Strategic Radiation-Hardened (SRH) Electronics Council (SRHEC) Public Summary from Analysis of Alternatives (AoA) for Domestic Single-Event Effects (SEE) Test Facilities

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SEE Test Perspective

- Existing heavy ion SEE test facilities can not meet current or future SEE test demand (~5000 hour/year gap)
- Department of Defense (DoD) nuclear modernization efforts as well as USG/commercial Space are driving significant increases in SEE testing demand
- Current heavy ion accelerators for SEE testing at U.S. universities and DOE labs have limited capacity and capability
- More complex electronics (processors, ASICs, FPGAs) require more test hours
- More advanced electronics and packaging (3D ICs, flip-chip packages, system-on-a-chip, or system-in-a-package) require higher ion energies >100MeV/n

SEE Testing AoA Background

- SRHEC Test & Evaluation Working Group (TEWG) commissioned an Analysis of Alternatives under guidance approved by DASD/NM & DD/RT&L to analyze *short-term and long-term solutions* to shortfalls in hours available for DoD SEE testing and their economic viability
  - SEE test capacity anticipated to be oversubscribed by 5000 to 6000 hours/year by 2025
  - Increasing future demand for higher-than-usual beam energy (>100 MeV/n) predicted as tests include larger and more complex components
- TEWG provided 9 key performance parameters (KPPs) for heavy ion testing covering near and long-term SEE testing. Primary KPP is beam energy:

	Threshold Near Term (0-5 yrs.)	Objective Long Term (>5<10 yrs.)
Low-Energy	5-25 MeV/n	25-100 MeV/n
Hi-Energy	25-100 MeV/n	>100 MeV/n

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SEE Test and DOE Science Missions

- Heavy-ion SEE test capacity is provided by TAMU (Texas A&M University) K500, LBNL (Lawrence Berkeley National Lab) 88 inch and NSRL (NASA Space Radiation Laboratory)
  - All facilities were built as part of DOE Science Programs
    - NSRL is a NASA-owned beamline on a DOE (Brookhaven National Lab) accelerator site
  - All continue to support a strong (DOE and NASA) Science mission today
- SEE Test utilizes the beam-time not used by Science research
  - Relationship has been mutually beneficial for nearly 50 years
  - SEE testing strengthens the financial model of each facility (generated revenue)
  - DOE will not reduce science hours to accommodate increased SEE test hours
- DOE strongly supports SEE testing as a critical service to nation
  - DOE Science will not reduce the baseline SEE test capacity in future
  - As SEE growth exceeds capacity, the need for alternate sources is critical

All hours presented here, capacity and demand, are for SEE testing only, Specified Science not included.

Demand for High Ion Energy Testing is Growing

Low Energy SEE Test

2020

- 90% of SEE test is Low Energy
  - 10-50 MeV/n (Mega-Electron Volts /n)

2030

- 60% of SEE test is Low Energy
  - Economical test for monolithic integrated circuits
  - Issues for flip-chip, stacked die, 2.5/3D packaging, and assemblies
- Access assured with low energy investments
- TAMU K500 & K150, LBNL, FRIB Lin Seg 1, and MSU K500 meet Low Energy demand

High Energy SEE Test

2020

- 10% of SEE test is High Energy
  - >100 MeV/n

2030

- 40% of SEE test is High Energy
  - New technology and CCA level testing will demand high energy
  - Economical for new technology
- Access assured by high energy investment
- 40% is ~4000 hours/yr
  - BNL AGS or MSU K1200 meets High Energy demand

AoA's Analytic Process

- AoA Team of analysts and experts visited 5 existing SEE test facilities to evaluate existing capacity and capability
- Data from these visits yielded more than 20 future options to increase capacity and capability at existing facilities.
- The AoA Team also modelled construction of a new greenfield facility on a DoD installation
- The AoA team established desired attributes & screening criteria to evaluate options
  - KPPs, capacity, capability, & commitment to DoD hours
- The team adopted 14 "Alternatives" for further analysis
  - 1 new-build SEE test facility at a military base
    - Utilized DoD approved methods for building cost estimate
    - Determined to be highest risk and highest cost option
  - 1 new-build SEE test facility on a university campus
  - 12 options to make infrastructure investments or increase OPTEMPO of existing SEE testing capabilities (near and long-term)
    - Alternatives included new cyclotrons, adding test stations, adding add'l shifts, refurbishing old cyclotrons, improving test infrastructure, etc.

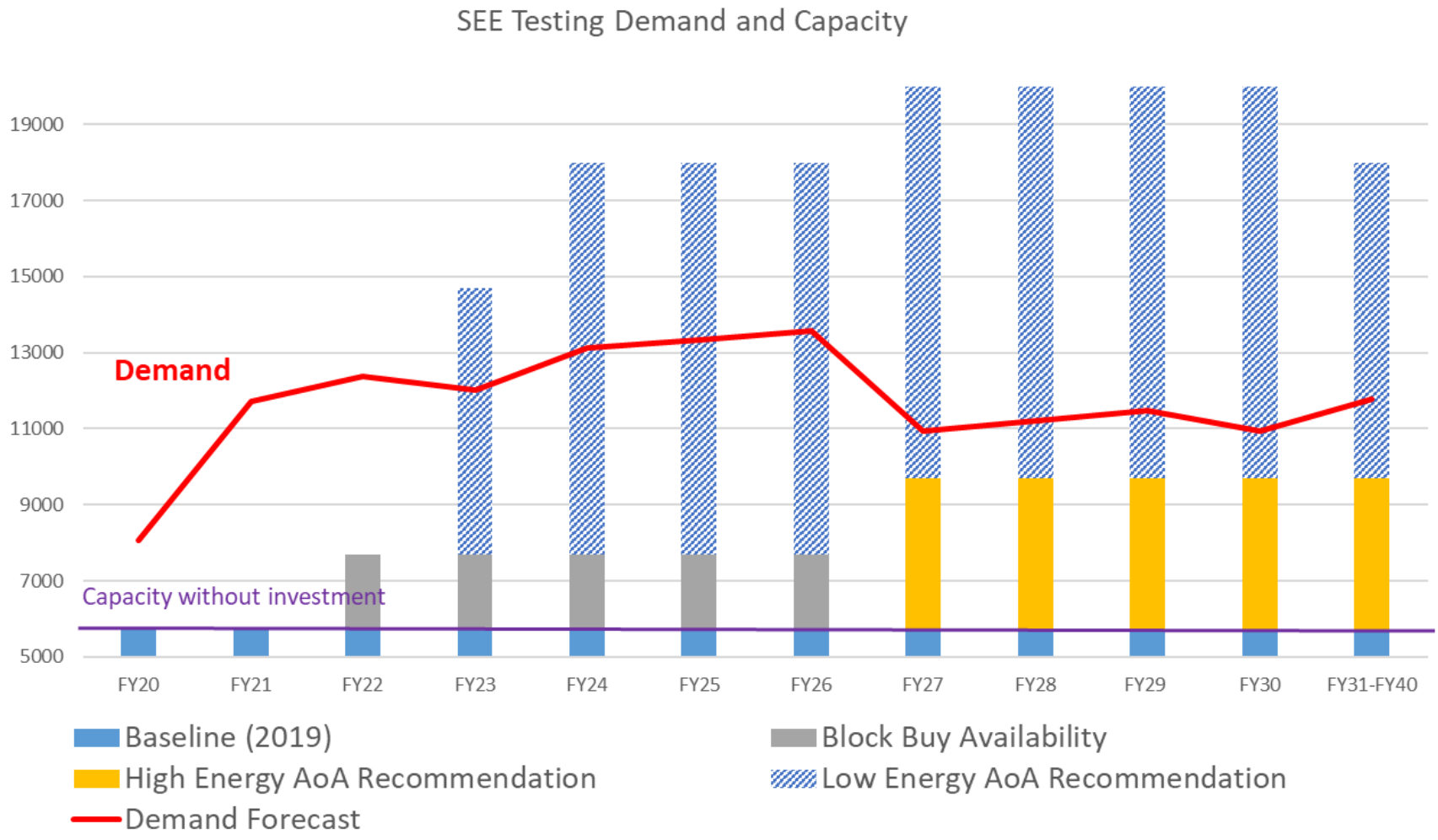
Current SEE Testing Conditions Determined by AoA Team

- DoD SEE test demand is not monitored or reported, is hard to predict, and is difficult to estimate. This needs attention from the acquisition community. *Both capacity and capability demand are increasing.*
  - *All current facilities are oversubscribed and rationing access*
- Modernization of several strategic programs will require significantly more SEE testing than previous upgrades. Current upgrades are more comprehensive and include more subsystems, thus more parts needs qualification.
- *Nationally,* demand for SEE testing appears to be growing significantly; with DoD modernization of strategic programs, increased space exploitation, and proliferation of satellites and terrestrial high-reliability applications.
- Radiation-effects testing is expertise is rare and testing details may not be fully appreciated by DoD leadership. SEE testing expertise is geographically and organizationally dispersed inside small specialized communities within DoD *and overall enjoys poor inter-community communication and synergistic collaboration*.
- While proton accelerators are commercially available, neither DoD nor commercial industry have built a heavy ion accelerator.
  - Indian heavy ion Facility (Kolkata) not fully functional after 11 years of initialization

Current SEE Testing Conditions Determined by AoA Team

- SEE test infrastructure within US is decreasing and degrading. MSU National Superconducting Cyclotron Laboratory is ceasing operations; Crocker Nuclear Lab has shifted priorities to medical therapy; Indiana U closed their cyclotron in 2014. Majority of facilites are near 50+ years of operation.
- Very strong interest by accelerator facilities to improve their SEE test capacity and capabilities. Many valuable and worthy alternatives were proposed to improve current conditions.
- Academic research does take precedence at university accelerators. This is a reality that limits how much capacity is available to DoD at current facilities.
- Commercial electronics companies are very interested in this AoA, and wish to be engaged with DoD and federal government as investments and decisions are made. Strong opportunity for collaboration with industry.
- Heavy-ion accelerator design/build expertise predominantly resides at DOE, universities, national laboratories, and a few international research facilities.

SEE Test Demand thru 2040



Demand forecast is based on FY20 projections of DoD Programs

Demand input from integrators, manufacturers, and suppliers would improve fidelity of demand forecast.

Immediate Actions Recommended by AoA

1. DoD should assess impact of COVID 19 schedule disruption for 2020 and 2021 test achievement
   - Significant bow-wave of unachieved test demand. SEE beam rationing in effect currently
   - In national interest to coordinate with DOE to see if Science beam-hours should be deferred to address SEE test bow-waved
2. DoD should enter into discussions with Michigan State University to express interest in (& evaluate funding for) sustainment of their 2 cyclotrons.
   a) There is competition with industry.
   b) MSU needs an official expression of interest by DoD so the Department does not lose future use of the two critical pieces of scarce infrastructure.
3. DoD should impose SEE demand accounting across the DoD user community to better manage growing demand against a shortage of resources; central demand management is critical to effective resource management.

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Immediate Actions Recommended by AoA

4. DoD should improve or formalize inter-agency collaboration with DOE and NASA for SEE test mgt. Since DOE controls or influences most of the existing facilities, cooperation and mutual understanding can only improve DoD access and usage.
5. DoD should install a holistic, enterprise-approach to radiation hardening (& include industry participation) and develop a Rad-Hard Roadmap to manage critical requirements and to:
   - Understand/leverage the impacts of growing commercial demand
   - Impose more efficient management of DoD demand and execution for Rad-Hard testing
   - Keep pace with technology and implications to radiation hardness of electronics
   - Explore synergies of shared industry usage of gov't facilities
   - Sustain senior DoD visibility of and funding for sustaining critical infrastructure for radiation-effects testing.

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SEE Testing AoA
Recommended Near-Term Investment

Investment	Alternative Description	**Beam Capability** Green is low-energy testing Blue is high-energy testing.	Additional Dedicated DoD SEE Hours Added	Investment (Constant FY20 $M)	Start Year of Additional Hours
Low Energy Capacity	**MSU Step 1: Add a dedicated SEE test beamline to FRIB LINAC Segment 1**	< 20 MeV/n	2021 – 2030: 2,000 Hrs >2031 - 300 Hrs	$3	2021
Low Energy Capacity	**Ready MSU K500 for Stand Alone Operations** ($4M adds Beam Line, Control Room and Test Stands)	1-50 MeV/n Heavy-Ions	'25 -3,000 Hrs 6,000 Hrs after 2025	$4	2025
Block Buy	**BNL Option A: Increase OPTEMPO at NSRL** (add a shift to yield more test hours)	> 100 MeV/n Heavy-Ions	1000	*$3.5 per year*	2022
Risk Reduc-tion	**TAMU Liquid Helium Investment** (New cooling system supports both K150 and K500, eliminates down-time which adds 500 hours) **[Stand alone TAMU K150 LHe now proposed]**	Applicable to both K150 & K500 devices	~~500~~	~~$4~~	~~2022~~

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SEE Testing AoA
Recommended Near-Term Investment

Investment	Alternative Description	Beam Capability Green is low-energy testing Blue is high-energy testing.	Additional Dedicated DoD SEE Hours Added	Investment (Constant FY20 $M)	Start Year of Additional Hours
High Energy Capacity	**BNL Option C: New Beam Line** (Dedicated beam line, control room and support facility inside AGS)	1- 100 MeV/n & > 100 MeV/n Heavy-Ions	4000	$59	2026
Low Energy Capacity	**Upgrade TAMU K150** (Upgrade to vacuum, ION source, New SEE beam-line development**)**	1- 50 MeV Protons; 15MeV/n HI	1500	$5	2023
Risk Reduc-tion	**LBNL Facility Maintenance Backlog & Repair** (Vacuum improvements, test hours will begin to diminish without investment)	Protons <60 MeV/n & Heavy-Ions 2-20 MeV/n	300	$2.5	2022
Block Buy	**LBNL Addition of a Shift** (Includes Alt 6 Mods plus $5M additional investments to vacuum, pumps, cooling to push machines to 6,000 hours)	Protons <60 MeV/n & Heavy-Ions 2-20 MeV/n	1000	*$5.0* *Plus $2.4 per yr.*	2022

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SEE Testing AoA
Recommended Long-Term Investment

When to fund	Invest-ment	Alternative Description	**Beam Capability** Green is low-energy testing Blue is high-energy testing.	Additional DoD SEE Hours Added	Investment (Constant FY20 $M)	Start Year of Additional Hours
2022 **Initiate study** of demand requirements	Long-Term	**Build 2nd New TAMU K500 Cyclotron** (adds Capacity/Test in Air)	1-60 MeV/n Heavy-Ions	5000	$100	2028
2022 **Initiate study** of DoD facility options	Long-Term	**Initiate New DoD Facility Options** with Multiple Accelerator Alternatives	15->100 MeV/n Heavy Ions	6000+	Range $225 - $641	2030
2022	Long Term	**Initiate Engineering Study and Preservation of MSU K1200** for potential refurbishment and DoD re-utilization	>150 MeV/n Heavy-Ions	6000	0.8	2026

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Findings/Recommendations of the AoA

Finding # 1: **Unpredictable funding creates unstable operations** at test facilities.

Recommendation: The NNSA, NASA, and DoD should find ways to stabilize funding for proton and heavy-ion accelerator facilities to restore resilience in national testing capabilities.

Finding #2: **Lack of DoD Roadmap** as the demand for US testing increases (federal & commercial), and potential capability/capacity shortages loom.

Recommendation: Create SEE Test Roadmap & OSD management office to manage demand, schedule investment and modernization, and structure a long-term method to stay ahead of the test demand.

Finding # 3: **Lack of sufficient Inter-Agency collaboration** between DOE, NASA and DoD to synchronize, de-conflict, and optimize SEE testing.

Recommendation: Establish a joint decision-making council to arbitrate and manage federal resource usage at accelerator facilities.

Finding # 4: **Lack of electronic components and common database.**

Recommendation: DoD and industry SEE test community should develop integrated parts data library to manage/share configuration and technical data.

Finding # 5: **Demand for testing often trumps maintenance activities** across the SEE test facilties.

Recommendation: DoD and/or DOE should impose a more robust maintenance philosophy on national laboratories and academic facilities that accept DoD funding or provide beam-hours for federal missions

Finding # 6: **Need to understand diverse SEE testing community** which has historically been geographically and organizationally diverse but isolated among services, laboratories, weapons test centers, acquisition commands & headquarters staffs, specific military occupations, and any number of smaller but interested parties; now to include US Space Force.

Recommendation: DoD needs to integrate its radiation-effects community of users, investigate the implications of the new Space Force and invite civilian commercial space industry actors in the national SEE test community.

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Findings/Recommendations of the AoA

Finding #7: **Lack of Adequate DoD SEE Test Coordination** for procuring and scheduling DoD SEE testing.
Recommendation: Create a central SEE Test office in OSD to coordinate DoD (and partner organizations') requirements. Current environment requires test managers to find own test source and time.

Finding #8: **Non-Beam test methods need development.** Several promising techniques for achieving parts characterization of SEE, such as physics based models and pulsed laser testing, do not require accelerated particles.

Recommendation: DoD should remain supportive of and potentially sponsor research into methods that can reduce demand on SEE test infrastructure.

Finding #9: **DoD needs to address COVID-19 impacts** on SEE test capacity and demand.
Recommendation: DoD should investigate the scheduling and capacity impacts caused by COVID shutdowns. DoD needs to implement a recovery program and investigate if DOE research programs can be temporarily deferred to allow critical SEE testing to catch up.

Unknown impacts to "Classified Testing" requirements. The need for and impacts of truly classified SEE testing is unknown. There are no written requirements or processes or standards on how to conduct SEE test of classified components, nor understanding of what that implies to facilities or testers.
Recommendation: DoD should act to investigate demand, define impacts to test community (industry, gov't programs, test facilities) and create workable processes and locations to accommodate.

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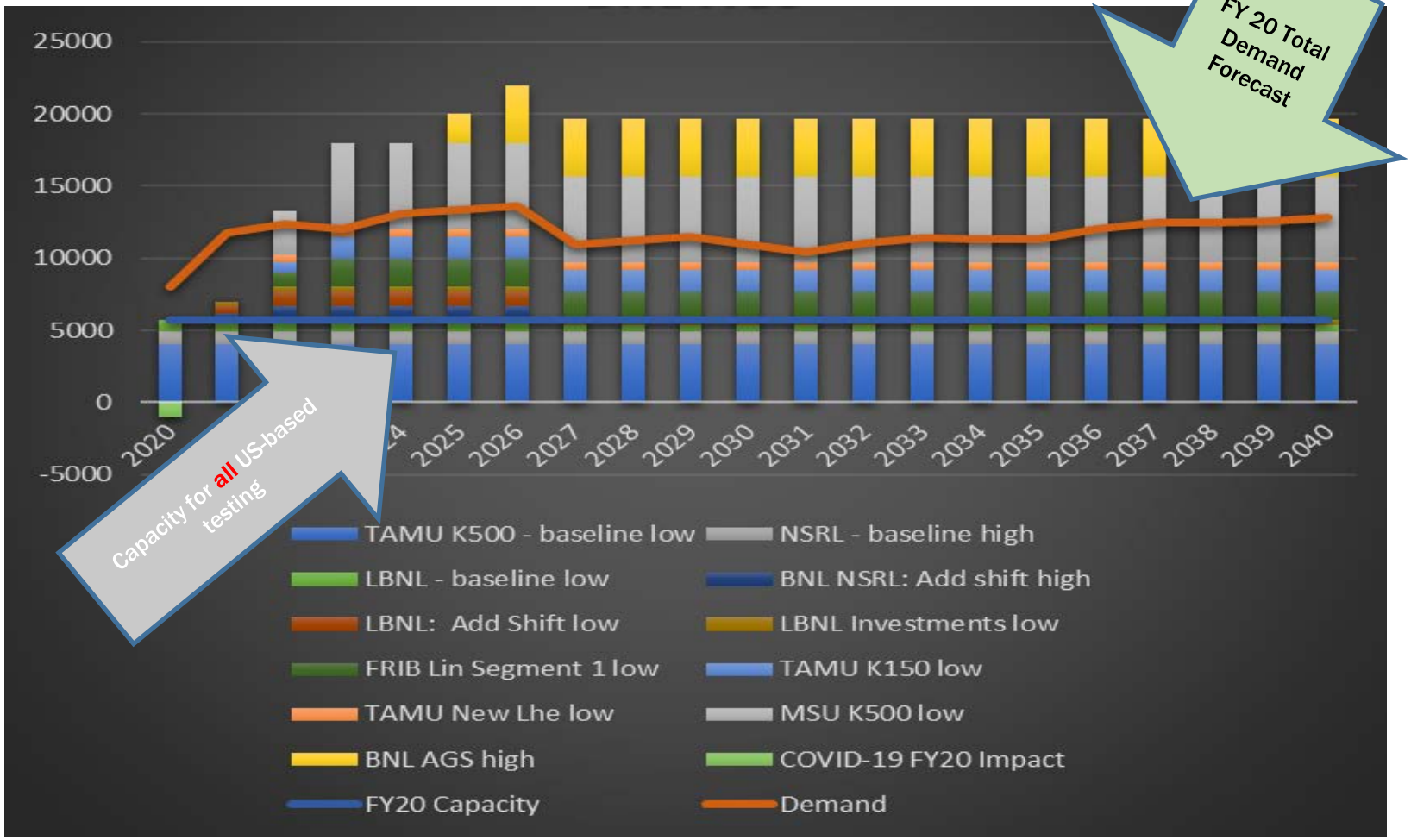
Capacity vs. Demand with AoA Recommended Investments



Feedback

The SRHEC Testing and Evaluation Working Group continues to seek input on SEE testing demand and capability needs, especially from manufacturers, integrators, suppliers, and the commercial space industry. To provide input or feedback please contact:

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