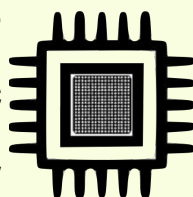## WHAT SEMICONDUCTORS DO

Overview: Semiconductors are an essential component of modern life! They are tiny electronic circuits made up of materials that partially conduct electricity. A broad portfolio of semiconductors are essential components of electronic devices and enable these devices to perform their functions. As such, semiconductors are considered the brains for millions of electronic devices and electrical systems located inside space vehicles, TVs, radios, video game consoles, car computers and electrical systems, smartphones, personal computers, supercomputers, advanced medical diagnostic equipment, appliances, military weapons systems, renewable energy systems, industrial equipment, data center servers, and telecommunications networks.
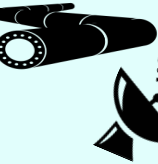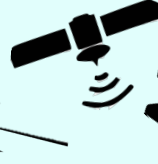
Composition and Function: A semiconductor is a material that allows current to flow more than an insulator but less than a pure conductor. Memory chips, microprocessors, and integrated chips are some examples of semiconductors. Semiconductors are made by imprinting a network of electronic components onto a semiconductor wafer. These devices are designed to perform various functions such as processing, amplifying and selectively filtering signals, controlling electronic system functions and processing, and transmitting and storing data.

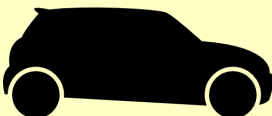### Products and Devices That Incorporate Semiconductors

GENERAL APPLICATIONS

Vehicles (See *Specific Cases*)	IT Devices (see *Specific Cases*)
Space Vehicles	Factory Automation Systems
Railcars	Appliances
Robotic Welding Machine	Smart Phones
Video Game Consoles	Supercomputers
Medical Diagnostic Equipment	Oil, Gas and NGL Pipelines
Data Center Servers	Military Weapons Systems

Embedded Systems (Small Computers that Form Part of a Larger Machine; They Control the Device and Allow User Interaction)

GPS Systems	TVs
Smart Watches	Fitness Trackers

Engine Management Systems

Central Heating Systems

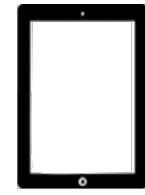| Thermoelectric Applications (including Lighting and LED Displays) |
|---|
| Radios |
| Telecommunications Networks |
| Networking Equipment |
| Solar Cells and Other Renewable Energy Systems |
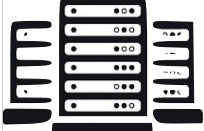
SPECIFIC CASES

Vehicles
The typical modern car is loaded with over 1,400 semiconductors to control safety, powertrain, electrical, comfort, infotainment, and connectivity systems. For this reason, vehicles are often referred to as "computers on wheels."

Connectivity
- Controller Area Network (CAN)
- Broadband, Wi-Fi, Bluetooth
- Over-the-Air Software Updates

Comfort
- Window/Mirror Controls
- Vibration Control
- Seat Controls
- Climate Controls
- Noise Suppression
- Adaptive Cruise Control

Infotainment
- Audio/Video
- Driver Display
- Navigation

Powertrain
- Engine Control
- Fuel-Injection System
- Hybrid-Electric Control
- Transmission Control
- Electric Power Steering

Safety
- Airbag Controls
- Collision Avoidance
- Parking-Assist
- Power Locks
- Braking-Assist
- Tire-Pressure-Monitoring
- Traction-Control System

Electrical
- Starter
- Lighter
- Vehicle-Diagnostics

IT Devices
Most people associate semiconductors with information technology devices, such as personal computers (desktop and laptop computers), mobile devices (smart phones and tablets), and servers in data centers.

Personal Computers
In 2021, approximately 342 million PCs were shipped around the world. It was expected that 310 million PCs were to be shipped in 2022. However, PC shipments only reached 286.2 million units (a 16.2% decrease from 2021). Most PCs include only one chip.

Mobile Devices
There are 6.6 billion smartphone subscriptions globally (91% of the world population). By 2027, the rise in the number of smartphone subscriptions is projected to grow to 7.7 billion. Current generations of smartphones come in a range of multi-range of processors, such as Dual-Core (2), Quad-Core (4), and Octa-Core (8), with the Octa-Core processor (used by Apple in iPhone 13 and 14) being the most powerful.

Servers
Servers today feature one or two x86 chips, or maybe an ARM processor. In 5 or 10 years they will feature many more. The typical data center with 850 Megawatts of capacity can run thousands to millions of servers:

- 6,314,256 Low-Powered 1U Servers
- 1,768,000 Mid-Powered 1U Servers
- 803,608 High-Powered 1U Servers

SEMICONDUCTOR ECOSYSTEM

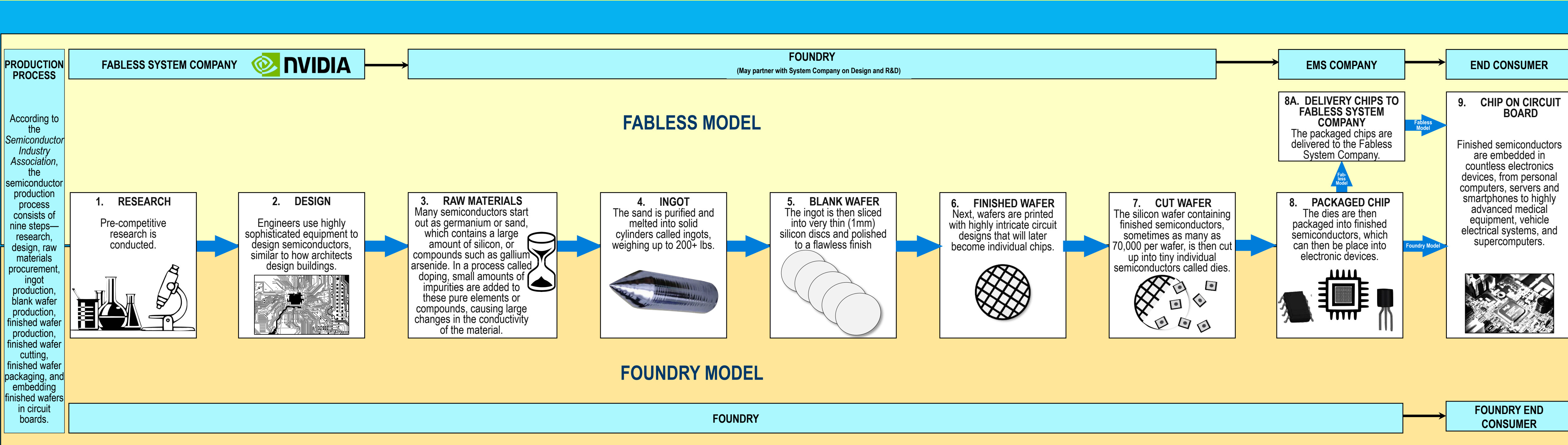### INDUSTRY PARTICIPANTS
Key semiconductor players include:

① SYSTEM COMPANIES
Semiconductor companies whose research and integrated circuit designs set the stage for chip production.
AMD, intel, Qualcomm, BROADCOM

② FOUNDRIES
Foundries or integrated circuit manufacturers perform front-end wafer manufacturing operations. The Foundry operator may be the System Company or a third-party contract manufacturer (if the System Company operates on a "fabless" basis).
tsmc, Infineon, Micron, intel

③ ELECTRONICS MANUFACTURING SERVICES
EMS companies provide integrated circuit assembly, packaging, testing, and repair services to the System Company (these companies are also capable of designing and manufacturing semiconductors).
Amkor Technology, JABIL, Foxconn, ASE GROUP

④ END CONSUMERS
End consumers are the original equipment manufacturers of electronic devices (or the makers of electronic components and assemblies of such devices) into which finished chips will be incorporated.
DELL Technologies, verizon, Ford, aws

PRODUCTION PROCESS
According to the *Semiconductor Industry Association*, the semiconductor production process consists of nine steps—research, design, raw materials procurement, ingot production, blank wafer production, finished wafer production, finished wafer cutting, finished wafer packaging, and embedding finished wafers in circuit boards.

FABLESS SYSTEM COMPANY — NVIDIA

FOUNDRY (May partner with System Company on Design and R&D)

EMS COMPANY

END CONSUMER

FABLESS MODEL

8A. DELIVERY CHIPS TO FABLESS SYSTEM COMPANY
The packaged chips are delivered to the Fabless System Company.

9. CHIP ON CIRCUIT BOARD
Finished semiconductors are embedded in countless electronics devices, from personal computers, servers and smartphones to highly advanced medical equipment, vehicle electrical systems, and supercomputers.

1. RESEARCH
Pre-competitive research is conducted.

2. DESIGN
Engineers use highly sophisticated equipment to design semiconductors, similar to how architects design buildings.

3. RAW MATERIALS
Many semiconductors start out as germanium or sand, which contains a large amount of silicon, or compounds such as gallium arsenide. In a process called doping, small amounts of impurities are added to these pure elements or compounds, causing large changes in the conductivity of the material.

4. INGOT
The sand is purified and melted into solid cylinders called ingots, weighing up to 200+ lbs.

5. BLANK WAFER
The ingot is then sliced into very thin (1mm) silicon discs and polished to a flawless finish

6. FINISHED WAFER
Next, wafers are printed with highly intricate circuit designs that will later become individual chips.

7. CUT WAFER
The silicon wafer containing finished semiconductors, sometimes as many as 70,000 per wafer, is then cut up into tiny individual semiconductors called dies.

8. PACKAGED CHIP
The dies are then packaged into finished semiconductors, which can then be place into electronic devices.

FOUNDRY MODEL

FOUNDRY

FOUNDRY END CONSUMER

CHIPMAKERS

SYSTEM COMPANIES
The numerous chipmakers range from (1) household names with global reach to (2) smaller suppliers little known outside their specialized market niche. Semiconductor firms focus their operations around one of three models:

⑤ FABLESS
Fabless companies focus only on chip design and then outsource the manufacturing of their chip designs to third party producers (e.g., Qualcomm).

⑥ INTEGRATED DEVICE MANUFACTURERS (IDMs)
IDMs conduct both design and manufacturing activities (e.g., Intel).

⑦ FOUNDRIES
Pure-play foundries are companies that focus primarily on manufacturing for third parties (e.g., TSMC).

FABLESS
MEDIATEK, Qualcomm, TOSHIBA, AMD, BROADCOM, HUAWEI, HISILICON (Huawei-Owned), SONY, NVIDIA, arm, Apple (Apple-Designed, TSMC-Produced), NXP

INTEGRATED DEVICE MANUFACTURERS
FUJITSU, intel, Micron, SAMSUNG, TEXAS INSTRUMENTS, Infineon, RENESAS, ST, SK hynix

PURE-PLAY FOUNDRIES
GlobalFoundries, tsmc, UMC

CHIP TYPES

KEY CHIP CATEGORIES
Semiconductors can be divided into five main categories:

⑧ MEMORY CHIPS

⑨ CPUs, MICROPROCESSORS AND MICROCONTROLLERS

⑩ INTEGRATED CIRCUITS

⑪ GPUs

⑫ SoCs

⑧ MEMORY CHIPS
A memory chip is a semiconductor comprising numerous capacitors and transistors that can hold data (a) temporarily through random access memory (RAM) or (b) permanently through read only memory (ROM). Memory chips can be volatile (i.e., require power to maintain the stored information) or non-volatile (i.e., does not require a continuous power supply to retain the data or program code stored in a computing device).

⑨ CPUs, MICROPROCESSORS AND INTEGRATED CIRCUITS

CENTRAL PROCESSING UNITS (CPUs)
The CPU is a chip that functions as the brains of the personal computer (PC). Also called the central processor, main processor or just process, the CPU is made up of a set of electronic circuits that execute instructions comprising a computer program to perform basic arithmetic, logic, controlling and I/O (input/output) operations specified in computer program.

MICROPROCESSORS
Microprocessors are used in (and mounted on the mother-boards of) virtually all desktop and laptop computers. They are also found in other types of electronic equipment, such as cell phones, tablets, and cars. Microprocessors require extremely precise manufacturing to function properly, are power-hungry, and are better suited for more demanding tasks. They respond to user input, process instructions and perform the calculations and logic operations used to run software programs—i.e., play games, browse websites, edit photos, create documents, stream media, and perform mathematical calculations. The microprocessor contains all the components found in an integrated circuit — a CPU, input *b*utput ports, and memory — but it also includes its own non-volatile storage for programs and data. This allows users to run software on computers without needing additional hardware devices.

MICROCONTROLLERS
In contrast to the microprocessor (which are used in applications where (a) the task is not pre-defined but depends on the user or (b) intensive processing is required), a **microcontroller** is used for a specific task. Based on input given by the user or a sensor, the microcontroller performs a light amount of processing and gives the result as an output. Examples include the washing machine and microwave oven, where the task is pre-defined -- once the user sets the power and timing, the microwave gives the user cooked food; once the user sets the parameters, the washing machine gives the user clean clothes.

⑩ INTEGRATED CIRCUITS

INTEGRATED CIRCUITS (ICs)
Integrated circuits are general-purpose devices that can be used for a variety of purposes and are found in everything from cell phones to cars to spacecraft. Unlike the microprocessor, which is designed to run software applications and gives better performance, integrated circuits are ideal for smaller applications that don't require as much computing power. Integrated circuits allow devices to be smaller and more lightweight. However, an integrated circuit cannot function independently because it doesn't have any program instructions or other information stored inside itself. In general, there are three types: (1) commodity integrated circuits (*CIC*s), which are simple chips produced in large batches and used in single purpose appliances to perform repetitive processing routines (e.g., barcode scanners), (2) ICs made for a specific purpose, called application-specific integrated chip (*ASIC*) and (3) the all-in-one "system on a chip" (*SoC*), one of the newer types of chips.

⑪ GPUs

GRAPHICS PROCESSING UNITS (GPUs)
A type of microprocessor, a **graphics processing unit** (GPU) is capable of rendering graphics display on an electronic device, such as a gaming console or vehicle infotainment system. GPUs also have application for video editing and content creation, machine and deep learning, and artificial intelligence (AI).

⑫ SoCs

SYSTEMS ON A CHIP (SoCs)
A form of integrated circuit, the SoC is among the newest types of chip. All the electronic components needed for an entire system (i.e., CPU, Random Access Memory (or RAM), storage, I/O (input/out ports) are built into a single chip. SoCs break from the traditional approach to system architecture (e.g., with motherboards) where each component is discretely installed. This enables the creation of smaller and more efficient devices. For this reason, SoCs are driving innovation in the creation of netbooks, laptops, smartphones, Internet of Things (IoT) devices.

SoC without Cover — SoC with Cover

OTHER

ANALOG CHIPS
Analog chips have been mostly, but not entirely, replaced by digital chips, but they are still required for wideband signals and used as sensors. In analog chips, voltage and current vary continuously at specified points in the circuit.