Deliver the promise of renewable energy with smarter semiconductor solutions

The Promise of Solar Energy

Global installed power generation capacity is forecasted to rise from 5,015GW in 2010 (*Source: Frost and Sullivan, see Figure 1*) to 7,906GW in 2030, with electricity generation rising from 20,834TWh to 32,750TWh over the same period. To meet this demand for electrical energy, the installed generation capacity will have to be grown by 58% in 2030 (compared to 2010 levels).

This demand could be met, in principle, from fossil energy resources such as coal. However, the cumulative nature of CO_2 emissions in the atmosphere and its effects on global warming, bring questions to this approach. Energy security, national security, environmental security, and economic security are factors that can be linked to this need for a clean source of energy. The supply of secure and clean sustainable energy is arguably the most important scientific and technical challenge facing humanity in the 21st century.

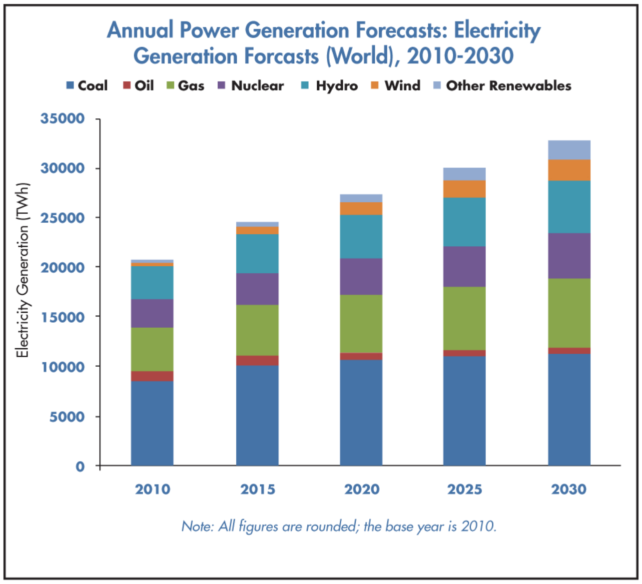


Figure 1: Source: Frost and Sullivan Report 2010

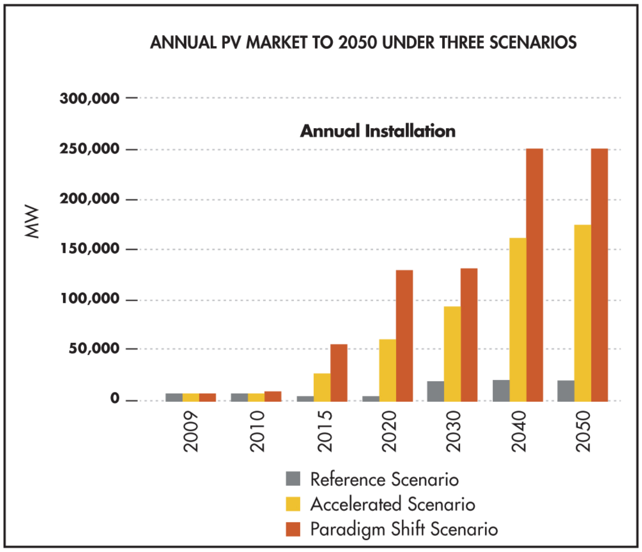


Figure 2: Source: EPIA 2010

Sun—the largest energy source available—provides more energy to the earth in one hour than consumed by humans in one year. While the harvested contribution of this solar energy is a very small portion of today's global power generation mix, it has been steadily growing over the last ten years. The EPIA forecasts that global Solar Power Generation capacity will reach 1,100GW by 2030 from 32GW in 2010 (under an accelerated forecast scenario, see *Figure 2*). This represents a growth from 0.6% of total power generation capacity in 2010 to 13% of total global power generation capacity in 2030.

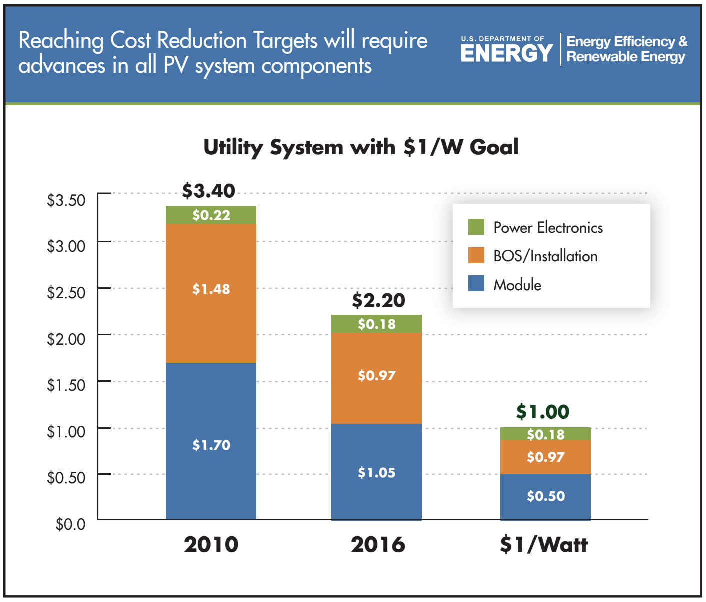


Figure 3: Source: Frost and Sullivan Report 2010

Challenges Facing Solar Power Generation

The growth of this global solar energy generation market is not without its challenges. Higher cell efficiency, lower system costs, reliability and geopolitical systems all pose challenges to this market's growth. The cost of a solar electric system is represented as dollar/watt. The current cost of a utility based solar electric system is $3.3/W (*Source: DOE*). Government programs, such as the SunShot initiative, are funding research to help drive down the cost to $1/W to help this market expansion. The different cost components that make up this system cost are provided in *Figure 3*. The panels represent more than 50% of the system cost; the balance of system (BOS) represents 43% and solar inverters represent 6%. In order to reach the aggressive $1/W target, advancement in all PV system components is compulsory. Power electronics, while a small portion of the total cost, will drive harvesting efficiency and therefore is critical.

Panel manufacturers have made significant progress in cost reductions through new manufacturing processes and improvements in the conversion efficiencies of the solar cells. As the panel costs drop further in the future, the BOS and Solar Inverter costs will become a dominant part of the total system cost.

New, innovative power electronic technologies are required to help solar inverter manufacturers reduce cost, improve efficiency and improve reliability. Semiconductor companies, such as Fairchild Semiconductor, with a long history of technology and manufacturing excellence, will be able to help meet these demands.

Renewable Energy Home

One significant advantage of solar energy generation is that it can be easily scaled down so that the generation, distribution and use of the energy are accomplished "locally." Whereas the use of individual wind turbines in rural environments is certainly possible, the concept of generating solar power for use within a home or building minimizes the potential issues (noise, aesthetics) often associated with wind power technology, simplifies the transmission of the electricity and allows for a fully integrated and manageable micro-energy system.

The Renewable Energy Home features systems and products that are now both technologically feasible and cost effective. The DC output from the PV modules is limited by the amount of sun energy, location, size and efficiency of the module. Improvements in semiconductor components coupled with advancements in battery technology make possible the implementation of all the functions cited in *Figure 4*, including energy harvesting, conversion, storage and distribution. For the purposes of this paper, our primary focus will be on the first two stages—energy harvesting and conversion.

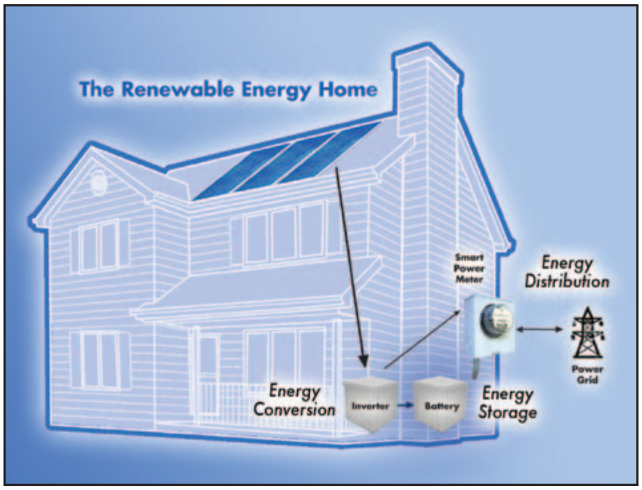


Figure 4

Energy Harvesting and Conversion

While the scale and deployment of systems designed to harvest and convert solar energy into electrical energy can be seen in individual homes, in communities and across geographic regions, the fundamental process in every system is essentially the same:

1. Conversion of solar energy to electrical (DC) power
2. Combining the DC output from each PV module
3. Conditioning of the DC power into higher voltage DC
4. Conversion from DC–AC
5. Interfacing to the grid

From a component standpoint, steps 2, 3 and 4 represent both the challenge and the opportunity to enhance the performance of the system through the maximization of efficiency and reliability, and the minimization of losses and cost. The core of this part of the system is the inverter that performs the boosting of the DC power and the conversion to AC. The designer must then make a careful choice as to the inverter topology and the components used to implement the selected topology. There are two primary ways to achieve this function: (1) central inverter topology and the (2) micro inverter topology.

Central Inverter Topology

In the central inverter system, the Maximum Power Point Tracking System (MPPT) is done centrally. Therefore, these are often known as C-MPPT systems (or "string" or "traditional" systems). Fundamentally, this inverter involves a power control unit which converts the DC output from a string of solar cells to AC power (*see Figure 5*). The output from the PV cells is typically between 150V and $1000V_{dc}$ and can produce in excess of 1kW of AC power.

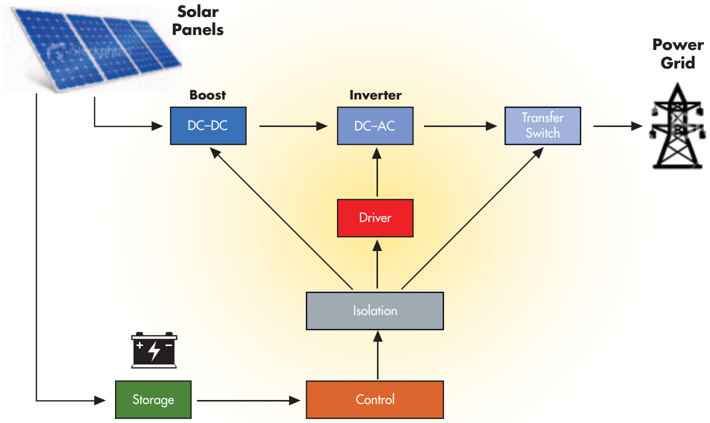
The traditional architecture uses a boost stage followed by an inverter stage using various isolated and non-isolated coupling schemes in order to maximize efficiency. Careful selection of the IGBTs and diodes is essential in order to achieve the optimum balance between switching speeds, fast recovery and power dissipation.

The three most popular topologies used in central inverters are listed below along with characteristics of each:

1. **Boost Converter and Full-Bridge Inverter**
   - Non-Isolated
   - Higher efficiency than isolated inverter topology
2. **Full-Bridge Converter and Full-Bridge Inverter**
   - Isolated PV module from grid
   - Lower efficiency than single stage inverter
3. **Boost Converter and Three-Level Inverter**
   - Used for higher input voltages ($700V_{dc}$)
   - Higher efficiency than two level inverter
   - Low-cost output filter

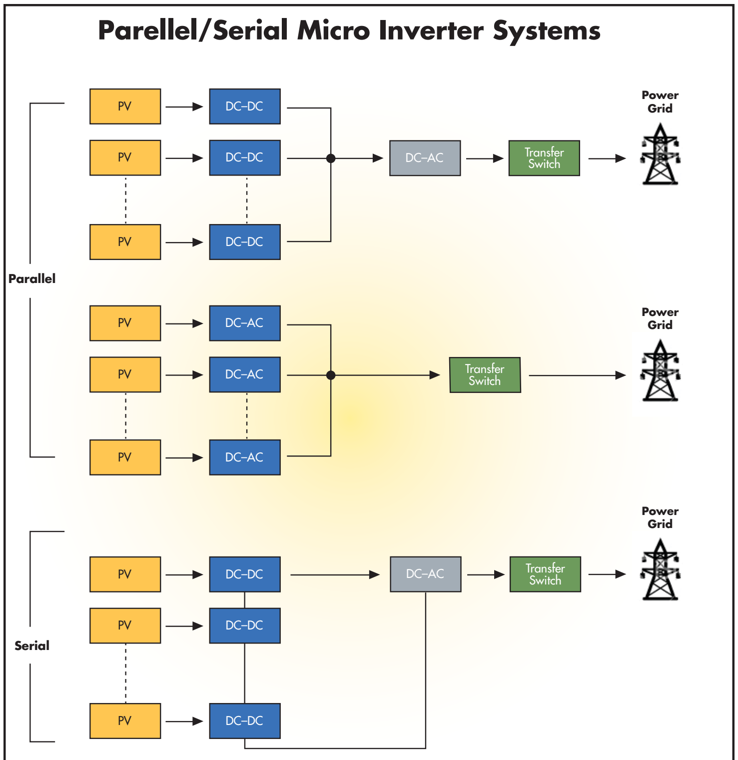
Potential drawbacks of the central inverter architecture are: (1) it is "centralized" and thus more prone to single point failures and, (2) individual components have to handle higher power levels and therefore require the selection of more robust and often higher priced components.

Central Inverter Topology



Central Inverter systems consist of a power control unit which converts the DC output from a string of solar cells to AC power.

Figure 5



Micro Inverter technology minimizes the amount of power handled by each inverter, thus reducing the demands on the individual component.

Figure 6

Micro Inverter Technology

This inverter topology is very similar to the central inverter architecture, but the power conditioning is distributed; that is, multiple inverters are connected to individual PV panels (*see Figure 6*). This approach minimizes the amount of power handled by each inverter, thus reducing the demands on the individual component.

The salient features of this topology include:

- MPPT is performed on the output from each PV module
- Individual failure does not impact entire system
- Individual modules can be maintained while the system continues to function
- No DC wiring or blocking diode required

Component selection for micro inverter topologies requires the application of medium voltage MOSFETs, high speed switching and low $R_{DS(ON)}$ devices. The tradeoff of "parallel" processing in a micro inverter vs. the central inverter topology requires careful analysis of the overall system migration path, initial vs. long term cost, reliability, complexity and maintenance schedules.

Component Choices for Efficient, Cost-Effective and Reliable Implementations

Regardless of which topology is used, designers must make careful choices when selecting the individual components. The necessary improvements in performance, cost, reliability and efficiency require special attention to the following factors and their ultimate impact on the overall system:

- **Component count**
  - Cost
  - Size
  - Total power dissipation
  - Reliability
- **Heat/thermal management**
  - Reliability
  - Size/weight
  - Cost
- **Minimization of losses and parasitics**
  - System performance
  - Total power dissipation

Fairchild Semiconductor is committed to the development of components that will help designers implement systems optimized for these three important factors.

Overall system cost and efficiency are being driven by the PV module. Recent technological advances in cadmium telluride thin films will certainly improve the electric output from the PV modules while simultaneously reducing cost. The introduction of high volume manufacturing techniques, along with the integration of semiconductors into the PV modules, will continue to drive down the cost of the cells.

From the components side, manufacturers are also improving the efficiency, reliability and cost of each device. Key building blocks from Fairchild Semiconductor for future harvesting and conversion implementations include:

- **IGBTs** such as the “field stop” technology from Fairchild featuring high current handling capability, low conduction and switching cost, positive temp coefficient, tight parameter distribution and large safe operating area.

- Fairchild’s **High-Voltage MOSFETs** such as the SuperFET®, SuperFET® II and SupreMOS® MOSFETs featuring multi-Epi processing, low $R_{DS(ON)}$ and fast switching.

- **Mid-Voltage MOSFETs** such as Fairchild’s PowerTrench® technology with low $R_{DS(ON)}$, low reverse recovery charge, incorporating soft reverse recovery body diode and which are 100% avalanche tested.

- **Optically Isolated Gate Drivers** such as the FOD31xx family from Fairchild featuring wide operating voltage range, output voltage swing close to the rail, high common mode transient immunity and 5kV isolation voltage rating.

- **High-Speed Low-Side Gate Drivers** such as the 20V FAN31xx and FAN32xx series that includes 1A to 9A peak drivers that offer an unequaled combination of high performance switching and time, flexible input and logic, and package options.

- **High-Voltage Gate Drivers** such as the FAN73xx series from Fairchild with excellent noise immunity, low power consumption, matched propagation delay and extended allowable negative V_S swing.

- **Bypass and Blocking Diodes** such as the MBR series, FYD0504SA and SB1245 Shottky diodes and rectifiers can be used in a bypass configuration with each PV cell to maximize energy system output, and utilized in a blocking function to prevent energy loss in storage systems.

- **High-Voltage Silicon Carbide [SiC]** devices as the next wave of semiconductor technology suitable for the solar market. Fairchild’s Silicon Carbide bipolar transistors operate with as much as 4x higher power density and less than half of the switching and conduction losses of the best silicon devices. In addition to over 250°C operation and ability to withstand avalanche voltage and short circuit stresses exceptionally well, the devices offer significant improvement on both cost and efficiency in energy conversion systems as well as higher reliability.

Complementary Renewable Technologies

Taking a broader point of view, other technologies are needed to allow for the full potential of energy harvesting and conversion. These can best be viewed from the perspective of the Renewable Energy Home, as cited in (*Figure 4*):

Energy Storage—the AC output from the inverter can be stored in a residential battery pack, typically with a 1kW capacity. System requirements of such battery units include high performance safety, rapid recharging and a long lifespan. Fairchild 600V SuperFET and 600V SupreMOS MOSFETs are ideal for the bi-directional buck/boost converter in these systems, and our field stop IGBTs meet the demands of the bridge inverter.

Energy Distribution—an example is the smart meter. This system monitors energy use and then relays the information to the utility, via either a wired or wireless interface. It can also be used to manage energy usage by allowing for the remote control of appliances and systems during peak and non-peak periods. Fairchild provides low-power AC-DC solutions for smart meter power with integrated FET converters with up to 650V rating and controllers coupled with ESBC high-voltage switches for 1300V or higher rated solutions. For service disconnect solutions, Fairchild's family of low-side gate drivers is ideal.

Another distribution example might be the electric vehicle parked in the driveway of our renewable energy home. A battery charger on-board the vehicle or off-board at the charging station will be required to deliver the solar energy that has been harvested, converted and stored. Fairchild MOSFETs, diodes and IGBTs cited above are performance-optimized for these systems as well.

Fairchild also provides MOSFETs (SuperFET or SupreMOS 600V), diodes, IGBTs, high voltage gate drivers, optically isolated gate drivers and highly efficient, with low standby capability, PWM controllers available with or without integrated MOSFETs.

Energy Conservation—the more energy is saved, the less that is needed for generation. Up to 10% of residential energy usage goes to standby power losses. Fairchild offers mWSaver™ technology products for power adapters, computers, displays and other consumer equipment that can cut standby power by 80%. Furthermore, our SPM® (Smart Power Modules) help to reduce the energy consumed by motors in white goods and other home appliances. And our LED controllers and components are helping to bring energy savings to lighting requirements inside and outside homes and offices.

As demonstrated here, a significant industry focus has been placed on solving the technical challenges associated with energy harvesting and conversion. Companies, such as Fairchild Semiconductor, continue to develop advancements in component performance, reliability and cost which are doing their part to help deliver the promise of renewable energy. Look for additional insights on energy storage, energy distribution and energy conservation on *www.fairchildsemicom*.

FOR INFORMATION ON FAIRCHILD PRODUCTS, TRADESHOWS, SEMINARS AND OTHER ITEMS, REGISTER HERE:
www.fairchildsemi.com/my_fairchild

For data sheets, application notes, samples and more, please visit: **www.fairchildsemi.com**

PRODUCTS | APPLICATIONS | DESIGN SUPPORT | ABOUT FAIRCHILD

POWER MANAGEMENT

Power Factor Correction
- Continuous Conduction Mode (CCM) PFC Controllers
- Critical/Boundary Conduction Mode (CrCM/BCM) PFC Controllers
- Interleaved PFC Controllers
- PFC + PWM Combination (Combo) Controllers

Off-Line and Isolated DC-DC
- AC-DC Linear Regulators
- Flyback & Forward PWM Controllers
- Flyback & Forward PWM Controllers with Integrated MOSFET
- LLC Resonant & Asymmetric Half Bridge PWM Controllers
- LLC Resonant & Asymmetric Half Bridge PWM Controllers with Integrated MOSFETs
- Primary-Side Regulation CV/CC Controllers
- Primary-Side Regulation CV/CC Controllers with Integrated MOSFET
- Standard PWM Controllers
- Supervisory/Monitor ICs
- Synchronous Rectifier Controllers

Non-Isolated DC-DC
- Charge-pump Converters
- DrMOS FET plus Driver Multi-Chip Modules
- Step-down Controllers (External Switch)
- Step-down Regulators, Non-Synchronous (Integrated Switch)
- Step-down Regulators, Synchronous (Integrated Switch)
- Step-up Regulators (Integrated Switch)

MOSFET and IGBT Gate Drivers
- 3-Phase Drivers
- Half-Bridge Drivers
- High- & Low-Side Drivers
- High-Side Drivers
- Low-Side Drivers

Voltage Regulators
- LDOs
- Positive Voltage Linear Regulators
- Negative Voltage Linear Regulators
- Shunt Regulators
- Voltage Detector
- Voltage Stabilizer
- Voltage to Frequency Converter

Motion Control
- BLDC/PMSM Controller
- Motion-SPM™ (Smart Power Modules)
- PFC SPM® (Smart Power Modules)

Diodes & Rectifiers
- Bridge Rectifiers
- Circuit Protection & Transient Voltage Suppressors (TVS)
- Diacs
- Rectifiers
- Schottky Diodes & Rectifiers
- Small Signal Diodes
- Zener Diodes

IGBTs
- Discrete IGBTs
- Ignition IGBTs

MOSFETs
- Discrete MOSFETs
- Level-Shifted Load Switches
- MOSFET/Schottky Combos

Transistors
- BJTs
- Darlingtons
- Digital/Bias-Resistor Transistors
- JFETs
- RF Transistors
- Small Signal Transistors

Advanced Load Switches
- Advanced Current Limited Load Switches
- Slew Rate Controlled Load Switches

Battery Management
- Battery Charger ICs

Ground Fault Interrupt
- Ground Fault Interrupt (GFI) Controllers

Backlight Unit (BLU)
- CCFL Inverter ICs

SIGNAL PATH ICs

Amplifiers & Comparators
- Comparators
- Operational Amplifiers

Audio Amplifiers
- Audio Subsystems
- Audio Headphone Amplifiers
- Digital Microphone Amplifiers

Battery Protection ICs
- Battery Protection ICs

Interface
- LVDS
- Serializers/Deserializers (μSerDes™)
- USB Transceivers

Signal Conditioning
- Video Filter Drivers
- Video Switch Matrix/Multiplexers

Signaling, Sensing & Timing
- Signaling, Sensing & Timing
- Timing

Switches
- Accessory Switches
- Analog Switches
- Audio Jack Detection Switches
- Audio Switches
- Bus Switches
- MIPI Switches
- Multimedia Switches
- USB Switches
- Video Switches

LOGIC

Buffers, Drivers, Transcievers
- Buffers
- Line Drivers
- Transceivers

Flip Flops, Latches, Registers
- Counters
- Flip Flops
- Inverters
- Latches
- Registers

Gates
- AND Gates
- NAND Gates
- OR Gates
- NOR Gates
- Schmitt Triggers
- Configurable Gates

Multiplexer / Demultiplexer / Decoders
- Decoders
- Demultiplexers
- Multiplexers
- Multivibrators

Voltage Level Translators
- Voltage Level Translators

LIGHTING ICs
- Fluorescent Lamp ICs
- HID ICs
- LED Lighting ICs
- Portable LED Drivers

OPTOELECTRONICS

High Performance Optocouplers
- Low Voltage, High Performance
- High Speed Logic Gate
- High Performance Transistor
- IGBT/MOSFET Gate Driver
- Specific Function

Infrared
- Emitting Diodes
- Photo Sensors
- Photo Sensor – Transistors
- Ambient Light Sensors
- Reflective Sensors
- Optical Interrupt Switches

Phototransistor Optocouplers
- Isolated Error Amplifier
- Phototransistor Output - DC Sensing Input
- Phototransistor Output - AC Sensing Input
- Photo Darlington Output

TRIAC Driver Optocouplers
- Random Phase TRIAC Driver
- Zero Crossing TRIAC Driver

AUTOMOTIVE PRODUCTS

Automotive Discrete Power
- Automotive Ignition IGBTs
- Automotive IGBTs
- Automotive N-Channel MOSFETs
- Automotive P-Channel MOSFETs
- Automotive Rectifiers

Automotive High Voltage Gate Drivers (HVICs)
- Automotive High Voltage Gate Drivers (HVICs)

High Side Smart Switches
- High Side Smart Switches

Solutions for Your Success™