



Orchestrating the Future of Data-Intensive Science

2024 ESNET ANNUAL REPORT

ABOUT ESNET

The Energy Sciences Network (ESnet) is the U.S. Department of Energy's high-performance network and user facility, delivering highly reliable data transport capabilities and services optimized for the requirements of large-scale integrated scientific research. ESnet's vision is that scientific progress will be completely unconstrained by the physical location of instruments, people, computational resources, or data. By offering highly specialized, continuously evolving networking systems and innovative services, ESnet provides the foundation for an integrated research infrastructure that enables the nation's scientists to collaborate on some of the world's most important scientific challenges.

ESnet is stewarded by the DOE Office of Science's Advanced Scientific Computing Research (ASCR) program and managed and operated by the Scientific Networking Division at Lawrence Berkeley National Laboratory (Berkeley Lab).

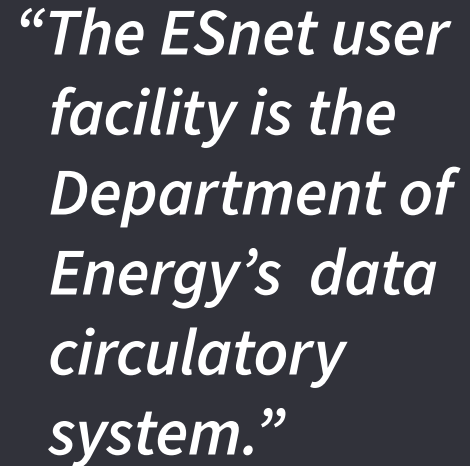




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THE LIFEBLOOD OF DISCOVERY



**We've used this phrase
for several years because
it perfectly describes
our mission.**

Like a human circulatory system, ESnet must operate continuously — without congestion or downtime — to keep the DOE research enterprise healthy. If we falter, the impact on U.S. scientific productivity and leadership would be significant. Yet, like the body's circulatory system, our work is often taken for granted.

This year, for our CY2024 annual report, I want to use that metaphor to explain how we balance operational excellence, innovation, and collaboration to serve the DOE mission, prepare for the future, and strengthen the global research ecosystem.

Operational Excellence: Maintain and deliver high-performance networking services that are reliable, cost-effective, and responsive — 24x7x365.

Keeping the circulatory system healthy is our foremost responsibility. ESnet cannot take days offline for network upgrades or repairs. We must operate every hour of every day while expanding capabilities, supporting new science use cases, and anticipating future demands.

In 2024, ESnet achieved 100% availability for all Office of Science sites. This reflects our proactive investment in the Site Resiliency Program and rigorous capacity planning to prevent congestion and meet the growing data needs of science. Our customer satisfaction score rose slightly, from 4.85 to 4.88 out of 5, a testament to our ability to serve DOE's "major organs" — the national labs and user facilities.

We strive for continuous improvement and to prioritize our efforts strategically through regular internal discussion and

careful allocation of resources. I want to be first to acknowledge that we must prioritize progress over perfection, because no matter how hard we try, we will always be limited by resources and unforeseen demands.

Serving the Mission: Create impactful, innovative solutions to “accelerate science” while serving the broader DOE mission (NNSA, DOEnet, and others).

As an Office of Science user facility, our first objective is to serve its mission, and we do so by “accelerating science.” This means holding regular requirement reviews so we can truly understand the long-term data needs of our science users. It means engaging in operational and technical innovation so we can enhance scientists' access to artificial intelligence and machine learning (AI/ML) tools, High Performance Computing (HPC), new instruments, enormous data sets, and expert collaborators. And it means building relationships through our human network so that users across scientific disciplines can learn from each other, better understand what the circulatory system has to offer, and leverage it to its full potential. That is why ESnet staff are invited to speak at so many conferences and why we host our flagship user meeting, Confab.

Executing Federal Program Priorities: Execute on DOE Office of Science priorities — including ASCR's priorities for HPC, the Integrated Research Infrastructure (IRI) program, the High Performance Data Facility (HPDF) project, AI, quantum, and cloud — through strategic planning and co-design engagements.

A man with a beard and glasses, wearing a red turban and a dark suit with a red patterned tie, is shown in profile from the waist up. He is holding a small black device in his right hand and gesturing with his left hand. The background is dark and out of focus.

“Every ESnet generation — now at six and counting — has transformed the facility to meet future demands... No vendor delivers turnkey solutions for ESnet. Our engineers design, build, and integrate the network themselves, balancing diverse requirements and best-of-breed technologies.”

Inder Monga giving a plenary speech, “Networking Alchemy: Transforming Science Through Connectivity,” at OFC24 in March 2024. (Photo Credit: Optica)

To meet the evolving needs of the “organs” we serve, we employ two primary strategies. The first is co-design: Embedding ourselves within science programs to develop custom solutions for first-of-its-kind research. This deep engagement ensures we grow alongside our partners, whether through new services, expanded capabilities, or increased impact. Examples include EJFAT, Greenfield Wireless, the LHC Data Challenge, GRETA/DELERIA, and SENSE/Rucio integration — all described in these pages.

The second is through our project contributions. We collaborate closely with ASCR program managers to advance initiatives such as IRI, the High Performance Data Facility (HPDF) project, AI operations, quantum networking, and enterprise cloud access.

Upgrading for the Future: Expand and evolve the facility to support the next generation of science.

Every ESnet generation — now at six and counting — has transformed the facility to meet future demands. We must continually refresh infrastructure to address equipment obsolescence, rising data volumes, and new scientific workflows such as AI-driven analysis and real-time streaming. Unlike HPC facilities, no vendor delivers turnkey solutions for ESnet. Our engineers design, build, and integrate the network themselves, balancing diverse requirements and best-of-breed technologies. This drives our pathfinder projects, vendor collaborations, and global community engagement.

In CY2024, we advanced planning for ESnet7, presenting our 10-year vision to ASCAC and aligning with major ASCR initiatives. This work continues into CY2025.

Strengthening the Global Research & Education Ecosystem: Collaborate internationally to ensure science data flows seamlessly worldwide.

A circulatory system is only as effective as its most clogged arteries. Similarly, ESnet’s performance depends on the health of our sites’ IT infrastructure, university networks, regional and national backbones, and international partners. The Vera Rubin Observatory project illustrates this interdependence. Capturing and transmitting images from a mountaintop in Chile to SLAC in California within 7 seconds requires flawless coordination among DOE, NSF, regional networks in South America and the U.S., and many other entities. This is just one example of the global partnerships that make modern science possible.

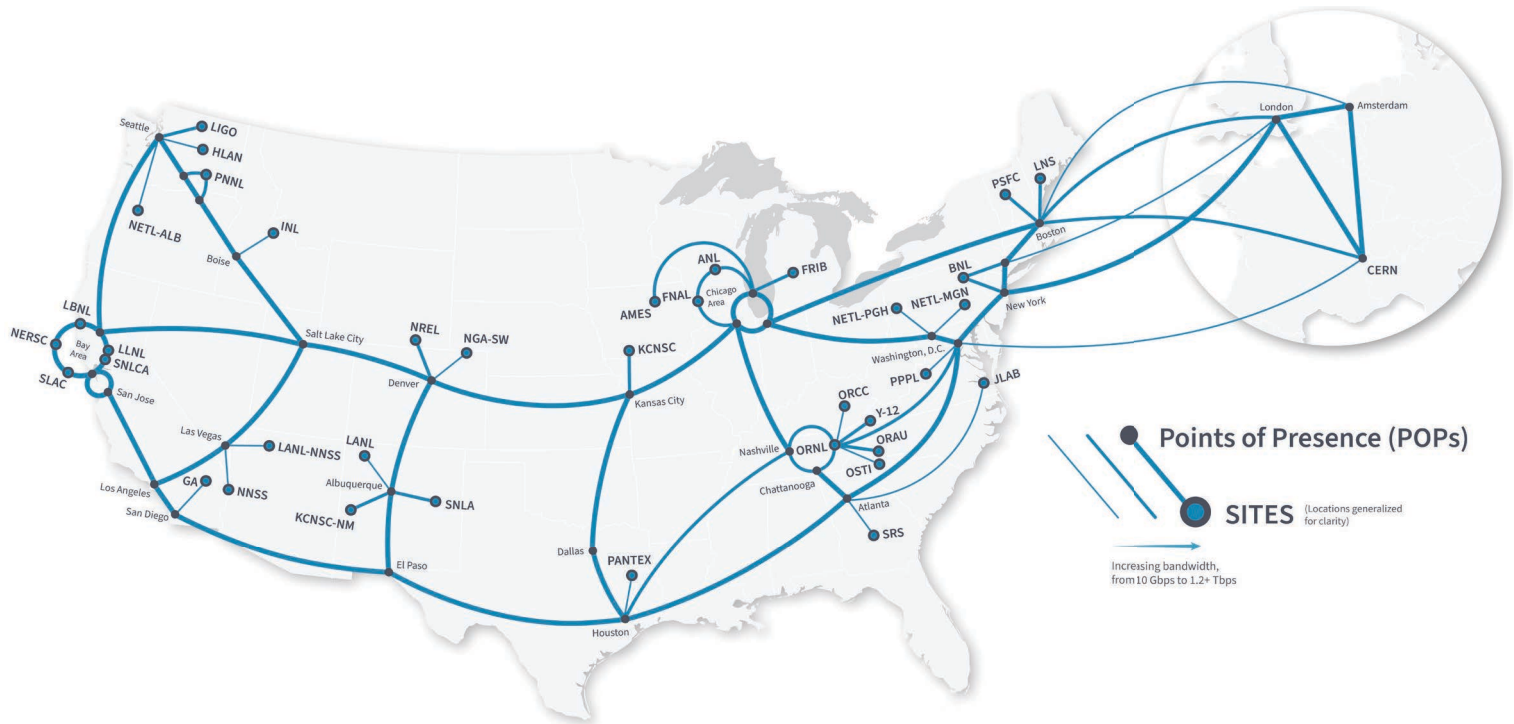
ESnet also contributes to the broader ecosystem by sharing best practices, releasing open-source tools such as perfSONAR and iperf3, and engaging with the global networking community to ensure that science everywhere can flourish.

In this note, I have tried to provide a lens through which to view the priorities driving our resource allocation, what we invest in as a user facility, and how we grow to meet the challenges of tomorrow. I hope you enjoy reading about our work in CY2024 as much as I have enjoyed leading this extraordinary team.

Sincerely,

Inder Monga
Executive Director, ESnet

ESNET BY THE NUMBERS



High Performance

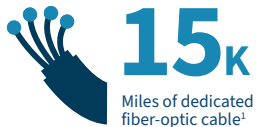
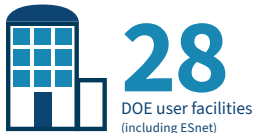
400 to 1.2 Tbps
Network backbone

57 Tbps
Aggregate capacity

2.7 Tbps
Trans-Atlantic capacity

1.8^{EB}
Transited in ESnet in CY2024

The Fiber-Optic Network



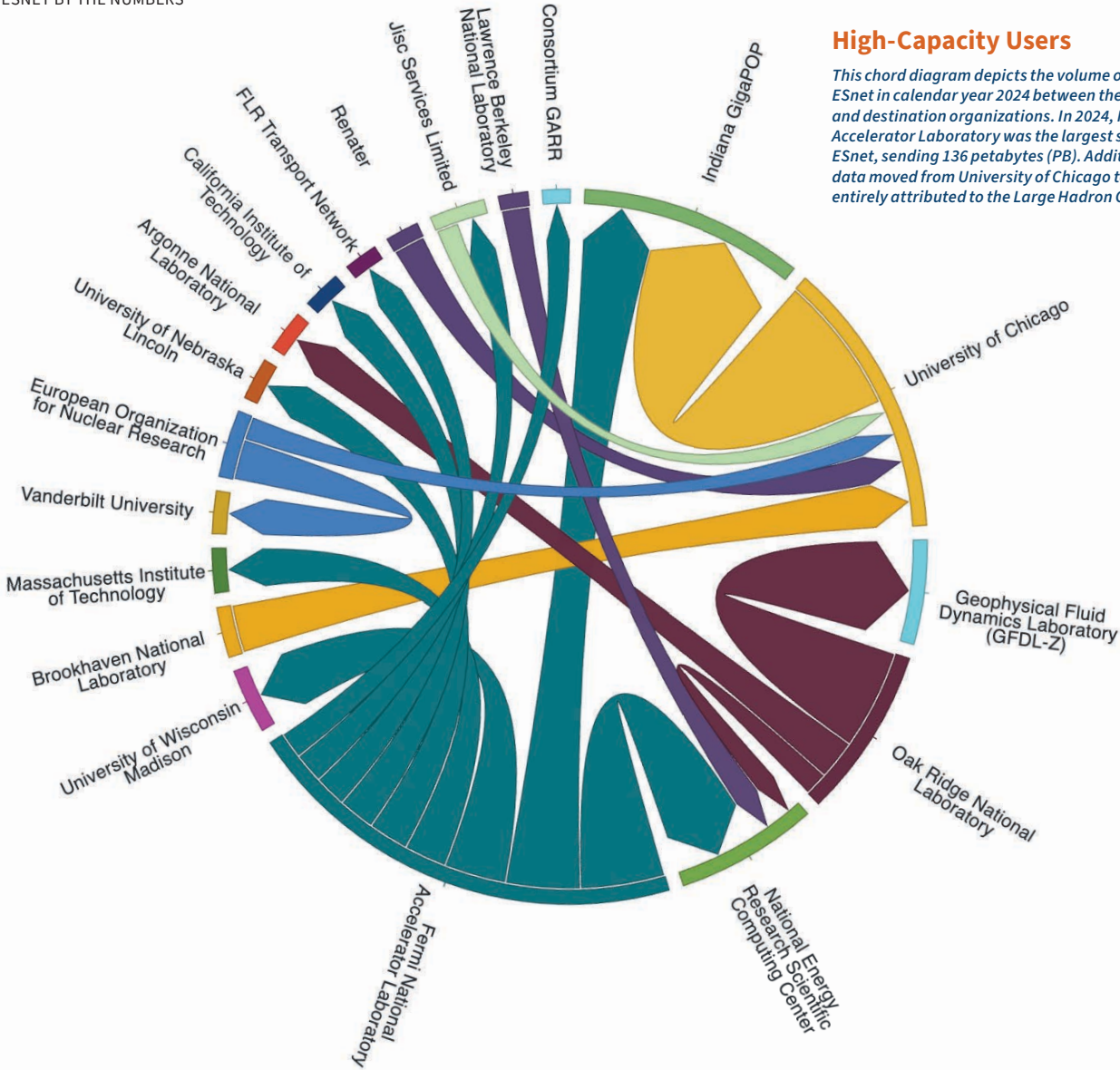
Reliable



The Human Network

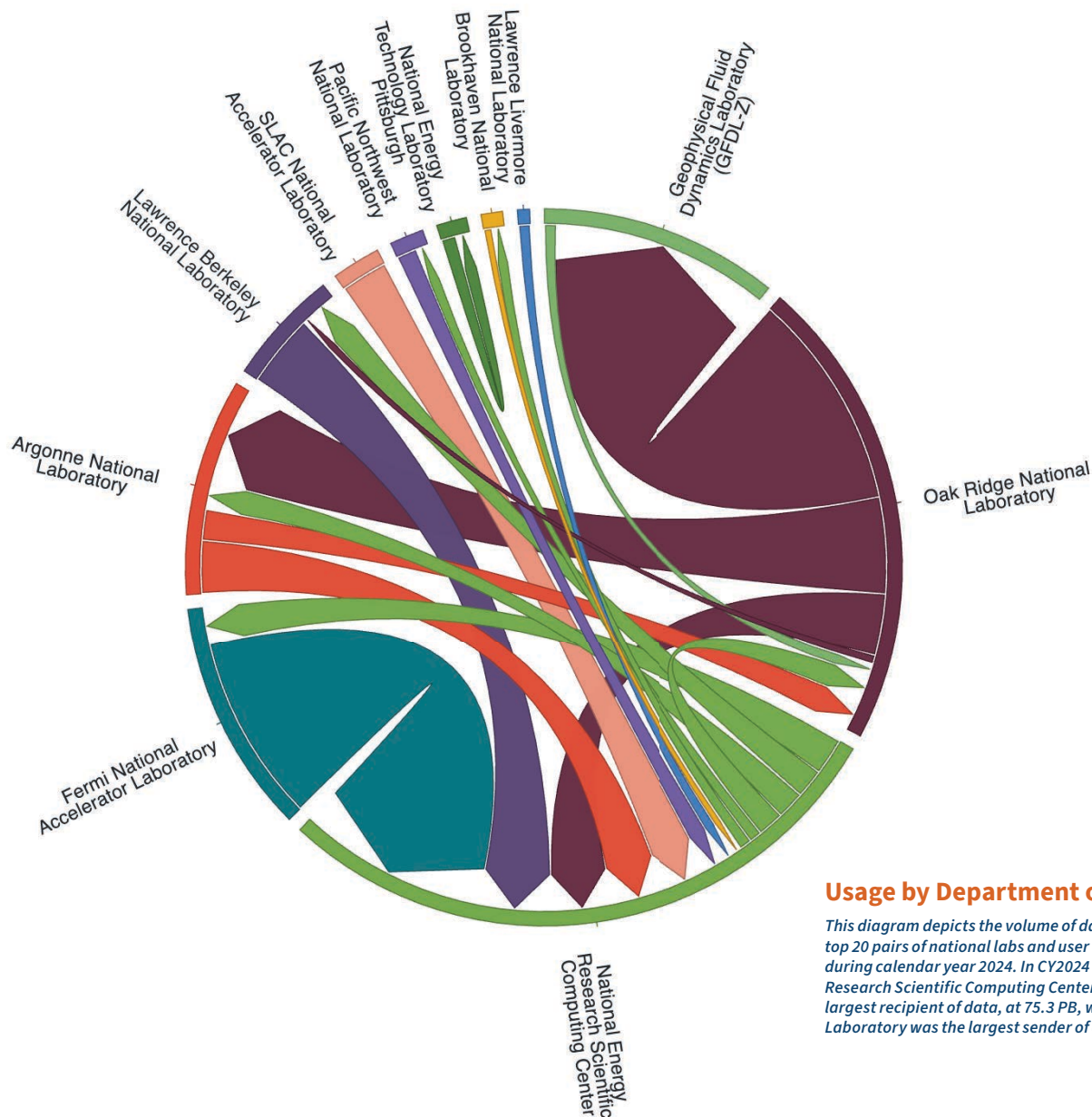


¹ In the U.S.
² ESnet is measured and expected to provide 99.9% site uptime. The network regularly exceeds that standard, providing near 100% uptime to almost all connected sites.
³ 2024 ESnet Site Coordinators Committee survey



High-Capacity Users

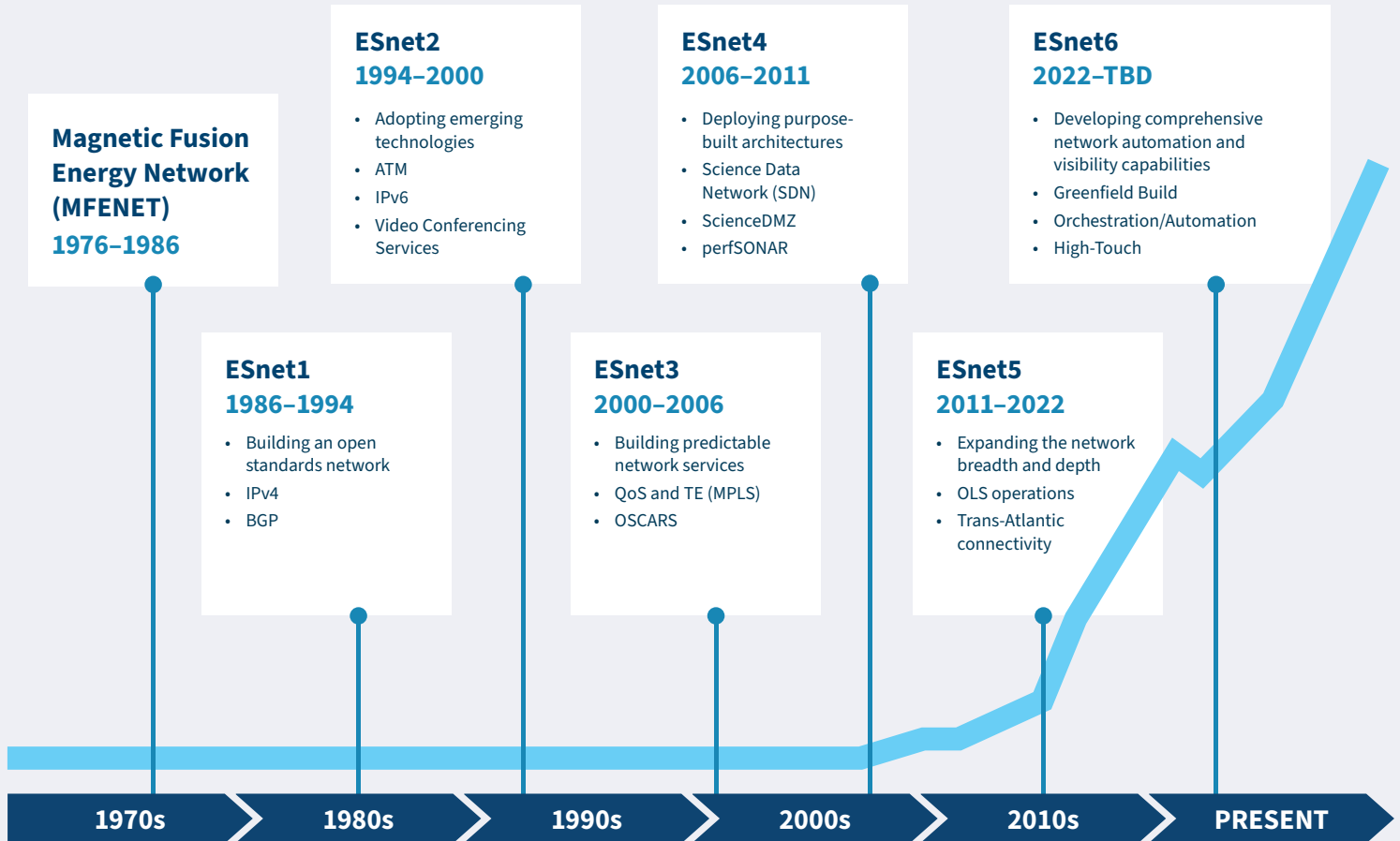
This chord diagram depicts the volume of data moved across ESnet in calendar year 2024 between the top 40 pairs of source and destination organizations. In 2024, Fermi National Accelerator Laboratory was the largest sender of data over ESnet, sending 136 petabytes (PB). Additionally, the 37.5 PB of data moved from University of Chicago to Indiana GigaPOP was entirely attributed to the Large Hadron Collider projects.



Usage by Department of Energy Sites

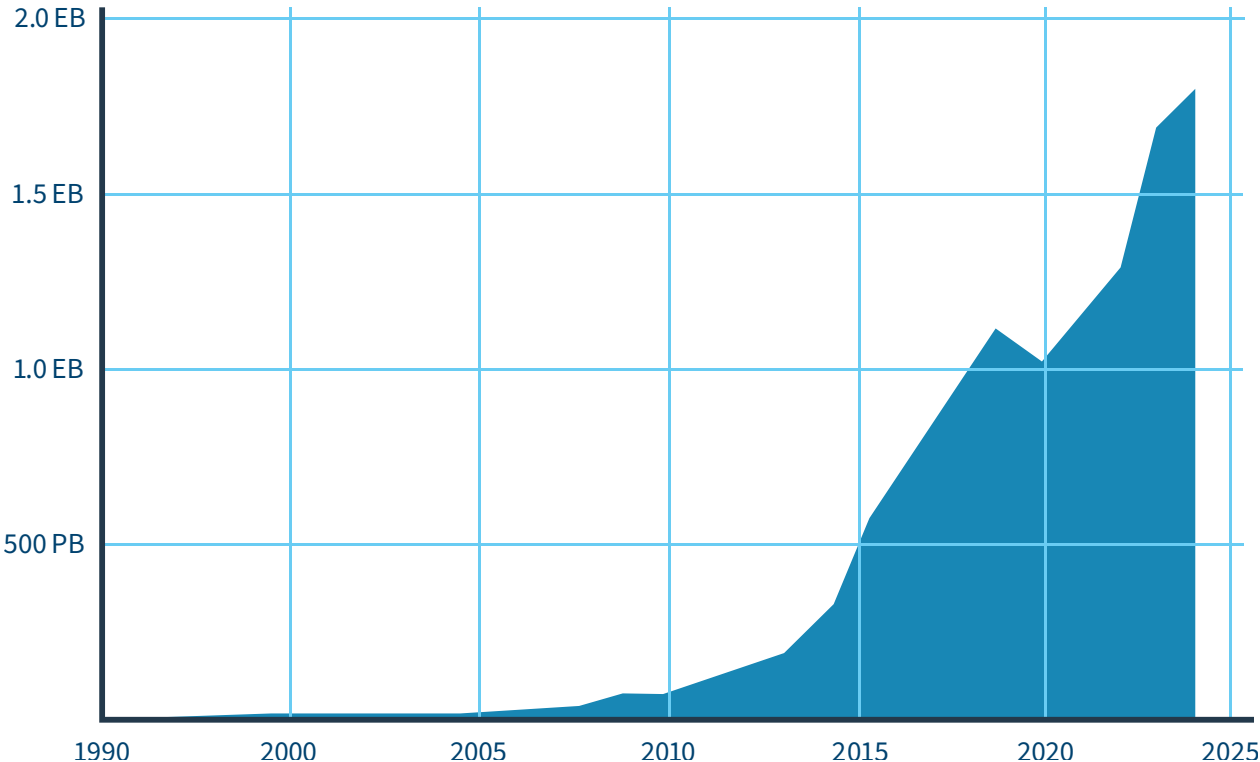
This diagram depicts the volume of data moved between the top 20 pairs of national labs and user facilities across ESnet during calendar year 2024. In CY2024 National Energy Research Scientific Computing Center (NERSC) was the largest recipient of data, at 75.3 PB, while Oak Ridge National Laboratory was the largest sender of data, at 58.3 PB.

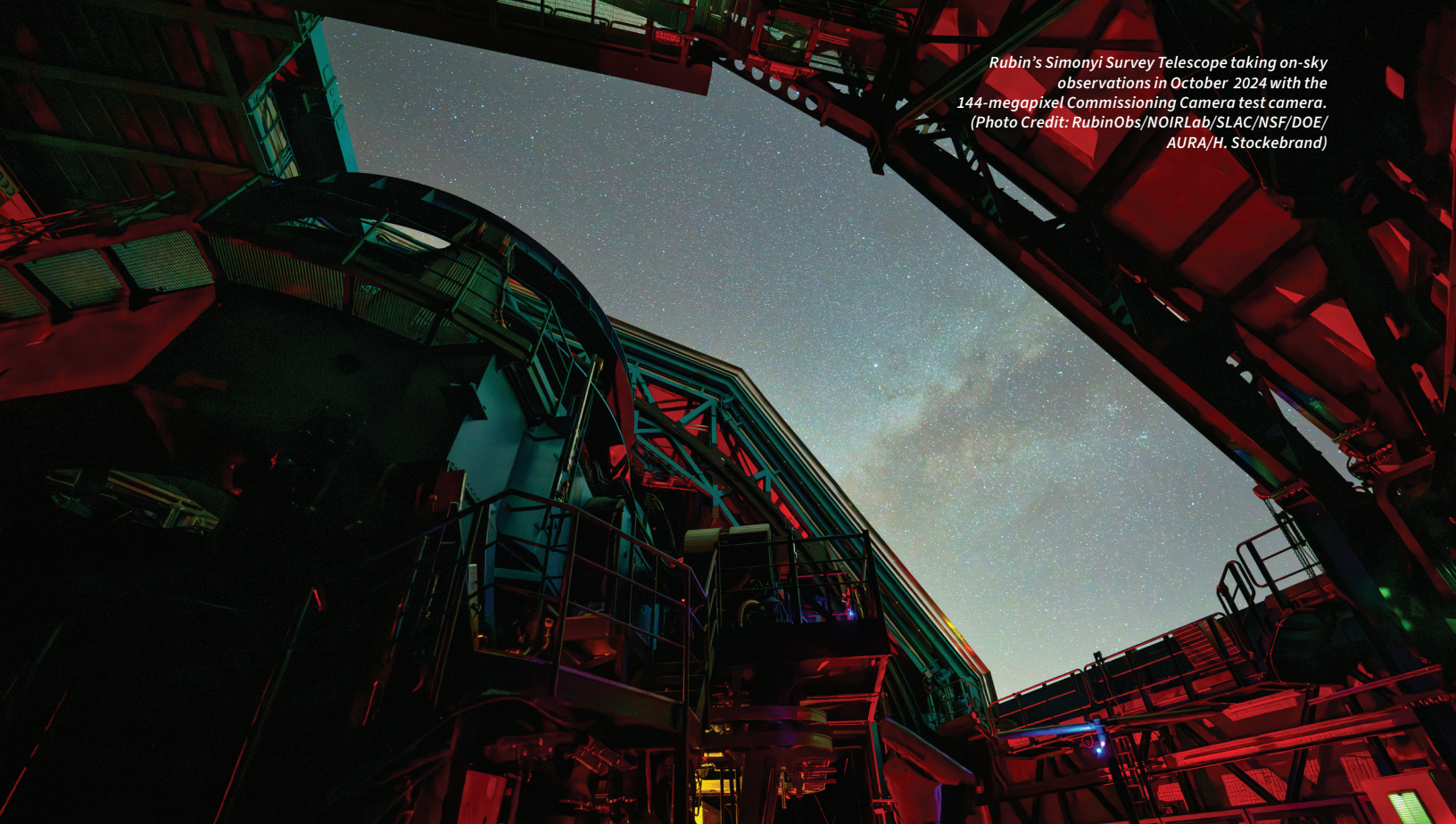
Evolution of ESnet



ESnet Traffic: Historic Usage

ESnet’s network traffic has grown exponentially in the past two decades. In 2024, ESnet carried 1.77 exabytes of data to and from the sites it connects, compared with 1.7 EB in CY2023. (This 4% increase is unusually low, but 2025 data indicate the rapid growth has resumed.) An exabyte is a nearly incomprehensible amount of data, equal to 1,000 petabytes or 1 billion gigabytes. This torrent of data is spurring ESnet to innovate in multiple areas to continue to deliver on its mission — and enable DOE scientists to move, store, and analyze that data using the fastest computing and AI resources available.





Rubin's Simonyi Survey Telescope taking on-sky observations in October 2024 with the 144-megapixel Commissioning Camera test camera. (Photo Credit: RubinObs/NOIRLab/SLAC/NSF/DOE/AURA/H. Stockebrand)

2024 HIGHLIGHTS

ESnet's goal is to create the best possible network environment for data-intensive, distributed scientific research projects across the DOE ecosystem. Achieving that goal requires strong co-design partnerships with various stakeholders as well as across the research & education networking community. The following projects illustrate ESnet's efforts to create an environment in which scientific discovery is completely unconstrained by geography — and scientists can remain unburdened by the sophisticated network infrastructure underlying their work.

Helping to Power the Universe's Fastest Sky Survey

In 2024, the Vera C. Rubin Observatory was nearing completion in Cerro Pachón, Chile, and preparing to transform astronomy with the Legacy Survey of Space and Time (LSST), a decade-long, ultra-high-definition time-lapse of the southern sky. Using the largest camera ever built (3,200 megapixels), Rubin will capture a 13 GB image every 30 seconds, each of which must reach the U.S. Data Facility at SLAC National Accelerator Laboratory within 7 seconds for rapid analysis and alerts to telescopes worldwide.

This is an enormous global networking challenge, and ESnet is proud to be a core partner in the Rubin Observatory Long-Haul Network — a 12,000-mile, high-reliability data path spanning Chile to California. The participating networks include REUNA, the NREN of Chile; the NSF-funded Americas-Africa Lightpaths Express and Protect (AmLight-Exp); RNP, the NREN of Brazil; rednesp, the NREN for the State of Sao Paulo; RedCLARA, the regional R&E network for Latin America; Florida LambdaRail, the regional network of Florida; Internet2; and ESnet.

The Long-Haul Network guarantees 40 Gbps end-to-end service with redundant, diverse routes into ESnet's backbone, ensuring high availability. ESnet also connects SLAC to Google Cloud for the Rubin Science Platform and to European data centers for additional processing.

From October to December 2024, Rubin engineers conducted on-sky tests with the 144-megapixel Commissioning Camera

(ComCam). ESnet and partner networks successfully transported the data in real time, confirming that the Long-Haul Network's performance, software stack, and security systems were ready for the real thing. ESnet's High-Touch telemetry project (page 27) provided deep visibility into traffic flows, yielding valuable insights into the network performance.

With the Long-Haul Network standing by, Rubin is ready to begin full-scale operations in 2025 — and ESnet will be there every night, ensuring cosmology's most ambitious survey can capture the sky at the speed of discovery.

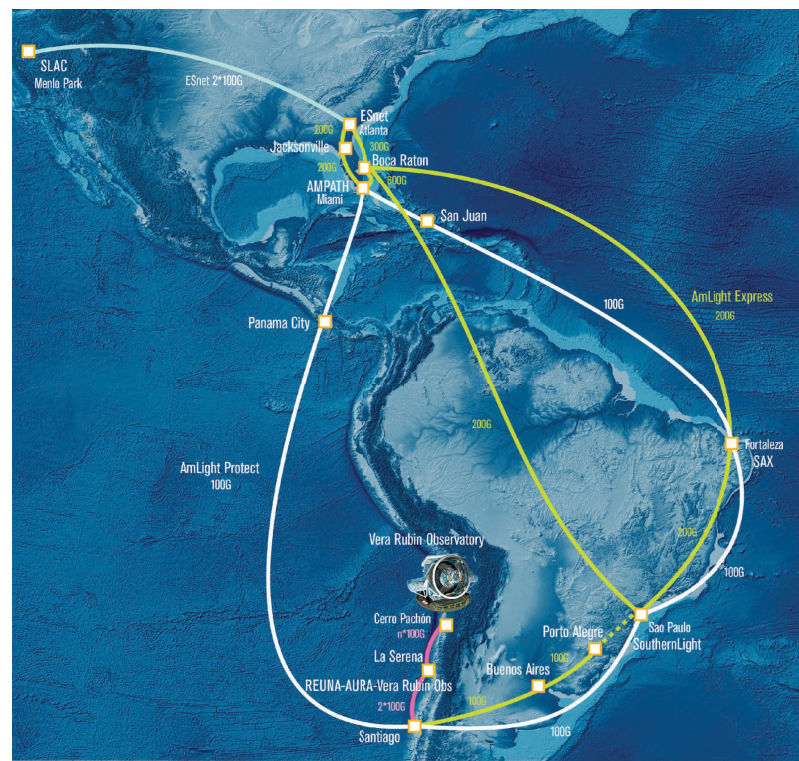


Image right: High-level topology showing the Vera Rubin Long-Haul Network. (Image Credit: Rubin Network Engineering Team)

Greenfield Wireless Prototype Connects Field Researchers to High-Speed Networks

Many emerging DOE science programs — from geothermal energy research to power-grid testbeds — take place in remote “greenfield” locations where traditional fiber connectivity is unavailable or impractical. These sites often rely on mobile sensors, drones, and IoT devices, but lack the robust data links needed to support real-time analysis and access to computing resources.

To bridge this gap, ESnet launched the Greenfield Wireless Edge Site Characterization project, in partnership with staff from Berkeley Lab’s Earth and Environmental Sciences Area. The portable, self-powered wireless tower they developed integrates multiple communication technologies to evaluate and deliver reliable connectivity from the field. Standing 13 feet and weighing about 200 pounds, the modular system supports private cellular (4G CBRS), Wi-Fi HaLow, standard Wi-Fi, satellite broadband, and directional radio links, operating continuously via solar power.

In 2024, ESnet’s Greenfield Wireless team deployed the Wireless Test Tower at Berkeley Lab for initial trials, achieving private cellular transmission up to 3.5 miles. They then conducted field tests at AmeriFlux soil-emissions sites in California and geothermal research sites in Utah and Nevada — and confirmed the system’s ability to identify optimal wireless solutions for each environment.

By lowering data retrieval costs, enabling real-time processing of large datasets, and integrating with ESnet’s fiber backbone or partner networks, the Greenfield Wireless prototype opens new possibilities for remote science. The team’s ultimate goal is to document and openly share this blueprint, enabling other research institutions and national labs to replicate and deploy similar systems, with ESnet providing support and expertise.



Left to right: Andrew Wiedlea (ESnet), Stijn Wielandt (Earth and Environmental Sciences Area), Howard Yao (EESA), and James Kafader (ESnet) with the Greenfield Wireless Edge prototype at Berkeley Lab in November 2024.

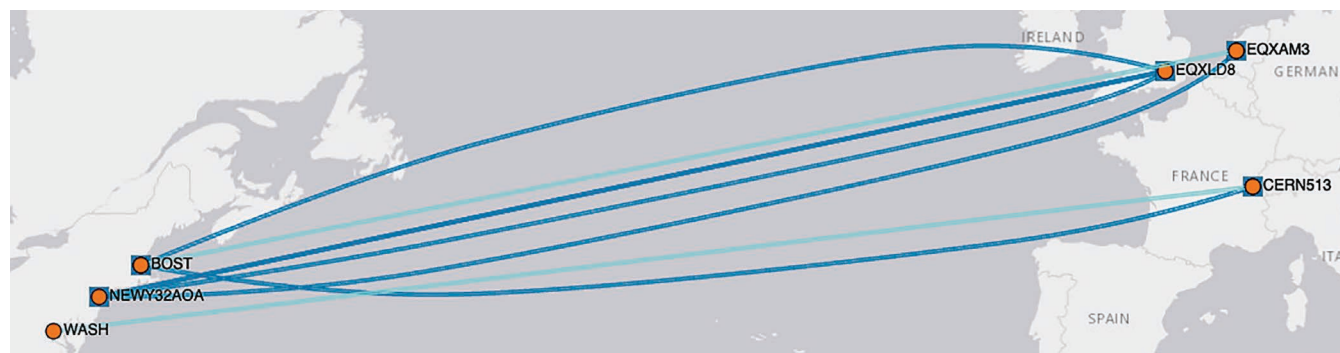
ESnet Signs First Trans-Atlantic Subsea Spectrum Lease

International connectivity is vital to ESnet’s mission, especially for data-intensive projects like the Large Hadron Collider (LHC), which generate roughly half of ESnet’s total traffic. Trans-oceanic links are particularly vulnerable to long outages — repairs can take weeks or months due to the limited number of submarine cable repair ships — making resilience a top priority. Because of this, ESnet is engineering our trans-Atlantic connectivity to support resilience for this mission-critical traffic even in scenarios where three cables have been severed at the same time.

ESnet’s trans-Atlantic plan includes a target of at least 3.2 Tbps of capacity across at least four completely physically diverse paths, using cutting-edge optical-spectrum services that will allow for long-term, cost-effective growth exceeding 10 Tbps in total.

In early 2024, ESnet signed our first trans-Atlantic spectrum lease — 25% of a fiber pair linking New York, Dublin, and London — through a 15-year agreement with Aqua Comms, with options to extend. To be good stewards of DOE funds, ESnet is collaborating with the European research network GÉANT to increase redundancy by splitting capacity and related costs for optical spectrum across four separate trans-oceanic cables.

In 2024, ESnet nearly quadrupled total trans-Atlantic bandwidth, from 700 Gbps to 2.7 Tbps, including lighting up 1.2 Tbps on the newly acquired spectrum. Another 25% of a trans-Atlantic fiber pair is in the process of being acquired, further strengthening resilience for mission-critical international science collaborations.



ESnet’s trans-Atlantic connectivity as of early 2025, with a total capacity of 2.7 Tbps across all circuits. (Darker blue indicates higher-bandwidth circuits.)

EJFAT Achieves Real-Time, Terabit-Scale Data Streaming

In April 2024, scientists at Thomas Jefferson National Accelerator Facility (Jefferson Lab) and ESnet achieved a major breakthrough for the transmission and processing of scientific data: they streamed raw physics data at 100 gigabits per second from Virginia to California, where it was processed on the Perlmutter supercomputer at NERSC and the results returned in real time — with no buffering, storage delays, or data loss.



Jefferson National Accelerator Facility Staff Scientist Vardan Gyurjyan and ESnet researcher Yatish Kumar gave an EJFAT demo at the SC24 DOE booth.

The test used the ESnet-JLab FPGA Accelerated Transport (EJFAT) prototype, a hardware-accelerated load balancer designed to connect high-speed scientific instruments directly to remote DOE high-performance computing (HPC) facilities. EJFAT uses Field Programmable Gate Arrays (FPGAs) to shape and route data within nanoseconds, dynamically balancing workloads across thousands of compute cores.

In this demonstration, 40 Perlmutter nodes (over 10,000 cores) continuously processed replayed data from Jefferson Lab's CLAS12 detector, sending results back every 400 microseconds — reducing turnaround from the 14 hours typical of traditional file-based workflows to near-instant feedback. Later tests replicated the 100 Gbps throughput and achieved simultaneous streaming across ~20,000 cores at NERSC, Oak Ridge Leadership Computing Facility, and the FABRIC testbed, in anticipation of projected demands of next-generation experiments like the Electron-Ion Collider.

EJFAT's success marks the first production-level demonstration of fully remote, distributed data stream processing for real physics data across multiple DOE facilities — a critical step toward the Integrated Research Infrastructure (IRI) vision of seamlessly linking instruments, compute, and storage across the DOE complex. With its scalable, stateless design, EJFAT is quickly being adapted to other time-sensitive facilities — from light sources to fusion devices — enabling scientists to steer experiments in real time and accelerating discovery across disciplines.

ESnet Delivers 100% Availability to All DOE Office of Science Sites

In 2024, ESnet achieved a major milestone: 100% service availability for all 10 of our DOE Office of Science sites: Ames, Argonne, Brookhaven, Berkeley, Oak Ridge, and Pacific Northwest national laboratories; Fermi, SLAC, and Thomas Jefferson national accelerator laboratories; and the Princeton Plasma Physics Laboratory.

This marks the first time every site met this standard, surpassing ESnet's already rigorous 99.9% uptime requirement. This achievement, which excludes planned maintenance, was made possible by the success of ESnet's Site Resilience Program.

Availability — the uninterrupted ability of researchers to connect to the network, 24 hours a day, 7 days a week — is critical to the success of DOE scientific collaborations. Launched in 2021, the SRP assesses each site's network resilience needs to ensure it can meet or exceed its mission requirements, and seeks to eliminate single and dual points of failure for all ESnet sites' connections to the ESnet backbone.

In 2024, ESnet continued to expand our SRP efforts, focusing on strengthening the network resilience culture amongst our users; improving our systems for tracking, measuring, and communicating about resilience; and establishing a solid baseline against which to measure future progress.

As DOE science becomes more distributed, collaborative, and reliant on cloud resources, the need for always-on, high-performance connectivity has never been greater. The 100% availability milestone shows that ESnet can exceed these already high expectations — and sets a new benchmark for operational excellence moving forward.

Advancing the DOE's IRI Vision

ESnet has been a key driver of the DOE's Integrated Research Infrastructure (IRI) program since its inception, helping to realize its vision of seamlessly linking world-class research tools, facilities, and data resources to accelerate discovery. In 2024, ESnet staff played a central role on the IRI Leadership Team, co-chaired two of the three technical subcommittees, and contributed to important co-design, software development, and testbed initiatives.

- The Outreach and Engagement Technical Subcommittee, co-chaired by ESnet's Science Engagement Team, worked to connect IRI pathfinder science teams, identify common workflow requirements, and foster adoption of shared technologies. Highlights included leading the launch of the IRI website (iri.science) and coordinating a strong IRI presence at SC24, with DOE booth demos, panels, and Birds-of-a-Feather sessions.
- The Interfaces Technical Subcommittee, also co-chaired by an ESnet staff member, advanced a standard facility-status API to support cross-facility workflows. In 2024, the group delivered a standardized information model, began defining API mechanics, and hosted a well-attended SC24 session on novel HPC interfaces.
- ESnet Security staff also contributed to the TRUSTID Subcommittee, exploring federated authentication, unified login approaches, and streamlined access for DOE researchers across multiple facilities.

In parallel, ESnet supported IRI-related research efforts through projects including GRETA, DELERIA, EJFAT, SENSE, and the IRI testbed. These efforts have continued into 2025, with ESnet maintaining a leadership role in shaping IRI's technical direction and enabling DOE's next-generation, cross-facility science.

OPERATIONAL INNOVATIONS

ESnet's network is operated as a high-availability network 24 hours per day, 365 days per year, and significant resources are devoted to ensuring its continuous and secure availability. Our staff continues to work on enhancing the technical systems that benefit both our internal team and external production services, to ensure our performance and reliability continue to stay ahead of demand.

In 2024, ESnet's operational achievements included (but were not limited to) nearly quadrupling our total trans-Atlantic bandwidth (see page 15); improving our tools for gathering, analyzing, and studying network performance data; and further automating the setup of devices on the production network. The increase in network capacity was planned to handle growth in network traffic easily, and we continue to plan for anticipated larger increases in the coming years due to adoption of AI tools.

An ESnet Data and Facilities team member replaces an EJFAT load balancer.



Strengthening Site and Data Center Resiliency

While ESnet is required to deliver “three 9s” — 99.9% availability — we routinely exceed that standard. In fact, in 2024 ESnet hit a 100% Availability milestone (see previous page), which was driven in large part by the Site Resiliency Program (SRP). The program’s importance only continues to grow as DOE science becomes more distributed, collaborative, and reliant on cloud-based resources.

The SRP seeks to align each site’s network resilience to its mission needs, supporting highly available, high-performance connectivity. In 2024, three sites improved their resiliency scores, and progress continued on major multi-year upgrades, including the complex Oak Ridge area connectivity project. Many efforts will carry forward into 2025.

Beyond site connectivity, ESnet advanced operational resiliency through our High Availability Location (HAL) initiative. For over a decade, ESnet has maintained redundant data centers at Berkeley Lab in California and Brookhaven National Laboratory in New York. However, the cross-country separation incurred latency and required manual intervention during some outages.

The HAL project addresses this by adding a San Jose facility that enables automated, real-time synchronization with Berkeley and dramatically reduces recovery times. In 2024, ESnet deployed secure overlay networks between the two sites and created a “stretched” VMware cluster, allowing services to migrate seamlessly between data centers with minimal downtime.

In 2025, ESnet will begin transitioning production services into this environment, improving availability, reducing operational complexity, and strengthening the resilience of critical systems that support DOE’s science mission.

perfSONAR Expands Global Reach and Capabilities

perfSONAR — the performance Service-Oriented Network monitoring ARchitecture — is a global platform for measuring and monitoring end-to-end network performance. ESnet is a core partner in the perfSONAR collaboration, with Internet2, Indiana University, GÉANT, the University of Michigan, and Brazil’s RNP. Each contributes staff, computing, and network resources. Today, perfSONAR is deployed at over 2,000 locations worldwide. In 2024, major new deployments supported critical science projects:

- The **Vera Rubin Observatory** used perfSONAR nodes to identify and resolve packet loss issues.
- **USDA’s Agricultural Research Service** added 65 nodes to its SCInet research network.
- **The Square Kilometre Array** began prototyping a large-scale deployment for its radio telescope sites in Australia and South Africa.

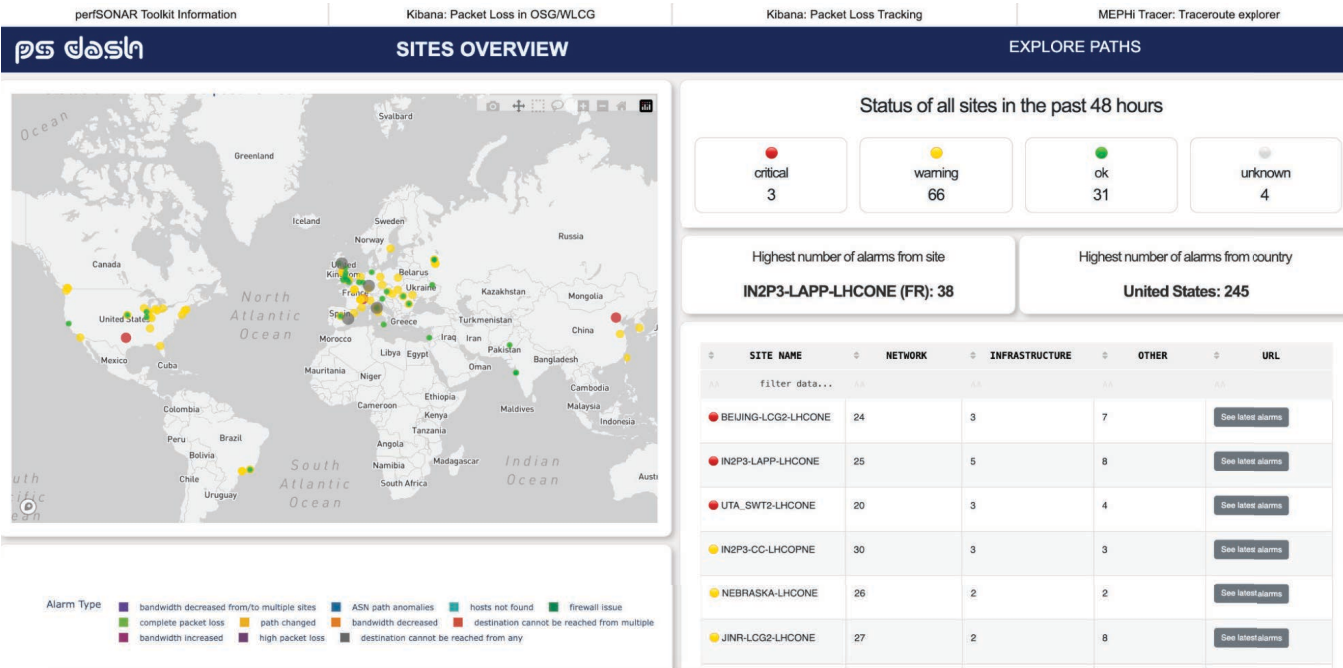
The release of perfSONAR 5.1.0 introduced a redesigned, more flexible user interface, enhanced host instrumentation, and integration of multi-threaded iperf3 (an ESnet innovation)



to support 100 Gbps network interfaces. Community engagement remained strong, with the partnership team holding quarterly office hours, running well-attended workshops at TNC24 in France and Internet2’s Technology Exchange in Boston, and offering hands-on training in deploying and customizing perfSONAR.

perfSONAR continues to prove its value for high-demand science communities such as that of the LHC projects, for which

it supports custom alerting systems and resolves performance issues. In 2024, the perfSONAR community helped troubleshoot problems ranging from packet loss to quality-of-service gaps, ensuring that research networks worldwide operate at peak performance.



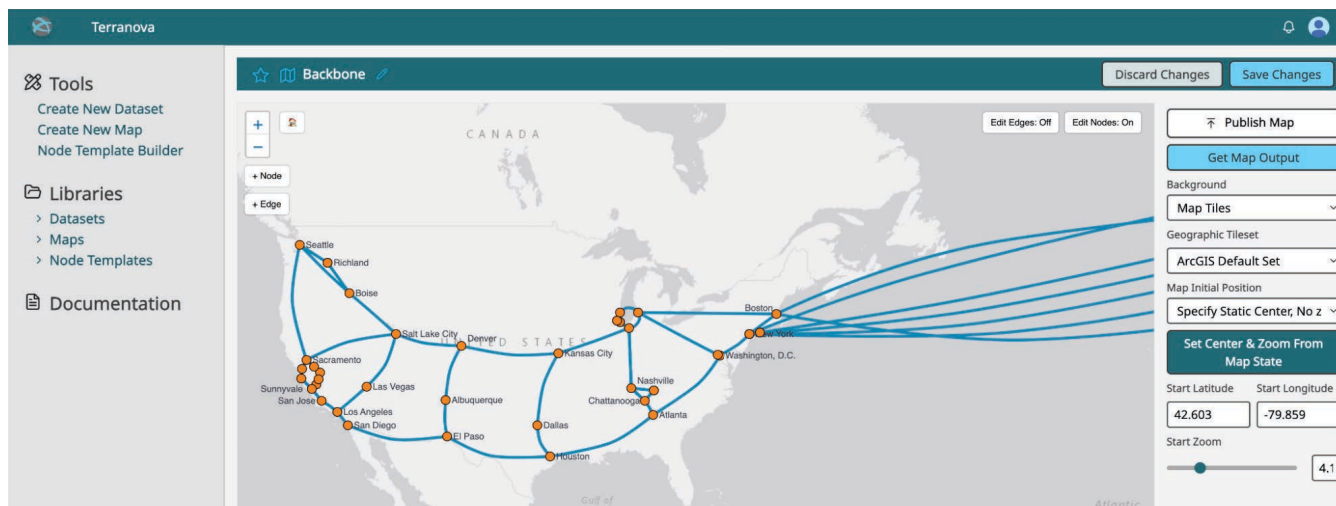
The LHCONE group developed an application using new features of perfSONAR to generate alerts.

Visualizing and Mapping the Network in Real Time

The my.es.net portal shows real-time graphs, giving ESnet's stakeholders a real-time view into their data flows from sites to facilities. In 2024, the Measurement & Analysis (M&A) team delivered 12 portal releases (two minor, ten patches), introducing OpenTelemetry-based logging, OS upgrades from CentOS to Ubuntu, API updates, and real-time analytics support for the LHC Data Challenge. Looking ahead, ESnet plans to enhance my.es.net with federated identity login and Grafana-based custom visualizations, enabling users to see project- and institution-specific data.

Beyond the portal, ESnet advanced its network mapping and visualization capabilities through two key tools:

- **ESnet Network Map Panel** – Renders network topologies from JSON data, overlays traffic information, and works as a Grafana plugin, React component, or stand-alone HTML object.
- **Terranova** – Generates JSON topology data from diverse sources via a flexible plugin architecture.



The Terranova User Interface, shown developing an ESnet Topology visualization.

In 2024, the Network Map Panel had 19 releases, adding multi-source topology loading, support for up to 20 data layers, and an end-to-end test harness. It was also published as a public Grafana plugin, now adopted by partners including GÉANT. Terranova saw eight releases, adding new data translation backends, Google Sheets import tools, and testing frameworks. These open-source tools are now widely used across the global research and education networking community, with ESnet showcasing them at SC24 and other venues.

Fine-Tuning Network Orchestration and Automation

In a high-performance science network such as ESnet’s, orchestration and automation are critical for speed, reliability, and scalability. Automating complex network and service configurations reduces human error, accelerates service deployments, and ensures consistent, predictable performance.

ESnet Database (ESDB) and Kubernetes Development:

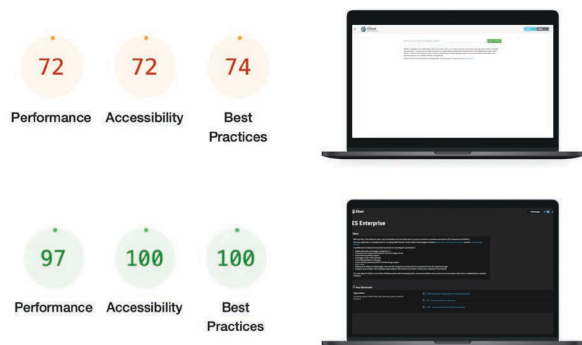
In 2024, the Orchestration & Core Data (OCD) and Platform Engineering teams streamlined deployment by migrating from Ansible to Kubernetes Helm charts, moving closer to Continuous Integration/Continuous Deployment. Developers also began migrating to Okteto, enabling standardized Kubernetes-based development environments, “hot-reload” capabilities, and cloud-hosted dev resources — saving hundreds of hours in debugging and reducing hardware costs.

Service Orchestration and Automation: The new Device Base Config service now allows engineers to create, test, and deploy standardized “day one” device configurations in minutes instead of weeks, improving reliability and paving the way for future orchestration enhancements. The Late Protocol Transitions (LPT) project automated the migration of all remaining customers to dedicated virtual route forwarding tables, reducing cybersecurity risk and service disruption.

Enterprise User Interface: The NextGen ES Enterprise (ESE) GUI modernized workflows for ESDB and OSCARS, dramatically improving performance and accessibility scores (see figure, facing page). New features include enhanced search, record history, relational lists, and circuit visualizations. The new OSCARS LSP Builder lets users create optimized Layer 2 VPN paths with custom constraints directly from the interface.

Topology and Discovery Services: The new Discovery Service consolidates network data collection into a single, scalable, Kubernetes-based system. It normalizes device configurations, provides real-time updates via an asynchronous message bus, and maintains historical records for trend analysis and potential AI-driven optimization. This reduces redundant polling, improves data consistency, and gives applications a coherent, up-to-date view of the network.

In 2024, these orchestration and automation advances significantly improved ESnet’s operational efficiency, reliability, and ability to adapt quickly to evolving science requirements.



Metrics from Google's web development tool Lighthouse show that the new ES Enterprise graphic user interface (bottom) to be a significant improvement over the legacy GUI (top).

Reducing Vulnerability and Tightening Up Security

In preparation for ESnet's first DOE Enterprise Assessments (EA-60) audit, scheduled for mid-2025, the Security team overhauled documentation, policies, and risk management processes. This included developing a formal Risk Assessment Self-Assessment (RASA), updating the enclave security plan, and producing hundreds of pages of documentation aligned with Berkeley Lab standards.

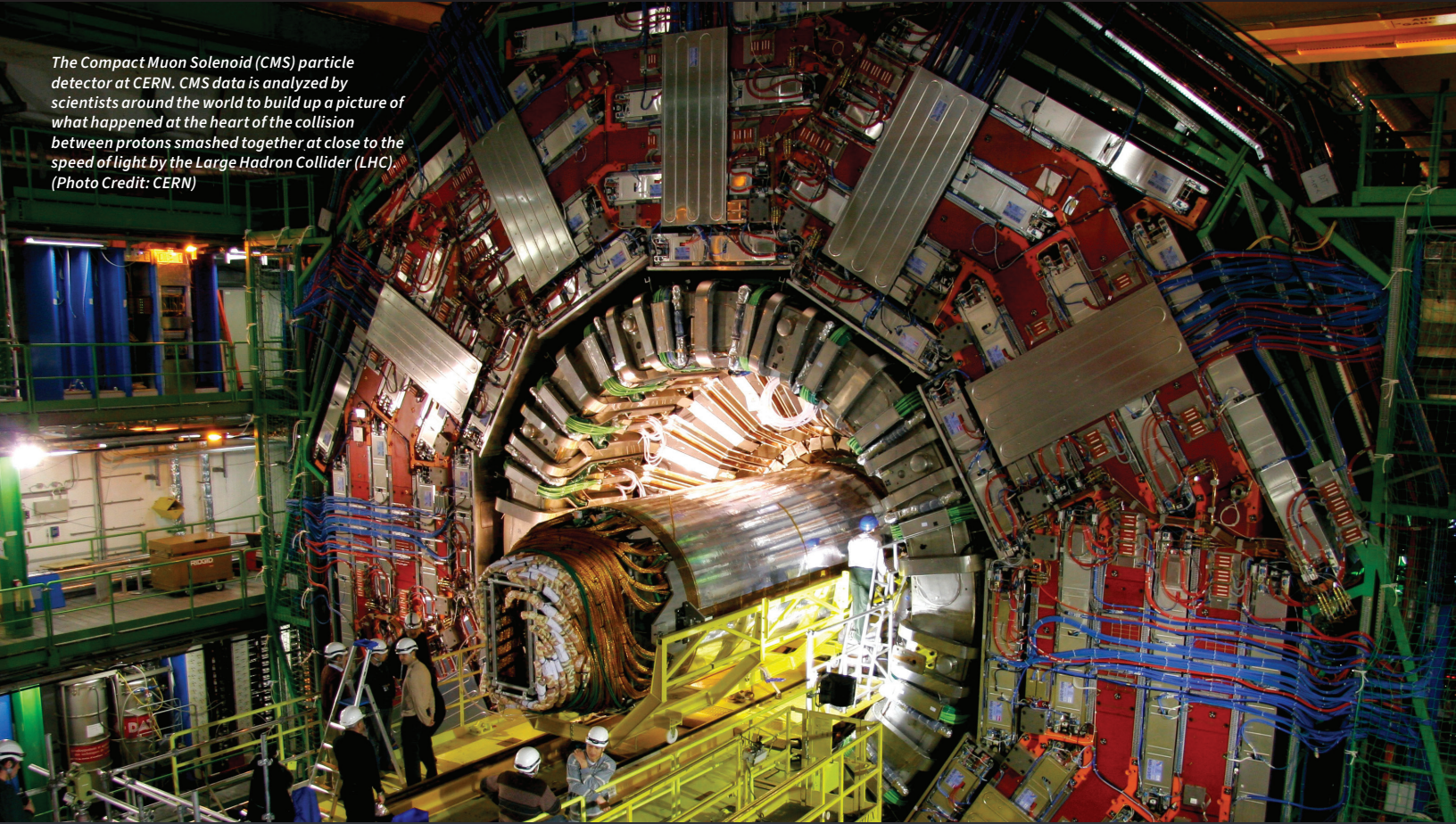
Significant progress was made on Zero Trust initiatives, particularly in Identity and Access Management (IAM). ESnet developed code and processes to transition from Feitian tokens to Yubikeys, enabling future NIST AAL3 Single Sign-On with phishing-resistant WebAuthn. Most web services migrated to the new SSO in 2024, and a Cloudflare pilot began to protect externally facing applications and reduce VPN dependency.

The Security team launched a new vulnerability management program, replacing Insight VM with Nessus, adding IPv6 scanning, and creating robust tracking workflows. ESnet deployed Endpoint Detection & Response (EDR) via CrowdStrike to laptops, workstations, and servers, and upgraded all firewalls as part of a Zero Trust-based data center refresh supporting IPv6-only networking and automated micro-segmentation.

Application security was strengthened through ESnet's first penetration tests of key internal applications (ESDB and SCRAM), which found no critical issues. Routing security was improved with Resource Public Key Infrastructure (RPKI) support for customers, and Splunk's Security Orchestration and Automated Response (SOAR) tools were implemented to enhance alerting and analysis.

These 2024 efforts significantly hardened ESnet's security posture, streamlined identity management, and positioned the organization for a successful 2025 audit.

The Compact Muon Solenoid (CMS) particle detector at CERN. CMS data is analyzed by scientists around the world to build up a picture of what happened at the heart of the collision between protons smashed together at close to the speed of light by the Large Hadron Collider (LHC). (Photo Credit: CERN)



APPLIED RESEARCH ACTIVITIES

ESnet's research and development activities are integral to ESnet's mission to push the boundaries of networking and meet the science needs of tomorrow. Since 1989, our traffic has grown an average of 55% every year. ESnet relies on continuous staff innovation as well as focused applied research and development to increase the network's efficiency in multiple areas. Our teams develop, test, and deploy new tools, protocols, and techniques to support the expanding needs of DOE scientists.

SENSE-ing How to Direct Network Resources

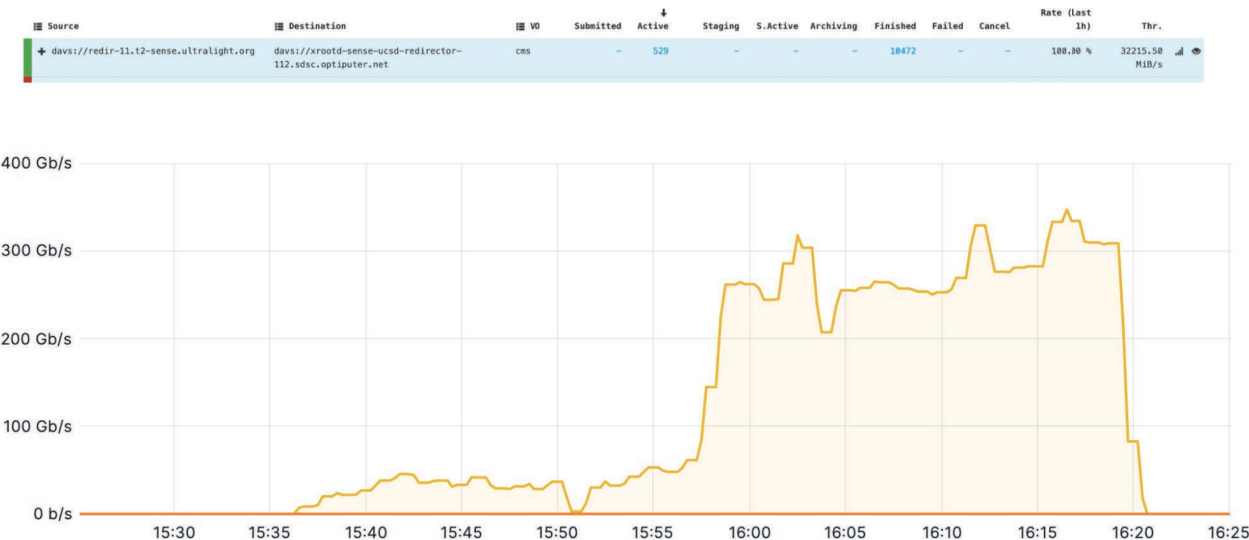
Most applications treat the network as a “black box,” sending packets without insight into network conditions or the ability to request resources. For complex, time-sensitive scientific workflows, ESnet offers application-driven orchestration — enabling applications to negotiate with the network for priority, bandwidth, and performance tuning.

ESnet’s OSCARS and Orchestrator tools already provide on-demand network provisioning in production. The SENSE (SDN for End-to-end Networked Science at the Exascale) project, still in the research phase, takes this further by building real-time models of networks, end systems, and data-transfer services. Science workflows can use SENSE to discover

capabilities, provision resources, and dynamically adjust operations across multiple domains.

In 2024, the SENSE team focused on supporting the Large Hadron Collider (LHC) Compact Muon Solenoid (CMS) workflows using the Rucio/FTS/XRootD data management stack. The SENSE project integrated with Rucio to identify high-priority transfers, dynamically allocating network and end-system resources and tuning the data-transfer stack in real time.

During the LHC Data Challenge 2024 (page 33) and demos at the SC24 conference, SENSE-enabled workflows achieved 330 Gbps sustained transfers between Caltech’s CMS Tier 2 storage and



SENSE and Rucio/FTS/XRootD interoperation System Data Transfers using Caltech Production Tier 2.

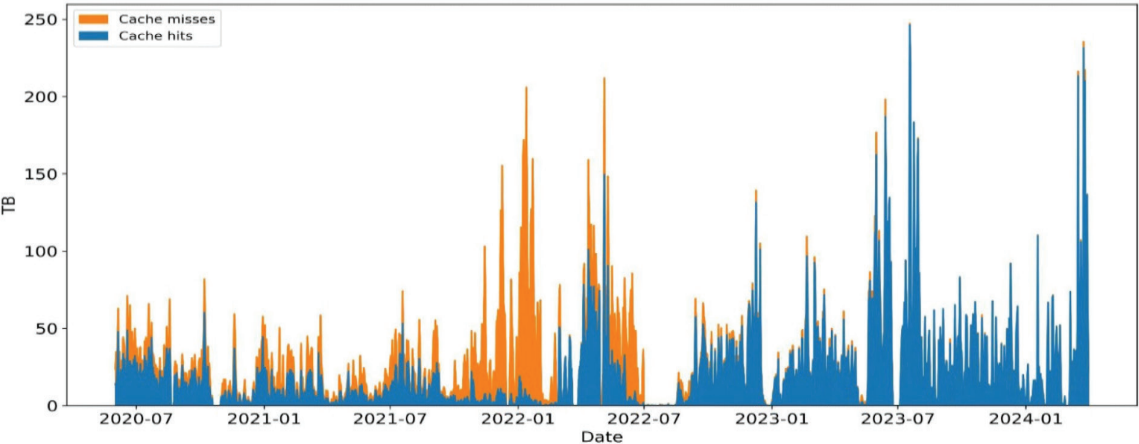
UC San Diego — close to the 400 Gbps target for the coming High-Luminosity LHC era. Deployments now span multiple LHC Tier 1 and Tier 2 sites, with more planned for 2025. Work also began on integrating SENSE with Globus-based transfers, which will extend deterministic, lifecycle-managed data movement to most large-scale science workflows.

In-Network Data Caching Reduces WAN Traffic

Scientific experiments and simulations generate large datasets that are often accessed repeatedly by researchers in the same region. These repeated transfers can unnecessarily consume bandwidth, increase congestion, and slow data access. In-network data caching stores frequently used datasets at strategic points in the network, reducing redundant transfers, lowering latency, and improving application performance.

In 2024, ESnet collaborated with two High Energy Physics experiments, US CMS and US ATLAS, for the LHC and Open Science Data Federation (OSDF), to deploy five regional caching nodes, with the objective of understanding network utilizations and characteristics. OSDF caches in Amsterdam and London primarily support DUNE and LIGO. US CMS caches were deployed in Southern California (2 PB), Chicago (340 TB), and Boston (170 TB), with the Boston node also serving US ATLAS.

Over 11 months, caching reduced WAN traffic by an average of 33 terabytes per day, with two-thirds of requests served locally and a 94% average hit rate. The SoCal, Chicago, and Boston caches cut WAN traffic by 69.3%, 48.4%, and 6.6%, respectively. Modeling shows doubling Chicago’s capacity could raise its hit rate to 80%. In 2025, ESnet will expand the study, converting single-service caches to multi-service platforms that can serve multiple science communities simultaneously, further enhancing efficiency and performance for data-intensive research.



Daily traffic volume for the ESnet SoCal cache, from June 2020 to March 2024, showing cache misses (in orange) that require WAN transfers and cache hits (in blue) that could be satisfied with cached files.

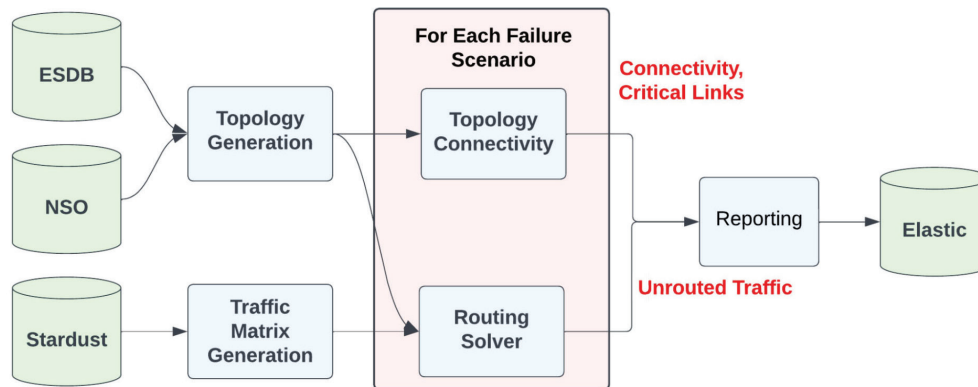
Testing the Network Vitals

If ESnet is the “data circulatory system for science” (page 2), then it also requires regular check-ups. In 2024, ESnet advanced three major initiatives to deliver higher-fidelity, predictive, and AI-driven insights into network health.

High-Touch Services: The High-Touch project combines programmable hardware with ESnet-developed software to capture detailed flow and packet-level telemetry data. In 2024, the High-Touch team remediated existing deployments, expanded into ESnet’s European sites, and deployed a new Clickhouse database cluster to ingest and query flow data from all High-Touch nodes. This capability supported the LHC Data Challenge 2024, revealing lower-than-expected throughput in LHCONE flows without signs of packet loss, and helped to troubleshoot Vera Rubin Observatory transfers by identifying upstream packet reordering. It has also been an asset in security investigations, helping our customers get increased visibility and being able to track threat actor movements.

Modeling Network Bottlenecks: The Network Bottleneck and Capacity Prediction project team automated an end-to-end modeling pipeline — from traffic matrix generation to failure scenario analysis — using advanced solvers and optimization techniques. New tools now identify critical links under single- and dual-fiber cuts, integrate spectral graph theory for connectivity insights, and explore robust optimization to account for traffic and network uncertainties.

AI/ML-Driven Analysis: ESnet and our partner researchers at UC Santa Barbara collaborated to use netFound, a domain-specific network foundation model, to transform High-Touch telemetry data into actionable intelligence for predictive maintenance, anomaly detection, and flow control. In parallel, ESnet and Fermilab built deep-learning models to classify streaming vs. file-transfer traffic using only a few initial packets, achieving 93% accuracy and improving model transparency with interpretability tools.



Overview of the system design of the Network Bottleneck project.

Advancing IRI with GRETA/DELERIA

The Gamma Ray Energy Tracking Array (GRETA) is a next-generation gamma-ray detector offering order-of-magnitude sensitivity improvements over existing arrays, using segmented germanium crystals and advanced signal processing to track individual gamma-ray interactions. Led by Berkeley Lab, the GRETA project is a 413.3 project funded by the DOE Office of Science's Nuclear Physics program in collaboration with Oak Ridge National Laboratory (ORNL), Argonne National Laboratory (ANL), and the Facility for Rare Isotope Beams (FRIB) at Michigan State University. ESnet's contribution focuses on the data acquisition system, including architecture design, performance engineering, software development, and networking and security support.

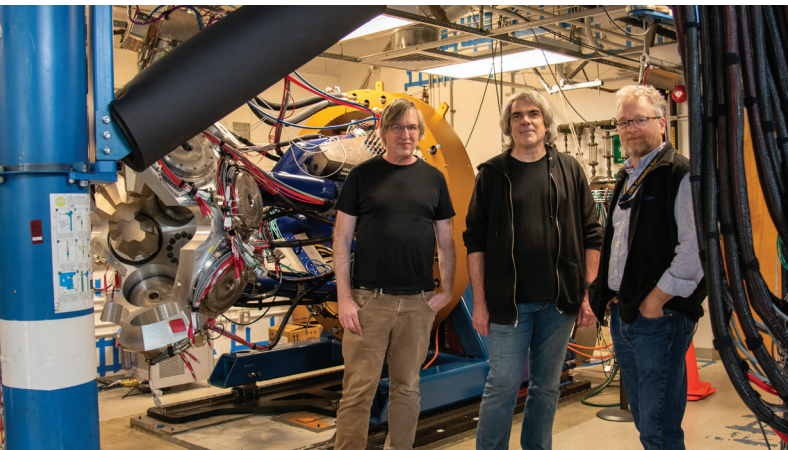
In 2024, ESnet staff worked with Berkeley Lab's Nuclear Sciences Division to integrate custom-developed components with GRETA's Signal Decomposition software and computing cluster,

optimizing performance to meet key performance parameters. The collaborators also completed the Distributed Event Level Experiment Readout and Analysis (DELERIA) project, which is part of Berkeley Lab's Laboratory Directed Research and Development (LDRD) program and enables real-time streaming of event-level detector data over high-speed wide-area networks (WANs) directly to remote HPC facilities for immediate analysis. The DELERIA computing pipeline was deployed within the ESnet testbed systems in Berkeley (six nodes) and the Oak Ridge Leadership Computing Facility at ORNL (24 nodes). A study and subsequent tuning of the software provided valuable insights into the behavior of scientific data streaming workflows in a multi-institutional environment and high-latency networks.

DELERIA's composable, reusable software components separate analysis, data transport, and control, enabling experiments — especially smaller collaborations — to leverage leadership-class computing without heavy software engineering investment, accelerating discovery across diverse scientific domains.

Supporting Innovative Experimentation through Testbeds

Testbeds are dedicated, controlled environments that allow researchers and engineers to experiment, validate, and refine new technologies without impacting production systems. For ESnet, testbeds are essential for advancing networking, computing, and data movement innovations that support the DOE's science mission. They provide the ability to prototype high-performance solutions, test interoperability, and evaluate operational readiness before transitioning to production and deployment at scale. In 2024, ESnet operated and contributed to multiple advanced testbeds in partnership with DOE facilities, academia, and the global R&E community.



DELERIA team members Mario Cromaz (Nuclear Sciences), Eric Pouyoul (ESnet), and Eli Dart (ESnet) with GRETA (background).

QUANT-NET

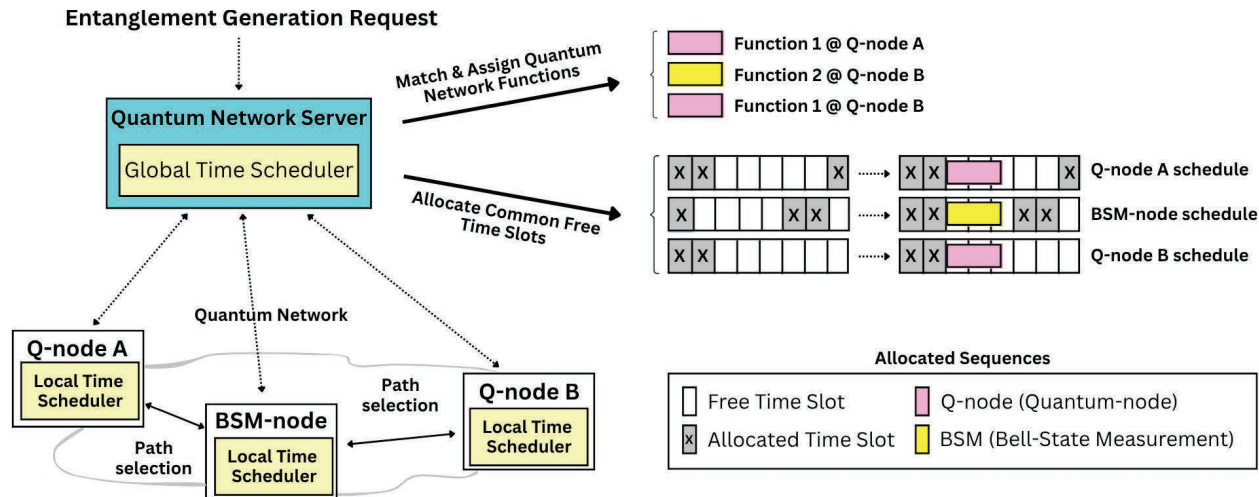
The Quantum Application Network Testbed for Novel Entanglement Technology (QUANT-NET) project, funded by DOE's ASCR program since 2021, is led by ESnet and Berkeley Lab with partners from UC Berkeley, Caltech, and the University of Innsbruck. Its goal is to build a three-node distributed quantum computing network linking Berkeley Lab and two UC Berkeley sites via a 5 km entanglement-swapping optical fiber link, managed by a quantum network protocol stack.

In 2024, the team:

- Built a new ion-trap system at Berkeley Lab capable of consistently trapping a single ion. The next step is to extract and couple single photons from ions to fibers as the first step for quantum networking experiments.

- Automated a Hong-Ou-Mandel interferometer for high-fidelity Bell state measurements, a key step toward remote entanglement experiments.
- Developed a two-level control framework for quantum networks, designed specifically for the QUANT-NET testbed and can also be extended to support other types of quantum networks.
- Developed an ARTIQ-based real-time control framework for trapped-ion quantum networking.

These milestones have laid the groundwork for teleporting quantum logic gates between remote quantum nodes — a fundamental building block for quantum repeaters and distributed quantum computing.



In QUANT-NET's two-level control framework for quantum networks, a two-level scheduler has been implemented to support network-wide on-time-critical tasks and node-wide time-critical tasks. Enabled by this two-level control framework and the scheduler, several basic quantum network operations have been automated in the testbed.

ESnet Testbed

The ESnet Testbed provides networking, computing, and storage resources for experimentation with novel technologies relevant to DOE science. Located primarily at Berkeley Lab, it features a dedicated 400 Gbps link to Starlight in Chicago with connectivity to the International Center for Advanced Internet Research (iCAIR).

In 2024, ESnet added six new 400G-capable high-performance servers. Key projects using the ESnet testbed included:

- **Naval Research Laboratory (NRL):** Investigated network resilience during catastrophic events, culminating in a large SC24 demonstration spanning multiple federated testbeds.
- **DELERIA:** Tested high-latency streaming of GRETA instrument simulations (page 28).
- **SciStream:** Led by ANL, this project developed secure, low-latency streaming for scientific workflows, demonstrated at SC24 using ESnet, SciNet, and iCAIR testbeds.

IRI Testbed and Testbed Next Generation (NG)

The IRI program requires shared resources to explore its three workflow patterns: Time-Sensitive, Data Integration-Intensive, and Long-Term Campaign. ESnet contributes networking, connectivity, and its own testbed resources to the IRI Testbed. In 2024, ESnet supported two IRI experiments — DELERIA and EJFAT — in collaboration with OLCF, demonstrating streaming of raw instrument data into high-performance computing HPC facilities over ESnet.

ESnet also began designing Testbed NG, a more capable successor to the current testbed, based on requirements from

the Federated IRI Testbed white paper. The conceptual design was completed in 2024, with the final draft released in February 2025.

FABRIC

FABRIC (FABRIC is Adaptive Programmable Research Infrastructure for Computer Science and Science Applications) is a national-scale research testbed funded by the National Science Foundation (NSF). ESnet is a core partner, leading the Scientific Advisory Committee, managing colocation hosting, and providing Layer-1 connectivity using spectrum from the ESnet6 Optical Line System.

In 2024, ESnet’s FABRIC team:

- Supported 400 Gbps upgrades at CERN, New York, and Los Angeles.
- Delivered major FABRIC Control Framework Software updates, improving stability, automation, and traffic engineering capabilities.
- Integrated Ciena 8100 “travel nodes” into the previously all-Cisco FABRIC network, extending Network Service Orchestrator services to enable multi-vendor interoperability for live demonstrations.
- Advanced FABRIC Federation (FabFed) software, enabling automated multi-testbed/cloud experiments, including new hybrid-cloud topologies demonstrated at NSF MERIF 2024.

These contributions ensured FABRIC remains a versatile, cutting-edge platform for distributed science experiments, tightly integrated with ESnet’s production infrastructure.



The FABRIC core network

Wireless Edge: Neutral-Host Multi-Core for Science Data Mobility

As DOE science increasingly moves into remote “greenfield” sites without robust communications infrastructure, ESnet’s Wireless Edge program is exploring cost-effective, high-performance wireless solutions to connect field researchers with DOE HPC and analysis resources (see also page 14).

ESnet Wireless Edge staff also focus on developing, enabling secure, seamless access for the research community even when they’re not in the field. In 2024, they deployed neutral-host multi-core capabilities at Berkeley Lab for evaluation. This approach allows DOE-owned Radio Access Network (RAN) equipment to simultaneously support multiple cellular networks — for

example, commercial cellular providers and one or more lab or university private scientific data networks — on the same hardware, as a private cellular network modeled on Eduroam, the international Wi-Fi internet access roaming service.

At Berkeley Lab, ESnet deployed cellular access points each capable of serving up to five networks, improving in-building coverage and reducing infrastructure costs. This shared, multi-core approach promises more efficient spectrum use, lower deployment expenses, and expanded wireless reach for DOE science.



The NORDUNet and ESnet teams at Berkeley Lab in November 2024.

ENGAGING OUR FAR-FLUNG COMMUNITIES

ESnet's mission compels us to share knowledge, experience, and findings with members of both the DOE ecosystem and the global R&E networking community, including commercial networking technology providers. We do so by technical consulting, publishing, and participating in DOE and other U.S. scientific planning endeavors; hosting and engaging with in-person collaborations; and contributing keynote speeches, technical presentations, demonstrations, and workshops at numerous high-profile conferences.

Supporting the LHC Data Challenge 2024

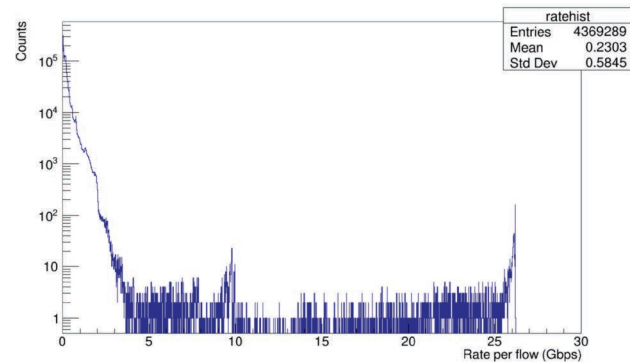
In February 2024, ESnet participated in the Large Hadron Collider Data Challenge 2024 (DC24), a global stress test of the Worldwide LHC Computing Grid (WLCG) in preparation for the LHC's High-Luminosity era, which will begin in 2030. The challenge set forth aggressive global targets: 1.2 Tbps for the minimal model focusing on Tier-0 export to the Tier-1 centers, and 2.4 Tbps for the flexible model, including complex experiment data flows. DC24 also included smaller-scale exercises by Belle-2 and DUNE, sharing network paths without interference.

ESnet contributed to DC24 in many areas:

- **Infrastructure readiness:** Coordinated peering exchange upgrades, worked with Tier-2 sites and local providers, and resolved over 70 pre-event work items.
- **Performance troubleshooting:** Identified and mitigated a multi-service throughput issue between ESnet and Fermilab, using perfSONAR with multi-threaded iperf.
- **Resiliency measures:** Minimized the impact of sub-sea cable outages by applying new ESnet6 traffic engineering capabilities and leveraging partner networks for backup routes.
- **Custom monitoring:** Built a dedicated Stardust portal for DC24 sites and infrastructure.
- **Advanced telemetry:** Used High-Touch services to profile and analyze DC24 traffic post-event.

Results showed that ESnet's network flowed smoothly, enabling WLCG experiments to focus on scaling their File Transfer Service (FTS) and Rucio data management tools. The data challenge effort surfaced valuable insights into performance bottlenecks, configuration optimizations, and operational improvements, strengthening the scalability and robustness of the global LHC data infrastructure.

The next Data Challenge is planned for spring 2027, aiming to handle 50% of High Luminosity traffic, and ESnet will continue to help ensure the global network can meet the demands of next-generation high energy physics.



Distribution of flow rates gathered using High-Touch data during LHC Data Challenge 2024. Each count/entry in this graph represents one flow.



Connecting People to Advance Global Innovation

ESnet frequently leads community building and knowledge exchange efforts with a range of academic, industry, government, and research & education thought leaders. Some highlights from 2024 follow.

High Energy Physics Requirements Review: One of the primary means by which ESnet engages a broad spectrum of its stakeholders is through the formal Requirements Review program, under which ESnet staff meet with scientists and program managers from each of the six DOE Office of Science programs that ESnet supports. The outcomes from each review are published in a comprehensive report with multiple case studies.

Image above: The ESnet, DOE, and NERSC participants of the High Energy Physics Requirements Review meeting in 2024.

Image right: Peter Vetter (left), President of Bell Labs Core Research at Nokia, gave ESnet CTO Chin Guok, Executive Director Inder Monga, Advanced Technologies and Testbeds Group Lead John Wu, and quantum networking engineer Wenji Wu a tour of Bell Labs historic headquarters.

In 2024, ESnet and the DOE High Energy Physics (HEP) program began a full review of the program, involving approximately 125 participants from HEP, ASCR, ESnet, university and DOE PIs, facility managers, and members of the ESCC. The review presented 14 scientific case studies and 7 technical case studies that embodied the primary aspects of the HEP portfolio. The in-person review was held in September 2024 in Rockville, Maryland, and followed by asynchronous collaboration. The recommendations will be detailed in the HEP Requirements Review final report to be published in CY2025.

Nokia Bell Labs: ESnet has a longstanding organizational friendship with this legendary R&D company owned by Nokia, and in 2024 their leadership teams convened for information-sharing sessions at ESnet's headquarters at Berkeley Lab, Nokia Bell Labs HQ in Murray Hill, New Jersey, and at several Bell Labs research locations.



NORDUnet: This global network interconnects the national R&E networks of the five Nordic countries and also links these networks to the rest of the world. ESnet leadership hosted a NORDUnet group in November 2024, discussing AI for networking, network orchestration, and more, and touring NERSC and the Joint Genome Institute.

Quantum Networking Community: ESnet’s QUANT-NET team actively engaged with the global quantum networking community through multiple invited talks, lab visits, and international collaborations with leading researchers and institutions in Japan, the Netherlands, Ireland, and Switzerland. Highlights included hosting prominent speakers such as Rodney Van Meter (Keio University), Sophia Economou (Virginia Tech), and Wolfgang Tittel (University of Geneva), as well as reciprocal visits to QuTech in the Netherlands and Trinity College Dublin to explore joint R&D opportunities.

Key Conferences for ESnet

SC: At the International Conference for High Performance Computing, Networking, Storage, and Analysis (SC), ESnet plays primarily a technical role, supporting the fastest temporary network in the world, SCinet, with connectivity and services for live demonstrations and tests. ESnet also provides more than a dozen volunteers to the team that builds this record-breaking conference network every year. ESnet staff also participate as panelists and speakers. In 2024, ESnetters spoke on IRI-related projects, including EJFAT, DELERIA, and DIII-D Fusion, and IRI interfaces; SENSE Services for Data Movement Systems; and more.

TNC: The largest research and education networking conference, TNC is funded by the European Union via the GÉANT (GN4-3) Project. It attracts more than 800 participants from 70+ countries. At TNC24 in France, ESnet staff presented on network orchestration, IPv6, MetraNOVA, perfSONAR, and trans-Atlantic fiber strategy, and met with many of their national research & education network (NREN) colleagues.

Internet2 Technology Exchange: Hosted by Internet2, the TechX conference brings together the global R&E community. At the 2024 TechX conference in Boston, ESnet’s presentation topics included security for automation engineering, 20 Years of perfSONAR, MetraNOVA, Stop-Gap Traffic Engineering, and more.

OFC: ESnet’s Executive Director Inder Monga gave a plenary talk, “Networking Alchemy: Transforming Science Through Connectivity,” at OFC 2024, the Optical Fiber Communication Conference and Exhibition sponsored by Optica, IEEE Communication Society, and IEEE Photonics Society. ESnet staff participated in building OFCnet, the high-speed network enabling demonstrations on the show floor.

IEEE Quantum Week: The IEEE International Conference on Quantum Computing and Engineering (QCE) seeks to bridge the gap between the science of quantum computing and the industry growing up around it. At QCE24, ESnet staff chaired a quantum network testbed panel and cohosted a session on quantum network protocols with Japan’s quantum networking experts.

GrafanaCON: ESnet Measurement & Analysis staff presented at GrafanaCON, an annual visualization conference hosted by Grafana Labs, sharing how ESnet uses and extends our Stardust data collection, analysis, and visualization platform to support science.

ESCC Meetings: The ESnet Site Coordinator Committee (ESCC) is made up of technical representatives from ESnet's supported sites who gather regularly with ESnet staff to share insights and collaborate on the operational, network engineering, and security innovations and challenges that will shape the future of the ESnet infrastructure. In spring 2024, ESCC held a successful two-day, hybrid meeting in Berkeley with more than 70 participants from 17 sites, ESnet, and DOE. A community call was held in August.

Technical Presentations & Publications

In 2024, ESnet staff published 7 major reports, 1 journal article, and 13 conference papers, as well as delivered 99 technical presentations. (For a full list, with links where available, visit <https://www.es.net/esnet-2024-pubs>.) The following examples were selected to illustrate ESnet's work in the operational innovation and applied research areas featured in this report.

Accelerating data movement

L. Brown, E. Marx, D. Bali, E. Amaro, D. Sur, E. Kissel, I. Monga, E. Katz-Bassett, A. Krishnamurthy, J. McCauley, T. Narechania, A. Panda, S. Shenker. "An Architecture For Edge Networking Services," ACM SIGCOMM '24: Proceedings of the ACM SIGCOMM 2024 Conference, August 4, 2024.



Y. Kumar, V. Gyurjyan. “Practical Hardware Accelerated Real-Time Multi-facility Streaming Workflow (EJFAT),” SC24, November 20, 2024.

AI for Networking

S. Guthula, R. Beltiukov, N. Battula, W. Guo, A. Gupta, I. Monga. “netFound: Foundation Model for Network Security,” ACM Conference on Computer and Communications Security (CCS), October 2024 (preprint).

In-Network Caching

R. Monga, A. Sim, J. Wu. “Comparative Study of the Cache Utilization Trends for Regional Scientific Data Caches,” ACM Student Research Competition Grand Final, November 2024.

Network Orchestration and Automation

S. Richmond, C. Cummings. “Going Beyond Network Automation Towards Service Orchestration,” TNC24, June 11, 2024.

Performance Measurement

E. Balas. “Introducing MetrANOVA: a consortium to advance the tools, tactics, and techniques of network measurement,” TNC24, June 12, 2024.

A. Lake, M. Feit, L. Delvaux. “20 Years of perfSONAR and the Road Ahead,” TechEX 2024, December 10, 2024.

Quantum Networking

I. Monga. Plenary Session: “Networking Alchemy: Transforming Science Through Connectivity,” OFC24 Keynote, March 26, 2024.

I. Monga, W. Wu, S.Y. Yu, et al. “The QUANT-NET Testbed Development and Preliminary Results,” IEEE International Conference on Quantum Computing and Engineering, QCE24, September 17, 2024.

Scientific Networking Requirements

J. Balcas, D. Carder, E. Dart, et al. “WLCG/DOMA Data Challenge 2024: Final Report,” Worldwide LHC Computing Grid, June 3, 2024.

J. Zurawski, B. Brown, G. Rai, et al. “Nuclear Physics Network Requirements Review Final Report,” July 26, 2024.

Security

F. Bannat Wala, S. Bohacek. “Zone-Hopping: Sensitive Information Leakage Prevention in DNSSEC-NSEC,” The 54th Annual IEEE/IFIP International Conference on Dependable Systems and Networks (DSN’24), June 24, 2024.

K. Agrawal. “Kubernetes Security: Re-Thinking Traditional Security Operations in this Brave New World,” NSF Cybersecurity Summit 24, October 7, 2024.

Standards

N. Buraglio. RFC 9637 “Expanding the IPv6 Documentation Space.” Internet Engineering Task Force, August 27, 2024.

Wireless Edge

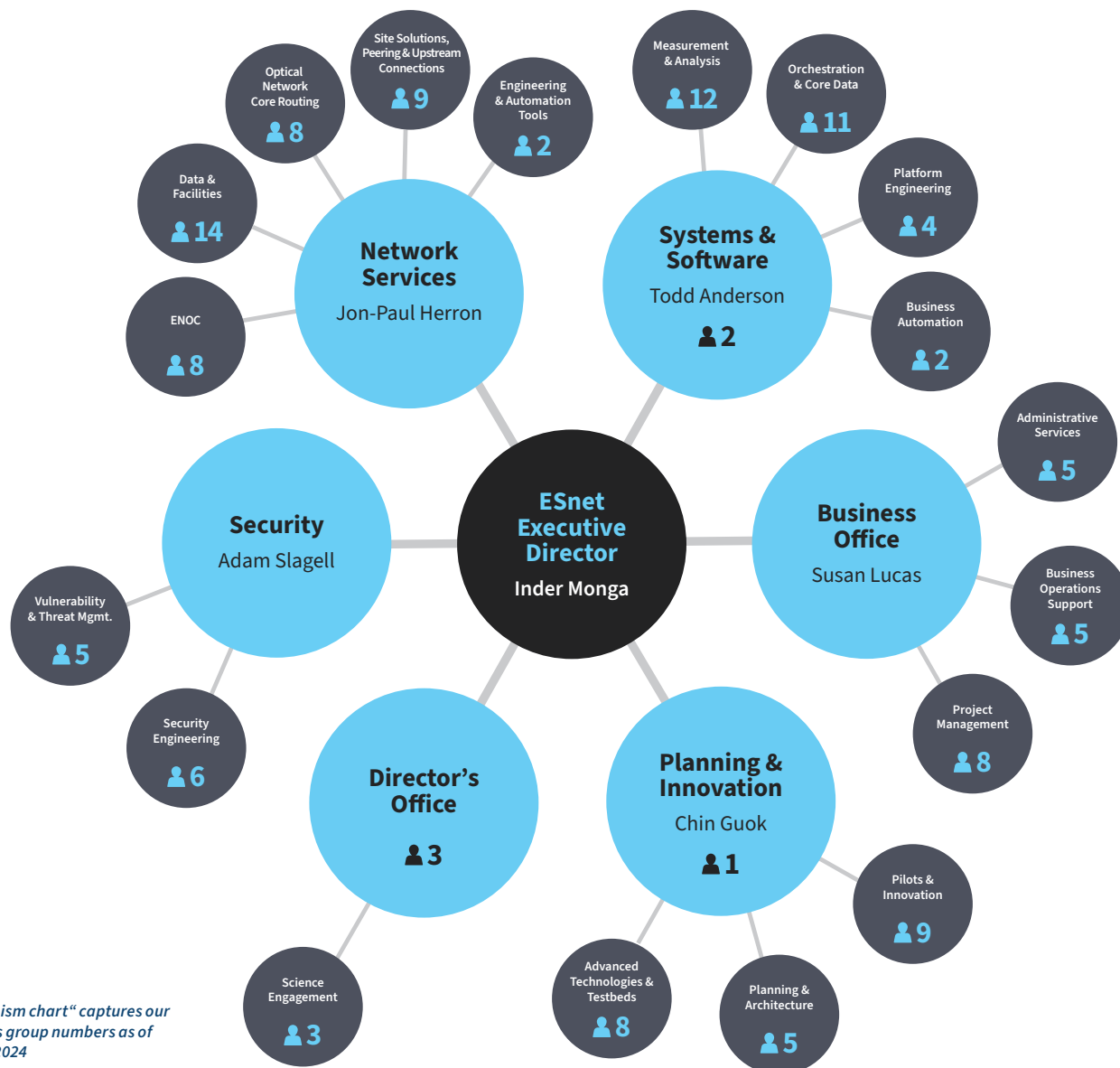
A. Wiedlea, I. Tarazi, C. Cowden, et al. “Revolutionizing Enterprise Wireless: Exploring Next-Gen Technologies,” Mobile World Congress 2024, February 27, 2024.

THE ENERGY BEHIND ESNET



The “energy” in Energy Sciences Network may date to our Department of Energy origins, but the source of ESnet’s power is our multitalented, passionate team.

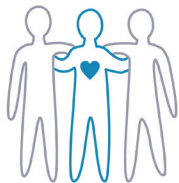
Although the pace of hiring at ESnet has slowed following the completion of the ESnet6 project in 2022, we welcomed 10 new staff members in 2024 and said goodbye to 6, ending the year with 137, a 3% increase for CY2024 over 2023. We continue to adjust our departments and groups to meet the needs of the mission.



This “organism chart” captures our structure as group numbers as of December 2024



One Team, One Goal



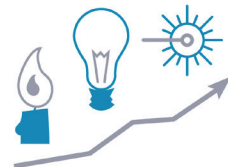
People First



Partner with Integrity



Lead with Humility



Progress over Perfection

Culture & Engagement at ESnet

Formed in 2022, the Culture & Engagement (C&E) Committee’s goal is to assess and bolster the health of the organization so that staff are in the best position possible to execute on ESnet’s mission. This requires understanding the current culture challenges, collaboratively developing change initiatives to address areas of friction, and measuring and reporting back on the success of initiatives and long-term organizational health.

All-Staff Survey

The C&E Committee has conducted a rigorous annual all-staff engagement survey since 2022. In 2024, participation in the survey remained strong once again, with 87% of staff completing it.

89%

Strongly agreed or agreed with the statement:

“I am proud to work for ESnet.”

85%

Strongly agreed or agreed with the statement:

“I would happily recruit qualified friends to work at ESnet.”

ESnet’s Core Values

In January 2024, ESnet’s Culture & Engagement team and the Values Committee — all volunteers from across the organization — shared a set of organizational values for ESnet resulting from a year’s worth of collaboration with staff:

- **One Team, One Goal:** We’re deeply committed to our core mission of serving and partnering with the science community.
- **People First:** Our well-being and how we treat each other are foundational to mission success.
- **Partner with Integrity:** Recognizing ESnet’s trusted role in many communities, we always act with transparency, honesty, and authenticity.
- **Lead with Humility:** Learn from all, share knowledge with grace.
- **Progress over Perfection:** We prioritize continuous improvement and innovation in every role.

These five core value statements were the product of engagement across the entire organization, finalized with input from ESnet’s executive leadership team. They were inspired by a



ESnet's 2024 MOR leadership program cohort.

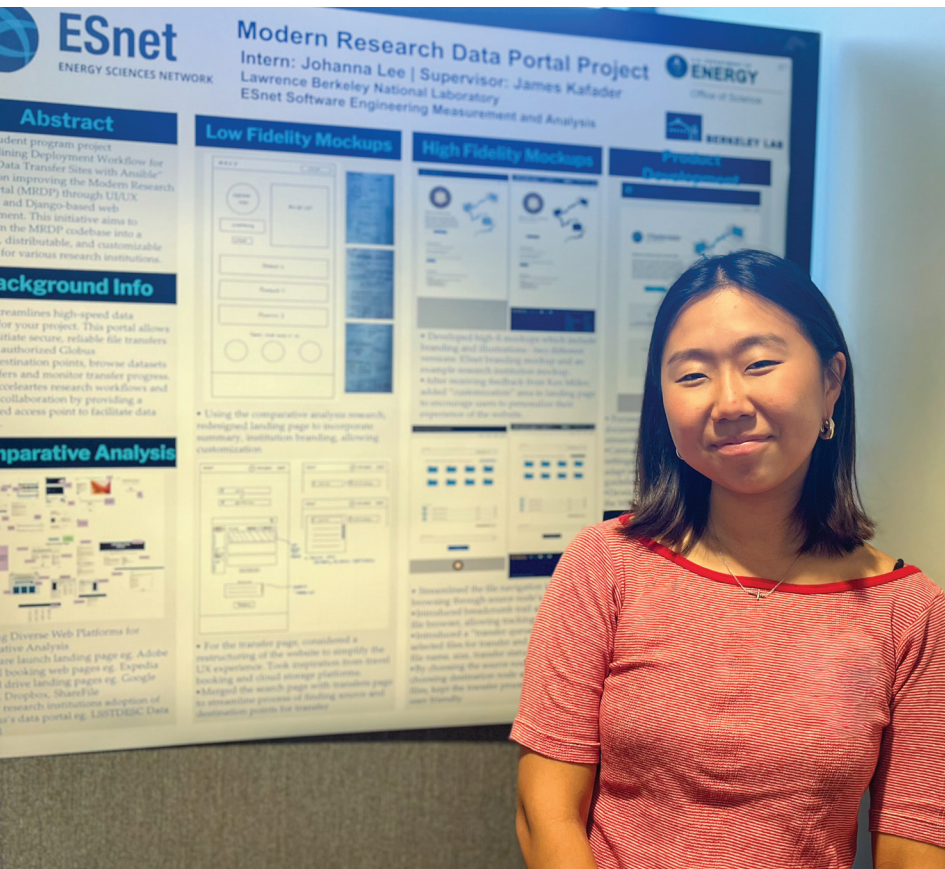
Harvard Business Review article, “What Does Your Company Really Stand For?” and informed by Berkeley Lab’s stewardship values. By articulating what is collectively most important to ESnet staff, the values help the organization stay in sync on strategic priorities internally and clarify how it engages with all stakeholders.

Leadership Development

ESnet continues to invest in building leadership capacity across the organization, complementing opportunities such as Berkeley Lab’s Director’s Stewardship Summit with an ongoing partnership with Maximizing Organizational Resources (MOR)

Associates, Inc. MOR delivers a five-month leadership program for cohorts of 20–25 employees with leadership potential.

In 2024, 21 staff completed MOR’s “Leading From Where You Are” series, covering strategic planning, adapting to change, influencing others, interpersonal skills, and transforming professional relationships. The program blends virtual and in-person learning, includes 360-degree feedback, one-on-one coaching, peer accountability groups, and practical assignments. Graduates earn a certificate and join a national network of peer leaders. The program has created a shared leadership language within ESnet and strengthened its pipeline of future leaders.



Johanna Lee, UC Berkeley '25, interned with ESnet in summer 2024 and was hired as staff in mid-2025.

The ESnet Student Program

Each year, ESnet invests in a 12–16 week paid student program for graduate, undergraduate, and high school students, offering hands-on research experience, mentorship, and professional development.

In 2024, 20 students participated: five Ph.D. candidates, three master's students, nine undergraduates, and three high school students from Berkeley Lab's Experiences in Research (EinR) program. Student projects spanned areas such as SENSE, quantum networking, network automation, data visualization, workflow orchestration, machine learning, and network performance prediction. Integrated with Berkeley Lab's broader student programs, participants also engaged in workshops, seminars, poster sessions, and career events. Seventeen ESnet staff served as mentors.

The program benefits students through real-world projects, human networking opportunities, and skill building, while providing ESnet staff with leadership experience and the organization with a pipeline for recruiting emerging talent. Several current staff members started their careers with ESnet as interns, most recently Johanna Lee (pictured).

LIST OF ACRONYMS

AI/ML: Artificial Intelligence and Machine Learning

ALCF: Argonne Leadership Computing Facility

AmLight-ExP: Americas-Africa Lightpaths Express and Protect (a partner network)

ANL: Argonne National Laboratory

ASCR: Advanced Scientific Computing Research (DOE Office of Science program that funds ESnet)

Berkeley Lab: Lawrence Berkeley National Laboratory

EB: Exabyte

ComCam: Commissioning Camera (used by Rubin Observatory)

DELERIA: Distributed Event Level Experiment Readout and Analysis (ESnet project with GRETA team)

DOE: U.S. Department of Energy

EJFAT: ESnet-JLab FPGA Accelerated Transport (prototype)

ESDB: ESnet Database (repository of all information about the physical ESnet network)

ESnet: Energy Sciences Network

FABRIC: FABRIC Adaptive Programmable Research Infrastructure for Computer science and science applications (a national research testbed)

FPGA: Field Programmable Gate Array

Gbps: Gigabits per second

GRETA: Gamma Ray Energy Tracking Array (new instrument led by Berkeley Lab)

HPC: High Performance Computing

HPDF: High Performance Data Facility

IRI: Integrated Research Infrastructure (ASCR initiative)

IoT: Internet of Things

Jefferson Lab: Thomas Jefferson National Accelerator Facility

LHC: Large Hadron Collider (CERN instrument with multiple DOE-funded projects)

LSST: Legacy Survey of Space and Time (Rubin Observatory survey)

NERSC: National Energy Research Scientific Computing Center

OLCF: Oak Ridge Leadership Computing Facility

ORNL: Oak Ridge National Laboratory

OSCARs: On-demand Secure Circuits and Advance Reservation System (an ESnet service for users)

PB: Petabyte

perfSONAR: performance Service-Oriented Network monitoring ARchitecture, a suite of network measurement tools

QUANT-NET: Quantum Application Network Testbed for Novel Entanglement Technology (DOE-funded quantum networking project led by Berkeley Lab)

S3DF: SLAC Shared Scientific Data Facility

SENSE: Software Defined Networking (SDN) for End-to-End Networked Science at the Exascale (ESnet research project)

SRP: Site Resilience Program (ESnet project to reduce network risk)

Tbps: Terabits per second

VPN: Virtual Private Network



Sunset view of Shyh Wang Hall, ESnet's home at Berkeley Lab



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