Conclusions – Dark Matter

- All the next generation (G2) dark matter experiments can be accommodated by existing and planned underground facilities, assuming no reduction in these facilities.
- Most G2 experiments are at facilities outside the U.S. U.S. physicists are participating in most G2 experiments around the world, and are leading many of them.
- A G3 experiment is likely to be 5-10x the volume of the G2 experiment of similar technology and mass reach.
- G3 depth requirements are uncertain, technology dependent, require additional simulations and G2 results. Today it seems likely that all the major G2 facilities will have sufficient depth for a G3 experiment.
- The U.S. does not now have an underground hall large and deep enough to house a large G3 experiment.
- It is premature to develop plans for a facility dedicated to a large directional experiment.

# Underground Capability Conclusions – $0\nu\beta\beta$

- Several $0\nu\beta\beta$ experiments already under construction at existing underground facilities, all but one outside the US. US involvement currently strong in many of these.
- Next generation ("tonne-scale") experiments likely to be accommodated by existing and planned facilities, but may face competition for space from G2/G3-scale dark matter experiments.
- Depth requirements for "tonne-scale" experiments depends on technology choice and are not yet entirely known. New information may be available on 6-month to 2-year timescale.
- One next-generation experiment with large US involvement, with potential participation in others, is current U.S. planning.
- Uncertain if next-generation experiment could be hosted by existing U.S. facility.
- Path beyond "tonne-scale" experiments not well-defined but may require new underground spaces and perhaps facilities.

# Underground Capability Conclusions – Long Baseline $\nu$, Nucleon Decay and Atmospheric $\nu$

- There is an international effort proposed to search for CP violation in the lepton sector using a massive detector in a neutrino beam.
- Atmospheric neutrinos, observable in a large underground detectors, may be sensitive to all of the currently unknown oscillation parameters.
- Some of the same detectors could be used to advance the search for nucleon decay, the study of atmospheric neutrinos and other physics if the detector is located underground.
- This is the plan for Hyper-K and LBNO. It would be a lost opportunity if this condition cannot be satisfied with LBNE.

# Underground Capability Conclusions - Low-Energy Neutrinos in Large Detectors

- Opportunities for physics and astrophysics from supernova neutrino burst:
  - Many existing & planned detectors; SN capability typically comes "for free" if underground
  - Very difficult on the surface
  - Bursts are rare (only every ~30 years): critical to gather as much information as possible
  - Diverse flavor sensitivity is important; unique LBNE $\nu_e$ sensitivity will be lost if detector is not underground
- Future directions for solar neutrino physics will need a large underground detector
  - Observation of MSW transition region and searches for new physics
  - Measurement of CNO neutrinos and resolution to solar "metallicity problem"
- Other physics opportunities with low-energy neutrinos for underground detectors (diffuse supernova, geo, ...) depending on technology and siting.

# Underground Capability Conclusions – Reactor and Other $\nu$

- Detectors for reactor experiments at > 100m baseline require medium-depth underground laboratories (several hundred mwe overburden). Such detectors may have capabilities beyond reactor neutrino detection.
- Strong US involvement in recent reactor experiments overseas.
- Overseas efforts towards future reactor experiments at medium baseline (~50km). Funding commitments from host countries (RENO-50, JUNO). May have US involvement, but no US facilities.
- Potential synergy with large (kT-scale), water-based detectors being considered for non-proliferation detectors e.g. at the 1600 mwe Fairport mine near Cleveland (former IMB site)
- Use of cyclotrons, intense sources or small modular reactors might increase the number of potential facilities for neutrino oscillation experiments in the U.S. and worldwide.

# Underground Capability Conclusions – Infrastructure

- Underground facilities are needed for materials assay and storage, and in some cases, production (e.g. radiopure Cu)
- Surveys of experimental needs worldwide outstrip current assay capability – need more.
- Underground facilities are needed for small prototype testing and experiments and generic R&D. New technologies need to go underground to validate background performance.
- There is likely to be enough U.S. infrastructure space for the future if existing US underground labs are maintained. Substantial past agency investments and future leverage of state, university, private and other agency(e.g. non-proliferation) funds could make it cost effective to maintain these sites.
- However, improved coordination among the U.S. labs is needed to realize this potential.

# Underground Capability Conclusions - Access

- Substantial variation around the world in how experiments gain access to underground facilities
  - From mostly domestic, not fully open competition
  - To respond to proposals, PAC-like structure, similar to accelerator labs
- As the scale (and thus cost) of underground experiments grows, it will become more important to foster open, competitive access as much as possible.
- The best way for the governments to support the international system of underground experiments is for each major country (or region) to support at least one major underground laboratory capable of hosting the forefront experiments.
- It is not clear whether it would be possible to sustain this international support if one country chose to take a major role in the research without supporting any facility.

# Underground Capability - Summary

- Substantial expansion in non – U.S. underground capabilities by 2016-2020.
- Critical that U.S. scientists continue to be supported in the future to take full advantage of international and domestic underground facilities.

“…aspirations of the community…”

- Key underground facilities goals for upcoming U.S. planning
  - Put LBNE underground to realize it's full science potential. This could also make it an anchor of possible future domestic underground capabilities at SURF.
  - The U.S. has leading roles in many of the future dark matter, $0\nu\beta\beta$ and a large variety of $\nu$ experiments.
  - More coordination and planning of underground facilities(overseas and domestic) is required to maintain this leading role, including use of U.S. infrastructure.
  - Maintaining an underground facility that can be expanded to house the largest dark matter and $0\nu\beta\beta$ experiments would guarantee the ability of the US to continue its strong role in the worldwide program of underground physics.