The *International Roadmap for Devices and Systems (IRDS) 2023* presents a forward-looking analysis of the limitations of conventional CMOS technologies and outlines the research directions needed to support the next generation of high-performance, energy-efficient systems. The “Beyond CMOS” (BC) chapter specifically explores alternative device technologies, novel materials, and system-level architectural shifts.

1. Motivation and Context

As Moore’s Law reaches physical and economic limits, traditional scaling is no longer sufficient to meet the growing demands of data-centric applications. The IRDS identifies Beyond-CMOS technologies as critical enablers for future computing systems, targeting improvements in power efficiency, scalability, and performance.

2. Emerging Device Paradigms

BC devices utilize novel state variables such as:

- **Spin** (e.g., spintronics),
- **Phase states** (e.g., phase-change memory),
- **Mechanical displacement**, and
- **Quantum effects** (e.g., tunneling, exchange interactions).

These alternatives to charge-based logic open pathways to ultra-low-power computing and new logic functionalities.

3. Architectural Co-Design

The report emphasizes a transition from monolithic general-purpose architectures to heterogeneous, application-specific, and brain-inspired systems. Such evolution demands close co-design of devices and system architectures, ensuring that novel device physics are effectively harnessed.

4. Design Principles for Future Systems

Key principles outlined include:

- **Non-equilibrium operation** for reduced energy use.
- **Novel energy transfer mechanisms** (quantum, spin-based).

- **Sub-lithographic fabrication** via techniques like self-assembly.
- **Thermal and fault management** at nanoscales.
- **Robust benchmarking** to assess performance, reliability, and integration potential.

5. Integration and Benchmarking Challenges

Despite theoretical advantages, current Beyond-CMOS options struggle with practical issues such as:

- Material integration into standard CMOS processes.
- Device-to-system reliability.
- Manufacturability at scale.
- Environmental sustainability.

No singular BC device currently surpasses CMOS in all metrics; however, hybrid architectures (combining CMOS with emerging devices) offer promising intermediate solutions.

Conclusion

The IRDS 2023 BC chapter serves as a strategic guidepost for academia and industry, emphasizing the need for holistic innovation—from device physics to system architecture. By investing in co-optimized, scalable technologies, the semiconductor ecosystem can extend performance scaling and enable new computing paradigms beyond the CMOS era.