A “cyber-physical” system takes on different definitions depending on the application and the underlying technology. As used here and as is prominent across UTC applications the issues that are central to cyberphysical systems are (a) scale and (b) interdependency.

Scale refers to the sheer size of the emerging *meta*-systems, composed of different physical systems and interconnected by diverse sets of communication networks. Building systems are one UTC application where scale could refer to the number of occupants in a building — new high rise buildings and campuses contain upwards of 30,000 participants and have thousands of points of sensing and controls for air quality and fire protection. Avionics systems are another example of scale — aircraft electric power systems are increasing in power density by factors of 3–5X in each new generation of aircraft and are connected by multiple networks with hundreds of thousands of switching scenarios.

Interdependency refers to coupling of physical systems through communication networks. Physical devices that were locally operated and controlled are now coupled by local and wide area communication networks with significantly enhanced computation distributed across the network – increasingly the networks are wireless and increasingly controlled by end users or consumers through PDA, cell phones or other mobile devices. An effect of these complex communications networks is that information can be obtained and used for control in ways that create new behaviors -both desired and so called “emergent” -that make the design and assurance of robust operation increasingly problematic.

Developing the underlying scientific and engineering knowledge base that allows full understanding and exploitation of these kinds of modern cyber-physical systems is critical. Elements that appear in UTC applications that today characterize the area and that form the basis of recommendations to NITRD include:

Scale. The systems that UTC sees emerging in building systems and in aerospace systems are of increasing scale -indeed, one could say “societal scale” -orders of magnitude different in qualitative and quantitative size to systems currently deployed today. The coupling of the diverse physical systems in the design and operation of products enables new functionality to be provided and especially tailored to customer needs and desires; however, the tools for engineering systems at societal scales do not currently exist.

Heterogeneity and Interconnected Systems. The systems that UTC sees emerging in building systems and in aerospace systems are diverse and the coupling provided by modem communication networks assembles cyber-physical systems where new coupling occurs.

Uncertainty. Uncertainty provides the motivation for a large degree of coupling in cyber-physical systems -the motivation is to react to environmental issues or to customer needs and desires. Uncertainty also is a key ingredient -with a high degree of interconnectivity -of “emergent” behavior.

Why does the area matter? There are three key issues that are represented by UTC applications and that are clear in other sectors (for example in transportation and health care).

Functionality. Products are being required to have higher levels of performance. An excellent example is in the area of buildings which are heading to “net zero energy” where over the course of a year the energy consumed is equal to the energy produced, requiring energy efficiency gains coupled to renewable energy sources. Computation and communication is essential to delivering these new levels of performance and the coupling of building functionality -HVAC, lighting, elevators together with thermal storage and renewable energy sources is exactly a “cyber-physical systems. The drivers of sustainability and reactions to global warming as well as energy security are accelerating the design and implementation of such functionality.

Delivering functionality at acceptable cost and risk. Coupling subsystems through communication networks makes information available globally and enables new performance. Coupling of subsystems however increases the cost of designing such systems — bringing different groups together — and increases the risk that coupling can cause undesirable behavior. The classic example of coupling on power grids and collapse during blackouts of entire regions is an excellent example of the cost and risk that “cyber-physical systems” bring forward. Risk also includes the development of dependable systems which focuses on the safety critical nature of cyber-physical systems and the role of dependable software.

National competitiveness. Increased energy efficiency is an example of the benefits that “cyberphysical systems” can bring to society. The product offerings will increase the value of both the physical and the “cyber” or information technology portions. The design and manufacturing base as well as the talent base is critical for national competitiveness.

Recommendations:

Public-private partnerships for R&D. There needs to be Federal and State investments in the basic science of “systems of systems” and technology that addresses key cyber-physical issues of scale, heterogeneity and uncertainty. These investments must produce new methodology, tools and talent and must involve academia, National Laboratories and industry working together.

Industrial involvement and involvement of mission oriented agencies. There must be investments in the mission oriented agencies including DOD and DOE to focus on industrial situations of national importance and that are targeted to identify and mature technology that can be effectively commercialized.

Standards. There must be investments at NIST and related Federal and State agencies to identify and put in place standards for communication and control that enable interoperability and effective commercialization of cyber-physical systems.