NSF CYBER-PHYSICAL SYSTEMS · BREAKOUT GROUP

Next-Generation CPS

From Proof of Possibility to Trusted Deployment

FRAMING

The question for NSF

Then

CPS research established ways to connect computation with physical systems and test them in realistic settings.

Now

AI makes prototypes much easier to build, but a compelling demonstration is not the same as a safe, reliable system.

Next 10 years

Invest where CPS can turn rapid prototyping into dependable performance in the physical world.

CONTEXT

What changed in the research landscape?

01 Transportation now has a substantial ecosystem of physical and virtual test beds, live-data access, and distributed-testing infrastructure. Similar capabilities and impact in other application domains (medical, robotics, etc.) These are stronger research foundations than existed roughly 15 years ago, though they are not necessarily ready for operational use.

02 AI and accessible design tools have sharply lowered the effort needed to produce a prototype. Small teams can attempt work that previously required much larger teams.

03 **The research bottleneck has shifted:** Can we establish when an integrated system works, detect when it does not, and recover safely? This was the breakout's central opportunity for CPS, not a claim that AI alone solves it.

WHY CPS

Why this is a CPS problem, not simply an AI problem

Problem	A learned component may perform well within its training domain, then degrade as operating conditions shift. Digital implementation and networking can also invalidate assumptions made about physical-system stability.
CPS role	Design and assess the whole loop (physical dynamics, sensing, computation, networks, people, and adversaries) rather than optimizing each component separately.
Investment direction	Fund compositional assurance, competence monitoring, and methods that explicitly trade agility or efficiency against verifiable safety. Passivity-based design was discussed as one concrete example of such a trade-off.

TRANSPORTATION AND INFRASTRUCTURE

Recover, don’t merely operate

Problem	Connected systems face failures and events outside historical operating conditions. For infrastructure decisions, researchers may also lack accessible, validated ground-truth data.
CPS role	Combine monitoring, digital models, control, and human decisions to reach safe failure states and restore service with justified confidence.
High-impact investment	Build shared resilience benchmarks and validation datasets on existing test-bed infrastructure. Measure time to safe state, time to restored service, and system uptime against an explicit baseline, for example after a road closure or bridge strike.

HEALTH AND MEDICAL DEVICES

Shorten the path to trustworthy intervention

Problem	Promising models and prototypes do not automatically become usable interventions in regulated care. Integrating multiple predictive models for depression treatment selection raised questions about assurance and eventual FDA certifiability.
CPS role	Connect models, devices, clinical workflows, and evidence of safety so that an intervention can be evaluated as a system.
High-impact investment	Fund reusable assurance and evaluation methods for integrated medical CPS. The breakout proposed reducing medical-device development from 17 years to 5 as an ambition; it should be presented as a research target, not a forecast.

ENERGY AND DATA CENTERS

Manage constrained resources at system scale

Problem	Energy demand, water use, and material constraints make system-level efficiency increasingly important. Battery packs also pose sensing, management, lifetime, and safety questions that cannot be resolved by studying cells in isolation.
CPS role	Integrate sensing, control, computation, and physical-resource constraints across facilities, grids, and energy storage.
High-impact investment	Develop verifiable controls for resource-constrained systems and methods to monitor large battery assemblies without impractical instrumentation. Evaluate energy and water used, service delivered, safety, and lifetime together, rather than maximizing a single metric.

ROBOTICS, AGRICULTURE, AND MANUFACTURING

Make adaptation dependable

Problem	Robots must operate amid uncertainty, changing tasks, and domain-specific constraints. A useful construction-robot application, for example, was found only after years of searching for a task that fit the technology.
CPS role	Co-design hardware, software, planning, and control around the actual job; determine where an adaptive system remains competent and what it should do when it does not.
High-impact investment	Support application-linked test beds and reusable tools for uncertainty-aware, collaborative systems. Require evaluation in real task conditions, not demonstration performance alone.

SECURITY AND HUMAN OVERSIGHT

Design for the whole failure surface

Problem	Linking AI, computing, physical processes, and biology expands the attack surface. At the same time, automation can leave a human operator supervising many systems and intervening only when something goes wrong.
CPS role	Treat cyber attacks, physical failures, recovery, and human-operator limitations as interacting system properties.
High-impact investment	Fund cross-domain security research and human-in/on-the-loop assurance, including intervention timing, operator readiness, and recovery. Incorporate safety, security, and recovery into design education rather than adding them after deployment.

RESEARCH INFRASTRUCTURE

A research infrastructure for CPS 2.0

Problem	A paper or one-off demonstration is difficult for others to test, extend, or bring into an application. Individual faculty, especially junior faculty, may lack access to domain experts, facilities, and professional engineering support.
CPS role	Make integrated methods usable: executable tools, shared test environments, realistic data, and clear interfaces between foundational researchers and application partners.
High-impact investment	Support maintained prototypes alongside papers, common benchmarks, and collaboration structures that bring researchers closer to operational problems. The breakout cited the CPS-VO “active content” idea as one starting point.

OUTCOMES

What NSF should be able to measure in 10 years

Scientific progress

Methods that establish operating competence, safe failure, security, and recovery for integrated systems, not just better component-level results.

Application progress

Demonstrated gains against domain baselines, such as recovery time and uptime in transportation, resource use and safety in energy, and evidence needed to evaluate medical interventions.

Research-community progress

Tools others can run, results others can reproduce, and stronger paths from foundational research to use. Startup and transition-to-practice rates were proposed in the breakout as possible indicators, but not as substitutes for safety or scientific evidence.

CLOSING MESSAGE

AI expands what can be attempted.

The next CPS program should establish what can be trusted, operated, and recovered in the real world.