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Solar Energy Technologies *A Review of Conversion, Solar Heating, Hybrid Systems, Solar Cooling and Applications*

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ABSTRACT :

Solar energy technologies convert sunlight into electricity, useful heat, cooling, or a combination of services. This paper reviews the principal technology families represented in the supplied term-paper references: photovoltaic (PV) conversion, solar thermal collectors, concentrating solar power, photovoltaic-thermal (PV/T) systems, hybrid energy systems, solar cooling, thermal and electrical storage, and solar-assisted end uses. It synthesizes the reported work on building systems, water heating, air heating, cooling, desalination, rural energy, and energy storage. The evidence shows that system performance depends on more than the efficiency of a collector or module. Resource conditions, temperature requirements, storage, controls, auxiliary power, water use, affordability, and system boundaries determine useful output. Hybridization can improve continuity and make better use of captured solar energy, but adds equipment and operational complexity. Reported numerical results are study-specific and are not directly ranked because methods, climates, and boundaries differ. The review concludes that solar installations should be selected and assessed against a defined service need using transparent energy, cost, reliability, and lifecycle measures.

Keywords: solar energy; photovoltaic; solar thermal; concentrating solar power; PV/T; storage; hybrid systems; solar cooling.

I. Introduction

Solar radiation is a widely available energy resource, but its conversion into dependable services requires technologies that match the timing and quality of supply to demand. Photovoltaic modules produce electricity, while thermal collectors capture heat at temperatures suited to water heating, space conditioning, drying, or industrial processes. Concentrating systems can deliver higher-temperature heat, and hybrid arrangements connect solar devices with storage, heat pumps, biomass, geothermal energy, wind, or conventional energy networks. These combinations are increasingly relevant where users need service after sunset or during variable weather [1]–[3].

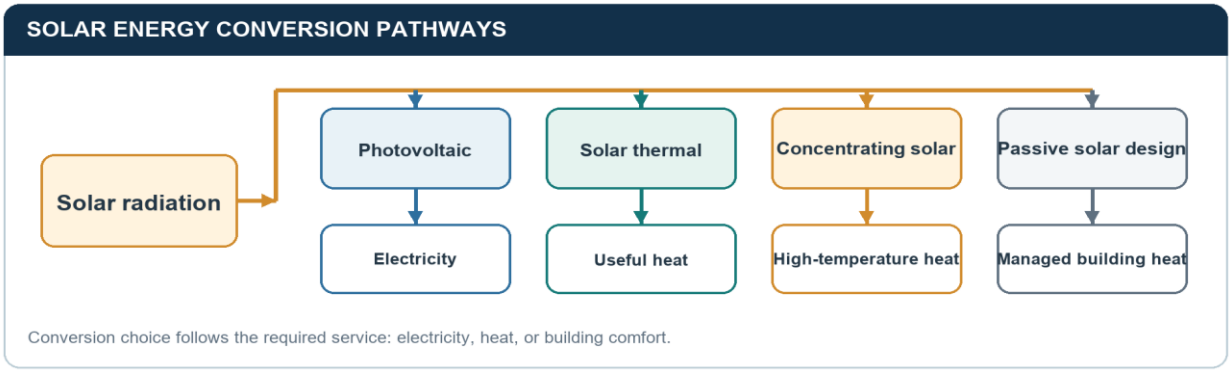


Fig. 1. Main pathways for converting or using solar radiation.

The topic “Solar Energy Technologies” covers both conversion devices and the systems surrounding them. A module-level efficiency does not describe how much useful electricity reaches a load after inverter, storage, and wiring losses. A collector’s thermal efficiency alone does not show whether the heat is available at the required temperature or when it is needed. A useful comparison therefore begins with the service delivered: electricity, hot water, cooling, process heat, or a combination. It then considers the local solar resource, demand profile, equipment, operating strategy, and system boundary.

II. Background and Review Framework

2.1 Solar radiation and conversion pathways

Solar systems receive direct and diffuse radiation. Their output varies with location, season, cloud cover, orientation, shading, and temperature. PV cells absorb photons and separate charge carriers to generate direct-current electricity; power electronics convert this output for appliances or the grid. Solar thermal collectors absorb radiation as heat and transfer it to water, air, or another working fluid. Concentrating solar power (CSP) uses optical surfaces to focus direct sunlight onto a receiver, producing heat that can drive a power cycle or serve a thermal load. Passive solar design instead uses building orientation, glazing, shading, and thermal mass to manage heat without a separate conversion device.

2.2 Scope and review method

This is a narrative synthesis of the three supplied student reports: a report on solar cooling, a report on solar heating, and a report on hybrid solar energy [1]–[3]. Their chapters and cited studies were used to identify technical principles, applications, findings, and limitations. The reports include reviews, simulations, experiments, and case studies. This paper summarizes those findings as reported and does not treat the student reports as interchangeable primary experiments. Results retain their original context; the review does not calculate a pooled performance ranking.

2.3 Assessment criteria

Technology selection should consider useful energy delivered, temperature or electrical quality, annual yield, reliability, storage losses, auxiliary electricity, operating cost, emissions, maintenance, and end-user affordability. For cooling, relevant measures include cooling capacity, coefficient of performance, module temperature, and pumping or fan power. For heating, useful heat and its temperature profile matter. For hybrid systems, renewable contribution and unmet demand must be reported alongside cost and reliability. These measures provide a common decision framework even when unlike technologies cannot be compared using one efficiency figure.

III. Photovoltaic Technologies

3.1 PV conversion and system components

PV modules convert incident light into electricity through semiconductor junctions. A practical installation also includes mounting structures, cabling, inverters, protection devices, monitoring, and—in off-grid or backup systems—batteries or other storage. System output depends on irradiance, module temperature, orientation, shading, conversion losses, and component availability. The supplied hybrid-energy report describes PV in combinations with batteries, hydrogen, wind, geothermal-supported buildings, biomass, and water or food applications [3]. Such cases illustrate that the module is one component of a larger service system.

3.2 Temperature and active cooling

PV modules convert only part of absorbed solar energy into electricity; the remainder contributes to heat. Elevated cell temperature can lower electrical output, making thermal management relevant in hot climates and concentrated PV. The solar-cooling reference describes natural and artificial cooling, air flow, water spray, evaporative approaches, and intelligent pump control [1], including neural-network control methods [4]. Cooling can reduce module temperature, but its net value depends on the electricity consumed by pumps or fans, the water required, control reliability, and maintenance. A reduction in cell temperature is not sufficient evidence of a net energy benefit unless auxiliary consumption is included.

3.3 PV/T systems

A PV/T collector combines electrical generation with thermal extraction. Air or liquid circulated behind or around PV cells can collect heat while limiting cell temperature. The recovered heat may support hot water or preheating, while the PV layer supplies electricity. This arrangement can make more complete use of a roof or collector area when both outputs have a useful destination. However, electrical and thermal performance are coupled: stronger heat extraction can increase thermal output and improve cell temperature, but pumps, pressure drop, temperature lift, and operating conditions affect the total result. The supplied cooling report reviews several PV/T heat-extraction methods and cautions that definitions and units must remain clear when performance claims are compared [1], [5].

3.4 Hybrid solar cells

The hybrid-energy reference also discusses organic–inorganic hybrid solar cells, where material combinations are intended to join complementary optical, electrical, or processing properties [3]. This is distinct from a hybrid energy system: the former refers to semiconductor and photovoltaic materials, while the latter combines resources, storage, or end-use equipment. The supplied review is historical, so it provides background on material concepts rather than a current benchmark of commercial cell performance [12].

IV. Solar Thermal and Concentrating Technologies

4.1 Solar water and space heating

Solar water-heating systems use collectors to transfer solar heat to a water store or directly to a load. Common designs use glazed flat plates or evacuated tubes; system layouts may circulate water directly or use a heat-transfer fluid and heat exchanger. The water-heating study summarized in the solar-heating report emphasizes operating controls: demand, weather, electricity prices, and auxiliary heating can influence when pumps and backup equipment should run [2]. Control strategies can improve the timing of useful heat, but their value depends on forecasts, sensors, user demand, and tariff conditions.

Buildings can also use solar gains passively through orientation, glazing, insulation, shading, and thermal mass. Solar air heaters warm ventilation air for space heating or drying. Their design balances heat transfer against pressure drop and fan power. The review summarized in [2] describes absorber modifications and collector geometries intended to improve air-side heat transfer while limiting parasitic energy. Applications include crop drying, building ventilation, and process heat where warm air is directly useful [11].

4.2 Concentrating solar power

CSP systems use mirrors or lenses to concentrate direct solar radiation onto a receiver. The receiver heats a fluid that may produce steam, drive a turbine, or supply industrial heat. Higher operating temperature can support power-cycle efficiency and thermal storage, but CSP depends strongly on direct normal irradiance and requires optical tracking, field maintenance, and careful thermal management. Thermal energy can be stored before conversion, allowing dispatch after the solar field stops producing. The supplied review of solar thermal storage stresses that material choice, heat exchangers, charging and discharging rates, cycling, and plant operation must be designed together [2], [6].

4.3 Thermal storage methods

Sensible-heat storage raises the temperature of a medium such as water, oil, rock, or molten salt. Latent-heat storage uses a phase change, often to store substantial heat over a narrow temperature interval. Thermochemical storage relies on reversible reactions or sorption processes and may offer compact or longer-duration storage, though reaction kinetics, heat transfer, stability, and containment can be challenging. Metal hydrides are one thermochemical route discussed in the supplied solar-heating review for concentrating solar heat [2], [7]. Across storage types, theoretical capacity must be distinguished from useful capacity delivered at the required rate and temperature.

V. Hybrid Systems, Storage, and Controls

5.1 Why hybridize solar energy

Solar output varies over time; hybridization combines it with a complementary resource, conversion device, or store. PV paired with batteries can shift electricity across hours. PV coupled to a heat pump can supply a portion of building heat, while a thermal store shifts heat production away from immediate demand. Solar and geothermal systems can combine intermittent surface energy with ground-source heating or cooling. Solar-biomass combinations may use biomass as a dispatchable backup, while wind-PV systems can diversify generation profiles. These examples appear in the supplied hybrid-energy report, which covers buildings, rural electrification, cooking, aquaculture, desalination, and PV-battery-hydrogen management [3].

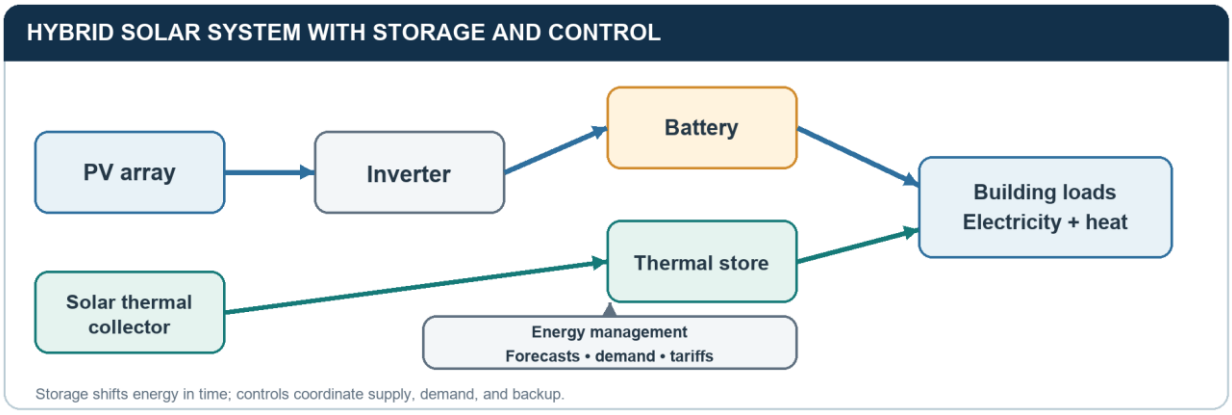


Fig. 2. Hybrid solar system linking generation, storage, end uses, and control.

5.2 Thermal and electrical integration

Integration creates interactions across equipment and networks. A solar-powered heat pump converts electricity into heat; its coefficient of performance

varies with source and delivery temperatures. A battery stores electricity but incurs charge-discharge losses, degradation, and replacement cost. Thermal storage can be a lower-cost means of shifting heating or cooling loads where the final service is heat or cold. The solar-heating report describes a market model in which consumers' PV, heat pump, and thermal-storage investments interact with electricity and district-heating prices [2]. Its modeled cost reductions depend on network conditions and consumer response rather than representing guaranteed savings for every location.

5.3 Control and energy management

Controls decide when to collect, store, release, or supplement solar energy. They can respond to temperature, demand, weather forecasts, electricity tariffs, or equipment constraints. The supplied studies include optimized solar water-heater operation, forecast-aware cooling of PV modules, and energy management of PV-battery-hydrogen systems [1]–[3]. A sound controller should optimize a defined service objective while respecting comfort, safety, storage limits, and equipment lifetime. Reported simulation improvements require field validation under changing weather, real user schedules, sensor errors, and component degradation.

5.4 Solar energy storage beyond batteries

The supplied solar-heating review also discusses a proposed solar-integrated liquid-air energy storage system. It uses recovered compression heat and solar thermal input at different stages of an electricity-storage cycle [2]. The paper reports modeled improvements in round-trip and combined heat-and-power efficiency relative to its reference configuration, with the combined measure counting useful heat as well as electricity. That boundary matters: a combined efficiency above 100 percent is possible when multiple useful outputs are summed against an electricity input, but it is not an electricity-only conversion efficiency. Such results should be interpreted using the paper's stated definitions and cost assumptions.

VI. Solar Cooling and Thermal Management

6.1 Photovoltaic-powered cooling

PV electricity can operate conventional vapor-compression air conditioners, refrigerators, pumps, or fans. Solar supply can coincide with daytime cooling demand, but system design still needs to account for peak loads, inverter sizing, cloud variability, and storage or grid backup. Cooling demand can also peak when PV temperature is high, linking generation and end-use performance. The solar-cooling report reviews PV module cooling and active systems, including a neural-network and Internet-of-Things concept that seeks to control pump power according to irradiance and cell temperature [1]. The reported reduction in cooling-system power is tied to the study's modeled comparison and requires field verification before being generalized.

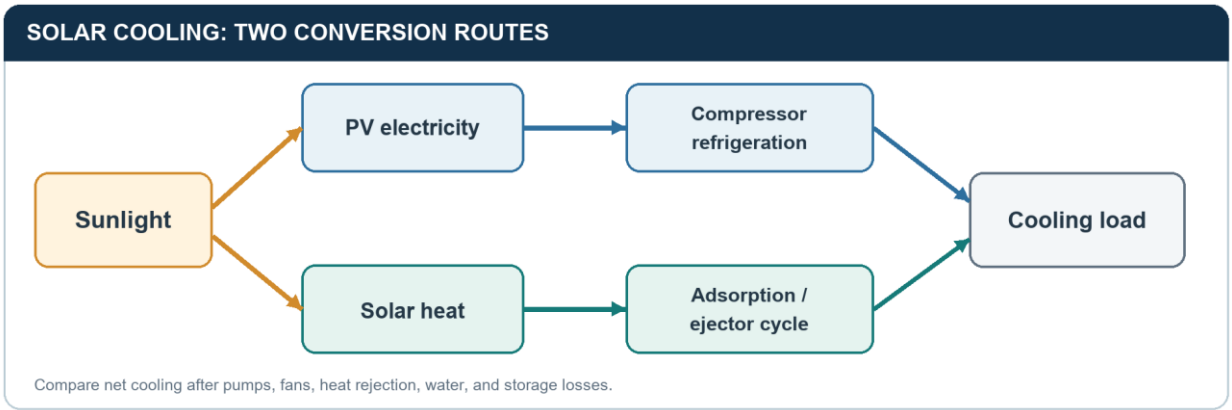


Fig. 3. PV-driven and solar-heat-driven cooling pathways.

6.2 Thermally driven cooling

Solar heat can drive adsorption, absorption, desiccant, or ejector cooling cycles. These systems convert thermal input into refrigeration and may be attractive where a heat source is available or electricity supply is constrained. Solar collectors, the cooling cycle, heat rejection, and storage must be sized as a combined plant. Performance depends on source temperature, ambient conditions, cooling-water availability, part-load behavior, and auxiliary loads. The supplied report summarizes studies of adsorption systems, facade-integrated cooling, off-grid refrigeration, and solar ejector cycles [1]. Their differing climates and models prevent a simple ranking by a single coefficient of performance.

6.3 Cooling and water trade-offs

Air cooling avoids direct water consumption but may have limited heat-transfer capacity or require fan power. Water spray and evaporative methods can produce stronger short-term cooling, yet water availability, treatment, scaling, corrosion, and maintenance become important. PV/T liquid cooling can recover heat but introduces pumping and plumbing. Phase-change materials can buffer temperature swings without continuous pumping, although

charge and discharge rates and long-term material behavior matter. A fair comparison reports net electricity, thermal output, water use, reliability, and maintenance alongside temperature reduction.

6.4 Solar desalination and other services

Solar energy can support desalination through thermal evaporation, membrane processes powered by PV, or hybrid systems that couple heat and electricity. The supplied hybrid-energy report includes solar desalination alongside aquaculture and cooking [3]. In these applications, the energy device is valuable only if it produces the needed service reliably: safe water, stable water quality, cooking capacity, or adequate environmental conditions for cultivation. Performance measures must therefore include service quality and operating continuity, not energy yield alone.

VII. Applications and Comparative Assessment

The reviewed technology families address different service needs. The following comparison summarizes their main engineering role and the questions that should be checked before selection [1]–[3].

Technology	Main output	Potential strength	Key design checks
PV	Electricity	Modular; serves electrical loads	Irradiance, temperature, inverter and storage losses
Solar thermal	Hot water or process heat	Directly supplies useful heat	Required temperature, demand timing, backup
CSP with storage	Power and/or high-temperature heat	Dispatchable heat or electricity	Direct sun, field cost, storage and heat transfer
PV/T	Electricity and heat	Uses collector area for two outputs	Simultaneous demand, pumping, temperature levels
Solar cooling	Cooling from PV or solar heat	Can align solar input with cooling demand	COP, auxiliary loads, water and heat rejection
Hybrid systems	Combined energy services	Can improve continuity and flexibility	Control, lifecycle cost, local resources and emissions

Table 1. Qualitative comparison of solar technology groups based on the supplied references.

7.1 Buildings and communities

Buildings can combine rooftop PV, solar water heating, heat pumps, thermal storage, building mass, and grid connection. The hybrid report describes a thermally activated building system supported by geothermal and solar technologies; the solar-heating report discusses PV-assisted heat pumps and district heating [2], [3]. These examples show why building envelope performance and control matter. Better insulation and demand management can reduce the size of solar equipment required, while thermal mass and storage can shift loads. Community-scale planning should consider roof area, network capacity, consumer access to investment, and the distribution of benefits.

7.2 Rural and productive uses

For rural applications, hybrid PV-battery systems can support lighting and productive loads, while biomass or hydrogen may extend supply when sunlight is low. Solar-powered drying, water pumping, refrigeration, cooking, and aquaculture can improve access to services but require locally maintainable equipment. The hybrid reference includes modeled and experimental cases in these areas [3]. Adoption depends on repair skills, spare parts, financing, safe operation, and whether the chosen service meets community priorities.

VIII. Findings, Limitations, and Recommendations

8.1 Findings from the supplied references

Across the reports, several consistent conclusions emerge. First, useful output depends on matching conversion technology to the required service and its timing. Second, storage can improve flexibility but introduces losses, cost, and design constraints. Third, controls can coordinate solar generation with demand and tariffs, yet forecasts and models need operational validation. Fourth, hybrid combinations broaden the services solar energy can provide, while increasing system complexity. Finally, reported performance values depend on each study's climate, assumptions, scale, and boundary and should not be presented as universal guarantees [1]–[3].

8.2 Evidence limits

The supplied references combine experimental work, simulations, case studies, and narrative reviews. Their objectives and measurement methods differ, and some reports describe duplicate or corrected source material. Therefore, this paper does not treat every chapter as an independent trial or

compare their numerical results as if they used common conditions. The analysis is limited to information represented in the supplied reports; conclusions about present market prices, standards, or current deployment volumes would require additional current data.

8.3 Engineering recommendations

Designers should report system boundaries and distinguish gross generation from net energy delivered after auxiliary use and storage losses. PV cooling studies should include pump or fan power and water use. Thermal systems should report useful heat by temperature level and time of delivery. Hybrid studies should identify component efficiencies, degradation, replacement, backup operation, reliability, and emissions assumptions. Cost assessments should include capital, maintenance, financing, and lifecycle replacement rather than only annual energy output.

Field testing should span seasons and include real demand, weather, and maintenance conditions. For buildings, compare comfort, unmet demand, self-consumption, and energy cost together. For solar cooling, account for heat rejection, water, and auxiliary electricity. For storage, report capacity and round-trip performance using explicit input and output definitions. Affordability evaluations should identify which households or users can access the investment and who benefits from lower operating costs. These practices make results more reproducible and useful for local decisions.

IX. Conclusion and Future Scope

Solar energy technologies range from PV modules and solar thermal collectors to CSP, PV/T, solar cooling, storage, and integrated hybrid systems. The supplied reports demonstrate applications in buildings, electricity supply, heating, cooling, water, and productive uses. No single technology is best for every situation. PV is suited to electrical loads; thermal collectors provide direct heat; CSP can deliver high-temperature heat and stored power; and hybrid systems can combine resources and end uses to improve flexibility. The practical result depends on local resource conditions, demand, operating strategy, lifecycle cost, maintenance, and affordability.

Future work should prioritize long-duration demonstrations, common performance definitions, transparent system boundaries, and lifecycle assessment. Research should evaluate control strategies under sensor and forecast uncertainty, quantify storage degradation, and measure water and auxiliary-energy requirements. Integrated studies should compare technical performance with service quality and distributional outcomes. Solar energy can make a dependable contribution when systems are designed around the service people need and validated under the conditions in which they will operate.

REFERENCES

[1] G. Dosymbetova et al., “Neural Network-Based Active Cooling System With IoT Monitoring and Control for LCPV Silicon Solar Cells,” IEEE Access, 2023, doi: 10.1109/ACCESS.2023.3280265.

[2] P. K. Pathak et al., “A State-of-the-Art Review on Heat Extraction Methodologies of Photovoltaic/Thermal System,” IEEE Access, 2023, doi: 10.1109/ACCESS.2023.3277728.

[3] L. F. Cabeza et al., “Review of Solar Thermal Storage Techniques and Associated Heat Transfer Technologies.”

[4] D. N. Harries et al., “Concentrating Solar Thermal Heat Storage Using Metal Hydrides.”

[5] W.-T. Li et al., “Improving the Operation of Solar Water Heating Systems in Green Buildings via Optimized Control Strategies,” IEEE Transactions on Industrial Informatics, 2018, doi: 10.1109/TII.2018.2797018.

[6] “Planning Framework for Integrating Solar-Powered Heat Pumps into Combined Heat and Power Systems,” IEEE Transactions on Sustainable Energy, 2018, doi: 10.1109/TSTE.2018.2810137.

[7] Y. Huang et al., “Unlocking the Potential of Solar Heating for Liquid Air Energy Storage: Multi-Regional Techno-Economic Insights.”

[8] W. R. Nazhat et al., “The Evolution of Solar Air Heating Strategies for Enhanced Energy Harnessing: A Comprehensive Critical Review,” Scientific African, 2026, doi: 10.1016/j.sciaf.2026.e03702.

[9] S. Tao et al., “Photothermal Regulation Materials: A Comprehensive Review of Passive Radiative Cooling, Passive Solar Heating, and Dynamic Photothermal Regulation Materials.”

[10] M. B. Wani et al., “Assessment of Energy Poverty in Estonia: A Spatial Analysis of Heating Affordability and Solar Heating Solutions.”

[11] A. M. Almogbel and F. S. Alkasmoul, “Simulation and Performance Analysis of Solar Adsorption Cooling Systems,” Energy Reports, 2025.

[12] J. Patel et al., “Solar Adsorption Cooling Systems for Off-Grid Sustainability: Recent Advances, Design Strategies, and Future Perspectives,” 2025.

[13] M. Khennich et al., “Thermodynamic Analysis of a Solar Powered Ejector Cooling System,” Case Studies in Thermal Engineering, 2024.

[14] M. Mahmoud et al., “Hybrid Solar-Geothermal Energy Systems: Technological Developments, Challenges, and Scientific Research Dynamics.”

[15] Y. Noorollahi et al., “Design and Evaluation of a Hybrid Solar-Biomass Energy System for Low-Carbon Rural Electrification.”

[16] M. T. Abdelghany and M. F. Orhan, “Empowering Water Security: High-Efficiency Hybrid Solar Desalination Systems.”